7.1 Vehicle Testing

Test	Test ID	Test Description	Requirements Verified	Status
Altimeter Firing Demonstration	VT1	Vacuum chamber test to verify the RRC3's barometric pressure sensor functionality.	TDRR 7	Complete
Sub-Scale Separation Demonstration	VT2	Ground separation testing for the sub-scale vehicle to ensure separation and verify black powder calculations.	TDRR 6, SLH Requirement 3.2	Complete
Coefficient of Drag Test 1	VT3	Verification of theoretical coefficient of drag value for the drogue parachute.	SLH Requirement 3.1	Complete
Coefficient of Drag Test 2	VT4	Verification of theoretical coefficient of drag values for the main parachutes.	SLH Requirement 3.1	Complete
Coefficient of Drag Test 3	VT5	Verification of theoretical coefficient of drag value for the streamer.	SLH Requirement 3.1	Complete
Sub-Scale Launch 1	VT6	The launch of the sub-scale vehicle for acquiring data on the apogee, velocity, acceleration, drift distance, and impact energy.	TDVR 8, SLH Requirement 2.18	Complete
Sub-Scale Launch 2	VT7	The launch of the sub-scale vehicle for acquiring data on the apogee, velocity, acceleration, drift distance, and impact energy.	TDVR 8, SLH Requirement 2.18	Complete
Sub-Scale Launch 3	VT8	The launch of the sub-scale vehicle for acquiring data on the apogee, velocity, acceleration, drift distance, and impact energy.	TDVR 8, SLH Requirement 2.18	Complete
Bulkhead Tensile Test	VT9	Utilized the Instron 5582 Universal Test machine to verify the bulkheads and epoxy will endure recovery forces.	TDVR 7	Complete
Full-Scale Separation Demonstration	VT10	Ground separation testing for the full-scale vehicle to ensure separation and verify black powder calculations.	TDRR 9	Complete
Full-Scale RF Tracking Demonstration	VT11	Verify the range of the RC-HP transmitters can reach at least 2,500 feet.	TDPR 2	Complete
Full-Scale Vehicle Demonstration Flight	VT12	Verify the full-scale launch vehicle's projected performance and ensure the payload system can be properly secured and tested.	SLH Requirement 2.6	Complete
Vehicle Flight Test	VT13	Verify the full-scale launch vehicle's projected performance and ensure the payload system can be properly retained and tested.	SLH Requirement 2.6, SLH Requirement 2.19.1	Complete
ANVIL Shear Pin Retention Demonstration	VT14	Verify the shear pins in the payload section can withstand the deployment of ANVIL	SLH Requirement 2.19.2.1	Complete
Integrated Payload Flight	VT15	Simulating the full mission performance with all components on the full-scale vehicle and payload.	SLH Requirement 2.6, SLH Requirement 2.19.2	Incomplete

7.1.1 VT1: Altimeter Firing Demonstration

Objective: The objective for the altimeter firing demonstration is to verify the altimeters will record data properly and fire the ejection charges at the programmed altitudes.

Justification: The purpose of this demonstration is to validate the use of the RRC3 altimeter and determine if each altimeter records data and ignites the E-matches at the programmed time.

Testing Variables:

- The RRC3 altimeters record data
- The RRC3 altimeters ignite E-matches at the correct times

Equipment:

- 4x Missile Works RRC3 Altimeters
- 8x E-matches
- Vacuum Chamber
- Vacuum Pump
- 9V Battery
- Masks
- Safety Glasses
- Laptop
- Flathead Screw Driver
- FingerTech Switch
- Allen Wrench
- Fire Extinguisher

Safety Precautions:

The E-matches ignite at their preprogrammed altitudes. The ignition of the E-match causes embers that fly off and can potentially cause burns. For this reason, while the test is in progress, team members present for the test will stand at least 5 feet from the vacuum chamber. All flammable materials will be removed the surrounding area within a 5-foot radius. Fire fighting equipment will be on standby. The safety officer and recovery officer must be present for the test.

Procedure:

1. Personal protective equipment will be donned before the test starts.
2. Test members will check the pneumatic oil level of the vacuum pump prior to testing to ensure no damage occurs to the vacuum pump.
3. The Missile Works RRC3 main altimeters will be preprogrammed to deploy the drogue at apogee and the main parachute at 600 feet. The backup altimeters will be programmed to deploy at apogee +1 second and the main parachute backup at 500 feet. One altimeter will be tested at a time.
4. A FingerTech switch will be connected to the "switch" terminals. The FingerTech switch is to be unscrewed until ready for testing.
5. Next a 9V battery is connected to the power terminals. If the RRC3 powers on with the FingerTech unscrewed, the RRC3 will be inspected for faulty connections and the test will restart to ensure a safe environment. If the RRC3 does not power on prematurely, an E-match will be connected to the proper terminal for the respective test, e.g. for the primary drogue, the E-match will be connected to the drogue terminal on the RRC3, etc.
6. Next, the FingerTech switch is closed to power on the RRC3.
7. Testers will stand back in case of a premature firing.
8. After the RRC3 completes its startup cycle, the altimeter, switch, battery, and E-match will be placed in the vacuum chamber.
9. The igniter end of the E-match will be placed outside of the test chamber to protect the vacuum pump from contaminants.
10. The top of the vacuum chamber is placed securely over the chamber to provide a tight seal.
11. The ball valves are checked to be in the correct orientation before pumping may begin. A diagram of the test chamber is shown in Figure 105 below.

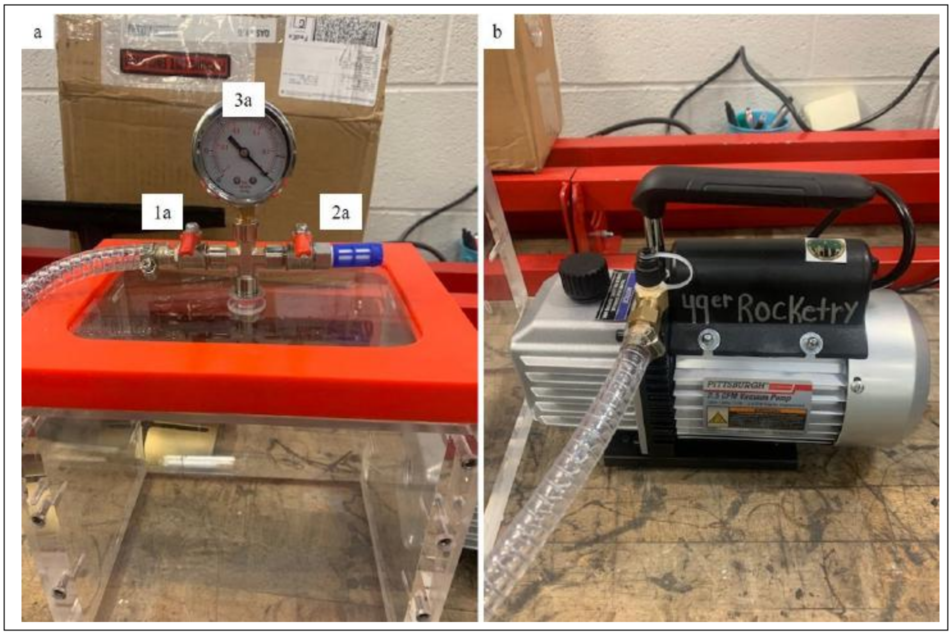


Figure 105: Vacuum Test Chamber and Pump

12. The atmospheric vent ball valve (2a) should remain in the closed position prior to pumping. In the figure above, the ball valve is in the “closed” position.
13. To open the ball valve, the handle should be rotated 90° counterclockwise (from a top down view). The ball valve will be “open” when the handle is in line with the air filter.
14. Next, the vacuum pump handle (1a) should be opened. In the above image, the vacuum pump handle is depicted in the “closed” position.
15. Rotating the handle 90° clockwise will open the ball valve. The handle will be in line with the connecting tube when in the “open” position.
16. The pump is to be powered on and allowed to reach at least -15 inHg (gage). By allowing the vacuum chamber to be depressurized to at least -15 inHg (gage), the altimeter has time to recognize the quick change in pressure and arm itself.
17. Because the E-match wires disrupt the seal of top plate, air will slowly leak in. By keeping all valves closed, the steady influx of atmospheric air will resemble a descent to the altimeter. For drogue deployments, the RRC3 should ignite the E-match shortly after the vacuum pump is powered off. For main deployments, the RRC3 should ignite the E-match at approximately $\frac{1}{2}$ psia.
18. After the test is complete, the atmospheric vent valve (2a) will be opened to ensure the chamber is at equilibrium with the surrounding air.
19. Once the chamber has reached equilibrium, the vacuum valve (1a) will be slowly opened to allow the vacuum pump to reach equilibrium. It is important not to rapidly open valve 1a to protect the vacuum pump from rapid pressurization.
20. Once all components are safe to handle, the chamber lid will be removed and the RRC3 will be powered off via the FingerTech switch.
21. The battery will be disconnected, and the E-match will be disposed of in the proper hazardous waste bin. The RRC3 is then connected to a laptop and the data will be downloaded and inspected for a successful test.

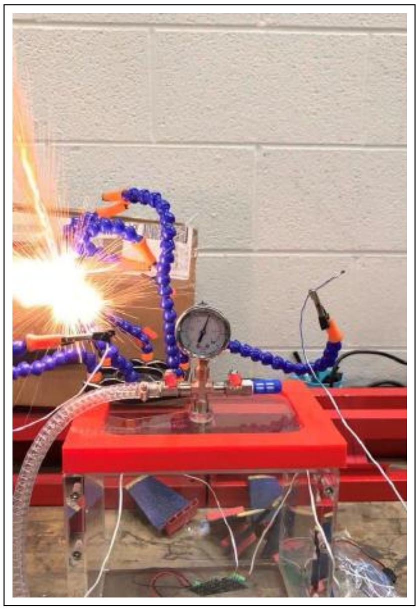
Success Criteria:

Table 98: VT2 Success Criteria

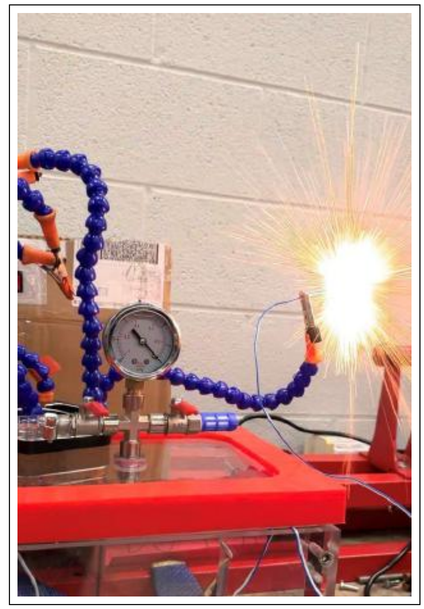
Requirement Verified	Requirement Summary	Success Criteria	Results
TDRR 7	The altimeters will fire at their respective altitudes and detonate the black powder charges.	The drogue primary and backup altimeters detonate 1 second apart.	Pass
		The main primary and backup altimeters detonate at 600 feet and 500 feet respectively.	Pass

Results:

Figure 106 displays the ignition of the drogue and main e-matches.



(a) Drogue E-match Ignition



(b) Main E-match Ignition

Figure 106: Vacuum Chamber Demonstration

All RRC3s were capable of recording data, igniting E-matches, and plotting the data from the demonstration. The drogue E-matches were ignited shortly after the pressure equalized in the vacuum chamber after the pump was turned off. This occurred approximately 1 second after the pump was turned off, and the RRC3s were able to detect a gradual increase in pressure. At 600 feet above the ground, the atmospheric pressure changes by approximately 0.3 inHg, which is not readable on the vacuum gage. The main parachutes deployed shortly after the gage read "0 inHg," which correlates to the inaccuracy of the gage divisions at small increments, as shown in Figure 106b.

Impact on Final Design:

The RRC3s correctly ignited the E-matches at their corresponding times. This was validated by the pressure chamber gage and the recorded data on each RRC3.

7.1.2 VT2 - Sub-Scale Separation Demonstration

Objective: The objective of the separation demonstration is to verify that the vehicle components will properly eject the recovery devices with the theoretically calculated black powder masses.

Justification: The purpose of this demonstration is to validate the use of the calculated black powder mass and recovery system.
Testing Variables:

- Shock cords fully extend

Equipment:

- Sub-Scale vehicle
- $\frac{1}{4}$ inch Kevlar shock cords
- 12.5 inch drogue parachute
- Nomex blankets
- Safety glasses
- Hearing Protection
- 36.5 inch main parachute
- Masks
- Black powder
- Scale
- Funnel
- Wadding
- Wire cutters
- E-matches
- Test stand
- 9V battery
- Aluminum tape
- 10 feet of 20 AWG wire
- Gloves (Latex and machining)
- 4x 1.5mL plastic vials
- Label maker
- 2-56 Nylon shear pins
- Fire Extinguisher

Safety Precautions:

To ensure the maximum achievable safe environment for this test, only essential personnel are allowed to be within 15 feet of the live black powder charges at any time. The recovery officer is the only individual allowed to measure, pack, and arm the black powder charges. Latex gloves are to be worn at all times by any persons handling electronics and black powder to ensure no electrostatic discharge prematurely ignites the charges. Safety glasses will be worn by all individuals who are in the presence of the test, and during the setup of the test. Hearing protection is to be worn at all times during live testing. Noise Reduction Rating (NRR) 25 dB (or better) earmuffs and/or ear plugs are required for individuals within 30 feet of the live fire event. Fire fighting equipment will be kept on hand at all times during testing.

Procedure:

1. Calculate the required mass of black powder using an Excel calculator and verify with a MATLAB code.
2. The safety officer and/or the back up officer is required to be present during the handling of black powder.
3. Don personal protective equipment prior to handling black powder.
4. The recovery officer will measure the exact amount of of black powder needed for testing by taring a small scale and slowly adding black powder until the required amount is reached.
5. The black powder is to be transferred into a capped funnel to be transferred into a prelabeled black powder vial. Each vial is to be named after its respective charge e.g., DB = Drogue Backup, MP = Main Primary, etc. A "P" or "B" will denote the payload or the booster section respectively.
6. Once all vials are filled, the black powder container is to be carefully resealed and placed back into storage.
7. The avionics bay is assembled and all components are checked to ensure no power is connected and all capacitors are fully discharged.
8. If capacitors are not fully discharged, a multimeter will be connected to each terminal on the capacitor to allow for full discharge.
9. The safety officer will inspect the avionics, if they are deemed safe the recovery officer can begin loading the black powder into the avionics bay.
10. The respective labeled vial will be used to fill the capped funnel and the black powder will transferred into the charge cup.
11. An E-match is to be prepared by removing the safety coverings and stripping the wires to ensure a good connection to the E-match terminal. Both wires are to be separated to prevent any shorts from occurring.
12. An E-match will be placed into charge cup and filled with black powder. The recovery officer is the only individual who can handle the E-matches at this point.
13. Wadding will be added to the top of the black powder until the charge cup is full.
14. Once the charge cup is full, a strip of aluminum tape is cut and placed over the top of the charge cup.
15. The E-match is fed through a hole in the avionics bay. The hole is then covered by electrical tape on both sides to protect the electronics.
16. The E-match is then fed through the pressure relief holes for the avionics bay to the outside of the body tube.
17. Once fully secured to the body tube, the shock cords and Nomex wrapped parachute will be attached. The recovery officer must wear machining gloves to protect their hands in the case of accidental ignition by the black powder.
18. When the parachutes and shock cords are fully attached, the respective body tube is attached, and shear pins are inserted to secure the two tubes together.
19. The test sections are placed on a test stand and 10 ft of 20 AWG (American Wire Gage) wire is attached to each end of the E-match. The wire is to ensure the black powder is ignited at a safe distance. Safety glasses and hearing protection are to be worn by all attending personnel.
20. The recovery officer will start a countdown and touch the 9V battery to each wire simultaneously. If the black powder does not ignite, the countdown will start again. If the black powder does not detonate a second time, the recovery officer and safety officer will wait 2 minutes before approaching the body tubes. Once the time has elapsed, the recovery officer will approach the tubes and remove the E-match as safely as possible, and the process will start over. If the black powder charge detonates but does not separate the tubes, the tubes, shock cords, parachutes, and avionics bay will be inspected for damage. If the black powder detonates and successfully separates the two pieces of the launch vehicle, the aforementioned components will still be inspected for damage, but the test will be considered a success, assuming no damage has occurred.
21. The vehicle sections are collected, and the E-match are removed from the avionics bay and disposed of in the proper hazardous waste bin.

Success Criteria:

Table 99: VT1 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDRR 6	The sub-scale vehicle will be capable of separating the drogue and main parachute sections.	The sections completely separate	Pass
		The parachutes are ejected from the airframe	Pass
		The shock cords are ejected from the airframe	Pass
SLH Requirement 3.2	Each team will preform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	The sections completely separate	Pass

Results:

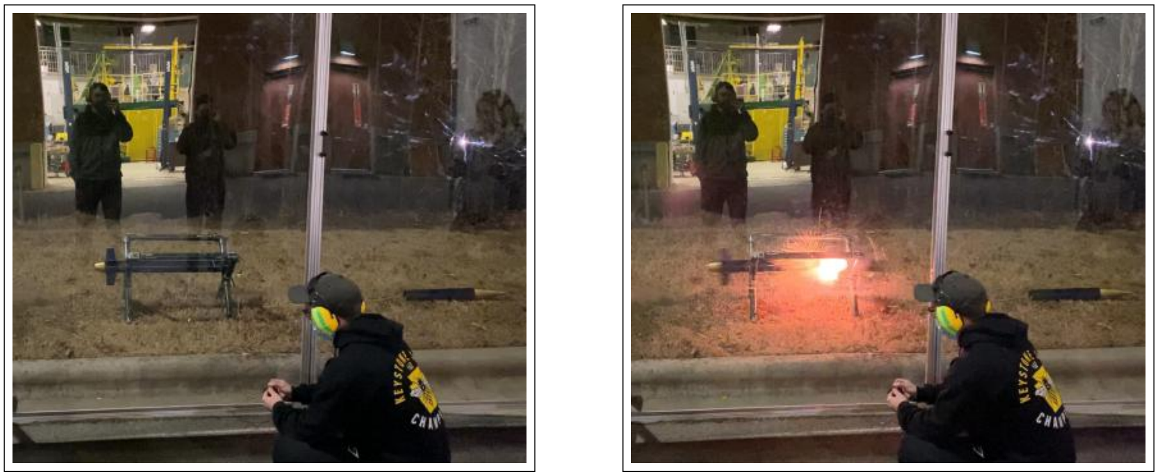
The sub-scale successfully ejected the drogue and main parachutes with the theoretically calculated black powder charges. The drogue and main parachutes were completely ejected with all of their shock cords taught. No damage was suffered by any components during the ejection process.

(a) Pre-ignition

(b) Drogue Ignition

Figure 107: Drogue Separation Test

The drogue deployment test fully expelled the shock cord and drogue parachute from the drogue compartment. The shock cord was fully extended upon deployment. Figure 107b depicts the black powder breaking the shear pins fully. Figure 108 depicts the main parachute deployment test. As shown in image 108b, the drogue section can be seen laying on the ground in front of the main section. This is the aftermath of the drogue separation test.



(a) Main Parachute Pre-ignition (b) Main Parachute Ignition

Figure 108: Main Separation Test

Figure 109 displays the aftermath of the main parachute deployment test. The booster section can be seen on the left of the image on the ground, and the avionics bay is shown on the far right stuck into the ground from the deployment forces. The main parachute can be seen at the end of the body tube of the payload section.

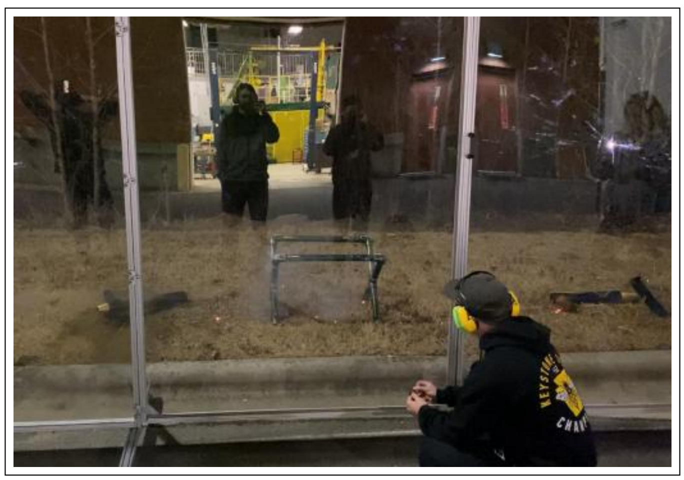


Figure 109: Main Parachute Deployed

All tests are classified as successful deployments.

Impact on Final Design:

If the calculated black powder masses did not eject the parachutes or separate the sub-scale components, the test would have been classified as a failure and recalculations on the black powder masses would have been made. Because this test was classified as a success, there is no need to increase the black powder masses.

7.1.3 VT3 - Coefficients of Drag Test 1

Objective: The objective of this test is to verify the theoretical coefficient of drag the 12.5 inch drogue.

Justification: It is necessary to find the empirical coefficient of drag for the 12.5 inch drogue parachute to accurately determine the descent velocity of the booster section under the drogue stage.

Testing Variables:

1. Parachute Coefficient of Drag

2. Velocity of the Mass Element

Equipment:

- 12.5 Inch Drogue
- 5 lb Weight
- Shock Cord
- 7 Story Parking Deck
- Hardhat
- Laptop
- Microsoft Excel

Safety Precautions:

Team members should never climb on top of the railings on the parking deck. Team members should not be directly below the falling weight. Before the mass element is dropped from the parking deck, the team member who is releasing the parachute/streamer will shout below to warn any bystanders. A team member will stand on ground level, and at least 75 feet from the test to ensure no one is allowed near the test. This member is required to wear a hardhat. The safety officer must be present for this test.

Procedure:

1. The atmospheric pressure and temperature is recorded.
2. The 12.5 inch drogue is attached to the 5 lb weight via a small shock cord.
3. A member of the team will stand on the ground at least 75 feet from the testing area with a hardhat to warn any bystanders who walk by.
4. The team member on top of the parking deck will shout below that the test is about to begin.
5. If the team member on the ground gives the "all clear", the parachute is dropped from the top of the parking deck and timed.
6. A shock cord with a quick link is thrown over the side of the parking deck to be attached to the 5 lb weight to expedite the testing process.
7. The 5 lb weight is attached to the shock cord and pulled to the top of the parking deck for retesting.
8. A phone is used to collect all data.
9. The test is repeated four more times, for a total of 5 trial runs.
10. After all data is collected, the data is upload into Excel to find the velocity of the mass. From this, and the known atmospheric density, the coefficient of drag can be found.

Success Criteria:

Table 100: VT3 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 3.1	Drogue recovery is deployed at apogee, and main parachutes at a lower altitude. Streamer recovery is permissible, provided that the kinetic energy during drogue descent is reasonable.	The coefficients of drag for the drogue parachute is found.	Pass
		The coefficient of drag is similar to the theoretical value.	Pass

Results:

The distance to the ground from the top of the deck is 69 feet. Using this known distance and the time it took for the weight to fall, Equation 21 can be used to calculate the coefficient of drag.

$$\mathrm{Cd} = \frac{2 \cdot \mathrm{W}}{\rho \cdot v^2 \cdot \mathrm{A}} \tag{21}$$

Here, W is the combined weight of the $5\mathrm{lb_m}$, parachute, and quick link. The atmospheric density (ρ) was calculated using the values recorded at the time of the test. These variables are shown in Table 101.

Table 101: Drogue Cd Test Atmospheric Data

Variable	Value
Temperature (°F)	46
Humidity (%)	37
Dew Point (°F)	27
Pressure (Pa)	101659.39
ρ $(\frac{\text{lb}}{\text{ft}^3})$	0.0786

Below in Table 102, the coefficients of drag for the 12.5 inch drogue are depicted. The average descent velocity was 34.7 ft/s, and the average coefficient of drag of the drogue was 1.59. The expected coefficient of drag for the drogue was 1.5, creating a percent error of 6%.

Table 102: 12.5 Inch Drogue Cd

Trial	Time (sec)	Velocity (ft/s)	Cd
1	2.07	33.33	1.79
2	2	34.5	1.61
3	1.95	35.38	1.5
4	1.9	36.32	1.38
5	2.03	33.99	1.69

Impact on Final Design:

The drogue parachute was found to have a coefficient of drag that is close to the theoretical value given by the manufacturer. The drift calculations shall be updated and the new coefficient of drag will be used.

7.1.4 VT4 - Coefficients of Drag Test 2

Objective: The objective of this test is to verify the theoretical coefficient of drag the parachutes will produce.

Justification: It is necessary to find the empirical coefficients of drag for each main parachute to accurately determine the descent velocity of the booster/payload sections.

Testing Variables:

1. Main Parachute Coefficients of Drag

Equipment:

- 72 Inch Parachute
- 84 Inch Parachute
- Quick Link
- 3.5 Foot Industrial Fan
- 2 Foot Fan
- DuPont Stren Fishing Scale
- Aircraft Stainless Steel Lock Wire
- Wind Gage
- Honeycomb Airflow Straightener
- Stopwatch
- 10 Foot Step Ladder
- Scale
- Laptop
- Microsoft Excel

Safety Precautions:

Team members should never put their fingers inside the fan. Team members should be aware of the fan inlet area to ensure no stray debris is sucked into the ducts. During recovery of the parachute, it is important to catch the parachute to keep the fans from pulling the chutes into the ducts.

Procedure:

1. The temperature, barometric pressure, humidity, and dew point are all recorded prior to testing.
2. Two swivel chairs are used to act as standoffs for the fans.
3. The 3.5 foot industrial fan is placed on the edges of the chairs to allow maximum airflow upwards.
4. The 2 foot fan is placed on the railings underneath the industrial fan to supply more volumetric airflow through the industrial fan.

5. The honeycomb airflow straightener is placed on top of the industrial fan to help reduce turbulence and vortices created by the spinning blades of the fans. This reduces the swaying of the parachute during testing; thus, the accuracy of the measurements are increased.
6. The honeycomb is tied to the top of the industrial fan via the aircraft stainless steel lock wire.
7. The lock wire is fed through the honeycomb channels and into the fan guard, where it is tied off and cut.
8. After securing the honeycomb to the fan guard, another wire is run across the honeycomb's top surface. A small loop is created in the wire to allow the DuPont scale to be securely attached.
9. The 10 foot step ladder is brought within reach of the testing setup, but not within 2 feet to allow for clearance for the parachutes and to keep the free stream airflow uninterrupted.
10. The fans are both powered on and set to their highest settings.
11. The parachute, quick link, and DuPont scale are weighed together to determine the force the parachute must exert to lift the testing apparatus. The total weight is recorded.
12. Once the fans are at full speed, the 84 inch parachute is attached via a quick link to the DuPont scale. The parachute is to be held shut and walked up the step ladder to the top.
13. Once the parachute is above the fans, it is released and allowed to open.
14. The force on the scale is read and recorded once the parachute is fully opened and stable.
15. The parachute is collected by holding the shroud lines and disconnected from the scale.
16. The wind gage is used to measure the free stream velocity. The gage is held halfway between the apex of the parachute and where the shroud lines connect to the canopy.
17. The wind gage captures the average wind speed over the course of one minute. This is timed using the stop watch.
18. The average wind speed is recorded.
19. Steps 11 through 18 are repeated two additional times for the 84 inch parachute. A total of three trials are to be completed.
20. Steps 11 through 18 are repeated three times for the 74 inch parachute.

Success Criteria:

Table 103: VT3 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 3.1	Drogue recovery is deployed at apogee, and main parachutes at a lower altitude. Streamer recovery is permissible, provided that the kinetic energy during drogue descent is reasonable.	The coefficients of drag for the parachutes are found.	Pass
		The coefficients of drag are similar values to the theoretical value of each parachute.	Pass

Results:

The testing setup is depicted in Figure 110. Three team members are shown completing the test for the 84 inch main parachute.

Figure 110: 84 Inch Parachute Test Setup

Below in Table 104, the recorded values for the ambient atmospheric data are shown. These values allowed for an accurate calculation of the air density inside the Motorsports Research Lab (MSR) at the time of the test. The total weight of the parachute, quick link, and DuPont scale are also tabulated.

Table 104: Parachute Cd Data

Variable	Recorded Value
Temperature (°F)	71
Barometric Pressure (Pa)	99712.8
Humidity (%)	43.6
Dew Point (°F)	47.5
ρ ($\frac{\text{lb}}{\text{ft}^3}$)	0.0708
84 Inch Parachute Weight (lbs)	1.45
72 Inch Parachute Weight (lbs)	1.18

Table 105 depicts the recorded data from the 84 inch main parachute test. The "Force" category is the recorded force from the DuPont scale. The "Total Force" category incorporates the additional weight of the parachute, quick link and DuPont scale. Using all of the recorded data and Equation 22 shown below, the coefficients of drag were calculated.

$$\text{Cd} = \frac{2 \cdot \text{F}_\text{d}}{\rho \cdot v^2 \cdot \text{A}} \tag{22}$$

Table 105: 84 Inch Main Parachute Test Data

Trial	Force (lb)	Total Force (lb)	Wind Speed (ft/s)	Cd
1	2.0	3.45	6.0	2.25
2	2.1	3.55	6.3	2.11
3	1.8	3.25	5.9	2.23

The average coefficient of drag from the three trial runs was 2.197. The theoretical value given by the manufacturer is 2.2, which creates a percent difference of 0.136%. Variation in the wind speed caused by the turbulent flow and vortices created by the spinning fan blades is likely to account for the differences between each test. The honeycomb mesh helped reduce turbulence, but could not eliminate it entirely.

The results from the 72 inch parachute test are tabulated below in Table 106.

Table 106: 72 Inch Main Parachute Test Data

Trial	Force (lb)	Total Force (lb)	Wind Speed (ft/s)	Cd
1	1.7	2.88	6.3	2.33
2	1.9	3.08	6.9	2.08
3	1.8	2.98	6.6	2.2

The average coefficient of drag from the three trials is 2.203. The theoretical value of the 72 inch parachute is 2.2. This produced a percent difference of 0.136%.

Impact on Final Design:

The coefficient of drag for each parachute is similar enough to the theoretical value that it is quixotic to believe the drift distances will be substantially larger with the new coefficients of drag.

7.1.5 VT5 - Coefficients of Drag Test 3

Objective: The objective of this test is to verify the theoretical coefficient of drag the streamer will produce via a test launch.

Justification: This test is to find the empirical coefficients of drag for the streamer.

Testing Variables:

1. Streamer Coefficient of Drag
2. Velocity of Vehicle Descent

Equipment:

See section 6.3.1 for all components of the full-scale vehicle.

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 300 feet from the launch vehicle (500 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

See section 6.3.1 through 6.3.1 for full assembly procedures.

Success Criteria:

Table 107: VT3 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 3.1	Drogue recovery is deployed at apogee, and main parachutes at a lower altitude. Streamer recovery is permissible, provided that the kinetic energy during drogue descent is reasonable.	The coefficients of drag for the streamer is found.	Pass
		The coefficients of drag are reasonable values that justify the use of each recovery device.	Pass

Results:

The streamer coefficient of drag was calculated from vehicle test 12 (Section 7.1.12). The payload section during the full-scale launch successfully deployed the streamer and recorded descent rates during streamer deployment. From the known mass of the payload section, the average descent velocity, and the atmospheric data recorded prior to launch, the coefficient of drag was calculated. The launch day atmospheric data is shown in Table 108.

Table 108: Launch Day Atmospheric Data

Variable	Value
Temperature (°F)	64
Humidity (%)	41
Dew Point (°F)	40
Pressure (Pa)	101760.98
ρ ($\frac{\text{lb}}{\text{ft}^3}$)	0.0758

The mass of the payload section was 16.85 lbs. Using this, and the data in Table 108, the coefficient of drag was calculated and is shown in Table 109.

Table 109: Streamer Coefficient of Drag

Payload Altimeter	Descent Rate (ft/s)	Cd
Primary	95.97	0.0774
Backup	96.67	0.0763

The original estimation for the coefficient of drag for the streamer was 0.08. The average of the two sections produced a coefficient of drag of 0.0769, with this empirical data, a percent difference was calculated between the estimation and the tested data and found to be 4.02% different from the original estimation.

Impact on Final Design:

The streamer successfully allowed the payload section to descend faster than the booster section during the drogue stage of recovery. Streamer recovery is now proven to work effectively as a drogue recovery stage.

7.1.6 VT6: Sub-Scale Launch 1

Objective: The sub-scale launches were preformed to verify the aerodynamic properties of the full-scale vehicle, the accuracy of the simulators used, and the success of recovery deployment.

Justification: The sub-scale flights predict the aerodynamic characteristics of the full-scale vehicle. The stability of the sub-scale vehicle will correlate to the stability of the full-scale vehicle if the CP and CG are similar.

Testing Variables:

1. Apogee
2. Acceleration
3. Velocity
4. Drift Distance
5. Impact Energy

Equipment:

- Sub-Scale Vehicle
- J-500G Motor
- 4x E-matches
- 12.5 Inch Drogue
- 38 Inch Parachute
- Avionics Bay
- 2x RRC3 Altimeter
- 2x 9V Battery
- Payload Mass Substitute
- RC-HP Tracker
- R-300A "Hot-Cold" Gun
- Black Powder
- Wadding
- 2x Nomex Blanket
- 3x Shock Cord
- Motor Igniter
- 4x 2-56 Nylon Shear Pins
- 2x $\frac{1}{4}$-20 Bolts
- 2x $\frac{1}{4}$-20 Nuts
- Fire Extinguisher

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 100 feet from the launch vehicle (200 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

1. The safety officer is present for the handling of black powder and the motor assembly. Only essential personnel are allowed within 15 feet.
2. The avionics bay (AV bay) is assembled with the 9V batteries on the launch field by the recovery officer.
3. E-matches and black powder is loaded into the AV bay.
4. The assembled AV bay is loaded into the launch vehicle.
5. The avionics bay is secured to the air frame via two $\frac{1}{4}$-20 bolts and nuts that attach to a permanent bulkhead inside the vehicle.
6. The mass equivalent payload is inserted and secured to the air frame.
7. The shock cords, and parachutes are attached to the air frame.
8. An RC-HP is attached to a shock cord and powered on.
9. Shear pins are inserted into the separation points to hold the vehicle together.
10. The motor is not to be inserted into the rocket until cleared by the RSO.
11. When cleared by the RSO, the launch vehicle will be brought to an 8 foot 10x10 launch rail.
12. The altimeters are powered on. If any altimeter does not power on, the launch vehicle is powered off and returned to home base for inspection.
13. After launch, the data from the RRC3s is downloaded and recorded for analysis of the acceleration, velocity, altitude, drift distance, and impact energy.

Success Criteria:

Table 110: VT4 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 8	The sub-scale launch vehicle will achieve an altitude within 5% of the simulated sub-scale altitude.	The sub-scale vehicle will reach an altitude within 5% of 3,151 ft, per launch day conditions.	Fail
SLH Requirement 2.18	A sub-scale vehicle will be successfully launched and recovered.	The sub-scale vehicle will be recoverable and reusable after achieving an apogee within 5% of the simulated altitude.	Fail
SLH Requirement 2.18.2	The subscale model will be capable of carrying an altimeter for recording data.	The subscale vehicle will contain 2 altimeters.	Pass

Results:

The first sub-scale launch was not deemed successful due to the motor failure. The launch vehicle did not reach a minimum altitude of 300 feet to arm the altimeters. The RRC3s are programmed to arm at 300 feet in case a CATO occurs. This helps keep the process of the recovery of the vehicle components safe. After careful analysis of the vehicle components and assembly process, it was found that the absence of the delay grain caused the motor to fail catastrophically. To prevent this in the future, all components of the motor are to be included in the motor assembly process.

Impact on Final Design:

No data was collected from the RRC3s during this launch. But to prevent further motor failures, a NAR mentor will oversee the motor construction.

7.1.7 VT7: Sub-Scale Launch 2

Objective: The sub-scale launches were preformed to verify the aerodynamic properties of the full-scale vehicle, the accuracy of the simulators used, and the success of recovery deployment.

Justification: The sub-scale flights predict the aerodynamic characteristics of the full-scale vehicle. The stability of the sub-scale vehicle will correlate to the stability of the full-scale vehicle if the CP and CG are similar.

Testing Variables:

1. Apogee
2. Acceleration
3. Velocity
4. Drift Distance
5. Impact Energy

Equipment:

- Sub-Scale Vehicle
- J-500G Motor
- 4x E-matches
- 12.5 Inch Drogue
- 38 Inch Parachute
- Avionics Bay
- 2x RRC3 Altimeter
- 2x 9V Battery
- Payload Mass Substitute
- RC-HP Tracker
- R-300A "Hot-Cold" Gun
- Black Powder
- Wadding
- 2x Nomex Blanket
- 3x Shock Cord
- Motor Igniter
- 4x 2-56 Nylon Shear Pins
- 2x $\frac{1}{4}$-20 Bolts
- 2x $\frac{1}{4}$-20 Nuts
- Fire Extinguisher

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 100 feet of the launch vehicle (200 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

1. The safety officer is present for the handling of black powder and the motor assembly. Only essential personnel are allowed within 15 feet.
2. The avionics bay (AV bay) is assembled with the 9V batteries on the launch field by the recovery officer.
3. E-matches and black powder is loaded into the AV bay.
4. The assembled AV bay is loaded into the launch vehicle.
5. The avionics bay is secured to the air frame via two $\frac{1}{4}$-20 bolts and nuts that attach to a permanent bulkhead inside the vehicle.
6. The mass equivalent payload is inserted and secured to the air frame.
7. The shock cords, and parachutes are attached to the air frame.
8. An RC-HP is attached to a shock cord and powered on.
9. Shear pins are inserted into the separation points to hold the vehicle together.
10. The motor is not to be inserted into the rocket until cleared by the RSO.
11. When cleared by the RSO, the launch vehicle will be brought to an 8 foot 10x10 launch rail.
12. The altimeters are powered on. If any altimeter does not power on, the launch vehicle is powered off and returned to home base for inspection.
13. After launch, the data from the RRC3s is downloaded and recorded for analysis of the acceleration, velocity, altitude, drift distance, and impact energy.

Success Criteria:

Table 111: VT5 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 8	The sub-scale launch vehicle will achieve an altitude within 5% of the simulated sub-scale altitude.	The sub-scale vehicle will reach an altitude within 5% of 3,032 ft, per launch day conditions.	Pass
SLH Requirement 2.18	A sub-scale vehicle will be successfully launched and recovered.	The sub-scale vehicle will be recoverable and reusable after achieving an apogee within 5% of the simulated altitude.	Fail
SLH Requirement 2.18.2	The subscale model will be capable of carrying an altimeter for recording data.	The subscale vehicle will contain 2 altimeters.	Pass

Results:

The second sub-scale flight was deemed unsuccessful due to the failure to deploy recovery devices. The motor preformed perfectly, but the parachute did not deploy as intended. The launch vehicle impacted the ground at 111 ft/s, cracking a body tube and breaking multiple fins after reaching an apogee of 3,033 feet. The simulated apogee was 3,032 feet, which is a 0.033% difference from the experimental apogee. The theoretical and experimental apogee of the launch are compared in Figure 111.

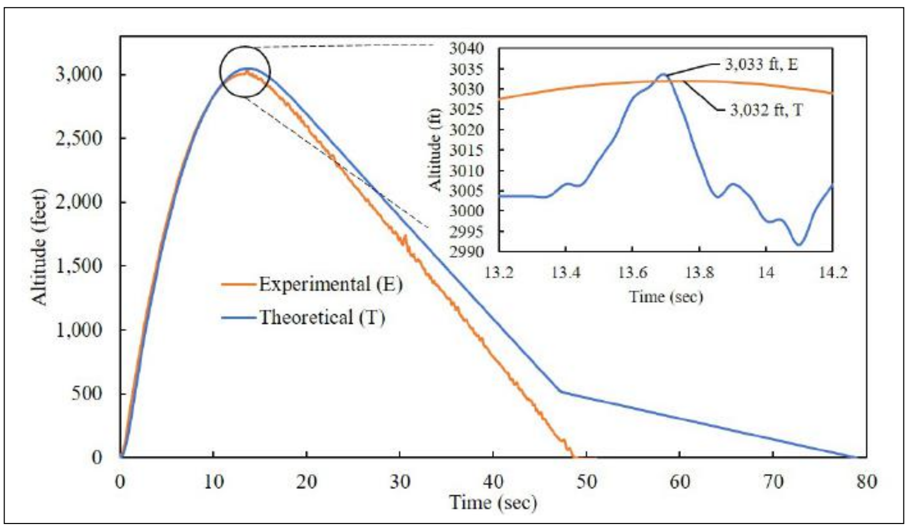


Figure 111: Sub-Scale Flight 2 Apogee Results

The velocity profile for the second sub-scale flight is shown below in Figure 112. The maximum velocity achieved by this flight was 469 ft/s. This is a percent difference of 1.27% from the theoretical maximum velocity.

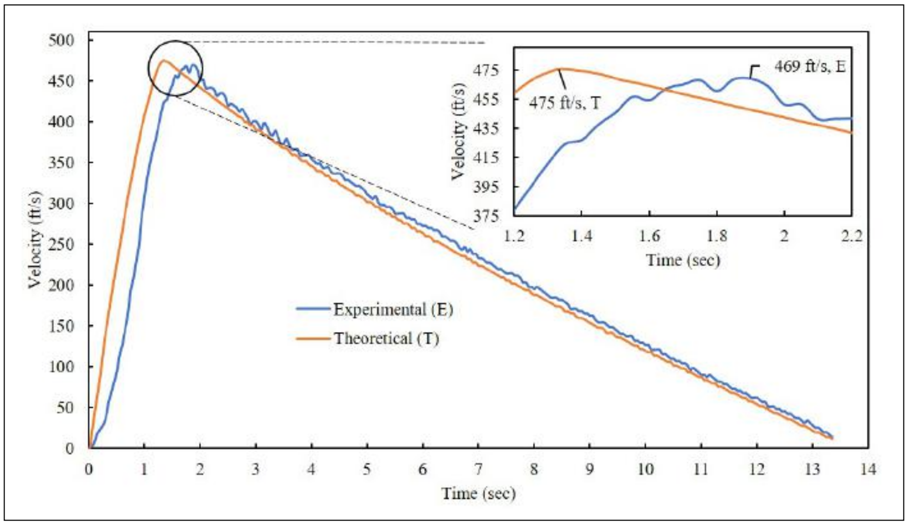


Figure 112: Sub-Scale Flight 2 Velocity Profile

Impact on Final Design:

Due to the failure to deploy properly, the black powder masses were increased by 25%. The order in which the parachutes and shock cord are packed will also be changed so that the parachutes are packed closest to the charge bay to ensure ejection from the vehicle.

7.1.8 VT8: Sub-Scale Launch 3

Objective: The sub-scale launches were preformed to verify the aerodynamic properties of the full-scale vehicle, the accuracy of the simulators used, and the success of recovery deployment.

Justification: The sub-scale flights predict the aerodynamic characteristics of the full-scale vehicle. The stability of the sub-scale vehicle will correlate to the stability of the full-scale vehicle if the CP and CG are similar.

Testing Variables:

1. Apogee
2. Acceleration
3. Velocity
4. Drift Distance
5. Impact Energy

Equipment:

- Sub-Scale Vehicle
- J-500G Motor
- 4x E-matches
- 12.5 Inch Drogue
- 38 Inch Parachute
- Avionics Bay
- 2x RRC3 Altimeter
- 2x 9V Battery
- Payload Mass Substitute
- RC-HP Tracker
- R-300A "Hot-Cold" Gun
- Black Powder
- Wadding
- 2x Nomex Blanket
- 3x Shock Cord
- Motor Igniter
- 4x 2-56 Nylon Shear Pins
- 2x $\frac{1}{4}$-20 Bolts
- 2x $\frac{1}{4}$-20 Nuts
- Fire Extinguisher

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 100 feet of the launch vehicle (200 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

1. The safety officer is present for the handling of black powder and the motor assembly. Only essential personnel are allowed within 15 feet.
2. The avionics bay (AV bay) is assembled with the 9V batteries on the launch field by the recovery officer.
3. E-matches and black powder is loaded into the AV bay.
4. The assembled AV bay is loaded into the launch vehicle.
5. The avionics bay is secured to the air frame via two $\frac{1}{4}$-20 bolts and nuts that attach to a permanent bulkhead inside the vehicle.
6. The mass equivalent payload is inserted and secured to the air frame.
7. The shock cords, and parachutes are attached to the air frame.
8. An RC-HP is attached to a shock cord and powered on.
9. Shear pins are inserted into the separation points to hold the vehicle together.
10. The motor is not to be inserted into the rocket until cleared by the RSO.
11. When cleared by the RSO, the launch vehicle will be brought to an 8 foot 10x10 launch rail.
12. The altimeters are powered on. If any altimeter does not power on, the launch vehicle is powered off and returned to home base for inspection.
13. After launch, the data from the RRC3s is downloaded and recorded for analysis of the acceleration, velocity, altitude, drift distance, and impact energy.

Success Criteria:

Table 112: VT6 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 8	The sub-scale launch vehicle will achieve an altitude within 5% of the simulated sub-scale altitude.	The sub-scale vehicle will reach an altitude within 5% of 3,084 ft, per launch day conditions.	Pass
SLH Requirement 2.18	A sub-scale vehicle will be successfully launched and recovered.	The sub-scale vehicle will be recoverable and reusable after achieving an apogee within 5% of the simulated altitude.	Pass
SLH Requirement 2.18.2	The subscale model will be capable of carrying an altimeter for recording data.	The subscale vehicle will contain 2 altimeters.	Pass

Results:

The third sub-scale flight was deemed a success. The launch vehicle reached an altitude of 3,030 feet AGL. This was a 54 foot difference (or 1.78%) from the simulated apogee. This error may have occurred due to a high wind gust upon takeoff. The changes made from the first and second launch helped achieve a successful launch. Reviewing the RRC3 data shown in Figure 113, it can be seen there is a pressure spike at deployment. This is indicative of a pressure leak into the AV bay. This is undesirable as it causes premature ejection of the main parachute.

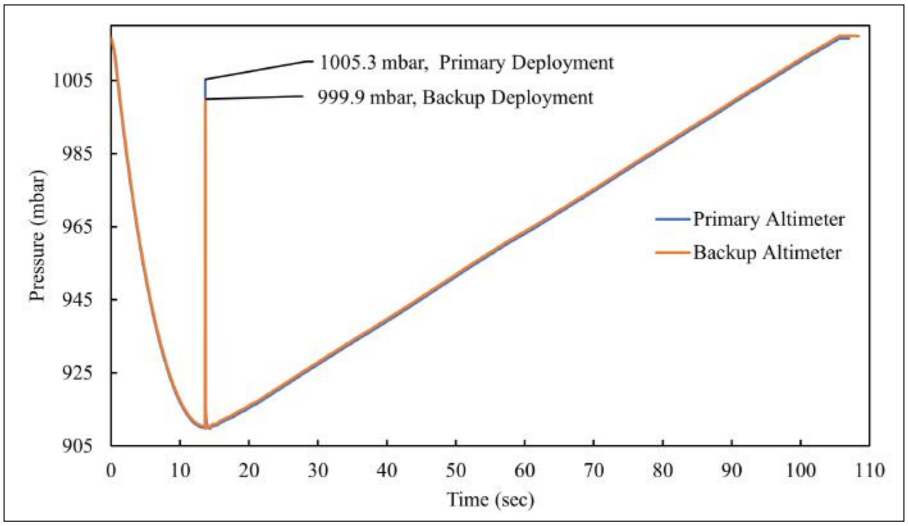


Figure 113: Sub-Scale Flight 3 Pressure Results

There is no second spike from the backup charge deploying because the vehicle had already separated from the first charge. No pressure could build up inside the vehicle, so the altimeters did not read a pressure spike.

The recorded altitude from the flight is shown in Figure 114. The altitude dips to around 300 ft and 450 ft for the primary and backup altimeter respectively. These spikes occur at the same time as Figure 113. Further investigating these spikes, by converting the value at each pressure spike into an altitude, the same altitude is found as shown below.

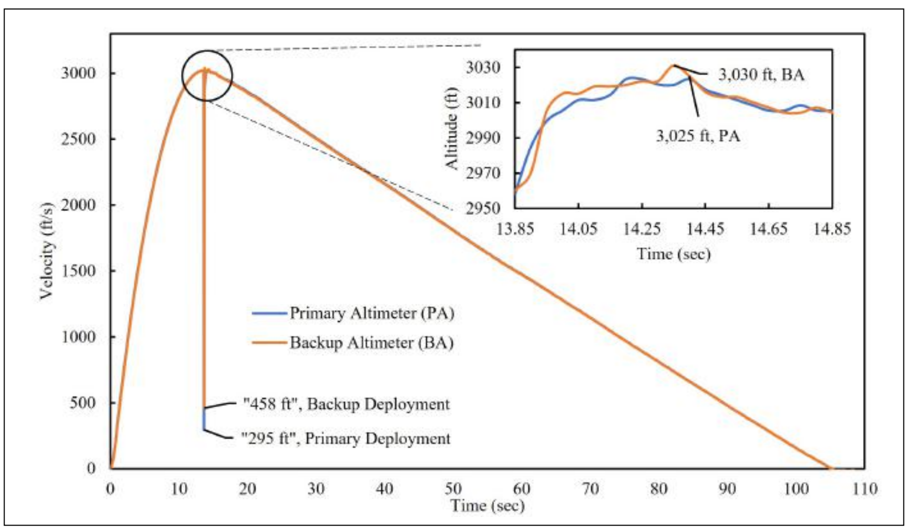


Figure 114: Sub-Scale Flight 3 Altitude Results

The correlation between the pressure and altitude spikes provides evidence of a pressure leak in the avionics bay. Below in Figure 115, the acceleration from the primary and backup altimeter is shown. This plot was created by the change in velocity per time step as recorded by the RRC3.

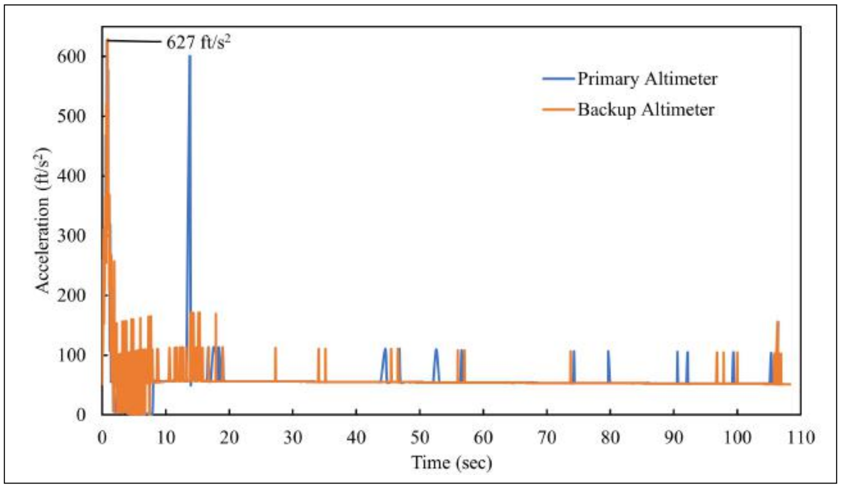


Figure 115: Sub-Scale Flight 3 Acceleration Results

The maximum acceleration achieved by the sub-scale was 627 ft/s^2. This was a 1 ft/s^2 (0.157%) difference from the simulated maximum acceleration of 628 ft/s^2. The sub-scale drifted approximately 3,000 feet down range, and the booster impact energy was calculated to be 53 ft-lb$_f$. This was the highest impact energy of the sections. The maximum velocity achieved by this launch was 457 ft/s. This is a 3.8% difference from the simulated value of 475 ft/s.

Impact on Final Design:

Due to the unexpected pressure spike in the altimeter data, the AV bay will be better sealed to prevent this occurring on the full-scale design. An O-ring will be used to seal the avionics bay from the deployment pressures and the holes for the E-matches in the bulkheads will be sealed with hot glue.

7.1.9 VT9 - Bulkhead Tensile Testing

Objective: The objective of the bulkhead tensile test is to verify that all bulkheads will properly withstand the forces of launch and recovery.

Justification: The purpose of this test is to verify the full-scale bulkheads are capable of withstanding launch and recovery forces.

Testing Variable(s):

1. Bulkhead Eye Bolt Strength
2. Epoxy Strength

Equipment:

- Instron 5582 Universal Tensile Test Machine
- 2x Carbon Fiber Bulkhead
- 2x $\frac{1}{4}$ Inch Shoulder Bolts
- 2x $\frac{1}{4}$ Inch Hole - $1\frac{1}{4}$ Inch Diameter Washers
- 2x $\frac{1}{4}$ Hex Nuts
- Aerospace Epoxy
- Body Tube Test Section
- Masks
- Safety Glasses

Safety Precautions:

The Instron 5582 is an extremely powerful machine capable creating tension forces up to 100kN. For this reason, personnel must take precaution with the placement of their extremities and be always aware of possible dangers. It is possible for the carbon fiber bulkheads to store substantial energy before failure and release this energy by ejecting materials into the surrounding environment; thus, protective eyewear is always required. Test personnel must never place their hands around the test apparatus during testing. During testing personnel must withdraw a minimum distance of 10 ft. If the test needs to be stopped immediately, the emergency stop button will terminate the test instantly.

Procedures:

1. A bulkhead sample is to be manufactured prior to testing. It will be produced in the exact way it is intended to be created for the launch vehicle, but without electronics. Personal protective equipment will be donned before the test begins. Figure 116 displays the Instron 5582 Universal Test machine and key components.

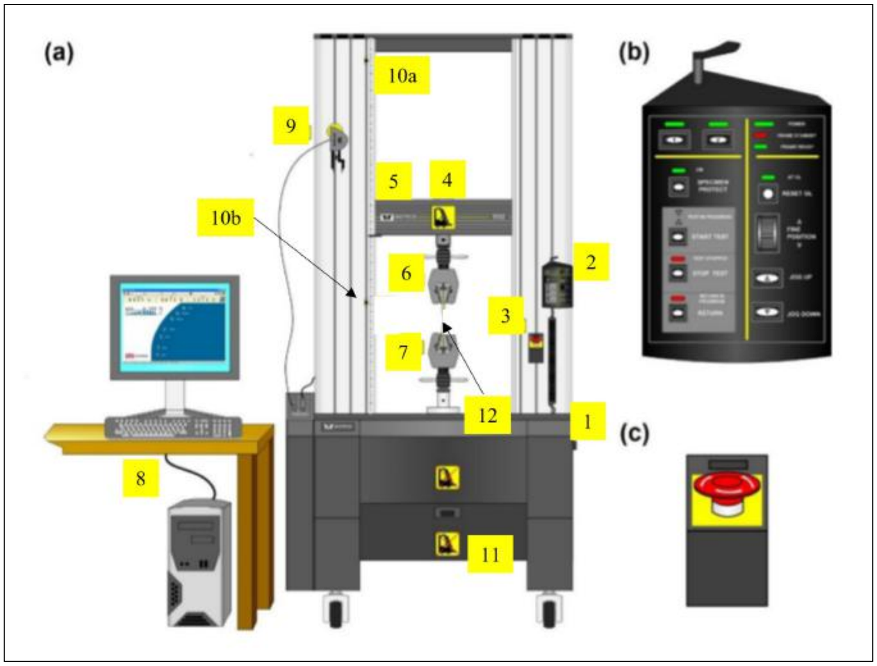


Figure 116: Instron 5582 Universal Testing Machine

Table 113 below lists all labeled components from Figure 116 above.

Table 113: Instron Key Components

Item Number	Description
1	Main power switch
2	Load frame control panel, also shown in 1b. Operators can jog up/down the specimen, reset gauge length, start/stop the test, and operate the crosshead return
3	Emergency stop, also shown in 1c
4	Interchangeable load cell
5	Crosshead
6	Upper grip
7	Lower grip
8	PC with Bluehill 3 software
9	Knife edge extensometer
10a	Upper crosshead stops
10b	Lower crosshead stops
11	Storage drawer
12	Sample

2. The Instron 5582 will be first powered (1) on and allowed to sit for 15 minutes to allow the transducer to warm up.
3. Next the PC is powered on and the software “Bluehill 3” is booted up. Data will be recorded using this software.
4. Wedges are used to clamp and secure the bulkhead for testing. The wedges secure to the shoulder bolts in the bulkhead. The jog buttons can be used to adjust the positioning of the wedges and crossheads for gripping the bulkhead.
5. The bulkhead is attached to the upper wedge first and lowered into place for the lower wedge to be attached. Both wedges are fully tightened onto the bulkhead sample.
6. The “Test” button is pressed on the main screen which opens the testing options.
7. The test type is set to “pull to failure” and the pull rate is set to 5.08 mm/min (0.2 in/min).

8. After verifying the correct test conditions, the "Balance" button on the software is pressed to balance the loading.
9. The start button is pressed to begin the test. The test will finish when the sample is pulled to failure.

Success Criteria:

Table 114: VT7 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 7	The bulkheads within the vehicle will be able to withstand the forces from launch and recovery.	The bulkhead can withstand at least 1.5 times the maximum forces experienced during launch and recovery.	Pass

Results:

The tensile test results are depicted below in Figure 117. The bulkhead made for testing was modeled to be similar to the full-scale bulkheads. It is reasonable to assume the bulkheads in the full-scale will also preform in the same manner as the tested bulkhead.

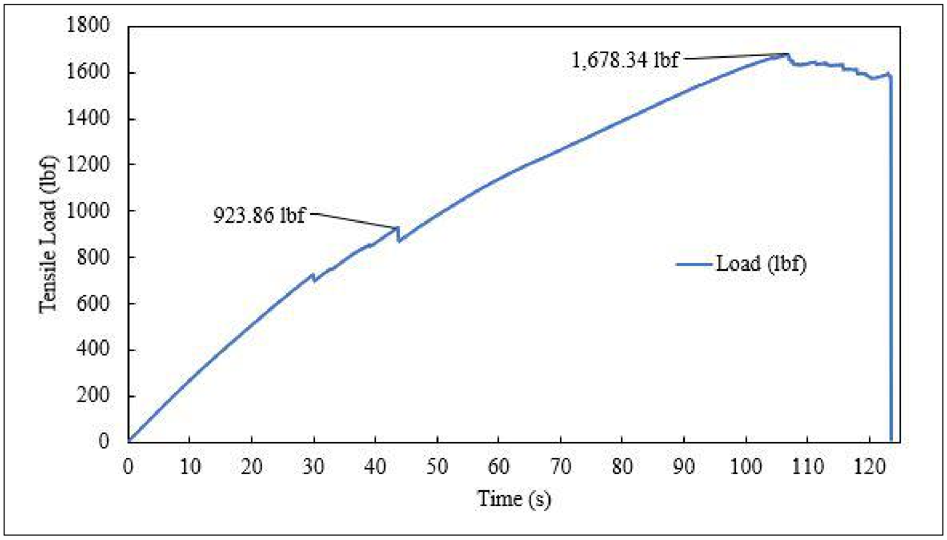
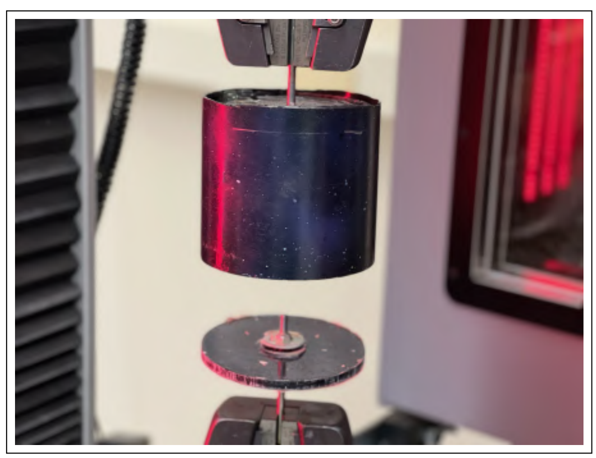


Figure 117: Bulkhead Pull-to-Failure Tensile Test

Below in Figure 118, the pre-tension and post-failure images of the bulkhead are shown.

(a) Pre-Tension



(b) Post-Failure Bulkhead

Figure 118: Pull-to-Failure Bulkhead Test

The bulkhead was able to withstand a maximum of 1,678 lb_f before failure occurred. Shortly before failure, audible cues that the epoxy was failing could be heard as cracking. A video was taken of the test to allow timestamped events to be accurately recorded. The first major audible cracking occurred at approximately 42 seconds into the test, which correlates to 924 lb_f on the graph. In order to maintain fatigue life of the design, the bulkheads should remain under this load even though they are capable of withstanding another 755 lb_f before critical failure.

Impact on Final Design:

The current design for the bulkheads was proved to be more than sufficient for the loading that occurs during flight. The booster section bulkheads have a safety factor of 1.95 with their current design, and the payload section bulkheads have a safety factor of 2.16. This proves they are capable of withstanding launch and recovery forces.

7.1.10 VT10 - Full-Scale Separation Demonstration

Objective: The objective of this demonstration is to determine if the calculated black powder quantities for the full-scale vehicle are large enough to separate the vehicle with enough force to pull the shock cords taught.

Justification: The full-scale separation demonstration needs to be completed to ensure the full-scale vehicle will fully separate upon deployment. By testing the vehicle on the ground, it is likely the vehicle will also deploy in the same manner in flight.

Equipment:

- 300 x 6 Inch Streamer
- 12.5 Inch Drogue
- 72 Inch Main Parachute
- 84 Inch Main Parachute
- 4x $\frac{1}{4}$ Inch Kevlar Shock Cord
- Wadding
- Aluminum Tape
- 4x E-match
- Black Powder
- 8x 2-56 Nylon Shear Pins
- 15 Feet 20 AWG Wire
- 9V Battery
- Safety Glasses
- NRR 25 dB (or better) Hearing Protection
- 2x Nomex Blanket
- Carbon Fiber Plate
- 4.5 Inch O-Ring
- Eye Bolt
- Surrogate Payload
- Fire Extinguisher

Safety Precautions:

To ensure the maximum achievable safe environment for this test, only essential personnel are allowed to be within 15 feet of the live black powder charges at any time. The recovery officer is the only individual allowed to measure, pack, and arm the black powder charges. Latex gloves are to be worn at all times by any persons handling electronics and black powder to ensure no electrostatic discharge prematurely ignites the charges. Safety glasses will be worn by all individuals who are in the presence of the test, and during the setup of the test. Hearing protection is to be worn at all times during live testing. NRR 25 dB (or better) earmuffs and/or ear plugs are required for individuals within 30 feet of the live fire event. A fire extinguisher will be kept on hand at all times.

Procedure:

1. Calculate the required mass of black powder using an Excel calculator and verify with a MATLAB code.
2. The safety officer and/or the back up officer is required to be present during the handling of black powder.
3. Don latex gloves, safety glasses, and any other protective gear prior to the black powder being handled.
4. The recovery officer will measure the exact amount of of black powder needed for testing by taring a small scale and slowly adding black powder until the required amount is reached.
5. The black powder is to be transferred into a capped funnel to be transferred into a prelabeled black powder vial. Each vial is to be named after its respective charge e.g., DB = Drogue Backup, MP = Main Primary, etc.
6. Once all vials are filled, the black powder container is to be carefully resealed and placed back into storage.
7. The avionics bay is assembled and all components are checked to ensure no power is connected and all capacitors are fully discharged.
8. If capacitors are not fully discharged, a multimeter will be connected to each terminal on the capacitor to allow for full discharge.
9. The safety officer will inspect the avionics, if they are deemed safe the recovery officer can begin loading the black powder into the avionics bay.
10. The respective labeled vial will be used to fill the capped funnel and the black powder will transferred into the charge cup.
11. An E-match is to be prepared by removing the safety coverings and stripping the wires to ensure a good connection to the E-match terminal. Both wires are to be separated to keep any shorts from occurring.
12. Once all black powder is placed into the charge cup, an E-match will be placed into the black powder directly to ensure ignition. The exposed E-match wires are not to be touched by anyone or anything besides the recovery officer once this happens.

13. Wadding will be added to the top of the black powder until the charge cup is full.
14. Once the charge cup is full, a strip of aluminum tape is cut and placed over the top of the charge cup to keep the charge from falling out.
15. The E-match is fed through a hole in the avionics bay that leads to the altimeters. The hole is then covered by electrical tape multiple times on both sides to protect the electronics.
16. The E-match is then fed through the pressure relief holes for the avionics bay to the outside of the body tube and is not to be touched again until after the test is complete.
17. Once fully secured to the body tube, the shock cords and Nomex wrapped parachute will be attached. The recovery officer must wear machining gloves to protect their hands in the case of accidental ignition by the black powder.
18. When the parachutes and shock cords are fully attached, the surrogate payload is inserted.
19. The 4.5 in. O-ring is inserted into the payload and a nomex blanket is sandwiched in between the O-ring and the carbon fiber plate.
20. The respective body tube is attached, and shear pins are inserted to secure the two tubes together.
21. The test sections are placed on a test stand and 10 ft of 20 AWG wire is attached to each end of the E-match. The wire is to ensure the black powder is ignited at a safe distance. Safety glasses and hearing protection are to be worn by all attending personnel.
22. The recovery officer will start a countdown and touch the 9V battery to each wire simultaneously. If the black powder does not ignite, the countdown will start again. If the black powder does not detonate a second time, the recovery officer and safety officer will wait 2 minutes before approaching the body tubes. Once the time has elapsed, the recovery officer will approach the tubes and remove the E-match as safely as possible, and the process will start over. If the black powder charge detonates but does not separate the tubes, the tubes, shock cords, parachutes, and avionics bay will be inspected for damage. If the black powder detonates and successfully separates the two pieces of the launch vehicle, the aforementioned components will still be inspected for damage, but the test will be considered a success, assuming no damage has occurred.
23. The test sections are collected, and the E-match are removed from the avionics bay and disposed of in the proper hazardous waste bin.

Success Criteria:

Table 115: VT8 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDRR 9	The full-scale launch vehicle will be capable of separating with a black powder charge of 1.93g for the payload streamer, 1.81g for the payload main, 1.56g for the booster drogue, and 2.04g for the booster main.	The full-scale launch vehicle will be capable of separating with a black powder charge of 1.93g for the payload streamer, 1.81g for the payload main, 1.56g for the booster drogue, and 2.04g for the booster main.	Pass
		The parachutes are ejected from the airframe	Pass
		The shock cords are ejected from the airframe	Pass

Results:

Images of the full-scale separation test are shown below. The full assembly can be seen in Figure 119a. The moment of the booster drogue ignition is captured in Figure 119b.

(a) Full Separation Test Assembly

(b) Booster Drogue Separation Ignition

Figure 119: Booster Separation Test

Figure 120 displays the ANVIL housing post-ignition. The housing was deployed from the payload section from the separation forces. Black powder residue can be seen on the bottom of the housing, while a spotless, wet paper towel (substituting as the gimbal/camera), sticks out from the gimbal bay.

Figure 120: ANVIL Housing Post-Deployment

The cleanliness of the paper towel post-ignition indicates the blast plate functions as protection for the gimbal assembly during separation. No black powder residue was found inside the gimbal bay after the test was complete.

During the booster drogue separation test, the blast plate was successfully deployed from the booster section. It protected the payload housing from the exhaust gasses of the black powder and was fully deployed during detonation. Figure 121a highlights the blast plate being ejected from the booster section. The drogue parachute can be seen draped over the test stand in Figure 121b.

(a) Blast Plate During Separation

(b) Booster Drogue Separation Aftermath

Figure 121: Blast Plate/Booster Drogue Separation

The booster main parachute separation is shown in Figure 122 below. Figure 122a displays the testing setup, while Figure 122b displays the moment of ignition and separation.

(a) Booster Main Deployment

(b) Booster Main Ignition

Figure 122: Booster Main Parachute Separation

The aftermath of the booster main parachute separation is shown below. The main parachute can be seen draped over the test stand in Figure 123b.

(a) Booster Avionics Bay Separation

(b) Booster Propulsion Section After Separation

Figure 123: Booster Section Separation

After the booster section was fully tested, the payload section was placed on the test stand. The streamer separation ignition is shown in Figure 124b.

(a) Payload Section Test Setup

(b) Payload Streamer Section Ignition

Figure 124: Payload Section Drogue Stage Ignition

Figure 125 displays the aftermath of the payload streamer separation. The streamer was fully deployed during the test and can be seen in between the nose cone and the payload section.

Figure 125: Payload Streamer Separation Aftermath

Next, the payload main parachute separation was tested. Figure 126a displays the pre-ignition setup, while the moment of main parachute ignition is shown in Figure 126b.

(a) Payload Main Parachute Test Setup

(b) Payload Main Parachute Separation Ignition

Figure 126: Payload Main Parachute Testing

The aftermath of the main parachute ejection is shown in Figure 127. The main parachute was fully ejected and can be seen laying in the middle of the test stand on the ground. The avionics bay is located on the left of the image next to the nose cone, while the ANVIL housing section was shot outside of the field of view of this image to the right. The shock cord was fully extended during this test.

Figure 127: Payload Main Parachute Aftermath

Impact on Final Design:

All separation points full ejected all recovery devices from the vehicle. The calculated black powder masses are sufficient in separating the vehicle. Additionally, the blast plate successfully protected the gimbal bay from the pressure and residue during the drogue deployment of the booster section.

7.1.11 VT11 - Full-Scale RF Tracking Demonstration

Objective: The objective of this demonstration is to verify the RC-HP trackers can be located using the hot-cold gun, and the FeatherWeight trackers can be located beyond 2,500 feet.

Justification: The RC-HP tracker is a backup system for recovery in the event the launch vehicle is lost during descent. The hot-cold gun accompanied by the RC-HP will help locate the vehicle. The FeatherWeight trackers are the main locating devices whose sole purpose is to find the components of the launch vehicle in accordance with the SLH requirement 3.12 and verify the success of the payload mission.

Equipment:

- R-300A Receiver
- 2x RC-HP RF Transmitters
- Two CR2032 Batteries
- 2x FeatherWeight GPS Trackers
- FeatherWeight Receiver
- iPhone

Procedure:

Note: Each RC-HP has their own specific channel written on the inside of the device. This number is for the R-300A hot-cold gun to track the specific frequency/channel the RC-HP will emit.

1. The RC-HP transmitter is turned on by inserting a CR2032 battery.
2. The R-300A hot-cold gun is turned on and the battery voltage is checked on the gun. This is to ensure the gun has enough battery to last the entire demonstration.
3. The R-300A gun is tuned to the same channel as the transmitters.
4. One team member will take an RC-HP transmitter and walk at least 2,500 feet away from the R-300A tracker.
5. The R-300A is then used to find the RC-HP transmitter.

Success Criteria:

Table 116: VT9 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 3.12	Electronic tracking device will be installed in the launch vehicle and will transmit the position to a ground receiver.	The RC-HP and FeatherWeight GPS are capable of transmitting at least 2,500 feet.	Pass

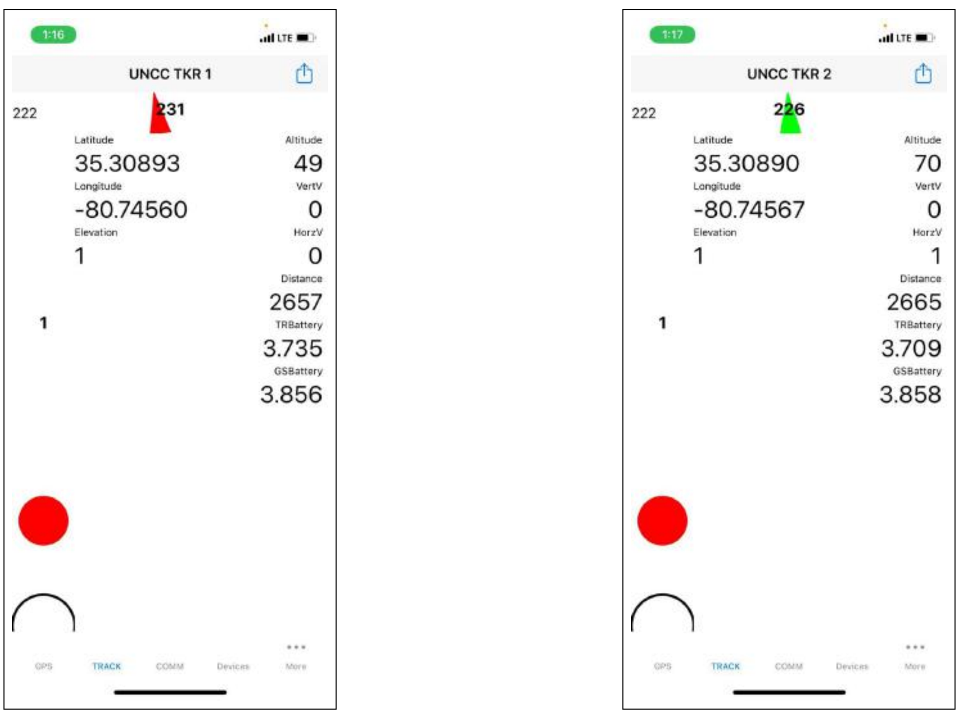
Results:

Figure 128 displays the locations of the transmitter and receiver for the FeatherWeight GPS trackers. The red circle in the center of image 128a is the location of the team member with the FeatherWeight GPS receiver.

(a) Transmitter POV (b) Receiver POV

Figure 128: Transmitter/Receiver Distance Test

Figure 129 depicts the telemetry from the FeatherWeight GPS transmitters. Both transmitters were able to maintain lock up to approximately 2,650 feet and from behind a hill.



(a) FeatherWeight Tracker 1 (b) FeatherWeight Tracker 2

Figure 129: FeatherWeight Telemetry

The RC-HPs were able to be tracked by the R-300A from over 2,500 feet away. The hot-cold gun is able to hone in on the signal produced by both RC-HPs within a radius of about 15 feet.

Impact on Final Design:

The FeatherWeight GPS transmitters were able to maintain a lock beyond the required 2,500 feet. In addition, they were also able to maintain a lock behind a hill, meaning they are not line-of-sight dependent. This makes the FeatherWeight GPS a good choice for the primary tracking of the launch vehicle. The RC-HP and R-300A are good choices for backup locating devices in the event the vehicle is lost during descent. Their ability to perform correctly under this demonstration provides good evidence they will also work in the full-scale launch vehicle.

7.1.12 VT12: Vehicle Flight Demonstration

Objective: The full-scale launch will be preformed to collect data on the apogee, acceleration, velocity, drift distance, and impact energy with the ground to ensure the vehicle falls within simulated values.

Justification: The full-scale vehicle flight will demonstrate the proposed capabilities of the launch vehicle while collecting data to be analyzed for vehicle verification.

Testing Variables:

1. Apogee
2. Acceleration
3. Velocity
4. Drift Distance
5. Impact Energy

Equipment:

See section 6.3.1 for all components of the full-scale vehicle.

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 300 feet of the launch vehicle (500 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

See section 6.3.1 through 6.3.1 for full assembly procedures.

Success Criteria:

Table 117: VT10 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 1	The full-scale vehicle will weigh no more than 51.9 lbs.	The total weight of the full-scale assembly is less than 51.9 lbs.	Pass
SLH Requirement 2.3	The vehicle will carry at a minimum, two commercially available barometric altimeters that are designed for rocketry.	The full-scale vehicle contains 4 altimeters.	Pass
SLH Requirement 2.4	The launch vehicle will be designed to be recoverable and reusable.	The launch vehicle will be able to be launched again after the full-scale launch without repairs.	Pass
SLH Requirement 2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	The launch vehicle will be constructed before 2 hours has elapsed.	Pass
SLH Requirement 2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	The launch vehicle will exit the rail at a minimum of 65 ft/s.	Pass
SLH Requirement 2.19.1	A full-scale launch vehicle will be launched prior to the FRR to validate the vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the vehicle for launch.	The full-scale vehicle will be successfully launched and recovered prior to the FRR.	Pass
SLH Requirement 3.3	Each Independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lb_f at landing	All sections will impact the ground with less than 75 ft-lb_f of kinetic energy.	Pass
SLH Requirement 3.10	The recovery area will be limited to a 2,500 feet radius from the launch pad	The vehicle will land within a 2,500 foot radius from the launch rail.	Pass
SLH Requirement 3.11	Descent time of the launch vehicle will be limited to 90 seconds	The vehicle will be fully on the ground before 90 seconds has elapsed from apogee.	Pass
SLH Requirement 3.12	An electronic GPS tracking device will be installed in the launch vehicle to transmit the location to a ground receiver.	The full-scale vehicle will house 2 FeatherWeight GPS trackers. A ground team will track both from home base.	Pass

Results:

The full-scale test flight occurred on February 12, 2022 at Dalzell South Carolina. The motor casing was double counted in the mass budget, so the entire vehicle was about 1.3 lbs lighter in the aft section. This caused the stability caliber to be different than the designed value. A higher apogee was reached than initially calculated due to the decreased weight of the vehicle. The maximum velocity achieved by the vehicle was 654.68 $\frac{\text{ft}}{\text{s}}$. This value is an average taken from all recording altimeters. Figure 130 displays the recorded velocity profile for the altimeters. The backup booster altimeter's data was corrupted for unknown reasons, and only the primary booster altimeter data was able to be recovered.

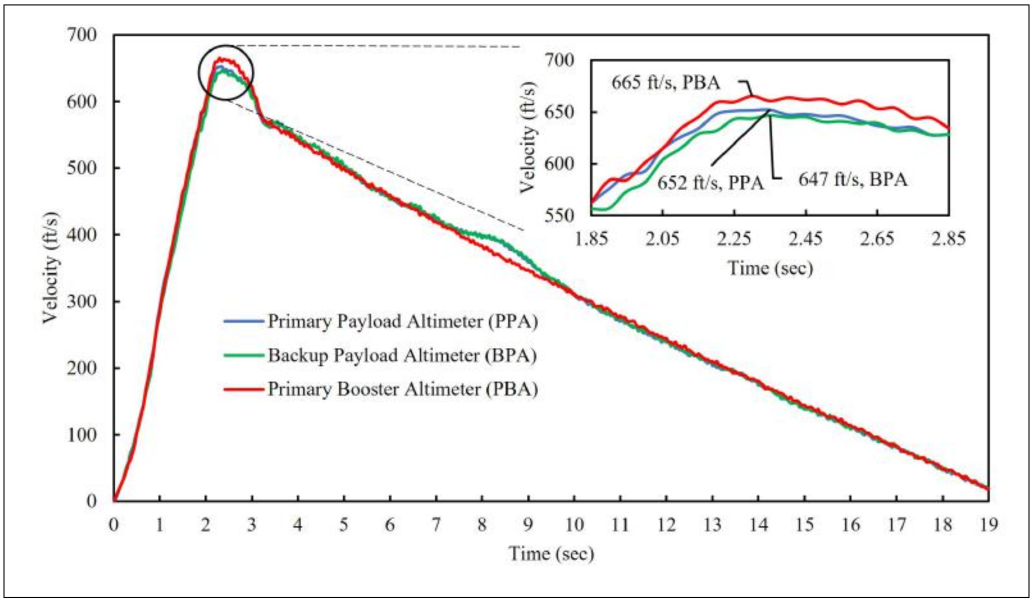


Figure 130: Full-Scale Velocity Profile During Ascent

The average maximum acceleration from the three RRC3 altimeters was 233.4 $\frac{\text{ft}}{\text{s}^2}$ or 7.25 G's. The lower weight of the vehicle caused a higher acceleration to be achieved during ascent. The acceleration reached a maximum around 0.8 seconds after motor ignition, which correlates with the maximum in the motor's theoretical thrust curve. The thrust curve can be viewed in Figure 42. Figure 131 displays the acceleration profile while the motor is burning.

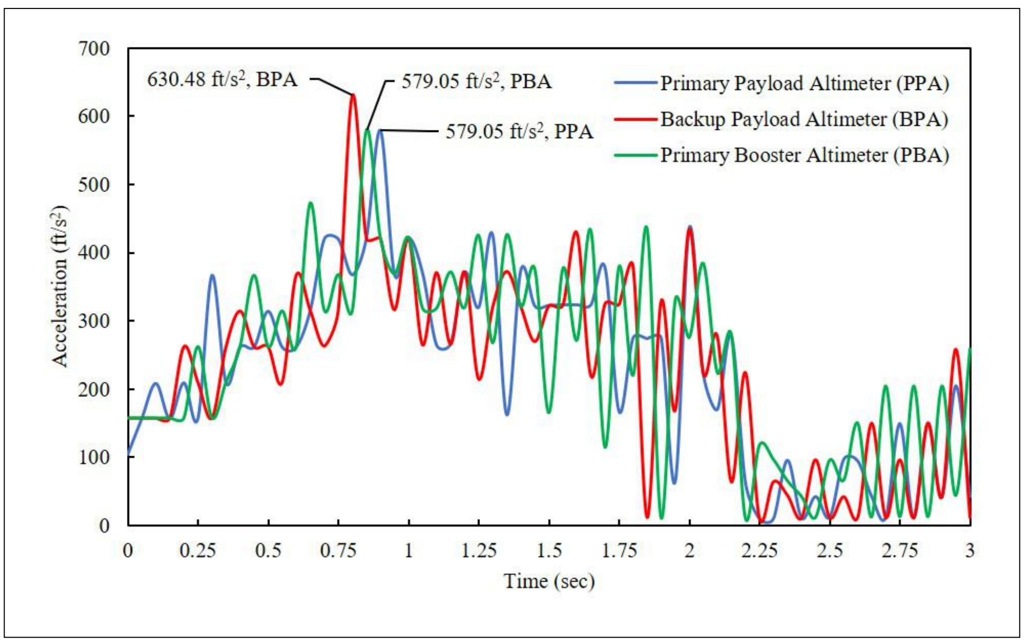


Figure 131: Full-Scale Acceleration Profile

Figure 132 displays the RRC3 altimeter data recorded in the payload section. The gaskets successfully prevented pressure leakage into the altimeter bays, allowing for a successful deployments of all parachutes at their intended altitudes.

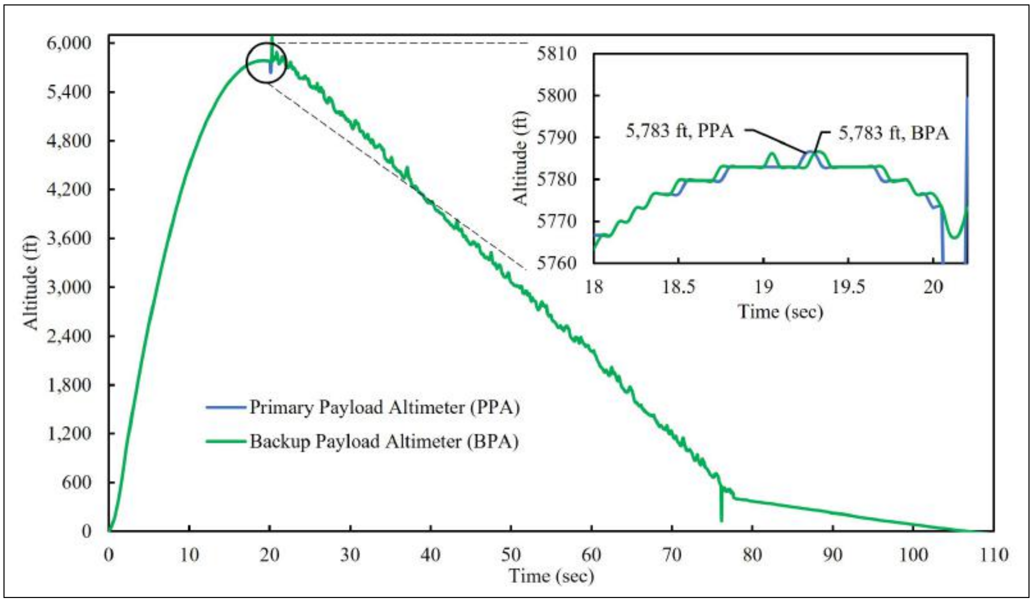


Figure 132: Full-Scale Payload Altimeter Data

Both altimeters recorded an apogee of 5,783 feet, which is 783 feet above the target altitude. Comparing this to an updated MATLAB simulation, the difference between the empirical data and the theoretical MATLAB apogee was less than 1 foot. Once apogee was reached, all drogue stage recovery devices successfully deployed and the payload section fell approximately 10 feet per second faster than the booster section, as anticipated. Upon main deployment, the payload section descended at a rate of 13.77 $\frac{\text{ft}}{\text{s}}$, and impacted the ground with a kinetic energy of 53.16 ft-lb_f. The RRC3 data from the booster section is shown in Figure 133.

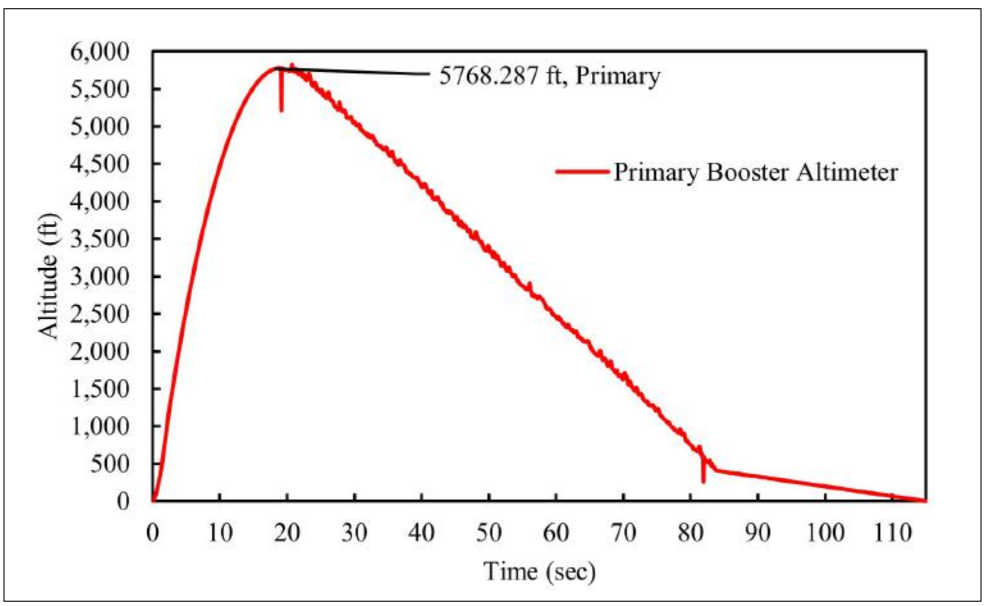


Figure 133: Full-Scale Booster Altimeter Data

The recorded apogee of this altimeter was 5,768 feet. Both sections descended in under 90 seconds, even with the additional 700 feet in altitude. The main parachute descent rate for the booster section was approximately 13.13 $\frac{\text{ft}}{\text{s}}$, producing an impact energy of 48.25 ft-lb_f.

The landed sections are depicted in Figure 134. The booster section and payload section landed approximately 50 feet from each other. The drift distance from the launch rail was 2,033 feet, which is inside the 2,500 foot maximum drift distance.

Figure 134: Full-Scale Landing Location

The raw RRC3 altimeter data for the primary booster altimeter is shown in Figure 135. Some of the listed data in the following flight summaries is not accurate. An example is the altitude; the RRC3 will report the maximum altitude "achieved," but this can be easily fooled by pressure spikes during deployments, or an influx of air from increased velocity during separation. Due to Bernoulli's principle, there may be a drop in altitude as air flows over the pressure relief holes during deployment. Other reported data such as the "main rate" are incorrect too. The main parachute was reported to deploy at 600 feet, but impacted the ground at "-60 ft AGL" within about 40 seconds. Also, the launch field in Dalzell, SC is a sod farm. It does not have 60 foot deep ditches and is relatively flat. It is mathematically impossible to have a "main rate" of 6 $\frac{\text{ft}}{\text{s}}$ with the reported numbers. For accurate data analysis of the flight, see Figures 130 through 133, because events like pressure spikes were ignored for an accurate apogee, velocity, etc. The data in these figures was exported from the .rff files into Microsoft Excel for processing.

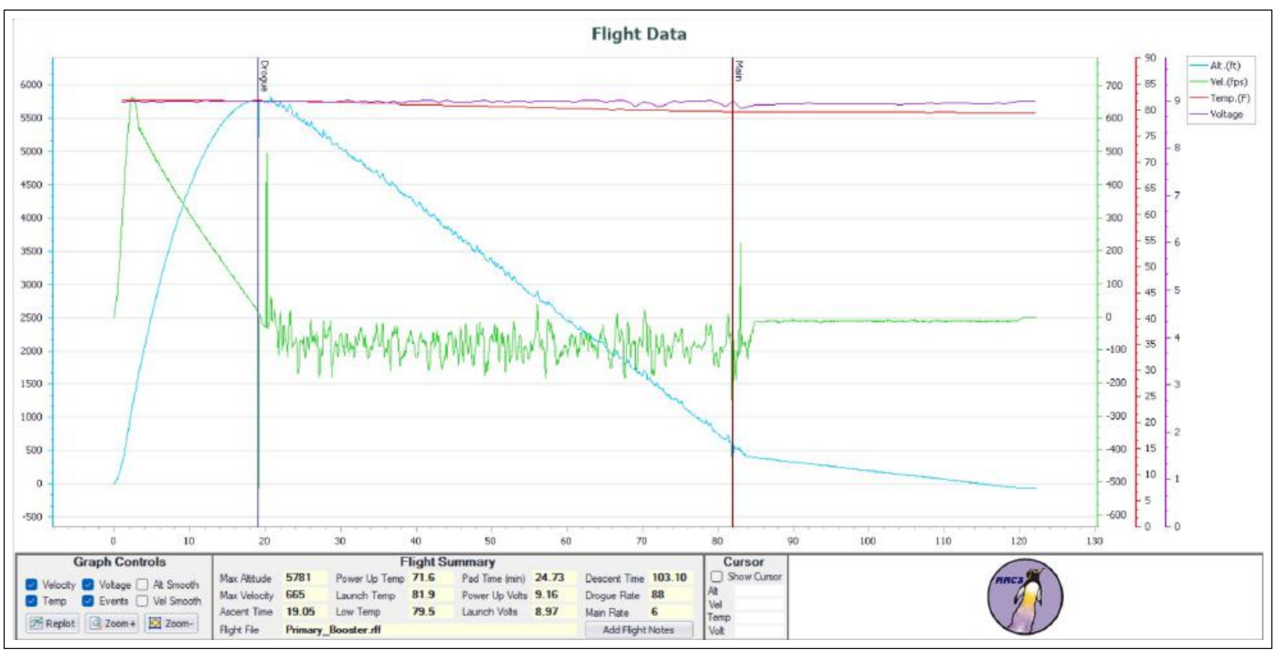


Figure 135: Raw Primary Booster RRC3 Data

The raw RRC3 altimeter data for the primary payload altimeter is shown in Figure 136.

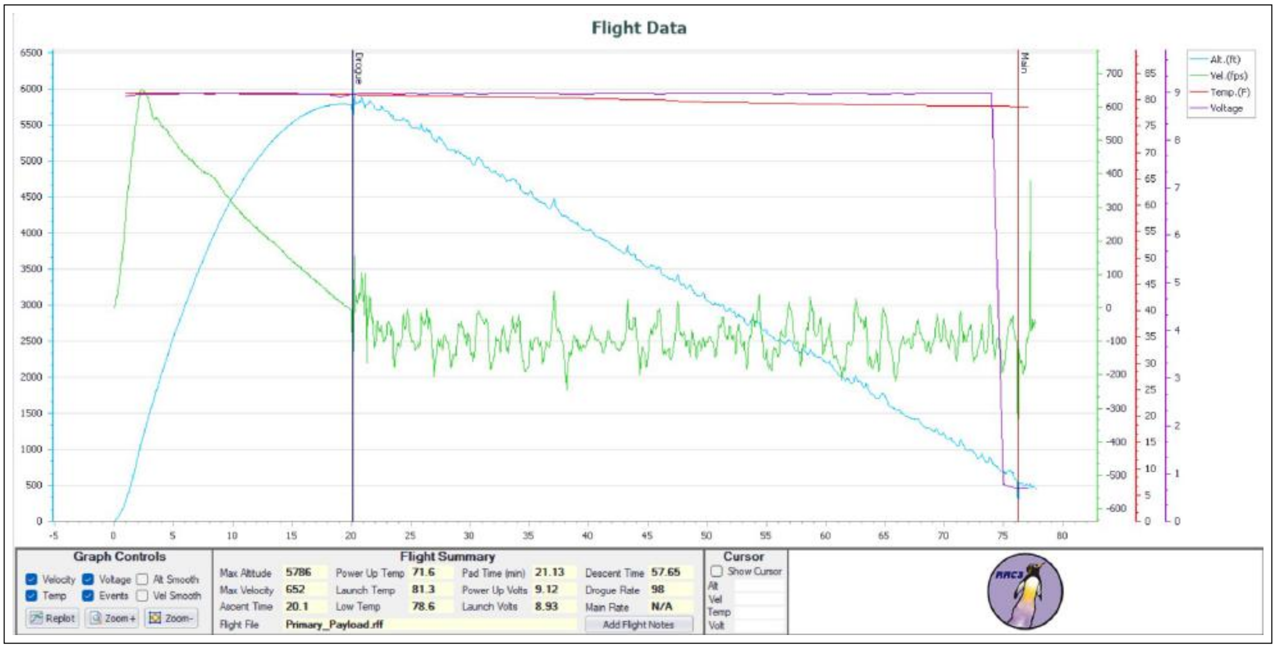


Figure 136: Raw Primary Payload RRC3 Data

The raw RRC3 altimeter data for the backup payload altimeter is shown in Figure 137.

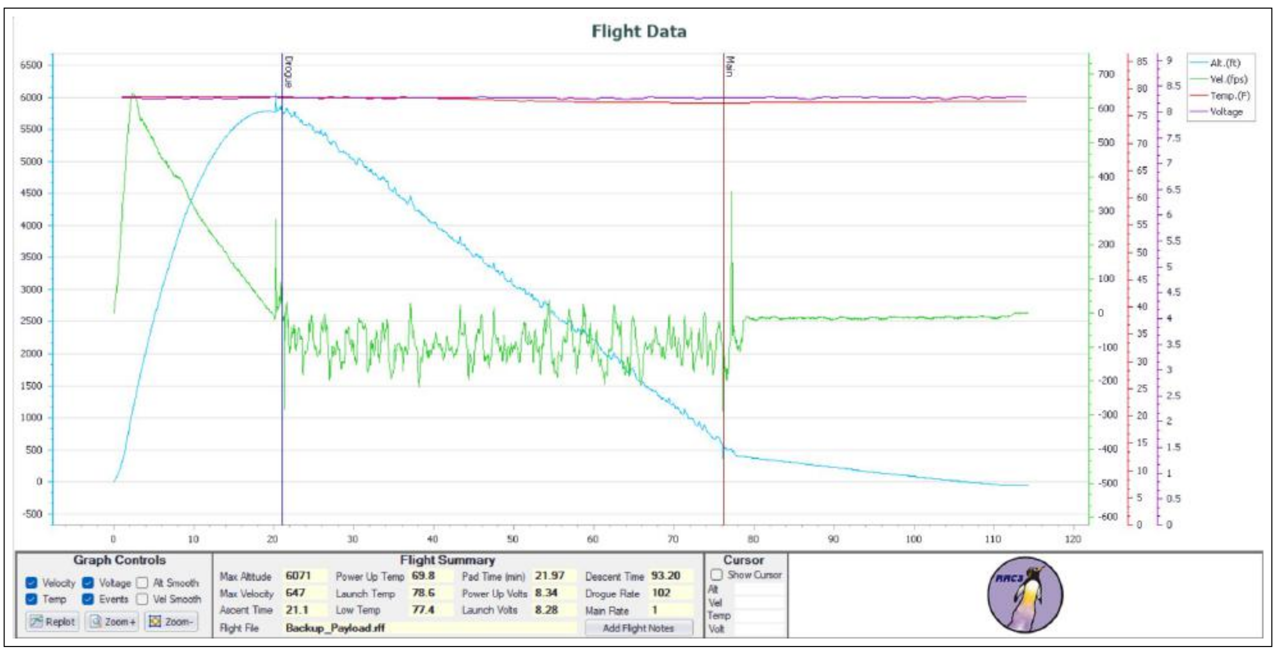


Figure 137: Raw Backup Payload RRC3 Data

Impact on Final Design:

An additional 1.3 lbs will be added to the boattail to account for the missing mass of the vehicle. Every other aspect of the launch was considered a success.

7.1.13 VT13: Vehicle Flight Test

Objective: The full-scale launch will be preformed to collect data on the apogee, acceleration, velocity, drift distance, and impact energy with the ground to ensure the vehicle falls within simulated values.

Justification: The full-scale vehicle flight will demonstrate the proposed capabilities of the launch vehicle while collecting data to be analyzed for vehicle verification.

Testing Variables:

1. Apogee
2. Acceleration
3. Velocity
4. Drift Distance
5. Impact Energy

Equipment:

See section 6.3.1 for all components of the full-scale vehicle.

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 300 feet of the launch vehicle (500 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

See section 6.3.1 through 6.3.1 for full assembly procedures.

Success Criteria:

Table 118: VT10 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 1	The full-scale vehicle will weigh no more than 51.9 lbs.	The total weight of the full-scale assembly is less than 51.9 lbs.	Pass
SLH Requirement 2.3	The vehicle will carry at a minimum, two commercially available barometric altimeters that are designed for rocketry.	The full-scale vehicle contains 4 altimeters.	Pass
SLH Requirement 2.4	The launch vehicle will be designed to be recoverable and reusable.	The launch vehicle will be able to be launched again after the full-scale launch without repairs.	Pass
SLH Requirement 2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	The launch vehicle will be constructed before 2 hours has elapsed.	Pass
SLH Requirement 2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	The launch vehicle will exit the rail at a minimum of 65 ft/s.	Pass
SLH Requirement 2.19.1	A full-scale launch vehicle will be launched prior to the FRR to validate the vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the vehicle for launch.	The full-scale vehicle will be successfully launched and recovered prior to the FRR.	Fail
SLH Requirement 3.3	Each Independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lb$_f$ at landing	All sections will impact the ground with less than 75 ft-lb$_f$ of kinetic energy.	Fail
SLH Requirement 3.10	The recovery area will be limited to a 2,500 feet radius from the launch pad	The vehicle will land within a 2,500 foot radius from the launch rail.	Fail
SLH Requirement 3.11	Descent time of the launch vehicle will be limited to 90 seconds	The vehicle will be fully on the ground before 90 seconds has elapsed from ignition.	Fail
SLH Requirement 3.12	An electronic GPS tracking device will be installed in the launch vehicle to transmit the location to a ground receiver.	The full-scale vehicle will house 2 FeatherWeight GPS trackers. A ground team will track both from home base.	Pass

Results:

The VDF occurred on February 26, 2022 in Bayboro, NC. This flight contained a myriad of issues. The main parachute for the payload section was deployed at apogee. Two main theories are proposed as to why this may have occurred; first, the payload is allowed to free fall for 4 feet from the body tube before the shock cords that retain it are fully extended. As the shock cords become taught, the change in acceleration produces a massive force on the shear pins. This theory is explored more in VT14 (section 7.1.14).

A second theory why the main parachute was deployed at apogee is due to incorrect wiring of the avionics bay. If the terminals for main parachute and streamer on the RRC3 altimeters were swapped, the main would deploy shortly after apogee, and the streamer would be deployed at 600 feet. However, when the launch vehicle broke the cloud layer, the streamer had already been deployed. This indicates that the nose cone was separated prior to reaching 600 feet in altitude. Additionally, the RSO and a few team members reported seeing "a puff of smoke" at approximately 600 feet, indicative of a black powder recovery deployment event.

Finally, two out of the four altimeters fully recorded data. Both were located on the booster section, which found its way into a water logged ditch. These altimeters are unfit for flying again. The payload section contained both malfunctioning altimeters. The primary payload altimeter did not record any data, nor did it initiate any black powder charges. Upon recovery of the payload section, the primary altimeter could be heard producing three short beeps. This indicates it was still in the "ready-to-fly" mode, and it never detected a launch. The backup payload altimeter did detect a launch, but only recorded the first 21 seconds of flight. Upon inspection of the recorded data, the altimeter voltage dropped to 2.18 volts at 16.55 seconds into the flight. The low voltage lock-out for the RRC3 is 2 volts. It is unknown what caused the RRC3 to lose power mid-flight, because the vehicle was still ascending at this time and it did not reach apogee for another few seconds.

With the advent of a series of misfortunes, some data was able to be recovered from the flight. The booster section altitude data is shown if Figure 138.

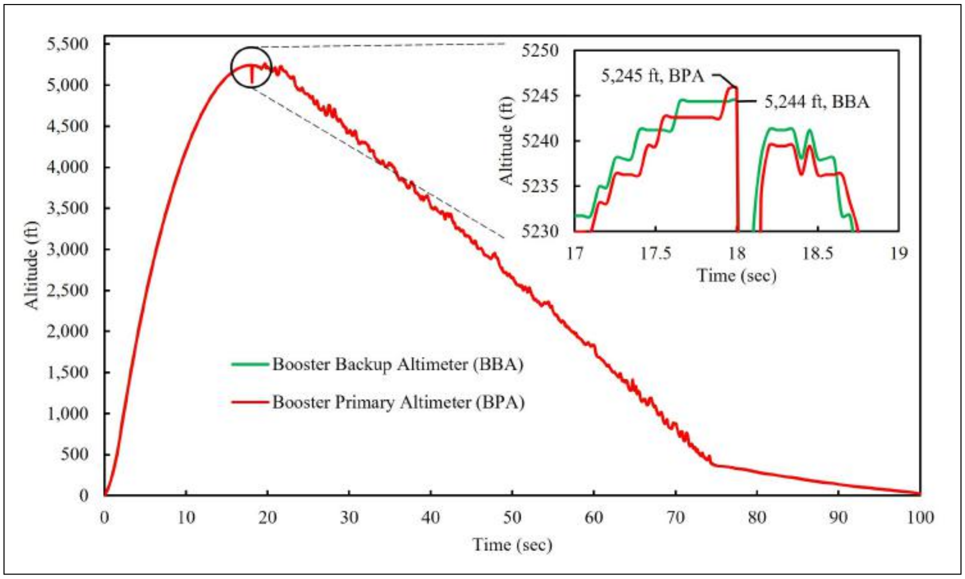


Figure 138: Vehicle Flight Test Booster Altimeter Data

The recorded apogee for the booster section was 5,244 feet for the booster backup altimeter, and 5,245 feet for the booster primary altimeter. The backup and primary booster altimeters recorded a maximum velocity of 611 and 607 $\frac{\text{ft}}{\text{s}}$ respectively. During the boosting stage of flight, the average acceleration was calculated to be 209 $\frac{\text{ft}}{\text{s}^2}$, or 6.5 G's. The main parachute descent rate was 13.7 $\frac{\text{ft}}{\text{s}}$, which produced a kinetic energy on impact of 56.6 ft-lb$_\text{f}$. The drift distance of the booster section was 2,563 feet from the launch rail. Figure 139 displays the recorded data from the payload backup altimeter and the recorded voltage.

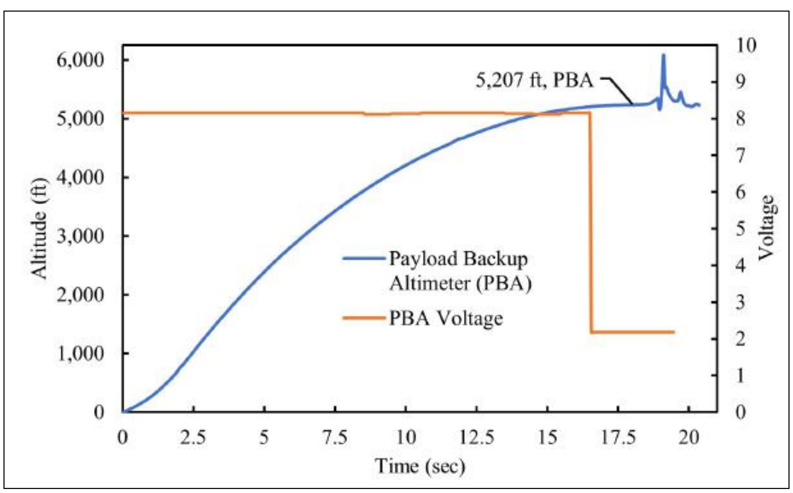


Figure 139: Vehicle Flight Test Payload Altimeter Data

The payload section reached a recorded altitude of 5,207 feet. The maximum velocity reached was 596 $\frac{\text{ft}}{\text{s}}$. The average acceleration during motor burn was 200 $\frac{\text{ft}}{\text{s}^2}$, or 6.2 G's. The payload section drifted 1,864 feet from the launch rail. Because the payload section did not record any data past 21 seconds, no further analysis could be completed.

The ascent velocity profile for all three altimeters is shown below in Figure 140. A zoomed graph was added to the top right to make the maximum values more discernible.

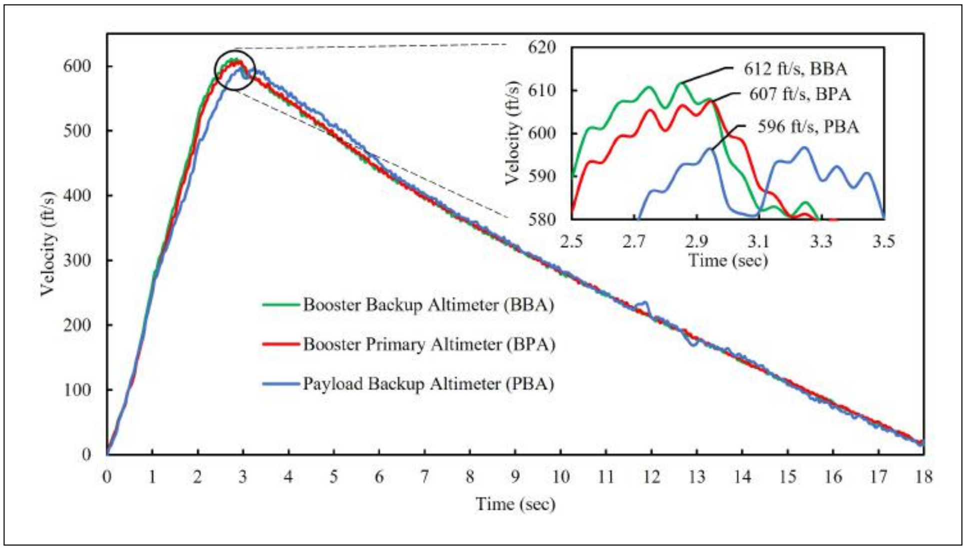


Figure 140: Vehicle Flight Test Ascent Velocity Profile

The raw RRC3 primary booster altimeter data is shown in Figure 141. As mentioned in section 7.1.12, some of the flight summaries in the following figures will not align with the reported data. For accurate data analysis, refer to Figures 138 through 140. The data in these figures was exported from the .rff files into excel for processing.

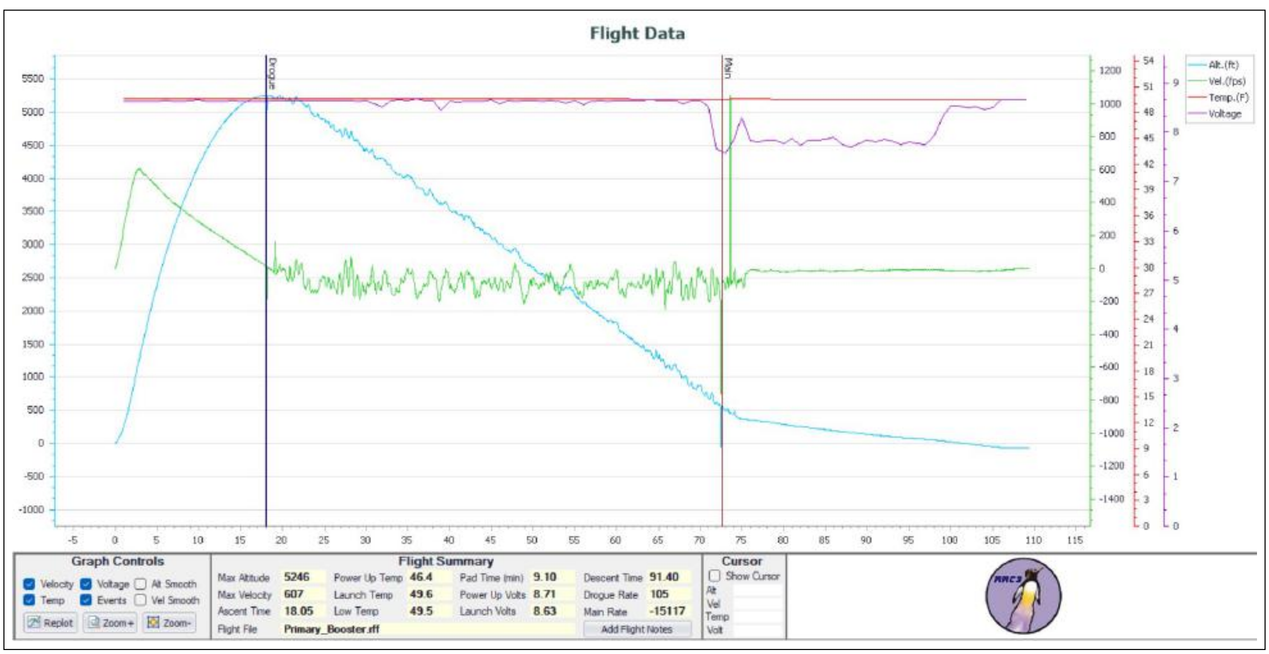


Figure 141: Raw Primary Booster RRC3 Data

The raw RRC3 backup booster altimeter data is shown in Figure 142.

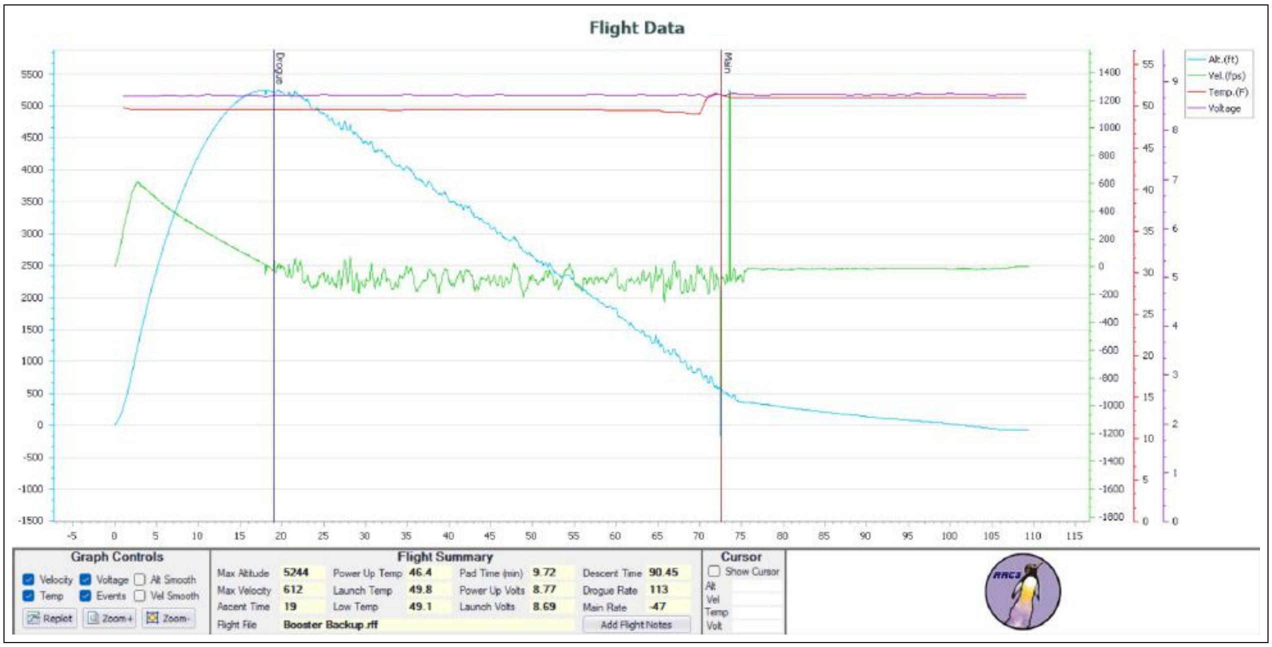


Figure 142: Raw Backup Booster RRC3 Data

The raw RRC3 backup payload altimeter data is shown in Figure 143.

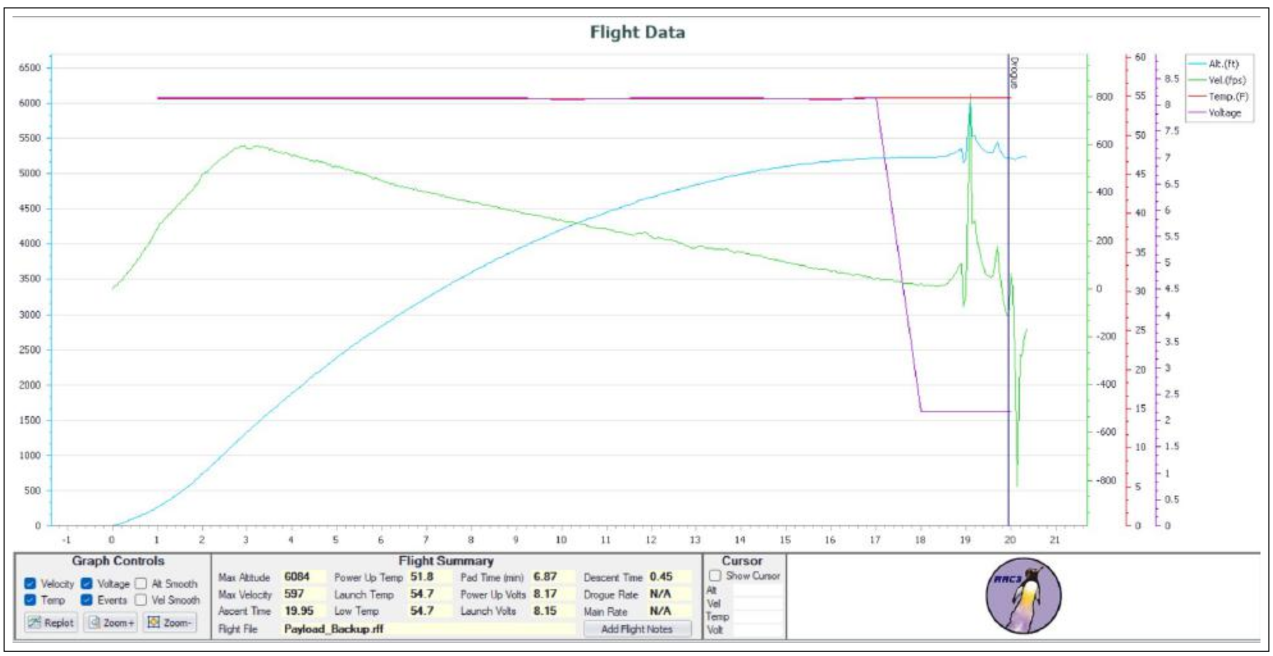


Figure 143: Raw Backup Payload RRC3 Data

Impact on Final Design:

This flight is considered a failed flight due to the lack of proper recovery deployment, data collected, and the drift distance of the booster section was outside of the 2,500 foot maximum. To correct the issues discovered during this VDF attempt, a few changes will be made to ensure safe flights in the future. A third shear pin will be added to the payload main parachute section to ensure the main parachute deploys at the 600 feet and not prior. The E-matches will be color coded to prevent any accidental mix-ups. The launch day check list was updated to include the two aforementioned fixes.

7.1.14 VT14 - ANVIL Shear Pin Retention Demonstration

Objective: The objective of this demonstration is to verify the ability for three shear pins to withstand the change in acceleration of ANVIL deploying from the payload section.

Justification: The force ANVIL produces upon deployment is capable of prematurely breaking the shear pins that hold the main parachute section together. This demonstration is used as a verification that three shear pins are able to withstand the forces of payload deployment.

Testing Variables:

1. Three shear pins are capable of withstanding the jerk produced by ANVIL deploying.

Equipment:

- 3x 2-56 Nylon Shear Pins
- Payload Body Tube Section
- Payload Avionics Bay Section
- ANVIL (see section 6.3.1)
- Payload Avionics Bay (see section 6.3.1).
- 6 ft Step Ladder

Safety Precautions:

During construction of ANVIL, team members should always be aware of pinch points. One team member is allowed on the step ladder at a time. This team member should never step on the top step of the ladder because it is not meant to withstand loads.

Procedure:

1. ANVIL is fully assembled (see section 6.3.1).
2. All mechanical components of the payload avionics bay are assembled (see section 6.3.1). No charges or electronics are to be included.
3. The avionics bay is inserted into the payload avionics section and secured.
4. The avionics vehicle section and the payload housing section are joined together. Three shear pins are inserted into the sections to secure them together.
5. Next, the payload shock cords are attached to ANVIL and to the payload body tube section.
6. ANVIL and the shock cords are inserted into the body tube section. The assembly is held sideways to keep ANVIL from falling out until the demonstration can begin.
7. The whole assembly is brought to the step ladder. A team member climbs to the top of the ladder to hold the payload avionics bay section high enough to allow the shock cords to fully extend.
8. To begin the demonstration, the assembly is turned vertically to simulate the release of the payload from apogee.

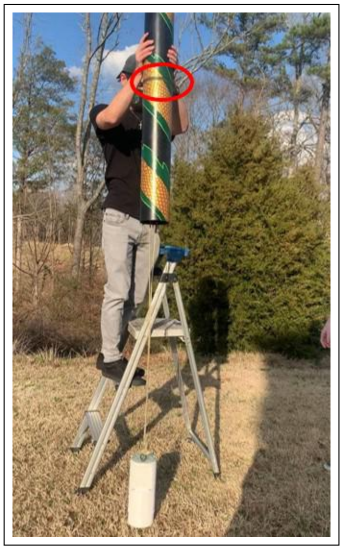
Success Criteria:

Table 119: PT8 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 2.19.2.1	The payload shall be fully retained until the intended point of deployment, all retention mechanism shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	Three shear pins are capable of holding the payload main parachute section together after ANVIL has fully deployed.	Pass

Results:

Figure 144 displays the payload drop demonstration with 2 shear pins. Figure 144a shows the moment shortly after the shock cords become taught. The red oval highlights the coupler starting to fall out of the payload avionics section. Figure 144b shows the main parachute section fully deployed from the payload mass.



(a) Payload Shock Cords In Tension

(b) Payload Mass Breaking Two Shear Pins

Figure 144: Payload Drop Demonstration With Two Shear Pins

The payload was able to break the shear pins that secure the main parachute bay under its own mass. The force exerted from accelerating for 4 feet, and then halting abruptly as the shock cords become taught, proved to be too much for two shear pins to hold.

Figure 145 displays the same demonstration, but with a third shear pin inserted. Figure 145a displays the moment shortly after the shock cords become taught. The momentum of the payload was unable to break three shear pins. Figure 145b shows the payload hanging freely with the main parachute bay unsevered.

(a) Payload Shock Cords In Tension

(b) Payload Hanging From Shock Cords

Figure 145: Unbroken Payload Avionics Section With Three Shear Pins

Impact on Final Design:

A third shear pin will be added to the payload main parachute section to prevent the payload from prematurely severing the shear pins. To account for the required force to break three shear pins, the primary and backup main parachute charges were both increased. The primary charge was increased from 1.81g to 2.71g, and the backup charge was increased from 2.17g to 3.26g.

7.1.15 VT15 - Integrated Payload Flight

Objective: The integrated payload flight will be preformed to test the retention system, the deployment of the payload off the guide rails, the ability for the payload to accurately locate itself on the launch field and relay its location to home base.

Justification: The integrated payload flight is to be preformed to ensure the vehicle and payload will operate as designed on the final launch day in Alabama.

Testing Variables:

1. The retention system keeps the payload attached with no structural damage
2. Deployment of the payload off the guide rails
3. The payload accurately locates itself on the launch field
4. The payload transmits its grid location to home base

Equipment:

1. See section 7.1.12 for full-scale vehicle equipment list
    (a) The payload mass equivalent is to be replaced with the real payload.
2. See section 7.2.8 for the payload components

Safety Precautions:

In order to follow NAR safety protocols for high powered rocketry, flight attendees must be no closer than 300 feet of the launch vehicle (500 feet for a "complex rocket"). While loading black powder masses, the same safety precautions used for black powder packing will be followed during the assembly of the full-scale. Only the recovery officer and safety officer are allowed to handle black powder charges, or be within 15 feet of them. A fire extinguisher will be kept on hand at all times.

Procedure:

1. See section 7.1.12 for the procedures to assemble the full-scale vehicle.
    (a) The payload mass equivalent is to be replaced with the real payload.
2. See section 7.2.8 for the payload assembly procedures.

Success Criteria:

Table 120: VT11 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDVR 1	The full-scale vehicle will weigh no more than 51.9 lbs.	The total weight of the full-scale assembly is less than 51.9 lbs.	Pass
TDPR 1	The payload must be able to protect the gimbal and camera upon landing	The payload must fully retract the gimbal to protect it upon landing.	Incomplete
TDPR 4	The payload must be capable of capturing at least one image covering the entire launch field at a minimum altitude of 3,000 feet.	The camera will capture an image above 3,000 feet that encapsulates the entire launch field.	Incomplete
TDPR 7	The camera system requires a gimbal capable of accurately positioning to an angle within 10° of perpendicular with the ground.	The captured images from the flight will be within 10° of perpendicular to the ground.	Incomplete
TDPR 10	The payload must be able to locate itself within 30 minutes upon landing.	The payload should complete its imaging algorithm and transmit its location before 30 minutes has elapsed upon landing.	Incomplete

Table 120: VT11 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 2.3	The vehicle will carry at a minimum, two commercially available barometric altimeters that are designed for rocketry.	The full-scale vehicle contains 4 altimeters.	Pass
SLH Requirement 2.4	The launch vehicle will be designed to be recoverable and reusable.	The launch vehicle will be able to be launched again after the full-scale launch without repairs.	Incomplete
SLH Requirement 2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	The launch vehicle will be constructed before 2 hours has elapsed.	Incomplete
SLH Requirement 2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	The launch vehicle will exit the rail at a minimum of 65 ft/s.	Incomplete
SLH Requirement 2.19.1	A full-scale launch vehicle will be launched prior to the FRR to validate the vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the vehicle for launch.	The full-scale vehicle will be successfully launched and recovered prior to the FRR.	Incomplete
SLH Requirement 3.3	Each Independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lb_f at landing	All sections will impact the ground with less than 75 ft-lb_f of kinetic energy.	Incomplete
SLH Requirement 3.10	The recovery area will be limited to a 2,500 feet radius from the launch pad	The vehicle will land within a 2,500 foot radius from the launch rail.	Incomplete
SLH Requirement 3.11	Descent time of the launch vehicle will be limited to 90 seconds	The vehicle will be fully on the ground before 90 seconds has elapsed from ignition.	Incomplete
SLH Requirement 3.12	An electronic GPS tracking device will be installed in the launch vehicle to transmit the location to a ground receiver.	The full-scale vehicle will house 2 FeatherWeight GPS trackers. A ground team will track both from home base.	Incomplete

Results:

TBD

Impact on Final Design:

TBD

7.2 ANVIL / Payload Testing

Test	Test ID	Test Description	Requirements Verified	Status
Near Ground Range Test	PT1	Verification that all antennas can transmit beyond 2,500 feet.	TDPR 2, SLH 4.2.1, SLH 4.2.2.6	Complete
Gimbal Orientation Calibration Demonstration	PT2	Verification that the gimbal can calibrate and orient itself perpendicular with the ground.	TDPR 7	Complete

ANVIL Retention Mechanism Analysis	PT3	Analysis of the retention mechanism for ANVIL in FEA software.	SLH 2.19.1.1	Complete
Imaging Algorithm Demonstration	PT4	Verification that the imaging algorithm can locate a payload through a series of successive images.	TDPR 5, SLH 4.1	Complete
Time Intensive Test for Processing Length and Image Scaling	PT5	Verification that the Raspberry Pi 4B can process selected data sets before 30 minutes has elapsed.	TDPR 5, SLH 4.1	Complete
Raspberry Pi Camera Imaging Demonstration	PT6	Verification that the Raspberry Pi 4B is capable of capturing and storing successive images during descent.	TDPR 5, SLH 4.1	Complete
Gimbal Retraction Test	PT7	Verification that the gimbal retraction system can fully retract the gimbal within 2 seconds.	TDPR 1, TDPR 6, TDPR 9, SLH 2.4	Complete
Incorporated Gimbal Camera Test	PT8	This test verifies the imaging algorithm can work with pictures taken from the gimbal-camera assembly and process them in a timely manner.	TDPR 6, TDPR 7, SLH 4.1	Complete
Full Payload Assembly Test	PT9	This test verifies all payload components can work properly without interference from each other.	TDPR 2, TDPR 6, TDPR 7, TDPR 9, TDPR 10, SLH 4.1	Incomplete

7.2.1 PT1 - Near Ground Range Test

Objective: The objective of this test is to verify the Xbee PRO s3b and various antennas are capable of transmissions on the ground from 2,500 ft away.

Justification: The purpose of this test is to validate the use an antenna near the ground and ensure it can transmit at least 2,500 feet as per the 2,500 feet maximum drift distance requirement.

Testing Variables:

1. Distance before transmission loss

Equipment:

- 2x RP-SMA Whip Antenna
- 2x Laird Technologies Phantom Omni Antenna
- 2x RobotShop Duck Antenna
- 2x Single Cell LiPo Battery
- 2x Xbee PRO XCS s3b
- LTE Yagi Antenna
- 2x Arduino UNO
- 2x Xbee Breakout Board
- 2x Solderless Breadboard
- 6x Wires

Procedure:

1. In order for the Xbee PRO s3b to set up a network, there must be a single Xbee PRO s3b setup as a coordinator. There also must be at least one Xbee PRO s3b operating as an end device. Every Xbee PRO s3b radio has the same ATDH address (Destination Address High) which is 0013A200. Every Xbee PRO s3b has a unique individual ATDL address (Destination Address Low) which must be input into the opposite Xbee PRO s3b radio's code. This ensures the two Xbee PRO s3bs only acknowledge each other's signals, and know exactly which radio is transmitting to them. In the case for these Xbee PRO s3b's, they are configured for peer-to-peer translucent mode, where this pairing is done automatically.
2. The pairing is double checked with XTCU, which is a multi-platform application designed to interact with Digi RF modules.
3. The Modem VID, hopping channel, destination address, source address, and address match are double checked to ensure the Xbee PRO s3bs are transmitting to the correct addresses.
4. Match the baud rates of the Xbee PRO s3bs to 9600.

5. To set up both Xbee PRO s3bs, each are connected to an Arduino with pins connected to the 5V and ground.
6. The transmitting Arduino is connected to an external 9V power supply with the Din pin on the break out board connected to the TX pin on the Arduino.
7. The transmitting Arduino is preloaded with code that prints a single number on repeat every second to a serial monitor.
8. The receiving Arduino will be connected to a laptop with the Dout pin on the break out board connected to the RX pin on the Arduino.
9. The receiving Arduino is preloaded with code that opens a serial monitor that prints the information transmitted from the transmitter.
10. Once the Xbees are connected to each other and communicating, the transmitting Xbee PRO s3b is walked across a field to the opposite end and the connection is continually checked at 50-foot increments until 2,500 feet is reached.
11. The process is repeated for each antenna. Only the LTE Yagi antenna is specifically for the receiving Xbee PRO s3b. This is to increase to range of the receiving Xbee PRO s3b due to its high gain.

Success Criteria:

The payload will transmit data to a receiver (also on the ground) at least 2,500 ft away. The near ground range test will be considered a failure if the Xbee PRO s3b and antenna cannot transmit at least 2,500 ft.

Table 122: PT1 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 3.1	The recovery area is limited to 2,500 feet in radius from the launch rail.	The antennas transmit at least 2,500 feet in distance.	Pass
TDPR 2	The payload must be able to transmit at least 2,500 feet.	The antennas transmit at least 2,500 feet in distance.	Pass

Results:

The antennas were able to transmit a signal from over 2,500 feet away while being close to the ground and having small obstacles in the way. All antennas were capable of transmitting to the end of the field which was approximately 3,000 feet. As of this time of the test, the range limit of all antennas is unknown, and more tests should be completed to find it. The test is considered a success, but a known range limit for each antenna is desired.

Impact on Final Design:

The antennas tested were all capable of transmitting data from over 2,500 feet away. This concludes that they will be capable of transmission across this same distance on a launch field.

7.2.2 PT2 - Gimbal Orientation Calibration Demonstration

Objective: The objective of this demonstration is to verify the gimbal can orient with the ground and maintain perpendicularity to the ground.

Justification: The purpose of this demonstration is to validate the gimbal choice from CopterLab.

Equipment:

- 2 Axis Raspberry Pi HQ Camera Gimbal
- 3 Cell LiPo Battery
- Raspberry Pi High Quality Camera
- Raspberry Pi HQ 90° FOV Lens
- 4x Plastic Washers
- 4x M2.5 Screw
- 4x M2.5 Nut

Procedure:

1. The Raspberry Pi High Quality camera is attached to the gimbal
2. The 90° FOV lens is attached to the camera.
3. The gimbal has a calibration mode that starts when the gimbal is powered on. In order to properly calibrate the gimbal, the gimbal must be placed on a flat surface and allowed to find the gravity vector that is perpendicular with the ground.
4. Next the battery is attached to the gimbal and the gimbal will power on.
5. After a few seconds the gimbal will orient itself with the camera facing the ground. Once this occurs, the gimbal is moved in all orientations to verify the camera maintains perpendicularity with the ground at all times.

Success Criteria

Table 123: PT2 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 7	The gimbal must remain within an angle of 10° of perpendicularity to the ground.	The gimbal will remain perpendicular to the ground throughout the demonstration.	Pass

Results:

The gimbal was able to orient itself with the ground in any orientation. Below in Figure 146, a screenshot from a video of the gimbal working is shown. It depicts the gimbal at an off angle, maintaining perpendicularity with the ground.

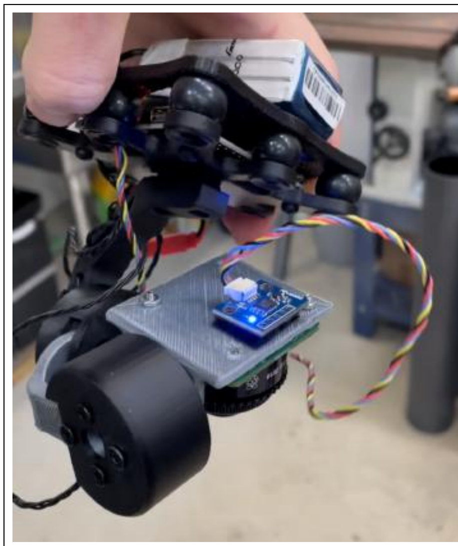


Figure 146: Gimbal Orientation Calibration Test

Impact on Final Design:

This demonstration proved the gimbal selected works properly and can be used in the final design.

7.2.3 PT3 - ANVIL Retention Mechanism Analysis

Objective: Validate the material and design choice of the ANVIL retention system under recovery loading.

Justification: The retention of ANVIL during descent is key for mission success. If ANVIL fails to be retained under recovery forces, the mission will fail.

Analyzed Components:

- ANVIL Payload Housing
- Fiberglass Reinforcement Plate
- 8x 2 Millimeter Bolts and Nut Assemblies

Procedure:

1. A stereolithography file of the payload housing and a fiberglass reinforcement plate was imported into Abaqus CAE. Abaqus is an FEA software that was used to evaluate the retention mechanisms of ANVIL.
2. Replica bolt and nut assemblies are produced in Abaqus.
3. Various constraints, interactions, and properties were input into the software to model every aspect. Material properties, frictional forces, and impulse loading were all inputs to evaluate how ANVIL will perform when the main parachute is deployed.

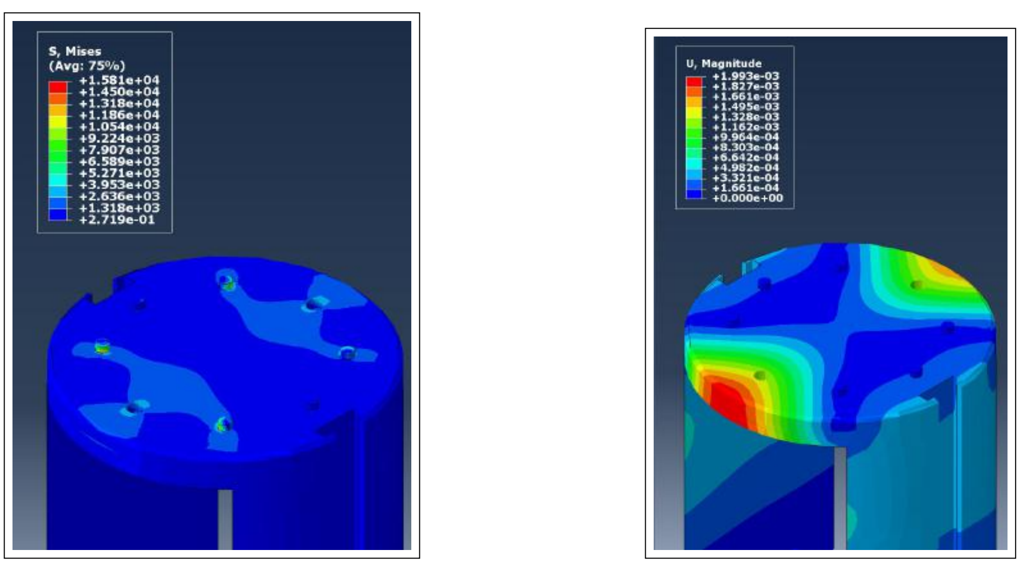
Success Criteria:

Table 124: PT3 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
SLH Requirement 2.19.2.1	The payload shall be full retained until its intended point of deployment. All retention mechanisms shall function as designed without sustaining damage.	The retention system experiences no plastic deformation during launch or recovery.	Completed

Results:

The FEA analysis results on the payload assembly are shown below in Figure 147a and 147b. The maximum Von Mises stress achieved in the assembly was 15,810 psi, which was on the 6 securing bolts. The fiberglass plate distributed the forces as intended, and only experienced a maximum Von Mises stress of 3,953 psi. The bolts are modeled as 316 annealed stainless steel. This steel has a tensile yield strength of 34,800 psi. The maximum experienced stress is well within the elastic region, so no permanent deformation will occur. The top plate is modeled as fiberglass, which has a tensile yield strength of 30,000 psi. The top plate is also well within the elastic limit of fiberglass. No permanent deformation or yielding occurred on any components. Because the six stainless steel bolts distributed the force, the PETG payload housing was able to withstand the theoretical force of the main parachute opening.



(a) Payload Tensile Analysis Von Mises Stresses (psi)

(b) Payload Tensile Analysis Deflection Magnitude (inches)

Figure 147: ANVIL Retention

The maximum deflection occurred at the the location of the eye bolt holes. A "surface traction", which models the shearing forces of the eye bolts in the assembly, was used to simulate the maximum force the payload would achieve upon the main parachute opening. Each eye bolt was modeled to exert 94 lb_f on the eye bolt holes. This resulted in a maximum deflection of approximately 2 thousandths of an inch.

Impact on Final Design:

The current payload retention design was capable of handling the parachute opening force, which was deemed to be the most traumatic event the retention system will undergo. The current design distributed the forces evenly as designed, and did not yield or deform under these loads. The fiberglass plate will preform well as a reinforcement to the plastic housing.

7.2.4 PT4 - Imaging Algorithm Demonstration

Objective: The objective of this test is to determine if the imaging algorithm compiled by the team is capable of locating the landing of the vehicle.

Justification: The purpose of this test is to validate the use of this algorithm and confirm the payload can operate correctly.

Equipment:

- DJI Mini 2 Drone with 4k Camera
- Drone Controller
- Computer
- Imaging Algorithm

Safety Precautions:

- Mask must be worn at all times

Procedure:

1. Initialize the drone setup, power on the drone, and confirm the drone is connected to the controller.
2. Fly the drone to a location on an open field and ascend to 150m above the ground.
3. Angle the camera perpendicular to the ground and take the first picture at 150m AGL.
4. Start the descent of the drone and take an image every 5m until the drone is 10m above the ground. Continually rotate the drone and shift the location of the drone in the horizontal plane above the field to simulate the swaying motion of the payload and gimbal.
5. Once the drone is 10m above the ground images will be taken once every meter until the ground is reached. Stop at 1 meter above the ground.
6. Upload the images to a computer and run the algorithm.
7. Confirm that the algorithm has successfully located the launch vehicle location

Success Criteria:

Table 125: PT5 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 5	The payload must be capable of the necessary computations to locate itself on the launch field.	The Raspberry Pi 4B completes the algorithm and finds its location on the field.	Pass
SLH Requirement 4.1	Teams shall design a payload that autonomously locates itself on the launch field without the use of GPS.	The Raspberry Pi 4B completes the algorithm and finds its location on the field.	Pass

Results:

The results of the algorithm demonstration proved the algorithm is working properly and can find the location of the vehicle accurately. Below in Figure 148, each image the algorithm tracked is overlaid and outlined by blue squares onto the original image at 150m. The pink dot displays the location of the launch vehicle in the last image.

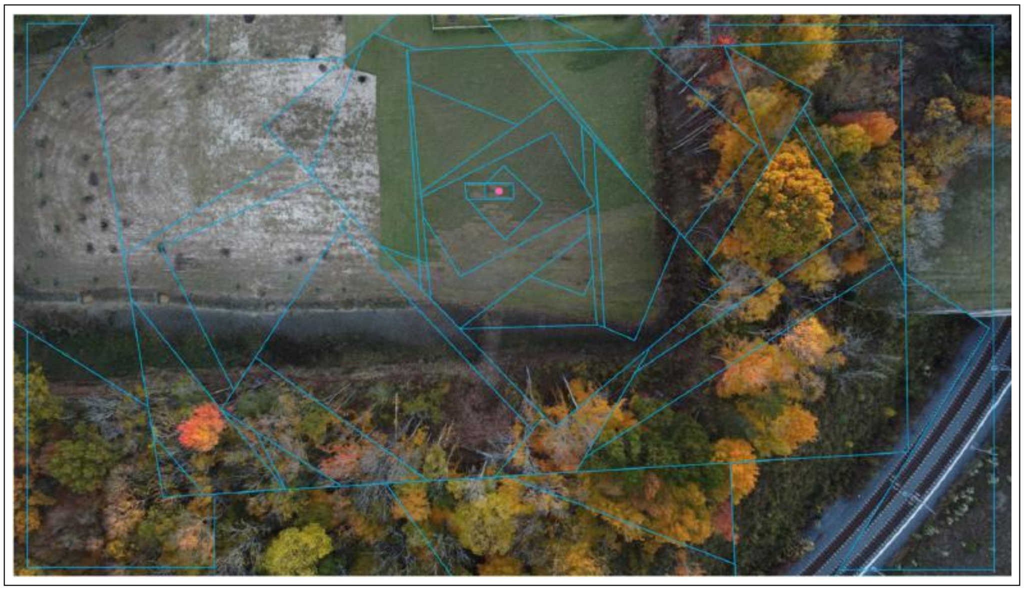


Figure 148: Algorithm Path Using Drone Images

Impact on Final Design:

The algorithm was proven to work well in this demonstration; however, further tests are to be completed in later dates for various environments to ensure the algorithm can work in any location.

7.2.5 PT5 - Time Intensive Test for Processing Length and Image Scaling

Objective: Prove the Raspberry Pi 4B is capable of processing multiple high quality images and determining a landing location within 30 minutes.

Justification: The purpose of this test is to validate the time requirement for the imaging algorithm and the Raspberry Pi 4B.

Testing Variables:

1. Algorithm/Image Processing Time

Equipment:

- Raspberry Pi 4B
- Micro SD Card
- Algorithm
- Laptop

Procedure:

1. The imaging algorithm is uploaded to the Raspberry Pi 4B. After the upload is complete, the Raspberry Pi is disconnected from the computer.
2. The Raspberry Pi 4B is connected to a 9V battery for power.
3. The images from PT4 are uploaded to a micro SD card to be inserted into the Pi 4.
4. Once all images are uploaded to the micro SD card, the card is inserted into the Raspberry Pi.
5. The Raspberry Pi begins the algorithm and a timer is started.
6. When the Raspberry Pi finishes matching the images, the timer is stopped.

Success Criteria:

Table 126: PT6 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 10	The payload must locate itself within 30 minutes.	The imaging algorithm and Raspberry Pi find the landing location before 30 minutes has elapsed.	Pass

Results:

The Raspberry Pi 4B took 14:13.87 (min:sec.ms) to process 29 8.3 megapixel images from the drone. The large image size cause the algorithm to spend a considerable amount of time matching shapes between each image.

Impact on Final Design:

To combat the processing time, the payload will take images every 440 feet while under streamer recovery. When the main parachute is deployed, the payload will take pictures every 50 feet. Assuming the first image is taken at 5,000 feet, 10 images will be taken under the streamer. For the main parachute, 11 images will be taken. This makes the total images taken 21, which is less than the 29 tested with the drone.

7.2.6 PT6 - Raspberry Pi Camera Imaging Demonstration

Objective: The objective of this test is to confirm the Raspberry Pi and camera can capture successive images during descent.

Justification: The payload needs to be capable of capturing multiple images throughout it's descent in order to accurately locate itself on the launch field.

Testing Variables:

1. Successive imaging capture
2. Altitudes with each image

Equipment:

- Raspberry Pi Housing Box
- Raspberry Pi 4B
- Raspberry Pi 4B High Quality Camera
- 3,000 mAh Battery
- FingerTech Switch
- 2x Allen Wrench
- Buzzer
- BMP280 Pressure Sensor
- Raspberry Pi HQ 90° FOV Lens
- 5V Converter
- Custom Drone

Safety Precautions:

Team members should not touch the drone during flight and stand clear of the propellers.

Procedure:

1. The Raspberry Pi 4B, camera, BMP280, and a 3,000 mAh battery are inserted into the housing box. The box is to protect the components from impacts.
2. The housing box is attached to the drone.
3. Next, the FingerTech switch is closed to power on the Raspberry Pi 4B and camera.
4. A buzzer in the payload box will beep when the Raspberry Pi has started taking images. Once the beeping has started, the drone lifts off the ground and flies to the center of the field.
5. Once at the center of the field, the drone ascends to an altitude of 400 feet.
6. At 400 feet, the drone will start to descend, taking pictures the entire way down.
7. Once the payload reaches an altitude of 50 feet, the drone returns to its launch location and lands.
8. When the drone is safely on the ground and powered off, a team member will walk over to the payload housing to open the FingerTech switch and power off the device. This stops the Raspberry Pi from continually capturing images.

Success Criteria:

Table 127: PT6 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 6	The camera must know the altitude at which an image was taken within 25 feet.	The Raspberry Pi camera captures successive images and records the altitudes for each image.	Pass

Results:

The Raspberry Pi was correctly able to incorporate the barometric pressure data into the imaging name. Each image from the test was correctly named at the altitude it was taken.

(a) Image Captured at 143 Feet

(b) Image Captured at 227 Feet

Figure 149: Altitude Named Images

Figure 149a was named "2022-02-04-17-19-52-143.jpg" by the Raspberry Pi. The "143" at the end of the name denotes the altitude at which the image was captured (in feet). Similarly, Figure 149b was named "2022-02-04-17-19-53-227.jpg", and the "227" denotes this image was taken at 227 feet.

Impact of Final Design:

The Raspberry Pi correctly identifies the altitude that the image was taken at. This is necessary for the safety of the gimbal because the Raspberry Pi must be able to recognize when ANVIL is 50 feet from the ground. This test is successful in displaying the functionality of the code.

7.2.7 PT7 - Gimbal Retraction Test

Objective: The objective of this test is to time the gimbal retraction inside the payload housing.

Justification: The payload needs to be reusable without any modification. It is extremely likely the gimbal will break upon impact if it is not protected inside the payload housing; therefore, it is necessary to test the retraction speed of the gimbal.

Testing Variables:

1. Retraction speed of the gimbal

Equipment:

- Payload Housing
- Gimbal Assembly (see section 7.2.2 for gimbal equipment)
- 2000 Series 5-Turn Servo
- 25-Tooth Pinion Gear
- 5 Inch Long, $\frac{3}{16}$x$\frac{3}{16}$ Inch 1018 Steel Rack
- Servo Housing
- 2x $\frac{1}{4}$-20 Bolts
- 2x $\frac{1}{4}$-20 Nuts
- M1.5x0.3 Bolt
- M2.5 Screw
- 4x M2 Screws
- 4x M2 Nuts
- 3,000 mAh Battery
- Raspberry Pi 4B

Safety Precautions:

Extremities should be kept away from the rack and pinion at all times during the test. Loose hair should be secured so it cannot get caught in the gears. Team members should always be aware of pinch points during this test.

Procedure:

1. The gimbal is assembled separately as described in section 7.2.2.
2. The servo sub-assembly is created next by inserting the pinion gear onto the servo and fastening it with the M2.5 screw. The HS-788HB has its own servo horn for mounting components.
3. The servo is placed inside the servo housing and fastened with the 4 M2 screws that come with the servo. They secure the HS-788HB to the servo housing.
4. Four M2 nuts are fastened to the back to keep the servo from loosening from its housing.
5. The rack is run through the assembly. The servo will hold the rack in place due to the back torque required to drive the servo.
6. The rack is then attached to the gimbal sub-assembly via a M1.4x0.3 bolt.
7. After both sub-assemblies have been joined, two $\frac{1}{4}$-20 bolts are inserted into the mounting holes.
8. The full gimbal and servo assembly is inserted into the bottom of the payload housing.
9. Two $\frac{1}{4}$ nuts are used to secure the entire assembly together.
10. The Raspberry Pi 4B is connected to the servo and will control the inputs.
11. Once the Raspberry Pi is programmed, the battery is connected and the servo will raise the gimbal assembly.
12. The time to raise and lower the gimbal is to be recorded.
13. Five trials will be completed and two members will simultaneously record the time to retract to find an average.

Success Criteria:

Table 128: PT8 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 9	The gimbal must retract within 2.5 seconds.	The gimbal fully retracts within 2 seconds of activation.	Pass

Results:

Differences in the retraction time can be accounted for by human error during timing. To negate this, multiple trials were run with two timers. The gimbal was able to withdraw within 2.5 seconds of initiation of the retraction code. Two retraction times per trial were recorded and are shown in Table 129 with their averages.

Table 129: Gimbal Retraction Times

Trial	Time (sec)	Average
1	2.31, 2.25	2.28
2	2.31, 2.21	2.26
3	2.35, 2.16	2.26
4	2.54, 2.29	2.42
5	2.18, 2.39	2.29

The overall retraction time average is 2.30 seconds. This is below the required 2.5 seconds to retract.

Impact on Final Design:

From this test, the gimbal will be able to retract before impact with the ground, thus, avoiding damaging the camera and gimbal system.

7.2.8 PT8 - Incorporated Gimbal Camera Test

Objective: The objective of this test is to determine if the gimbal can steady the camera for imaging during a descent.

Justification: The imaging algorithm does not compensate for highly erratic images, and therefore, needs the gimbal to keep the camera perpendicular with the ground.

Testing Variables:

1. Capability of the gimbal to maintain perpendicularity with the ground.
2. Capability of the imaging algorithm to work with the gimbal images.
3. Time it takes for the imaging algorithm to run through the captured images.

Equipment:

- Gimbal Assembly (see section 7.2.2)
- Raspberry Pi Housing Box (see section 7.2.6)

Safety Precautions:

Team members should not touch the drone during flight and stand clear of the propellers.

Procedure:

1. Assemble the Raspberry Pi housing box as described in section 7.2.6.
2. Assemble the gimbal as described in section 7.2.2.
3. Once both assemblies are completed, the gimbal is attached to the payload housing box.
4. Follow steps 4 through 7 in the procedure section of PT6 for this test.
5. After the components are collected, the images captured are inspected for their perpendicularity with the ground.
6. The captured images are then ran through the imaging algorithm and timed.

Success Criteria:

Table 130: PT8 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 6	The camera must know the altitude at which an image was taken within 25 feet.	The Raspberry Pi camera captures successive images and records the altitudes for each image.	Pass
TDPR 7	The gimbal must remain within an angle of 10° of perpendicular to the ground.	The gimbal will remain perpendicular to the ground throughout the demonstration.	Pass

Results:

The results from the gimbaled drone test are shown below in Figure 150. Each image the algorithm tracked is overlaid on the original image taken at 400 feet. The gimbal was able to maintain perpendicularity to the ground to allow the imaging algorithm to find the landing location of the drone.

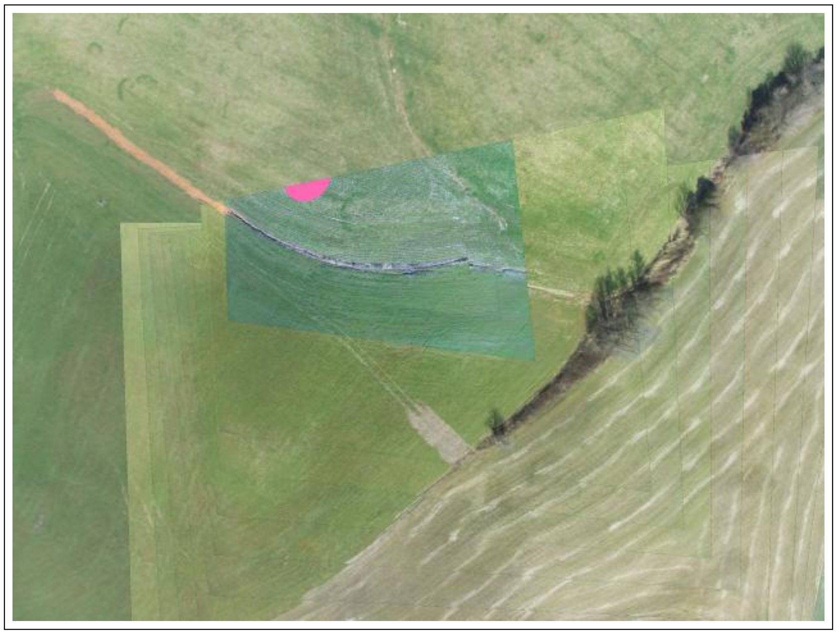


Figure 150: Image Registration Test Result

Impact on Final Design:

The gimbal was able to adjust to the drone's movement and capture stabilized images during descent. The gimbal will be used on the final payload for image stabilization.

7.2.9 PT9 - Full Payload Assembly Test

Objective: The purpose of this test is to verify all components are capable of operating together.

Justification: All components in the full payload assembly must be able to operate without interfering with one another.

Testing Variables:

1. Gimbal Retraction
2. Imaging Algorithm Run Time
3. Transmitted Message

Equipment:

See section 6.3.1.

- Fiberglass Plate
- 2x Eye Bolt
- Electrical Bay
- Gimbal Bay
- 2x Guide Rails
- 2x Electrical Bay Doors
- 3.5 Inch Long, $\frac{1}{2}$x$\frac{1}{2}$ Inch 1018 Steel Rack
- 25-Tooth Pinion
- 8x $\frac{1}{4}$-20 Screw
- 4x $\frac{1}{4}$-20 Nut
- 4x $\frac{1}{4}$-20 Brass Heat Set Insert
- 4x 4-40 Screw
- 4x 4-40 Heat Set Insert
- 12x Rubber Washer
- 4x M4.5 Screw
- 4x M4.5 Nut
- 4x M2-25 Screw
- 4x M2-25 Nut
- Raspberry Pi 4B
- Raspberry Pi HQ Camera
- Trinket M0
- ADXL326 Accelerometer
- BMP280 Pressure Sensor
- DC-DC Converter
- Xbee PRO s3b
- RP-SMA Duck Antenna
- 3000 mAh LiPo Battery
- Electrical Components PCB

Safety Precautions:

Extremities should be kept away from the rack and pinion at all times during the test. Loose hair should be secured so it cannot get caught in the gears. Team members should always be aware of pinch points during this test.

Procedure:

1. The gimbal is assembled separately as described in section 7.2.2.
2. The servo assembly is also made separately as described in section 7.2.8.
3. The gimbal is attached to the retraction system via two $\frac{1}{4}$-20 screws and nuts.
4. The full gimbal assembly is then attached to the gimbal bay by two $\frac{1}{4}$-20 screws and nuts.
5. Mount the electrical component PCB with the Raspberry Pi, Trinket, ADXL326 accelerometer, and the BMP280 to the electrical bay door with four 4-40 screws and four rubber washers.
6. Mount the Xbee PRO s3b with the RP-SMA duck antenna attached to the electrical bay wall with four rubber washers and four 4-40 screws.
7. Connect all components to the Raspberry Pi 4B.
8. Finally connect the 3000 mAh battery to the Raspberry Pi for power.
9. The payload will be taken at least 2,500 feet from the "home base" receiver.
10. A team member will hold the payload and inspect the gimbal to ensure it is oriented with the ground.
11. A team member will test the retraction speed of the gimbal assembly and time it.
12. The team member at "home base" will check to make sure the payload is still transmitting without interference while the gimbal and servo assemblies are being tested.
13. The payload will also continually capture images while the test is running.

Success Criteria:

Table 131: PT8 Success Criteria

Requirement Verified	Requirement Summary	Success Criteria	Results
TDPR 2	The payload must be able to transmit at least 2,500 feet.	The payload successfully transmits a message at least 2,500 feet.	Incomplete
TDPR 6	The camera must know the altitude at which an image was taken within a range of 25 feet.	The camera takes an image of the ground and records the current altitude.	Incomplete
TDPR 7	The gimbal must remain within an angle of 10° of perpendicular to the ground.	The gimbal will remain perpendicular to the ground throughout the demonstration.	Incomplete
TDPR 9	The gimbal must retract within 2 seconds.	The gimbal fully retracts within 2 seconds of activation.	Incomplete

Once this test is successful, the integrated payload test flight can be performed. This is described in section 7.1.15.

Results:

TBD

Impact on Final Design:

TBD

7.3 Requirements Compliance

7.3.1 Verification Requirements

The verification of Student Launch Handbook Requirements are found in Tables 132 through 136. Verification of these requirements ensures the safety and success of the team's mission. Requirements are verified by: testing, analysis, demonstration, and inspection. These tables also include a verification method, status of each requirement, and the location within this report.

1. Test:
   - A test collects quantifiable data based on predetermined testing variables. The data collected can be interpreted and analyzed to yield a significant result.
2. Analysis:

- Analysis is a methodical study of specific components or assemblies through the use of simulations or models to predict the expected performance of a design.

3. Demonstration:

    - Demonstration is the physical method of analysis that provides no quantifiable data, but rather qualitative data regarding the performance in a controlled environment.

4. Inspection:

    - Inspection is the observation of a system to verify all components meet expectations.

Following the Student Launch Handbook Requirements, team derived vehicle, recovery, payload, and safety requirements are given in Tables 137 through 140. These follow the same method of verification as the Student Launch Handbook Requirements. The team derived requirements are designed to ensure certain criteria are met for each sub-section of the competition.

7.3.2 Verification of General Requirements

Table 132: Verification of General Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing, and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	Demonstration	**Status: In Progress** UNCC's Rocketry Team is entirely independent. The team creates all projects in accordance with UNCC's regulations on intellectual property. The Rocketry Team will only use designated team member to complete tasks specified by the project lead. No outside help will be used to create the project, aside from operations that must be preformed by the team mentor such as motor assembly, preparing e-matches, etc.	Section 1.1
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Inspection	**Status: In Progress** The UNCC Rocketry Team holds weekly meetings to discuss completed, current, and future tasks. A synchronized online database contains all information regarding the team, project milestones, and event dates.	Section 6, 7
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Inspection	**Status: Complete** Any Foreign National team members will be reported prior to the PDR. The team does not have any foreign national students.	N/A
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: • 1.4.1 Students actively engaged in the project throughout the year. • 1.4.2 One Mentor (see requirements 1.13). • 1.4.3 No more than two adults educators.	Inspection	**Status: Complete** All student team members, the team mentor, and any educators who are interested in attending the Launch Week activities will be identified before the CDR is due. The team leads will report all expected attending persons and ensure that any attendees meet the prerequisites to travel to Launch Week.	N/A
1.5	The team will engage a minimum of 250 participants in direct educational, hands-on Science, Technology, Engineering, and Mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.	Inspection	**Status: Complete** Outreach opportunities will be conducted. Reports on the outreach events will give accurate descriptions of the transpired events as well as the number of individuals reached.	Sections 1.1, 7.4.7
1.6	The team will establish and maintain a social media presence to inform the public about team activities.	Inspection	**Status: Complete** The team's social media platforms will be up-to-date on information regarding the progress of the project. This includes the website, Facebook, YouTube, Instagram, and Twitter pages.	N/A

Table 132: Verification of General Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.	Inspection	**Status:** In Progress The Project Lead will confirm the deliverables are sent and received prior to the deadline posted by NASA. If a document is too large to be transferred through email, a link will be provided to the document.	N/A
1.8	All deliverables must be in PDF format.	Inspection	**Status:** In Progress The UNCC Rocketry's team deliverables and documents will be created on a web-based platform called Overleaf and compiled into PDF format for submission.	N/A
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Inspection	**Status:** In Progress All reports and deliverables will contain a table of contents with section and subsection headings labeled. All team members will be responsible for their respective portions of the reports and deliverables.	Page 4
1.10	In every report, the team will include the page number at the bottom of the page.	Inspection	**Status:** In Progress Reports and deliverables will contain an up-to-date page number at the bottom of the page. All team members will be responsible for their respective portions of the reports and deliverables.	N/A
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Inspection	**Status:** Complete The UNCC Rocketry Team will reserve a conference room from the College of Engineering (COE) at least two weeks prior to any teleconference and ensure all systems are operating correctly for the review panel.	N/A
1.12	All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8 *feet* 1010 rails and 12 *feet* 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	Demonstration	**Status:** Complete The launch vehicle will be capable of launching from a 12 ft, 1515 launch rail.	Section 1.2

Table 132: Verification of General Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
1.13	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class prior, to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the numbers of teams he or she supports. The stipend will only be provided if the team passes the FRR and the team and mentor attend launch week in April.	Inspection	**Status: Complete** The project lead will speak with the mentor to ensure they are in compliance with NAR and TRA as well as the responsibility they have towards the team and the rocket.	Section 1.1
1.14	Teams will track and report the number of hours spent working on each milestone.	Inspection	**Status: Complete** All members of the UNCC Rocketry team will track their respective hours via a spreadsheet that delineates what was done during said time.	Table 2

7.3.3 Verification of Vehicle Requirements

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet Above Ground Level (AGL). Teams flying below 4,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	Demonstration Analysis	**Status: Complete** OpenRocket simulations were used to approximate the apogee of the launch vehicle and Matlab was used to verify the OpenRocket predictions. The sub-scale flights verified the simulations. The final apogee will be determined by the full-scale flight.	Sections 3.4, 3.4.1, 3.4.3, 4.2, 7.1.12, 7.1.13
2.2	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.	Analysis	**Status: Complete** The target altitude was declared to be 5,000 feet in the PDR. This altitude was chosen from the simulation data based on vehicle geometry, mass, motor selection, and simulated environmental conditions.	Section 3
2.3	The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.	Inspection	**Status: Complete** Prior to launch, an inspection will be done to ensure two Missile Works RRC3 Altimeters are located in the payload recovery section of the launch vehicle, and two Missile Works RRC3 Altimeters are located in the booster recovery section and all altimeters are working and wired correctly.	Sections 3.3.6, 7.1.12, 7.1.15

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.4	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Testing Analysis	**Status: Complete** The selected material for the airframe was chosen for its high impact toughness. Parachutes were also chosen to minimize the kinetic energy the vehicle experiences upon impact. the parachutes are wrapped in a Nomex blanket to ensure it does not burn from the charges. The motor casing is reloadable, allowing for same-day launches.	Sections 3.2, 3.3.2, 3.3.6, 3.4.6, 7.1.12, 7.1.15
2.5	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Inspection	**Status: Complete** The launch vehicle will be comprised of four sections: booster propulsion, booster recovery, payload section, and payload recovery.	Section 3.3
2.5.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Inspection	**Status: Complete** There are three body separation points in the vehicle and each has a ten inch carbon fiber coupler.	Section 3.2.7
2.5.2	Nose cone shoulders which are located at in-flight separation points will be at least $\frac{1}{2}$ body diameter in length.	Inspection	**Status: Complete** The nose cone shoulder is 5 inches in length.	Section 3.2.7
2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	**Status: In Progress** A full vehicle assembly will be tested before launch days and at each launch to ensure it can be completed within 2 hours. The AV bays were designed to to fully removable to aid in the assembly of the recovery system. The same hardware was used in the ANVIL payload and on the vehicle to minimize the amount of time spent switching tools.	Sections 7.1.12, 7.1.15
2.7	The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Testing Demonstration	**Status: Complete** A power budget will be generated for both the vehicle and payload to ensure that they will be able to remain on the launch pad for at least 2 hrs. This will be done by putting the payload into sleep mode and waking it up only when 5 G's are detected by the Adafruit DXL326 3-AXIS Accelerometer Breakout Board.	Sections 4.11.1, 4.9.3
2.8	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated services provider.	Inspection	**Status: Complete** Commercially available igniters will be used for sub-scale and full-scale flights.	Sections 7.1.6, 7.1.7, 7.1.8, 7.1.12, 7.1.15
2.9	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other that what is provided by the launch services provider).	Inspection	**Status: Completed** All electrical components of the launch vehicle are housed internally, and each section has its own dedicated electronics bay.	Sections 7.1.12, 7.1.15

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Inspection	**Status: Completed** The launch vehicle will use the AeroTech L1390G motor, which has been purchased from Wildman Rocketry.	Sections 1.2, 3.4.1
2.10.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Inspection	**Status: Completed** The final motor choice has been chosen and is the AeroTech L1390G.	Sections 1.2, 3.4.1
2.10.2	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	Analysis	**Status: Complete** Simulations have been ran to ensure the motor selection can achieve the goal altitude within an acceptable range. If the motor selection needs to be changes, a petition will be submitted to the RSO stating the reason for the change.	Sections 1.2, 3.4.1
2.11	The launch vehicle will be limited to a single stage.	Inspection	**Status: Complete** The AeroTech L1390G is the only motor that will be used in the launch vehicle and will be inspected during the full-scale flight demonstration.	Section 3.4.1
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Inspection	**Status: Complete** The Aerotech L1390G has a total impulse of 3965 N-s.	Section 3.4.1
2.13	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria listed in the handbook	Inspection	**Status: Complete** There are no pressure vessels on the vehicle.	N/A
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Ma Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	Analysis	**Status: Complete** There are no pressure vessels on the vehicle.	N/A
2.13.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Analysis	**Status: Complete** There are no pressure vessels on the vehicle.	N/A
2.13.3	The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	Inspection	**Status: Complete** There are no pressure vessels on the vehicle.	N/A
2.14	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis Demonstration	**Status: Complete** The static stability was determined to be 2.90 using OpenRocket and verified through hand calculations. The CG will be determined physically on launch day before flight once the motor is loaded.	Section 3.4.4

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.15	The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0	Analysis	**Status: Complete** Through the mass budget and motor thrust curve, the current thrust to weight ratio is 7.76 : 1.0. This will be verified once vehicle construction is complete.	Sections 3.4.9, 3.4.1
2.16	Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Inspection	**Status: Complete** The rail buttons will be positioned below the post-burn CG location.	Sections 3.2.6, 3.4.4
2.17	The launch vehicle will accelerate to a minimum velocity of 52 ft/s at rail exit.	Analysis Testing	**Status: Complete** OpenRocket will be used to verify the velocity of the launch vehicle at the rail exit.	Sections 3.4, 7.1.12, 7.1.15
2.18	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	Analysis Testing	**Status: Complete** A sub-scale model of the launch vehicle using a J500G motor has been successfully launched and recovered.	CDR Section 3.7.6, Sections 7.1.6, 7.1.7, 7.1.8
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model.	Analysis Testing	**Status: Complete** A 60% sub-scale model of the launch vehicle was created using the same materials for each component, as well as the same fin, boattail, and nosecone geometries. The stability is also the same as the full-scale vehicle to verify mission performance predictions.	CDR Section 3.7.2
2.18.2	The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Demonstration	**Status: Complete** The sub-scale vehicle carried two Missile Works RRC3 Altimeters onboard to record the model's apogee altitude.	CDR Section 3.8.4.1, Sections 7.1.6, 7.1.7, 7.1.8
2.18.3	The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project	Inspection	**Status: Complete** The sub-scale vehicle was newly designed and constructed by the 49er Rocketry Team for the 2021-2022 competition.	CDR Section 3.7.1
2.18.4	Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.	Demonstration Testing	**Status: Complete** The sub-scale model of the launch vehicle has been successfully tested and data from the RRC3 altimeters has been recorded and analyzed in the CDR document.	CDR Section 3.7.6, Section 7.1.8
2.18.5	The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket.	Inspection	**Status: Complete** The sub-scale model of the launch vehicle is a 60% scale of the full-scale launch vehicle.	CDR Section 3.7.2

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.19.1	Vehicle Demonstration Flight - All teams will 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 (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The criteria in the SLH shall be met during the full-scale demonstration flight.	Testing	**Status: Complete** Three vehicle demonstration flights are planned: two in Bayboro, NC and one in Dalzell, SC.	Sections 5.3, 7.1.12, 7.1.13, 7.4.6
2.19.1.1	The vehicle and recovery system will have functioned as designed.	Demonstration Testing	**Status: In Progress** The data obtained from the Missile Works RRC3 Altimeters will verify the success of the vehicle launch and recovery.	Sections 5.3, 7.1.12, 7.1.13
2.19.1.2	The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	Inspection	**Status: Complete** The full-scale launch vehicle will be newly designed and constructed by the 49er Rocketry Team for the 2021-2022 competition.	Section 3.2.7
2.19.1.3	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The requirements from the SLH still apply.	Inspection	**Status: Complete** The payload was flown in all flight tests.	Sections 5.2, 5.4, 7.1.12, 7.1.13
2.19.1.3.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Inspection	**Status: Complete** The payload was flown for all full-scale flight tests.	Sections 5.2, 5.4, 7.1.12, 7.1.13
2.19.1.3.2	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Inspection	**Status: Complete** All flights had use the fully assembled payload.	Sections 5.2, 5.4, 7.1.12, 7.1.13
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 will be active during the full-scale Vehicle Demonstration Flight.	Inspection	**Status: Complete** The payload will not affect the external surface or manage the total energy.	Section 4.4
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.	Inspection	**Status: Complete** The team will use the chosen Aerotech L1390G motor for the vehicle demonstration flight.	Sections 5.3, 7.1.12, 7.1.13
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 may not be added without a reflight of the full-scale launch vehicle.	Inspection	**Status: In Progress** The full-scale vehicle demonstration launch will be flown with the same ballast that will be used on launch day.	Sections 5.3, 7.1.12, 7.1.13

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.19.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Inspection	**Status: In Progress** The launch vehicle will not be altered after the full-scale demonstration flight without permission of RSO.	Sections 5.3, 7.1.12, 7.1.13
2.19.1.8	Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement.	Demonstration Testing	**Status: Complete** Altimeter data from the successful full-scale test flight will be included in the FRR document.	Sections 5.3, 7.1.12, 7.1.13
2.19.1.9	Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will 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.	Testing	**Status: In Progress** The launch vehicle demonstration flight is scheduled for March 12th, 2022 in Dalzell, SC. A backup launch is scheduled for March 26, 2022 in Bayboro, NC. If a vehicle demonstration re-flight is required, the team lead will submit an FRR Addendum by its deadline.	Section 7.4.6
2.19.2	Payload Demonstration Flight - All teams will 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.	Testing	**Status: In Progress** The payload demonstration flight is scheduled for March 12, 2022 in Dalzell, SC.	Section 7.4.6
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	Demonstration	**Status: Complete** The payload will be fully retained until apogee is reached via the coupler at the booster drogue separation.	Sections 4.7.4, 5.2, 5.4, 7.1.12, 7.1.13
2.19.2.2	The payload flown shall be the final, active version.	Inspection	**Status: In Progress** The payload that is flown will be the final, active version.	Section 4.5
2.19.2.3	If the above criteria 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 are not required.	Inspection	**Status: Incomplete** If the payload requirements are met during the vehicle demonstration flight and included in the FRR package, the additional flight and FRR Addendum will not be required.	N/A
2.19.2.4	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	Inspection	**Status: Incomplete** Back up launch dates are scheduled in the event a re-flight is required or there in inclimate weather.	Section 7.4.6
2.20	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	Inspection	**Status: In Progress** The FRR Addendum will be submitted if a payload or vehicle demonstration flight is completed after the submission of the FRR document.	N/A
2.20.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.	Inspection	**Status: Incomplete** All required documentation will be submitted on time.	N/A

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.20.2	Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.	Testing	**Status: Incomplete** A payload demonstration flight will be completed before launch week.	Section 7.4.6
2.20.3	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	Testing	**Status: Incomplete** In the even the payload demonstration flight is not completely successful, the team will petition the NASA RSO for permission to fly the payload at launch week.	N/A
2.21	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Analysis	**Status: Complete** Team information will be incorporated into the exterior design of the air frame.	N/A
2.22	All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Demonstration	**Status: In Progress** All batteries will be carefully housed within the vehicle, protected from impact forces and marked as a fire hazard.	Section 6.2.4, Tables 72, 74, 77
2.23.1	The launch vehicle will not utilize forward firing motors.	Analysis	**Status: Complete** The Aerotech L1390G motor used in the launch vehicle is not a forward firing motor.	Sections 1.2, 3.4, 3.4.1
2.23.2	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Analysis	**Status: Complete** The Aerotech L1390G motor used in the launch vehicle does not expel titanium sponges.	Sections 1.2, 3.4, 3.4.1
2.23.3	The launch vehicle will not utilize hybrid motors.	Analysis	**Status: Complete** The vehicle uses a single AeroTech L1390G motor which burns solid fuel.	Sections 1.2, 3.4, 3.4.1
2.23.4	The launch vehicle will not utilize a cluster of motors.	Analysis	**Status: Complete** The launch vehicle uses a single AeroTech L1390G motor.	Sections 1.2, 3.4, 3.4.1
2.23.5	The launch vehicle will not utilize friction fitting for motors.	Analysis	**Status: Complete** The motor will be housed within a motor tube that is epoxied to the airframe by carbon fiber centering rings.	Section 3.2.4, 3.2.6
2.23.6	The launch vehicle will not exceed Mach 1 at any point during flight.	Analysis	**Status: Complete** The vehicle will only reach a maximum of Mach 0.54.	Sections 5.3, 7.1.12, 7.1.13
2.23.7	Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 43.74 lbs. on the pad may contain a maximum of 4.374 lbs. of ballast).	Analysis	**Status: Complete** The current design utilizes 1.2 lbs of ballast weight, or 2.93% of the total mass.	Section 5.3.2.

Table 133: Verification of Vehicle Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Analysis	**Status: Complete** The Xbee transmitters used for communication are set to 250 mW transmitting power.	Sections 3.3.7, 4.9.4
2.23.9	Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Analysis	**Status: Complete** The frequencies used for communication are 920 MHz.	Section 4.9.4
2.23.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Analysis	**Status: Complete** The vehicle will be primarily constructed from carbon fiber and 3D printed parts. Lightweight metal fasteners will only be used when needed.	Section 3.2.2

7.3.4 Verification of Recovery Requirements

Table 134: Verification of Recovery Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer from apogee to main parachute deployment is also permissible, provided that the kinetic energy during drogue stage descent is reasonable, as deemed by RSO.	Design	**Status: Complete** The payload section will descend under a streamer until main deployment at 600 ft. The booster section will descend under a drogue under main deployment at 600 ft.	Section 3.3.1
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Testing Design	**Status: Complete** The altimeters will be programmed for main deployment at 600 ft. Altimeter firing testing will be preformed in a pressure chamber to test the barometric pressure sensor on the RRC3 fires at the programmed main parachute deployment altitude of 600 ft.	Section 3.3.1
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	Design	**Status: Completed** All the altimeters will be programmed to contain a delay no longer than 2 seconds.	Section 3.3.1
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	Design	**Status: Complete** The motor will be constrained with the booster section held in by the boattail. There is no motor ejection charge in the motor.	Section 3.2.6

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
3.2	Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the sub-scale and full scale vehicles.	Testing	**Status: Complete** Ground ejection testing will be performed to ensure the calculated black powder masses will generate enough force to break the shear pins for parachute deployment. Sub-scale testing has been completed while full-scale testing will be conducted when vehicle construction is done.	Sections 7.1.2, 7.1.10
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Analysis	**Status: Completed** Using the mass of the independent vehicle sections, the minimum parachute sizes were determined to ensure the sections will land under 75 ft-lbs of kinetic energy. The calculations prompted the selection of a 72 in. main for the payload section and a 84 in. main for the booster section.	Sections 5.3.2, 7.1.12, 7.1.13
3.4	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Design Inspection	**Status: Completed** The recovery system will utilize utilize Missile Works RRC3 Altimeters to serve as the primary and backup. The altimeters will be located in the altimeter bays of the payload and booster section.	Sections 3.3.4.1, 3.3.6
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries	Design Inspection	**Status: Complete** Each recovery altimeter will be powered by their individual typical 9 V battery. The batteries will be retained in the altimeter bay, neighboring to their corresponding altimeter.	Sections 3.3.5, 3.3.6
3.6	Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in launch configuration on the launch pad.	Design	**Status: Complete** There will be four FingerTech switches in the vehicle which connect to the primary and redundant altimeters. Holes will be drilled to the vehicle frame to allow the switches to be turned on by an allen wrench.	Section 3.3.6
3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Demonstration	**Status: Complete** The FingerTech switch will be used as the altimeter arming switch which requires an allen key to control the power of the altimeters. The sub-scale flights demonstrated the altimeters will not power off during flights.	Section 3.3.6
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Design	**Status: Complete** All of the recovery electrical systems are individually powered by its own source and is completely independent of any payload electrical system. The recovery systems are designed to not be dependent of the payload electronics.	Section 3.3.5

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
3.9	Removable shear pins will be used for both main parachute compartment and the drogue parachute compartment.	Analysis Design	**Status:** **Complete** The separation points on the vehicle were designed to be connected with 2-56x1/4 in. Nylon Shear Pins. The black powder mass calculations were derived from the properties of the shear pins.	Sections 3.3.1, 3.3.3, 3.3.4
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis	**Status:** **Complete** With the selected parachute sizes and their respective section masses, the descent rates under drogue/streamer and main were found. The descent rates were then multiplied by a wind speed of 20 mph. The calculations showed the vehicle sections will not drift further than 2,500 ft under the influence of the worst wind conditions.	Sections 5.1.2, 5.3.2, 7.1.12, 7.1.13
3.11	Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).	Analysis	**Status:** **Complete** With the descent rates and the altitudes of the parachute deployments, the descent times of the booster and payload section were confirmed to be less than 90 seconds.	Sections 5.3.2, 7.1.12, 7.1.13
3.12	An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Design	**Status:** **Complete** Both vehicle sections will have their own GPS system. For the payload section, a FeatherWeight GPS will be located in the nosecone. For the booster section, a Featherweight GPS will be tethered to the main parachute shock cord.	Sections 3.3.7, 7.1.12, 7.1.15
3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	Design	**Status:** **Complete** The independent vehicle sections will be equipped with their own active electronic tracking device. The payload and the booster section will contain a Featherweight GPS.	Section 3.3.7
3.12.2	The electronic tracking device(s) will be fully functional during the official flight on Launch Day.	Testing	**Status:** **In Progress** The Featherweight GPS Systems and RC-HP Trackers will be tested before the launch.	Section 3.3.7
3.13	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Design Demonstration	**Status:** **In Progress** The recovery system electronics will be located in an altimeter bay 10 in. or further from all other vehicle electronics. This will be demonstrated during full-scale test launches.	Sections 3.3.5, 3.3.6
3.13.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Design Demonstration	**Status:** **Complete** The Missile Works RRC3 primary and redundant altimeters will be retained in altimeter bays between two carbon fiber bulkheads at least 10 in. away from any GPS or other electronic. This will be demonstrated during full-scale test launches.	Sections 3.2.5, 3.3.6, 3.3.5

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
3.13.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Design Demonstration	**Status: Complete** The recovery system electronics will be inside an altimeter bay that is retained between two carbon fiber bulkheads that will shield the electronics from all transmitting devices. This will be demonstrated during full-scale test launches.	Sections 3.2.5, 3.3.6, 3.3.5
3.13.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Design	**Status: Complete** There are no generators, solenoid valves or Tesla coils onboard the vehicle that will inadvertently excite the recovery system.	N/A
3.13.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Design Demonstration	**Status: Complete** The recovery system electronics will be inside an altimeter bay that is retained between two carbon fiber bulkheads that will shield the electronics from all transmitting devices. This will be demonstrated during full-scale test launches.	Sections 3.2.5, 3.3.6, 3.3.5

7.3.5 Verification of Payload Requirements

Table 135: Verification of Payload Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
4.1	Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a Global Positioning System (GPS). The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.	Demonstration Testing	**Status: In Progress** Utilizes camera vision and a series of photos taken throughout recovery to determine the landing location based on image comparison.	Section 4.4
4.2.1	The dimensions of the gridded launch field shall not extend beyond 2,500 ft in any direction; i.e, the dimensions of your gridded launch field shall not exceed 5,000 ft by 5,000 ft.	Inspection Demonstration	**Status: Completed** The team will be careful when designing the grid to not exceed 2,500 ft in any direction or the 5,000 ft by 5,000 ft limit	Section 4.6
4.2.1.1	Your launch vehicle and any jettisoned components must land within the external borders of the launch field.	Inspection Demonstration	**Status: In Progress** The team will carefully consider the recovery stage of the flight to ensure a minimum drift distance to stay within the launch field.	Sections 5.1.2, 5.3.2
4.2.2	A legible gridded image with a scale shall be provided to the NASA management panel for approval at the CDR milestone.	Analysis	**Status: Completed** The team will be careful when designing the grid to put over the high quality aerial photograph and ensure it is included on the CDR document.	Section 4.6
4.2.2.1	The dimensions of each grid box shall not exceed 250 ft by 250 ft.	Analysis Testing	**Status: Completed** The team will be careful when designing the grid to not exceed these limits.	Section 4.6
4.2.2.2	The entire launch field, not exceed 5,000 ft by 5,000 ft, shall be gridded.	Demonstration	**Status: Completed** The team will be careful when designing the gridded aerial image to encompass the entire launch field within a high quality photo and grid it appropriately.	Section 4.6
4.2.2.3	Each grid box shall be square in shape.	Demonstration	**Status: Completed** The team will be careful to create boxes over the aerial image that are square in shape.	Section 4.6

Table 135: Verification of Payload Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
4.2.2.4	Each grid box shall be equal in size, it is permissible for grid boxes occurring on the perimeter of your launch field to fall outside the dimensions of the launch field. Do not alter the shape of a grid box to fit the dimensions or shape of your launch field.	Testing	**Status:** **Completed** The grid put over the high quality aerial photograph will have each grid box of equal size, as per NASA specifications.	Section 4.6
4.2.2.5	Each grid box shall be numbered	Testing	**Status:** **Completed** Prior to CDR, the high quality aerial photograph will have a grid applied to it and each grid box will be given an integer in increasing order from left to right, and top to bottom.	Section 4.6
4.2.2.6	The identified launch vehicle's grid box, upon landing, will be transmitted to your team's ground station.	Demonstration	**Status:** **In Progress** The payload will perform all necessary calculations to locate itself on the gridded aerial image and autonomously transmit this grid box to the ground station.	Section 4.9.4
4.2.3	GPS shall not be used to aid in any part of the payload mission.	Demonstration	**Status:** **Complete** The team will design a payload that is able to identify the launch vehicle's location without the need of GPS.	Section 4.4
4.2.3.1	GPS coordinates of the launch vehicle landing location shall be known and used solely for the purpose of verification of payload functionality and mission success.	Demonstration	**Status:** **In Progress** The launch vehicle will contain a GPS transmitter that will continuously stream GPS coordinates of its location to a receiver at the base station.	Section 3.3.7
4.2.3.2	GPS verification data shall be included in your team's PLAR.	Demonstration	**Status:** **In Progress** The team will include the GPS coordinates of the launch vehicle obtained during the launch in the PLAR report.	Section 3.3.7
4.2.4	The gridded image shall be of high quality, as deemed by the NASA management team, that comes from an aerial photograph or satellite image of your launch day launch field.	Demonstration	**Status:** **Complete** The gridded image of the launch field shall be a high quality aerial image that is approved by the management team.	Section 4.6
4.2.4.1	The location of your launch pad shall be depicted on your image and confirmed by either the NASA management panel for those flying in Huntsville or your local club's RSO. (GPS coordinates are allowed for determining your launch pad location).	Demonstration	**Status:** **Complete** The gridded, high quality aerial image will show and label the launch pad location.	Section 4.6
4.2.5	No external hardware or software is permitted outside the team's prep area or the launch vehicle itself prior launch.	Demonstration	**Status:** **In Progress** The team will keep all external hardware inside the prep area and within the launch vehicle.	N/A

Table 135: Verification of Payload Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Demonstration	**Status:** **Complete** The team will only use black powder for the deployment of recovery devices. No energetics will be use on ground operations.	N/A
4.3.2	Teams shall abide by all FAA and NAR rules and regulations.	Inspection	**Status:** **In Progress** All team members will follow all rules and regulations. The payload designs will also adhere to all rules and regulations throughout the entire competition.	Section 6.3
4.3.3	Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.	Inspection Demonstration	**Status:** **In Progress** No part of the vehicle is going to be jettisoned during the recovery phase of the flight as all parts will remained tethered together.	N/A
4.3.4	Unmanned Aircraft System (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	Demonstration	**Status:** **Complete** No UAS is included in this payload design.	N/A
4.3.5	Teams flying UASs will abide by all applicable FAA regulations, including FAA's Special Rule for Model Aircraft.	Inspection	**Status:** **Complete** No UAS is included in this payload design.	N/A
4.3.6	Any UAS weighing more than 0.55 lbs will be registered with the FAA and the registration number marked on the vehicle.	Design Demonstration	**Status:** **Complete** No UAS is included in this payload design.	N/A

7.3.6 Verification of Safety Requirements

Table 136: Verification of Safety Requirements

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Demonstration	**Status:** **In Progress** The final safety checklist will be finished and included in the FRR for use during launch days and the LRR.	Section 6.3.1
5.2	Each team shall identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	**Status:** **Complete** Daniel Naveira has been selected to be the team's Safety Officer.	Section 6.1

Item	Requirement Description	Verification Method	Verification Plan and Status	Report Location
5.3	The role and responsibilities of the safety officer will include, but not limited to: 5.3.1-5.3.4.	Procedure	**Status:** **In Progress** The Safety Officer has assumed the role and is undertaking the responsibilities listed.	Section 6
5.3.1	Monitor team activities with an emphasis on safety during: Design of vehicle and payload, Construction of vehicle and payload components, Assembly of vehicle and payload, Ground testing of vehicle and payload, Sub-scale launch test(s), Full-scale launch test(s), Launch Day, Recovery activities, and STEM Engagement Activities.	Demonstration	**Status:** **In Progress** The SO will ensure that safety is upheld and is at the forefront of all activities conducted by the team.	Section 6.1
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration	**Status:** **In Progress** The SO will ensure that all designs have safety factors and create a safety checklist.	Section 6.3.1
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	Demonstration	**Status:** **In Progress** The So will maintain up-to-date safety checklists and Safety handbooks.	Section 6
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	**Status:** **In Progress** The SO will maintain hazard analysis for personnel, and FMEA's for vehicle, recovery, payload, and environmental hazards.	Section 6.2
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	**Status:** **In Progress** The SO will ensure that the team abides by NAR and TRA guidelines.	Section 8.4
5.5	Teams will abide by all rules set forth by the FAA.	Demonstration	**Status:** **In Progress** The SO will ensure that the team abides by all FAA and local laws.	Section 8.4

7.3.7 Team Derived Vehicle Requirements

Table 137: Team Derived Vehicle Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDVR 1	Vehicle weight will not exceed 51.9 lb.	Demonstration	**Status: Complete** As components are purchased or constructed, accurate masses will be taken and added to the mass budget to verify each section and total mass.	Using OpenRocket software with a simulated wind speed of 20mph using the largest motor allowed, a vehicle that exceeds 57.69 lb will not achieve the minimum altitude of 4,000 ft. A 10% buffer was added to this.	Section 3.4.9
TDVR 2	The minimum inner diameter must be 5 in.	Demonstration	**Status: Complete** The inner diameter of the launch vehicle is 5 inches.	The current fin retention system requires an inner diameter of 5 in. in order to properly retain the fins.	Section 3.2
TDVR 3	The total length of the vehicle must be at least 100 in.	Demonstration	**Status: Complete** The vehicle is designed to have a total length of 100 inches.	In order to safely retain the ANVIL payload as well as maintaining a stability margin higher than 2.0, the vehicle must be 100 in. long.	Section 3.2
TDVR 4	The maximum allowable distance between rail buttons is 54.3 in.	Demonstration	**Status: Complete** The rail buttons are designed to be 18.41 in. apart and the final measurement will be taken once the launch vehicle construction is complete.	The vehicle must have a rail exit velocity of at least 52 ft/s. In order for this to occur, the vehicle requires 75 in. of effective rail length or it will not meet the required velocity. The rail buttons must have a distance less than 63.9 in. between them. A 15% buffer was used to ensure proper exit rail velocity.	Section 3.2.6
TDVR 5	The booster section cannot exceed 21.9 lbs to stay under the 75 $\mathrm{ft-lb_f}$ impact energy.	Inspection	**Status: Complete** The booster section as designed will experience 65.2 $\mathrm{ft-lb_f}$ of energy on impact with a mass of 24.75 lbs. Full-scale demonstration flight data will verify the calculations.	With the booster section mass being 20.55 lb, the impact energy comes out to be 65.98 $\mathrm{ft-lb_f}$. A 10% buffer was used as a safety factor	Section 3.2
TDVR 6	The nose cone must be made from transmissible material.	Demonstration	**Status: Complete** The nosecone was constructed from ABS plastic and tested to ensure transmissibility.	For the GPS to verify the location of the launch vehicle after landing, the nosecone must allow signals to be transmitted out of it.	Sections 3.2.6, 3.3.7
TDVR 7	The bulkheads within the vehicle will be able to easily withstand the forces experienced from launch and recovery.	Test	**Status: Complete** The bulkhead test is designed to emulate the bulkhead positioning the full-scale vehicle. The Instron Tensile Testing machine was used to perform a pull-to-failure test on the bulkhead system.	The tested bulkhead was able to withstand a maximum of 1,678 lbf before failure occurred, which shows that the bulkhead design is more than capable of withstanding the launch and recovery forces.	Section 7.1.9
TDVR 8	The sub-scale launch vehicle will achieve an altitude within 5% of the simulated sub-scale altitude.	Test	**Status: Complete** The second sub-scale flight achieved an altitude within 0.03% of the goal altitude and the third sub-scale flight achieved an altitude within 1.78% of the goal altitude.	The full-scale vehicle will receive a deduction multiplier of 0.015 if the percent difference between the goal altitude and actual altitude is 5%, securing an altitude score of 96.25. The sub-scale flight will ensure these values are achievable based on aerodynamic stability and construction methods.	Sections 7.1.7, 7.1.8

7.3.8 Team Derived Recovery Requirements

Table 138: Team Derived Recovery Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDRR 1	For the booster section, the main parachute will not exceed 96 in. For the payload section, the main parachute will not exceed 84 in.	Analysis	**Status: Complete** The drift calculations of the booster and payload sections with their respective masses showed if their parachute sizes exceed the sizes described the drift distances will be greater than 2,500 ft.	Based on the weight of the vehicle and its apogee, if the parachute sizes exceed the diameters specified, the vehicle sections will drift greater than 2,500 ft.	Section 3.3.2
TDRR 2	The booster's and payload's main parachute must be released no higher than 600 ft.	Analysis	**Status: Complete** The booster main parachute will be released at 600 feet from the RRC3 altimeter with the redundant altimeter set to 500 ft.	Based on the parachute sizes that were selected, the calculations show the drift distance will exceed 2,500 ft and the descent time will exceed 90 seconds if the main parachutes are deployed higher than 600 ft	Section 3.3.1
TDRR 3	Parachute blankets and shock cords must be made out of a fire resistant material.	Design Inspection	**Status: Complete** All the parachutes will be wrapped in Nomex blankets and the shock cord used will be made out of Kevlar.	In order to have a safe recovery, the parachutes and shock cords need to be protected from the black powder detonations during the separation events. If not protected, the parachutes will deteriorate from the heat of deflagration causing the vehicle to fracture on impact.	Section 3.3.1
TDRR 4	The two pressure holes for the altimeters must be no smaller than $\frac{1}{10}$ in.	Design Analysis	**Status: Complete** Two $\frac{1}{10}$ in. holes will be drilled between the bulkheads of the altimeter bays in the payload and booster section.	From calculation, if the pressure holes are smaller than $\frac{1}{10}$ in. then pressure will not be read by barometric sensor on the altimeters. If the pressure is not read correctly by the altimeters the parachutes will not deploy causing a kinetic energy greater than $75\ \mathrm{ft-lb_f}$ at landing.	Section 3.3.6
TDRR 5	The length of the shock cords must be at least 3 times the length of the section the cord is tethered to in the vehicle.	Design	**Status: Complete** Each section of the launch vehicle that a parachute will be deployed from will have a minimum 3 times the length of shock cord per section. Shock cord will be measured and length will increase as needed per section.	In order to prevent collision among each section upon descent addition lengths are added to the shock cord per section to avoid these conflicts.	Section 3.3.3
TDRR 6	The sub-scale launch vehicle will be capable of separating with a minimum black powder charge of 0.76g for drogue deployment and 1.37g for main parachute deployment.	Demonstration	**Status: Complete** The force required to break the shear pins holding the sections of the rocket together will be theoretically calculated to verify the amount of black powder used will be sufficient. Separation testing will be conducted to ensure the amount of black powder used is enough to break the shear pins.	In order to ensure the vehicle properly separated, the calculated black powder charge sizes will be scaled out and placed in their designated ejection charge locations.	Section 7.1.2
TDRR 7	The altimeters will fire at their designated altitudes allowing the black powder charges to detonate at the correct time.	Demonstration	**Status:** Complete The RRC3 altimeters will be placed in a vacuum chamber where simulated air pressure can be generated. The change in air pressure will trigger the RRC3 to detonate the E-matches attached to it.	The altimeter firing demonstration is important to validate the use of RRC3 altimeters and determine if each altimeter works.	Section 7.1.1

Table 138: Team Derived Recovery Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDRR 8	Since the vehicle is made of carbon fiber, the GPS Recovery Systems must be placed in a location of the vehicle to allow for data transmission.	Design	**Status:** Complete The Eggfinder TX transmitter will be placed in the nosecone that is manufactured out of ABS to allow for data transmission. The Featherweight GPS will be tethered to the main parachute shock cord of the booster section so the GPS will be located outside the carbon fiber bodytube once the parachute is deployed.	To ensure the vehicle sections can be located after landing, the payload section's GPS will be located in the nosecone and the booster section's GPS will be tethered to the main parachute's shock cord.	Section 3.3.7
TDRR 9	The payload section of the full-scale launch vehicle will be capable of separating with a minimum black powder charge of 1.93g for streamer deployment and 1.81g for main parachute deployment. The booster section will be capable of separating with a minimum black powder charge of 1.56g for drogue deployment and 2.04g for main parachute deployment.	Demonstration	**Status: Complete** The force required to break the shear pins holding the sections of the rocket together will be theoretically calculated to verify the amount of black powder used will be sufficient. Separation testing will be conducted to ensure the amount of black powder used is enough to break the shear pins.	In order to ensure the vehicle properly separated, the calculated black powder charge sizes will be scaled out and placed in their designated ejection charge locations.	Section 7.1.10

7.3.9 Team Derived Payload Requirements

Table 139: Team Derived Payload Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDPR 1	The payload must be able to protect the gimbal and camera upon landing.	Demonstration Testing	**Status: Completed** A rack and pinion was designed to extend and retract the gimbal. In addition to calculations, testing will also be used to verify the viability of this system.	If exposed, the gimbal and camera system would not be able to withstand the maximum allowable kinetic energy of 75 ft-lb$_f$.	Sections 4.7.6, 7.1.15
TDPR 2	The payload must be able to transmit its grid location to a ground base at a minimum range of 2,500 ft.	Testing	**Status: Complete** The payload will be tested to ensure successful transmission at distances greater than 2,500 ft.	Without a successful transmission of the payload location, the payload would be considered "lost" and the mission would be considered a failure. A range of 2,500 ft covers the worst case scenario, in which the vehicle lands on the edge of the recovery area.	Sections 7.2.1, 7.2.9
TDPR 3	The payload will be set to sleep mode to save power until the accelerometer senses launch. After exiting sleep mode the payload must remain powered for a minimum of 40 minutes.	Demonstration Analysis	**Status: In Progress** ANVIL will power minimal electronics until a launch has been detected.	The payload electronics must have the capability to sit on the a launchpad for at least two hours, while remaining powered long enough to complete the mission after waking.	Sections 4.9.3, 4.11.1

Table 139: Team Derived Payload Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDPR 4	The payload must be capable of capturing at least one image covering the entire length of the field above a minimum altitude of 3000 ft.	Analysis Testing	**Status: In Progress** ANVIL will be equipped with a 90° FOV lens, allowing it to capture images of the entire field at an altitude of 3000 ft or above. Future testing will be done to ensure the components required are powered in time to capture the required image.	In order to determine the grid box of vehicle's landing position, the payload must be able to compare the overlaid image with the gridded satellite image.	Sections 4.11.2, 7.1.15
TDPR 5	The payload must be capable of the necessary computation to locate itself within the grid box indicated by GPS.	Testing	**Status: Complete** 29 images captured by a drone were compared by the Raspberry Pi 4 to ensure that the chosen microcontroller is capable of the required computation.	The payload cannot use GPS or external systems at any point during its mission. The payload must solely use onboard components to determine the landing location of the launch vehicle.	Sections 7.2.4, 7.2.5, 7.2.6
TDPR 6	ANVIL must know the altitude it is at within a range of 25 ft.	Analysis Testing	**Status: Complete** ANVIL will be equipped with a barometric pressure sensor to know the altitude so that it can begin retraction of the gimbal. Further testing will be done to ensure the required accuracy of the chosen sensor.	In order to accurately determine when to begin retraction of the gimbal the altitude of ANVIL must be known, otherwise the gimbal may begin retraction too late resulting in damage to the camera or gimbal.	Sections 7.2.8, 7.2.9
TDPR 7	The camera system requires a gimbal capable of accurately positioning to an angle within 10° of perpendicularity with the ground.	Testing	**Status: Complete** The gimbal's ability to maintain perpendicularity with the ground will be tested.	It was determined that angles greater than 10° would cause image distortion potentially resulting in severe accuracy loss.	Sections 4.7.5, 7.1.15, 7.2.2, 7.2.8, 7.2.9
TDPR 8	The payload is required to have lower lip diameter of greater than 4.85 in.	Inspection	**Status: Complete** The payload lower lip diameter was designed to be 4.9 in. and was measured upon printing to verify proper sizing.	If the lower payload lip is smaller than 4.85 inches, the payload will not be retained by the coupler and fall into the body tube.	Section 4.7.1
TDPR 9	The gimbal must retract within 2.5 seconds	Testing	**Status: Complete** The gimbal retraction system will be tested to verify it retracts within two seconds.	In order to properly protect the gimbal assembly, the gimbal must be able to retract quickly.	Sections 7.2.7, 7.2.9
TDPR 10	The payload must be able to locate itself within 30 minutes after landing.	Testing	**Status: Complete** The payload will be time tested to ensure the algorithm can complete the locating within 30 minutes.	The payload must be able to locate itself within 30 minutes to complete the mission in a timely manner.	Sections 7.1.15, 7.2.9

7.3.10 Team Derived Safety Requirements

Table 140: Team Derived Safety Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDSR 1	The SO will maintain both a physical and digital safety handbook that will be easily accessible to all team members.	Demonstration	**Status:** In Progress The physical copy of the safety handbook will be kept up-to-date by printing out all SDS and kept in a binder located in the teams work space for ease of access, and the digital copy will be kept in the teams Google Drive safety folder.	This will allow easy access to the safety handbook at all times to reference mitigation procedures for hazards.	Sections 6, 8.2, 8.4, 8.5
TDSR 2	The SO will maintain a safety checklist that will be used as a set of procedures for launch day operations.	Demonstration	**Status:** In Progress The SO has created a preliminary safety checklist for the Sub-scale and full-scale launches that will act as launch day procedures.	The safety checklist will ensure that the team follows all safety guidelines and requirement, while also acting as a procedural checklist for vehicle and payload assembly.	CDR Section 5.2.1, Section 6.3.1
TDSR 3	The safety checklist will include an altimeter arming/disarming and immediate action/troubleshooting procedure manual.	Demonstration	**Status:** In Progress A preliminary altimeter arming/disarming manuals and immediate action/troubleshooting procedure manual have been made by the SO.	The safety checklist will ensure that the proper steps are taken while troubleshooting to mitigate possible hazards.	Section 6.3.1
TDSR 4	All team personnel attending a launch must be present during the launch day safety briefing covering launch operation hazards.	Demonstration	**Status:** In Progress The SO and/or the backup SO will conduct a safety briefing presentation prior to every launch.	Safety briefings will ensure that all team personnel understand the safety protocols for launch day and the possible risks of injuries prior to launch.	Section 6
TDSR 5	All team members must be briefed on any new hazardous materials by the SO prior to the use of the material.	Demonstration	**Status:** In Progress The SO and/or the backup SO will conduct a safety briefing presentation for any new hazardous materials introduced to the team prior to use.	Since the team will have to work with hazardous materials to complete this project the safety briefings will ensure that all personnel understand the risks and how to mitigate them.	Section 6.2
TDSR 6	All team member must wear masks and follow CDC guidelines because of the ongoing COVID-19 pandemic.	Demonstration	**Status:** In Progress The SO will enforce the use of masks and other CDC guideline for COVID-19 prevention.	COVID-19 is still an ongoing hazard, so avoid the spread of COVID-19 the CDC recommends wearing face masks.	Section 8.3
TDSR 7	All team members must follow all rule and regulations for the use of UNCC facilities.	Demonstration	**Status:** In Progress The SO will enforce the rules and regulations for all UNCC facilities.	Following UNCC rules and regulations will ensure that team personnel stay safe and able to complete the project using UNCC facilities.	Section 8.2
TDSR 8	The 49er Rocketry Team shall abide by all federal, state, and local laws pertaining to the launching of unmanned rockets and the handling of rocket motors.	Demonstration	**Status:** In Progress The team has designed the launch vehicle in accordance with all federal, state, and local laws, and the SO will ensure all laws continue to be followed on launch days.	The team must follow all laws to ensure that the completion of the project it done in a safe manner.	Section 8.4
TDSR 9	All E-matches are to be color coded to prevent any accidental wire crosses.	Demonstration	**Status:** In Progress The team has decided it is necessary to color code all E-matches to make the assembly process of the avionics bay easier.	A wire mix-up possibly caused the failure of a full-scale vehicle flight.	Sections 5.3

Table 140: Team Derived Safety Requirements

Unique ID	Requirement Description	Verification Method	Verification Plan and Status	Justification	Report Location
TDSR 10	No elemental lead or lead products shall not be used in the vehicle.	Demonstration	**Status: Complete** The team has decided not to include lead or any products using lead in the vehicle construction	Lead is identified as a hazardous material by the safety officer. To keep environmental impact at a minimum, no lead shall be used in any part of the construction of the vehicle. Lead is also toxic, and the team wishes to avoid any possibility of injury.	Sections 3.2.2, 4.8, 4.10, Tables 77, 72