NC STATE UNIVERSITY

Tacho Lycos

2025 NASA Student Launch

Flight Readiness Review Addendum

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

April 14, 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 Summary of Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

Name: High-Powered Rocketry Club at NC State, Tacho Lycos

Mailing Address: 1840 Entrepreneur Drive, Raleigh, NC 27606

Primary Contact: Katelyn Yount, kvyount@ncsu.edu, (980) 258 - 2628

1.1.2 Time Spent on FRR Addendum Milestone

Approximately 250 hours were spent by the senior design team completing the FRR addendum milestone.

1.2 Purpose of Flight

This flight was conducted to fulfill the requirements for the Vehicle Demonstration Re-flight.

1.3 Flight Summary

1.3.1 Launch Conditions

The Vehicle Demonstration Re-flight took place on April 5th, 2025 in Bayboro, North Carolina. At the time of launch, the temperature was 88 degrees Fahrenheit, the pressure was 101910 Pa, and the wind speed was measured to be 14 mph. Skies were clear.

1.3.2 Motor Selection

The motor used for this flight was the Aerotech L1520T, the selected competition motor.

1.3.3 Ballast

This flight utilized 1.02 lbs of ballast. This was less than 10 percent of the full weight of the vehicle.

1.3.4 Static Stability

The static stability of the Launch Vehicle was 2.125 calibers on the pad.

1.3.5 Payload

The final Payload STEMCRaFT was successfully flown and retained in the Nose Cone during the entirety of the flight. The on-board camera functioned as intended.

1.3.6 Air Brakes

The Air Brakes system functioned as expected with the exception that the fins failed to completely retract when they were supposed to do so. This was caused by a failure of one of the servos prior to launch, resulting in the slipping of teeth between the central gear and the driving gear. The system was deemed safe to fly prior to launch with the intention of full deployment and retraction.

1.3.7 Altitude Summary

The official target altitude for the competition is 4600 ft and the altitude reached from this flight was 3783 ft. This was significantly lower than the predicted altitude of 4300 ft due to Air Brake deployment throughout the entire coast phase of the flight. The target apogee for the launch was 4000 ft, which was undershot because Air Brakes were unable to retract due to a mechanical failure.

1.4 Changes Made Since FRR

1.4.1 Changes Made to Vehicle Criteria

Table 1.1: Changes made to vehicle criteria since FRR submission.

Change Description	Justification	Affected Subsystem(s)
Drogue parachute was changed from a Fruity Chutes 15” Classic Elliptical parachute to a Rocketman 24” Ballistic Mach II parachute.	During the team’s failed VDF attempt, the drogue parachute did not produce enough drag, and the Fin Can fell above the rest of the vehicle during drogue descent. When the main parachute deployed, it deployed into the drogue parachute shock cord. This caused the main parachute to flip inside out, decreasing its effectiveness. With a larger drogue parachute, the Fin Can should fall below the rest of the vehicle during drogue descent, preventing this from happening in future flights.	Recovery

1.4.2 Changes Made to Payload Criteria

No changes have been made to the payload criteria since FRR.

2 Vehicle Demonstration Flight Results

2.1 Successful Systems

2.1.1 Vehicle Structure

The overall vehicle airframe performed as designed throughout all phases of flight. After landing, the separated but tethered sections of the vehicle were dragged approximately .5 miles by the main parachute, through an asphalt road, flooded irrigation ditches, and rough soil. The airframe and fins suffered only abrasion to the paint, with no structural damage. All fasteners and recovery system connections remained tight and secure upon post-flight inspection. Additionally, the ballast system remained secure within the tip of the Nose Cone.

Figure 2.1: Drogue Parachute Bay/Fin Can post-recovery.

2.1.2 Payload Retention

The STEMCRaFT capsule remained successfully retained inside the Nose Cone for the duration of flight and recovery.

2.1.3 Air Brakes Software

The on-board camera footage provides evidence that the flight computer software attempted to both extend and retract Air Brakes. This meant the apogee prediction algorithm converged and likely correctly predicted that the Launch Vehicle was overshooting the target apogee.

2.2 System Failures

2.2.1 Air Brakes Hardware

Prior to launch, one of the servos was determined to be non-functional. This resulted in the Air Brakes staying deployed throughout the entire flight due to the driving gear slipping upon retraction. The on-board camera footage shows that the fins extend and attempt to retract but fail to fully retract. This led to their deployment throughout the duration of the flight and recovery.

2.3 Payload Overview

The STEMCRaFT capsule remained fully retained inside the Nose Cone in the same configuration as described in FRR. Due to prior damage to the transmitter from testing, the sole mission for this flight was to act as an appropriate mass for the Vehicle Demonstration Flight and to give functionality for the camera system to operate. The payload met these mission objectives.

2.4 Flight Profile Data

The flight profiles from both the Stratologger altimeter data and Easy Mini altimeter data are shown below in Figure 2.2. The Stratologger was the primary altimeter. These profiles will be discussed further in Section 2.7 of this document.

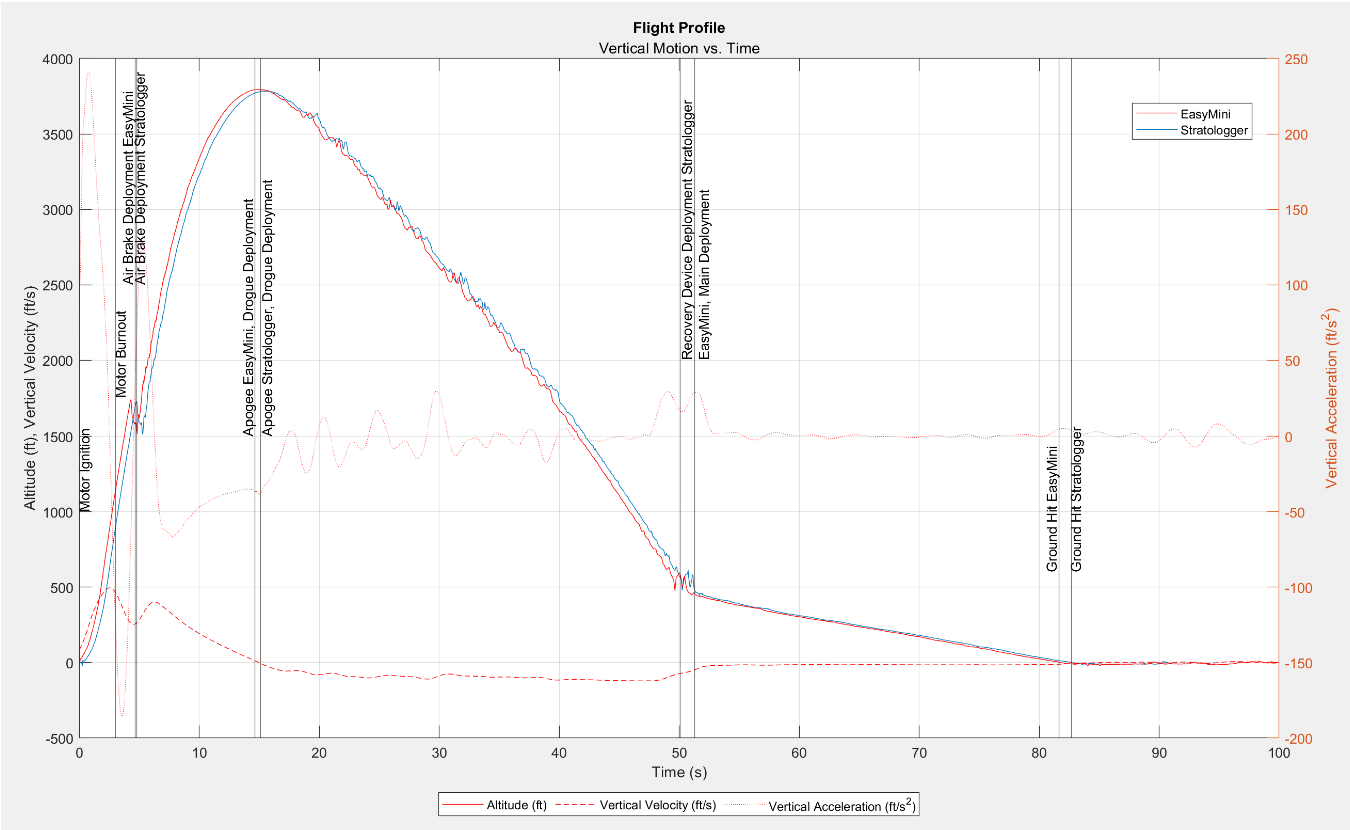


Figure 2.2: Flight Profile Data

As shown in Figure 2.2, around 5 sec into the flight, the altimeters recorded a sudden drop in altitude. Through analysis of the on board Nose Cone camera footage, the team has confirmed that this spike occurred at the same time as when the Air Brakes deployed. Since both the StratologgerCF and the EasyMini rely on pressure to calculate altitude, the deployment of the airbrakes caused a small spike of increased pressure, resulting in this perceived drop in altitude. The spike has proven to be consistent across all flights using Air Brakes.

Both altimeters have Mach protections in place that require the recorded speed during flight to fall below a threshold for a short period of time before looking for apogee conditions. Since this pressure spike always occurs at relatively high speeds during flight, the team is not concerned about any premature apogee detection by either of the altimeters as a result of Air Brake deployment.

2.5 Recovery System

The only change in the recovery system since FRR was the switch of the drogue parachute from a Fruity Chutes 15" Classic Elliptical parachute to a Rocketman 24" Ballistic Mach II parachute.

During the team's previous Vehicle Demonstration Flight, the high winds produced more lift on the fins of the Fin Can than the team anticipated. Due to this extra lift, the drogue parachute did not produce enough drag to ensure that the Fin Can descended below the rest of the Launch Vehicle. When the main parachute deployed, it inflated directly into the drogue shock cord, causing it to flip inside out and thus decreasing its overall performance.

In the Vehicle Demonstration Re-flight that took place on April 5th, 2025, the larger drogue parachute deployed at apogee and did help to ensure the proper orientation of the Launch Vehicle; however, the Fin Can still fell roughly parallel with the Launch Vehicle, instead of below it. Regardless, the main parachute deployed as expected at 550 ft. without any collisions with the rest of the vehicle or the shock cord.

Figure 2.3 below shows still images of the drogue and main parachutes captured by the Nose Cone camera during flight. As seen, both parachutes deployed and inflated as expected.

(a) Drogue Parachute

(b) Main Parachute

Figure 2.3: Still images of the parachutes captured by the Nose Cone camera during flight

2.5.1 Landing Configuration

With winds up to 15 mph, the Launch Vehicle was dragged almost a half mile by the main parachute after touchdown. A small portion of the trail left by the Fin Can can be seen in Figure 2.4 below.

Figure 2.4: Fin Can after it was dragged by the wind

Figures 2.5a, 2.5b, and 2.5c show the configuration of the Launch Vehicle upon landing. Due to the high wind conditions at the launch field, the main parachute was collapsed before any photographs were taken. This was required to stop the Launch Vehicle from continuing to be dragged further away and prevent the vehicle from colliding with recovery personnel.

(a) Nose Cone landing configuration (b) AVAB and Main Bay landing configuration (c) Full landing configuration

Figure 2.5: Flight landing orientation

As shown in Figure 2.5, 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. As seen in Figure 2.5b, the drogue parachute was wrapped around the shock cord and collapsed in on itself from all the mud. After analysis from the Nose Cone video, the team has concluded that this happened as a result of the Launch Vehicle being dragged through the mud by the main parachute after landing, not during descent.

The primary drogue deployment charge was not properly ignited during the flight and remained unblown upon landing. For more information on this, see Section 2.7.2.

Despite the unblown drogue primary deployment charge, the secondary drogue deployment charge functioned as expected and successfully separated the vehicle at the Fin Can/ AVAB connection point, deploying the drogue parachute. Overall, the recovery system worked as intended and the vehicle descended safely.

2.5.2 Kinetic Energy at Landing

The data from the primary altimeter, the PerfectFlite StratologgerCF, was used to get the drogue and main descent speeds for the flight. Figure 2.6 below shows the altitude plotted against time for this flight.

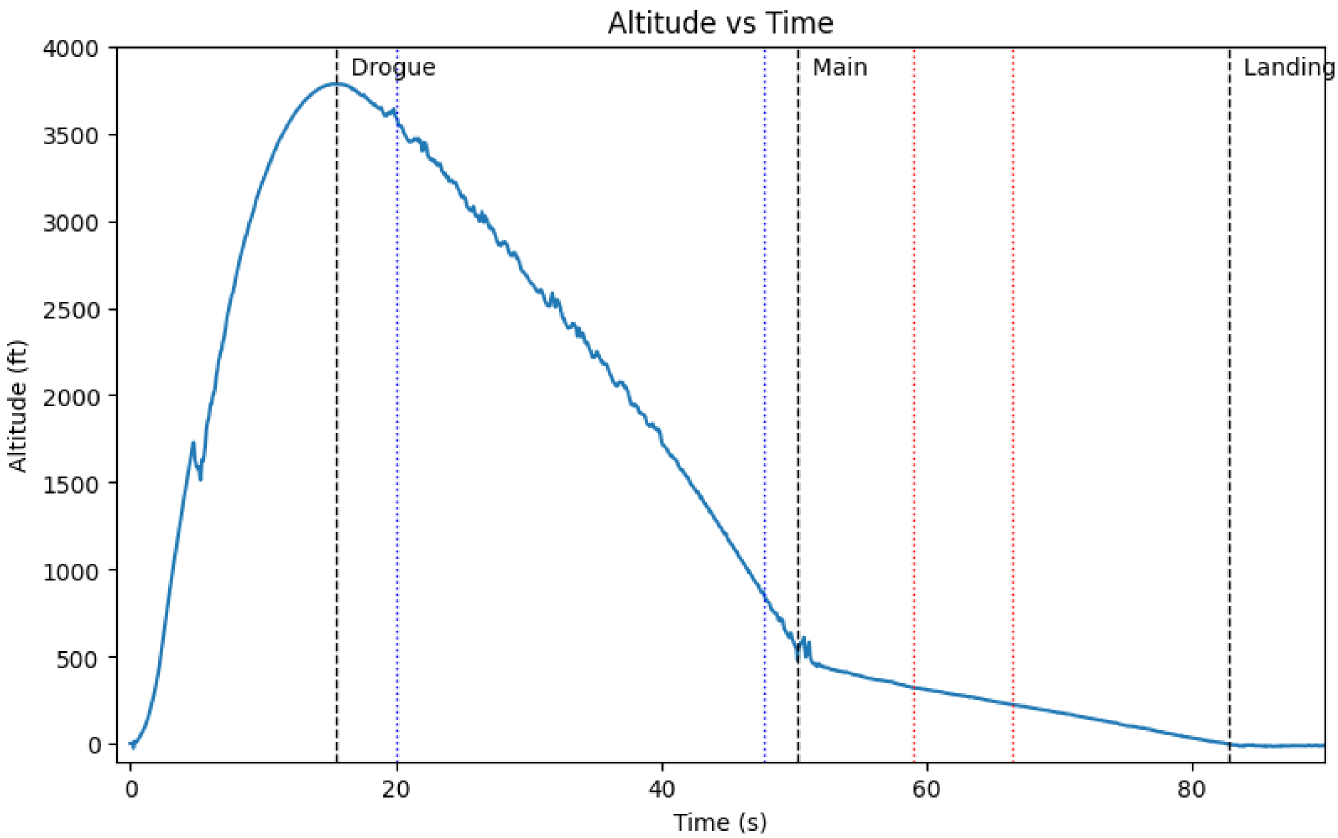


Figure 2.6: Primary Altimeter Altitude Plot

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 velocity. In the Figure 2.6, 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.

$$Drogue\ Descent\ Velocity = \frac{47.75 - 20.00}{853 - 3596} = -98.8 fps \tag{1}$$

$$Main\ Descent\ Velocity = \frac{66.5 - 59.00}{225 - 323} = -13.1 fps \tag{2}$$

Using those descent rates and the masses of all the sections of the Launch Vehicles, their kinetic energies were calculated. The results can be seen in Table 2.1 below.

Table 2.1: VDF Kinetic Energy Values

<table>
<tr><th>Section</th><th>Take-off Mass (lbm)</th><th>Landing Mass (lbm)</th><th>Drogue Descent Velocity (fps)</th><th>Drogue Kinetic Energy (ft-lbf)</th><th>Main Descent Velocity (fps)</th><th>Main Kinetic Energy (ft-lbf)</th></tr>
<tr><td>Nose Cone</td><td>8.5</td><td>8.5</td><td>98.8</td><td rowspan="2">3337</td><td>13.1</td><td>22.7</td></tr>
<tr><td>AVAB + Main Bay</td><td>13.5</td><td>13.5</td><td>98.8</td><td>13.1</td><td>36.0</td></tr>
<tr><td>Fin Can + Drogue Bay</td><td>18.3</td><td>14.2</td><td>98.8</td><td>2154</td><td>13.1</td><td>37.9</td></tr>
</table>

Table 2.2 below compares the data from the Vehicle Demonstration Flight to the projected values. The predicted values are based on the masses of the vehicle during the flight and the recorded apogee of 3783 ft.

Table 2.2: VDF Descent Data Comparison

Parameter	Actual Value	Predicted Value	Difference
Drogue Descent Velocity (fps)	98.8	90.8	8.8%
Main Descent Velocity (fps)	13.1	16.8	-21.9%
Total Descent Time (sec)	67.3	68.4	-1.6%
Nose Cone Landing KE (ft-lbf)	22.7	37.1	-38.9%
AVAB + Main Bay Landing KE (ft-lbf)	36.0	59.0	-38.9%
Fin Can Landing KE (ft-lbf)	37.9	62.0	-38.9%

The coordinates of the launch pad were 35.17621°N, 76.82939°W. The team is unsure of the vehicle's exact landing location after bring dragged a considerable distance, however, it was recovered at 35.18224°N, 76.83000°W. This brought the total drift distance of the Launch Vehicle to 2207.3 ft. While the true drift distance was uncertain, it was significantly lower than the recovered distance, which was still under the required 2500 ft.

While the drogue descent speed was slightly higher than anticipated and the main descent speed was considerably lower than anticipated, these values meet all team derived and NASA derived requirements. With an underestimation of drogue descent speed, and an overestimation main descent speed, these differences canceled out to make the team's descent time prediction relatively accurate. During our competition flight, the team anticipates an apogee closer to 4600 ft, which would increase the descent time under drogue parachute. This would likely make the overall descent time deviate even lower than the team's prediction of 77.4 seconds.

2.6 Air Brakes System

During assembly checklists, performing item 1.61 regarding testing the Air Brakes showed that the fins could not deploy while inside the AVAB. The sound of the servos attempting to actuate and subsequently stalling could be heard, but no movement of the fins occurred. After disassembly and further inspection/debugging, one of the servos was determined non-functional and was providing extra resistance against the one working servo when actuating the system. Twelve hours prior, the system performed final checks and was completely functional during the deployment tests and the software tests. It is unknown as to what could have caused the servo to fail, with the best theory being that it was a used servo which was incorporated for the first VDF attempt. To circumvent this issue so that the launch could proceed with a functional Air Brakes control, the non-functional servo was unplugged from the PCA 9685 driver board so the system would be operated with a single servo. The non-functional servo remained in place such that the system was consistent in weight and mechanical connections. The non functional servo, once unplugged, was no longer providing as much resistance against the operational servo, although there was still some inherent mechanical resistance from the non functional servo. This setup, while only being a slight deviation from the final design, showed a defect that is not present with two function servos. With the added resistance and the off center actuation, the driving gear of the operational servo had the tendency to slip with the central gear, which synchronizes and actuates the 4 fins.

This failure mode was experienced during the design process and is a big reason for the addition of the second servo to balance the forces on the central gear. During the initial testing with one servo, the slipped gears resulted in a loss of rotational positioning of the fins such that the physical deployment angle did not match the angle the control software commanded. When the fins were supposed to be fully deployed, they were actually partially deployed and visa versa. However, an important note about this failure mode was that the 4 fins remained synchronized the entire time. Their deployment angles remained the same despite any slipping from the driving gear, which would result in an even distribution of moments on the rocket if this were to occur during flight. This would only result in a loss of altitude control while maintaining the rocket's stability. Having this prior experience, and knowing the gears were remaining synchronized with tests conducted at the field, the system was deemed safe to fly.

The Air Brakes system prior to launch would intermittently slip on retraction with it working just fine a majority of the time during testing. With these facts taken into consideration, it was still possible to have a successful flight with successful Air Brakes deployment. The risk posed by this change was the failure to hit the target apogee by significantly undershooting the flight. There was no added risk to the safety of personnel or the Launch Vehicle's ability to stay within VDF requirements.

The pre-flight simulations estimated an apogee of 4300ft with the extra ballast and high winds taken into consideration. The target apogee was set at 4000ft. During the flight, a little before 3 seconds after the motor burned out, the Air Brakes successfully deployed and fully extended as seen by figure 2.7. They stayed deployed for 1.6 seconds before attempting to retract.

Figure 2.7: Zoomed in image of Air Brakes after ’extend’ command sent as captured by on-board camera.

At this point, it is believed that the driving gears slipped upon retraction. As seen by figure 2.8, the fins retracted a tiny bit before not moving further.

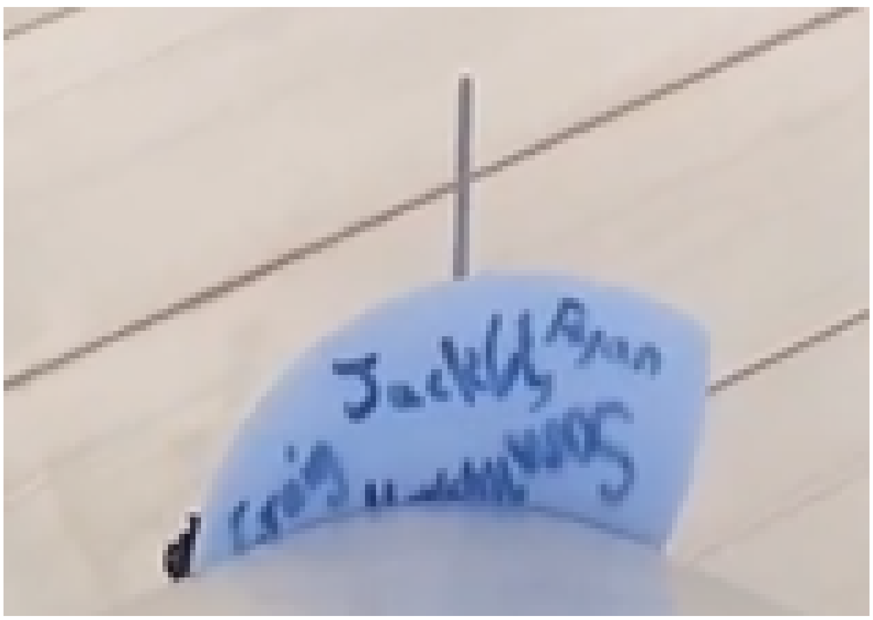


Figure 2.8: Zoomed in image of Air Brakes after ’retract’ command sent as seen by on-board camera.

From the on-board camera, the fins can be seen deployed throughout the rest of the flight, failing to retract again during free fall state (this is a redundant implementation to ensure the fins are fully retracted after apogee to prevent tangling and damage upon landing). This resulted in the actual apogee according to the altimeters to be 3783ft, which was significantly lower than the target apogee of 4000ft. It is believed that the system survived the initial landing, but suffered all of its damage during the time it took to recover the vehicle. All the sections of the rocket, with the exception of the Fin Can, were repeatedly lifted into the air and slammed to the ground, all while being dragged about a half mile across the field and across water-filled irrigation ditches. The damage sustained to the Air Brakes system is further discussed in Section 2.9.2.

The resulting damage from water and harsh impacts caused the flight computer’s mirco SD card to be bricked. All of the initial data recovery attempts failed and the SD card is currently being looked at by professionals at a local computer repair and data recovery shop. At the time of this report, there is no flight data from the Air Brakes flight computer to report.

2.7 Flight Analysis

2.7.1 Predicted vs Actual Flight Data

The predicted flight was expected to reach a higher apogee than the actual flight did. This difference is highlighted in the comparison below shown as Figure 2.9. The discrepancies are due to the Air Brake mechanical failure of not retracting the fins when appropriate, as well as some weather-cocking off of the rail. The target of 4000 ft was undershot by 217 ft due to these conditions.

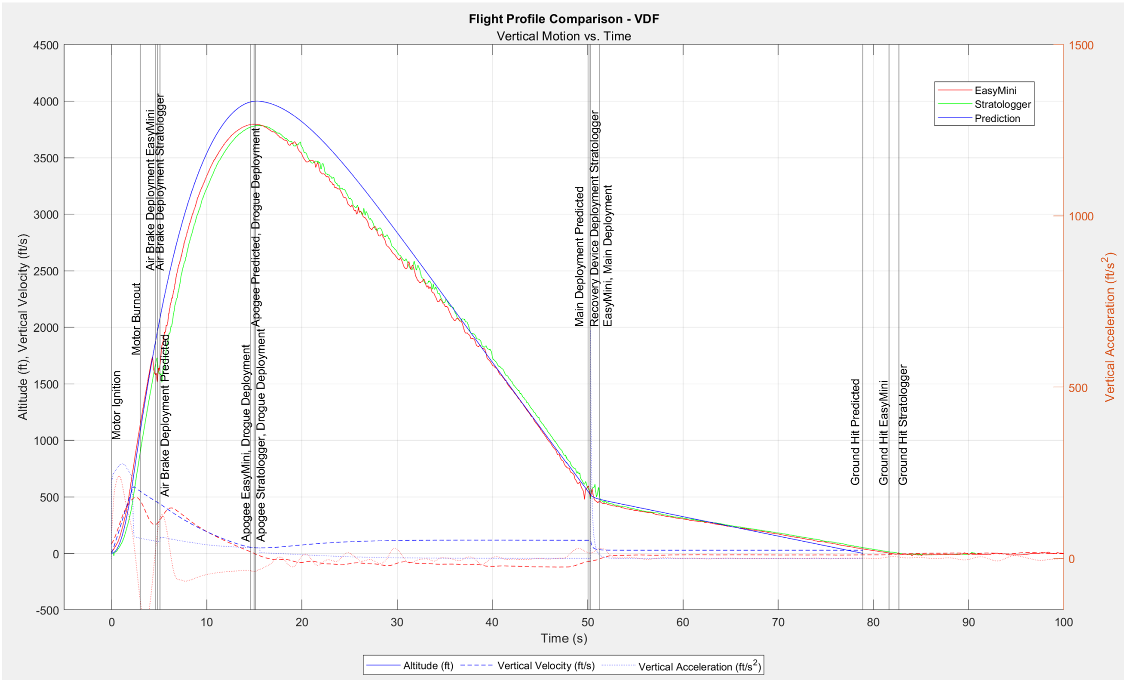


Figure 2.9: Flight Profile Comparison

2.7.2 Off-nominal Events

Upon landing, the team could see that the primary drogue deployment charge was not blown during the flight. The flight data from the Perfect Flite StratologgerCF shown in Figure 2.10 indicates that the altimeter attempted to trigger the primary drogue deployment charge.

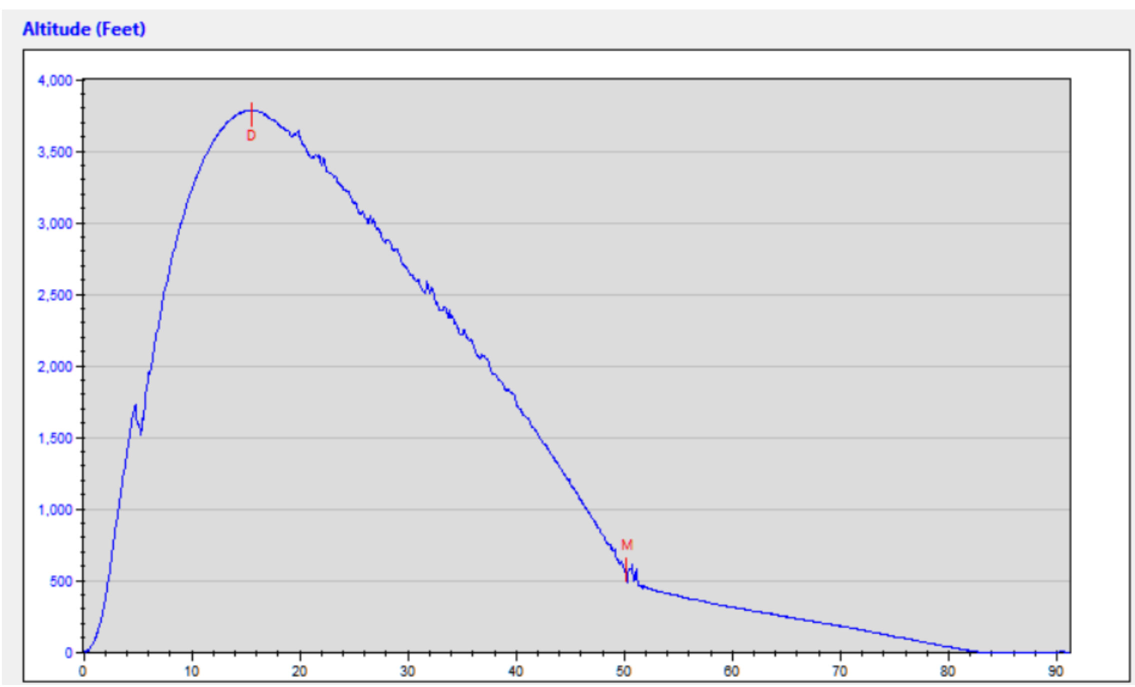


Figure 2.10: Primary Altimeter Flight Data

While testing the altimeter after the flight, the team confirmed that the altimeter is functioning as expected and can properly ignite an e-match when signaling a drogue or main deployment event. Further testing has led the team to conclude that small dirt buildup on the inside of the primary altimeter terminal block used to connect the e-match to the primary altimeter likely resulted in an intermittent loss of continuity between the altimeter and e-match during the flight. In order to ensure that this will not happen in subsequent flights, this terminal block will be replaced with a new, identical, terminal block.

As discussed in Section 2.6, the Air Brakes system failed to fully retract, causing the Launch Vehicle to reach a significantly lower altitude than targeted. This was caused by actuating the Air Brakes system with only one working servo, which led to the driving gear slipping its position upon retracting. This failure will be mitigated by replacing the current servos with new ones as well as having a set of replacement servos on standby.

2.8 Estimated Drag Coefficient

During this VDF attempt, unfortunately, significant data typically collected and used for drag analysis was lost due to damage sustained to components when the rocket was dragged after landing. Instead of comparing drag coefficient curves, as done in previous documentation, the drag coefficient can only be estimated during coast phase. Air brakes were deployed for the entirety of this coast phase, so only the drag coefficient with Air Brake deployment can be estimated. This process is completed using equation 3, below, where the relationship between burnout weight, acceleration from flight data, and the force of drag is shown.

$$F_d = -mg - ma \tag{3}$$

After the drag force is calculated, Equation 4, yields a value for drag coefficient.

$$C_d = \frac{2F_d}{(\rho)v^2 A} \tag{4}$$

Table 2.3, below, shows the values produced from this derivation. A median coefficient of drag value is used for sake of comparison. The similarity of these values shows confidence in simulations, despite having lower quality data to analyze.

Table 2.3: Estimated Drag Coefficients- Coast Phase

Coefficient of Drag, Estimated	Coefficient of Drag, Predicted	Percent Error
0.65	0.64	1.5%

For the purpose of completion, the drag curve established from a previous VDF attempt is included below. This drag curve, alternatively, does not include Air Brake deployment. This figure was included in the FRR document and serves as a secondary verification of simulations.

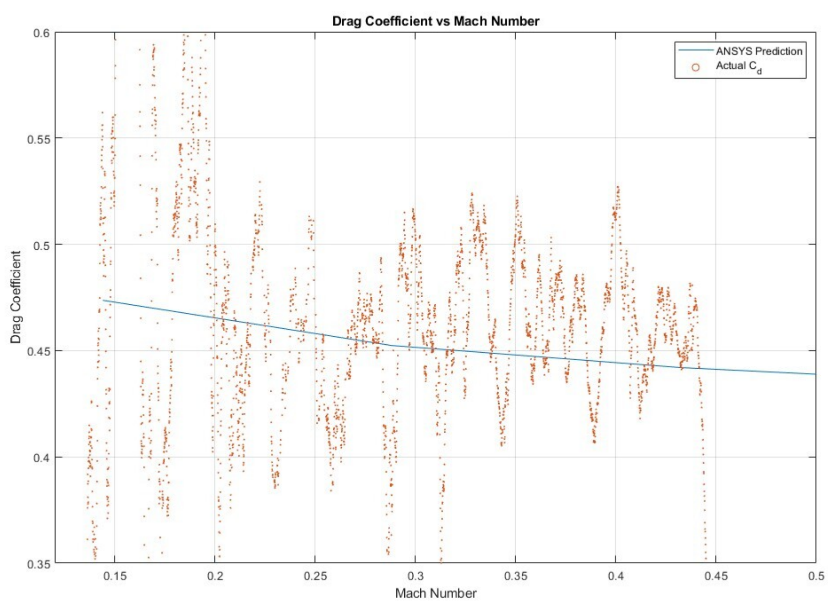


Figure 2.11: Drag Coefficient Comparison - No Air Brakes

Table 2.4: Estimated Drag Coefficients- Without Air Brakes

Coefficient of Drag, Estimated	Coefficient of Drag, Predicted	Percent Error
0.46	0.44	4.5%

2.8.1 Post Flight Simulation

In order to more accurately match flight patterns, post flight simulations were performed. Air Brake deployment was set to the same time as actual deployment and weather-cocking off of the rail was updated to be approximately 10 degrees. This yielded an apogee of 3809 ft, which is a 0.7 percent error off of the actual apogee, 3783 ft. This simulated profile is extremely similar, as shown below in Figure 2.12. In the future, some degree of weather-cocking will be expected in high wind conditions and implemented into flight predictions.

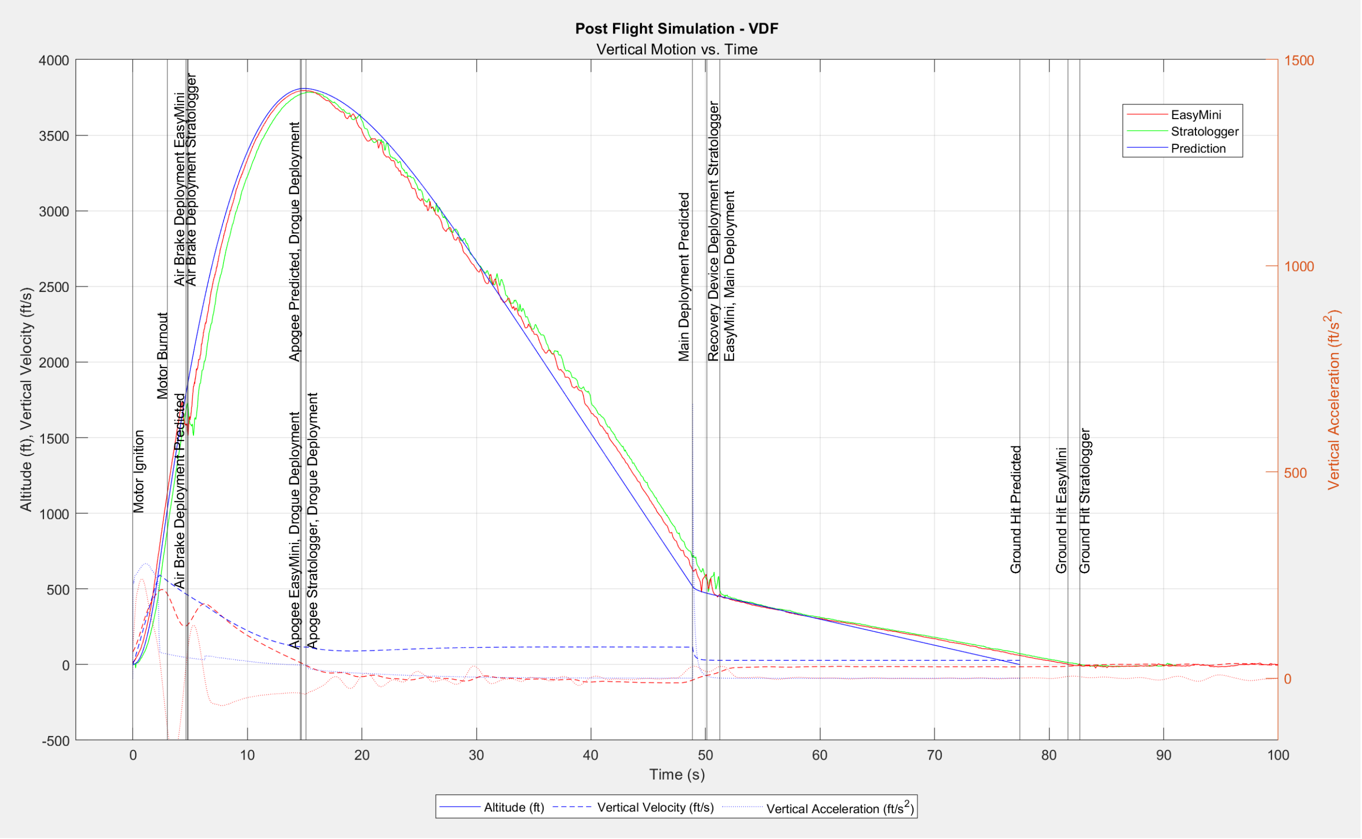


Figure 2.12: Post Flight Simulation

2.9 Damaged Hardware

2.9.1 Charge Well

One 3D printed PLA charge well on the aft AVAB bulkhead was bent off of its fastener post-landing due to dragging and repeated ground impacts from the inflated main parachute. Excessive bending of the well body caused the PLA material around the fastener head to yield and tear. The fastener remained attached to the aft AVAB bulkhead and there was no damage to the bulkhead. This will be mitigated in the future with addition of a small washer within the bottom of the charge well.

Figure 2.13: Bottom view of damaged 3D printed charge well.

2.9.2 Air Brakes

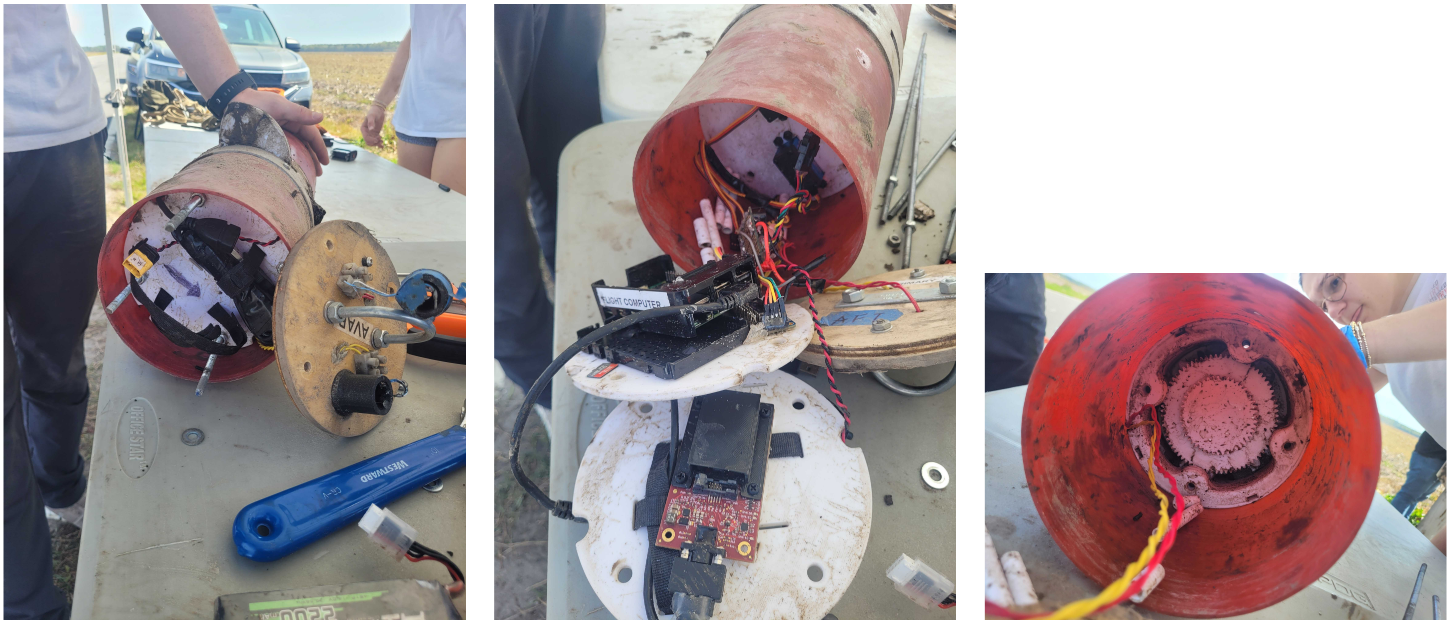
The Air Brakes system sustained severe damage after the initial landing. This was the result of the off nominal event of the Launch Vehicle being dragged half a mile across the launch field while repeatedly being lifted into the air then impacted back into the ground due to the main parachute remaining inflated. As seen in 2.14a, the AVAB has been covered in water and dirt, with some damage sustained to the Air Brakes fins. The damaged blast cap can also be seen on the aft bulkhead. In Figure 2.14b, one fin is shown completely sheared off and the other fin has experienced delamination.

(a) Image of AVAB after recovery.

(b) Close up image of switchband after recovery.

Figure 2.14: Recovered components of the AVAB system after landing.

The AVAB disassembly was difficult due to the broken Air Brakes fins stuck in the fin slots. Due to this, the threaded rods were removed to further disassemble the AVAB. As seen by Figure 2.15a, the internal structure is still intact and there was no apparent damage to the sleds. Figure 2.15b shows the threaded rods completely removed, and the subsequent electronics sleds and spacers laid out. After disconnecting the encoder and servo, the electronics sleds, including the servo sled, could be removed for further inspection. Figure 2.15c shows the moisture and debris on the inside of the AVAB. Despite all the damage received, the central gear remained in place and still synchronized to all of the fins.



(a) AVAB with aft bulkhead removed.
(b) AVAB with threaded rods removed.
(c) AVAB with Air Brakes electronics removed.

Figure 2.15: Various stages of AVAB disassembly.

The Air Brakes housing remained secured to the switchband and did not endure any damage. Three Air Brakes fins were sheared off and one fin was severely delaminated. Despite this, the fins remained in sync with each other. The mud and water damage rusted out the bearings and non rust-resistant hardware such as the roller bearings, PCA9685 driver, and servos. These components will be replaced before the competition launch in Huntsville.

Figure 2.16: Damage sustained to the Air Brakes housing and fins.

The Air Brakes system will be completely rebuilt, with all new 3D printed components meeting the design requirements outlined in FRR. Due to the possibility of corrosion of the electronic components from the water damage sustained, new electronics will be used with the exception of the Raspberry Pi 5. Filament, bearings and the necessary electronics have been ordered and the system will be reassembled in the following week.

2.10 Lessons Learned

2.10.1 Air Brakes

Considering that a substantial amount of damage could have been avoided and a successful Air Brakes launch could have been achieved if there were two working servos, the team will have a back-up set of servos on standby to avoid having to launch with one servo. Alternatively, if this situation were to happen again, further risk assessment would be taken into consideration for the possibility of damaged hardware to the mechanism and electronics. For this flight it was deemed a necessary risk, but on less critical flights, it may be wise to make a no-go call for flying without a fully functional Air Brakes system.

2.11 Plan of Action

Prior to the competition flight, the Air Brakes will be rebuilt with new 3D printed components. Additionally, extra charge wells will be printed and will be assembled with washers to better secure them to the AVAB bulkheads.

3 Requirements Compliance

3.1 NASA Requirements

Below is a list of requirements and verification statuses that solely depend on the successful demonstration of the Vehicle Demonstration Flight. All requirement verifications were updated with the new flight information and meet NASA criteria.

Table 3.1: NASA 2024-2025 Vehicle Requirements

NASA Req No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
2.19.1	Vehicle Demonstration Flight— All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown SHALL be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the Launch Vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the Launch Vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). Requirements 2.19.1.1-9 SHALL be met during the full-scale demonstration flight:	The team will successfully launch and recover their designed full-scale Launch Vehicle prior to FRR in its final flight configuration. The team will validate all aspects of the Launch Vehicle during this flight and meet NASA requirements 2.19.1.1-9.	**(1)** The full-scale rocket is successfully launched and recovered in its final flight configuration. **(2)** Full-scale Rocket meets NASA Requirements 2.19.1.1 - 2.19.1.9.	**(1) Demonstration:** Verify the Launch Vehicle completes a successful launch and recovery event. **(2) Inspection:** Ensure that all hardware functions properly and meets NASA Requirements 2.19.1.1 - 2.19.1.9.	Verified	Project Management	**(1)** A VDF with nominal performance was performed on 3/8/2025. See Section 2.5.1 for VDF recovery photos. **(2)** See Verification Results for NASA Requirements 2.19.1.1 - 2.19.1.9.
2.19.1.1	The vehicle and recovery system SHALL have functioned as designed.	The Integration Lead and Team Lead will verify that the vehicle and payload system functioned as it was designed.	The vehicle and recovery system operate as designed.	**Review:** Inspect flight data from VDF to confirm that the vehicle and recovery system functioned properly (correct deployment of the drogue and main chutes, etc).	Verified	Integration, Project Management	Drogue and main parachute deployment performed nominally during VDF on 4/5/2025. See Figure 2.3 (photo a and b) for confirmation.
2.19.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics Lead and Structures Lead will facilitate the design and construction of a new full-scale rocket, built for the purpose of this years NASA SL challenge.	**(1)** Design and construction process documented via photos & CAD models. **(2)** Newly constructed rocket, designed and built for this years challenge.	**(1) Review:** Verify that multiple construction and CAD models are included in report documentation. **(2) Review:** Verify that report documentation have new and purposeful appendices and references.	Verified	Aerodynamics, Structures	**(1) & (2)** See Section 3.5 in the FRR report for the manufacturing process of the Full-scale LV.

Table 3.1: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
2.19.1.3.1	During Vehicle Demonstration Flight - If the payload is not flown, mass simulators SHALL be used to simulate the payload mass.	The Payload Team and Structures Lead will use a mass simulator to simulate the payload mass if the payload is not flown during the Vehicle Demonstration Flight.	**(1)** A mass simulator is securely integrated into the Launch Vehicle if the payload is not flown during the VDF. **(2)** The mass simulator accurately replicates the payload mass and center of gravity (CG) properties. **(3)** The flight dynamics of the vehicle with the mass simulator meet performance expectations (apogee predictions align within acceptable error margins).	**(1) Inspection:** Verify secure integration of the mass simulator and inspect its design to match payload mass and CG specifications if using a mass simulator. **(2) Analysis:** Use simulations (OpenRocket or RockSim) to confirm the mass simulator's impact aligns with predicted outcomes for the payload configuration if using a mass simulator. **(3) Test:** Conduct a VDF with the mass simulator and compare apogee and flight stability with simulation predictions to ensure acceptable performance if using a mass simulator.	Verified	Payload, Structures	**(1), (2), & (3)** The payload was flown in its fully manufactured state during the VDF on 4/5/2025. See Section 6.3 in the FRR report for the PDF payload summary.
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	The Structures lead will place the mass simulators in the same approximate location in the Launch Vehicle as the missing payload mass.	**(1)** The mass simulator is positioned within the Launch Vehicle at the same approximate location as the missing payload to ensure accurate center of gravity (CG) replication. **(2)** The vehicle's center of gravity (CG) with the mass simulator matches the expected CG with the payload within an acceptable margin of error.	**(1) Inspection:** Confirm the placement of the mass simulator in the same approximate location as the missing payload. **(2) Measurement:** Measure the center of gravity (CG) of the Launch Vehicle with the mass simulator and compare it to the expected CG with the payload.	Verified	Structures	The payload was located in its official position in the Nose Coned during VDF. See VDF results in Section 2.
2.19.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	Payload Team and Team Lead ensure that Air Brakes is on the full-scale rocket and is functioning during VDF.	**(1)** Air brakes are installed and integrated into the rocket for the VDF. **(2)** Air brakes are fully functional and actively manage the vehicle's total altitude during the flight.	**(1) Inspection:** Verify the Air Brakes are installed and operational before the VDF. **(2) Test:** Observe the Air Brakes' performance during the VDF to confirm proper deployment and functionality.	Verified	Payload, Project Management	The competition payload does not have external surfaces. The experimental payload, Air Brakes, was active during the VDF attempt.
2.19.1.5	Teams SHALL fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	The Aerodynamics Lead and Team Lead will ensure that the competition launch motor is used for the Vehicle Demonstration Flight. If unable, the Team Lead will request a waiver for the use of an alternative motor from NASA in advance.	**(1)** The competition launch motor is installed and flown during the Vehicle Demonstration Flight (VDF). **(2)** If the competition motor cannot be used, a waiver is submitted and approved by NASA for an alternative motor. **(3)** The alternative motor performs similarly to first motor choice.	**(1) Inspection:** Verify that the competition motor is installed in the Launch Vehicle before the VDF launch. **(2) Inspection:** Confirm the submission and approval of the waiver for an alternative motor, if applicable. **(3) Analysis:** Compare thrust and impulse data for the alternative motor to ensure compliance with competition requirements if required.	Verified	Aerodynamics, Project Management	The VDF motor is the L1520T and can be seen in Section 1.3.2. It is the same as the final selected motor for the Huntsville launch.

Table 3.1: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
2.19.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast SHALL not be added without a re-flight of the full-scale Launch Vehicle.	The Aerodynamics Lead and Team Lead will ensure that the full-scale Launch Vehicle is flown in its fully ballasted configuration during the Vehicle Demonstration Flight. The Aerodynamics Lead will not add additional ballast without a re-flight of the full-scale Launch Vehicle.	**(1)** The full-scale Launch Vehicle is flown with the maximum ballast configuration during the Vehicle Demonstration Flight (VDF). **(2)** No additional ballast is added without a re-flight of the vehicle. **(3)** The ballast configuration used during the VDF is verified to match the maximum ballast planned for the competition flight.	**(1) Inspection:** Confirm the ballast configuration before the VDF to ensure the correct amount of ballast is used. **(2) Inspection:** Ensure that no additional ballast is added after the VDF unless a re-flight is conducted. **(3) Measurement:** Measure the ballast weight and configuration during the VDF and compare it to the planned competition ballast configuration.	Verified	Aerodynamics, Project Management	The LV was flown with 1.02 lbs. of ballast (minimum ballast configuration) during VDF. The total weight of the LV is 40.3 lbs (including 1.02 lbs of ballast). See Section 2 for VDF results.
2.19.1.7	After successfully completing the full-scale demonstration flight, the Launch Vehicle or any of its components SHALL not be modified without the concurrence of the NASA management team or Range Safety Officer (RSO).	The team will not modify the Launch Vehicle or any of its components after completing the full-scale demonstration flight without the approval of the NASA management team or RSO.	**(1)** No modifications are made to the Launch Vehicle or its components after the full-scale demonstration flight. **(2)** Any proposed modifications are approved by NASA management or the RSO before being implemented.	**(1) Inspection:** Verify that no modifications are made to the Launch Vehicle or components after the full-scale demonstration flight. **(2) Inspection:** Confirm the approval of any modifications by NASA management or the RSO.	Verified	Project Management	The LV will not undergo any modifications after VDF on 4/5/2025.
2.19.1.8	Proof of a successful flight SHALL be supplied in the FRR report.	The Team Lead will ensure that proof of a successful full-scale demonstration flight is supplied in the FRR report.	FRR report includes proof of a successful full-scale demonstration flight (including flight profile graphs, apogee, etc.).	**Inspection:** Confirm that the flight data provided (apogee, stability) aligns with simulations and is included in FRR.	Verified	Project Management	Proof of a successful VDF is included in Section 2.7 and Figure 2.10 for the flight profile graph.
2.19.1.8.1	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet Requirement 2.19.1.8. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead will include altimeter flight profile data with accompanying altitude and velocity versus time plots in the FRR report for the full-scale Launch Vehicle.	**(1)** Altimeter flight profile data is provided in the FRR report with accompanying altitude and velocity versus time plots. **(2)** The flight profile graph includes data from liftoff through landing.	**(1) Inspection:** Verify that the altimeter flight profile data is included in the FRR report. **(2) Inspection:** Confirm that the altitude and velocity versus time plots cover the entire flight from liftoff to landing.	Verified	Recovery	**(1) & (2)** The altimeter flight profile graph for the VDF can be seen in Section2. See Figures 2.2, 2.6, 2.10, and 2.9.
2.19.1.8.2	Quality pictures of the as landed configuration of all sections of the Launch Vehicle SHALL be included in the FRR report. This includes, but is not limited to: Nose Cone, recovery system, airframe, and booster.	The Recovery Lead and Team Lead will include quality photos of the landing configurations for all parts of the Launch Vehicle in the FRR report.	**(1)** High-quality pictures of all sections (Nose Cone, recovery system, airframe, booster) in the as-landed configuration are included in the FRR report. **(2)** The pictures are clear, detailed, and capture the full vehicle configuration post-landing.	**(1) Inspection:** Review the FRR report to ensure that high-quality pictures of the landed configuration are included. **(2) Inspection:** Verify that all required sections (Nose Cone, recovery system, airframe, booster) are clearly represented.	Verified	Project Management, Recovery	**(1) & (2)** Recovery photos of the VDF attempt on 4/5/2025 can be found in Figure 2.5.
2.19.1.8.3	Raw altimeter data SHALL be submitted in .csv or .xlsx format.	The Recovery and Team Lead will submit all raw altimeter data is submitted in .csv or .xlsx format.	**(1)** Raw altimeter data is submitted in either .csv or .xlsx format. **(2)** The data is complete and includes all necessary information for flight analysis.	**(1) Inspection:** Verify that the raw altimeter data is submitted in the correct format (.csv or .xlsx). **(2) Inspection:** Check the completeness and quality of the raw data for analysis.	Verified	Project Management, Recovery	See the separately attached raw altimeter data.

Table 3.1: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
2.19.1.9	Vehicle Demonstration flights SHALL be completed by the FRR submission deadline. No exceptions SHALL be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team will complete the Vehicle Demonstration flights by the FRR submission deadline.	**(1)** The Vehicle Demonstration flight is completed by the FRR submission deadline. **(2)** If a re-flight is required, it is completed with an FRR Addendum submitted by the Addendum deadline. **(3)** Extensions are only requested for re-flights and not for the first-time flight.	**(1) Inspection:** Confirm the completion of the Vehicle Demonstration flight by the FRR submission deadline. **(2) Inspection:** Ensure that an FRR Addendum is submitted if a re-flight occurs.	Verified	Project Management	The VDF re-flight attempt occurred on 4/5/2025 (prior to FRR addendum submission deadline).
2.19.2	Payload Demonstration Flight— All teams SHALL successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown SHALL be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the Launch Vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. Requirements 2.19.2.1-4 SHALL be met during the Payload Demonstration Flight.	The team will launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The Payload Team and Structures Team will ensure that the Launch Vehicle and payload flown are to be flown the exact same as their competition launch.	**(1)** The rocket experiences a stable ascent and smooth recovery events. **(2)** The payload is retained as designed throughout the flight until deployment (if applicable).	**(1) Demonstration:** Proof of successful Payload Demonstration Flight shown in FRR document. **(2) Inspection:** Post-flight payload retention verification proof shown in FRR document.	Verified	Payload, Project Management, Structures	A PDF attempt was performed on 3/8/2025. The payload remained fully contained for the entirety of the flight. See Section 6.3 in the FRR report for the PDF results.
2.19.2.1	The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	The Payload Team does not design a jettisoning payload.	The payload does not jettison.	**Inspection:** Payload is designed not to jettison.	Verified	Integration, Payload	The payload remained fully encased in the Nose Cone for the entire flight (PDF). See Section 6.3 in the FRR report for more PDF details.
2.19.2.2	The payload flown shall be the final, active version.	The Payload Team and Team Lead will ensure that the payload flown during the Payload Demonstration Flight is the final, active version of the payload.	**(1)** The payload flown matches the finalized design. **(2)** The payload is active and functional during flight.	**(1) Inspection:** Inspect payload design prior to PDF. **(2) Demonstration:** Demonstrate proper collection and transmission during PDF flight, providing proof in FRR.	Verified	Payload, Project Management	The payload flown is the final structural version. See Section 4.5 in the FRR report for the manufactured payload details.
2.19.2.3	If Requirements 2.19.2.1-2 are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum SHALL not be required.	The team will adhere to and meet NASA Requirements 2.19.2.1-2. The Team Lead will ensure all criteria for the VDF are complete and submitted before the FRR deadline. If the criteria is not properly met, the team will submit an additional flight and an FRR Addendum.	**(1)** All required data from the original Vehicle Demonstration Flight is complete. **(2)** The data is accurate and included in the FRR package by the deadline.	**Review:** Confirm VDF data is detailed and complete in FRR report document.	Verified	Project Management	VDF data is complete and can be found in Section 2.

Table 3.1: NASA 2024-2025 Vehicle Requirements

NASA Req. No.	Requirement Statement	Planned Action	Verification Success Criteria	Verification Method	Phase	Subsystem Allocation	Verification Results
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline. NO EXTENSIONS SHALL BE GRANTED.	The team will complete the Payload Demonstration Flights by the FRR Addendum deadline.	The Payload Demonstration Flight is successfully completed before the FRR Addendum deadline.	**Demonstration:** PDF submitted by FRR addendum deadline.	Verified	Project Management	The PDF attempt occurred on 3/8/2025 (prior to FRR Addendum deadline).
2.20	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	The team will submit an FRR Addendum if the team needs to complete a Payload Demonstration Flight or a NASA required Vehicle Demonstration Re-flight after the FRR Report.	A complete FRR Addendum is submitted by the deadline if required.	**Demonstration:** VDF re-flight is submitted by FRR addendum deadline.	Verified	Project Management	See the submission for this document (FRR addendum).

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4 Appendices

4.1 Additional Full-Scale Information

4.1.1 2/22/2025 Flight Launch Day Checklist

Initial Flight Launch Day Checklist

4.1.2 3/8/2025 VDF/PDF Flight Launch Day Checklist

VDF/PDF Flight Launch Day Checklist

4.1.3 4/5/2025 VDF Re-Flight Launch Day Checklist

VDF Re-Flight Launch Day Checklist

Full-Scale Night Before Checklist & Packing List

Night Before Checklist

Full-Scale Launch Day Checklist

Full-Scale Launch Day Checklist

Full-Scale Post-Launch Checklist

Full-Scale Post-Launch Checklist

4.2 Additional Subscale Information

Subscale Launch Procedure / Checklist

Subscale Launch Day Checklist

4.3 Team / Club Documentation and Information

NC State University High-Powered Rocketry Club Constitution

NC State University High-Powered Rocketry Club Constitution

4.3.1 Social Media Accounts

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

Signed Safety Acknowledgment/Contract

Signed Safety Acknowledgment/Contract

- Details the safety agreement signed by team members for compliance.

4.4 Safety and Training Materials

NC State University High-Powered Rocketry Club Lab Safety Quiz

NC State University High-Powered Rocketry Club Lab Safety Quiz

- Contains the quiz questions used for training and certifying lab safety knowledge.

High-Powered Rocketry Club Safety Handbook

HPRC Safety Handbook

- Detailed safety guidelines and procedures for the NC State High-Powered Rocketry Club. Includes local RSO rules for Tripoli Rocketry and NAR.

Wake County Waste Disposal Guidelines and Resource Website

Wake County Waste Disposal Guidelines and Resource Website

- A resource website for proper disposal practices in compliance with county regulations.

Energetics Safety

Black Powder Safety Presentation

- A presentation going over the safe handling of energetics and black powder.

First Aid Kit

Safety Bin Inventory

- A detailed list of all of the safety equipment located in the lab's safety bins (first aid kit). Items are located in bins in the NCSU HPRC lab and are transported to the launch field.

4.5 Technical Datasheets

West Systems 105/206 Epoxy Resin Datasheet

West Systems 105/206 Epoxy Resin Datasheet

- Technical information on the properties and use of epoxy resin for rocket construction.

4.6 Mental Health and Support Resources

Mental Health Resource Slide for HPRC General Body Meetings

- Includes resources and contacts for mental health support. Shared during weekly club meetings (General Body Meetings).