49er Rocketry Team

The University of North Carolina at Charlotte

The William States Lee College of Engineering

2021-2022 NASA Student Launch Initiative

Flight Readiness Review

The University of North Carolina at Charlotte
William States Lee College of Engineering
9201 University City Blvd.
Charlotte, North Carolina, 28223
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Acronym Dictionary

ABS = Acrylonitrile Butadiene Styrene
ACK = Acknowledgement Signal
AGL = Above Ground Level
ACS = Auxiliary Control Surfaces
APCP = Ammonium Perchlorate Composite Propellant
API = Application Programming Interface
ARM = Advanced RISC Machine
AV = Avionics
AWG = American Wire Gage
CAD = Computer Aided Design
CAR = Canadian Association of Rocketry
CATO = Catastrophic on Take-Off
CDR = Critical Design Review
CFD = Computational Fluid Dynamics
CG = Center of Gravity
COE = College of Engineering
CP = Center of Pressure
CPU = Central Processing Unit
CV = Computer Vision
DSP = Digital Signal Processor
DXF = Drawing Exchange Format
EM = Electromagnetic
E-match = Electronic Match
EPIC = Energy Production and Infrastructure Center
ESC = Electronic Speed Controller
FAA = Federal Aviation Association
FDM = Fused Deposition Modeling
FEA = Finite Element Analysis
FN = Foreign National
FOD = Foreign Object Debris
FoS = Factor of Safety
FoV = Field of View
FRR = Flight Readiness Review
GCS = Ground Control Station
GSOS = Ground Stabilization and Orientation System
GPIO = General Purpose Input Output
GPS = Global Positioning System
GPU = Graphics Processing Unit
HAL = Hardware Abstraction Layer
I2C = Inter-Integrated Circuit
ID = Inner Diameter
IMU = Inertial Measurement Unit
IO = Input/Output
ISA = Instruction Set Architecture
ISR = Interrupt Service Routine
LiDAR = Light Detection and Ranging
LiPo = Lithium Polymer
LRR = Launch Readiness Review
MSRL = Motorsports Research Lab
NACK = Non-Acknowledgement Signal
NAR = National Association of Rocketry
NASA = National Aeronautics and Space Administration
NFPA = National Fire Protection Agency
NIOSH = National Institute for Occupational Safety and Health
OD = Outer Diameter
ODA = Object Detection and Avoidance
PCB = Printed Circuit Board
PDB = Power Distribution Board
PDF = Payload Demonstration Flight
PDR = Preliminary Design Review
PETG = Polyethylene Terephthalate Glycol-modified
PPE = Personal Protective Equipment
PWM = Pulse Width Modulation
RAM = Random Access Memory
RF = Radio Frequency
RISC = Reduced Instruction Set Computer
ROCC = Rocketry of Central Carolina
RP = Rapid Prototype
RPI0 = Raspberry Pi Zero
RPL = Rapid Prototyping Lab
RSO = Range Safety Officer
RTOS = Real Time Operating System
SBC = Single Board Computer
SCS = Sample Collection System
SDS = Safety Data Sheet
SIMD = Single Instruction Multiple Data
SLCF = PerfectFlite Stratologger CF
SONAR = Sound Navigation and Ranging
SOW = Statement of Work
SPI = Serial Peripheral Interface
SRA = Sample Recovery Area
STEM = Science, Technology, Engineering, and Mathematics
TARC = The American Rocketry Challenge
TD = Tender Descender
TIC = Test ID Code
TRA = Tripoli Rocketry Association
UART = Universal Asynchronous Receiver/Transmitter
UAS = Unmanned Aerial System
UNCC = The University of North Carolina at Charlotte
USB = Universal Serial Bus
USLI = University Student Launch Initiative
VBS = Vehicle Booster Section
VDF = Vehicle Demonstration Flight

1 Summary

1.1 Team Summary

Team Name: 49er Rocketry Team
Mailing Address: The University of North Carolina at Charlotte, William States Lee College of Engineering
9201 University City Blvd, Motorsports Research Laboratory, Charlotte, NC 28223

NAR Mentor: Dr. Jerry Dahlberg - Associate Director of Aerospace And Defense University of Tennessee Space Institute
Email: jerry.dahlberg@gmail.com
Phone: (704) 687-1394
NAR L2 Certified: NAR #95976

Final Launch Date/Location: April 23, 2022; Bragg Farms, Huntsville, AL

Table 1: Summary of STEM Engagements

Outreach Event	Events	Type	Participants	Description
Rocketry Club Outreach	3	Direct - Educational	68	Rocketry Workshops
Saturday Academy	1	Direct - Educational	20	Straw Rockets
Explore Charlotte	1	Direct - Outreach	291	Lab Tour
Engineering Learning Community	1	Direct - Outreach	96	Rocketry Presentation
Fall Festival	1	Indirect - Outreach	89	Rocketry Booth
Girl Scouts - Meck 13	1	Direct - Outreach	22	Rocketry Activity
VEX IQ	2	Direct/Indirect - Educational	79/232	Robotics Competition
MEGR 1202 Presentation	1	Direct - Outreach	154	Rocketry Presentation
Springfield Elementary	1	Direct - Educational	130	Kit Rockets
Total	**6**	**Direct - Educational**	**297**	
Total	**6**	**All Other Outreach**	**884**	

Table 2: Member Time Distribution of Flight Readiness Review

Team Members	Net Hours Spent on FRR
Chase Atherton	282.6
Daniel Naveira	100
Caitlin Bunce	347.85
Sarah Vitarisi	183.28
Corey Drummond	155.4
Joseph Petite	355.75
Jason Ellisor	219
Brandon Kepley	201.25
Caden Pyne	235
John Allman	190.75
Wilson Yates	206.75
Connor Thomas	116.37
Total	**2,594**

1.2 Launch Vehicle Summary

A summary of the launch vehicle with its length, mass, and recovery operations can be seen in Table 3.

Table 3: Launch Vehicle Summary

Target Altitude	5000 ft
Final Motor Choice	Aerotech L1390-G
Payload Section	Length: 53.99 in. Mass: 16.6 lb_m
Booster Section	Length: 46.03 in. Pre-Burn Mass: 24.4 lb_m Post-Burn Mass: 20.05 lb_m
Payload Section Recovery System	348 in. streamer deployed at apogee +1 second and 72 in. main deployed at 600 ft
Booster Recovery System	12.5 in. drogue deployed at apogee and 84 in. main deployed at 600 ft
Rail Size	12 ft 1515 Rail

1.3 Payload Summary

The Autonomous Vehicle Imaging Localization (ANVIL) payload is an image-based system in which a gimballed camera is used to take photos throughout the recovery. A custom camera vision algorithm is used to compare paired images and isolate groups of similar pixels. Through these comparisons, an image of lower altitude can be found within an image of higher altitude, eventually deriving the landing location in a preselected satellite image of the launch site. ANVIL will then wirelessly transmit the landing location to the ground station.

2 Changes Made from CDR

2.1 Launch Vehicle

Table 4: Changes Made: Vehicle

Item	Changes Made	Reason for Change	Section
1	Charge well material changed from PVC to aluminum.	Machined charge wells can be screwed onto the carbon fiber plate and be fully secure for multiple flights.	Section 3.2.1
2	O-ring changed to TPU gasket and putty included.	TPU could be used to create a custom shaped gasket. Putty will further reduce possible pressure leakage.	Section 3.2.1
3	Notches cut into nose cone.	Notches prevent the altimeter bay rods from interfering with the nose cone.	Section 3.2.1
4	Accelerometer added to the payload altimeter bay.	Accelerometer will gather data needed to ensure the ANVIL wake-up sequence will run correctly.	Section 3.2.1
5	ANVIL t-track rails screwed into airframe.	Screws will ensure the rails will withstand multiple launches.	Section 3.2.1
6	Streamer will be 29 ft rather than 25 ft.	Difference in width requires the length to be longer to have the same drag force.	Section 3.2.1

2.2 Payload

Table 5: Payload Changes Made Since CDR

Item	Changes Made	Reason for Change	Section
1	Changed ANVIL housing material from PETG to ABS.	Due to supply issues obtaining PETG in the quantity needed to produce the housing structure was not feasible.	Section 4.7.3
2	Housing connections changed to threaded rods.	Increase the structural integrity of the connection between ANVIL's electrical bay and gimbal bay.	Section 4.7.3
3	Select gimbal parts changed to machined aluminum.	Increase the structural integrity of parts under heightened stresses during launch and recovery.	Section 4.7.5
4	Stronger and smaller actuator for retraction system.	Increase the torque provided to the retraction system in order to account for increase of gimbal weight and allow for more space within the gimbal bay.	Section 4.7.6
5	Attachment method for retention rails changed from epoxy to screws.	Increase the rail's ability to withstand separation forces.	Section 4.7.4.1

2.3 Project Plan

Table 6: Changes Made: Project Plan

Item	Changes Made	Reason for Change	Section
1	The team has received a sponsorship from Averna, increasing the team's funding.	Due to the sponsorship, the funding sources table must be updated to track the accurate funding sources for the team.	Section 7.4.1
2	The team budget in Table 141 has been updated to provide up-to-date expenditures for each sub-section of the project.	The team has purchased more components for the completion of the full-scale vehicle as well as the payload. To be able to accurately follow the expenditures of the team, Table 141 must be updated.	Section 7.4
3	STEM Educational Engagements has been updated.	The team had to schedule and partake in additional outreach events since CDR to complete the 250 outreach engagement.	Section 7.4.7
4	The travel plan has been updated for launch week in Huntsville, AL.	Due to the competition dates being condensed to April 22nd and April 23rd, the travel plan had to be adapted to the new schedule.	Section 7.4.5
5	Additional test plans added to the vehicle testing section.	The vehicle required additional coefficient of drag tests for each type of recovery device. Additionally, a full-scale flight test and a retention demonstration for the payload avionics section was added.	Section 7.1

3 Launch Vehicle Criteria

3.1 Mission Statement and Success Criteria

3.1.1 Mission Statement

The 2021 - 2022 49er Rocketry Vehicle Team's mission is to design, construct, test, and launch a high-powered, recoverable and reusable rocket capable of achieving a height of 5,000 feet Above Ground Level (AGL) while safely housing and retaining the

ANVIL payload.

3.1.2 Success Criteria

The launch vehicle must meet the vehicle requirements outlined by the 2021-2022 NASA Student Launch Handbook as well as the Mission Success Criteria (MSC) shown in Table 7 to be considered successful.

Table 7: Vehicle Mission Success Criteria

Criteria Code	Criteria
VMSC 1	The launch vehicle will reach the goal altitude within 250 ft.
VMSC 2	Separation will occur at apogee and allow the ANVIL payload to fully deploy before 4,000 ft is reached during descent.
VMSC 3	The launch vehicle will experience at least 5 G's of acceleration off the rail.
VMSC 4	The payload section of the vehicle will descend faster than the booster section.
VMSC 5	The vehicle will land the ANVIL payload without damage.

3.2 Launch Vehicle Design and Construction

Overview

The launch vehicle consists of four sections: the payload recovery section, the payload section, the booster recovery section, and the booster propulsion section. The airframe was constructed with 3K 2x2 twill weave carbon fiber with an Inner Diameter (ID) of 5.0 in. and a 0.065 in. wall thickness. The nose cone, fins, fin block, fin guide, and boattail were all additively manufactured with the use of the Rapid Prototyping Lab (RPL). The Center of Pressure (CP) is located 75.51 in. from the tip of the nose cone, and the Center of Gravity (CG) is located 59.33 in. from the tip of the nose cone. The resulting pre-burn stability for the full-scale vehicle is 3.16, and the post-burn stability margin is 3.80 The full-scale vehicle weighs a total of 41.06 lb_m pre-burn and 36.71 lb_m post-burn. The dimensions of the full-scale vehicle is shown below in Figure 1.

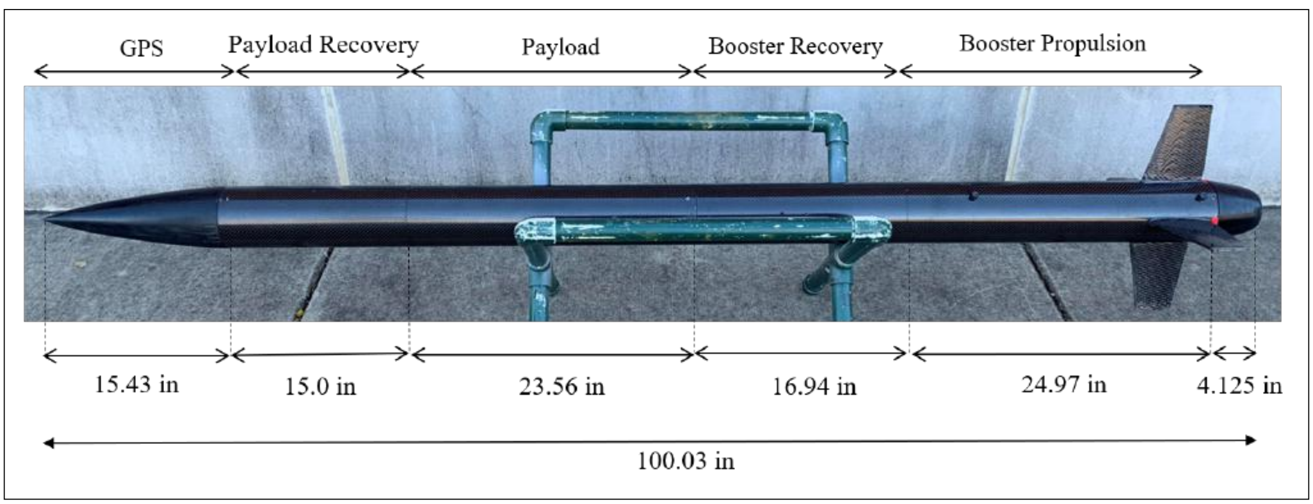


Figure 1: Launch Vehicle Dimensional Overview

3.2.1 Justification of Changes Made to the Vehicle Design

Several changes were made to the vehicle design since the CDR. The charge well material was changed from PVC to aluminum. This change was made to allow the charge cups to be screwed onto the carbon fiber plate to ensure they are fully secure for multiple launches. The contact area between the PVC and the carbon fiber plate was too small for the epoxy to hold for multiple launches, causing the charge wells to break off after each launch of the sub-scale vehicle. The O-ring outlined in the CDR was replaced with a TPU gasket that is the same shape as the altimeter bay rings to further decrease the chance of pressure leaks.

Once the altimeter bays are fully assembled within the vehicle, putty will also be applied around the eyebolts and charge wells for redundancy. Notches were cut in the nose cone shoulder to prevent the threaded rods of the altimeter bay from interfering with the nose cone. An accelerometer was added to the payload altimeter bay to identify the forces experienced upon launch. The accelerometer data will ensure the Trinket can successfully run the wake-up sequence and the payload will survive the forces experienced. The t-track rails used to retain the ANVIL housing will be screwed into the side of the airframe using four 4-40 button head screws and heat-set inserts. The screws will ensure the rails do not move from the vehicle after many launches, whereas epoxy may not withstand multiple launches due to the small contact area between the rails and the airframe. A 29 ft streamer will be used in place of a 25 ft streamer. A streamer with a width of 7 in. was purchased and upon receiving the streamer, it was determined that the width was 6.5 in. The streamer will be 4 ft longer to account for the decrease in width and remain at the same drag force.

3.2.2 Materials Summary

The airframe, couplers, bulkheads, and centering rings were constructed of 3K 2x2 twill weave carbon fiber. The high strength-to-weight ratio of carbon fiber will ensure the structural integrity of the full-scale launch vehicle is maintained. The nose cone, fins, and fin block were additively manufactured with Acrylonitrile Butadiene Styrene (ABS), while the boattail was additively manufactured with ULTEM 9085 due to its heat resistance properties. The fins were also wrapped in a layer of 1x1 twill weave carbon fiber to provide additional impact strength during launch and landing of the vehicle. Table 8 shows a complete list of the structural components and their respective materials.

Table 8: Launch Vehicle Subsystem Material Selections

Component	Material
Nose Cone	ABS Plastic
Payload Airframe	3K 2x2 twill weave Carbon Fiber
Payload Recovery Airframe	3K 2x2 twill weave Carbon Fiber
Booster Propulsion Airframe	3K 2x2 twill weave Carbon Fiber
Booster Recovery Airframe	3K 2x2 twill weave Carbon Fiber
Couplers	3K 2x2 twill weave Carbon Fiber
Bulkheads	1x1 twill weave Carbon Fiber
Fins	ABS Plastic with a 1x1 twill weave Carbon Fiber coating
Centering Rings	1x1 twill weave Carbon Fiber
Boattail	ULTEM 9085
Fin Block	ABS Plastic

3.2.3 Payload Section

The payload section is comprised of the nose cone, payload recovery section, and the ANVIL system housing section. The airframe of the payload section was constructed with 3K 2x2 twill weave carbon fiber that has the same inner and outer diameters discussed within Section 3.2. The payload recovery section will house an altimeter bay and recovery implements that are discussed further in Section 3.3.6. The payload section is a total of 53.99 in. long and has a total weight of 16.6 lb_m. The bottom of the ANVIL housing is located at the initial point of separation, which occurs apogee. Retention of the ANVIL system is ensured with two T-track rails. Two 4-40 button head screws and heat-set inserts are used to secure the rails to the airframe. The rails prevent rotational movement of the ANVIL housing within the airframe. The booster recovery coupler prevents the ANVIL housing from shifting toward the aft of the vehicle. Following separation at apogee, the ANVIL housing will slide out of the airframe and remain attached to a permanently epoxied bulkhead through the use of two 4ft long shock cords. Figure 2 shows the payload section of the full-scale launch vehicle and the location of the interior components.

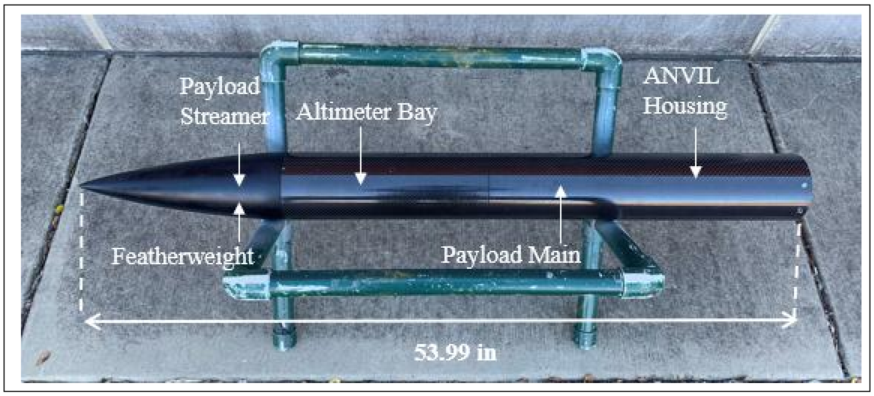


Figure 2: Launch Vehicle Payload Section

3.2.4 Booster Section

The booster section is comprised of the booster recovery section and booster propulsion section. The booster section is 46.03 in. long, has a total pre-burn weight of 24.40 lb_m, and has a post-burn weight of 20.05 lb_m. The airframe of the booster section was constructed using 3K 2x2 twill weave carbon fiber with the dimensions discussed in Section 3.2. The booster recovery section is 16.94 in. long and houses the booster section altimeter bay, booster drogue and booster main parachute. The booster propulsion section of the launch vehicle houses the motor retention system, fins, boattail, fin retainer, and motor tube, in addition to the rail buttons fastened to the exterior. Figure 3 shows the booster section of the full-scale launch vehicle and the location of the interior components.

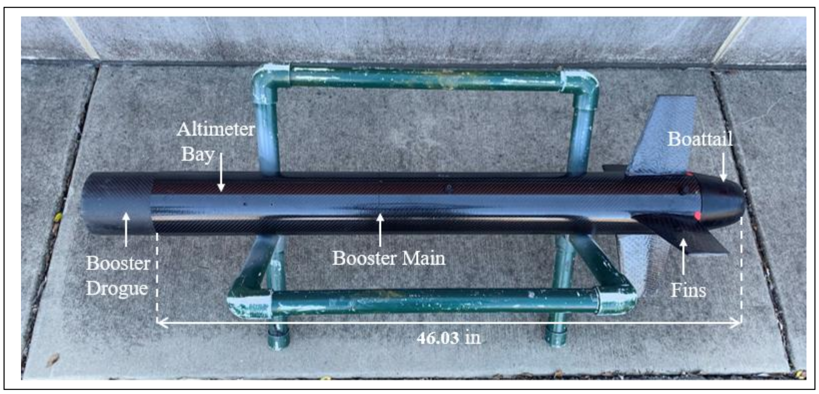


Figure 3: Vehicle Booster Section

3.2.5 Locations of the Separation Points and Black Powder Charges

The vehicle design consists of four separation points for parachute deployment. There is a primary and backup black powder charge for each separation point. The black powder charges are located on the top and bottom of the altimeter bays retained in the payload and booster sections. The primary black powder charges on the payload section's altimeter bay are responsible for streamer deployment one second after apogee and main parachute deployment at 600 ft. For this section, the backup charges detonate two seconds after apogee for the streamer and at 500 ft for the main parachute. The primary black powder charges on the booster section's altimeter are responsible for drogue deployment at apogee and main parachute deployment at 600 ft. The backup charges for this section detonate one second after apogee for the drogue and at 500 ft for the main parachute. Figure 4 below displays the locations of the separation points and the black powder charges. The separation points are labeled alphabetically by the order in which they occur.

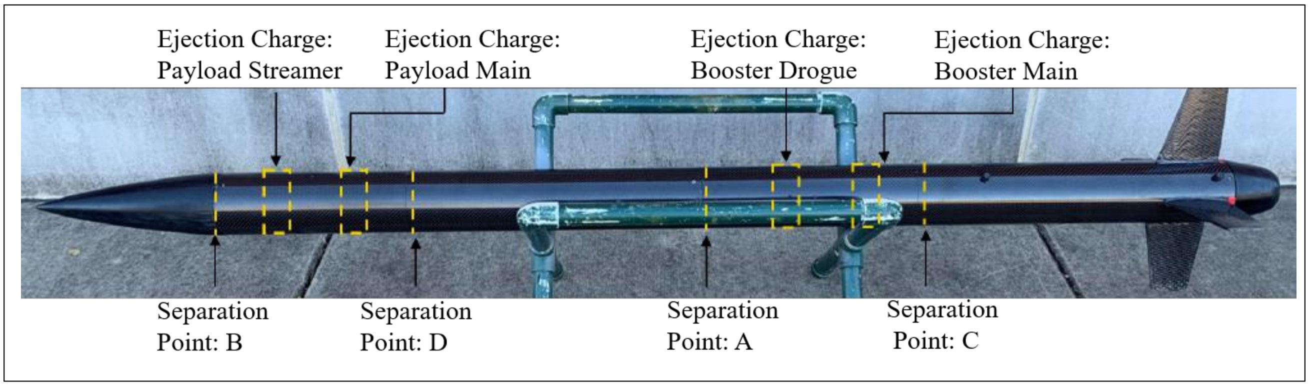


Figure 4: Separation Points and Energetics Locations

3.2.6 Launch Vehicle Features

Nose Cone

The LD-Haack series nose cone was additively manufactured out of ABS plastic. The nose cone profile is 15.43 in. long and has an outer diameter of 5.13 in. to ensure a seamless transition from the nose cone to the airframe outer diameter. The nose cone shoulder is used as an integrated 4.96 in. long coupler, ensuring that the nose cone can be directly attached to the payload recovery section. Two shear pins were used to fasten the nose cone to the payload recovery. Cutouts were made in the nose cone shoulder to prevent the altimeter bay rods from scraping the edges of the shoulder. Figure 5 and Figure 6 show the comparison of the 3D modeled nose cone versus the additively manufactured nose cone. The small differences in dimensions may be explained by the print orientation and the lower dimensional stability of ABS.

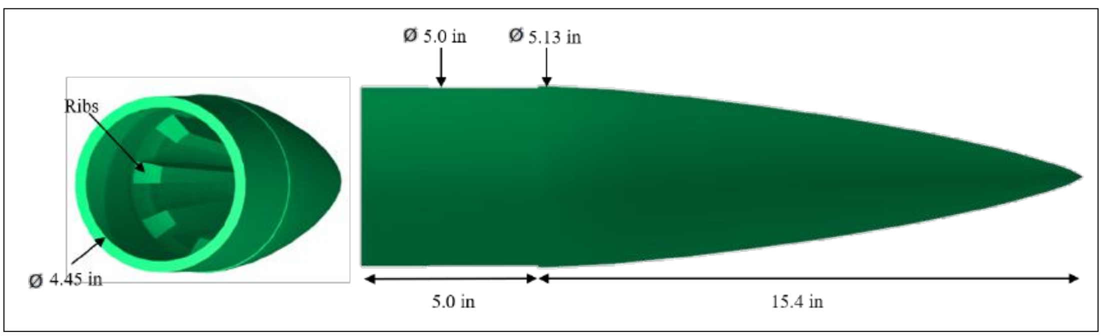


Figure 5: Nose Cone CAD

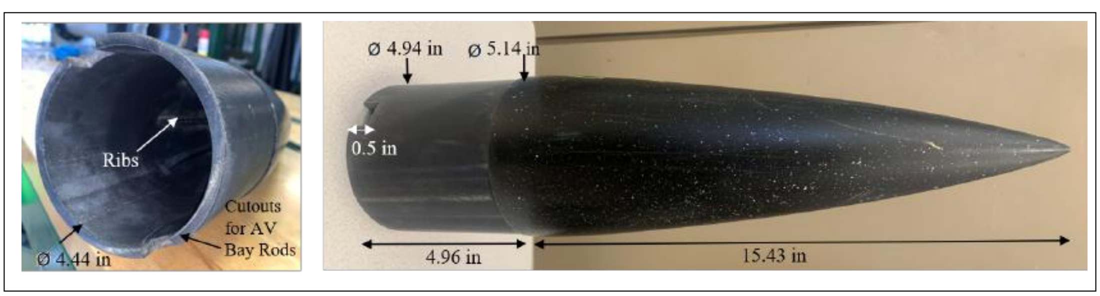


Figure 6: Nose Cone Dimensions

Airframe

The airframe was made with 3K 2x2 twill weave carbon fiber tubes with an ID of 5 in. and OD of 5.13 in. The total mass of the carbon fiber airframe is 4.46 lb_m. The airframe is divided into four independent subsections: payload recovery, payload, booster recovery, and booster propulsion.

Fins

Four trapezoidal fins are used to achieve the CP necessary to ensure that the vehicle remains stable during flight. The total mass of the set of fins is 1.48 lb_m. The fins were designed with a modified NACA 0012 airfoil cross-section to reduce drag and increase in-flight stability. The airfoil is symmetric to produce zero lift. The maximum thickness is approximately 9.7% of the total length and is located approximately 22.1% of the total length back from the leading edge. The fin CAD is shown in Figure 7 below. The fins are additively manufactured using ABS and wrapped with a layer of carbon fiber. Further discussion on the construction of the fins can be seen in 3.2.7.3 and 3.2.8.1. A dimensional image of the fins as constructed can be seen in Figure 8. The fin as it is constructed has larger dimensions than the modeled fin due to the additional thickness of the carbon fiber. The simulations discussed in Section 3.4 use the dimensions as constructed to note any impact of the dimensional differences on the mission performance.

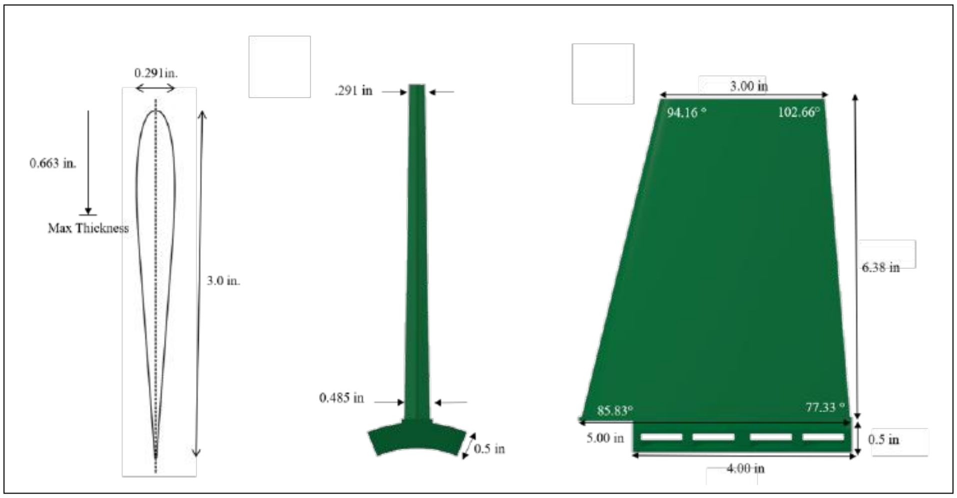


Figure 7: Fin CAD

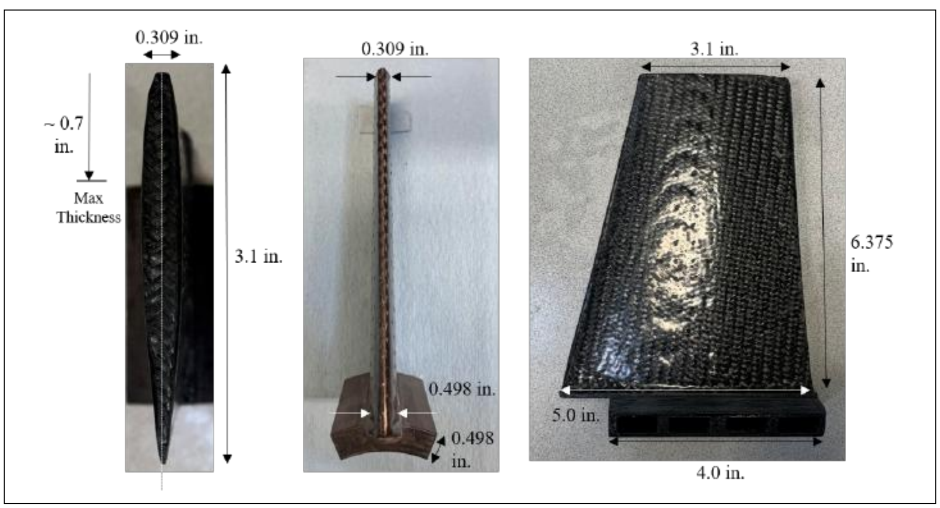


Figure 8: Fin Dimensions

Fin Block

The fin block is used to secure the fins in place during flight. It was additively manufactured using ABS. More information on the manufacturing process can be found in Section 3.2.8.1. The fin block is located directly behind the fins and secured to the airframe using steel $\frac{1}{4}$ - 20 socket set screws and brass $\frac{1}{4}$ - 20 threaded heat-set inserts. The raised portions of the fin block sit flush with the outside of the airframe to achieve a more streamlined airflow. The ID of the fin block is 3.51 in. to ensure it can slide over the motor retainer on the motor tube. Figure 9 and Figure 10 show the differences between the CAD model and the actual component. The hole size for the heat-set insert was increased to ensure plastic would not settle in the threads while placing the inserts. The other dimensions are very close to the CAD model.

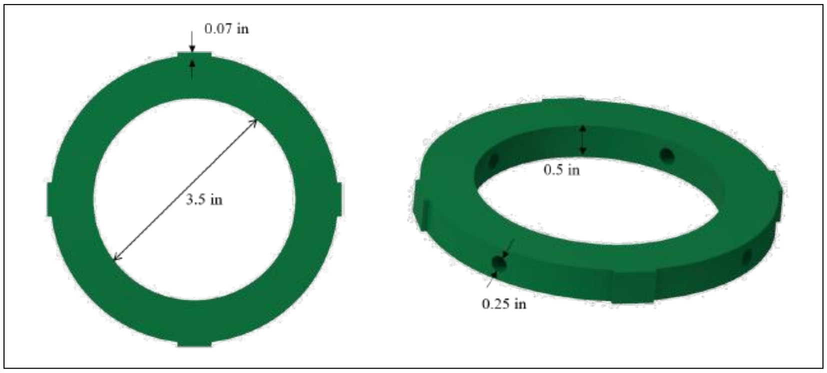


Figure 9: Fin Block CAD

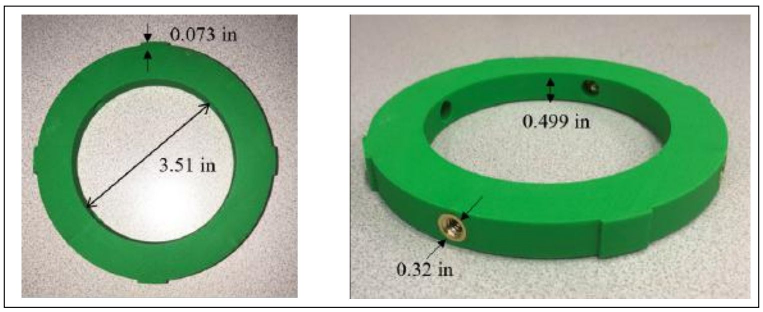


Figure 10: Fin Block Dimensions

Boattail

The boattail was additively manufactured out of ULTEM 9085 which is discussed further in 3.2.8.4. The bottail was designed to have a parabolic profile that aids in the reduction of after-body drag experienced by the launch vehicle. The parabolic profile also aids in pressure recovery and aerodynamic recovery. The boattail has an Aeropack motor retainer which is used to retain the L1390-G motor casing. The Aeropack motor retainer is epoxied with a 1:1 ratio of ES6209 Aeropoxy 2.91 in. into the boattail. The boattail CAD and the boattail as constructed can be seen in Figures 11 and 12, respectively. The differences in dimensions from the CAD model and the 3D printed boattail are likely due to the post processing required once the print was complete. The boattail was sanded to smooth out a layer shift during the printing process. This was done rather than 3D printing a new boattail because of the high cost of the print material.

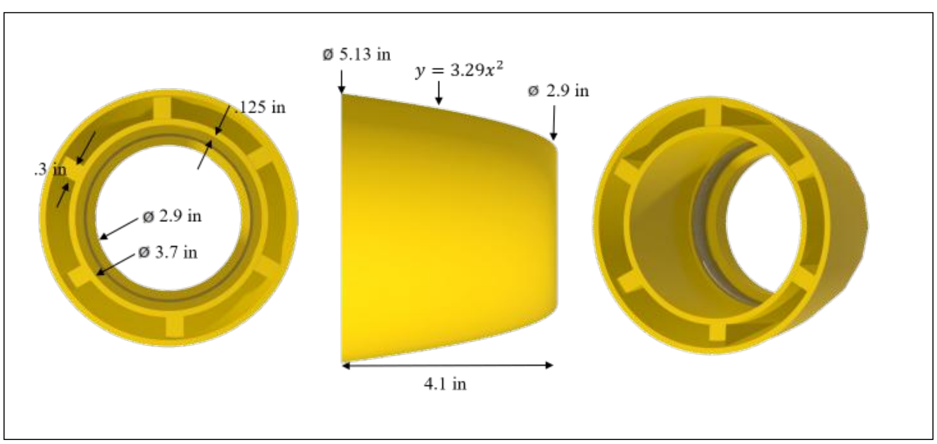


Figure 11: Boattail CAD

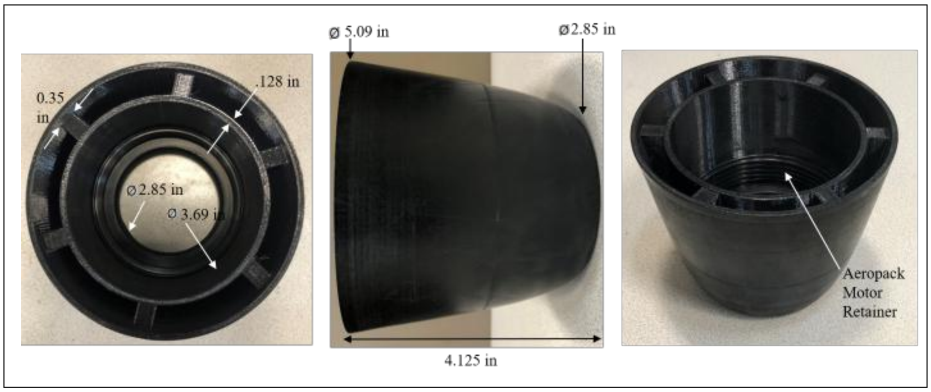


Figure 12: Boattail as Constructed

Motor Tube

The carbon fiber motor tube is 20.5 in. long with an ID of 3.0 in. The motor tube retains the motor casing and is secured in the rocket with four centering rings that have an ID of 3.125 in. The motor tube and centering ring construction is further discussed in Section 3.2.7.1 and Section 3.2.7.2 respectively. Two of the centering rings have an OD of 4.99 in. and are epoxied to the inside of the airframe. The other two centering rings have an OD of 3.84 in. and are epoxied to the fin guide. Without the presence of the fin guide, the tabs on the bottom of the fins would have to be large enough to fill the 0.935 in. gap between the inner surface of the airframe and the outer surface of the motor tube. As a result, when sliding the fins into the airframe the 0.17 in. thick motor retainer would interfere with the assembly process, requiring the bending of the carbon fiber airframe around the fin slots. The image below shows the construction steps of the motor tube assembly. The first three steps of assembly are one-time, permanent construction steps and the final step will be completed for each launch. The centering rings were first epoxied onto the motor tube. The fin guide was then epoxied to the two lower centering rings. This assembly was then epoxied into the airframe. The ES6209 Aeropoxy was used with a 1:1 ratio for each epoxying stage and was separated by the recommended 24 hour cure time. The final step is to insert the fins into the slots of the airframe, secure the fin block with the appropriate hardware, and screw the boattail onto the motor tube.

Figure 13: Motor Tube Assembly

Rail Buttons

The vehicle has two acetal 1515 rail buttons on the booster propulsion section to position the vehicle onto the launch rail. The rail buttons are secured to the vehicle using 10 - 32 x 3/4 screws and flange nuts. The location of the top and bottom rail buttons were both shifted forward by 1 in. to decrease the risk of a fracture in the airframe while maintaining the same effective rail length. The previous location of the bottom rail button 0.5 in. from the back of the airframe left too little material to support the rail button from the aft. The upper and lower rail buttons are located 5.375 in. and 23.81 in. back from the aft end of the booster propulsion section, respectively. To ensure the rail buttons can be accessed if they need to be replaced, the upper rail button is located toward the fore of the engine block, and the lower rail button is in line with a screw that is used to secure the fin block. Since the rail button is in line with the fin block screw, that screw was changed from a 316 stainless steel button head screw to a steel 1/4 – 20 socket set screw so that there is no head to obstruct the rail button when on the launch rail. On a 12 ft launch rail, the effective rail length is 120.19 in. An image of the rail buttons can be seen in Figure 14 below.

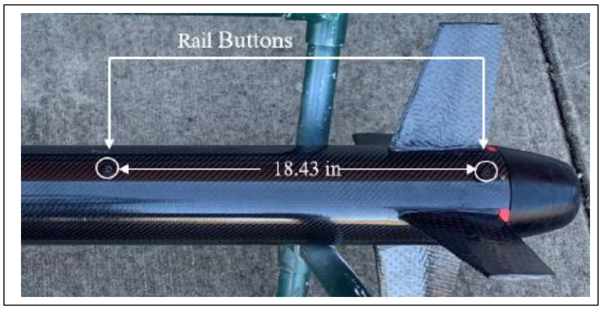


Figure 14: Rail Button Locations

Bulk heads

The launch vehicle contains two permanently epoxied 1x1 twill weave carbon fiber bulkheads. These bulkheads are used to attach recovery hardware to the airframe in the payload and booster sections. In addition, two permanently epoxied carbon fiber rings are used to fasten the removable altimeters bays into place during flight. These rings were designed to affix the fully removable altimeter bays to the vehicle during launch and recovery.

3.2.7 Vehicle Construction

3.2.7.1 Airframe Construction

The tubes are composed of 9-10 unidirectional layers of pre-preg 3K 2x2 twill weave carbon fiber that are each approximately 0.006 in. thick. The tubes were purchased from Rockwest Composites in 60 in. sections and were cut down to match the design of each subsection. The payload recovery, payload, booster recovery, and booster propulsion subsections were cut into sections of 15 in, 23.5 in, 17 in, and 25 in, respectively. The subsections were joined using 3K 2x2 twill weave carbon fiber couplers that were purchased from Rockwest Composites in 29.5 in. tubes and cut into three 10 in. sections. The ID of the couplers is 4.75 in. and the OD is 4.99 in. The motor tube was constructed from leftover sub-scale airframe material with an ID of 3.0 in. and an OD of 3.125 in. The total length of the motor tube was cut down to 20.5 in.

The tubes and couplers were cut down to size in the machine shop using the horizontal band saw, shown in Figure 15. At least two team members were present anytime work was done in the machine shop and appropriate Personal Protective Equipment (PPE) was worn at all times, following all safety guidelines described in Appendix 8.2.2. Cutting fluid was used and the cutting speed was set to low to reduce splintering and uneven cuts of the carbon fiber. The cut edges of the tubes were sanded smooth using 200 grit sandpaper. A two-part ES6209 Aeropoxy was mixed with a 1:1 ratio and used to epoxy the couplers 5 in. into the airframe, and to epoxy the motor retainer onto the end of the motor tube. The tubes were set aside for 18-24 hours to cure. The couplers were epoxied into the fore ends of the payload, booster recovery, and booster propulsion sections. Nitrile gloves were worn at all times when handling epoxy.

Figure 15: Cutting Tubes Using Horizontal Band Saw

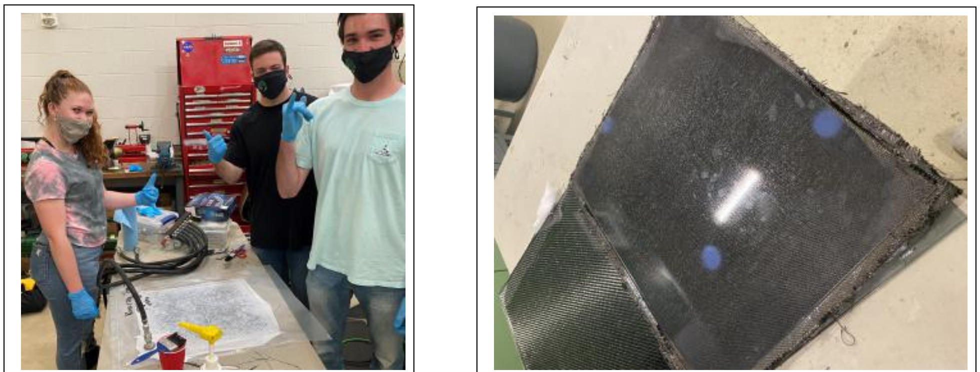
A stencil with an ID of 5.15 in. was 3D printed and used to mark the locations of the slots for the modular fins. The slots were cut out using a Dremel cutting wheel and sanded with 60 grit sandpaper to smooth the rough edges. Pressure holes, FingerTech holes, shear pin holes, and holes to secure the fin block were also drilled in their appropriate locations. Safety glasses and cut-resistant gloves were worn anytime the Dremel or drill was used. The process to cut out the fin slots in the airframe can be seen in Figure 16 below.

(a) Fin Slots Stencil (b) Fin Slots Traced Out (c) Cut-out Fin Slots

Figure 16: Fin Slot Construction

3.2.7.2 Carbon Fiber Construction

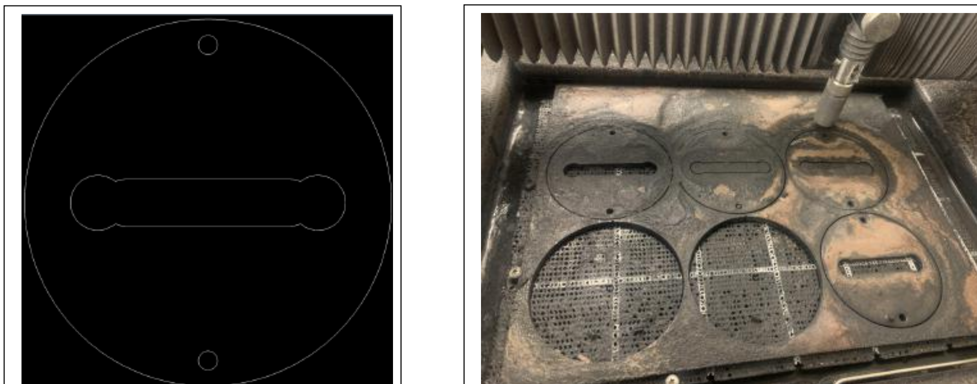
Carbon fiber plates were constructed for the bulkheads and centering rings. A roll of carbon fiber was cut into ten 12 in. x 18 in. sections, which corresponds to the size of the cut bed of the abrasive waterjet cutter. West System's 105 Epoxy Resin and West System's 206 Hardener were mixed with a 5:1 ratio. A generous layer of the epoxy mixture was applied to a 15 in. x 18 in. glass plane. All ten sections were layered onto the glass plane with the epoxy resin applied in between each layer until the top-most layer was saturated. The combined ten layers resulted in a plate that is 0.25 in. thick. A layer of perforated plastic was cut and layered on top of the carbon fiber. Absorbent cloth was cut and layered on top of the perforated plastic and added around the nozzle in the vacuum bag to prevent the nozzle from clogging with epoxy resin. The glass plane was placed into a vacuum bag, connected to the pressure vacuum, and pressurized for 6-7 hours, or until the plates had fully cured. This process was repeated three more times. Cut-resistant gloves were worn when handling carbon fiber and nitrile gloves were worn when handling epoxy. Figure 17 shows the plates in the pressure vacuum and the finished plate.



(a) Constructing Carbon Fiber Plate (b) Finished Carbon Fiber Plates

Figure 17: Carbon Fiber Plate Construction

Once the carbon fiber plates are fully cured, they are removed from the vacuum bag and separated from the glass plate to reveal a hard, smooth surface. These plates are used to create the bulkheads and centering rings for the vehicle. A CAD model of each type of bulkhead and centering ring was saved as a Drawing Exchange Format (DXF) file and sent to the Wazer Water Jet Cutter. The Wazer cut plate is 12 in. x 18 in. which allows the entire carbon fiber plate to be utilized. The DXF files allow the water jet to know where to move the nozzle of the water-abrasive mix to cut the plates. Once the water jet is done, the bulkheads and centering rings are removed from the cut bed. An image showing the DXF file for the altimeter bay ring and the finished part in the water jet can be seen in Figure 18.



(a) DXF File of Altimeter Bay Ring (b) Finished Carbon Fiber Plates

Figure 18: Altimeter Bay in Wazer Waterjet

3.2.7.3 Fin Construction

The fins were 3D printed from ABS plastic which provides moderate strength and impact resistance. More information on the 3D printed construction can be found in Section 3.2.8.1. To increase the mechanical properties, a layer of carbon fiber was added over the fins and cured with resin in the pressure vacuum. This process was accomplished by first tracing the fins on a 2x2 twill weave section of carbon fiber and cutting out one piece that wrapped around the entire fin. Loctite Spray Adhesive was applied to the carbon fiber to help the carbon fiber stay on the fin while applying the epoxy resin. The West System 105 Epoxy Resin and West System 206 Hardener were mixed with a 5:1 ratio and applied to the fins. Perforated plastic was applied to the fins and trimmed down to prevent the vacuum bag from being epoxied shut. Cut-resistant gloves were worn when handling carbon fiber and nitrile gloves were worn when handling epoxy.

To ensure the carbon fiber did not wrinkle in the pressure vacuum, a silicon mold of the fins was used. To create the mold, the Smooth-On OOMOO 30 Silicone Moldmaking Rubber was mixed in a 1:1 ratio, applied to a modified model of the fin, and set for 20 minutes. The mold can be seen in Figure 19 below. This mold was layered onto the perforated paper on the fins to preventing wrinkling of the carbon fiber while in the pressure vacuum and provide an even layer of epoxy resin.

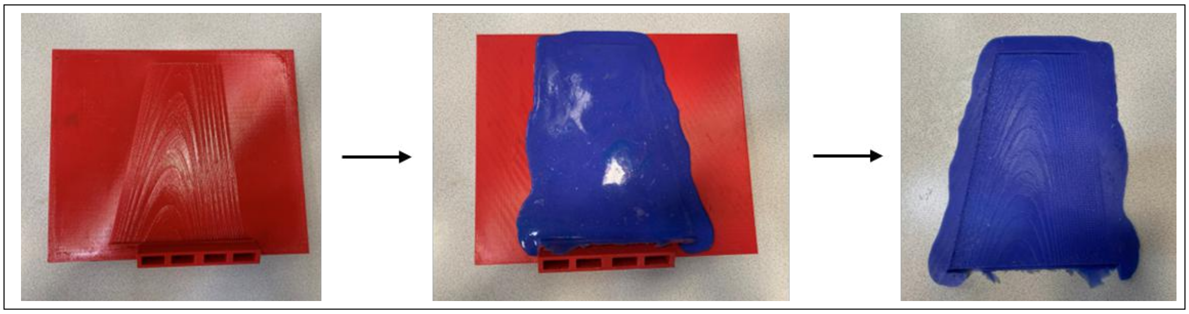


Figure 19: Fin Mold Constuction

3.2.7.4 Altimeter Bay Construction

Each altimeter bay was constructed from two 4.99 in. diameter carbon fiber bulkheads and a 4.95 in. diameter PLA electronics sled, separated by two PLA spacers that are 1.5 in. long. More information on the 3D printing construction can be found in Section 3.2.8.2. Two $\frac{1}{4}$ in. holes are located 180 degrees from each other on each carbon fiber plate and the electronics sled. To secure the plates and sled together, two $\frac{1}{4}$-20 threaded 5.5 in. hex head rods were aligned through the holes from the bottom carbon fiber plate and slid through the first set of spacers, the electronics sled, the second set of spacers, and the top carbon fiber plate. Once together, these assemblies slide into the airframe of the payload recovery and booster recovery airframe sections. A carbon fiber ring is permanently epoxied into the airframe that the altimeter bay assembly attaches to. The threaded rods of the altimeter bay align with two $\frac{1}{4}$ in. holes in the ring and $\frac{1}{4}$ - 20 nylon lock nuts secure the assembly into the airframe. The lock nuts are identified to show the component, but will be located on the other end of the ring when fully assembled. Figure 20 shows the full assembly of the altimeter bay.

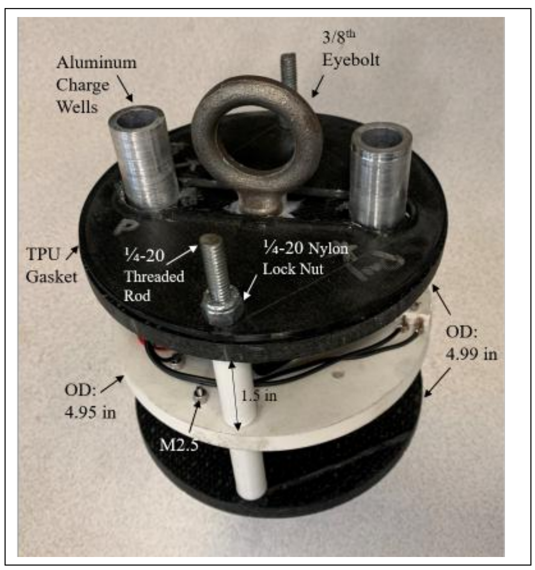


Figure 20: Altimeter Bay Assembly

The payload altimeter bay electronics sled, shown in Figure 38a includes a 9V battery and battery holder, a 7.4V lipo battery, a Teensy 3.6, a 5V voltage regulator, an ADXL326 Accelerometer, a Perfboard, two Fingertech switches, and two Missile Works RRC3's. The components of the payload altimeter bay are fully removable from the electronics sled to allow them to be swapped out without reconstructing the entire electronics sled if damage occurs. The 9V battery holder is secured to the electronics sled using threaded brass 2-56 heat-set inserts and 18-8 stainless steel 2-56 screws. To ensure the 9V batteries do not come out of the holders upon launch or recovery events, zip ties will slip under the holder and tightened over the battery. The Lipo battery is secured using a PLA battery mount with four M2.5 x 20mm screws and M2.5 nylon lock nuts. All other components are secured through holes in the sled using M2.5 x 20mm screws with M2.5 nylon lock nuts. The RRC3's and the Perfboard utilize plastic washers at each screw to ensure the solder points on the bottom of the components are not damaged when tightened down onto the sled. The electronics sled has two holes for the E-match wires to pass through.

The booster altimeter bay electronics sled, shown in Figure 39a, includes two 9V batteries and battery holders, two Fingertech switches, and two Missile Works RRC3's. One of each component is on each side of the sled and are all secured to the electronics sled with the same hardware as the payload altimeter bay. Two holes were also drilled for E-match wires to pass through the electronics sled.

Each carbon fiber plate for the altimeter bays has a 3/8 in. eyebolt that is secured with a nylon lock nut on the other end that is also epoxied to the eyebolt shaft. Two aluminum charge cups are secured on either side of the eyebolt for each carbon fiber plate. Aluminum was the chosen material for the charge cups because it is a light-weight metal that can be secured with screws, ensuring that they will not detach from the altimeter bays. The charge cups were machined in the machine shop. At least two team members were present when working in the machine shop, proper PPE was worn, and all safety guidelines as described in Appendix 8.2.2 were followed. Aluminum stock was secured in the lathe and turned down until an outer diameter of $\frac{3}{4}$ in. was reached. A 21 drill bit (0.19 in.) was used to drill a through hole, or 1.25 in. The drill size was slowly increased until a $\frac{1}{2}$ in. drill bit could be used to drill down 1 in. of the charge cup. This left a $\frac{1}{4}$ in. lip on the bottom of the charge cup. A 10-32 tap was used on the charge cup and the carbon fiber plate to better secure the charge cups. To secure the charge cups to the carbon fiber, a 1 in. 10-32 screw was used and secured with a nylon lock nut. This process was repeated for a total of eight charge cups. This method allows the charge cups to be replaced in the event that black powder sizes need to be increased and the charge cup size is no longer sufficient. Two $\frac{1}{4}$ in. through holes are also on the carbon fiber plates to allow for the E-match wires to pass through from the electronics sled.

3.2.8 3D Printing

Many components of the vehicle were 3D printed. The use of the Rapid Prototyping Lab (RPL) enabled cheap, lightweight, and impact resistant plastics to be used. Each material was chosen based on what plastics had the material properties required for the application. The plastics used for the full-scale construction were Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), and Polyether Imide (PEI).

3.2.8.1 ABS

ABS provides moderate strength and impact resistant properties and is used for components that are not designed to withstand large impact forces. The nose cone, fins, fin block, jigs for construction, payload housing, payload rails, and blast protection wedges were all made from ABS. Depending on the size of the part, either the Stratasys Fortus 400MC or Stratasys Dimension BST 768 was used. The printers have a build volume of 16 x 14 x 16 in. and 8 x 8 x 12 in. respectively. The printing temperature was set to 320 °C and the bed temperature was set to 95 °C for each printer. Every ABS component was printed at 100% infill for maximum strength.

3.2.8.2 PLA

PLA is a cheap bio-plastic used for components that do not experience high temperatures or high impacts. These components include the altimeter bay spacers, the altimeter bay electronics sleds, a custom battery holder for the altimeter bay LiPo, stencils, and replacement parts for the gimbal to increase the infill density from the manufacturer and provide higher tolerances in the payload housing. The Ender 3 Pro with a print volume of 8.6 x 8.6 x 9.8 in. was used for all of the PLA prints. The infill density was set to 100% to increase component strength. The print temperature was set to 213 °C with a bed temperature of 60 °C. The print speed was set to 60mm/s to reduce print time.

3.2.8.3 TPU

TPU is a high-performance thermoplastic elastomer with high heat and chemical resistance. TPU was used to create the gaskets, shown in Figure 21, that are included in the altimeter bays because custom shapes could be modeled and quickly and easily 3D printed. It is also abrasion resistant, which is necessary when used for multiple flights. The Prusa i3 MK3 with a print volume of 9.8 x 8.3 x 8.3 in. was used to print the TPU gaskets. The print temperature was set to 240 °C and the bed temperature was set to 60 °C. The print speed was set to 15 mm/s. TPU filament cannot be printed at a fast speed because the flexibility of the filament will clog as it tries to extrude through the nozzle if it is not printed slowly. All-Purpose Elmer's glue was applied to the build platform prior to printing to increase bed adhesion. The infill density was set to 60% to allow for more flexibility in the final part since it is meant to create an air-tight seal.

Figure 21: TPU Gasket

3.2.8.4 PEI

PEI is an amorphous thermoplastic with superior heat resistant properties. It is inherently flame retardant with a flame classification of UL94-5VA. ULTEM 9085 was the PEI used for components that required higher temperature performance and impact resistance, such as the boattail and the fin guide. Due to the high cost, ULTEM 9085 is not used for any other components. The boattail and fin guide were printed in the Stratasys Fortus 400MC 3D printer. Before setting up the print, the chutes were cleaned thoroughly to ensure no other material, such as ABS, is left over from previous prints. This is critical to ensure that upon heating, no left-over material can burn and produce hazardous flames. Due to the high temperature resistance, the print temperature is set to 410 °C and the enclosed chamber temperature is 225 °C. Once the print is complete, oven mitts must be used to safely remove the part from the build platform due to the high temperatures.

3.2.8.5 Post Processing

Based on the print orientation, some post processing was required for the 3D printed parts. The fins, for example, were printed tab side down on the build plate to ensure the airfoil cross-section printed smoothly. Due to this print orientation, support material was required in between the ribs in the fin tab. The complex shape would make it difficult to remove the support material, so the Stratasys SR-30 Soluble Support Material was used, which dissolves in a bath. The nose cone was another component that required post-processing due to the printing orientation. The nose cone is larger than the Z-axis dimensions of the largest printer available, therefore it could not be printed with the shoulder flat on the build platform and instead was printed diagonally. This orientation required extra material to support the weight of the nose cone while it printed, leaving behind a rough finish once the support material was removed. To combat this issue, the nose cone was sanded with 60, 150, 200, 400, and 600 grit sandpaper, in increasing grit size, until completely smooth. The same grit sandpaper was used on the boattail in order to remove a bump caused from a layer shift during the printing process.

3.3 Recovery Subsystem

The 49er Rocketry Team has designed the recovery subsystem by selecting the most suitable components for the design of the launch vehicle. To ensure the vehicle descends safely after reaching apogee, the components of the subsystem were selected after reviewing past designs, researching robust recovery systems, and calculating the various forces the components would need to withstand. This includes the selection of parachutes, shock cords, black powder charge sizes, electrical devices for the altimeter bay, and vehicle tracking systems.

3.3.1 Overview

For the recovery procedure, there are six total events, four of which are separation events to release a parachute. The first recovery event will occur at apogee where the vehicle will separate into two independent sections: the booster section and the payload section. From separation at this event, the drogue parachute for the booster section will release and the payload capsule will begin to exit the payload section of the vehicle. For the second event, separation will occur one second after apogee at the payload section to release its streamer. Due to the lower coefficient of drag of the streamer, the payload section of the vehicle will descend at a faster rate than the booster section. This prevent ANVIL's images from being obstructed by the descending booster section. The next two events will occur once the vehicle sections reach 600 ft. At these events, both sections will separate to release their main parachute. For the final events, the booster and payload section will land below a kinetic energy of 75 $\text{ft} - \text{lb}_\text{f}$ and within 2,500 ft of the launch rail. The description of the events can be seen in Table 9 and are depicted in Figure 22.

Table 9: Recovery Events

Event	Description	Location	Redundancy
1	The vehicle will separate at Separation Point A to disconnect the vehicle into two independent sections while also releasing the drogue parachute for the booster section.	Apogee	Apogee + 1 sec
2A	The vehicle will separate at Separation Point B to release the drogue streamer for the payload section of the vehicle .	Apogee + 1 sec	Apogee + 2 sec
2B	The booster section will separate at Separation Point C to release the booster's main parachute.	600 ft	500 ft
3A	The payload section will separate at Separation Point D to release the payload's main parachute.	600 ft	500 ft
3B	The booster section will touch down with less than 75 $\text{ft} - \text{lb}_\text{f}$ of kinetic energy, within 2,500 ft of the launch pad, and under 90 sec. of descent time.	0 ft	N/A
4A	The payload section will touch down with less than 75 $\text{ft} - \text{lb}_\text{f}$ of kinetic energy, within 2,500 ft of the launch pad, and under 90 sec. of descent time.	0 ft	N/A

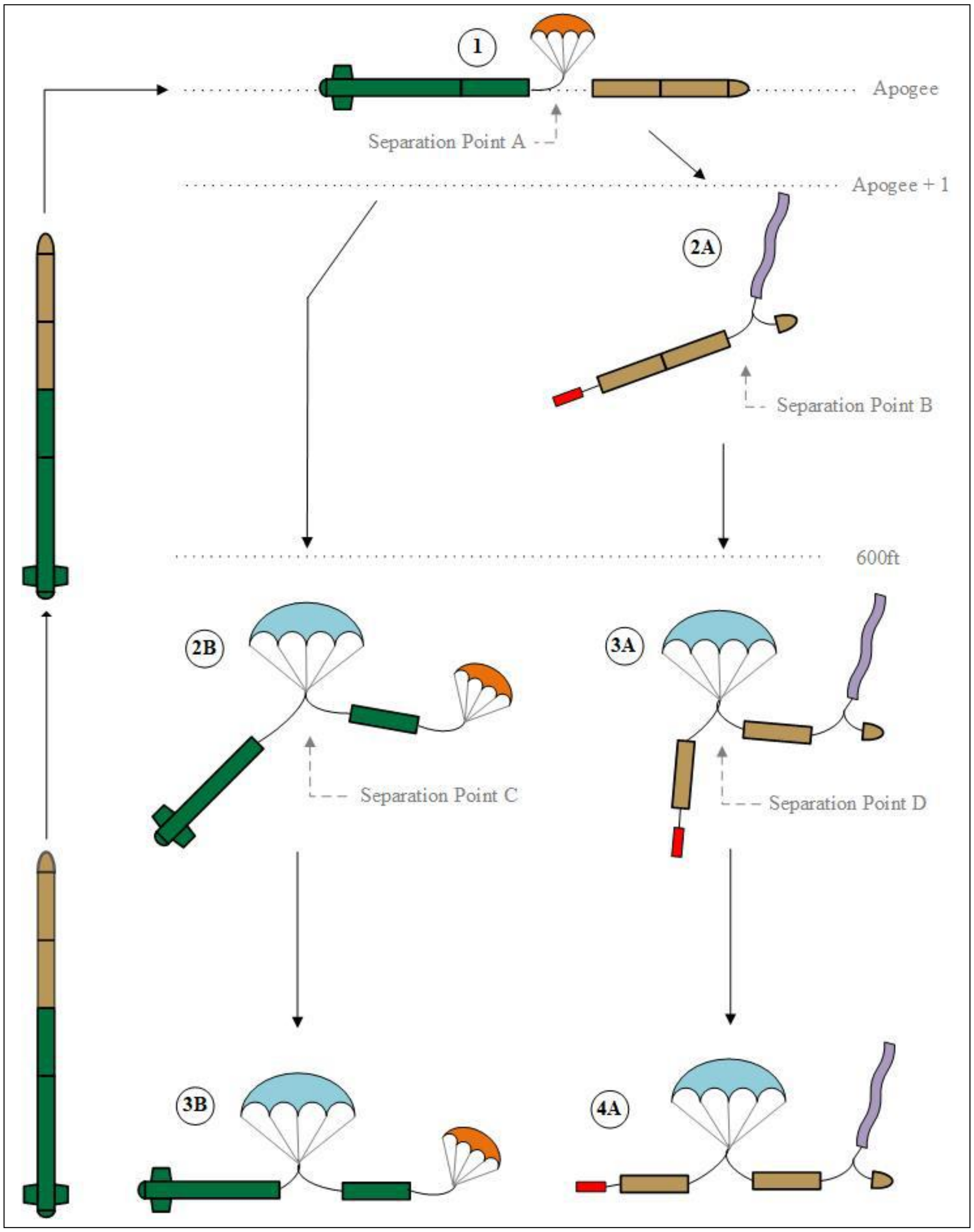


Figure 22: Recovery Overview

Table 10: Recovery Procedure Diagram Legend

Legend	
(tan)	Payload Vehicle Section
(green)	Booster Vehicle Section
(red)	ANVIL Payload
(light blue)	Main Parachute
(orange)	Drogue
(lavender)	Streamer

3.3.2 Parachutes

With correct parachute selection, the sections of the vehicle shall descend in under 90 seconds, drift less than 2,500ft, and land under 75 ft-lbs of kinetic energy. The parachute specifications investigated to meet the identified criteria were the shape, material, size, and coefficient of drag of the parachutes. The descent velocities for each independent section under their respective parachutes are further discussed in Section 3.4.5.

Booster Section: Drogue Parachute

The drogue parachute selected for the booster section was the 12.5 in. Compact Elliptical Parachute. This parachute is released at Separation Point A when the section reaches apogee to slow the descent velocity before main parachute deployment. The coefficient of drag test for the drogue parachute is discussed in Section 7.1.3.

Figure 23: 12.5 in. Drogue Parachute

Table 11: 12.5 in. Drogue Specifications

Specification	Value
Weight	0.85 oz
Packing Volume	4.7 in^3
Coefficient of Drag	1.5

Payload Section: Streamer

To ensure the payload section descends at a faster rate than the booster section, the 29 ft. streamer was selected. The faster descent rate will allow ANVIL to capture unobstructed images of the ground to locate the vehicle section. The streamer will be released at Separation Point B one second after apogee. The coefficient of drag test for the streamer is discussed in Section 7.1.5.

Figure 24: 29 ft. Streamer

Table 12: 30 x 0.4 ft Streamer Specifications

Specification	Value
Weight	2.6 oz
Packing Volume	21.99 in^3
Coefficient of Drag	0.08

Payload Section, Booster Section: Main Parachute

The main parachutes for the payload and booster sections are annular shaped parachutes. The parachutes are equipped with 400lb nylon shroud lines that connect to a 3000lb swivel. Both the parachutes will release at 600 ft to lower the sections' descent velocity for a low impact landing. The coefficient of drags of the main parachutes were verified with testing discussed in Section 7.1.4. The booster section's 84 in. main parachute will cause it to descend at 14.11 ft/s. The specifications for the parachute are shown in Table 13.

Figure 25: 84 in. Main Parachute

Table 13: 84 in. Main Parachute Specifications

Specification	Value
Weight	2.8 oz
Packing Volume	21.99 in^3
Coefficient of Drag	2.2

Since the payload section weighs less than the booster section, it is attached to a smaller sized main parachute. The section will descend under a 72 in. parachute at 14.99 ft/s to reduce the landing kinetic energy. The specifications for the 72 in. parachute is shown in Table 14.

Figure 26: 72 in. Main Parachute

Table 14: 12.5 in. Compact Elliptical Parachute

Specification	Value
Weight	13.4 oz
Packing Volume	74.1 in^3
Coefficient of Drag	2.2

Nomex Blanket

Nomex blankets will be wrapped around the parachutes to ensure they are protected from the combustion of the black powder charges. The fire protection blankets will be attached to the shock cords with their corresponding parachute's quick links. The streamer will not require a Nomex blanket since a sheet of Kevlar was sewn to it by the manufacturer. The parachutes required different sizes of Nomex to allow the blanket to fully cover the chute and the shroud lines. Figure 27 shows the dimensions of the 18 in. Nomex blanket and the sizes of the Nomex blankets are shown in Table 15.

Figure 27: 18 in. Nomex Blanket

Table 15: Nomex Blanket Sizes

Parachute	Nomex Size
12 in. Booster Drogue	9 in.
72 in. Payload Main	18 in.
84 in. Booster Main	18 in.

3.3.3 Recovery Attachment Hardware

Shock Cord

All of the parachutes will be attached to $\frac{1}{4}$ in. Kevlar shock cord which is selected for its 2200 lb tensile strength, high fire resistance, and compact volume. Since the vehicle's recovery is a dual deployment system, all four parachutes will have their own shock cord. The shock cord lengths were determined by a 3:1 ratio in comparison to the vehicle sections specified shock cord. The 3:1 lengths of the cords was chosen to avoid collision between separated vehicle sections during descent. Table 16 shows the lengths of the four parachute shock cords.

Figure 28: Recovery Kevlar Shock Cord

Table 16: Shock Cord Length

Shock Cord	Section Length (in.)	3:1 Length (in.)	Selected Cord Length (in.)
Payload Streamer	17.8	53.4	54
Payload Main	38.5	115.5	240
Booster Drogue	17	51	120
Booster Main	46	136	300

Quick Links

Quick links used for parachute deployment were determined by their loading capacity and size. For shock cord connections to bulkheads, all the quick links have a load capacity of 2200lb. All parachute to shock cord connections use a 1400lb load capacity quick link excluding the 12.5 in. drogue. The drogue uses a smaller, 400lb quick link due to size constraints and a low opening force. Table 17 shows the locations, sizes, and load capacities for all the quick links in the vehicle.

Figure 29: Recovery Quick Links

Table 17: Quick Link Location

Location	Length (in.)	Load Capacity (lb)
Nose Cone	3	2200
Payload Streamer	2	1400
Payload Streamer Bulkhead	3	2200
Payload Main Parachute Bulkhead 1	3	2200
Payload Main Parachute	2	1400
Payload Main Parachute Bulkhead 2	3	2200
Booster Drogue Parachute	1	400
Booster Drogue Bulkhead	3	2200
Booster Main Bulkhead 1	3	2200
Booster Main Parachute	2	1400
Booster Main Bulkhead 2	3	2200

Eyebolts

At the center of all the bulkheads in the vehicle, an 1 $\frac{3}{4}$ in. eyebolt is epoxied for parachute deployment. Due to space constraints and lesser forces, a smaller, 1 $\frac{1}{2}$ in., eye bolt is epoxied inside the nose cone. All the eye bolts are occupied by one quick link that is connected to a shock cord.

Figure 30: Altimeter Bay Eyebolt

Shear Pins

The vehicle requires nine shear pins to hold the sections of the vehicle together. There are two 2-56 x $\frac{1}{4}$ in. nylon shear pins at Separation Point A, B, and C which require 197 lb_f to break to release the parachutes. The two shear pins at these separation points are apart by 180°. Separation Point D requires three shear pins due to the deployment force of ANVIL. The three shear pins are 120°apart and require a shear force of 296 lb_f to break.

3.3.4 Ejection Charges

To break the two nylon shear pins for Separation Points A, B, and C, the ejection charges need to apply 197 lb_f and generate 10.03 psi of pressure on the neighboring bulkhead. At Separation Point D the ejection charges need to generate 296 lb_f and 15.05 psi. These values were substituted into the Ideal Gas Law, Equation 1, to find the required black powder mass to generate the force at the four separation points with varying volumes. Table 18 shows a description of each variable in equation 1 below.

$$m = \frac{P \cdot V}{R \cdot T} \tag{1}$$

Table 18: Ideal Gas Equation Variables

Variable	Description
m	Mass of Black Powder (lb_m)
P	Pressure (psi)
V	Volume (in^3)
R	Gas Constant ($\frac{in \cdot lb_f}{°R \cdot lbm}$)
T	Ignition Temperature (°R)

Separation Point A: Booster Drogue

$$m = \frac{(10.03\ \text{psi}) \cdot (201.26\ \text{in.}^3)}{(266\ \frac{\text{in.} \cdot \text{lb}_f}{°\text{R} \cdot \text{lb}_m}) \cdot (3307\ °\text{R})} \left(\frac{453.592\ \text{g}}{1\ \text{lb}_m} \right) = \boxed{1.04\ \text{g}}$$

Separation Point B: Payload Streamer

$$m = \frac{(10.03\ \text{psi}) \cdot (248.33\ \text{in.}^3)}{(266\ \frac{\text{in.} \cdot \text{lb}_f}{°\text{R} \cdot \text{lb}_m}) \cdot (3307\ °\text{R})} \left(\frac{453.592\ \text{g}}{1\ \text{lb}_m} \right) = \boxed{1.29\ \text{g}}$$

Separation Point C: Booster Main

$$m = \frac{(10.03\ \text{psi}) \cdot (262.62\ \text{in.}^3)}{(266\ \frac{\text{in.} \cdot \text{lb}_f}{°\text{R} \cdot \text{lb}_m}) \cdot (3307\ °\text{R})} \left(\frac{453.592\ \text{g}}{1\ \text{lb}_m} \right) = \boxed{1.36\ \text{g}}$$

Separation Point D: Payload Main

$$m = \frac{(15.05\ \text{psi}) \cdot (233.17\ \text{in.}^3)}{(266\ \frac{\text{in.} \cdot \text{lb}_f}{°\text{R} \cdot \text{lb}_m}) \cdot (3307\ °\text{R})} \left(\frac{453.592\ \text{g}}{1\ \text{lb}_m} \right) = \boxed{1.81\ \text{g}}$$

The masses for the primary charges for all the separation points are tabulated in Table 19. A safety factory of 1.5 was applied to the calculated values to take into consideration possible air leakage due to pressure holes and gaps in the airframe. Separation testing will be performed to ensure there is an adequate amount of black powder at the separation points. All the separation points will be equipped with a backup black powder charge. The masses of the backup charges are shown under the Recovery Subsystem Redundancy Section 3.3.4.1.

Table 19: Separation Charge Masses

Separation Point	Calculated Mass (g)	Safety Factor	Primary Charge (g)
A	1.04	1.5	1.56
B	1.29	1.5	1.93
C	1.36	1.5	2.04
D	1.81	1.5	2.71

3.3.4.1 Redundant Ejection Charges

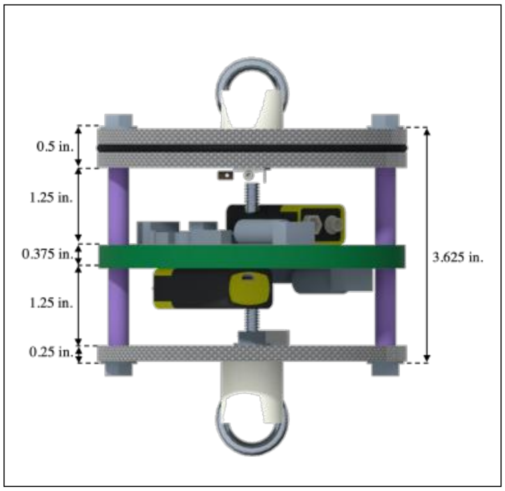
For every separation event there will be a redundant charge. A redundant charge is implemented in case the primary charge fails to ignite or generate enough force to break the shear pins. All redundant charges will detonate after the primary charges and provide more shear force by increasing the mass by 20%. The resulting redundant charge masses are listed in Table 20.

Table 20: Redundant Separation Charge Masses

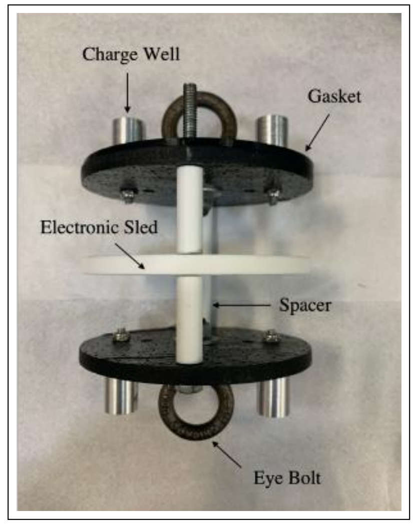
Separation Point	Redundant Charge (g)
A	1.87
B	2.31
C	2.45
D	3.26

3.3.5 Altimeter Bay Mechanical Design

There are two altimeter bays for the dual deployment recovery system. The altimeter bays are first fully assembled and wired outside the vehicle and then fastened with nuts to an epoxied centering ring.



(a) Altimeter Bay 3D Model

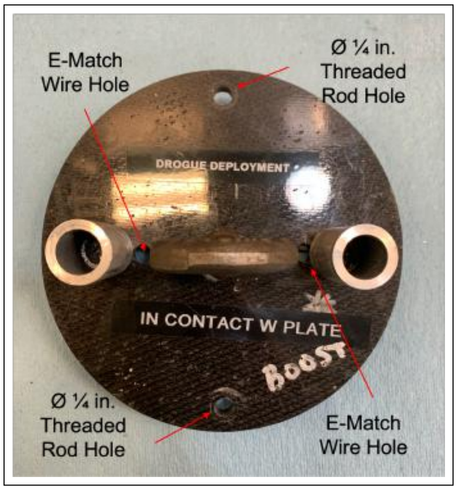


(b) Altimeter Bay Manufactured

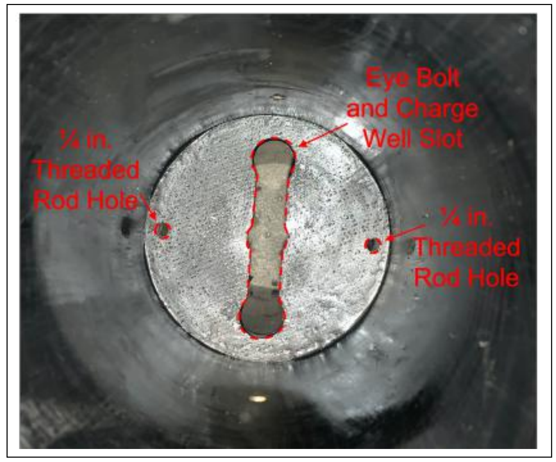
Figure 31: Altimeter Bay Design

Altimeter Bay Bulkhead and Centering Ring

On the top and bottom of the altimeter bays are $\frac{1}{4}$ in. carbon fiber bulkheads that are 4.99 in. in diameter. To accommodate the charge wells and e-match wire placement, $\frac{1}{4}$ in. holes were drilled next to the charge wells. There are two $\frac{1}{4}$ in. holes that threaded rods are placed through to assemble the altimeter bay. The threaded rods also retain the altimeter bay to the epoxied $\frac{1}{4}$ in. carbon fiber centering ring in the vehicle. Figures 32a and 32b shows the altimeter bay's bulkhead and centering ring.



(a) Bulkhead

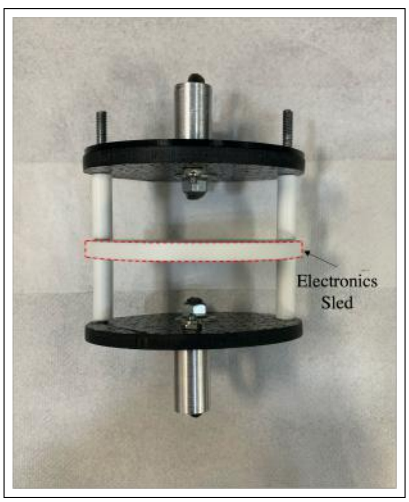


(b) Epoxied Centering Ring

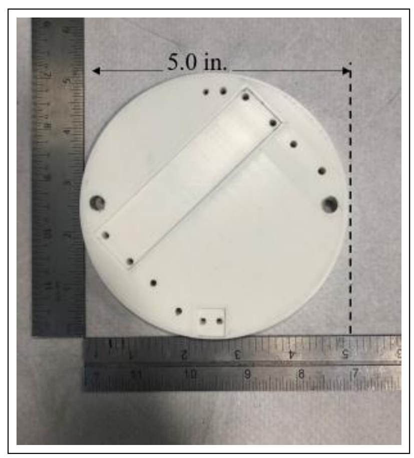
Figure 32: Altimeter Bay Bulkhead and Epoxied Centering Ring

Electronics Sled

The electronics sled is additively manufactured out of PLA and will retain the primary RRC3, backup RRC3, a 9V battery or 7.4v Lipo for power source, and FingerTech switches. The payload section's electronic sled features a 7.4v Lipo to power an RRC3 and an accelerometer. More information on the accelerometer is shown in Section 3.3.6. The sled is placed between the bulkheads with the threaded rods inserted through $\frac{1}{4}$ in. holes in similar placement as the holes in the bulkheads. Multiple $\frac{1}{8}$ in. holes are drilled into the electronics sled for component retention and e-match wires to feed through. Figures 33a and 34b show the electronics sled and its location on the altimeter bay.



(a) Electronics Sled on Altimeter Bay

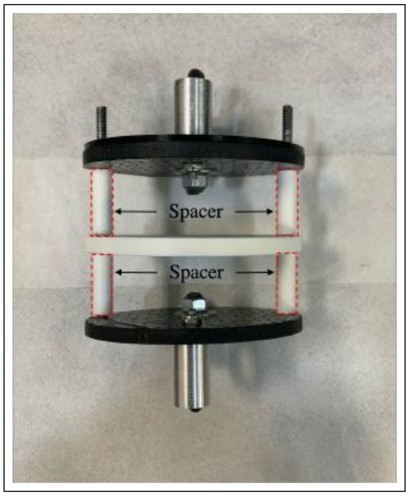


(b) Electronics Sled 3D Model

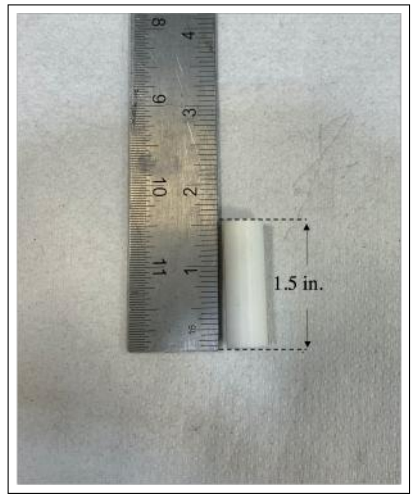
Figure 33: Altimeter Bay Electronics Sled

Spacers

The spacers on the altimeter bay are additively manufactured out of PLA and placed on the screws. The spacers are used to separate the electronics sled from the bulkheads, allowing for components to be placed. Figure 34a shows the placement of the four spacers between the electronics sled and bulkheads.



(a) Spacers on Altimeter Bay

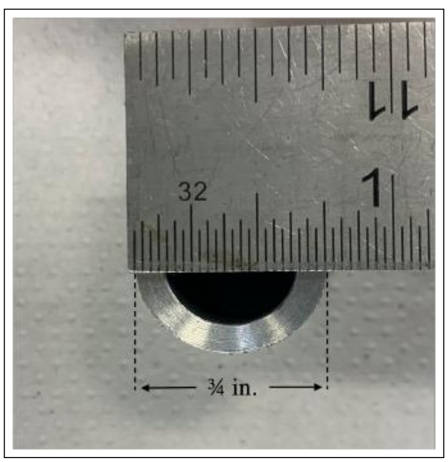


(b) Spacers Dimension

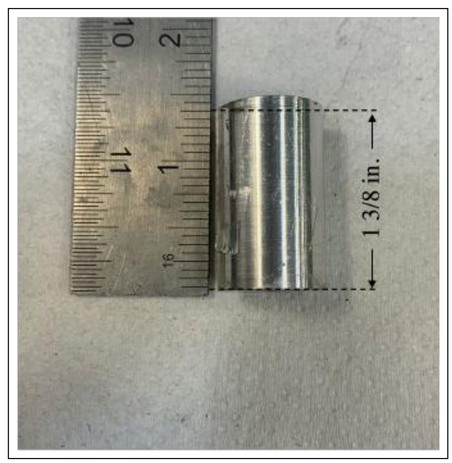
Figure 34: Altimeter Bay Spacers

Charge Wells

There are four charge wells manufactured from aluminum located on each altimeter bay for the primary and redundant charges. The aluminum material was selected to allow the charge wells to be retained to the bulkheads with screws and nuts. Adequate space is created in the charge wells for all the black powder charges, wadding, and the igniter to be placed inside. Figures 35a and 35b show the diameter and length of the charge wells.



(a) Charge Well Diameter Dimension

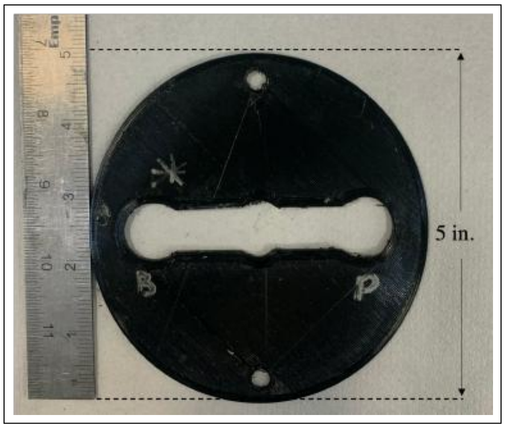


(b) Charge Well Length Dimension

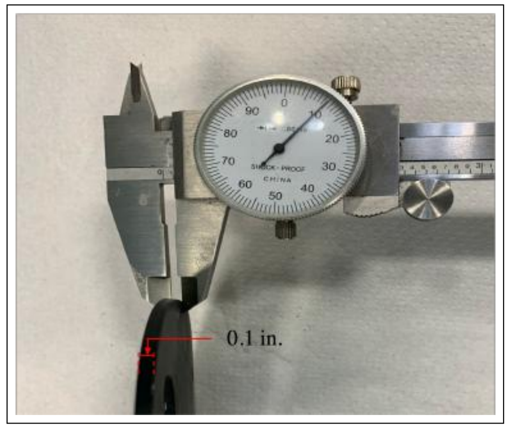
Figure 35: Charge Well Dimensions

Gasket

From previous testing of the altimeter bay inside the sub-scale model, it was learned there was a pressure leak between the centering ring and bulkhead connection. A TPU gasket was then designed to stop the pressure leakage that occurs from black powder charge detonations. The gasket has holes on opposing sides for the altimeter bay's screws and a slot in the middle for the eye bolt and charge wells. Figures 36a and 36b show the dimensions of the gasket to fit between a centering ring and bulkhead.



(a) Gasket Diameter Dimension



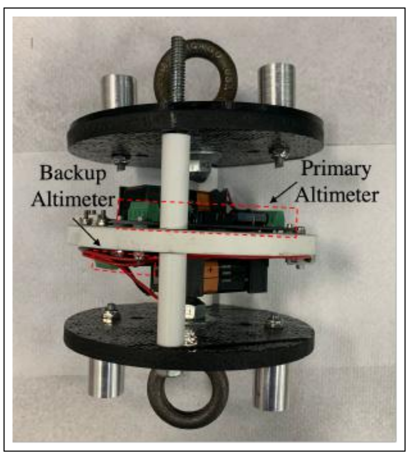
(b) Gasket Thickness Dimension

Figure 36: Altimeter Bay Gasket Dimensions

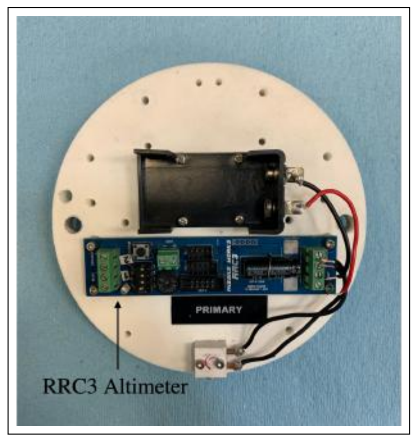
3.3.6 Altimeter Bay Components

Altimeters

Four Missile Works RRC3 altimeters will be required for the redundant, dual deployment system. The altimeters are retained to the top and bottom of the electronics sled with M2.5 screws and nylon locknuts. Each primary altimeter is retained on the top and each backup altimeter is retained to the bottom of the sled. Pressures holes were drilled into the airframe with a diameter of 0.101 in. for the barometric sensor to accurately read the ascending and descending altitudes.



(a) RRC3 Locations on Altimeter Bay

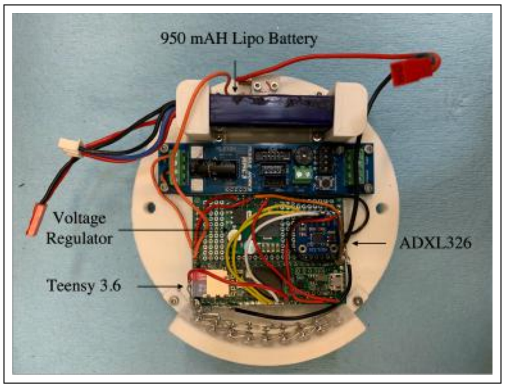


(b) RRC3 Location on Electronics Sled

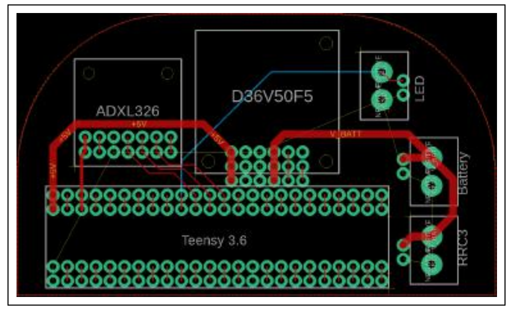
Figure 37: RRC3's on Altimeter Bay

Accelerometer

On the payload section's altimeter bay, an Adafruit ADXL326 Accelerometer is retained on the electronics sled to measure the acceleration of the vehicle during ascent. The accelerometer is connected to a Teensy 3.6, a 5V voltage regulator, and a 950 mAH Lipo battery. The Lipo battery is also the power source for the backup altimeter for the payload section. Figure 38a shows the layout of the accelerometer configuration on the electronics sled. A Printed Circuit Board (CPCB) was designed for the accelerometer circuit to replace the perf board circuit. Figure 38b shows the PCB layout that has been designed for this altimeter bay.



(a) Accelerometer Circuit

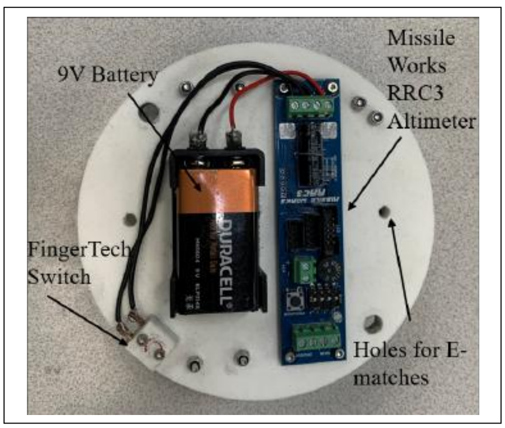


(b) RRC3 Location on Electronics Sled

Figure 38: Accelerometer Altimeter Bay

FingerTech Switch

The altimeter bay electronics are powered on from outside the vehicle onto the launch rail with the use of a FingerTech Switch. The switches are screwed on the edge of the electronics sled next to a hole in the airframe allowing access from the exterior with an Allen wrench. The pressure holes for the altimeters are 0.1 in. Figure 39a and 39b show the location of the FingerTech Switch on the altimeter bay and the hole in the airframe allowing access to the mechanical arming switch.



(a) FingerTech Switch on Electronics Sled

(b) FingerTech Switch Hole

Figure 39: Fingertech Switch

3.3.7 Vehicle Tracking Systems

For tracking of the two independent sections, electronic GPS tracking devices will be installed in the booster section and payload section of the vehicle. The payload and booster sections will each contain a Featherweight GPS Tracking System. The GPS units will be retained in 3D printed housing capsules which will be tethered to the streamer's shock cord in the payload section and the main parachute's shock cord in the booster section.

Featherweight GPS Tracking System

The Featherweight GPS tracker was selected for its small size and low power draw. With the SubMiniature Version A (SMA) antenna installed, the Featherweight tracker is 4.1 in. long. Ground testing has shown the GPS will locate the vehicle section in a line of sight setting within 2,500 ft. The Featherweight transmits on the license free 915 MHz band to a ground receiver and has 100mW of transmission power. The transmitter requires a minimum operating current of 309.6 mAh to achieve the capacity to run for three hours. The Featherweight will be powered by a 400 mAh 7.4V 2s lithium polymer (LiPo) battery. Figure 40 below shows the configuration for featherweight GPS that will be used.

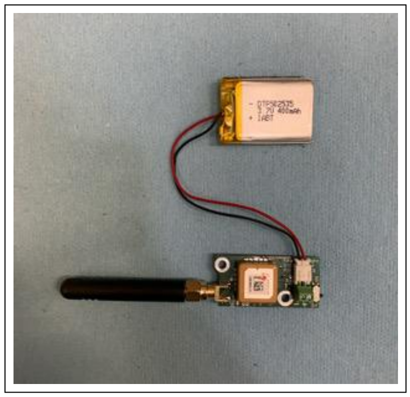
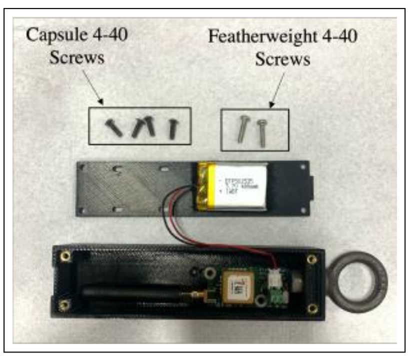


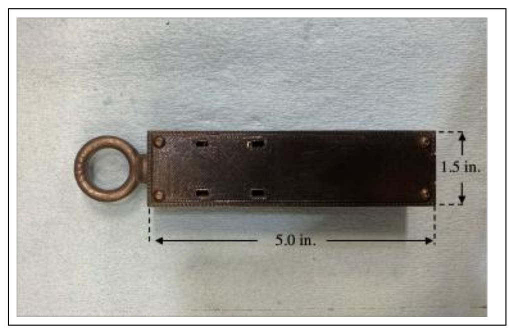
Figure 40: Featherweight GPS

Featherweight GPS Retention

A Featherweight GPS tracker is retained inside a housing capsule, in both the payload and booster section of the vehicle. Eye bolts are screwed to the housing capsules to attach a quick link on a parachute shock cord. For the payload section, the GPS is located inside the nose cone while tethered to the streamer's shock cord. Since the nose cone will be manufactured with ABS, the GPS will track the location of the vehicle during ascent. The booster section's Featherweight GPS is located between the altimeter bay and the main parachute. The GPS is tethered to the shock cord and deploys with the main parachute upon separation. As the airframe is manufactured with carbon fiber, the GPS will not be able to transmit its location until the separation event occurs at 600 ft. The trackers are housed inside a 5.0 in. long 3D printed container constructed out of ABS plastic. The trackers are retained to the capsule with 4-40 screws and the LiPo is retained with velcro. Figures 41a and 41b show Featherweight GPS housing capsule assembled and disassembled.



(a) Featherweight Capsule Disassembled



(b) Featherweight Capsule Assembled

Figure 41: Featherweight Capsule

Redundant Vehicle Tracking System

For redundancy, the Communications Specialist R-300A Receiver and Tracker-RCHPs are implemented for radio GPS telemetry. The trackers have a range up to 10 miles, a transmitting frequency of 222.25 MHz, and 30mW of transmission power. Each independent section of the vehicle has tracker tethered to its main parachute shock cord.

3.4 Mission Performance Predictions

OpenRocket and a 2 Degree of Freedom (2-DOF) MATLAB code were used to model the launch vehicle's flight profile. The software was used to verify the launch vehicle's performance prior to launch. General flight profiles were generated in addition to velocity and acceleration plots.

3.4.1 MATLAB Flight Profile Simulations

The primary analysis was completed with the use of data from MATLAB, however, Openrocket was used to verify the MATLAB results. The MATLAB code used a linearized motor thrust curve for the ascent phase of the launch vehicle's flight path. The forces of gravity, experienced drag force, and thrust of the launch vehicle were evaluated over millisecond time increments to find the total force experienced during each time increment of flight. Kinematic equations were used, in conjunction with force values found, to calculate position, velocity, and acceleration at each time increment. The drag coefficients of the parachutes used for each vehicle section were used to simulate the descent phase. The rail cant was not accounted for in the MATLAB code, therefore the OpenRocket simulations will provide rail cant data. The MATLAB code outputted ascent time, apogee, descent time of each section and the corresponding kinetic energy of each section at impact. The same inputs were used for both simulation softwares and are shown below in Table 21.

Table 21: Flight Profile Simulation Inputs

Variable	Value	Unit
Vehicle Drag Coefficient	.3438	N/A
Vehicle Diameter	5.13	in.
Payload Section Mass	16.6	lb_m
Booster Section Burnt Mass	20.46	lb_m
Booster Drogue Diameter	12.5	in.
Booster Drogue Coefficient of Drag	1.5	N/A
Booster Main Diameter	84	in
Booster Main Coefficient of Drag	2.2	N/A
Booster Main Deployment Altitude	600	ft
Payload Streamer Length	30	ft
Payload Streamer Width	.4	ft
Payload Streamer Coefficient of Drag	0.08	N/A
Payload Main Diameter	72	in
Payload Main Coefficient of Drag	2.2	N/A
Payload Main Deployment Altitude	600	ft
Effective Rail Length	10.02	ft
Nose Cone Mass	3.0	lb_m

Simulated Motor Thrust Curve

Tested motor data for the Aerotech L1390-G was gathered from thrustcurve.org, along with propellant mass curves, and was used in the MATLAB simulations. Figure 42 shows the thrust curve provided by Chris' Rocket Supplies on the left, and the simulated thrust curve is shown on the right.

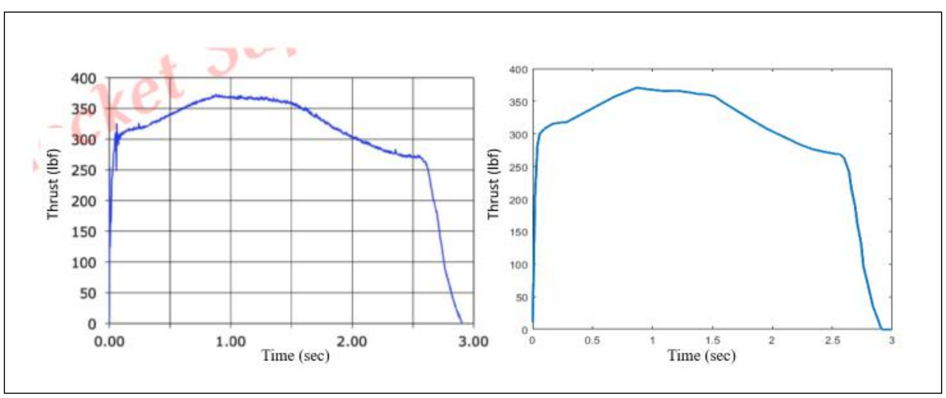


Figure 42: Thrust Curve Comparison

The L1390-G specification sheet, provided by Chris' Rocket Supplies, indicates a total impulse of 891 lbf-s. While the simulated motor used for MATLAB simulation, provided by linearizing data points from thrustcurve.org, indicates a total impulse of 887.7 lbf-s. The percent difference between the two sources, for total impulse, is 0.37 %. Additionally, the maximum thrust specified by Chris's Rocket Supplies is 370 lbf, while thrustcurve.org specifies a maximum thrust of 370.86 lbf. The percent different in the maximum thrust is 0.23 % and shows that a plausible maximum thrust is being simulated in MATLAB. Therefore, simulated the rail exit velocity, maximum velocity, and maximum acceleration are accurate for the launch vehicle with an AeroTech L1390-G.

Flight Path

The launch vehicle follows an expected flight profile through the different flight phases that occur. The ascent portion of flight is denoted by a single blue curve until apogee occurs at 5353.3 ft. The ascent path of the launch vehicle shows that apogee is achieved in under twenty seconds. Following apogee, the booster and payload sections of the launch vehicle descend at different rates. The difference in descent times for each section matches the different coefficients of drag that the payload section streamer and the booster section drogue have. Even with the booster section weighing 3.86 lbs more than the payload section, the payload section descends faster due to the lower drag of the streamer. Both sections descend rapidly until the main parachutes deploy at 600 ft AGL. The large drag due to the main parachutes leads to a drastic reduction in terminal velocity, shown by the decreased slope on the altitude vs time plot in Figure 43. Additionally, The velocity and acceleration curves simulated during this flight path are shown below in Figure 44.

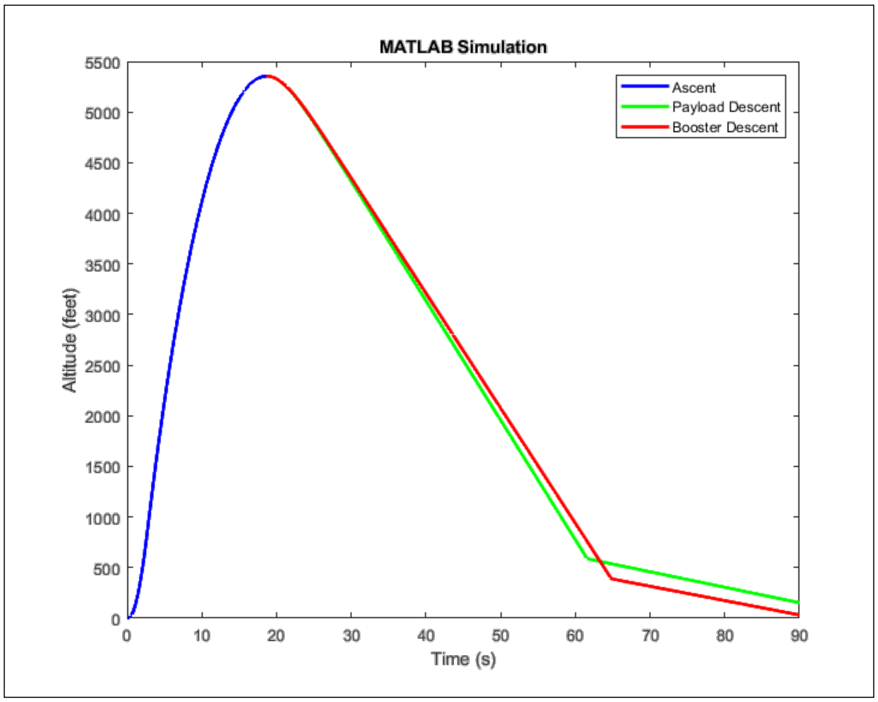


Figure 43: MATLAB Simulated Flight Path

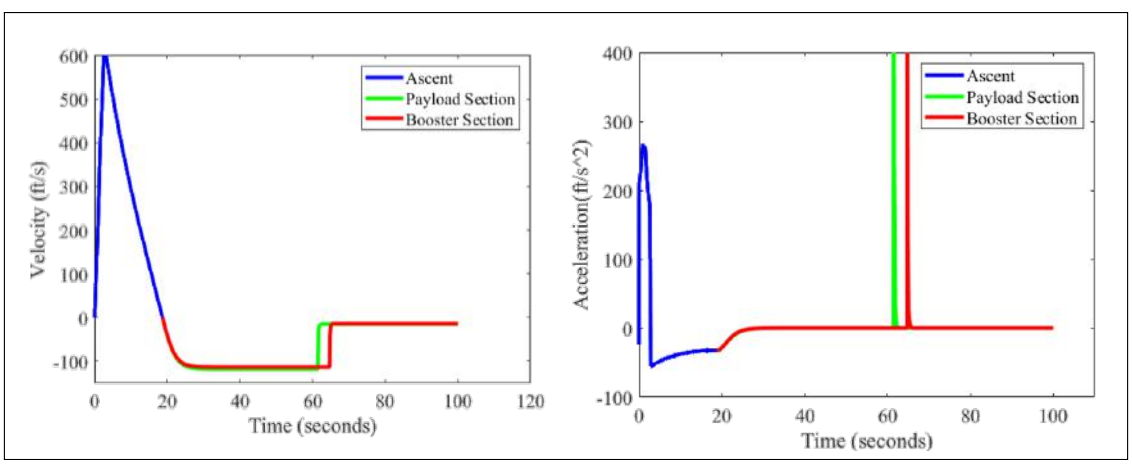


Figure 44: a) Simulated Velocity of the Launch Vehicle b) Simulated Acceleration of the Launch Vehicle

3.4.2 Ascent Characteristics

The MATLAB simulation is separated into two subsections, ascent and descent. The ascent values assessed in the MATLAB simulation are: rail exit velocity, maximum velocity, maximum acceleration, apogee, and ascent time. These values and their corresponding NASA USLI handbook requirements are shown below in Table 22.

Table 22: Ascent Characteristics

Variable	Value	Unit	Requirement
Maximum Acceleration	266.7	ft/s^2	N/A
Rail Exit Velocity	76.1	ft/s	SLH: 2.16
Maximum Velocity	617.7	ft/s	SLH: 2.22.6
Apogee	5353.3	ft	SLH: 2.1
Ascent Time	18.68	s	N/A

The maximum acceleration value was found with the linearized motor thrust curve, provided by data points from thrustcurve.org, evaluated over 1 ms time intervals. A linearized motor mass curve was used to properly account for the change in mass during motor burn, allowing accelerations to be calculated throughout simulation. The maximum acceleration was calculated to occur at 1.18 seconds and occurs at the same time that maximum motor thrust is calculated.

The MATLAB simulated off rail velocity was calculated with the linearized motor thrust curve data for the AeroTech L1390-G. Equations 2 and 3 were used in conjunction with the simulated values to calculate the time when the launch vehicle left the rail. The change in altitude was calculated in Equation 2 with time and acceleration data over 1 ms intervals. From the altitude change, a rail exit velocity was found with Equation 3.

$$\Delta \mathrm{x} = \mathrm{v}_1 \cdot \mathrm{t} + \frac{1}{2} \cdot \mathrm{a} \cdot \mathrm{t}^2 \tag{2}$$

$$\mathrm{v}_2^2 = \mathrm{v}_1^2 + 2 \cdot \mathrm{a} \cdot \Delta \mathrm{x} \tag{3}$$

The off rail velocity was calculated to be 76.1 ft/s, which is above the minimum requirement of 52 ft/s established in Section 2.17 of the NASA Student Launch Handbook, providing the launch vehicle with an off rail velocity safety factor of 1.39. To calculate the off rail velocity of the launch vehicle, the velocity at an altitude of the vehicle's effective rail length, 120.9 in., was calculated. A constant off-rail velocity across multiple simulations is expected due to the rail providing a consistent flight path that cannot be affected by wind. Therefore, wind will only begin to affect the flight path after the launch rail has been exited by the vehicle. Figure 45 shows the rail exit velocity plotted against the effective rail length of the launch vehicle. The figure has two distinct markers, one being the handbook minimum rail exit velocity and the other being the launch vehicles simulated rail exit velocity.

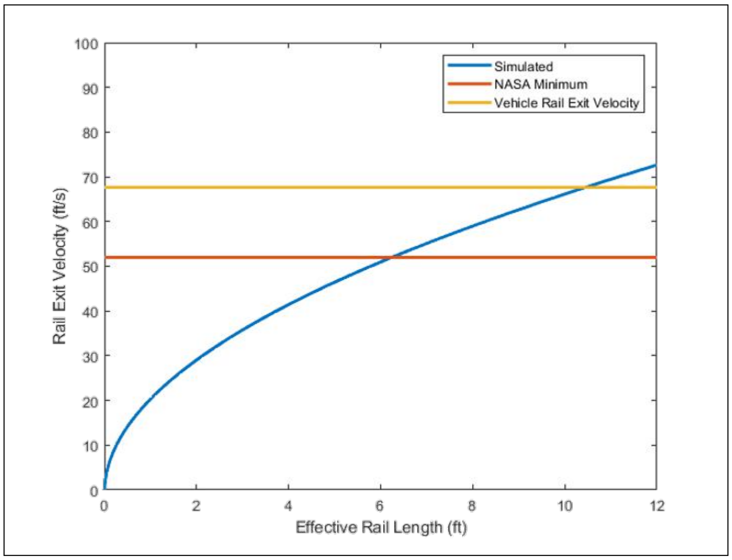


Figure 45: Rail exit velocity as a function of effective rail length

The MATLAB simulation projected an apogee of 5353.3 ft for the launch vehicle, and is 353.3 ft off from the declared apogee of 5000 ft stated at the Preliminary Design Review milestone. Due to the exact weight of the motor and casing not being specifically provided, the weight of the motor casing was accounted for twice. This has resulted in an unexpected altitude given that the weight of the vehicle is 1.0 lbs under the measured weight of 41.0 lbs. The simulated flight from MATLAB had no rail cant and 0 MPH winds, therefore MATLAB is expected to simulate higher altitudes than OpenRocket. From the MATLAB altitude data, the launch vehicle has an altitude buffer of 650 ft within the altitude bounds of 4000 ft to 6000 ft AGL. The launch vehicle will not be able to go above 6,000 ft given the selected AeroTech L1390-G motor and a mass of 42.0 lbs; while the launch vehicle will not be able go below 4,000 ft even with 20 mph wind and 10 rail cant. The simulated time to apogee is 18.6 seconds and while there is no handbook requirement relating to ascent time, the ascent time was calculated in order to ensure that there is sufficient time for the Raspberry Pi to boot prior to reaching 4,000 ft in descent altitude. This will ensure that the ANVIL system can begin taking pictures with enough ground coverage to successfully identify where the vehicle lands.

Descent Characteristics

The descent characteristics of the launch include the vehicle sections' kinetic energy at landing, descent time, and drift distances. Table 23 displays the descent time values from the MATLAB simulation along with the section of the handbook they verify.

Table 23: Simulated Descent Time

Vehicle Section	Descent Time (s)	Requirement
Booster Section	87.29	SLH: 3.11
Payload Section	83.29	SLH: 3.11

The descent time was simulated with an apogee value of 5353 ft with 0 mph wind speed and 0°rail cant which was derived form the Ascent Characteristics shown previously in Table 22. For the payload section, the descent time is 41.3 seconds under streamer and 41.9 seconds when descending under the 72 in. main parachute which totals to 83.29 seconds. For the booster section, the descent time is 42.82 seconds under the 12.5 in. drogue and 44.47 seconds under the 84 in. main parachute having 87.29 seconds of total descent time. The total descent times from the MATLAB simulation for the two independent sections obey the SLH: 3.11 requirement stating the times shall not exceed 90 seconds.

For landing kinetic energy, SLH Section 3.3 states all independent sections must impact the ground less than 75 ft-lbs. Following this requirement ensures all the vehicle components will be in good condition for future launches. Table 24 shows the landing kinetic energies for the components that will touchdown under their main parachute.

Table 24: Simulated Landing Kinetic Energy

Vehicle Component	Kinetic Energy $(\mathrm{ft}-\mathrm{lb_f})$	Requirement
Booster Propulsion Section	39.98	SLH: 3.3
Booster Recovery Section	22.64	SLH: 3.3
Payload Section	9.6	SLH: 3.3
Payload Recovery Section	22.5	SLH: 3.3
Nose Cone	10.89	SLH: 3.3
ANVIL	18.15	SLH: 3.3

The kinetic energies for the vehicle components listed in Table 24 were derived from the weight of each component and their simulated descent velocity when falling under a main parachute.

The drift distances were also simulated in MATLAB for the two independent sections with 5, 10, 15, and 20 mph wind conditions. The resulting drift distances from the simulation are shown in Table 25.

Table 25: Simulated Drift Calculations

Vehicle Section	5 mph (ft)	10 mph (ft)	15 mph (ft)	20 mph (ft)	Requirement
Booster Section	646.1	1286.7	1916.7	2472.9	SLH: 3.10
Payload Section	611.7	1218	1814.2	2340.6	SLH: 3.10

The drift distances were calculated in conjunction with the altitudes of parachute deployment and the descent velocities. At worst case scenario of 20 mph wind speeds, the simulation shows the payload section will drift 2340.6 ft and the booster section will drift 2472.9 ft. These values coincide with SLH Section 3.10 which states the drift must not exceed 2,500 ft under the flight worst conditions.

3.4.3 OpenRocket Flight Profile Simulations

To provide a second set of mission performance data, an OpenRocket model was created and simulated. There are two main differences between the OpenRocket and MATLAB simulations. The first difference is that OpenRocket can model rail cant while the MATLAB simulations cannot. The second difference is that OpenRocket does not model a dual deployment recovery descending in two separate sections while the MATLAB simulation does. The flight paths of the launch vehicle with varying wind speeds are shown below in Figure 46.

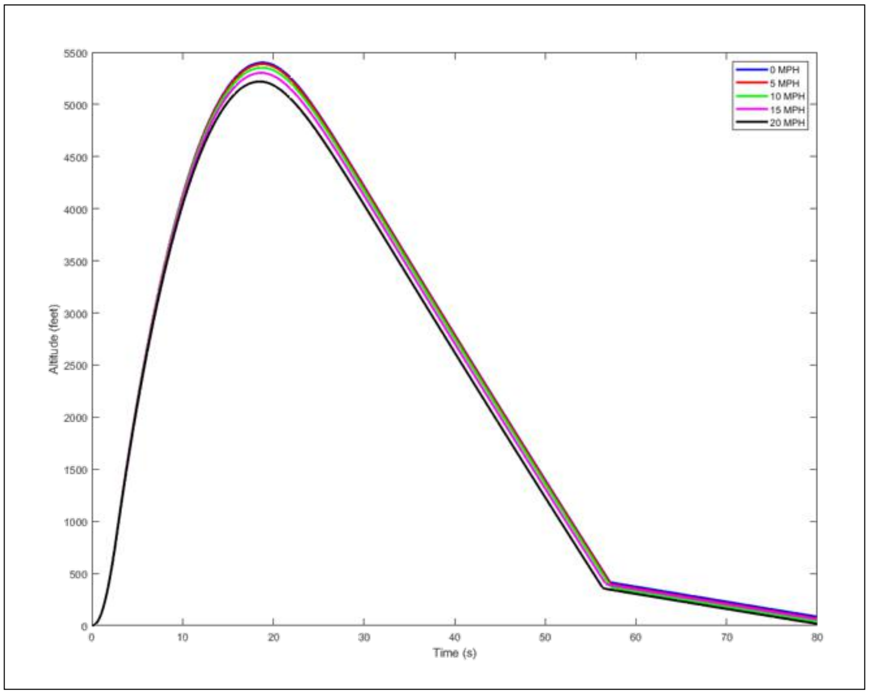


Figure 46: OpenRocket Simulations in Varying Wind Conditions

The flight profiles over various wind speeds were generated for the launch vehicle and should all share similar flight profiles. The main result that changes from an increase in wind speed is the altitude achieved by the launch vehicle. The launch vehicle's achieved altitude decreases as the wind speed increases. This trend shows that as higher wind speeds occur, greater lift will be experienced by the launch vehicle. As lift is generated and wind acts on the launch vehicle's center of pressure, the launch vehicle will rotate around its center of gravity, and increase the vehicle's angle of attack. This phenomenon causes the launch vehicle to travel into the direction of the wind. By pointing into the wind, a horizontal component of thrust increases while also decreasing vertical thrust. The decrease in vertical thrust greatly reduces the expected altitude performance. A decreased descent time is also expected with a lower apogee and higher wind speeds. The launch vehicle exhibits the same descent profiles across wind speed besides the altitudes in which recovery events occur. The similar descent across wind speeds shows that wind is a horizontal force that does not affect vertical velocity, therefore the landing kinetic energy of the launch vehicle will not change with wind.

In addition to evaluating the effect that wind has on vehicle performance, another set of simulations were executed in OpenRocket to evaluate the effect that rail cant has on apogee. Figure 47 shows a group of flight profiles over a varying set of rail cants.

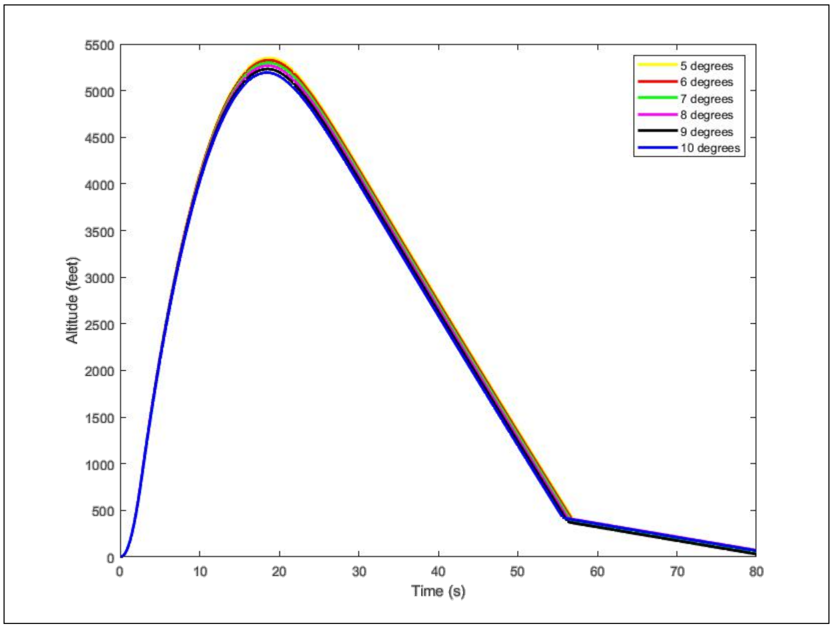


Figure 47: OpenRocket Simulations with Varying Rail Cants

A constant wind speed of 5 MPH was used to isolate the effect of rail cant on apogee. As expected, rail cant greatly reduced the altitude performance of the launch vehicle. An altitude difference between the lowest rail cant of 5°to the highest rail cant of 10°was 153 ft.

To simulate the best and worst possible combinations of rail cants and wind speeds, a wide range of simulations were run. Table 26 shows the apogee values for the variety of wind speeds and rail cants simulated.

Table 26: Open Rocket Apogee Simulation Data

Altitude Simulations					
Rail Cant	**0 mph**	**5 mph**	**10 mph**	**15 mph**	**20 mph**
5°	5350	5293	5231	5158	5060
6°	5326	5269	5197	5048	4987
7°	5299	5221	5130	5016	4944
8°	5268	5190	5084	4983	4854
9°	5232	5146	5033	4958	4813
10°	5193	5099	4987	4885	4759

The worst possible combination of rail cant and wind speed caused the simulated vehicle to reach 4759 ft. This performance would still be considered a success according to VMSC 1. Figure 48 shows a surface plot that displays the effect that rail cant and wind speed have on apogee.

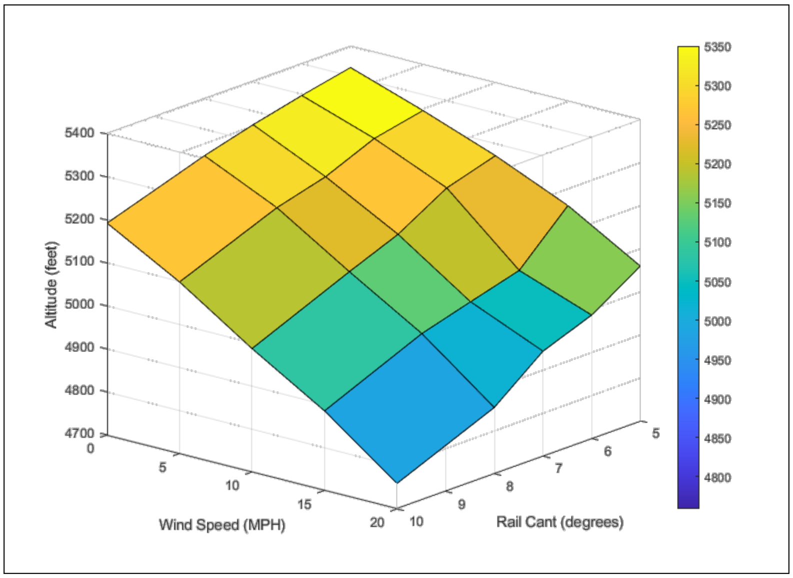


Figure 48: Surface Plot of Wind Speed and Rail Cant Affecting Apogee

In the figure shown above, the apogee of the launch vehicle, was plotted against rail cant and wind speed. Rail cant was evaluated from 5°to 10°to account for the rail cant guidelines specified in the NASA USLI Competition Handbook. The wind speeds were evaluated in 0 to 20 MPH to account for the wind range specified by the NASA USLI Competition Handbook. The yellow portion of the surface plot signifies the highest achieved altitudes and the blue signifies the lowest achieved altitudes.

3.4.4 Flight Stability

Flight stability was calculated by OpenRocket and verified by a team created Microsoft Excel code using the extended Barroman method. Equations 4 - 11 were used in the Excel code to calculate the launch vehicle's center of mass and center of pressure. From the center of mass and center of pressure, the corresponding variables for the Barroman method are displayed in Table 27. From the Barroman method, a calculated stability of 3.16 caliber was found for the launch vehicle. OpenRocket calculated that the full-scale launch vehicle has a pre-launch stability caliber of 3.16. A percent difference of 0.0% was found, and shows that the pre-launch stability of the vehicle is above 2.0 caliber. With a pre-launch stability at 3.16 caliber, the launch vehicle will experience a stable flight.

Table 27: Center of Pressure Variable Definitions

Variable	Definition
$(C_N)_T$	Normal force coefficient on transition
a	Hand calculated Stability Values
b	OpenRocket Stability Values
$(C_N)_T$	Normal Force Coefficient on fin
d_r	Diameter Aft of Transition
d	Diameter at Base of Nose cone
d_f	Diameter at Beginning of transition
X_T	Centroid of Transition
X_P	Distance From Tip of Nose Cone to Start of Transition
L_T	Length of Transition
L_F	Length of Fin Mid-chord line
S	Height of Fin
R	Radius at Aft End of Airframe
N	Number of fins
C_T	Fin Tip Chord
M_{tot}	Sum of All Masses
C_R	Fin Root Chord
X_R	Distance Between Root Leading Edge and Tip Leading Edge
X_F	Distance From Nose Cone to Centroid of Fins
CP	Center of Pressure
CG	Center of Gravity
θ	Fin Sweep Angle

$$X_{cm} = \frac{\sum x_i m_i}{\sum M_{tot}} \tag{4}$$

$$(C_N)_T = 2\left[\left(\frac{d_R}{d}\right)^2 - \left(\frac{d_F}{d}\right)^2\right] \tag{5}$$

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1-(\frac{d_F}{d_R})}{1-(\frac{d_F}{d_R})^2}\right] \tag{6}$$

$$L_F = \sqrt{S^2 + \left(\frac{1}{2}C_T - \frac{1}{2}C_R + \frac{S}{\tan\theta}\right)} \tag{7}$$

$$(C_N)_F = \left[1 + \left(\frac{R}{S+R}\right)\right]\left[\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_F}{C_R+C_T})^2}}\right] \tag{8}$$

$$X_F = X_B + \left(\frac{X_R}{3}\right)\left(\frac{(C_R+2C_T)}{(C_R+C_T)}\right) + \frac{1}{6}\left[(C_R+C_T) - \frac{(C_R C_T)}{(C_R+C_T)}\right] \tag{9}$$

$$\bar{x} = \frac{(C_N)_N X_N + (C_N)_T X_T + (C_N)_F X_F}{(C_N)_R} \tag{10}$$

$$\text{Stability} = \frac{CP - CG}{\text{Diameter}} \tag{11}$$

The stability calculations performed above provide a valid static stability, but upon motor ignition a stability increase will occur due to the decrease in propellant mass in the motor, located in the back of the vehicle. OpenRocket was used to find a post-burn stability of 3.8. Figure 49 shows the pre-burn stability and Figure 50 shows the post-burn stability of the launch vehicle.

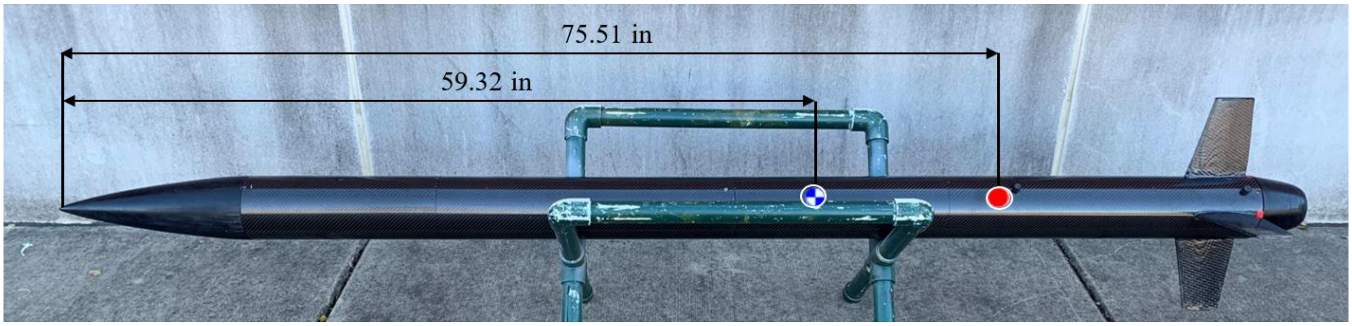


Figure 49: CP and CG Before Burn

$$\text{Stability} = \frac{75.51 - 59.32}{5.13} = \boxed{3.16} \tag{12}$$

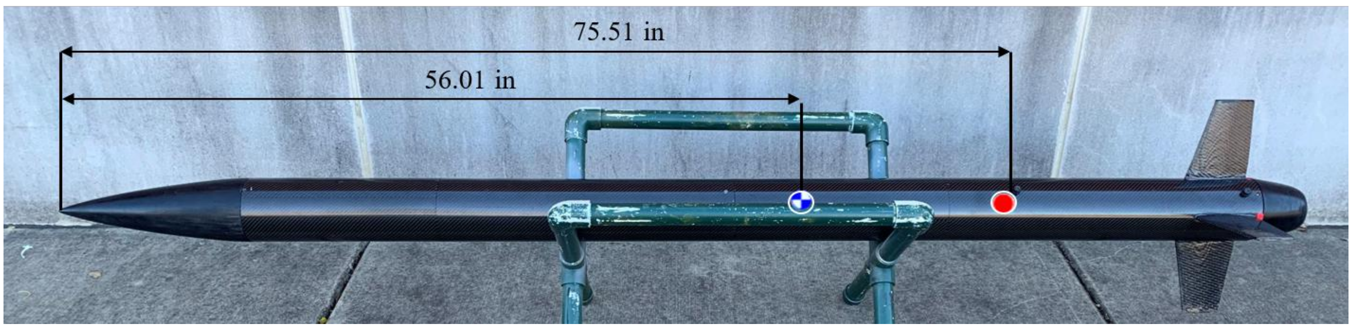


Figure 50: CP and CG After Burn

$$\text{Stability} = \frac{75.51 - 56.01}{5.13} = \boxed{3.83} \tag{13}$$

3.4.5 Parachute Descent Rates

The descent rates were calculated for each independent section under their respective parachutes. The terminal velocities were found by using Equation 14 with the section's mass, parachute's area, parachute's Cd, and the density of air.

$$\mathrm{V} = \sqrt{\frac{2 \cdot \mathrm{m}}{\mathrm{A} \cdot \rho \cdot \mathrm{C_d}}} \tag{14}$$

The post-burn weight of the booster section is 20.05 $\mathrm{lb_m}$ and the payload section's mass is 16.61 $\mathrm{lb_m}$. The masses of the independent sections are further discussed in Section 3.4.9. All the parachute's sizes and coefficient of drags were previously shown in Section 3.3.2. The descent velocities for the two independent sections under each of their parachutes are shown in Table 28.

Table 28: Parachute Descent Velocities

Parachute	Vehicle Section	Vehicle Section Mass	Parachute Area ($\mathrm{ft^2}$)	Parachute $\mathrm{C_d}$	Descent Velocity (ft/s)
29 ft Streamer	Payload Section	16.61	15.71	0.08	105.50
12.5 in. Drogue	Booster Section	20.05	0.83	1.5	116.39
72 in. Main	Payload Section	16.61	28.27	2.2	14.99
84 in. Main	Booster Section	20.05	38.48	2.2	14.11

As previous launches have shown, the descent velocities are lower than the values shown as these calculations do not supplement the drag caused by the vehicle airframes. With the C_d of the booster section's airframe supplemented, the section will not be in ANVIL's field of view for image capturing as it will descend slower than the payload section.

3.4.6 Kinetic Energy at Landing

For calculating the landing kinetic energies of the vehicle components, the terminal velocities of each independent section were substituted into Equation 15. The calculations for terminal velocities were shown previously in Table 28. The masses, terminal velocities, and kinetic energies of all the vehicle components that will impact the ground at landing are shown in Table 29.

$$\mathrm{KE} = \frac{1}{2}\mathrm{m} \cdot \mathrm{V}^2 \tag{15}$$

Table 29: Kinetic Energies of Vehicle Components

Parachute	Vehicle Component	Mass (lb_m)	Descent Velocity (ft/s)	Kinetic Energy (ft-lbf)
Under Streamer/Drogue	Nose Cone	3.00	105.97	523.12
	Payload Recovery Airframe	6.02	105.97	1,049.73
	Payload Airframe	8.98	105.97	1,565.87
	Booster Recovery Airframe	6.80	116.39	1,430.39
	Booster Propulsion Airframe	14.55	116.39	3,060.61
	ANVIL	5.00	105.97	871.87
Under Main Parachute	Nose Cone	3.00	14.99	10.47
	Payload Recovery Airframe	6.02	14.99	21.00
	Payload Airframe	8.98	14.99	31.33
	Booster Recovery Airframe	6.80	14.11	21.20
	Booster Propulsion Airframe	14.55	14.11	44.98
	ANVIL	5.00	14.99	17.45

The kinetic energies listed in the "Under Streamer/Drogue" section of the table are the impact force values if the main parachute does not deploy. The kinetic energies listed in the "Under Main Parachute" section are the values expected at the landing of a successful recovery with the main parachute deployed.

3.4.7 Descent Time

With the altitudes at which the parachutes will deploy and the descent velocities of the vehicle sections, Equation 16 was used to find the descent times. The descent velocities, the altitudes at which the parachutes are deployed, and descent times are shown in Table 30.

$$\mathrm{t} = \frac{\mathrm{H}}{\mathrm{V_d}} \tag{16}$$

Table 30: Descent Times For Launch Vehicle

Parachute	Vehicle Section	Descent Velocity (ft/s)	Altitude Deployed (ft)	Descent Time (s)
Streamer/Drogue	Payload Section	105.50	5318	44.75
	Booster Section	116.39	5350	40.03
Main	Payload Section	14.99	600	40.81
	Booster Section	14.11	600	42.51
			Total (Payload Section)	**84.78**
			Total (Booster Section)	**83.32**

The apogee value of 5350 ft used in the descent time calculation originates from the simulation shown previously in Table 22 under Section 3.4.2. The booster section's drogue parachute will deploy at apogee and descend for 44.75 seconds until the main parachute deploys at 600 ft. The booster section descends for another 42.51 seconds creating a total descent time of 83.32 seconds. Since the payload section's streamer will deploy one second after apogee, the parachute is released at 5318 ft and descends for 44.75 seconds to reach main parachute deployment at 600 ft. The payload section will take 40.81 seconds to descend from 600 ft which totals to 84.78 seconds for the entire descent time.

Table 31: Descent Time Calculation Comparison

Vehicle Section	Simulation (s)	Kinematic Equation (s)	Percent Difference
Payload Section	83.29	84.78	5.25%
Booster Section	87.99	83.32	5.45%

There is slight difference between the simulation and kinematic equation descent speeds. The high coefficient of drag from the booster section's airframe and fins influenced a longer descent time.

3.4.8 Drift Distance

For calculating the drift distances of the vehicle sections, the descent times used in the calculations were shown in Table 30. The wind speeds used were 5, 10, 15, and 20 mph. If wind speeds are greater than 20 mph at the launch site, the flying conditions will be deemed unsafe and the launch will be postponed. Table 32 shows the drift distances computed for the payload and booster section.

$$\mathrm{Drift} = \mathrm{V_{wind}} \cdot \mathrm{t} \tag{17}$$

Table 32: Launch Vehicle Drift Distances

Vehicle Section	5 (mph)	10 (mph)	15 (mph)	20 (mph)
Payload Section	623	1243	1865	2486
Booster Section	611	1833	1833	2444

3.4.9 Vehicle Mass Budget

A mass budget of the launch vehicle was generated. These masses were compared to the theoretical mass values to ensure mission performance predictions are accurate and adequate recovery equipment is used. The mass budget was divided into two sections: booster section and payload section. The overall masses for these sections, as well as the post-burn booster mass, are shown in Table 33 below.

Table 33: Launch Vehicle Section Weights

Vehicle Section	Theoretical Mass ($\mathrm{lb_m}$)	Actual Mass ($\mathrm{lb_m}$)	Percent Difference (%)
Payload Section	18.02	16.61	8.14
Booster (Loaded)	25.72	24.4	5.27
Booster (Burnout)	21.35	20.05	6.28
Total (Loaded)	**43.74**	**41.01**	**6.44**
Total (Burnout)	**39.37**	**36.66**	**7.13**

The payload section was divided into two subsections: payload recovery and payload. The payload recovery mass consists of all the hardware used to ensure a safe and successful recovery of the payload. The payload mass is the mass of ANVIL and all components that secure the payload in the rocket. Table 34 below shows the complete payload section mass breakdown. A more detailed breakdown of the payload mass is discussed in Section 4.7.2.

Table 34: Payload Section Mass Breakdown

Component	Theoretical Mass (lb_m)	Actual Mass (lb_m)	Percent Difference (%)
Payload Recovery			
Nose Cone	3.44	3.00	13.7
Recovery Body Tube	0.84	0.84	0.0
Streamer w/ Featherweight GPS	0.97	1.0	3.05
Quicklinks (4)	0.28	0.28	0.0
AV Bay	2.5	2.0	22.2
Payload Main Parachute (72 in.) + Nomex	0.84	0.59	35.0
Payload Main Shock Cord (20 ft.)	0.32	0.33	3.08
Payload			
Payload Body Tube	1.29	1.29	0.0
Coupler	1.02	1.02	0.0
Eyebolts 1.5 in. (3)	0.45	0.42	6.90
Bulkhead w/ 3/8 Chicago 23 eyebolts (x3)	0.7	0.59	17.05
ANVIL	5.5	5.25	4.65
Total	**18.02**	**16.61**	**8.14**

The booster section was broken down into two subsections: booster propulsion and booster recovery. The breakdown of these two subsections can be seen in Table 35 below.

Table 35: Booster Section Mass Breakdown

Component	Theoretical Mass (lb_m)	Actual Mass (lb_m)	Percent Difference (%)
Booster Recovery			
Booster Recovery Body Tube	0.94	0.94	0.0
Coupler	1.02	1.02	0.0
Drogue	0.11	0.11	0.0
Nomex - Booster Drogue	0.25	0.25	0.0
Quicklinks (3)	0.21	0.21	0.0
Drogue Shock Cord (10 ft)	0.16	0.16	0.0
Featherweight (w/ Casing/Hardware)	0.20	0.20	0.0
Booster Main Parachute (84 in.)	1.19	1.19	0.0
Booster Main Shock Cord (25 ft)	0.40	0.32	22.2
Nomex - Booster Main	0.46	0.46	0.0
AV Bay	2.5	1.86	29.4
Booster Propulsion			
Booster Propulsion Body Tube	1.39	1.39	0.0
Coupler	1.02	1.02	0.0
Bulkhead	0.25	0.21	17.4
Engine Block w/ Eyebolt	0.25	0.25	0.0
1515 Rail Button	0.01	0.01	0.0
Motor Tube (w/ Aeropack Motor Retainer)	0.78	0.78	0.0
RMS-75/380 Motor Casing	2.69	2.75	2.21
Aerotech L1390 - G	8.56	7.92	7.77
Fins w/ Carbon Fiber (CF)	1.35(no CF)	1.47	8.51
Fin Guide	0.26	0.17	41.9
Boattail (w/ Aeropack Motor Retainer)	0.67	0.67	0.0
Motor Tube Centering Rings (2)	0.53	0.29	58.5
Fin Guide Centering Rings (2)	0.25	0.23	8.33
Fin Block (w/ Hardware)	0.24	0.24	0.0
Quicklinks (4)	0.28	0.28	0.0
Total (Loaded)	**25.97**	**24.4**	**6.23**
Total (Burnout)	**21.35**	**20.05**	**6.28**

3.4.10 Recovery Deployment Forces

With a fast descent velocity under drogue, the vehicle components will endure a large force when their main parachutes deploy. The retention of the bulkheads may fail and cause the vehicle to free-fall if the force is too high. Since the drogue and streamer are deployed at apogee, the vehicle will not reach a high enough descent velocity to apply a large force to the components of the vehicle so the main parachute deployment force was only examined. By finding the drag force of the main parachutes during the descent of the vehicle under drogue, the accelerations applied to the vehicle components can be calculated. The descent velocities under drogue for the payload and booster section are shown in Table 36.

Table 36: Velocities Under Drogue

Payload Section	Booster Section
122.21 ft/s	120.12 ft/s

The system was modeled with a differential equation to calculate the force applied to the vehicle components when the main parachute opens. The equation used to represent the system is shown in Equation 18 with its variables listed in Table 37.

$$\mathrm{m} \cdot \ddot{\mathrm{x}} = \frac{1}{2} \cdot \rho \cdot \mathrm{C_d} \cdot \mathrm{A} \cdot \dot{\mathrm{x}}^2 - \mathrm{m} \cdot \mathrm{g} \tag{18}$$

Table 37: Recovery Deployment Acceleration Equation Variables

Variable	Definition
m	Section Mass ($\mathrm{lb_m}$)
$\ddot{x}$	Acceleration of the Section ($\mathrm{ft/s^2}$)
ρ	Air Density ($\mathrm{lb_m/ft^3}$)
$\mathrm{C_d}$	Main Parachute Coefficient of Drag
A	Area of Main Parachute ($\mathrm{ft^2}$)
$\dot{x}$	Terminal Velocity under Drogue (ft/s)
g	Acceleration due to Gravity ($\mathrm{ft/s^2}$)

The differential equation determines the acceleration of the vehicle section at each time step. After finding acceleration at a specific time, it is multiplied by the section's mass to find the deployment force. At 0 seconds, the acceleration of the payload section is 1,939 $\mathrm{ft/s^2}$. The acceleration from 0 to 0.1 seconds of the 72 in. parachute deployment on the payload section is shown in Figure 51.

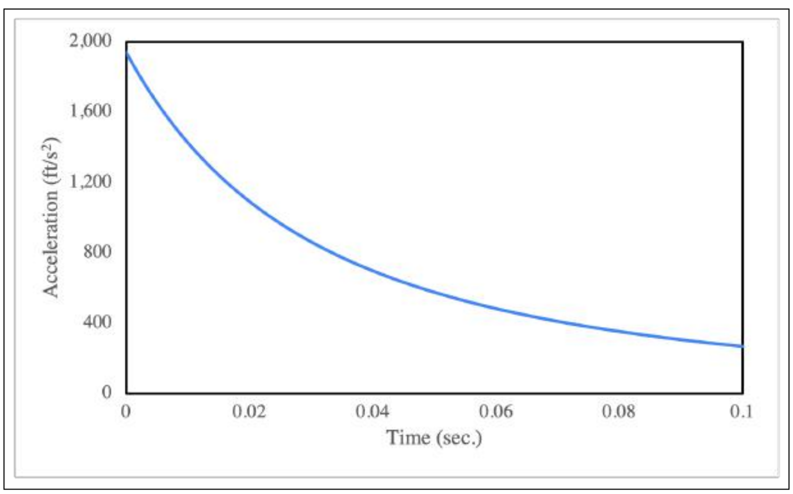


Figure 51: Payload Section Parachute Deployment Forces

The plot shows the acceleration of the payload section during the deployment of the 72 in. parachute from 0 to 0.1 seconds. At 0 seconds, the acceleration of the booster section is 2,157 $\mathrm{ft/s^2}$. The acceleration from 0 to 0.1 seconds of the 84 in. parachute deployment on the booster section is shown in Figure 52 below.

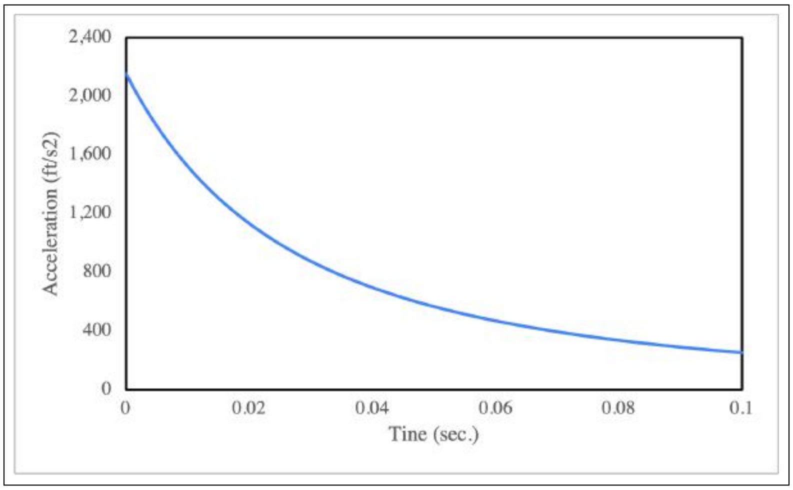


Figure 52: Booster Section Parachute Deployment Forces

The force applied to components inside vehicle were then found by dividing the mass of the components by gravity and multiplying the values by the acceleration of their corresponding vehicle section. Table 38 displays the force applied to components retained in the vehicle.

Table 38: Deployment Forces Exerted on Vehicle Components

Component	**Component Mass** (lb_m)	**Acceleration** (ft/s^2)	**Force** (lb_f)
Payload Altimeter Bay	2.00	1,939	150.54
Booster Altimeter Bay	2.00	2,157	167.47
ANVIL	5.00	1,939	331.20
Motor Assembly	8.56	2,157	573.15

4 Payload Criteria

4.1 Mission Statement

The 2021-2022 Payload Team's mission is to design, build, and test a system that will autonomously locate its landing position on the field without the use of GPS. The payload will then translate its landing position to the corresponding grid box on the satellite image of the launch field and wirelessly transmit that location to the base station.

4.2 Mission Success Criteria

In order for the mission to be viewed as successful, it must meet all payload and safety requirements outlined in the 2021-2022 NASA Student Launch Handbook, in addition to the team derived payload mission success criteria which are listed in Table 39 below.

Table 39: Team Derived Payload Mission Success Criteria

Criteria Code	Criteria
PMSC 1	The payload will maintain an accuracy of within 250 feet of its actual GPS verified landing location.
PMSC 2	The payload will be safely retained for the duration of the flight.
PMSC 3	The payload will be able to consistently work across various launch conditions and locations.
PMSC 4	The payload will determine a landing position within 30 minutes of touchdown.
PMSC 5	The payload will be able to be assembled and retained in the vehicle within 1 hour of reaching the launch site.
PMSC 6	The payload electrical systems will be able to operate for a minimum of 2.5 hours.

4.3 Payload Demonstration Flight

There have been two attempted payload demonstration flights so far. The first flight was attempted on 2/12/2022 in Dalzell, South Carolina, and the second on 2/26/2022 in Bayboro, North Carolina. Both of these flights are outlined in Sections 5.2 and 5.4. A third flight is planned for 3/12/2022 at the launch field in Dalzell, South Carolina. This flight is meant to prove ANVIL is able to be safely retained throughout the vehicle's flight and recovery, while still being recoverable and re-flyable.

4.4 Autonomous Vehicle Imaging Localization (ANVIL) Overview

The Autonomous Vehicle Imaging Localization (ANVIL) payload, seen below in Figure 53, is an image-based system in which a gimballed camera is used to take photos throughout recovery. A custom image processing algorithm is then used to compare paired images and isolate groups of similar pixels. Through these comparisons, an image of lower altitude can be found within an image of higher altitude, eventually deriving the landing location in a pre-selected satellite image of the launch site. ANVIL will then wirelessly transmit the landing location to the ground station.

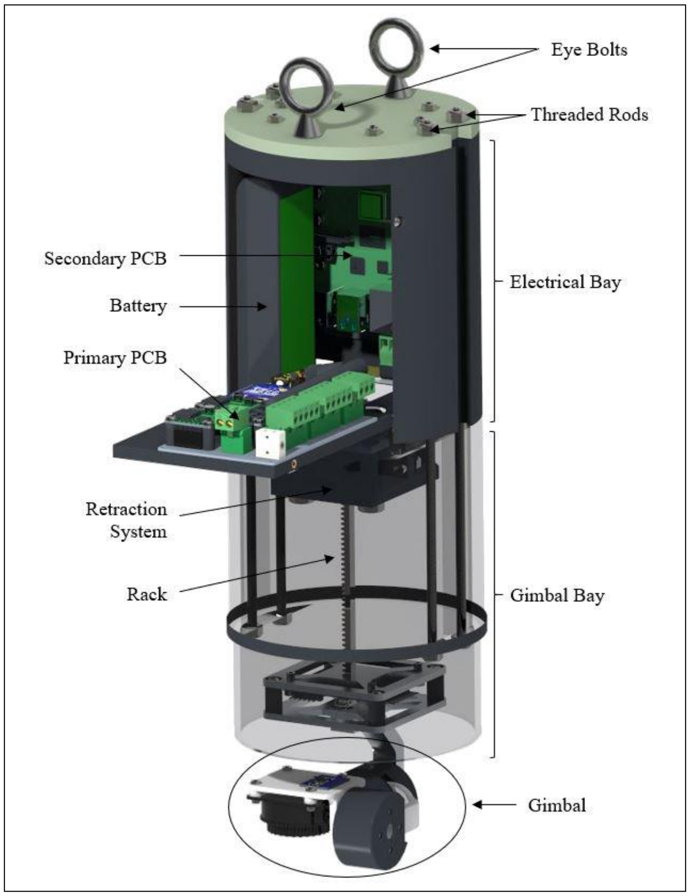


Figure 53: ANVIL Overview

ANVIL's components are enclosed within a housing unit that is suspended from the payload section of the launch vehicle during recovery. The payload hangs on two 4 ft shock cords in order to ensure the system remains lower than all other sections and has an unobstructed view of the ground. A retraction system is used to lower and raise the gimbal and camera, allowing for free range of motion, and reducing the probability of capturing sections of the housing structure within the photos. The gimbal will be retracted prior to landing to protect the camera from impact forces. The payload is retained on a rail system that is fixed to the inside of the vehicle airframe to prevent upwards translation and axial rotation as well as guide the payload out of the vehicle during separation. Additionally, the payload sits on a coupler in order to prevent downwards translation on the rail system before separation, and has a blast protection assembly to protect sensitive components within the payload from separation forces and debris.

4.5 Changes Made to Payload Since CDR

Table 40, seen below, displays the changes that have been made to ANVIL since the CDR, why they were incorporated and what section these changes are discussed in.

Table 40: Payload Changes Made Since CDR

Item	Changes Made	Reason for Change	Section
1	Changed ANVIL housing material from PETG to ABS.	Due to supply issues obtaining PETG in the quantity needed to produce the housing structure was not feasible.	Section 4.7.3
2	Housing connections changed to threaded rods.	Increase the structural integrity of the connection between ANVIL's electrical bay and gimbal bay.	Section 4.7.3
3	Select gimbal parts changed to machined aluminum.	Increase the structural integrity of parts under heightened stresses during launch and recovery.	Section 4.7.5
4	Stronger and smaller actuator for retraction system.	Increase the torque provided to the retraction system in order to account for increase of gimbal weight and allow for more space within the gimbal bay.	Section 4.7.6
5	Attachment method for retention rails changed from epoxy to screws.	Increase the rail's ability to withstand separation forces.	Section 4.7.4.1

4.6 Gridded Aerial Image

The gridded aerial image of the launch field, seen in Figure 54, is 5,000 x 5,000 ft and comprised of a high quality aerial image. Divided into a total of 400 grid squares, these grid boxes are 250 x 250 ft, square in shape and equal in size. Each grid square is given an integer in increasing order from left to right, and top to bottom. Additionally, this gridded aerial image has the location of the launch rail depicted at the the center of the photo. This image will be used to compare the photos taken throughout recovery and determine the grid box in which the payload has landed.

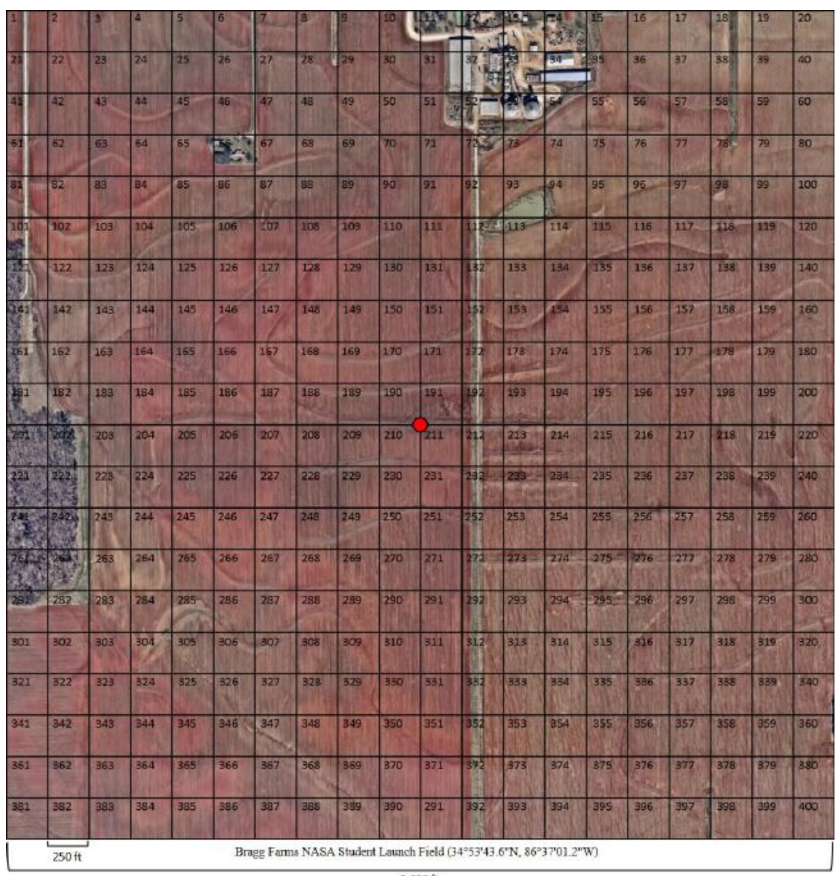


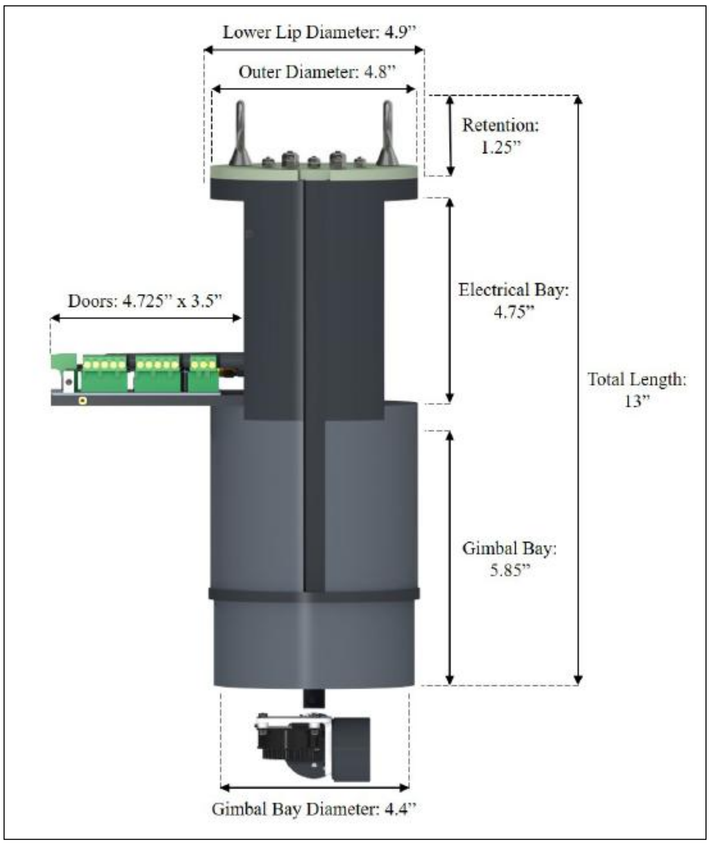
Figure 54: Gridded Aerial Image

4.7 ANVIL Mechanical Overview

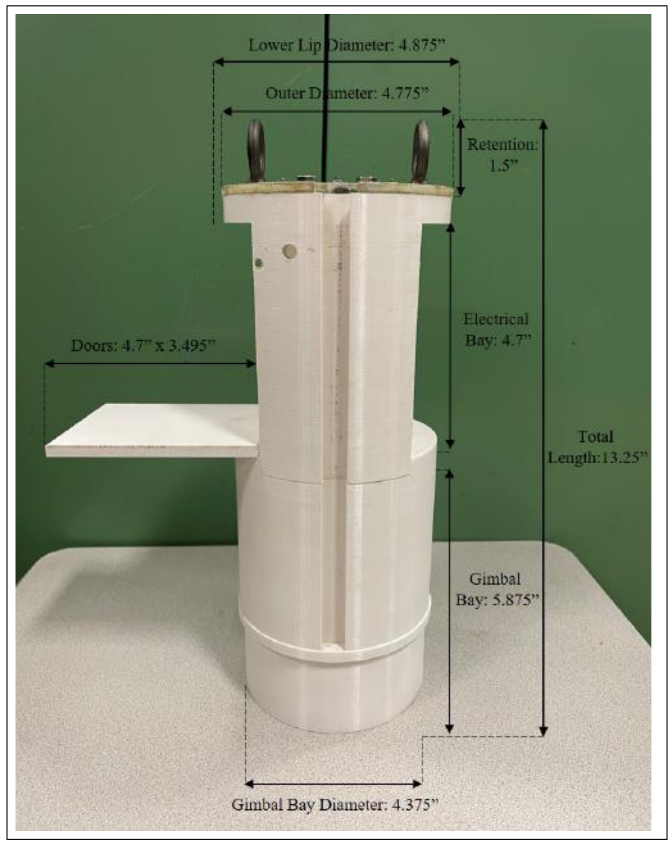
The mechanical overview section covers the purpose of each mechanical component along with the changes made to the design since the CDR. These mechanical aspects include ANVIL's overall dimensions, the mass budget, the housing structure, the retention system, including the rails and fiberglass plate, the gimbal, the gimbal retraction system, and blast protection.

4.7.1 Dimensions

ANVIL's housing structure has a total length of 11.75 in. that is divided into two major sections, including the gimbal bay and the electrical bay. The gimbal bay, housing the gimbal and retraction system, offers 5.85 in. of usable length and an inner diameter of 4.4 in. The electrical bay, housing all of the payload's electronics, has a usable length of 4.75 in. with a width of 3.53 in. The electrical bay doors, offering mounting locations for both PCBs, each allot a surface area of 4.725 in. in length and 3.5 in. in width. The overall ANVIL structure has an outer diameter of 4.8 in. and a lower lip diameter 4.9 in., which is used for retention during flight. These dimensions were chosen to accommodate the space needed for the components located within each section. Including the eyebolts located at the top of the housing structure and the two shock cords necessary for retention, ANVIL takes up a total length of 13 in. within the launch vehicle. A dimensioned model of ANVIL is shown in Figure 55a with true dimensions shown in Figure 55b.



(a) Dimensioned 3D Model of ANVIL



(b) Dimensioned Constructed ANVIL

Figure 55: ANVIL Housing Structure and Fastening

4.7.2 Mass Budget

The mass budget of ANVIL is shown below in Table 41. All the values listed in this table have been measured using a scale in order to obtain the true mass of each component.

Table 41: ANVIL Component List and Mass Budget

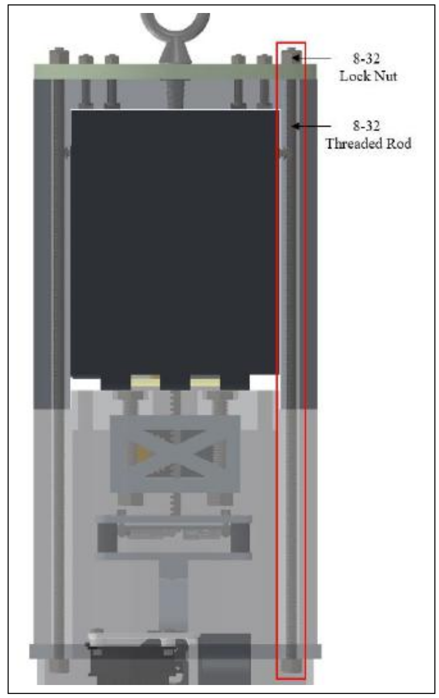
Component	Quantity	Mass (lbs)	Total Mass (lbs)
PCB 1	1	0.33	0.33
PCB 2	1	0.24	0.24
3000 mAh LiPo Battery	1	0.42	0.42
Door 1	1	0.18	0.18
Door 2	1	0.16	0.16
Gimbal and Retraction	1	1.00	1.00
Gimbal Bay	1	1.06	1.06
Electronic Bay	1	1.05	1.05
Threaded Rods	4	0.05	0.21
Blast Protection	1	0.26	0.26
Shock Cords and Carabiners	2	0.17	0.34
		Net Total	5.25

With a final mass of 5.25 lbs, ANVIL comes in at 0.30 lbs under the previously predicted mass of 5.55 lbs. This gives a 5.71 percent error. This error is largely caused by a reduction in the size of the servo motor being used as well as the addition of wiring holes and a recess for the retraction system. These additions have reduced the overall mass of the housing structure.

4.7.3 Housing Structure

The housing structure, seen in Figure 56a, offers mounting locations and protection to all payload components. This structure is composed of two major sections, which are the electrical bay and the gimbal bay. The two sections are printed independently from one another and are later fastened together during the assembly process. The original design of this housing structure was planned to be 3D printed from PETG and fastened together using four $\frac{1}{4}$-20 bolts and heat set inserts secured into the side of the payload. Due to the heightened strength of PETG, this method of fastening was found to be adequate during FEA simulations. Supply chain setbacks, however, caused issues when attempting to acquire PETG filament in the quantity needed. Due to the supply shortages, the housing structure had to be printed from ABS which is weaker than PETG and raised concerns in relation to stresses the fasteners may exert onto the housing structure during portions of flight. In order to alleviate these concerns, the $\frac{1}{4}$-20 bolts were replaced with four, 10-inch-long 8-32 threaded rods, secured at the top of the payload with locking 8-32 nuts. These rods run through the length of the payload's walls, and are capped off within the gimbal bay with more 8-32 locking nuts. This method of fastening results in the ABS being subjected to compression, rather than tension. 3D printed filament is much stronger during compression as the filament layers are pressed together rather than pulled apart. Additionally, in order for this method of fastening to fail, the 8-32 nuts must be stripped from the threaded rod. This method of fastening the housing together can be seen in Figure 56b.

(a) ANVIL Housing Structure



(b) Fastening with Threaded Rod

Figure 56: ANVIL Housing Structure and Fastening

Calculations for the stresses these fasteners and the eye bolts would endure during flight were carried out in order to ensure retention. Through this process, it was found that this method of fastening is capable of withstanding 5,297 lbf before failure. The highest stress the payload experiences is approximately 968 lbf during main deployment, giving the eyebolts and payload fasteners a safety factor of 5.47.

4.7.4 Retention

Two T-track style rails were fastened and epoxied inside the payload section of the launch vehicle. ANVIL will remain retained to the vehicle on these rails. The rails have to restrict all motion of the payload housing until deployment at apogee. In order to accomplish this, the lower section of the payload housing has a lip that rests on top of the coupler once it is assembled. This lip has a 4.9 in. diameter, and the coupler has a 4.75 in. inner diameter. These dimensions physically restrain the payload housing from downward vertical translation. The top of the rail that is screwed into the vehicle is also blocked off. This stop is designed to be printed as a part of the rail. The stop physically blocks the payload section from moving upward on the rail for any reason. The coupler is permanently attached to the booster section of the vehicle, so it will be removed from the payload section during separation at apogee. Upon this separation, the payload housing freely falls down the rail and exits the vehicle while being help by the shock cord. The shock cord, being 4 ft in length, is long enough for the payload housing to hang below the body tube. Figure 57 shows where the payload housing is blocked by the rail. With both the coupler and rail secured within the vehicle, ANVIL is properly retained throughout the flight until deployment at apogee.

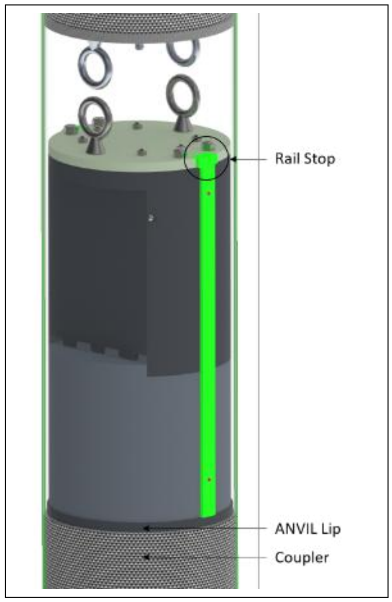


Figure 57: ANVIL Housing Retention

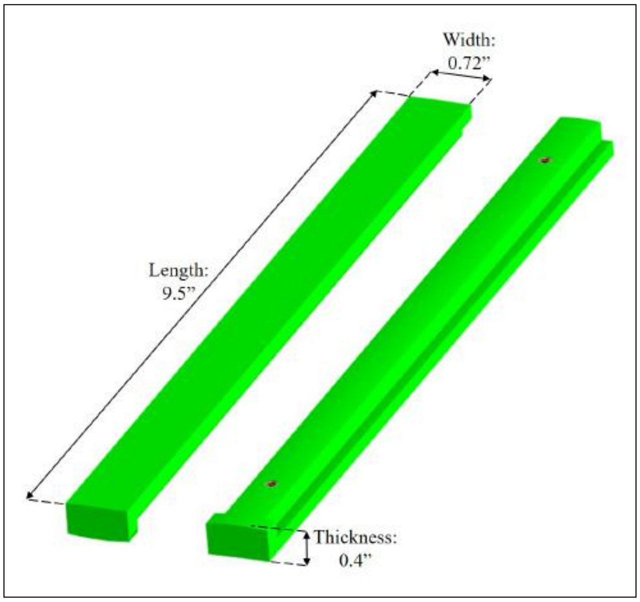
Because the largest forces experienced by ANVIL are on the lid where the eyebolts connect, a fiberglass plate was fixed onto the top of the housing on ANVIL. Two 4 ft segments of shock cord are used to retain ANVIL post deployment. The shock cord is 1/4 in. thick and made out from Kevlar. The cords are rated for 2,200 lbs and are tethered to one in. quick links with a overhand knot. The quick links are attached to the eye bolts. The shock cord connects the eye bolts on ANVIL to the eye bolts that are epoxied onto a fixed carbon fiber bulkhead located 3.25 in. above ANVIL before deployment. There is enough room in this space to hold the two shock cords and quick links. Figure 58 shows ANVIL when it is fully extended upon separation while attached to the constructed payload section.

Figure 58: ANVIL Fully Extended on Shock Cords

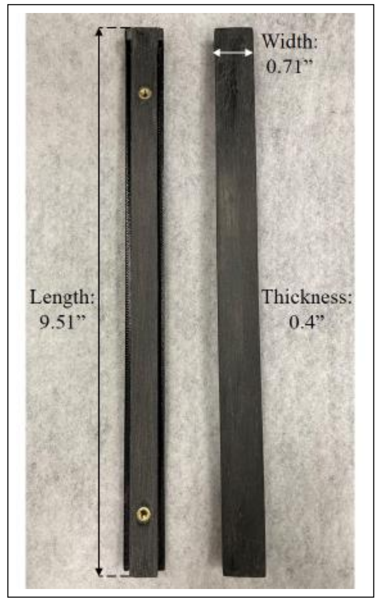
In order to ensure the eye bolts are not ripped off ANVIL during the deployment process, an FEA analysis was performed on ANVIL as outlined in the test plan on Section 7.2.3. This confirms that ANVIL will safely remain connected to the rest of the vehicle during recovery. ANVIL was successfully retained during both test flights on 2/12 and 2/26. Further information regarding these flights are found in Sections 5.2 and 5.4.

4.7.4.1 Rails

The rails used inside the payload section that houses ANVIL were printed out of PETG instead of ABS for its superior impact strength. The rails were printed .01 in. smaller in all directions in order to allow ANVIL to slide smoothly on the rails. Both rails were secured inside the vehicle for use in retaining ANVIL during flight. The process of installing these rails inside the vehicle is outlined in Section 4.8.5. Figure 59a shows the 3D CAD model for the rails, and Figure 59b shows the constructed rails.



(a) 3D CAD Model Of Rails



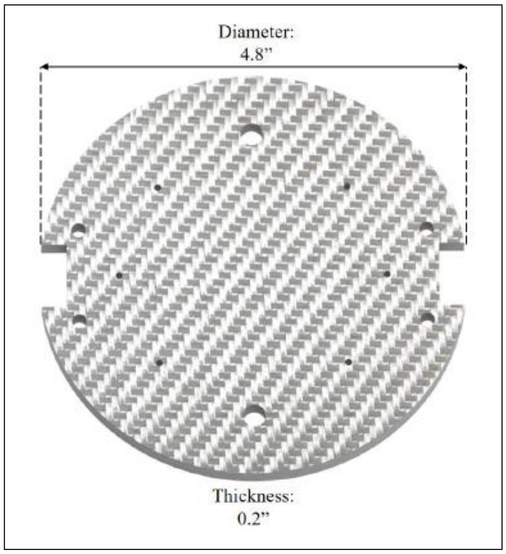
(b) Constructed Rails

Figure 59: Rail Design and Construction

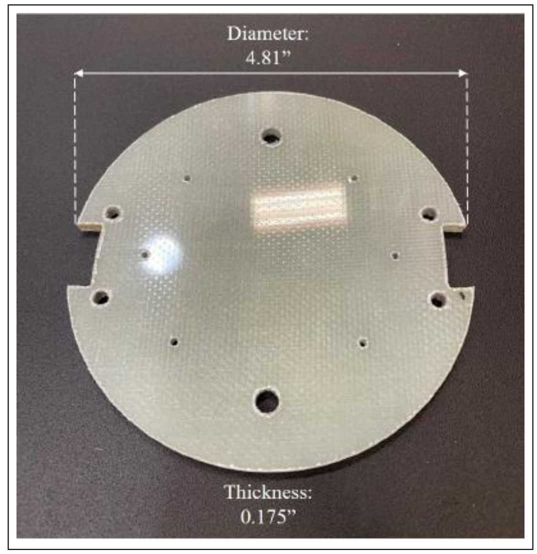
The length of these rails changed to 9.75 in. due to the changes made to ANVIL's housing structure. Originally, the airframe was prepped with sandpaper and alcohol, and the rails were epoxied into place. This proved to be a point of failure in the February 12th test launch. Upon inspection after the launch, the rails were snapped off due to the forces of separation. To prevent this, they are now bolted into the airframe using two 4-40 screws and heat set inserts for each rail. These heat set inserts are located in the center laterally and an inch away from the ends of the rails longitudinally.

4.7.4.2 Fiberglass Plate

The fiberglass plate is used to provided additional structural support to the eye bolts that are fastened into the housing structure and tether the payload to the launch vehicle. A 3D model of the fiberglass plate can be seen in Figure 60a, and the fully constructed plate in Figure 60b.



(a) 3D CAD Model Of Fiberglass Plate



(b) Constructed Fiberglass Plate

Figure 60: Fiberglass Plate Used On Top Of Anvil

This plate is secured to the top of the electrical bay by six 1 in. long 4-40 bolts. The presence of this plate prevents the threaded metal inserts that restrict the eye bolts from being ripped out. Fiberglass was the selected material for this application because it provided the strength necessary to provide confidence that ANVIL could safely deploy while also not interfering with radio frequencies that would be used to transmit the final grid box location. Figure 147b shows how the fiberglass plate and eye bolts are fastened to ANVIL's housing.

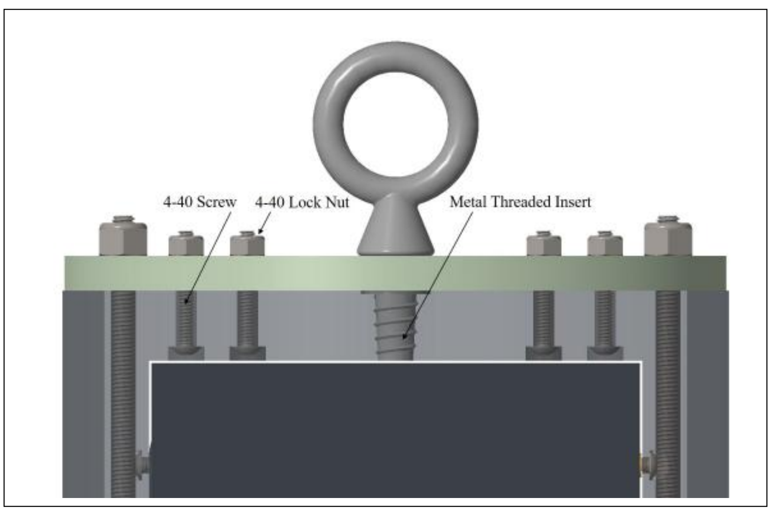


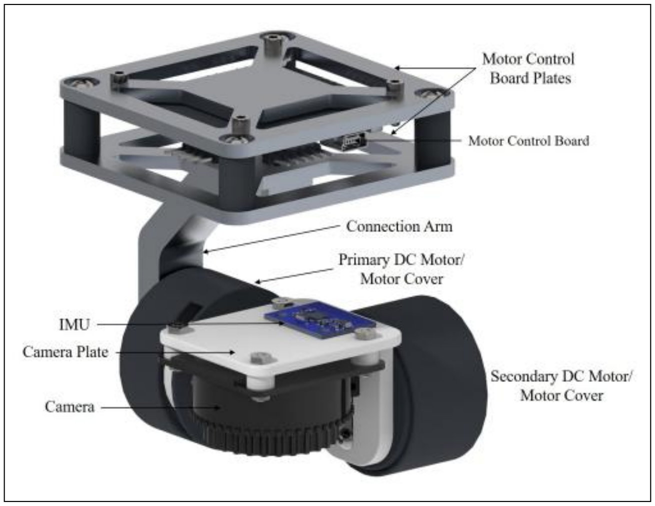
Figure 61: Fastening the Fiberglass Plate and Eye Bolts to ANVIL Housing

Threaded metal inserts are used to screw the eye bolts into the payload housing instead of heat set inserts because of their increased resistance to loads normal to the surface. In addition to the normal threads, the selected metal threaded inserts have a small lip on the top of them. This lip is positioned above the 3D printed housing, but below the fiberglass plate. This lip makes it even less likely for the eye bolts to come out during recovery because the lip would have to push through the fiberglass plate in addition to ripping out of the 3D printed components.

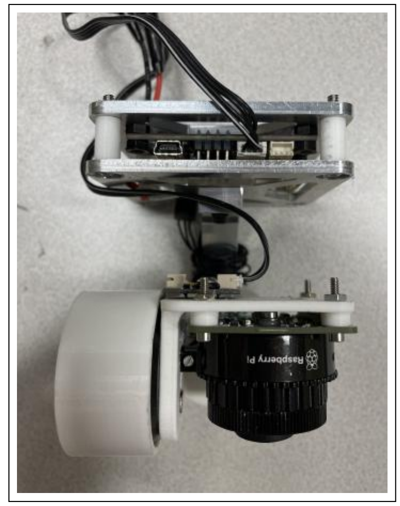
4.7.5 Gimbal

At apogee ANVIL will deploy from the launch vehicle and be suspended from two parallel shock cords. Due to winds and the momentum produced during deployment, a pendulum effect is likely to occur during recovery. The gimbal's purpose is to counter these movements, allowing the camera to capture clear images that are perpendicular to the ground. It is important to maintain these qualities within each image as it improves ANVIL's ability to accurately derive the landing location.

A CAD model of the gimbal is shown in Figure 62a, and the actual constructed gimbal is shown in Figure 62b. This gimbal is manufactured from both 3D printed parts as well as machined aluminum. Aluminum was used for heightened strength while still maintaining a lightweight design. Both the gimbal connection arm and the two plates that secure the motor control board and the gimbal retraction system are machined from aluminum. The material of these parts was changed due to the issues observed in the first payload flight. The issues observed in the first payload flight are further explained in Section 5.2. The DC motor connection arm as well as the camera mount will be 3D printed in order to maintain a lightweight design. It is important that these parts are lightweight because both are driven by the DC motors. Heavy components within these locations can cause imbalances in the system or result in the motors being incapable of effectively countering the payload's motion. Additionally, these parts are not subjected to significant levels of stress and therefore do not need the extra strength of metal.



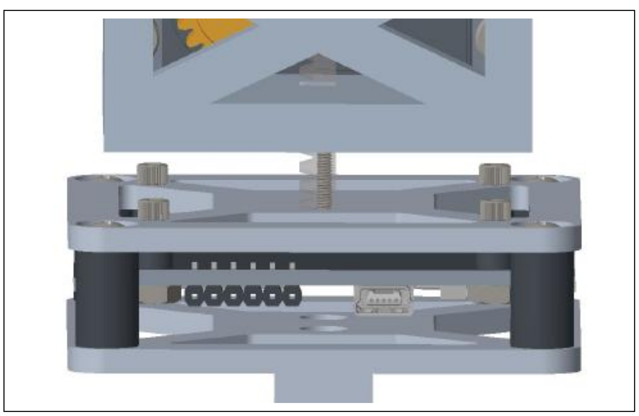
(a) 3D CAD Model Of Gimbal



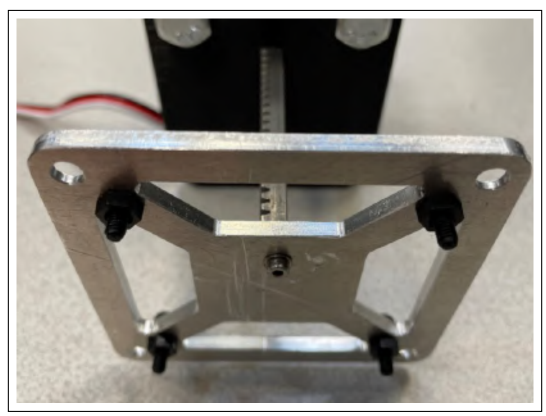
(b) Constructed Gimbal

Figure 62: Gimballed Camera System

This gimbal system is attached to the rack of the retraction system with a M2.5 screw fastened through the top motor control plate. The threads of this screw are then reinforced and locked in place by high strength adhesive. This method of fastening can be seen below in Figures 63a and 63b.



(a) Gimbal Secured to Retraction System



(b) Constructed Gimbal Attached to Rack

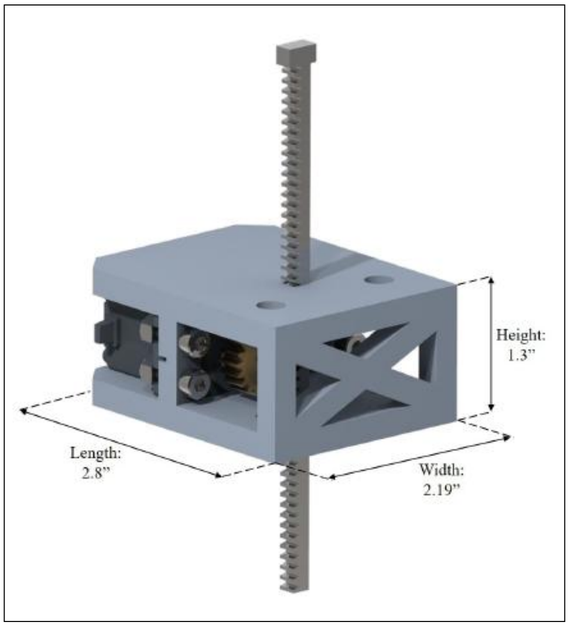
Figure 63: Constructed Gimbal Secured to Retraction System

The construction and assembly process of the gimbal is thoroughly explained in Section 4.8.3.

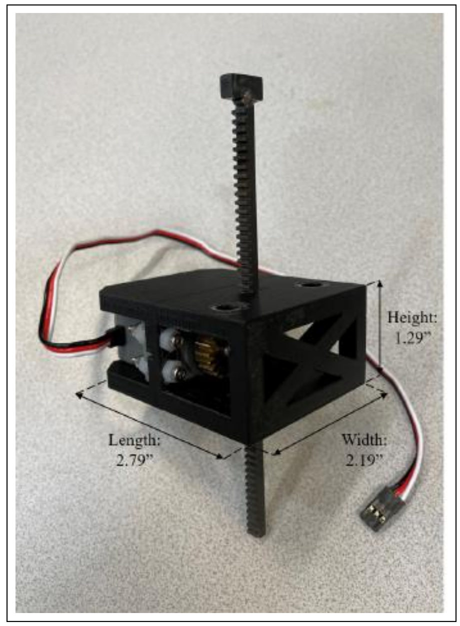
4.7.6 Retraction System

An unobstructed view and free range of motion are two critical design requirements of the payload. Unobstructed views reduce the likelihood of incorrect matches within the image processing algorithm, while a free range of motion ensures the gimbal is capable of countering the majority of movement the payload may experience during descent. In order to achieve both of these requirements, the gimbal and camera must be located beneath all parts of the housing structure during descent. If this system were to remain outside the housing structure during landing, the gimbal or camera may break on impact.

In order to protect the gimbal and camera from this impact while still fulfilling these requirements, a rack and pinion was designed to both lower the system outside the payload housing and retract it before landing. Slight alterations to the retraction system's design have been made in order to account for material changes of some gimbal parts. Due to the fact that some parts on the gimbal are now machined from aluminum, the gimbal is heavier than before, weighting approximately 0.55 lbs. The additional weight requires a stronger motor to accomplish the same goal with similar safety factors. In order to account for this additional weight, a 2000 series, 5 turn servo motor is now used, exerting a torque of 17.2 kg-cm. In addition to the increased torque, this servo motor is also smaller than the previous. The smaller servo reduces the size of the the retraction system, therefore offering the gimbal system more space within the gimbal bay and relieving the spacing concerns expressed in Section 4.7.3. Images of the 3D modeled retraction system and the constructed retraction system can be viewed below in Figures 64a and 64b.



(a) 3D CAD Model Of The Retraction System



(b) Constructed Retraction System

Figure 64: Design and Construction of Retraction System

This retraction system is attached to the housing structure with two 4-40 screws and lock nuts as seen in Figure 65.

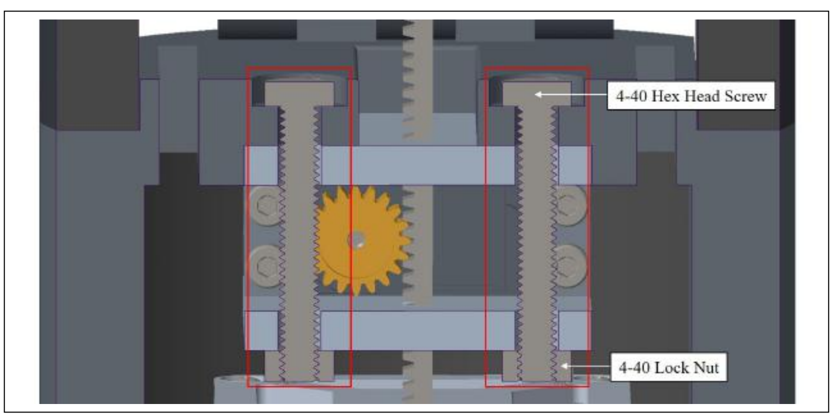
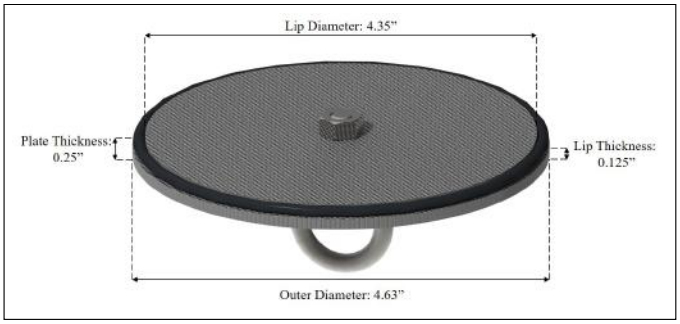


Figure 65: Retraction System Secured to Housing Structure

The construction and assembly process of the retraction system is thoroughly explained in Section 4.8.2.

4.7.7 Blast Protection

To protect vital components that are housed within the payload's gimbal bay, a removable bulkhead assembly was used. This assembly consists of a carbon fiber plate with a machined groove around the edge that an O-ring is permanently epoxied to. This assembly is attached to the booster drogue shock cord, so as to avoid hanging below the payload and interfering with the image processing algorithm. The O-ring is essential as it creates a seal, which helps mitigate the potential accumulation of black powder residue on the camera lens. The CAD dimensions of the of the blast protection plate are shown in Figure 66a. The measured dimensions of the blast plate are shown in Figure 66b.



(a) 3D CAD Blast Protection Plate

(b) Constructed Blast Protection

Figure 66: Design and Construction of Retraction System

The carbon fiber plate was machined down to create space for the O-ring. The selected O-ring has a 4.25 in. inner diameter and is 0.125 in. thick. The O-ring is slightly smaller than the lip diameter in order to ensure a tight fit prior to fixing the O-ring with epoxy.

To keep the bulkhead pressed tightly against the payload housing, three wedges were epoxied into the coupler that connects the booster and payload sections. The wedges have a rounded face that is flush with the coupler to allow maximum surface area for epoxy. A wedge shape was chosen to minimize the chance of the drogue parachute getting caught. As a result, the three wedge shapes creates a funnel that guides the drogue out of the vehicle during deployment. The carbon fiber plate is able to rest on top of these wedges which increases ease of assembly and ensures that the removable plate will consistently form a seal at the bottom of the payload. These wedges allow the blast protection to be retained during rocket assembly, and prevent the plate from shifting further into the coupler during the launch. The wedges will also help to protect against the plate from getting friction locked inside the coupler and preventing the drogue from deploying.

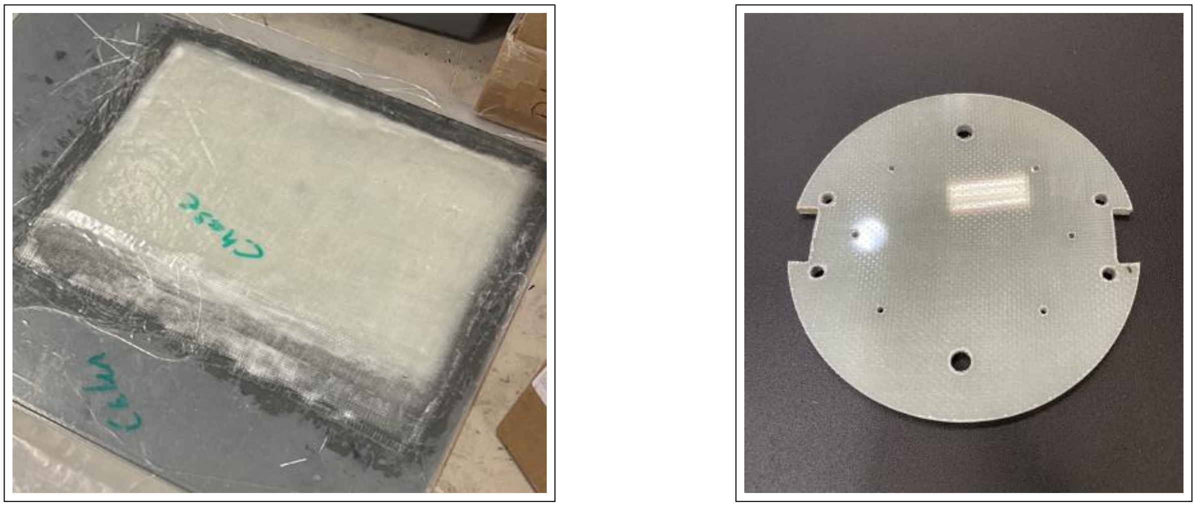
The wedges were 3D printed from ABS because of the unique geometry required to maintain a flush connection with the inside of the launch vehicle. More information on ABS filament and its qualities can be found in Section 3.2.8.1. Section 4.8.4 shows the construction process of installing these wedges into the vehicle along with the creation of the carbon fiber blast protection plate.

4.8 Mechanical Construction Process

This section serves the purpose of outlining the construction process of each mechanical component. These components include the fiberglass plate, blast protection, retraction system, gimbal, and rails.

4.8.1 Fiberglass Plate Construction

The pane of fiberglass, from which the plate was later cut from, was formed using the same basic process found in Section 3.2.7.2. Instead of 10 layers, like was used for the carbon fiber, 23 layers of fiberglass were used because the fabric was thinner. In Figure 67a, an image of the fiberglass pane curing can be seen.



(a) Sheet of Fiberglass Used For Creating The Fiberglass Plate

(b) CNC Fiberglass Plate

Figure 67: Design and Construction of Retraction System

After allowing the pane of fiberglass to harden, it was taken to the on-campus machine shop where it was fabricated using a CNC. The plate, after being cut with the CNC machine, can be seen in Figure 67b. The CNC machine allowed for excellent dimensional accuracy, while limiting manufacturing time. The fiberglass plate mounted to ANVIL can be seen in Figure 68.

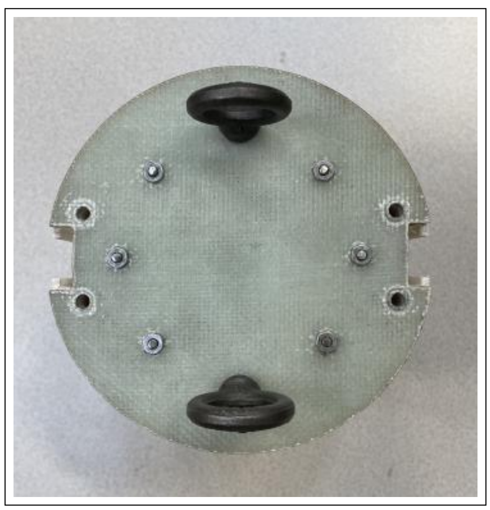


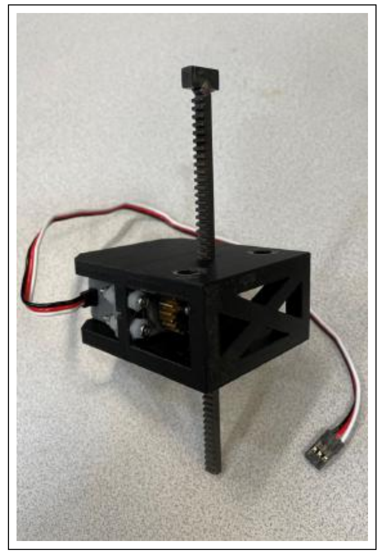
Figure 68: Fiberglass Plate Secured to ANVIL

The fiberglass plate was attached to the main ANVIL housing with six 4-40 bolts and nuts. The fiberglass plate was not permanently secured to the payload housing because if either the plate or the housing were to be damaged then both parts would have to be reconstructed.

4.8.2 Retraction System Construction

The retraction system is comprised of a 2000 series, 5-turn servo motor, a 5.5 in. rack, and a 3D printed rack guide. The rack was purchased from an online source in a single 2 ft long part. As a result, a 5.5 in. segment was measured with calipers and cut off using a horizontal band saw. Once cut, a hole was drilled in one end to a depth of 0.25 in. using a #54 drill bit. Threads were then created in this hole using a M2.5 tap. On the other end of the rack, a 0.375 x 0.1875 x 0.25 in. steel stop was bead welded to the rack. The stop, used to ensure retention even if the servo were to fail, was measured with calipers and cut using a horizontal band saw. The finished rail can be observed in Figure 69a, seen below.

(a) Constructed Rack



(b) Constructed Retraction System

Figure 69: Retraction System Construction

The rack guide is 3D printed from PLA front face down, using break away supports. Once the part had finished printing, the supports were broken off and any imperfections were sanded away. After the part's surface finish was improved, the rack was slid into the rack guide and the servo motor was inserted into the two supporting plates. Once in place, the servo motor was secured using four 4-40 screws, four plastic washers, and four 4-40 lock nuts. The finished retraction system can be viewed above in Figure 69b.

4.8.3 Gimbal Construction

The gimbal was manufactured with a combination of aluminum and 3D printed parts, as explained in Section 4.7.5. The 3D printed parts, including the motor connection arm, motor covers and the camera plate, were 3D printed from PLA on an Ender 3 Pro. The finalized 3D prints can be seen below in Figure 70.

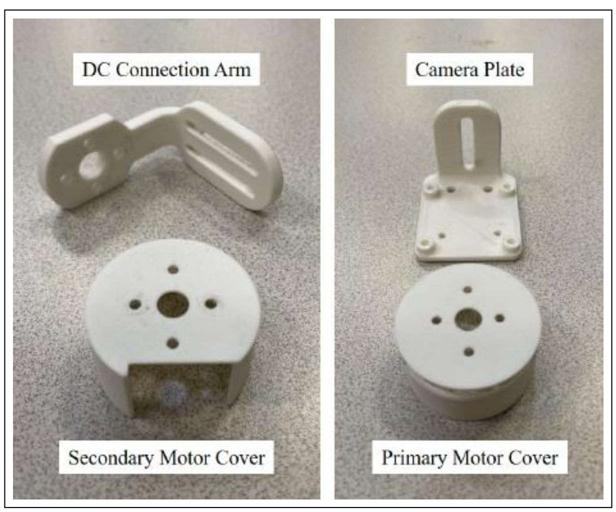
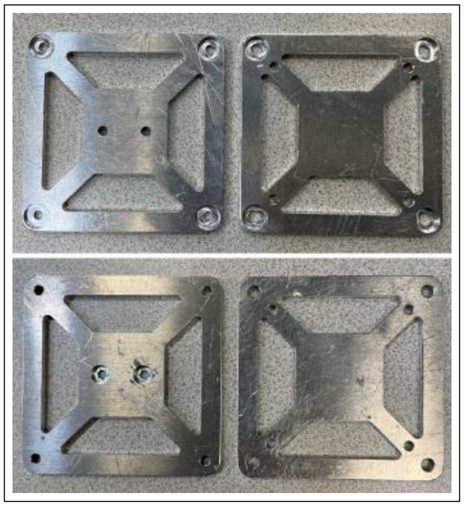


Figure 70: 3D Printed Parts of the Gimbal

Other parts of this gimbal, including the two control board plates and the connection arm, are machined from aluminum for greater stress resistance. Using a 3/4 in. aluminum slab and a 1/8 in. aluminum sheet, both these parts were manufactured on-campus using a Computerized Numerical Control (CNC) machine. The finished parts can be found below in Figures 71a and 71b.

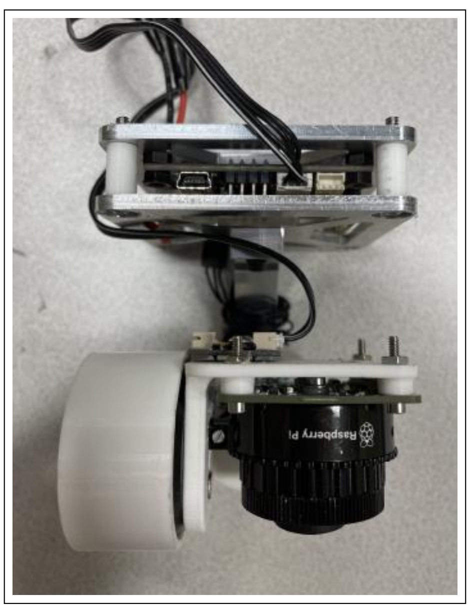


(a) Top Control Board Plates

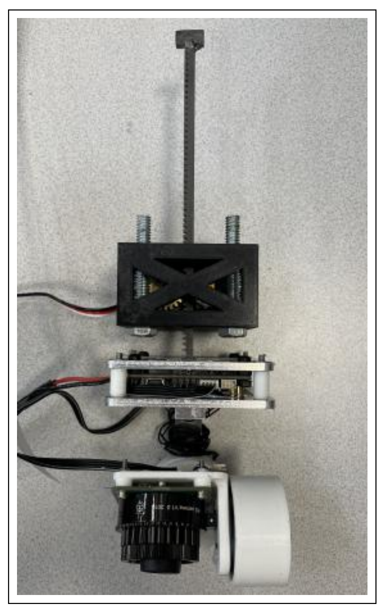
(b) Connection Arm

Figure 71: Machined Parts Of The Gimbal

Once all these parts were manufactured, the motor control board was fastened to the top mounting plate using four 4-40 plastic nuts and two 4-40 plastic screws. These plastic fasteners were used create space between the two metal plates and the control board as well as to prevent shorting the board. The connection arm was then fastened to the bottom mounting plate and the two plates were secured together with four 1/2 in. plastic spacers and 4-40 screws and nuts. The primary brushless DC motor was then attached to this connection arm along with its correlating motor cover. The motor connection arm was then fastened to the primary DC motor. The secondary DC motor and motor cover were then attached to the other end of this arm. Once securely fastened, the camera plate was then attached to the secondary DC motor. The IMU and camera were then connected to this camera plate with six M2.5 screws and nuts. The IMU is mounted at the center of both actuators, ensuring smooth and accurate movement. Once everything was connected, the motor control board was programmed for the particular IMU and motors being used. The fully constructed gimbal can be viewed in Figure 72a, and in Figure 72b, once attached to the retraction system.



(a) Constructed Gimbal



(b) Gimbal Secured to Retraction System

Figure 72: Gimbal And Retraction System Construction

4.8.4 Blast Protection Construction

The carbon fiber blast protection plate was cut from a larger sheet with an abrasive water jet cutter. This process is outlined in Section 3.2.7.2. Once the initial plate was created, it was sent to a CNC machine in the on campus machine shop to create the groove that fits the O-ring. The O-ring was epoxied in place with an aerospace grade epoxy to make sure it will not come loose at any point during the launch. The constructed blast protection plate can be viewed in Figure 4.8.4.

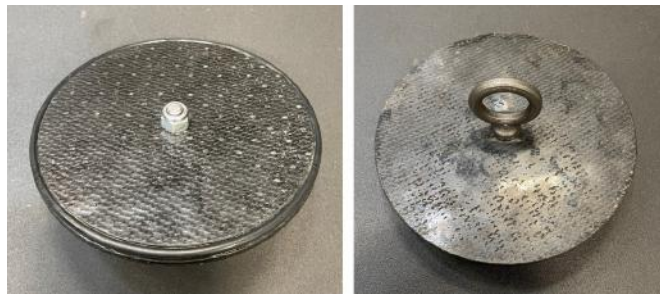


Figure 73: Constructed Blast Protection

The wedges were epoxied 120 degrees apart with the flat contact surface level to the ground and aligned to each other so the plate will sit on top of them. The location of each wedge was marked on the airframe, and a single wedge was epoxied at a time. Prior to epoxying, the surface was thoroughly sanded and prepped with alcohol. The airframe was placed horizontally with the wedge on the lower side so that it would not shift while the epoxy cured. Each wedge was installed 24 hours from the previous to allow enough time for the epoxy to cure. The top of the wedges sit 2.25 in. below the top of the airframe section. Figure 74 shows this airframe section after the wedges have been installed.

Figure 74: Wedges Installed Inside of Launch Vehicle

The full blast protection setup with the installed wedges and blast plate was also used during the team's separation test. This proved the system is capable of protecting the gimbal and camera from the forces of separation, as well as from black powder residue that could interfere with the operation of the payload. This test and its results are found in Section 7.1.10.

4.8.5 Rail Installation

The rails are installed inside the launch vehicle 180 degrees apart, and are aligned with each other. In order to ensure the rails are installed correctly, holes had to be drilled in the correct location that align with the heat set inserts on the rails. The location of these holes are important because it determines the orientation of ANVIL inside the vehicle. The location of the FingerTech hole that is used to turn on ANVIL's electronics depend on this orientation. The location of the rail holes were found by aligning ANVIL with the pre-existing FingerTech hole within the airframe. Using measurements taken of ANVIL and its rails, the location of the heat set inserts were marked on the outside of the vehicle. ANVIL was then taken out and 1/4 in. holes were drilled. The rails were inserted into location to ensure proper placement, and fastened with 4-40 button head screws. ANVIL was inserted onto the rails afterwards and confirmed to slide freely. A picture of the rails mounted inside the vehicle is shown in Figure 75 below.

Figure 75: Rails Mounted Inside Airframe

To test the rails, ANVIL, along with its blast protection, was fully assembled and placed onto the rails for the separation test of the vehicle. The rails did were not damaged or shifted after the test, which proves that it is able to withstand the forces involved in separation. More information about this test is found in Section 7.1.10.

4.9 ANVIL Electrical Overview

The electrical overview section covers each electrical component, the purpose of the component, any changes implemented within the design, and why those changes were made. These electrical aspects include the electrical design, PCBs, power budget, and transmission.

4.9.1 Electrical Design

A high level diagram for the electrical system of ANVIL is shown in Figure 76. The system design is divided into five main sections: Power, Power Distribution, Power Management, Image Processing, and Transmission. The legend in the top right shows the color that corresponds to the type of connections. The red boxes represent power and power distribution. A 11.1V, 3000 mAh, three-cell, LiPo battery will be used to power all electrical components when the payload is turned on using the FingerTech switch. When powered on, the voltage from the battery will go through two Pololu D36V50F5 5V Step-Down Voltage Regulators and a Pololu Mini LV MOSFET. The first regulator will power the Trinket M0. This microcontroller will indicate the payload has been powered on with the buzzer and read the analog values from an ADXL326 accelerometer. When the acceleration from launch is detected, the Trinket M0 will enable the second voltage regulator to power the Raspberry Pi. The Raspberry Pi will be connected to the Raspberry Pi HQ camera, BMP280 pressure sensor, 2000 Series 5-Turn Dual Mode servo motor, gimbal MOSFET, and Xbee-PRO XSC S3B transceiver. When the Raspberry Pi is powered on, it will enable the MOSFET to power the gimbal. Once the Raspberry Pi has determined its grid location after flight, it will activate the Xbee transceiver out of sleep mode and, using the antenna, transmit the location back to ground station.

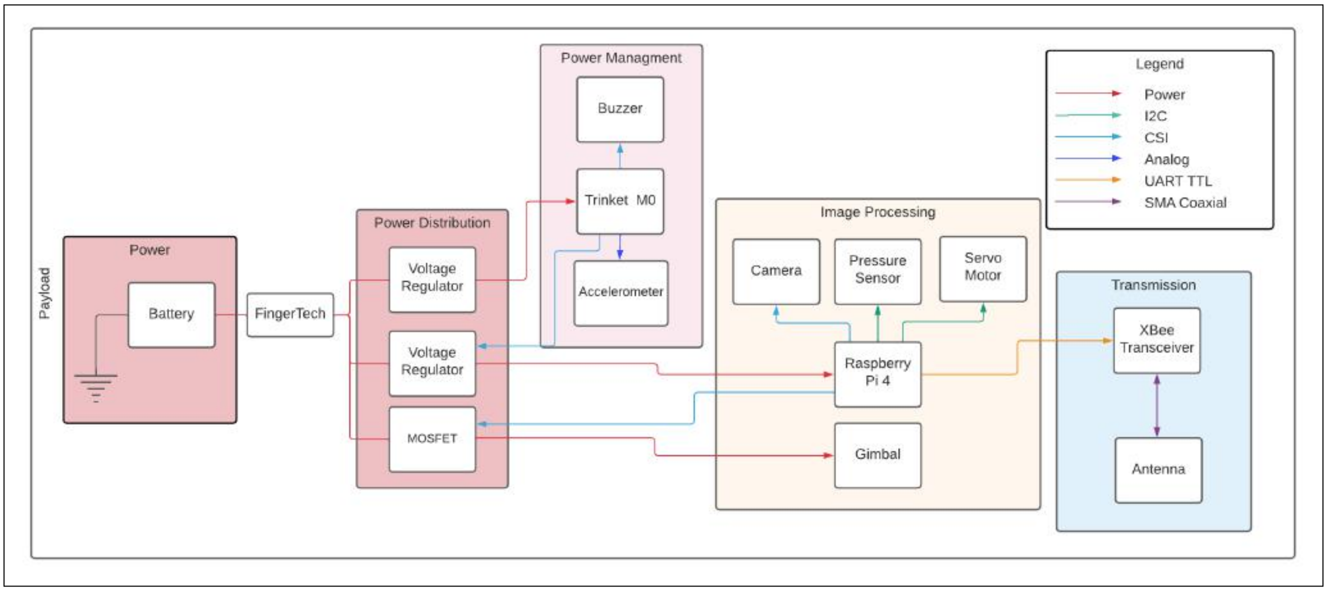


Figure 76: ANVIL Electrical Diagram

4.9.2 Printed Circuit Boards

Due to space constraints inside the payload, two Printed Circuit Boards (PCBs) were designed to connect all electrical components. The PCBs ensure that all wiring within ANVIL is compact and reliable. The boards were placed on the interior of each payload door, facing each other. The first PCB contains the Power Management components, transmission components, battery, FingerTech switch, both voltage regulators, and servo motor connector. The second PCB contains the Raspberry Pi, pressure sensor, gimbal MOSFET, and gimbal connector. The boards are connected using two 5 position terminal block connectors. The electrical schematics for both boards are shown in Appendix 8.6. All components were connected using female to male header pins. The use of the header pins allowed the boards to be modular, so that components can be installed and removed easily. In order for the Raspberry Pi to be connected using the female to male pins and the ribbon cable to be easily connected, the pre-installed male header pins were removed and resoldered on the opposite side of the board.

4.9.3 Power Budget

In order to choose the appropriate battery capacity for the payload, the estimated battery budget was calculated. To save power, certain components will be turned on during ascent. Table 42 shows the calculated battery budget for ANVIL. The average current draws seen for each component within this table were obtained through physical tests or online sources.

Table 42: ANVIL Battery Budget

Component	Average Current Draw (mA)	Quantity	Operation Time (min)	Total Energy Used (mAh)
Raspberry Pi 4	1,000	1	35	583.33
Trinket M0	9	1	125	18.75
Camera	225	1	5	18.75
Accelerometer	3	1	125	6.25
Pressure Sensor	2	1	5	0.17
XBee	215	1	10	35.83
Gimbal	330	1	5	27.5
Servo Motor	1,800	1	5	150.00
			Total	**840.58**

The estimated total energy was calculated to be 840.58 mAh. In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. This brings the estimated total energy to be approximately 1009 mAh. A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.

4.9.4 Transmission

Once ANVIL has landed, it must be capable of transmitting the grid of the landing location back to the ground station. To do so, two Xbee Pro XSC S3B long range RF modules are used. One module will be located inside ANVIL, and the other will be located at the ground station. The RF transmission power output maxes out at 250 mW for the transceiver on each Xbee, and operates at a chosen frequency of 920 MHz. This bandwidth was chosen because it does not require a HAM radio license to operate on and it does not interfere with any of the other transmission systems onboard the launch vehicle. This module and its relevant specifications, are shown in Figure 77 and Table 43.

Table 43: Xbee Pro XSC S3B Specifications

Xbee Pro XSC	
Supply Voltage	2.4 to 3.6 V DC
Range	9 mi with dipole antenna
Operating Frequency	902-928 MHz
Baud Rate	19200 bits per second
Transmit Current	215 mA
Idle Current	29 mA
Sleep Current	2.5 μA
Max Transmission Power	250 mW (software selectable)

Figure 77: Xbee Pro XSC Radio Frequency Module

4.9.4.1 Antenna

In order to maximize the range of transmission, careful consideration went into the decision regarding what antennas will be used with each Xbee. Each Xbee is fitted with an male SMA adaptor for use with a wide variety of antennas. For the Xbee located within ANVIL, a 900 MHz Reverse Polarity SubMiniature version A (RP-SMA) duck antenna was chosen. For the Xbee at the ground station, a Phantom Omni antenna was chosen. These antennas both have gains of 3 dBi. Both antennas are shown below in Figures 78a and 78b.

(a) Duck Antenna Located Inside Anvil

(b) Phantom Omni Antenna Located at Ground Station

Figure 78: Antennas Used With Each Xbee Module

Extensive testing was performed on both antennas to ensure they transmit and receive from within 2500 ft. A test apparatus using two Arduinos was constructed prior to the CDR milestone that proved the capabilities of the Xbee's paired with these antennas. This test is found in more detail in Section 7.2.1.

4.9.4.2 Transmission Process And Testing

In order to properly transmit between the Raspberry Pi and the ground station, a few steps must be followed. First, the Raspberry Pi has to be set up for serial communication. To do so, the GPIO pins 14 and 15 have to be enabled. These pins correspond to the TX and RX pins on the Raspberry Pi. Once enabled, only a few extra lines of code have to be added to the python script to enable serial communications. The time, GPIO, and serial libraries are added to the script, and the properties of the serial connection have to be specified that match the Xbee at the ground station. Once configured, a single statement saying that ANVIL has started its process of determining the grid location is transmitted using the ser.write function. This transmission will also confirm valid communication between ANVIL and the ground station. Once the system has determined the final grid location, it will transmit the location inside a while loop, repeating every second. The Xbee will be put into sleep mode while ANVIL is determining the final grid location in order to minimize current draw. The ground station will consist of an Arduino with the same setup used in the antenna test described in Section 7.2.1. This will read and display any serial communications on a laptop connected to the Arduino.

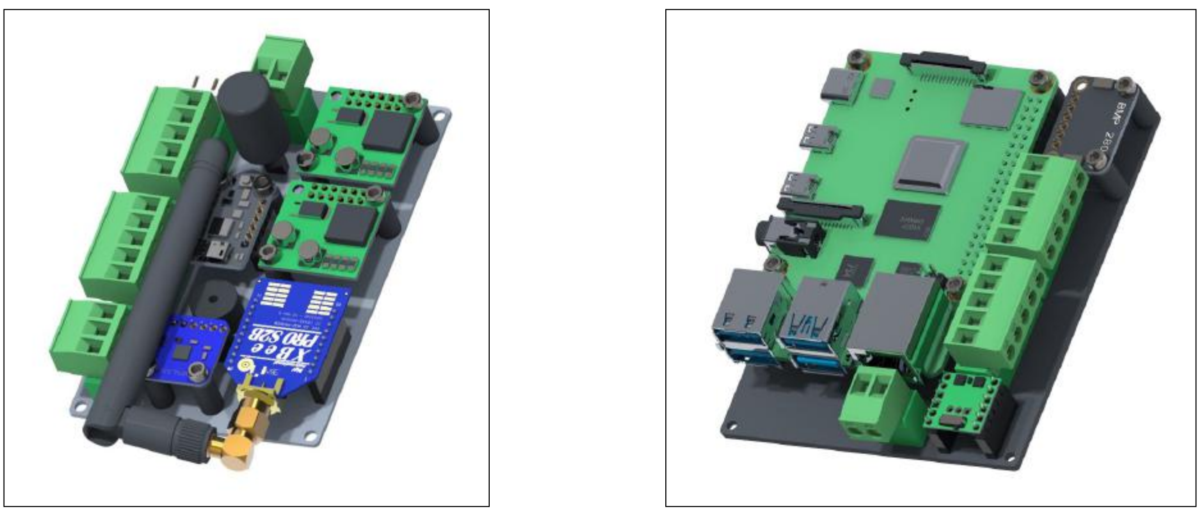
The transmission test outlined in the CDR document also was changed to replace the transmitting Arduino with the Raspberry Pi 4B used in ANVIL. This test was successful and proved serial communication between the Raspberry Pi and Ardiuno is possible. This test will be repeated once more with the Xbee and antenna installed onto the PCB and put into ANVIL. ANVIL will be put on its side and be constantly transmitting in order to find the max transmitting distance of the fully assembled system.

4.10 Electrical Construction Process

This section serves the purpose of outlining the construction process of each electrical component. These components include both the primary and secondary PCB's.

4.10.1 Designing the PCB

To ensure that all the electrical components would fit properly onto the PCBs, each one was 3D modeled and arranged on modeled payload doors. This method allowed for different configurations to be tested to find the best placement of all components. The 3D models are shown in Figure 79a and 79b.

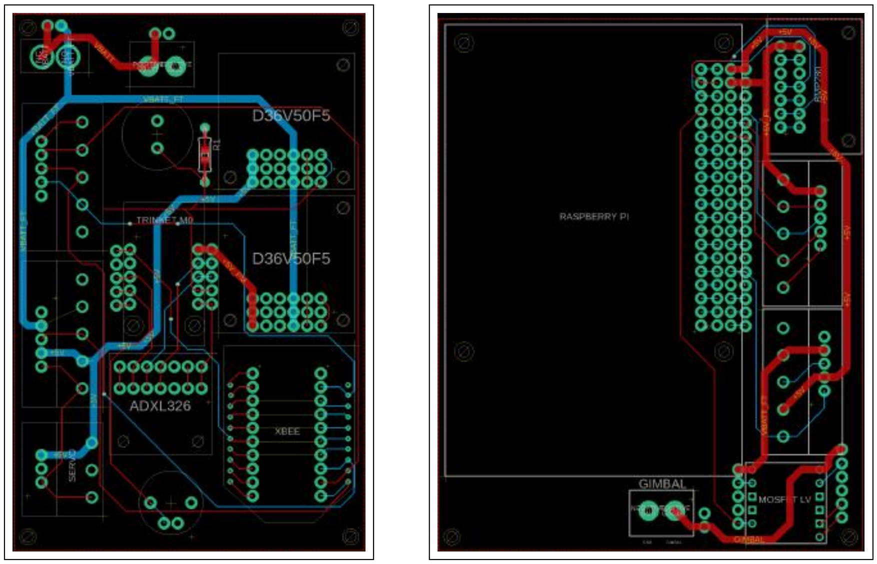


(a) 3D Model of Primary PCB

(b) 3D Model of Secondary PCB

Figure 79: 3D Model of Printed Circuit Board

Components from the same section were placed near each other to minimize the traces inside the PCB. The FingerTech was placed on the left edge of the first board so it can easily be turned on from the outside of the rocket on the launch pad. The battery connector was placed towards the top of the board to ensure the wires from the battery did not interfere with the rack and pinion system. Both the gimbal connector and servo motor connector were placed towards the bottom of the PCBs. Both components are located below the boards and the placement ensures that the wires do not interfere with the rack and pinion system. The antenna can only fit vertically in the payload, therefore the Xbee was placed with the RP-SMA connector facing towards the gimbal bay on the board. A right angle RP-SMA adapter was connected to the Xbee to allow the antenna to fit facing upwards. The connectors used to communicate between boards were placed on opposite sides to ensure that the wires would be on the same size of the payload. Extra through holes were added to the board for each component as a precaution in case of a wrong connection. To use the additional through holes, the trace inside the PCB would be cut and an external wire would be soldered to the through holes correcting the connection. The layouts of both boards are shown in Figure 80a and 80b.



(a) Primary PCB

(b) Secondary PCB

Figure 80: Printed Circuit Board Layouts

The original PCB layouts were purchased. Through preliminary testing, issues arose with the boards and changes had to be made. The first was an open connection in the board. The trace that connected the Trinket M0 to the enable pin of the second voltage regulator was not connected. This caused the voltage regulator to power the Raspberry Pi instantly. With the use of the extra through holes, a white wire was added. Since there was no connection, no traces had to be cut. The regulator was able to power on the correct components when launch was simulated. Extra precaution was used when designing the finalized PCBs and each trace was fully connected. Another issue that arose was turning the voltage regulator on after it entered its sleep mode. The enable pin required more than 0V but less than 1.2V to stop the flow of current. To turn this mode off, more than 1.3V was needed. In order to increase the output voltage from the Trinket, an analog output had to be used instead of the intended digital output. The analog output creates a PWM wave and a RC filter was needed to smooth out the waveform. A 470 μF capacitor and a 1 MΩ resistor was added to the finalized PCBs to ensure that all components will turn on during launch. All issues were resolved in the finalized PCBs.

4.10.2 Assembling the PCB

When the PCBs arrived, they were first tested for continuity. A multimeter was used on the smallest resistance setting. First, the probes of the multimeter were connected to through holes that were connected through the traces in the board. The multimeter would beep when there was a connection. Once all the right connections were tested, different connections were tested to ensure that there was no issues with the boards. Slowly the female to male header pins were soldered onto the board. After each line of pins was soldered, the multimeter was used to test the board again. One probe was put into one header pin and the other checked for continuity using the soldered pin on the back of the board. The pins next to the corresponding header pin were also checked to ensure that soldering did not bridge any pins together. This process was repeated for each line of header pins. Once all the header pins were connected, components were added gradually. The first were the battery and voltage regulators to ensure the board could handle the voltage and the right voltage went to the right pins. The Raspberry Pi was added to ensure it could be powered on from the voltage regulator. The gimbal, pressure sensor, and servo motor were tested one at a time through the Raspberry Pi. Once each component ran by itself, the gimbal with the camera and servo motor were tested together. Finally, all components were tested together as they would work during flight.

4.11 ANVIL Software

ANVIL's processing is broken down into four stages: launch, flight, image processing, and transmission. The sequence begins on the launch pad with the payload in sleep mode, until the Trinket M0 detects launch and distributes power to the components in sleep mode. Once the vehicle separates, the Raspberry Pi extends the gimbal and begins capturing images. When payload descends to 50ft the final image is captured and the gimbal is retracted. ANVIL will then begin processing the images and determine the landing location of the vehicle. After determining the grid square of the vehicle, it is then transmitted to the ground station. This process is represented in the state diagram in Figure 81 below.

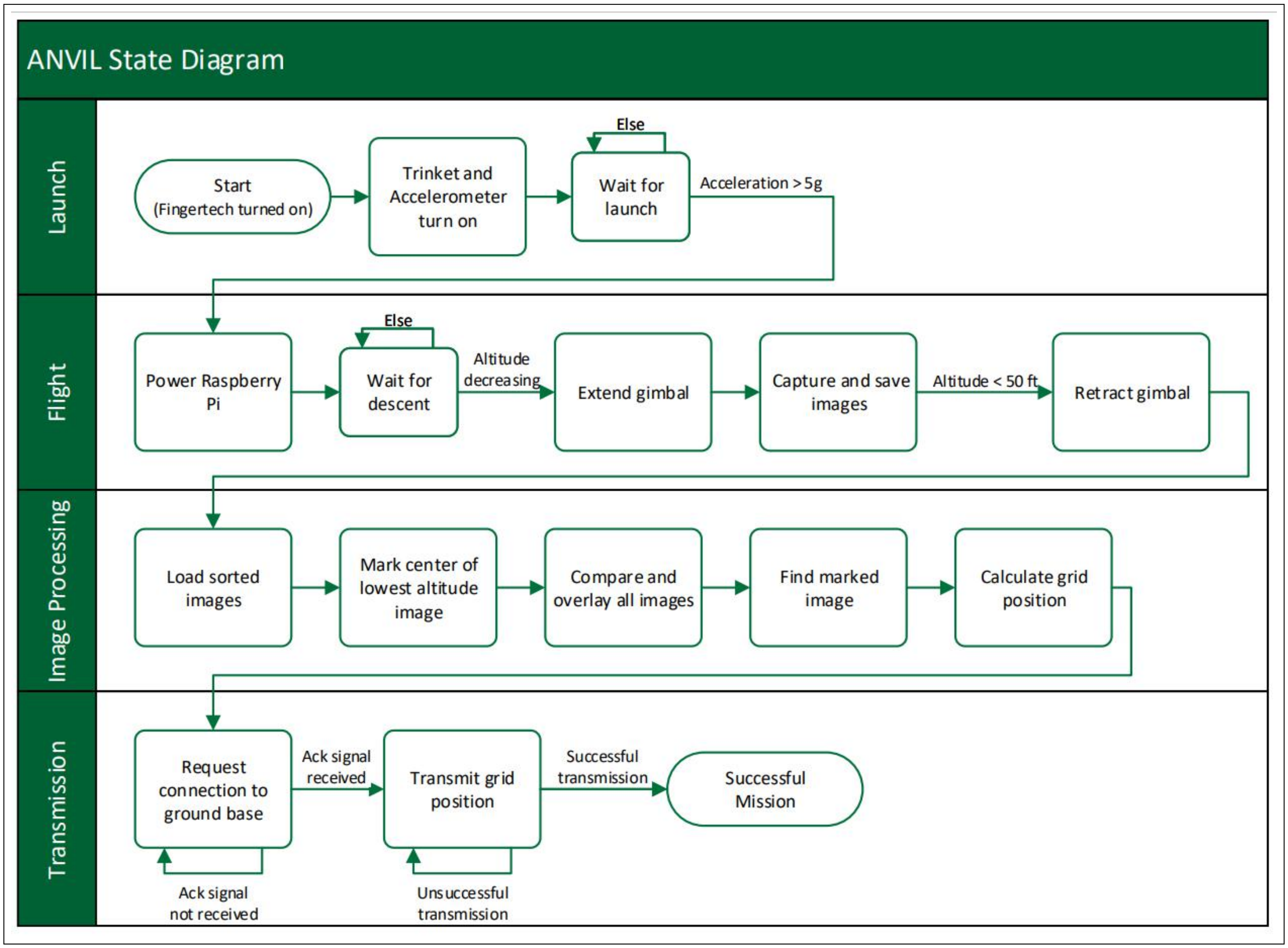


Figure 81: ANVIL State Diagram

4.11.1 Sleep Mode

Most of the electrical components remained off until the ascent of the flight was recorded. The Trinket M0 and ADXL326 accelerometer was used to turn on all other electrical components by enabling the second voltage regulator. The accelerometer reads acceleration on all three axis. The component is mounted onto the PCB with the positive y-axis facing upwards. When the microcontroller reads more than 5G's in acceleration in the y-axis, the Trinket outputs 3.3V to the enable pin of the voltage regulator. This powers on the Raspberry Pi which powers all the other components.

4.11.2 Image Capturing

ANVIL will process the images taken during descent to determine the location of one image within the previous. These comparisons allow the captured images to track the location of the vehicle over the field. As the altitude of each image changes, other properties of the image change as well. An example of the differences between images at different altitudes is shown in Figures 82a, 82b, and 82c below.

(a) 400 ft

(b) 150 ft

(c) 20ft

Figure 82: Sample images at varying altitudes

As seen in the images above, the resolution of features in each image changes drastically as the altitude changes. The detail in the ground is almost unnoticeable in Figure 82a, but is the focal point of the image in Figure 82c. This change requires the images to be captured without a drastic difference in altitude between two images. To account for this limitation, the imaging system will be capturing images as quickly as possible. The imaging system was timed and it was found that an image could be captured in approximately one second. A flowchart representing the image capturing process can be found in Figure 83.

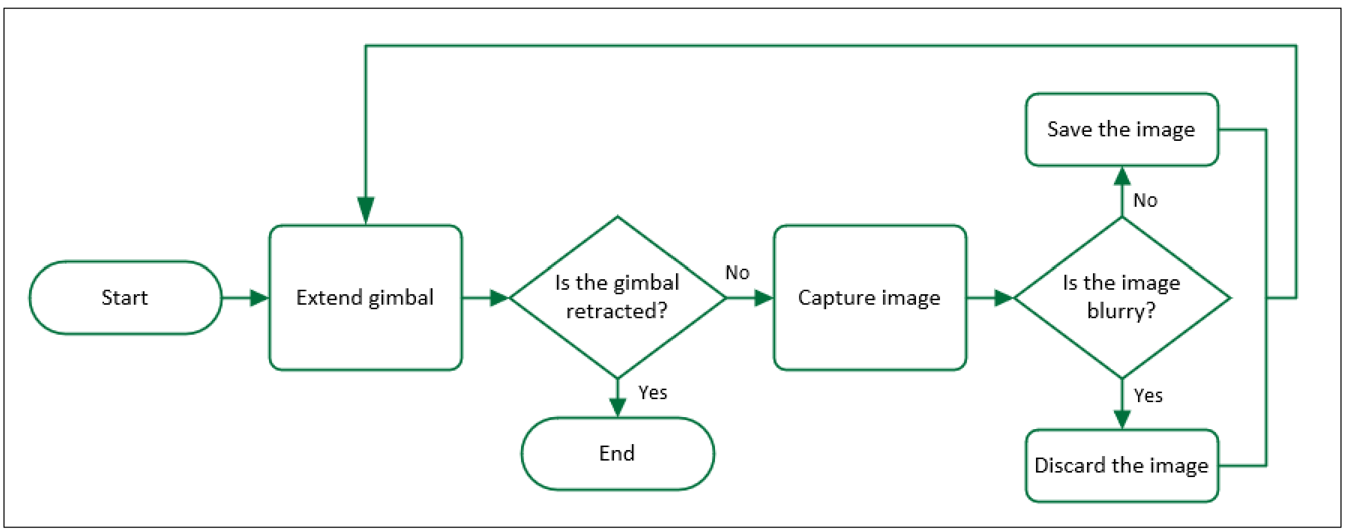


Figure 83: Image Capturing Flowchart

4.11.3 Image Processing

Once the vehicle lands, ANVIL will begin processing the images captured during recovery. The center of the lowest altitude image is marked and considered as the landing point of the vehicle. The images are compared in pairs until all original images have been used. This image comparison, denoted by the gold boxes in Figure 84, will be discussed further in Section 4.11.4. The images created from overlaying each pair are used to refill the input images. This process repeats until there is a single image remaining. The final image created as a result of all comparisons is then searched for the marked landing location. The pixel coordinates of this mark are then converted to the grid position which is transmitted to the ground station. A flowchart representing this process is shown in Figure 84 below.

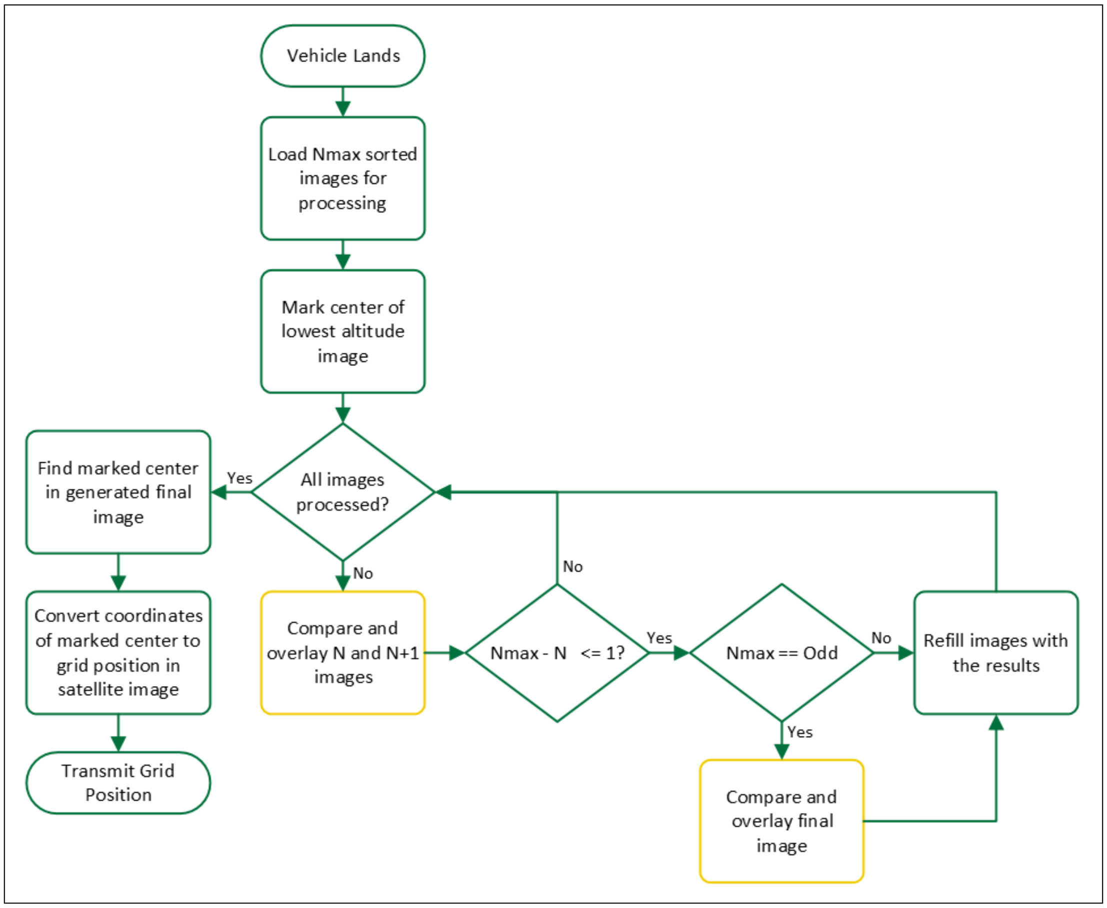


Figure 84: ANVIL Image Processing Flowchart

4.11.4 Image Registration

ANVIL will compare images using a custom function to align and overlay two images. The images are compared using Accelerted-KAZE (AKAZE) features, which are invariant to image rotation and scale. These features will be identified using the AKAZE class provided by OpenCV. The features found in each image are then used to identify potential matches between the two images. The found matches are then filtered using the Lowe's ratio test. This test filters the matches based on the distance between the two best matches found for each feature. If the distance between the two matches is not large enough, the features are removed and not used in further calculation. This test allows any ambiguous matches to be removed before determining a transformation between the images. Once a transformation is calculated, one image is warped to align with the other image. The transformed image is then masked to remove the border created by the transformation. The two images are then merged together and output from the function. A flowchart showing the process can be seen in Figure 85 below.

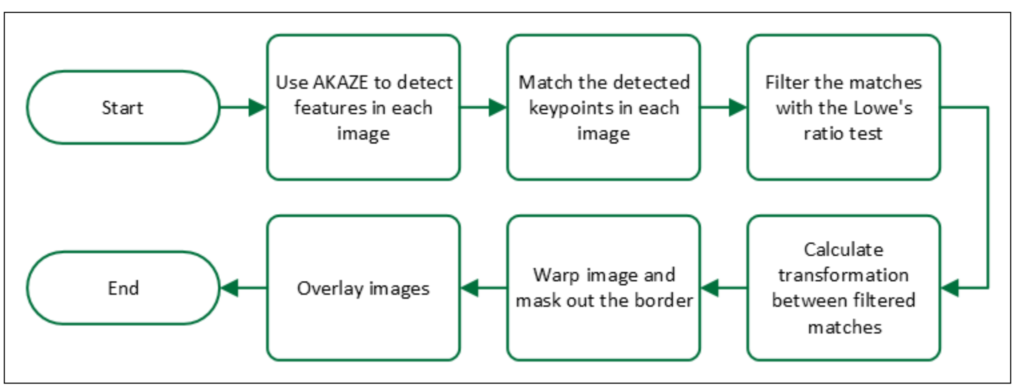


Figure 85: ANVIL Image Registration Flowchart

A visual walk-through of the process with two sample input images can be seen in Figure 86.

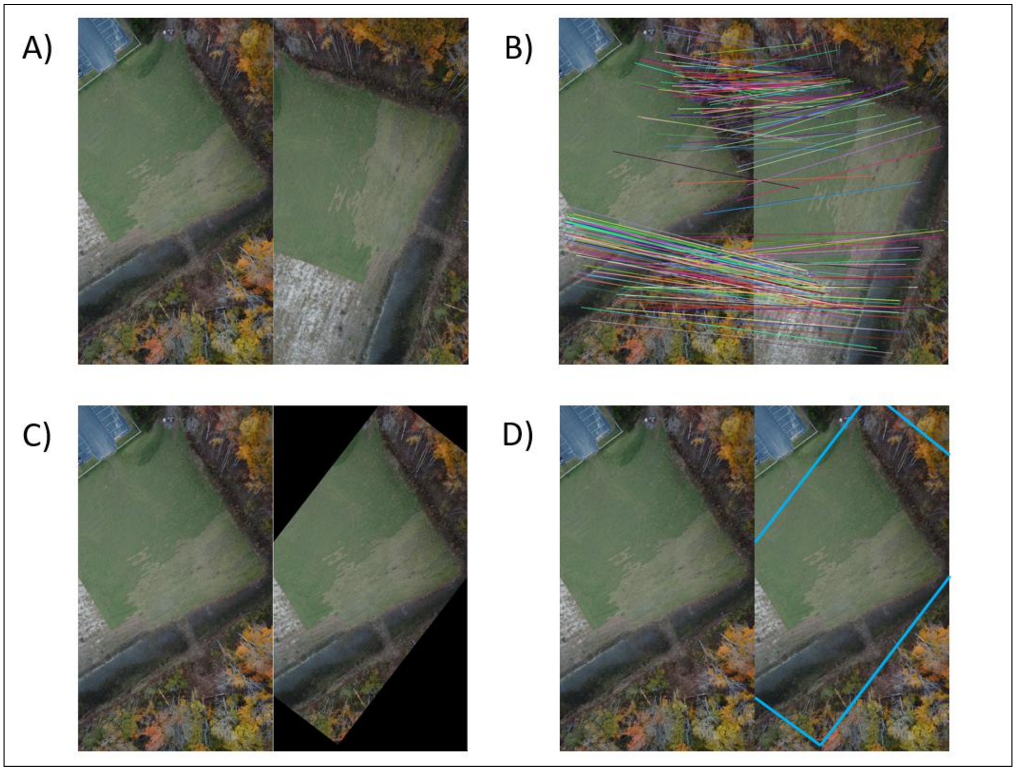


Figure 86: Image Registration: A) Input Images, B) Matches Between Images
C) Input and Warped Image, D) Input and Resulting Image

4.11.5 Algorithm Testing

The payload imaging system was tested using a drone, the full details of this test can found in Section 7.2.6. This test allowed images to be captured using the Raspberry Pi HQ Camera, these images were then used to test the image registration algorithm. The dataset for this test consisted of 41 images taken from 400 ft down to 20 ft, with an altitude difference of 10 ft. A sampling of the images at various altitudes was shown above in Section 4.11.2. The result of using these images with the algorithm is shown in Figure 87 below.

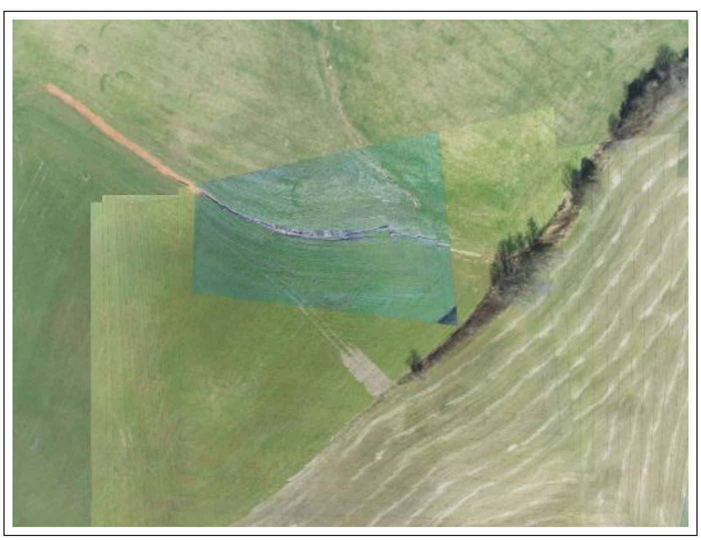


Figure 87: Original Dataset Image Registration Result

This result revealed an issue with the process by which the images are overlaid. The images are a fixed size which leads to areas of each image being cut-off, in this case our landing location. The solution to this issue is to resize the images created as a result of each comparison. The increased size of each image would account for any translation or rotation required to compose the image. A potential issue of this approach is the introduction of additional corners into each image. These corners could cause misalignment and be mistaken for features contained in each image. This issue can be accounted for by specifying the region in which to look for features in each image.

This dataset was also tested to determine how many images could be skipped and still have the proper alignment determined. The images were able to maintain alignment using only every third image from the original set, the reduced set used only 13 images with an altitude difference of 30 ft per image. The result of alignment using the reduced dataset is shown in Figure 88 below.

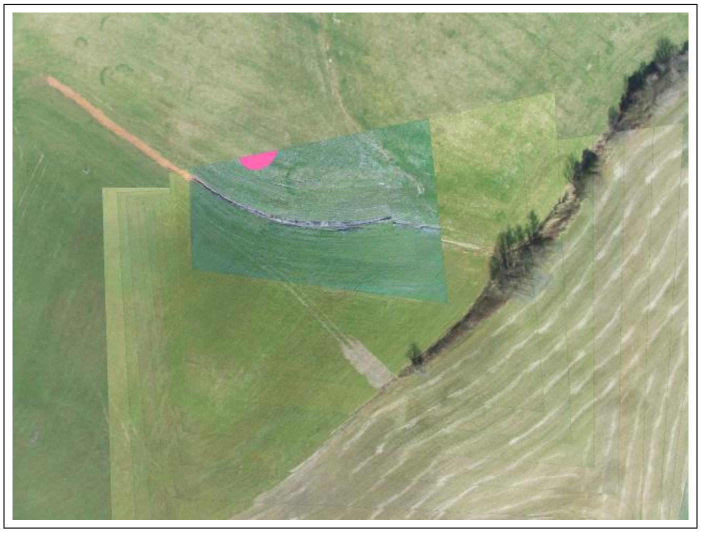
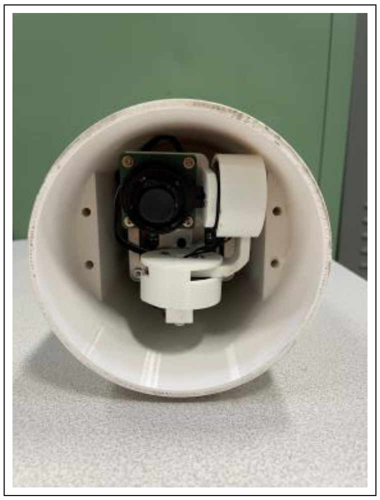


Figure 88: Reduced Dataset Image Registration Result

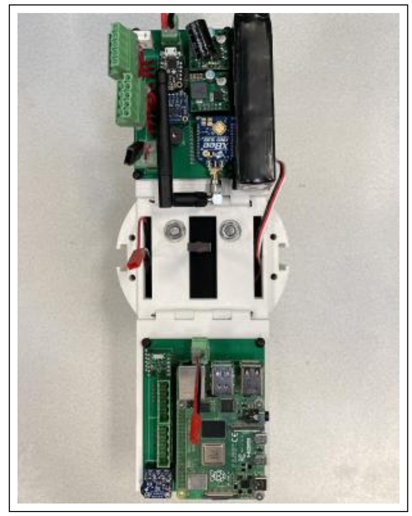
As seen in the image, reducing the amount of images also helped to alleviate regions being cut-off from each image. The pink mark indicating the assumed landing location is only partially obstructed. This reduction is caused by having fewer images, this reduces the scaling on each image when aligning the whole dataset.

4.12 ANVIL Assembly

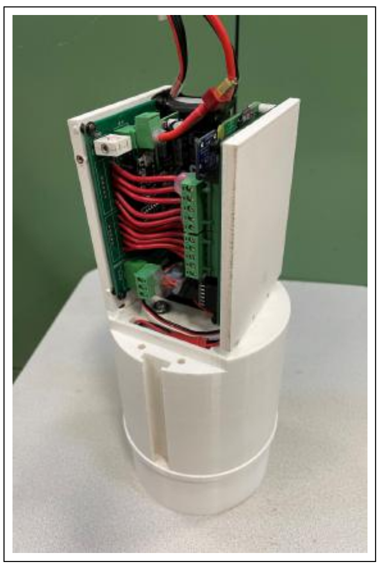
The full ANVIL assembly guide is outlined in Section 6.3.1. These steps must be followed in full for ANVIL to carry out the mission safely and efficiently. In addition to this assembly guide, photos of key steps in the assembly process were taken. The first photo shows the installation of the gimbal and retraction system, and can be seen in Figure 89a below. Figures 89b and 89c show the installation of the doors onto ANVIL. These doors have all the electronics mounted on them, but they are not connected or powered on until the doors are closed. These doors are mounted onto the hinge using dowel rods. The last photo, shown in Figure 89d, shows both halves of ANVIL being put together and screwing the doors in.



(a) Assembly of Gimbal and Retraction System Into Lower ANVIL Bay



(b) ANVIL Doors Being Mounted With Dowel Rods



(c) ANVIL Doors Being Closed With Electronics Connected

(d) ANVIL Housing Installed With Doors Screwed In

Figure 89: ANVIL Assembly Guide

Once ANVIL has been assembled, the quick links are ready to be attached along with the shock cord, and it is able to be installed into the vehicle. A hole was drilled into the vehicle that is aligned with a hole in ANVIL to access the FingerTech switch. This switch is turned on at the launch pad which will power on ANVIL's electronics.

5 Demonstration Flight Results and Analysis

5.1 Vehicle Flight 1

5.1.1 Launch Conditions

The first full-scale demonstration flight occurred on February 12th in Dalzell, South Carolina. This flight was completed to validate the full-scale vehicle design, test retention as well as recovery devices, to ensure all systems operated as designed. This launch was also compared to the mission performance predictions. The launch day conditions are shown in Table 44 below. This launch will be evaluated to fulfill the Vehicle Demonstration Flight.

Table 44: Launch Day Conditions

Location	Date	Temperature	Wind Speed	Wind Gusts	Air Pressure
Dalzell, SC	2/12/2022	69 °F	8 mph	16 mph	1016 hPa

5.1.2 Flight Results and Analysis

Vehicle Overview

The vehicle that was flown on the first launch day included all recovery systems and the payload retention system that will be used for the competition flight. The payload housing retention system operated as expected and remained tethered to the vehicle. Due to cyclic loading and coding error, which will be discussed in section 5.2, portions of the payload were not retained and separated from the vehicle during flight. Due to the failure to fully retain the payload, only the vehicle data will be discussed in this section.

The motor that was used for this launch day was the Aerotech L1390-G, which was designated as the motor that will be used for the competition flight. The total mass of the vehicle on launch day was 39.8 lb_m including all vehicle and payload components, resulting in a thrust-to-weight ratio of 7.76. The propellant mass accounted for 4.35 lb_m of the total pre-burn mass. Table 45 shows the pre-burn and post-burn masses of the launch vehicle which are used for the Ascent and Descent Analysis. On the launch field, it was determined that there was not a 12 ft launch rail present on the day of the flight. The team was offered the use of a 16 ft rail for the flight by the local NAR chapter. This changed the effective rail length from 120.15 in to 186.25 in. This change in rail length will be accounted for in comparisons between actual and simulated data. The goal altitude for the flight was 5,000 ft AGL.

Table 45: Vehicle Flight 1 Masses

Vehicle Component	Mass (lbm)
Payload Section	16.85
Booster Section (Pre-Burn)	22.95
Booster Section (Post-Burn)	18.60
Total (Pre-Burn)	**39.80**
Total (Post-Burn)	**35.45**

Ascent Analysis

Four Missile Works RRC3 Altimeters were on-board the vehicle during the flight and the apogee recorded from each can be seen in Table 57 below.

Table 46: Launch Characteristics

Altimeter	Apogee(ft)
Booster Primary	5874
Booster Backup	-
Payload Primary	5783
Payload Backup	5783

The data from the backup booster altimeter was corrupted during flight, leaving only the primary altimeter data for the booster sections to be analyzed. The RRC3 altimeter that was corrupted has been tested, found faulty and has been replaced. The primary and backup payload altimeters are identical and will be used when comparing flight data to simulated data.

All of the apogees recorded from the RRC3's are outside of the acceptable range to meet VMSC 1. The vehicle was designed to achieve an apogee of 5,000 ft and the closest recorded apogee was 5,783 ft, or 15.66% off from the goal altitude. The launch vehicle had a mass of 39.8 lb_m on launch day with the fully loaded motor, which was lighter than the vehicle design used in simulations. Upon further investigation, it was determined that the mass of the motor casing had been accounted for twice due to both OpenRocket and the item description from Chris' Rocket Supplies including the weight of the casing in the listed motor weight. Additional simulations were run with the launch day mass to determine if the simulations can be validated. The results of the updated OpenRocket and Matlab simulations can be seen in Tables 47 and 48 below, respectively.

Table 47: Updated OpenRocket and Recorded Data Comparison

Characteristic	Actual	Simulated	Percent Difference
Apogee (ft)	5783	5782	0.017%
Velocity off the Rail (ft/sec)	86.7	87.7	1.14%
Max Velocity (ft/sec)	652	640	1.86%
Time to Apogee (sec)	19.2	19.4	1.04%

Table 48: Updated MATLAB and Recorded Data Comparison

Characteristic	Actual	Simulated	Percent Difference
Apogee (ft)	5783	5858	1.28%
Velocity off the Rail (ft/sec)	86.7	87.6	1.03%
Max Velocity (ft/sec)	652	643	1.39%
Time to Apogee (sec)	19.2	19.5	1.5%

As seen above in Table 47, the altitudes simlated in OpenRocket and MATLAB are very close to the actual apogee logged by the on board RRC3 altimeters. There was a 0.017% difference for the OpenRocket simulation and a 1.28% difference for the MATLAB simulations. The higher percent difference in altitude as simulated in Matlab may be due to the inability to account for wind turbulence intensity and wind direction in the simulation. The low percent differences show that the recorded flight data is within a predictable range.

The velocity data for the OpenRocket and MATLAB simulations were within a predictable range of the actual flight. The velocity data logged by the RRC3 altimeter implemented a smoothing function to the velocity curve. This caused a slightly higher percent differences of 1.14% and 1.03% for OpenRocket and MATLAB respectively. The velocity at 16 ft was recorded at being 86.7 ft/s, and was calculated in incremental velocity evaluations prior to rail exit.

The recorded time to apogee was slightly lower than that of the simulated values. This difference is most likely due to a filter used to denote when apogee occurs within the RRC3 altimeter. The percent difference for the OpenRocket simulation was 1.04%, and the percent difference for MATLAB was 1.5%. Sources of error can also be attributed to variable motor impulse between the simulated and actual motor.

The simulated velocity profile and RRC3 recorded velocity profile are compared against one another in Figure 90.

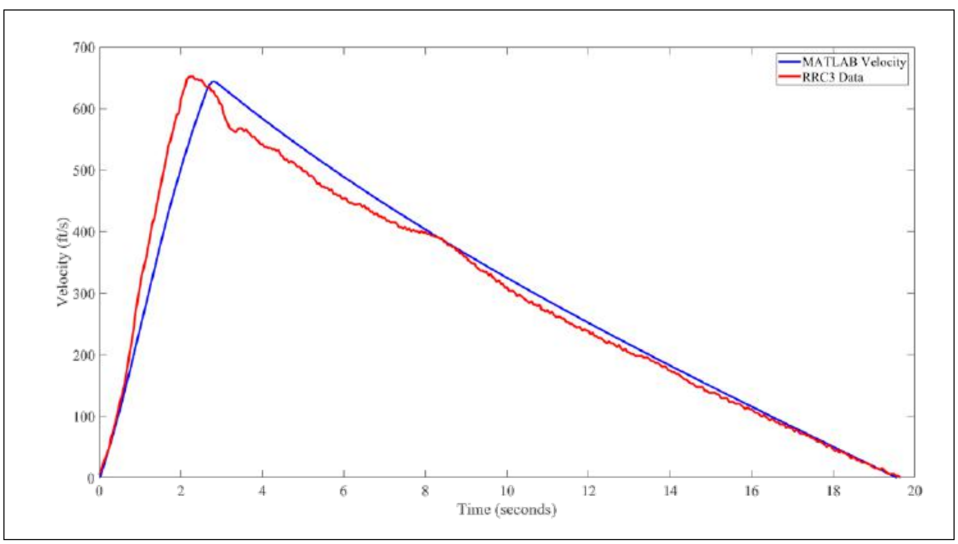


Figure 90: Data Comparison between the MATLAB and experimental velocity data

As seen in the figure above, the velocity ascent curves are very close in magnitude to one another. The RRC3 velocity profile spikes to a maximum velocity slightly before the MATLAB curve. The differences in the velocity profiles can be attributed to the burn rate of the AeroTech L1390-G varying from data provided by the supplier. The difference in specific velocity values between actual flight and simulations can be found in Table 48.

Altitude data from OpenRocket, MATLAB, and on-board RRC3 altimeters were plotted against one another. The altitude curves are shown below in Figure 91.

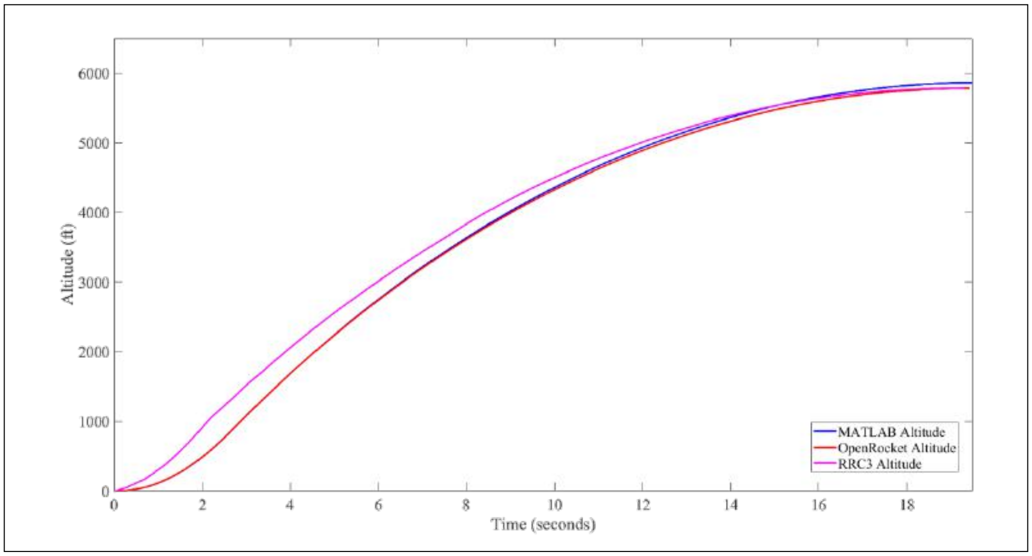


Figure 91: Data Comparison between the MATLAB, OpenRocket, and experimental altitude data

The altitude plots from MATLAB and OpenRocket are in line with one another while the RRC3 flight curve is slightly shifted. However, the OpenRocket simulation and RRC3 flight curve achieve the same altitude. While The MATLAB Simulation has a higher apogee, and this difference can be attributed to the MATLAB simulation using an average coefficient of drag. The difference between the actual flight data and the other simulation methods is likely due to the different wind speeds experienced by the launch vehicle during ascent, and a different burn rate of the AertoTech L1390G. A model of the post-burn flight path to apogee is shown in Figure 92.

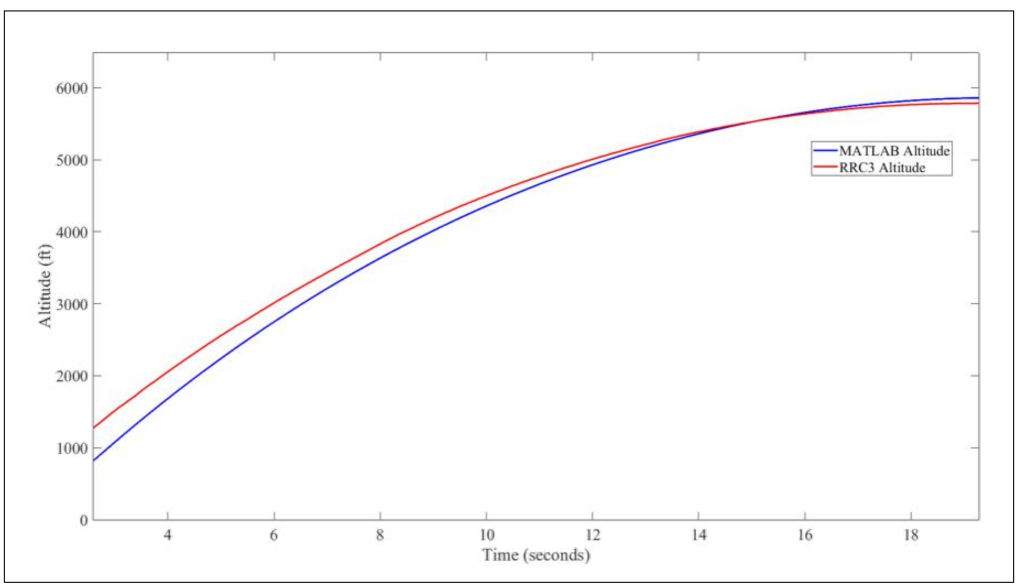


Figure 92: The post burnout altitude experimentally and simulated with a Cd of 0.3438

The MATLAB flight profile uses a constant drag coefficient of 0.3438, and was compared against the RRC3 flight profile. The difference in profiles corresponds to the drag coefficient of the vehicle changing based on experienced velocity, while the MATLAB simulation uses a constant coefficient of drag. The post burnout altitude data was examined to isolate the drag forces on the vehicle and eliminate the impact of possible thrust variation.

Payload Section

The data obtained from the primary payload altimeter can be seen in Figure 93 below. Apogee was reached 19.2 seconds after launch and the payload section of the vehicle section touched down at 106 seconds post launch. This difference gives a descent time of 86.8 seconds. While the descent time was under the 90 second requirement, it was longer than expected. This is due to the additional altitude achieved from the mass of the vehicle being lower than expected.

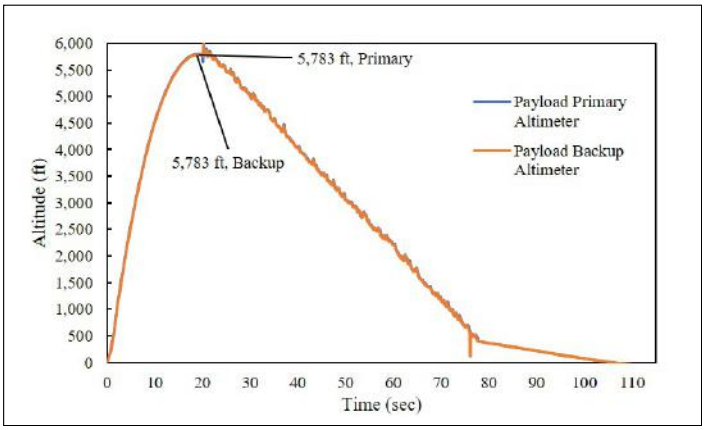


Figure 93: Primary Payload Altimeter Data

The theoretical descent rate and the experimental descent rate were also compared and the percent difference was found for the payload section. The results can be seen in Table 49.

Table 49: Vehicle Flight 1 - Payload Section Descent Velocities

Parachute	Theoretical Descent Velocity (ft/s)	Actual Descent Velocity (ft/s)	Percent Difference (%)
29 ft Streamer	108.24	102.00	5.94
72 in. Main	15.10	13.78	1.39

Booster Section

The data obtained from the primary booster altimeter can be seen in Figure 94 below. Apogee was reached 19.2 seconds after launch and the booster section of the vehicle touched down at 115 seconds post launch. This difference gives a descent time of 95.8 seconds. This descent time is much higher than expected. The decreased mass of the vehicle produced a higher altitude and since the booster section contained the mass error, the descent velocity was also much slower than intended.

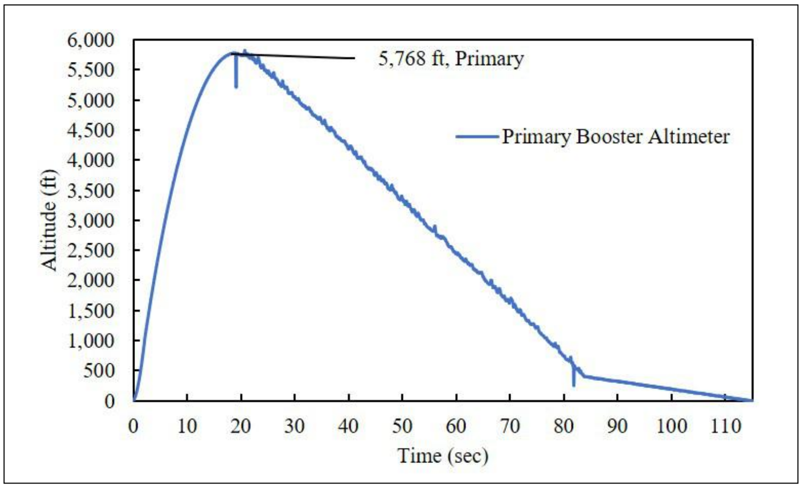


Figure 94: Booster Primary Altimeter Data

The theoretical descent rate and the experimental descent rate were also compared and the percent difference was found for the booster section. The results can be seen in Table 50.

Table 50: Vehicle Flight 1 - Booster Section Descent Velocities

Parachute	Theoretical Descent Velocity (ft/s)	Actual Descent Velocity (ft/s)	Percent Difference (%)
12.5 in. Drogue	112.10	103.10	8.36
84 in. Main	13.59	13.78	1.39

The actual descent rate for the booster section under drogue was lower than the theoretical, as expected since the theoretical does not include vehicle drag. With the booster section descending slower than the payload section, ANVIL's image capturing was not obscured.

Descent Time

The descent time for the payload and booster sections was determined by subtracting the time to apogee from the total launch time, based on the data obtained from the RRC3 Altimeters. For the theoretical data, an apogee value of 5738 ft and the simulated descent rates were used in the comparison to the altimeter data. Table 51 shows the descent time comparison between the theoretical and actual data.

Table 51: Vehicle Flight 1 Descent Time Comparison

Vehicle Section	Theoretical Descent Time (s)	Actual Descent Time (s)	Percent Difference (%)
Payload Section	87.33	86.80	0.61
Booster Section	90.37	95.80	5.83

Drift Distance

The drift distance was calculated by dropping a geo-pin at the landing location of both the payload and booster sections and using the GPS coordinates on Google Earth to determine the distance from the launch location. The payload section drifted 2,033 ft and the booster section drifted 2,200 ft. An image of the Google Earth map with the landing locations and distances for the payload and booster section can be seen in Figure 95.

(a) Payload Section (b) Booster Section

Figure 95: Drift Distances

Table 52 below shows both sections of the vehicle drifted less than the 2,500 ft maximum drift distance. The expected drift distance was calculated with the apogee achieved, which was 1,250 ft for the payload section and 1,187 ft for the booster section. The difference is drift distance may be due to high wind gusts experienced on launch day, and slower descent times due to vehicle drag.

Table 52: Vehicle Section Drift Distances

Vehicle Section	Theoretical Drift (ft)	Actual Drift (s)	Difference (%)
Payload Section	1,250	2,033	47.07
Booster Section	1,187	2,200	59.82

Landing Kinetic Energy

Using the descent rates and measured masses of each section, the kinetic energy upon landing from the flight was calculated. The equation used to calculate the kinetic energy at impact was Equation 15 from Section 3.4.6. The landing kinetic energy values for all the vehicle components are shown in Table 53.

Table 53: Vehicle Flight 1 Landing Kinetic Energy

Vehicle Component	Mass ($\mathrm{lb_m}$)	Descent Velocity (ft/s)	Landing Kinetic Energy ($\mathrm{ft-lb_f}$)
Nose Cone	3.0	13.78	8.85
Payload Recovery Section	6.20	13.78	18.28
Payload Airframe Section	2.65	13.78	7.81
Booster Recovery Section	7.25	13.13	4.50
Booster Propulsion Section	11.35	13.13	30.29
ANVIL	5.00	13.78	14.74

All values are within the required 75 $\mathrm{ft-lb_f}$ kinetic energy. The percent differences between the theoretical and experimental data are provided in Table 54.

Table 54: Vehicle Flight 1 Theoretical Vs. Actual Kinetic Energy

Vehicle Component	Actual KE ($\mathrm{ft-lb_f}$)	Theoretical KE ($\mathrm{ft-lb_f}$)	Difference (%)
Nose Cone	8.85	10.62	18.18
Payload Recovery Section	18.28	21.95	18.25
Payload Airframe Section	7.81	9.38	18.27
Booster Recovery Section	19.41	20.79	6.87
Booster Propulsion Section	30.38	32.55	6.90
ANVIL	14.74	17.70	18.25

Post-Flight Analysis

Figure 96 shows the flight profile from launch to apogee of the MATLAB simulation and the gathered RRC3 flight data. a new drag coefficent of .3438 was used for the MATLAB simulations and shows the simulated apogee of the launch vehicle is higher than the actual flight. This difference in apogee can be equated to increased wind speeds at higher altitudes and inconsistencies in motor performance.

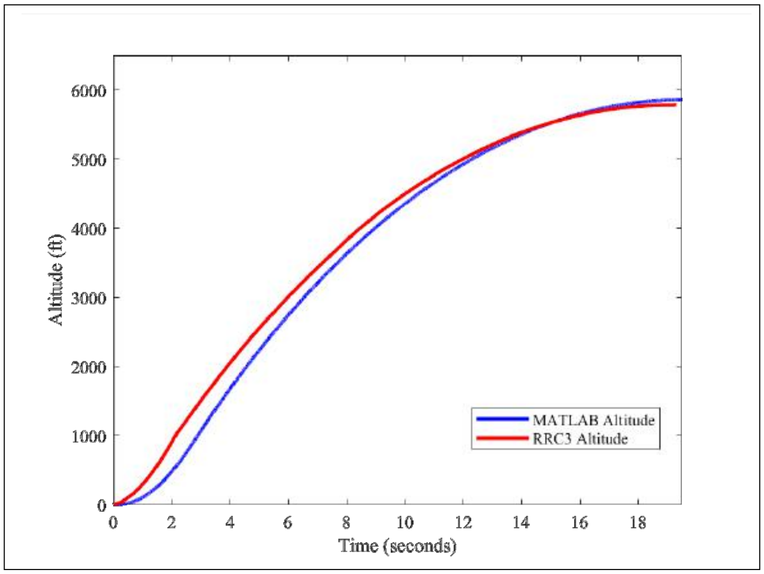


Figure 96: Updated Simulation

Full-scale and Sub-scale Flight Comparison

The sub-scale launch vehicle had a stability caliber of 2.9 and the full-scale vehicle had a stability caliber of 3.37. The large difference in stability is due to the motor casing mass being accounted for twice. The difference in stability does not allow for an accurate comparison to be made between the aerodynamic performance of the sub-scale and full-scale vehicles. An additional launch will be completed with ballast weight, which will decrease the stability caliber of the full-scale vehicle to more closely match the stability caliber of the sub-scale vehicle.

Full-scale and Sub-scale Drag Comparison

Equations 19 and 20, along with data from an on board accelerometer, were used to calculate the coefficient of drag for the full-scale vehicle. The drag coefficient was calculated to be 0.3438 for the full-scale launch vehicle. While the drag coefficient of the sub-scale was calculated to be 0.44. The difference between the two drag coefficients is expected due to the sub-scale having a maximum velocity of 350ft/s and the full-scale having a maximum velocity of 650 ft/s.

$$\mathrm{F_d} = 1/2 \cdot \rho \cdot \mathrm{C_d} \cdot \mathrm{V}^2 \cdot \mathrm{A} \tag{19}$$

$$\mathrm{C_d} = \frac{2 \cdot \mathrm{F_d}}{\rho \cdot \mathrm{V}^2 \cdot \mathrm{A}} \tag{20}$$

5.2 Payload Flight 1

The first attempt at the payload's demonstration flight occurred on February 12th in Dalzell, South Carolina. This flight was carried out with the intention of testing ANVIL's ability to withstand the stresses of flight and recovery while capturing data critical to the success of the payload's mission. Flight 1 of the payload revealed structural concerns with the rails and the gimbal as well as issues with the code's ability to accurately calibrate the pressure sensor.

5.2.1 Flight Results and Analysis

Once the payload had landed it was found that the epoxy holding the rails inside the launch vehicle had broken free during separation at apogee, resulting in the rails falling out of the launch vehicle. Despite remaining intact during separation testing, the rail's epoxy likely failed due to reoccurring stresses being implemented to the adhesive as well as an increase of the force experienced at apogee. Due to the fact the vehicle is in motion at the point of separation, the rails experience higher levels of stress than that see during a ground separation test. This increase of loading as well as cyclic loading likely caused this failure. In order to prevent this failure from occurring in future flights, four 4-40 screws and heat set inserts are now used to attach both rails to the airframe. An in depth explanation of the changes implemented and how these changes were carried out is broken down in Section 4.7.4.1.

In addition to the rails breaking free at apogee, it was also found that the gimbal connection arm had broken during main deployment. This fracture, seen below in Figure 97, occurred where the DC motor is secured to the 3D printed part.

Figure 97: Broken Gimbal Part

There is a mounting hole at the location of the fracture, resulting in the material being significantly thinner and therefore subject to higher stresses. During main deployment, the payload experienced approximately 22 times the force of gravity. This sudden velocity decrease resulted in the overloading of this section due to the weight of both DC motors, the motor connection arm, camera plate, and camera. In order to prevent this issue from occurring in future flights, parts within the gimbal that are subject to higher stresses will be machined from aluminum. These changes and how they are implemented are further broken down in Section 4.7.5.

The last observation made during this launch revolved around the calibration of the pressure sensor. Due to an incorrect calibration, the pressure sensor was reading approximately 260 feet higher than the true altitude. This offset of values resulted in the gimbal being extended prematurely and pressed against the ANVIL's blast protection. In addition to the gimbal being extended early, the camera began taking images within the launch vehicle. Being that the gimbal was pressed against the blast protection during separation, it is likely that this system absorbed some of the separation shock. It is possible that this shock could have induced a fracture within the gimbal's structure. During landing it was also observed that due to this calibration issue the pressure sensor never read a value lower than 260 feet and therefore never passed the 50 foot checkpoint necessary to retract the gimbal. As a result of this numerical offset, the payload landed with the remaining parts of the gimbal extended.

Other than these issues there was no additional damages to the payload. ANVIL's eyebolt retention system worked as intended, allowing the payload to be safely suspended from the launch vehicle during the entire recovery process. In addition, the housing structure suffered no damage during landing, effectively protecting all electrical components housed within it from impact forces.

5.3 Vehicle Flight 2

5.3.1 Launch Conditions

The second attempt at the full-scale demonstration flight occurred on February 26th in Bayboro, North Carolina. This flight was completed in an attempt to analyze the flight performance of the vehicle with ballast weight added to the booster section. This launch was compared to updated mission performance predictions. The launch day conditions are shown in Table 55 below.

Table 55: Launch Day Conditions

Location	Date	Temperature	Wind Speed	Wind Gusts	Air Pressure
Bayboro, NC	2/26/2022	46 °F	10 mph	13 mph	1027 hPa

5.3.2 Flight Results and Analysis

Vehicle Overview

The vehicle that was flown on this launch day included all recovery systems and the payload retention system that will be used for the competition flight. The payload was fully retained throughout the flight. Further analysis of the payload during the second launch attempt is discussed in Section 5.4.

The motor that was used for this launch day was the Aerotech L1390-G, which was designated as the motor that will be used for the competition flight. The total mass of the vehicle on launch day was 41.0 lb_m including all vehicle and payload components, producing a thrust-to-weight ratio of 7.53. The propellant mass accounted for 4.35 lb_m of the total pre-burn mass. This mass increased by 1.2 lb_m from the first launch attempt due to ballast included in the booster section. The ballast weight was included to bring down the stability caliber and decrease the altitude after accounting for the weight of the motor casing twice. A 10 ft launch rail was used for this launch due to the only rail sizes available being 8 ft or 10 ft. This changed our effective rail length from 120.15 in to 96.15 in. This change in rail length will be accounted for in comparisons between actual and simulated data. The goal altitude for the flight was 5,000 ft AGL and the masses of the vehicle are shown in Table 56.

Table 56: Vehicle Flight 2 Masses

Vehicle Component	Mass (lb_m)
Payload Section	16.61
Booster Section (Pre-Burn)	24.4
Booster Section (Post-Burn)	20.05
Total (Pre-Burn)	**41.0**
Total (Post-Burn)	**36.65**

Ascent Analysis

Four Missile Works RRC3 Altimeters were on-board the vehicle during the flight and the apogee recorded from each can be seen in Table 57 below.

Table 57: Launch Characteristics

Altimeter	Apogee(ft)
Booster Primary	5245
Booster Backup	5244
Payload Primary	-
Payload Backup	5207

The apogee achieved was much closer to the goal altitude on the second launch attempt compared to the first, and all recorded altitudes met the mission success criteria. The primary payload altimeter did not record any data, and the backup payload altimeter stopped recording data shortly after apogee. The circuit containing the accelerometer possibly had cold joints, leading to a voltage drop that prevented the RRC3's from having enough battery to store the data collected. For subsequent launches, a PCB as shown in 38b will be used. The apogee recorded from the primary and backup booster altimeters also showed a one ft difference, so the primary booster altimeter will be used to compare the actual data to the simulated data.

Table 58: OpenRocket and Recorded Data Comparison Flight 2

Characteristic	Actual	Simulated	Percent Difference
Apogee (ft)	5245	5359	2.15%
Velocity off the Rail (ft/sec)	66.8	66.4	0.60%
Max Velocity (ft/sec)	607	615	1.31%
Time to Apogee (sec.)	18	18.8	4.35%

Table 59: MATLAB and Recorded Data Comparison Flight 2

Characteristic	Actual	Simulated	Percent Difference
Apogee (ft)	5245	5345	1.80%
Velocity off the Rail (ft/sec)	66.8	66.2	0.90%
Max Velocity (ft/sec)	607	617	1.63%
Time to Apogee (sec.)	18	18.6	3.27%

The ascent data for the second launch showed higher percent differences between the actual and simulated data than the first launch. One cause of the higher percent differences between simulated and actual data may be due to the weathercocking experienced by the vehicle upon launch. Weathercocking was not experienced on the first launch, despite the high stability caliber, because a 16 ft launch rail was used, increasing the off-rail velocity enough to overcome the wind speeds experienced. On the second launch, however, a 10 ft rail was used, which provides a smaller effective rail length than the vehicle was designed for. The decrease in rail length decreased the off-rail velocity from 73.1 ft/s to 66.2 ft/s. Combined with the moderate wind speeds and high wind turbulence, the smaller off-rail velocity was enough to cause the vehicle to weathercock into the wind and achieve a lower altitude. Without weathercocking, the actual data would be much closer to the simulated data, which would result in an apogee that does not fall within the Mission Success Criteria.

The simulated velocity profile and RRC3 recorded velocity profile for the second launch vehicle flight are compared against one another below in Figure 98.

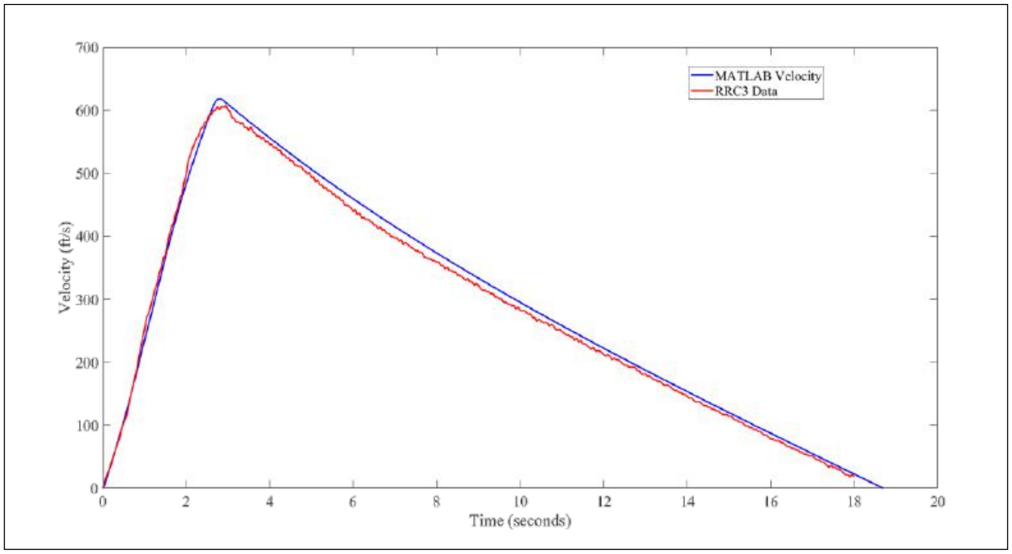


Figure 98: Data Comparison Between the MATLAB and Experimental Velocity Data for the Second Vehicle Flight

Given that the launch vehicle had an increase of post burn mass by 1.2 lb_m, the maximum velocity of the launch vehicle dropped from 652 ft/s to 607 ft/s. The velocity curve recorded by the RRC3 matches the MATLAB simulated curve, even with weathercocking being experienced by the launch vehicle.

Descent Time

The descent time for the booster section was determined by subtracting the time to apogee from the total launch time, based on the data obtained from the RRC3 Altimeters. Due to errors with the RRC3's, the descent was not recorded on the RRC3 for the payload section and instead will be evaluated using the data obtained from the accelerometer on-board the payload section.

Payload Section

The data obtained from the accelerometer located on the payload section electronics sled can be seen in Figure 99 below. The accelerometer only records the G forces that are exerted on the vehicle over the course of the flight. The time was calculated from this data, which was possible because the sample rate is known. The accelerometer records approximately 285 samples per second. The data point corresponding to the acceleration spike that indicates launch was subtracted from the data point corresponding to the acceleration spike that indicates separation at apogee, and divided by the sample rate. The time to apogee was calculated to be 18.7 seconds after launch. The same method was used to calculate the time from apogee to touch down and that time was determined to be 238 seconds. The total descent time for the payload section was 219.3 seconds. This high descent time is due to the main payload parachute deploying at apogee.

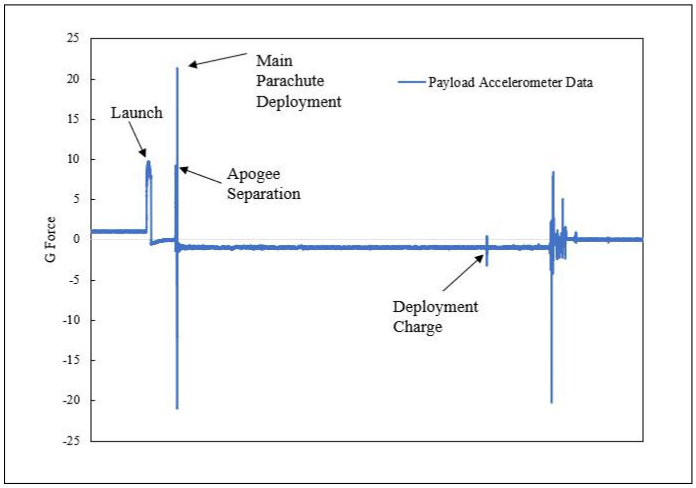


Figure 99: Accelerometer Data

The backup payload altimeter recorded flight data up until apogee. Figure 100 below shows apogee achieved at approximately 18.7 seconds, corresponding to the time to apogee determined from the accelerometer data. This validates the method used to calculate the total descent time of the payload section.

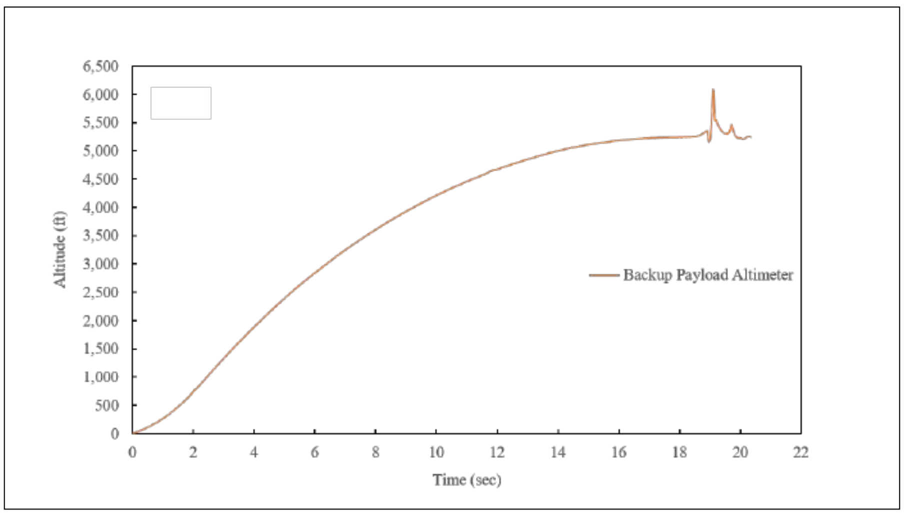


Figure 100: Backup Payload Altimeter Data

Since the main parachute deployed at apogee for the payload section, simulations were updated to match this event. Table 60 shows the updated theoretical and actual descent times of the payload section of the vehicle based on the data obtained from the accelerometer.

Table 60: Vehicle Flight 2 - Payload Section Descent Time

Section	Theoretical Descent Time (sec)	Actual Descent Time (sec)	Percent Difference
Payload	349.94	238.71	37.79%

The accelerometer data was used to calculate a descent velocity of 23.92 ft/s, or a 53.79% difference from the theoretical data. The large difference may be due to errors while extrapolating time from the accelerometer data. This large difference will also be seen in the proceeding calculation for kinetic energy as the value is derived from the descent velocity. Table 61 shows the comparison between theoretical and actual descent velocity of Vehicle Flight 2.

Table 61: Vehicle Flight 2 - Payload Section Descent Velocities

Parachute	Theoretical Descent Velocity (ft/s)	Actual Descent Velocity (ft/s)	Percent Difference
72 in. Main	13.78	23.92	53.79%

Booster Section

The data obtained from the primary booster altimeter can be seen in Figure 101 below. Apogee was reached 18.7 seconds after launch and the booster section of the vehicle touched down at 101.9 seconds post launch. This difference gives a descent time of 83.2 seconds. The increased post-burn mass of the booster section from the first launch to the second decreased the altitude and increased the descent rate, providing a time from apogee to touchdown that is under the 90 second maximum.

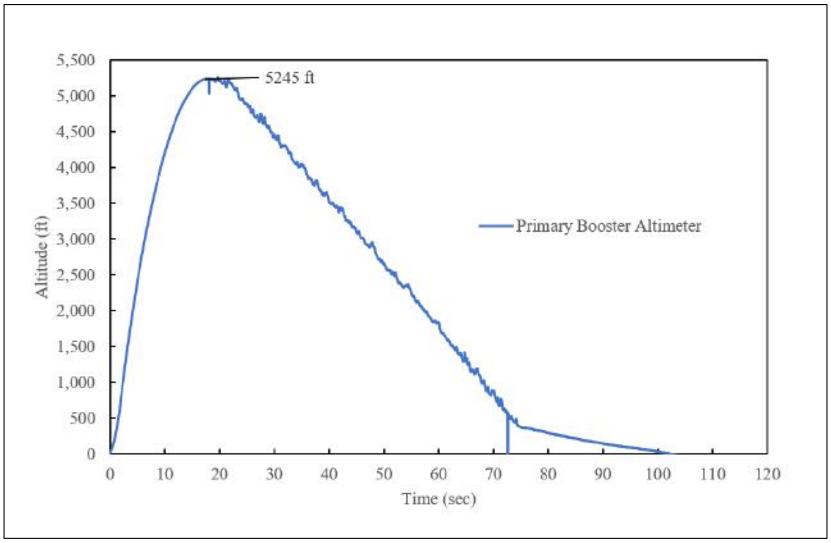


Figure 101: Primary Booster Altimeter Data

Table 62 shows the theoretical and actual descent times of the booster section based on the RRC3 data. The low percent difference proves the validity of the theoretical descent time calculations when recovery events occur as intended.

Table 62: Vehicle Flight 2 - Booster Section Descent Time

Section	Theoretical Descent Time (sec)	Actual Descent Time (sec)	Percent Difference
Booster	82.42	83.20	0.95%

Shown in Table 63, there is a large difference between the theoretical and actual descent velocity for the booster section falling under drogue. The large percent difference is due to the theoretical data including only the drag coefficient of the parachute and not the vehicle. The result is similar in the comparison between theoretical and actual descent velocity for descent under the main parachute. Since the booster section has a vertical orientation during main descent, the section outputs less drag than in its horizontal orientation during drogue descent.

Table 63: Vehicle Flight 2 - Booster Section Descent Velocities

Parachute	Theoretical Descent Velocity (ft/s)	Actual Descent Velocity (ft/s)	Percent Difference
12.5 in. Drogue	116.39	86.09	29.93%
84 in. Main	14.11	13.74	2.66%

Drift Distance

The drift distance was calculated by dropping a geo-pin at the landing location of both the payload and booster sections and using the GPS coordinates on Google Earth to determine the distance from the launch location. The payload section drifted 1,864 ft and the booster section drifted 2,563 ft from the launch pad. An image of the Google Earth map with the landing locations and distances for the payload and booster section can be seen in Figure 102

Figure 102: Drift Distances from Location of Launch Pad

The payload and booster sections both landed on the same side of the launch pad that the vehicle weathercocked toward. The payload stayed within the 2,500 ft maximum with the main deployment occurring at apogee because the descent time was much longer, allowing the section to drift back to the launch pad after weathercocking into the wind upon launch. The booster section drift was above the 2,500 ft maximum with correct recovery because the descent time was much quicker, and did not have the same amount of time to drift closer to the launch pad after weathercocking. Figure 103 shows the GPS coordinates at apogee and the GPS coordinates from the landing location of each section as recorded from the Featherweight GPS Trackers and the distances between them, which was determined using Google Earth. With a 12 ft launch rail, the off-rail velocity will be high enough to reduce the weathercocking and therefore, the vehicle will achieve apogee much closer to the location of the launch pad. Without the presence of severe weathercocking, the drift distance will be much closer to the drift distances calculated from apogee. Table 64 below shows the drift distance for each section as measured from the launch pad and as measured from apogee.

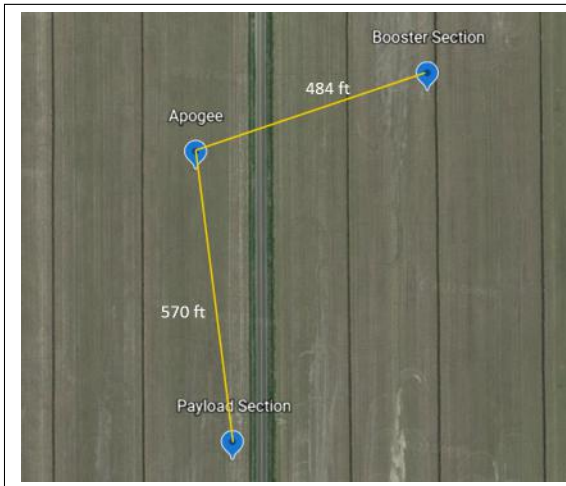


Figure 103: Drift Distances from Location of Apogee

Table 64: Vehicle Section Drift Distances

Section	Drift - Launch Pad	Drift - Apogee
Payload	1,864 ft	570 ft
Booster	2,563 ft	484 ft

The drift distances experienced by the payload and booster sections of the vehicle did not correlate to the expected drift distances of 1,314 ft for the payload section and 1,203 ft for the booster section. The weathercocking experienced by the vehicle and high wind turbulence intensity may have caused these large differences.

Landing KE

Using the descent rates and measured masses of each section, the kinetic energy upon landing was calculated. Equation 15 from Section 3.4.6 was used to calculate the kinetic energy on impact, and the results are shown below in Table 65.

Table 65: Vehicle Flight 2 Landing Kinetic Energy

Vehicle Component	Mass (lbm)	Descent Velocity (ft/s)	Landing Kinetic Energy $(\mathrm{ft-lb_f})$
Nose Cone	3.00	23.92	26.65
Payload Recovery Section	6.21	23.92	55.17
Payload Airframe Section	2.65	23.92	23.54
Booster Recovery Section	7.25	13.74	21.25
Booster Propulsion Section	12.80	13.74	37.52
ANVIL	4.75	23.92	42.20

The percent difference between theoretical and actual kinetic energy at landing is much higher for the payload subsections than for the booster subsections. This larger percent difference may be due to the time extrapolated from the accelerometer data. The kinetic energy values from Vehicle Flight 1 are a more precise representation of the expected impact force at landing for the payload subsections. Table 65 shows an accurate depiction of the kinetic energy at landing for the booster section's components as the descent velocity was obtained from the RRC3. Table 66 displays the comparison between theoretical versus actual data for each section.

Table 66: Vehicle Flight 2 Theoretical Vs. Actual Kinetic Energy

Vehicle Component	Actual KE $(\mathrm{ft-lb_f})$	Theoretical KE $(\mathrm{ft-lb_f})$	Percent Difference
Nose Cone	26.65	26.6	0.10%
Payload Recovery Section	55.17	55.1	0.12%
Payload Section	23.54	23.1	1.80%
Booster Recovery Section	21.25	22.7	6.50%
Booster Propulsion Section	37.52	39.9	6.10%
ANVIL	42.20	44.4	5.00%

Failure Analysis

The second launch attempt was deemed unsuccessful due to the payload main parachute deploying at apogee. There are two possible sources of error that may have caused the issue and changes will be implemented to address each possibility.

5.3.2.1 Shear Pins

One possible source of error would be from ANVIL deployment forces shearing the shear pins between the payload and payload recovery sections at apogee, releasing the main parachute. While this failure did not occur during the first launch attempt, a third shear pin will be added at this separation point to ensure the payload deployment does not cause premature deployment of the main parachute. Separation testing will be conducted again with updated black powder charge masses to ensure that successful separation occurs at 600 ft.

5.3.2.2 Wiring

Another possible cause of the failure could be from the incorrect wiring of the e-matches. Once the vehicle was loaded onto the rail and the FingerTechs were being turned on, it was discovered that one of the switches on the payload section was not turning on. The arming beep for the altimeters never sounded so the vehicle was taken off the rail to inspect that section and it was discovered that the switch had been stripped. The altimeter bay was disassembled to solder new leads to a new FingerTech switch. Upon reassembling the altimeter bay, the e-matches may have been wired into the wrong terminals. This would cause the main to deploy at apogee and the streamer to deploy at 600 ft. The streamer did, however, deploy at apogee, possibly due to the high deployment forces of the main parachute shearing the shear pins on the nose cone. An additional charge was identified visually at 600 ft, indicating that a charge was detonated at apogee and at main deployment, whether or not it was wired to the correct RRC3 terminal.

To ensure this possible issue is not repeated, the launch day safety checklist was updated. The checklist will be completed anytime a sub-assembly of the vehicle is disassembled or changed. The assembly of the altimeter bays will be supervised and checked by the Safety Officer, as stated in the safety checklist. An additional team member who was not involved in the initial assembly process will also be required to verify all critical steps have been followed correctly. To further mitigate this possibility of error, E-match wires will be color-coded with electrical tape on each end prior to assembling the altimeter bays. The primary drogue and streamer wires will be denoted with yellow electrical tape, while the backup drogue and streamer wires will be denoted with green electrical tape. The primary payload and booster main wires will be denoted with red electrical tape, while the backup payload and booster main wires will be denoted with blue electrical tape. This will further prevent errors when following the wires through the E-match holes. These steps have been added to the payload and booster avionics bay launch day checklists described in Sections 6.3.1 and 6.3.1.

5.4 Payload Flight 2

The second payload demonstration flight took place in Bayboro, North Carolina on the 26th of February, 2022. There were no parts of ANVIL that were damaged during the flight or the recovery process, demonstrating the mechanical robustness of this design. In addition to not sustaining damage, ANVIL was also able to effectively slide off the rails and deploy safely.

5.4.1 Flight Results and Analysis

During this flight the changes that had been made following the first flight were largely shown to be effective as the retention of the ANVIL housing functioned as intended. The gimbal pieces manufactured from aluminum showed little to no wear or damage, and the screws added to the rails effectively solved the problems that were observed during the first launch. Unfortunately, with the main parachute deploying at apogee the payload did not go through the most extreme forces that would normally be experienced over the course of the flight. However, the AV bay accelerometer still experienced about 20 g's of force at apogee and despite this the payload eye bolts and fiberglass plate were able to withstand this deployment.

Unfortunately, there was a software configuration issue that resulted in no photos being taken during the flight. Without photos there is no way of knowing whether the gimbal retraction system extended and retracted as intended. When the payload's FingerTech was turned on, the servo motor could be heard extending and retracting in order to verify its home location. This verification shows that this system was functioning as intended prior to launch. Despite the gimballed camera not extending or retracting, the set home position was the same as the position the gimbal was recovered in. The final position of the gimbal on recovery can be seen below in Figure 104.

Figure 104: Gimbal Following Recovery

The most important retention lesson learned was that the servo motor chosen can hold the gimballed camera in place during both launch and recovery without slippage or undesired rotation of the pinion. Slippage was a potential concern with the previous servo motor chosen; this concern has been alleviated by the new servo motor.

The payload was intended to function identically to the first attempted payload demonstration flight, with the altitude checkpoint adjusted to reflect what was learned from the first launch. In this launch the code was not supposed to run until a checkpoint altitude of 2000 ft was read by the pressure sensor which tells the payload that a flight is occurring and to observe data. Upon recovery the camera was still being actively gimballed, which shows that the payload was still receiving power. The lack of photos demonstrated that either an error occurred somewhere within the code before the vehicle exited the launch rail or that the pressure sensor had an error and never read an altitude of 2000 ft to know when begin the code.

5.5 Future Flights

The third flight will be conducted on March 12thin Dalzell, South Carolina. This flight is meant to verify the vehicle safety and flight performance with added ballast. This flight will also serve as a Payload Demonstration Flight, which will ensure ANVIL is safely retained throughout launch and recovery.

6 Safety

6.1 Safety Officer

The Safety Officer (SO), Daniel Naveira, is responsible for ensuring that the safety regulations are followed by all team members and that a safe work environment is maintained. The Safety Plan, which will address the hazards associated with the materials and facilities, will be developed and maintained in the safety handbook by the SO. The risks that must be accounted for include, but are not limited to: risks of personal injury, risks of damaging lab equipment, risks of damaging vehicle and/or payload, environmental risks, and risks to the completion of the overall project. The Backup SO will be Caden Pyne, who will fill in for the SO in case of sickness or scheduling conflicts.

6.2 Failure Mode and Effects Analysis

6.2.1 Risk Analysis Definitions

Tables 67, 68, 69, and 70 are the working tables that show how the hazard analyses and Failure Modes and Effect Analyses (FMEA) probability and severity ranks are determined. These tables will be referred to as the Risk Assessment Codes (RAC) and are designed to classify the probability and severity of hazards in order to identify when mitigation solutions are necessary. Color coding will be used to act as a visual representation of the probability and severity of a specific hazard. Furthermore, a more specific RAC Ranking System will be utilized that uses alphabetical letters to identify the severity of a hazard and an increasing numerical counter associated with the increasing probability of its occurrence. The RAC Ranking System can be seen below in Table 67.

Table 67: RAC Ranking System

Probability	Severity			
	A	B	C	D
	Catastrophic	Critical	Minor	Negligible
5 - Frequent	5A	5B	5C	5D
4 - Likely	4A	4B	4C	4D
3 - Occasional	3A	3B	3C	3D
2 - Seldom	2A	2B	2C	2D
1 - Improbable	1A	1B	1C	1D

From the RAC Ranking System table the specific alphanumerical rankings can be categorized in a Probability/Severity Index. This, along with an Assessment/Management Level definition will be used to determine which hazards need SO approval and mitigation planning. Table 68, seen below, defines the acceptance and management requirements associated with each category of the Probability/Severity Index.

Table 68: Risk Assessment and Management Level

Probability/Severity Index	Assessment/Management Level
High Risk 5A, 5B, 4A, 4B, 3A	Unacceptable at current state. Mitigation is required.
Moderate Risk 5C, 5D, 4C, 3B, 2A, 2B	Unwanted and avoid when possible. Safety Officer's signed approval. Mitigation is required.
Low Risk 4D, 3C, 2C, 1A, 1B	Tolerable. Safety Officer's signed approval recommended. Mitigation is required.
Minimal Risk 3D, 2D, 1C, 1D	Acceptable. Safety Officer's evaluation recommended. Little to no mitigation is required.

The hazards that are identified by the SO and the team will be examined to determine the primary cause and effect that it may have on personnel, the success of the project, and/or the equipment. During the examination of a hazard, a RAC ranking will be assigned and the safest plan for mitigating the hazard will be made. The criteria used to determine the severity portion of the RAC ranking of a Hazard can be seen in Table 69.

Table 69: Severity Definitions

Description	Health and Safety of Personnel	Facilities and Equipment	Environment	Mission Success
A - Catastrophic	Death, permanently disabled	Unrepairable damage to facility/equipment	Permanent damage to environment, violation of environmental laws	Leads to mission failure
B - Critical	Serious injury requiring paramedics	Severe damage to facility/equipment	Severe but reversible damage to environment	Serious effect on the success of the mission
C - Minor	Mild injury	Mild damage to facility/equipment	Mild damage to environment with no violation of laws	Marginal effect on the success of the mission
D - Negligible	Minimal injury, only requires basic first aid	Wear/no damage to facility/equipment	Insignificant damage to environment with no violation of laws	Trivial effect on the success of the mission

The criteria used to determine the probability portion of the RAC ranking of a Hazard are based on of the probability of occurrence. These probabilities of occurrence are defined below in Table 70.

Table 70: Probability Definitions

Description	Qualitative Definition	Quantitative Definition
5 - Frequent	Likely to continuously occur.	Occurrence: >50% of the time.
4 - Likely	High probability of occurring.	Occurrence: 25% - 50% of the time.
3 - Occasional	Expected to occur from time to time.	Occurrence: 10% - 25% of the time.
2 - Seldom	Low probability of occurrence.	Occurrence: 1% - 10% of the time.
1 - Improbable	Unexpected to occur.	Occurrence: <1% of the time.

The plan to mitigate each specific hazard will be provided within the hazard analyses and FMEA tables. For each hazard's mitigation plan a simpler "Mitigation Type" will be assigned to the hazards for a quick reference of the mitigation plan. These mitigation types and how they are defined by the team can be seen in Table 71.

Table 71: Mitigation Types

Mitigation Type	Description
Design	Mitigation of hazards will be built into the initial design.
Guards/Barriers	Use of equipment to minimize or eliminate the hazard.
Analysis	Detailed evaluation of the components and overall structure.
Testing	Field testing of critical components, systems, and overall structure.
PPE	Personal Protection Equipment will be worn to mitigate hazard.
Procedure, Safety Plan	Safety checklist and regulations will be made and followed.

Tables 72, 73, 74, and 75 show the hazard analysis and FMEA associated with personnel, launch vehicle, recovery system, and the payload ANVIL. These tables do not include all of the hazards that will be faced throughout the project, and will need to be updated as the project advances. Tables 76 and 77 discusses the team's environmental concerns in FMEA format.

6.2.2 Personnel Hazard Analysis

Table 72: Personnel Hazard Analysis

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Injury to personnel due to the detonation of the motor e.g. (catastrophic at take-off (CATO), installation, transportation, etc.)	1. Minimum withdrawal distance requirements of personnel not met. 2. Premature installation of motor igniter. 3. Mishandling of rocket motor during transportation. 4. Failure to follow rocket motor assembly instructions. 5. Faulty rocket motor.	Death, loss of limbs, loss of eyesight, severe injury, burns	4A	1. In accordance with *NAR High Power Rocket Safety Code*, team personnel will withdraw a minimum distance of 300 ft when using a L motor type respectively prior to the launch depending upon the full-scale vehicle design selected. 2. Installation of the igniter will only occur once the launch vehicle has been placed on the launch rail, and all nonessential personnel have withdrawn to the safe minimum distance. 3. Transportation, general handling, and assembly of all rocket motors will only be conducted by NAR certified personnel and/or the SO. 4. Reputable vendors will be used for the purchase of motors. 5. Motor preparations will be done in direct accordance with manufacturer's assembly guidelines.	Procedure, Safety Plan	1A	1. FRR 3 Launch Vehicle Summary, Final Motor Choice: Aerotech L1390-G. 2. FRR 6.3.1 Full-scale safety checklist, Igniter Installation, ****WARNING** All nonessential personnel must withdrawal a minimum distance of 300 *feet* at this time.** 3. FRR 6.3.1 Full-scale safety checklist, Motor Preparation, NOTE: The following procedures will be completed strictly by the 49er Rocketry Team NAR mentor (Jerry Dahlburg) or certified NAR personnel (Caitlin Bunce). Motor preparations will be done in direct accordance with manufacturer's assembly guidelines. 4. FRR 6.3.1 Full-scale safety checklist, Igniter Installation, ****WARNING** The igniter installation procedures will only be conducted once all other steps of the checklist have been completed.** 5. FRR 8.4 Appendix E: *NAR High Power Rocket Safety Code* part 6. "Launch Safety."
COVID-19 infection	1. Not abiding by CDC and/or UNCC COVID-19 prevention guidelines.	Becoming sick, permanent lung damage, weakness, fatigue, need to take time off, and death	3A	1. Team personnel will follow all CDC and UNCC guidelines for COVID-19 prevention. 2. All team member will be required to wear masks. 3. Team personnel are encouraged to get vaccinated. 4. Lab spaces and equipment will be cleaned prior and after use.	PPE, Procedure, Safety Plan	1A	1. FRR 8.3 Appendix D: COVID-19 Guidelines

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Inadvertent ignition of separation charges	1. Static electricity discharged into separation system. 2. Prematurely arming the altimeter. 3. Minimum withdrawal distance not met.	Loss of fingers, severe injury to extremities, burning of skin and eyes, loss of hearing	3A	1. The launch vehicle will be designed so that the altimeter(s) of the separation system can be armed/disarmed on the launch rail. 2. The safety checklist will be used as instructions for the assembly of the separations system and guideline for the use of PPE (Nitrile gloves and safety glasses). 3. Personnel assembling separation system will ground themselves prior to handling the black powder and e-matches. 4. Nonessential personnel must withdraw a minimum of 15 ft during assembly of separation system. 5. Altimeter(s) will not be armed until the launch vehicle has been placed on the launch rail.	Design, PPE, Procedure, Safety Plan	1A	1. FRR 3.3.6 FingerTech Switch, The altimeter bay electronics are powered on from outside the vehicle onto the launch rail with the use of a FingerTech Switch. 2. FRR 6.3.1 Full-scale Safety Checklist, Launch Pad Setup, (LPS.8) Arm the recovery altimeters by screwing the FingerTech switches to the on position and verify there is an audible tone for both altimeters. 3. FRR 6.3.1 Full-scale Safety Checklist, Booster Avionics Bay Assembly and Payload Avionics Bay Assembly, NOTE Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or SecondaryRecovery Officer (John Allman) will conduct all AV bay preparations. 4. FRR 6.3.1 Full-scale Safety Checklist, Payload Avionics Bay Assembly, ****WARNING** All nonessential personnel must withdraw at least 15 *feet* at this time.** 5. FRR 6.3.1 Full-scale Safety Checklist, Launch Pad Setup, Disarm
Injury during bulkhead tensile test	1. Not meeting minimum withdrawal distance. 2. Not wearing safety glasses. 3. Failure to follow lab guideline. 4. Failure to follow safety and testing plan procedures. 5. Flying debris.	Fracturing of bones, loss of vision, cuts, bruising	3A	1. Personnel will follow the testing procedures outlined in the test plans. 2. Personnel will follow the safety requirements outlined in the test plan. 3. The SO must be present in order to preform this test. 4. Personnel must wear safety glasses while preforming this test. 5. In the event of an emergency personnel will use the red emergency stop button.	Procedure, Safety Plan, Design	1A	1. FRR 7.1.9 VT9 - Bulkhead Tensile Testing, Safety Precautions: protective eye wear is always required. 2. FRR 7.1.9 VT9 - Bulkhead Tensile Testing, Safety Precautions: Test personnel must NEVER place their hands around the test apparatus during testing. 3. FRR 7.1.9 VT9 - Bulkhead Tensile Testing, Safety Precautions: If the test needs to be stopped immediately, the emergency stop button will terminate the test instantly.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Injury during coefficient of drag tests	1. Not meeting minimum withdrawal distance. 2. Not wearing hardhat. 3. Failure to follow safety and testing plan procedures. 4. Personnel not paying attention during testing. 5. Personnel struck by falling weight. 6. Personnel sticking extremities into fan.	Severe bruising, concussion, cuts, loss of extremities	3A	1. Personnel will follow the testing procedures outlined in the test plans. 2. Personnel will follow the safety requirements outlined in the test plan. 3. The SO must be present in order to preform this test. 4. Personnel must wear hardhats while preforming this test. 5. Personnel must withdraw at least 75 ft from landing zone. 6. The team will announce the commencement of the test to ensure all personnel are paying attention to the test. 7. Personnel shall never stick their extremities inside the fan area.	PPE, Procedure, Safety Plan	1A	1. FRR 7.1.3 VT3 - Coefficients of Drag Test 1, Safety Precautions: 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. 2. FRR 7.1.3 VT3 - Coefficients of Drag Test 1, Safety Precautions: This member is required to wear a hardhat. The safety officer must be present for this test. 3. FRR 7.1.4 VT4 - Coefficients of Drag Test 2, Safety Precautions: Team members should never put their fingers inside the fan. 4. FRR 7.1.5 VT5 - Coefficients of Drag Test 5, Safety Precautions
Injury due to a failure in the recovery system	1. Parachute not opening/shroud lines being tangled. 2. Damage to parachute (holes, tearing, cut shroud lines, etc.). 3. Shock cord not being attached. 4. Failure to separate booster sections of launch vehicle.	Death, Severe injury, heavy impact by high velocity falling object, injury from component fragmentation	3A	1. The safety checklist will be used as instructions for the assembly of the launch vehicle to ensure that the shroud lines are checked for tangling, parachutes are correctly folded, and shock cords are attached. 2. Parachutes will be inspected for damage (holes, tearing, cut shroud lines, etc.) prior to use. 3. E-match will be checked for continuity before the assembly of the separation system. 4. The team will calculate the black powder needed and conduct a separation test for verification.	Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 3.3.4 Ejection Charges: Black powder mass calculation Equation 1 Ideal Gas Equation. 2. FRR 6.3.1 Full-scale Safety Checklist: Inspection Form (PRE.1), Post-flight Inspection, (PFI.1) and (PFI.2) 3. FRR 6.3.1 Full-scale Safety Checklist: Payload Streamer Preparations, Payload Parachute Preparations, and Booster Parachute Preparations. 4. FRR 7.1.2 VT1 vehicle Sub-scale separation demonstration 5. FRR 7.1.10 VT10 Full-scale Separation Demonstration
Lead poisoning	1. Use of lead components/parts 2. Use of lead base paint 3. Ingestion of lead	Becoming sick, high blood pressure, abdominal pain, fatigue, constipation, reduced sperm count, nausea, vomiting and death	3A	1. The team will not use the toxic metal lead for any portion of the project. 2. The mass element for the launch vehicle will be made up of the less toxic metal tungsten.	PPE, Procedure, Safety Plan	1D	1. FRR 3.2.2 Material Summary: Table 8: Launch Vehicle Subsystem Material Selections, There is no lead used in the construction of the vehicle.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Injury during Altimeter firing demonstration	1. Not meeting minimum withdrawal distance. 2. Not wearing safety glasses. 3. Failure to follow safety and testing plan procedures. 4. Inadvertent ignition of electronic matches.	Mild thermal burns, loss of vision	3A	1. Personnel will follow the testing procedures outlined in the test plans. 2. Personnel will follow the safety requirements outlined in the test plan. 3. The SO must be present in order to preform this test. 4. Personnel must wear safety glasses while preforming this test. 5. The recovery officer will handle all E-match preparations and ensure to be grounded while handling the E-matches. 6. Personnel must withdraw a minimum distance of 5 ft during testing.	PPE, Procedure, Safety Plan	1A	1. FRR 7.1.1 Altimeter Firing Demonstration, Safety Precautions: Team members present for the test will stand at least 5 feet from the vacuum chamber. 2. FRR 7.1.1 Altimeter Firing Demonstration, Safety Precautions: The safety officer and recovery officer must be present for the test.
Injury during drone testing	1. Propeller blades activate during assembly. 2. Minimum recommended withdrawal distance not met by personnel. 3. Personnel not paying attention during flight. 4. Drone falling out of sky. 5. Losing connection and/or control of drone during flight. 6. PPE requirements are not met by personnel.	Severe to mild injuries, scrapes, cuts and bruising	4B	1. All personnel will withdraw a minimum distance of 25 ft before testing and activation of the propeller blades. 2. All personnel will use caution and pay attention during test flights using a drone. 3. All personnel present during test involving a drone will wear safety glasses and hardhats. 4. The SO and/or backup SO will be present during all testing and prepare a safety checklist along with the test procedures. 5. The team will follow all FAA laws regarding UAS especially public law *112-95 Section 336 for model aircrafts, and the Federal Aviation Regulations 14 CFR, Subchapter F, Part 107; Small Unmanned Aircraft Systems.* 6. The team will use a drone sold by reputable dealers for all drone tests to reduce drone connection issues.	Procedure, Safety Plan, PPE	1B	1. FRR 7.2.6 PT6 - Raspberry Pi Camera Imaging Demonstration, Safety Precautions: Team members should not touch the drone during flight and stand clear of the propellers. 2. FRR 7.2.8 PT8 - Incorporated Gimbal Camera Test, Safety Precautions

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Injury due to LiPo battery rupturing	1. Failure to follow manufacturer's storage requirements. 2. LiPo battery pack being punctured or damaged by sharp objects. 3. Charging battery packs over manufacture's recommended limit. 4. Overheating of battery. 5. Exposure to water.	Severe irritation and chemical burns to skin, eyes, and respiratory system	4B	1. Storage of battery packs will be in accordance with manufacturer SDS requirements. 2. All battery packs will be inspected for signs of damage prior to use. 3. Battery packs will be charged in accordance with manufacturer's recommended limits. 4. LiPo battery charger has a fail safe to ensure batteries are not overcharged. 5. In accordance with *NASA, 2021-2022 USLI Handbook, General and Proposal Requirements 2.22* all batteries will be sufficiently protect from ground impacts, brightly colored, and easily identifiable from the other hardware. 6. LiPo batteries will be brightly colored with tape and marked as fire hazards. 7. LiPo Batteries will be significantly protected from impact.	Design, Procedure, Safety Plan	1B	1. FRR 3.3.6 Altimeter Bay Components, Accelerometer 2. FRR 4.7.1 Dimensions: The electrical bay, housing all of the payload's electronics, has a usable length of 4.75 in. with a width of 3.53 in. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1) 4. FRR 6.3.1 Full-scale Safety Checklist: Post-flight inspections (PFI.1) 5. FRR 6.3.1 Full-scale Safety Checklist: Batteries are to be placed in LiPo safe battery bags during transportation.
Injury due to soldering iron	1. Coming in contact with soldering iron during use or shortly after use. 2. Not wearing required PPE. 3. Not soldering in a well ventilated area	Severe to mild burns, irritation to eyes and lungs	4B	1. Personnel will use caution and abide by the PPE requirements outlined in the SDS (goggles, respirator, and gloves) when soldering. 2. Soldering iron will be used in a well ventilated area. 3. Soldering iron will be placed in its stand when it is not actively being used to prevent accidental contact.	Guards, Procedure, Safety Plan, PPE	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. Safety glasses will be worn at all times while preforming tasks on the checklist. 2. FRR 8.2 Appendix B: Lab Safety Guidelines

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Carbon fiber and/or fiberglass dust particles	1. Manufacturing of carbon fiber or fiberglass parts with insufficient ventilation. 2. Not wearing required PPE (safety glasses, mask/dust respirator, and full body covering clothing).	Permanent lung damage, loss of vision, irritation to skin, eye, and lungs	4B	1. The fabrication of carbon fiber and fiberglass parts will be conducted outside or in well ventilated areas. 2. Team personnel will abide by the PPE requirements outlined in the SDS of carbon fiber and fiberglass (safety glasses, mask/dust respirator, and full body covering clothing).	Guards, PPE, Procedure, Safety Plan	1B	1. FRR 3.2.7.2 Carbon Fiber Construction: Cut-resistant gloves were worn when handling carbon fiber and nitrile gloves were worn when handling epoxy. 2. FRR 4.8.1 Fiberglass Plate Construction: CNC machine was used to cut the fiberglass plate to ensure personnel was not in direcct contact with cutting. 3. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references.
Personnel injured in machine shop	1. Not abiding by machine shop rules and guideline. 2. Using a machine shop equipment for a process and/or with a material it was not designed for. 3. Using equipment without receiving training for it.	Severe injuries, loss of limbs, vision, and death	2A	1. All personnel will abide by the machine shop rules and guidelines. 2. Machine shop equipment will only be used as intended and by personnel that have received their green badge. 3. Personnel will only use equipment they have received training for. 4. Safety glasses will be worn at all times. 5. When machining in being preformed at least two team member must be present.	PPE, Procedure, Safety Plan	1A	FRR 8.2 Appendix B: Lab Safety Guidelines
Food allergies	Ingestion or exposure to peanut butter, bananas, cantaloupe, pineapple, or shellfish depending on specific personnel.	Anaphylactic shock, Death	2A	1. All team personnel will be made aware of the food allergies of other team members. 2. All team personnel will avoid ordering or eating the food listed in the cause column when around team members and at team meals. 3. During all team meals there will be two epinephrine auto-injector (EpiPens) present.	Guards, Procedure, Safety Plan	1A	FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Paking list, PPE, Epipens (x2)

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Skin, eye, and/or respiratory exposure of chemicals during construction	1. Personnel failing to abide by PPE requirements outlined in the respective SDS. 2. Personnel failing to follow the handling procedures outlined in the respective SDS.	Skin, eye, and/or respiratory irritation, chemical skin burns, loss of vision	2A	1. Personnel must review the SDS of a hazardous chemical prior to handling it. 2. Personnel handling a hazardous chemical must adhere to the PPE requirements listed in the SDS for the chemical. 3. Personnel must adhere to the handling procedures outline in the SDS for the particular chemical.	PPE, Procedure, Safety Plan	1A	1. FRR 6.1 Safety Officer, The Safety Plan, which will address the hazards associated with the materials and facilities, will be developed and maintained in the safety handbook by the SO. 2. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. Safety glasses will be worn at all times while preforming tasks on the checklist.
Electrocution	1. Coming into contact with frayed power cord. 2. Contact with exposed wires.	Severe to mild burns, death	2A	1. Examine power cords for signs of damage prior to use. 2. Design vehicle and payload to minimize exposed wires. 3. Examine wires for damage prior to assembly of vehicle and payload.	Procedure, Safety Plan, Design	1A	1. FRR 6.1 Safety Officer, The Safety Officer (SO), Daniel Naveira, is responsible for ensuring that the safety regulations are followed by all team members and that a safe work environment is maintained. 2. FRR 6.3.1 Full-scale Safety Checklist: Inspection Form, (PRE.1)
Unstable launch resulting in injury	1. Miscalculation of launch vehicle stability or launch angle. 2. Launch day wind conditions exceeding 20 mph crosswinds. 3. Launching with lighting storms and/or heavy rain within a 5 mile radius of launch field. 4. Visibility under 5 miles.	Serious to mild injury	3B	1. The launch vehicle will be designed to have a minimum static stability margin of 2.0 at rail exit in accordance with the NASA USLI Handbook. Calculations will be done using OpenRocket and by hand once constructed. 2. The CP and CG will be marked on the vehicle and the CG will be verified at the launch site. 3. The *NAR High Power Rocket Safety Code* and safety checklist will be used on launch days to determine if conditions are safe enough to launch.	Design, Analysis, Testing, Procedure, Safety Plan, PPE	1B	1. FRR 3.2 Launch Vehicle Design and Construction, Overview: pre-burn stability margin of 3.16 and post-burn stability margin 3.80 2. FRR 6.3.1 Full-scale Safety Checklist: Constraints 3. FRR 6.3.1 Full-scale Safety Checklist: Launch Pad Setup, ****WARNING** All nonessential personnel must withdrawal a minimum distance of 300 *feet* at this time.** 4. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Location: Adverse weather conditions for this launch are described as: crosswinds in excess of 20 mph, lightning storms within a 5 mile radius of the launch field, heavy rain, visibility under 5 miles, or any other scenario that is deemed unsafe by the primary, secondary, or range safety officer.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Bug bite	1. Working outside 2. Coming in contact with bugs 3. Not using bug spray 4. failure to bring bug spray	Skin rashes, redness, itchiness, swelling	5C	1. The team will bring bug spray to all launches. 2. Personnel will be advised to use bug spray when necessary.	PPE, Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing list, PPE: Bug Spray
Personnel become sun burnt	Overexposure to the sun and its UV light during operations.	Moderate pain to skin, long term skin cancer	4C	A pop-up tent will be brought to launches to provide shade and sunscreen will be provide to the team for skin protection.	Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Paking list, PPE: sunscreen , Tools: Tent
Injury during ground testing of separation system	1. Personnel struck by an element of the vehicle. 2. Minimum withdrawal distance not met by personnel. 3. Premature activation of separation system. 4. Not wearing safety glasses.	Mild bruising, burns, cuts, hearing damage	3C	1. Personnel will stand clear of the direct path of the vehicle at a minimum distance of 15 ft. 2. The ground separation test will be carried out by the recovery officer under the supervision of the SO. 3. The safety checklist will be used as a guideline for the ground separation test. 4. Team personnel will wear safety glasses during ground testing. 5. Personnel must wear hearing protection.	PPE, Procedure, Safety Plan	1C	1. FRR 7.1.2 VT1 - vehicle Sub-scale separation test: Safety Precautions, Procedures 2. FRR 7.1.10 VT10 - Full-Scale Separation Demonstration: Safety Precautions, Procedures 3. FRR 7.1.10 VT10 - Full-Scale Separation Demonstration: Safety Precautions, Hearing protection is to be worn at all times during live testing. NRR 25 dB (orbetter) earmuffs and/or ear plugs are required for individuals within 30 feet of the live fire event.
Heat Exhaustion	1. Overheating due to excessive sun exposure. 2. Not staying hydrated.	Dizziness, heavy sweating, headache, and fainting	3C	1. Water will be brought to every launch and available for all team personnel. 2. A tent will be brought to all launches to provide a shaded area for team personnel.	Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Paking list, PPE: Water, Tools: Tent
Inadvertent ignition of electronic matches (E-match)	1. Electrostatic buildup and discharge into E-match. 2. Not following safety checklist and SDS requirements.	Mild thermal burns to skin	2C	1. The recovery officer will handle all E-match preparations and ensure to be grounded while handling the E-matches. 2. The safety checklist and SDS will be used as a guideline for E-match preparations.	PPE, Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. 2. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, Booster Avionics Bay Assembly

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Personnel injured during successful recovery deployment	1. Personnel not paying attention during launch and recovery. 2. Minimum withdrawal distance not met by personnel.	Mild injuries, bruising, cuts, light impact with vehicle	2C	1. Team personnel will stop working and pay attention throughout the entire launch and recovery process to avoid the falling vehicle. 2. In accordance with *NAR High Power Rocket Safety Code* team personnel will withdraw a minimum distance of 300 ft when using a L motor type.	Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Launch Pad Setup, ****WARNING** All nonessential personnel must withdrawal a minimum distance of 300 *feet* at this time.**
Injury to personnel during assembly of vehicle or payload	1. Not following safety checklist hazard warnings. 2. Not being cautious of pinch points.	Minimal injuries, cuts, and bruising	2C	1. Team personnel will follow the safety checklist during assembly of the vehicle and payload. 2. Personnel will pay close attention for safety icons in the safety checklist to identify possible pinch points.	Procedure, Safety Plan	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Safety Icons table
Injury to personnel caused by tripping, slipping, or falling	1. Messy work space (Components, equipment, and/or power cords left on the floor and walkways). 2. Roots, rocks, and/or other objects on launch field.	Minimal injuries, scrapes, cuts, and bruising	2D	1. Personnel are required to maintain a clean work space by returning all equipment, components, and materials to their storage location after use. 2. Personnel will avoid having power cords in walkways when possible, and tape down the power cords when not possible. 3. Personnel will pay attention when walking around launch fields. 4. Team personnel will be requited to wear closed toe shoes in all lab spaces and launch fields.	PPE, Procedure, Safety Plan	1D	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: All team personal must wear closed toe shoes for launch days. 2. FRR 6.3.1 Full-scale Safety Checklist: Post-Flight Recovery, ***CAUTION* All personnel must walk not run to recover the launch vehicle and payload. Failure to follow there these procedure may result in injury to personnel.** 3. FRR 8.2 Appendix C: Lab Safety Guidelines

6.2.3 Vehicle FMEAs

Launch Vehicle

Table 73: FMEA of Launch Vehicle

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Motor detonation causing CATO	1. Failure of motor casing. 2. Failure to follow rocket motor assembly. 3. Mishandling of rocket motor during transportation, storage, and general handling. 4. Faulty rocket motor.	Irreparable damage to vehicle	5A	1. Team personnel will conduct a pre-flight inspection of the motor and motor casing in accordance with the safety checklist to check for any evidence of damage. 2. The SO and NAR mentor will supervise the motor preparations to ensure manufacturer guidelines are followed. 3. Transportation and general handling of all rocket motors will only be conducted by NAR certified personnel and/or the SO. 4. The team's NAR mentor will be in-charge of all motor storage. 5. The team will only purchase rocket motors from reputable vendors.	Procedure, Safety Plan	1A	1. FRR 3 Launch Vehicle Summary, Final Motor Choice: Aerotech L1390-G. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1) 3. FRR 6.3.1 Launch Checklist, Motor Preparation, NOTE: The following procedures will be completed strictly by the 49er Rocketry Team NAR mentor (Jerry Dahlburg) or certified NAR personnel (Caitlin Bunce). Motor preparations will be done in direct accordance with manufacturer's assembly guidelines.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Failure in airframe structural integrity	1. Failure to select material strong enough to withstand the forces placed upon the vehicle during launch, recovery, and impacts. 2. Material damaged prior to launch (construction, transportation, storage).	Loss of launch vehicle, Failure of mission	4A	1. The team will select a material for the airframe based on calculation for compressive and tensile strength. 2. The team will run comprehensive Finite Element Analysis (FEA) simulations on the vehicle airframe. 3. The vehicle airframe will be inspected for signs of damage prior to and after launch in accordance with the safety checklist. 4. The team will test the strength and hardness of the airframe once constructed.	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 3.2.2 Launch Vehicle Material Summary: The launch vehicles airframe is made of carbon fiber, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 3.2.3 Payload Section, 3.2.4 Booster Section 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspection, (PFI.1) and (PFI.2) 4. FRR 7.1 Vehicle Testing: VT6, VT7, VT9, VT12, VT13 The bulkhead was able to withstand a maximum of 1,678 lbf. 5. CDR 3.9.10 Material Structural Analysis: Table 49 Material Tensile and Compressive Strengths 6. CDR 3.9.10 Material Structural Analysis: Table 50 Material Stresses
Failure of boattail	1. Boattail not being screwed all the way down. 2. Boattail threads shear from overload.	Severe to irreparable damage to vehicle, loss of motor retention, failure of mission	3A	1. The threaded motor retainer cap will be permanently epoxied to motor tube. 2. Boattail and motor retainer cap will be inspected for damage prior to and after launch of vehicle in accordance with the safety checklist.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 3.2.2 Material Summary: Boattail was additively manufactured with ULTEM 9085. 2. FRR 3.2.6 Boattail The Aeropack motor retainer is epoxied with a 1:1 ratio of ES6209 Aeropoxy 2.91 in. into the boattail. 3. FRR 3.2.8.4 PEI: ULTEM 9085 was the PEI used for components that required higher temperature performance and impact resistance, such as the boattail and the fin guide 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1) 5. FRR 7.1 Vehicle Testing: VT6, VT12, VT13 6. CDR 3.6.6 Boattail: ULTEM 9085 has a glass transition temperature of 186°C, impact toughness properties and will be capable of withstanding the expected 65.2 ft-lbf of impact energy.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Engine block failure	1. Material selected cannot withstand forces applied to it. 2. Epoxy fails due to insufficient quantity and curing time. 3. Damage to engine block prior to launch.	Mild to irreparable damage, CATO, failure of mission	3A	1. The engine block will be made of carbon fiber and be permanently epoxied to the airframe. 2. Manufacturer's specifications for set time of epoxy will be followed. 3. Inspection of the engine block prior to and after all launches will be conducted to identify any possible damage. 4. The team will verify the strength of the engine block by conducting an Instron test.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 3.2.2 Launch Vehicle Material Summary: The launch vehicles airframe is made of carbon fiber, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 3. FRR 7.1 Vehicle Testing: VT6, VT9 The bulkhead was able to withstand a maximum of 1,678 lbf. 4. CDR 3.9.10 Material Structural Analysis: Table 49 Material Tensile and Compressive Strengths 5. CDR 3.9.10 Material Structural Analysis: Table 50 Material Stresses
Nosecone damaged	1. Nosecone sustains impact exceeding material strength. 2. Failure to fasten down nosecone to airframe. 3. Nosecone damaged prior to launch.	Damage or loss of nosecone, change to flight profile, increase of drag, loss of electronics	3A	1. The Nosecone will be 3D printed using ABS for its strength and it is easily replaceable using the RPL. 2. The safety checklist will be used prior to launch to inspect the nosecone for damage and verify the nosecone is attached to the airframe.	Design, Procedure, Safety Plan	1A	1. FRR 3.2.6 Nosecone, The LD-Haack series nose cone was additively manufactured out of ABS plastic. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) and (PFI.2) 3. FRR 7.1 Vehicle Testing: VT6, Sub-scale launch 2, VT12 full-scale Flight Demonstration, VT13 Full-scale flight test. 4. CDR 3.9.10 Material Structural Analysis: Table 49 Material Tensile and Compressive Strengths
Failure of fins due to fin flutter	1. Fin material selected not strong enough. 2. Launch vehicle greatly exceeds velocity that it was designed for. 3. Fins being damage prior to launch.	Flight profile drastically changing, loss of fins and vehicle stability	4B	1. The team will be using a modular fin design that will be 3D printed and then covered by a carbon fiber layer to increase strength and rigidity. 2. Fins will be designed and tested to withstand the forces placed upon them during flight and recovery. 3. The fins will be inspected prior to and after all launches for signs of damage.	Design, Analysis, Testing, Procedure, Safety Plan	1B	1. FRR 3.2.2 Materials Summary: The fins are additively manufactured using ABS Plastic with a 1x1 twill weave Carbon Fiber coating, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 3. FRR 7.1 Vehicle Testing,VT6, VT7, VT8 VT12, VT13

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Centering ring failure	1. Centering ring material not strong enough to withstand forces applied. 2. Epoxy fails due to insufficient quantity and curing time. 3. Centering rings being damaged prior to launch.	Loss of motor and flight stability, severe damage to booster section and vehicle	4B	1. The centering rings will be made out of carbon fiber to ensure they are strong enough. 2. The centering rings will be epoxied to the booster section airframe and motor tube. 3. Once the epoxy has set in accordance with the manufacturer specification, the centering rings will be inspected and tested to verify attachment strength.	Design, Testing, Procedure, Safety Plan	1B	1. FRR 3.2.2 Materials Summary: The centering rings are made of 1x1 twill weave Carbon Fiber, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 3.2.6 Motor Tube, The centering rings were epoxied onto the motor tube using ES6209 Aeropoxy with a 1:1 ratio. 3. CDR 3.6.3 Motor Retention: The motor tube will be permanently epoxied into the booster section of the airframe via two $\frac{1}{4}$ in. carbon fiber centering rings located 14 in. and 5 in. from the aft end of the airframe. 4. CDR 3.9.10 Material Structural Analysis: Table 49 Material Tensile and Compressive Strengths 5. CDR 3.9.10 Material Structural Analysis: Table 50 Material Stresses
Fin guide failure	1. Does not hold fins in place due to poor tolerances. 2. Epoxy fails due to insufficient quantity and curing time. 3. Damage to fin guide.	Fins become loose or misaligned changing flight profile	2B	1. Fin guide will be made of ABS and epoxied to two centering ring that are epoxied to the motor tube. 2. Epoxying will be done in accordance with manufacturer's specifications and tested to ensure attachment. 3. Fin guides must be inspected prior to launch.	Testing, Procedure, Safety Plan	1B	1. FRR 3.2.6 Motor Tube, The fin guide was epoxied to the two lower centering rings using ES6209 Aeropoxy with a 1:1 ratio. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 3. CDR 3.6.5 Fin Retention: The fin guide will be attached to the motor tube via two carbon fiber centering rings to ensure the fins cannot slip further into the vehicle upon launch.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Fin block failure	1. Material selected is not strong enough or heat resistant. 2. Failure to fasten down fin block to airframe. 3. Poor tolerances when designed and 3D printed. 4. Damage prior to launch.	Flight profile drastically changes, fins become loose, loss of vehicle stability	2B	1. The fin block will be 3D printed using ABS because of its strength properties. 2. The fin block will be fastened down using $\frac{1}{4}$-20 brass heat set inserts. 3. Inspection of the fin block for damage prior to and after launch will be conducted. 4. On launch day the safety checklist will be followed to ensure the fin block is secured to the airframe.	Design, Testing, Procedure, Safety Plan	1B	1. FRR 3.2.2 Materials Summary: The fin block was made using ABS plastic, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 3.2.6 Fin Block: The fin block is located directly behind the fins and secured to the airframe using steel $\frac{1}{4}$- 20 socket set screws and brass $\frac{1}{4}$- 20 threaded heat-set inserts. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)
Rail button failure	1. Rail buttons are too small or too big for the launch rails. 2. Rail buttons comes loose or fall off. 3. Rail buttons are misaligned. 4. Binding caused by high winds.	Not able to launch, loss of vehicle stability off of rail	3C	1. The team will call ahead to NAR launch sites to state its intentions and ensure the rail buttons used will fit a launch rail. 2. Rail buttons will be tightened and secured prior to launch in accordance with the safety checklist. 3. During construction, the rail buttons will be aligned and inspected to ensure straight alignment. 4. Spare rail button will be brought to all launch in case damage is caused to a rail button.	Design, Testing, Procedure, Safety Plan	1C	1. FRR 3.2.6 Rail Buttons: The vehicle has two acetal 1515 rail buttons on the booster propulsion section to position the vehicle onto the launch rail. 2. FRR 3.2.6 Rail Buttons: Figure 14 Rail Button Locations 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Rail button (x4) 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Failure of modular fin	1. Fin does not fit into cutouts on body tube. 2. 3D printed fin with carbon fiber layer not made within allowable tolerances. 3. Fin breaking before or after launch.	New fins must be made, increase of cost	3D	1. Modular fin design allows for fins to be easily replace if broken or if imperfections are found. 2. Carbon fiber layer of fins allows for the fins to be stronger and withstand larger impact forces. 3. The team will always have spare fins in case of fins failing. 4. Fins will be inspected prior to and after all flight looking for any signs of damage in accordance with safety checklist.	Design, Testing, Procedure, Safety Plan	1D	1. FRR 3.2.2 Materials Summary: The fins are additively manufactured using ABS Plastic with a 1x1 twill weave Carbon Fiber coating, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 3.2.6 Fins: The fins were designed with a modified NACA 0012 airfoil cross-section to reduce drag and increase in-flight stability. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Launch Packing List, Modular Fins (x6) 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 5. FRR 7.1 Vehicle Testing, VT6, VT7, VT8, VT12, VT13

Recovery

Table 74: FMEA of Recovery

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Failure to deploy parachute	1. Altimeter(s) fail to be armed or calibrated for the correct altitude. 2. Altimeter being broken. 3. E-matches fail to go off. 4. Separation charges fail to separate the vehicle.	Launch vehicle and payload become irreparable, failure of mission	5A	1. The safety checklist will be used during assembly of the recovery system. 2. Altimeters will inspected during assembly to check for damage and to ensure the correct altitude settings have been set. 3. A backup altimeter will be used for each separation point controlling a backup ejection charge to ensure redundancy. 4. The amount of black powder needed for separation will be calculated and then tested for confirmation prior to the vehicles first flight.	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, (PAVB.1)-(PAVB.19), Booster Avionics Bay Assembly, (BAVB.1)-(BAVB.19) 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 3. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Altimeter Settings: Booster Section Drogue: Apogee (primary) and Apogee + 1 *s* (secondary) Booster Section Main: 600 *feet* (primary) and 500 *feet* (secondary) Payload Section Streamer: Apogee + 1 *s* (Primary) and Apogee + 2 *s* (Secondary) Payload Section Main: 600 *feet* (Primary) and 500 *feet* (Secondary) 4. FRR 7.1 Vehicle Testing: VT1, VT11 vehicle separation tests.
Over pressurization of vehicle	1. Simultaneous ignition of separation charges. 2. Using too much black powder in separation charges. 3. Failure to seal AV bay.	Catastrophic rupture of airframe or bulkheads, premature deployment of main parachute, failure of mission	4A	1. The altimeter will be set to have a delay for the backup separation charge. 2. Black powder calculation for separation will be conducted and tested prior to launch. 3. The team will use a gasket and clay/putty to properly seal the AV bays.	Design, analysis, Procedure, Safety Plan	1A	1. FRR 3.3.4 Ejection Charges Equation 1 Ideal Gas law used to calculate the amount of black powder. 2. FRR 3.3.4 Ejection Charges Table 19: Separation Charge Masses 3. FRR 3.3.5 Gasket: A TPU gasket was then designed to stop the pressure leakage that occurs from black powder charge detonations. 4. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, (PAVB.1)-(PAVB.19), Booster Avionics Bay Assembly, (BAVB.1)-(BAVB.19) 5. FRR 7.1 Vehicle Testing: VT2, VT10 vehicle separation tests.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Failure of Jolly Logic chute release system	1. Jolly Logic not turned on prior to launch. 2. Jolly Logic runs out of batteries. 3. Not properly setting Jolly Logic altitude settings. 4. Jolly Logic is defective or malfunctions.	Parachute doesn't open, catastrophic damage to vehicle and payload, failure of mission	4A	The team will not use a Jolly Logic chute release system, but instead employ a dual deployment system of the parachutes.	Design	1D	FRR 3.3.1 Recovery Subsystems, Table 10: Recovery Events
Damage to parachutes	1. The parachutes exposed to separation charges without protection. 2. Landing in trees or exposure to other sharp objects. 3. Not storing parachutes in designated container.	SO cancels launch, reduction in drag leading to an increase in descent speed and impact forces, catastrophic damage to vehicle and payload, failure of mission	3A	1. Safety checklist will be followed to ensure that all parachutes are completely wrapped in protective nomex blankets prior to being inserted into the airframe. 2. Prior to and after every launch all parachutes will be inspected for damage (fraying, burns, holes, discolorations). 3. All parachutes will be stored in the designated parachute container.	Procedure, Safety Plan	1A	1. FRR 3.3.2 Nomex Blanket: Nomex blankets will be wrapped around the parachutes to ensure they are protected from the combustion of the black powder charges. 2. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation (BPP.1), Payload Streamer Preparation (PSP.1), Payload Parachute Preparation (PPP.1) 3. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation (BPP.8) and (BPP.M.8), Payload Streamer Preparation (PSP.7), Payload Parachute Preparation (PPP.8) 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)
Shroud lines on parachute being tangled	1. Shroud line are already tangled when parachute is packed. 2. Not following the safety checklist steps on how to pack the parachute.	Increase in descent speed and impact forces, catastrophic damage to vehicle and payload, failure of mission	3A	1. The safety checklist will be followed as procedures on how to pack a parachute. 2. All tangles, knots, and twists will be removed for the shroud lines prior to the packing of parachutes. 3. Parachute preparations will be conducted by the Recovery Officer under the supervision of the SO.	Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation (BPP.4) and (BPP.M.4), Payload Parachute Preparation (PPP.4) 2. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation and Payload Parachute Preparation, ***CAUTION*** During the preparation and installations of the parachutes ensure all shroud lines remain free of knots and tangles throughout. **Failure to follow the proper preparation guidelines may result in the failure of the recovery system.**

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Failure of bulkhead	Selecting a material that cannot handle the stresses placed upon it leading to the shearing or rupturing of the bulkhead.	Loss of vehicle section attachments, catastrophic damage to vehicle and payload, failure of mission	2A	1. The bulkheads will be made of carbon fiber due to its high strength to weight ratio. 2. Epoxy will be used to set bulkheads permanently in place and will be done following the manufacturer's directions. 3. Bulkheads will be inspected for any signs of damage prior to installation.	Design, Analysis, Procedure, Safety Plan	1A	1. FRR 3.2.2 Launch Vehicle Material Summary: The bulkheads are made of 1x1 twill weave carbon fiber, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 7.1 Vehicle Testing: VT6, VT9 The bulkhead was able to withstand a maximum of 1,678 lbf. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)
Premature deployment of main parachute	1. Altimeter ignites separation charges prior to intended altitude. 2. Payload deployment shears the shear pins prematurely. 3. Over pressurization of altimeter bay by separation charges.	Launch vehicle drifts outside the maximum 2500 ft. radius recovery area from the launch pad, failure of mission	2A	1. The safety checklist will be used to make sure the altimeters' altitude settings are correctly set. 2. AV bays will be sealed with gasket and clay during construction. 3. The payload housing section and payload AV bay section will be secured with three shear pins instead of the normal two. 4. The safety checklist will be used to make sure the altimeters' altitude settings are correctly set.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 3.3.5 Gasket: A TPU gasket was then designed to stop the pressure leakage that occurs from black powder charge detonations. 2. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, (PAVB.1)-(PAVB.19), Booster Avionics Bay Assembly, (BAVB.1)-(BAVB.19) 3. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Altimeter Settings: Booster Section 4. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, (PAVB.20), Booster Avionics Bay Assembly, (BAVB.20) 5. FRR 147 Vehicle Testing: VT10 - Full-Scale Separation Demonstration, VT12 Vehicle Flight Demonstration

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Payload section tracking system failure	1. GPS transmitter and receiver do not have enough range. 2. GPS transmitter power loss. 3. GPS transmitter antenna is damaged. 4. GPS transmitter retention failure. 5. Failure to follow safety checklist.	Inability to track and locate the payload section of the vehicle, failure of mission	2A	1. The safety checklist will be used to ensure that the the GPS system is working. 2. A Featherweight GPS will be used as the primary tracking system for the booster section of the vehicle. 3. The booster section will have a RCHP trackers for a redundant tracking system. 4. The Featherweight GPS will be powered by a battery that can provide power for 3 hours and has at least a 20% buffer on the current draw. 5. LiPo batteries will be brightly colored with tape and marked as fire hazards. 6. LiPo Batteries will be significantly protected from impact.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 3.3.7 Vehicle Tracking System: Featherweight GPS Tracking System, Is powered by a 400 mAh 7.4V 2s lithium polymer (LiPo) battery. 2. FRR 3.3.7 Vehicle Tracking System: Featherweight GPS Retention, A Featherweight GPS tracker is retained inside a housing capsule, in both the payload and booster section of the vehicle. 3. FRR 6.3.1 Full-scale Safety Checklist: Payload Tracking System Assembly, (PTSA.1)-(PTSA.6) 4. FRR 6.3.1 Full-scale Safety Checklist: Payload Parachute Preparation, (PPP.9)-(PPP.10) 5. FRR 7.1.11 VT11 - Full-Scale RF Tracking Demonstration, VT12, VT13
Booster section tracking system failure	1. GPS transmitter and receiver do not have enough range. 2. GPS transmitter power loss. 3. GPS transmitter antenna is damaged. 4. GPS transmitter retention failure. 5. Failure to follow safety checklist.	Inability to track and locate the payload section of the vehicle, failure of mission	2A	1. The safety checklist will be used to ensure that the the GPS system is working. 2. A Featherweight GPS will be used as the primary tracking system for the booster section of the vehicle. 3. The booster section will have a RCHP trackers for a redundant tracking system. 4. The Featherweight GPS will be powered by a battery that can provide power for 3 hours and has at least a 20% buffer on the current draw. 5. LiPo batteries will be brightly colored with tape and marked as fire hazards. 6. LiPo Batteries will be significantly protected from impact.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 3.3.7 Vehicle Tracking System: Featherweight GPS Tracking System, Is powered by a 400 mAh 7.4V 2s lithium polymer (LiPo) battery. 2. FRR 3.3.7 Vehicle Tracking System: Featherweight GPS Retention, A Featherweight GPS tracker is retained inside a housing capsule, in both the payload and booster section of the vehicle. 3. FRR 6.3.1 Full-scale Safety Checklist: Booster Tracking System Assembly, (BTSA.1)-(BTSA.6) 4. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation, (PPP.11)-(PPP.12) 5. FRR 7.1.11 VT11 - Full-Scale RF Tracking Demonstration, VT12, VT13

6.2.4 Payload FMEA

ANVIL

Table 75: FMEA of ANVIL

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Payload system loses power	1. Battery is not fully charged prior to launch. 2. Battery selected cannot sustain power requirements. 3. Battery become disconnected or damaged. 4. Short circuit of system.	Inability to track and locate vehicle payload section grid location, mission failure	5A	1. The battery will be charged the day before launch in accordance with manufacturer specification. 2. Safety checklist will be used during assembly to ensure the batteries are connected and secured. 3. Inspection of wires will be conducted during assembly and prior to launch. 4. Locking connectors will be used for the battery connections. 5. In order to ensure all electrical components are supplied enough current throughout the duration of the mission, an additional 20% buffer is added to the total energy. 6. The payload will have a sleep mode which will keep most electronics powered down until the ascent phase of the launch is initiated and more than 5g of acceleration is detected by the Adafruit ADXL326.	Design, Analysis, Procedure, Safety Plan	1A	1. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 2. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 4. FRR 6.3.1 Full-scale Safety Checklist: ANVIL Assembly (AA.1)-(AA.24) 5. FRR 4.11.1 Sleep Mode: Most of the electrical components remained off until the ascent of the flight was recorded. The Trinket M0 and ADXL326 accelerometer was used to turn on all other electrical components by enabling the second voltage regulator.
Blast protection failure	1. Airtight seal is not made 2. Not following safety checklist	Camera is covered in black powder residue, camera or gimbal breaks, inability to track grid location, failure of mission	4A	1. ANVIL will have a carbon fiber plate and rubber O-ring to make an airtight seal. 2. The safety checklist will be used to inspect and assemble the blast protection system. 3. The blast protection system will be ground tested to ensure it has an airtight seal.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 4.8.4 Blast Protection Construction: The carbon fiber blast protection plate was cut from a larger sheet with an abrasive water jet cutter. 2. FRR 4.8.4 Blast Protection Construction: The O-ring was epoxied in place with an aerospace grade epoxy to make sure it will not come loose at any point during the launch. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form, (PFI.1)

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Camera malfunction	1. Camera lens breaks, is damaged, or is obstructed during or prior to deployment. 2. Unstable flight causing blurry images. 3. Forgetting to connect camera. 4. Camera becomes loose from gimbal. 5. Power failure to camera. 6. Not following safety checklist. 7. Defective camera. 8. Overheating or short circuit of camera system. 9. Camera covered by black powder residue.	Inability to identify grid location of vehicle, payload mission failure	4A	1. The safety checklist will be used to ensure a pre-flight and post-flight inspection of the camera is conducted looking for any signs of damage to the lenses or wires. 2. Safety checklist will be used as procedures to ensure camera is secured to gimbal system. 3. The camera will be tested to verify functionality during recovery. 4. The camera gimbal will be retractable to reduce chance of damage during landing. 5. The battery selected for this payload will be required to supply power to the system for 2 hours, with a safety factor of 2. 6. Two 4 ft Shock Cords will be used to dampen the swinging affect during recovery. 7. The dampening affect of the shock cords will be simulated using MATLAB. 8. The team will be using a Raspberry Pi High Quality Camera.	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form, (PFI.1) 2. FRR 7.2 ANVIL/ Payload Testing: PT4 (Imaging Algorithm Demonstration), PT6 (Raspberry Pi Camera Imaging Test), PT7 (Gimbal Retraction Test), PT9 (Incorporated Gimbal Camera Test) 3. FRR 4.8.4 Blast Protection Construction: The O-ring was epoxied in place with an aerospace grade epoxy to make sure it will not come loose at any point during the launch. 4. FRR 4.9.1 Electrical Design: The Raspberry Pi High Quality Camera is being used for ANVIL's image capturing. 5. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 6. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload. 7. FRR 4.7.7 Blast Protection: The blast plate will be attached to the booster section with shock cord, and will hang beneath the drogue parachute during recovery. 8. CDR 4.6.7 Shock cord, A MATLAB simulation was created to determine the theoretical period of ANVIL based on a 4 ft shock cord. 9. CDR 4.6.7 Shock cord, Figure 64: Shock Cord Oscillation Frequency

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Wire become disconnected during flight	1. Rack and pinion pulls on wires 2. Wires not being secured 3. Wires are excessively long 4. Wires are damaged	Payload system failure, inability to track grid location, circuit becomes broken, failure of mission	3A	1. ANVIL will use PCB boards to reduce the mount of wires needed. 2. The wires connecting the battery to the electronics will be secure to the ceiling of the electronics bay to avoid the rack and pinion system. 3. The wires and PCB boards will be inspected prior to and after launches.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 4.10.1 Designing the PCB: The 3D models are shown in Figure 79a and 79b. 2. FRR 4.12 ANVIL Assembly: Figures 89b and 89c show the installation of the PCB on the doors of ANVIL. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form, (PFI.1)
Primary microcontroller failure	1. Microcontroller selected does not have enough processing power. 2. Loss of power. 3. Microcontroller becomes damaged. 4. Microcontroller becomes disconnected. 5. Error in code or while uploading code. 6. Failure to follow safety checklist. 7. Sleep mode failure.	Inability to track and locate vehicle grid location due to image processing failure, payload mission failure	3A	1. The team will be using a Raspberry Pi 4 for the primary microcontroller because it has a processing speed of 1.5 GHz. 2. The safety checklist will be followed during assembly to ensure the Raspberry Pi 4 has been inspected for damage, secured in place, connected, activated, and code is functioning as intended prior to launch. 3. Ground testing of Raspberry Pi 4 and payload system will be conducted prior to launch tests. 4. The battery selected for this payload will be required to supply power to the system for 2 hours, with a safety factor of 2. 5. ANVIL will have a sleep mode which will keep most electronics powered down until the ascent phase of the launch is initiated and more than 5g of acceleration is detected by the Adafruit ADXL326.	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 4.11.1 Sleep Mode: The Trinket M0 was chosen as the secondary microcontroller. It is extremely small, lightweight, and includes all the necessary pins to communicate between the accelerometer and converter. 3. FRR 7.2 ANVIL/ Payload Testing: PT4 (Imaging Algorithm Demonstration), PT5 (Raspberry Pi Camera Imaging Test), PT7 (Incorporated Gimbal Camera Test) 4. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 5. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Sleep mode failure	1. Accelerometer failure 2. Secondary microcontroller failure	Payload main electrical components never get power up, all electrical components are always active and battery power is drained before mission completion, mission failure	3A	1. The team will be using a Trinket M0 for the secondary microcontroller because it is small and lightweight. 2. The safety checklist will be followed during assembly to ensure the Trinket M0 has been inspected for damage, secured in place, connected, activated, and code is functioning as intended prior to launch. 3. Ground testing of Trinket M0 and payload system will be conducted prior to launch tests. 4. The battery selected for this payload will be required to supply power to the system for 3 hours, with a 20% buffer	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 2. FRR 4.11.1 Sleep Mode: The Trinket M0 and ADXL326 accelerometers are used to turn on all the other electrical components by enabling the second voltage regulator once 5G's is detected in the y-direction. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 4. FRR 7.2 ANVIL / Payload Testing: PT9 - Full Payload Assembly Test
Secondary microcontroller failure	1. Microcontroller selected does not have enough processing power. 2. Loss of power. 3. Microcontroller becomes damaged. 4. Microcontroller becomes disconnected. 5. Error in code or while uploading code. 6. Failure to follow safety checklist. 7. Accelerometer fails	Sleep mode failure, Inability to track and locate vehicle grid location due to image processing failure, payload mission failure, mission failure	3A	1. The team will be using a Trinket M0 for the secondary microcontroller because it is small and lightweight. 2. The safety checklist will be followed during assembly to ensure the Trinket has been inspected for damage, secured in place, connected, activated, and code is functioning as intended prior to launch. 3. Ground testing of Trinket M0 and payload system will be conducted prior to launch tests. 4. The battery selected for this payload will be required to supply power to the system for 2 hours, with a safety factor of 2.	Design, Analysis, Testing, Procedure, Safety Plan	1A	1. FRR 4.11.1 Sleep Mode: The Trinket M0 was chosen as the secondary microcontroller. It is extremely small, lightweight, and includes all the necessary pins to communicate between the accelerometer and converter. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 3. FRR 4.11.1 Sleep Mode: The Trinket M0 and ADXL326 accelerometers are used to turn on all the other electrical components by enabling the second voltage regulator once 5G's is detected in the y-direction. 4. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 5. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Accelerometer failure	1. Accelerometer loses power. 2. Defective accelerometer. 3. Accelerometer comes loose inside payload.	Sleep mode failure, Inability to identify acceleration of vehicle, payload does not turn on, position tracking error, data corruption, payload mission failure, mission failure	3A	1. An Adafruit ADXL326 3-AXIS accelerometer breakout board will be the accelerometer for the payload. 2. Safety checklist will be used to ensure the accelerometer is working and power is being supplied prior to launch. 3. Accelerometer will be tested for functionality. 4. Accelerometer will be screwing onto the payload door using heat set insert. Prior to launch screws will be inspected to ensure components are secured in place. 5. Rubber O-rings will be used to avoid damaging the accelerometer while screwing it down. 6. ANVIL will have a sleep mode which will keep most electronics powered down until the ascent phase of the launch is initiated and more than 5g of acceleration is detected by the Adafruit ADXL326.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Payload, Rubber O-rings 3. FRR 4.11.1 Sleep Mode: The Trinket M0 and ADXL326 accelerometers are used to turn on all the other electrical components by enabling the second voltage regulator once 5G's is detected in the y-direction. 4. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 5. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload. 6. CDR 4.7.1.5 Accelerometer: The Adafruit ADXL326 3-AXIS Accelerometer Breakout Board, seen in Figure 75, is capable of measuring ± 16 g in the x, y, and z axis and is suitable for measuring acceleration in air vehicles.
T-track rail failure	1. Rails detach from airframe. 2. Not having rail stops. 3. Rail stop breaks. 4. Rails become bent/ misaligned. 5. Binding of rail system. 6. Failure to follow safety checklist.	Payload housing becomes loose inside vehicle, payload does not deploy, Unstable flight, mission failure	3A	1. The T-track rail will have a rail stop to prevent ANVIL from sliding at the top. 2. The T-track style rails will be permanently epoxied and screwed into the payload section of the launch vehicle. 3. Epoxying will be done in accordance with manufacturer's specifications and tested to verify attachment. 4. Payload upper and lower housings will be screwed together in four locations ensure that the payload housing rail cutouts stay aligned.	Design, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 4.7.4 Retention: There will be two T-track style rails epoxied inside the payload section of the launch vehicle. 3. FRR 4.7.4 Retention: The top of the rail that is epoxied into the vehicle also is blocked off. Reference Figure 57: ANVIL Housing Retention 4. FRR 4.7.4.1 Rails: The rails will be bolted into the airframe using two 4-40 screws and heat set inserts for each rails.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Payload retention failure during deployment	1. Eye bolts is ripped out of payload housing. 2. Eye bolts in vehicle fail 3. Shock cord breaks. 4. Recovery system failure 5. Failure to follow safety checklist.	Loss of payload, personnel or bystanders injured, payload failure of mission	3A	1. The payload housing will be 3D printed out of ABS for its high strength. 2. ANVIL will use two eye bolts to help better distribute the load exerted on the payload housing during payload deployment. 3. The two eye bolt design will act as a redundancy system for shock cord because only one shock cord would be required to keep the payload attached. 4. The payload upper housing will have a Fiberglass plate to increase structural integrity during deployment. 5. ANVIL will be using two 4 ft. kevlar shock cords that will be inspected prior to launch for any signs of damage. 6. ANVIL will be connect to two eye bolts that are permanently epoxied to a carbon fiber bulkhead.	Design, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 4.7.4.2 Fiberglass Plate: The fiberglass plate is used to provided additional structural support to the eye bolts that are fastened into the housing structure and tether the payload to the launch vehicle. 3. FRR 4.7.4 Retention: Two four-foot segments of shock cord are connected to each eye bolt. 4. FRR 4.7.4 Retention: Two eye bolts are bolted through the fiberglass plate and into wire threaded inserts. 5. FRR 4.7.4 Retention: These segments are then connected to two eye bolts that are epoxied onto a fixed carbon fiber bulkhead located 3.25 inches above ANVIL. 6. FRR 7.1 Vehicle Testing: VT6, VT9 The bulkhead was able to withstand a maximum of 1,678 lbf.
Payload fails to deploy	T-track sliding rail becomes jammed or damaged.	Payload becomes stuck in vehicle and unable to transmit grid location through carbon fiber airframe	3A	1. The rail system will be inspected for damage and debris prior to launch. 2. Payload deployment will be rigorously ground tested to verify functionality.	Design, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 6.3.1 Full-scale Safety Checklist: Launch Vehicle Assembly, (LVA.13) - (LVA.14) Ensure ANVIL slides freely and set the payload section of the launch vehicle aside.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Pressure sensor failure	1. Defective or damaged pressure sensor. 2. Loss of power. 3. Pressure holes being covered. 4. Pressure sensor becoming disconnected or never connected.	Altitude for when picture is taken lost, image pairing lost, image tracking lost, failure of mission	3A	1. The safety checklist will be followed during assembly to ensure the pressure sensor has been inspected for damage, secured in place, connected, active, and all pressure holes are clear of debris prior to launch. 2. The team will use a Adafruit BMP280 Pressure Sensor to record the altitude of the payload.	Design, Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 4.9.1 Electrical Design: The Adafruit BMP280 Pressure Sensor has an absolute barometric pressure accuracy of ±1 hPa. 3. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 4. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.
Servo motor failure	1. Loss of power. 2. Servo motors are unable to provide the redundant torque. 3. Servo motors become damaged during launch or landing. 4. Servo motors become disconnected from the gimbal.	Inability to freely rotate the camera using the gimbal system	2A	1. ANVIL will be powered by 1 battery that will be required to power the system for at least 2 hours with a safety factor of 2. 2. Servo motors will meet torque requirements with a safety factor. 3. Servo motors will be tested for verification of intended functionality. 4. Gimbal system will be retractable for protection.	Design, Analysis, Testing	1A	1. FRR 4.8.2 Retraction System Construction: The retraction system is comprised of a 2000 series, 5-turn servo motor, a 5.5 in. rack, and a 3D printed rack guide. 2. FRR 7.2.7 PT7 - Gimbal Retraction Test: The overall retraction time average is 2.30 seconds. This is below the required 2.5 seconds to retract. 3. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 4. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
LiPo battery damage	LiPo battery pack becomes punctured or damaged by sharp object.	Battery pack ignites into flames, loss of payload and vehicle, failure of mission	2A	1. The battery will be housed inside ANVIL between the upper and lower housing sections on one of the doors of the payload. 2. The battery will be inspected prior to and after all launches. 3. LiPo batteries will be brightly colored with tape and marked as fire hazards. 4. LiPo Batteries will be significantly protected from impact.	Design	1A	1. FRR 4.7.1 Dimensions: The electronics bay, located on the upper half of ANVIL and housing all electrical components, has a usable height of 4.725 in. and width of 3.53 in. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)
Failure to transmit grid location	1. Transceiver maximum range exceeded. 2. Defective or damaged transceiver. 3. Damaged antenna. 4. Material selection does not allow transmissions.	Inability to transmit grid location to home base, serious effect on mission success	2B	1. The team will be using a Xbee to transmit the grid location. 2. Safety checklist will be used to ensure inspection of the Xbee and antenna is conducted during assembly looking for sign of damage. 3. ANVIL will slide out of the vehicle payload section and be made of ABS to allow for transmission. 4. Both Xbees will be tested prior to assembly.	Design, Testing, Procedure, Safety Plan	1B	1. FRR 7.2 Payload Testing: PT1 - Near Ground Range Test, The purpose of this test is to validate the use a turnstile antenna near the ground. 2. FRR 7.2.1 PT1 - Near Ground Range Test, PT1, Near Ground, 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. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 4. FRR 4.9.4 Transmission: Once ANVIL has landed, it must be capable of transmitting the grid of the landing location back to the ground station. To doso, two Xbee Pro XSC S3B long range RF modules are used.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Loss of camera gimbal functionality	1. Gimbal damaged from high velocity impact. 2. Loss of power to gimbal rotary system. 3. Debris or foreign object hinders rotary system. 4. Camera becomes disconnected from gimbal.	Camera can no longer freely rotate	3C	1. For ANVIL the camera gimbal will retract into the housing to prevent damage. 2. The payload battery will be required to provide a battery life of 2 hours on the launch rail with a safety factor of 2. 3. The safety checklist will be used to verify that the gimbal system is free of foreign objects and can freely rotate prior to launch. 4. Gimbal arms will be made out of aluminum using a CNC machine.	Design, Analysis, Procedure, Safety Plan	1C	1. FRR 4.7.5 Gimbal: Aluminum was used for heightened strength while still maintaining a lightweight design. 2. FRR 4.7.5 Gimbal: A CAD model of the gimbal is shown in Figure 62a, and the actual constructed gimbal is shown in Figure 62b. 3. FRR 4.8.3 Gimbal Construction: The finished CNC machine parts can be found below in Figures 71a and 71b 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 5. FRR 6.3.1 Full-scale Safety Checklist: Payload Preparation, ANVIL Assembly (AA.1)- (AA.24) 6. FRR 4.8.2 Retraction System Construction: The retraction system is comprised of a 2000 series, 5-turn servo motor, a 5.5 in. rack, and a 3D printed rack guide. 7. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 8. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.
Electronics bay size restriction	Battery that meets power requirements of payload system don't fit in battery bay.	Need to redesign battery bay or battery location	2D	Electronics bay has been designed to fit the battery that currently meets power budget.	Design, Analysis	1D	1. FRR 4.7.1 Dimensions: The electrical bay, housing all of the payload's electronics, has a usable length of 4.75 in. with a width of 3.53 in. 2. FRR 4.12 ANVIL Assembly: Figures 89b and 89c show the installation ANVIL's electronics.

6.2.5 Environmental Hazards

Table 76: Environmental Affect on Vehicle

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Excessive crosswinds speeds	1. Incoming storm front. 2. Atmospheric pressure variation.	1. Weather cocking. 2. Alteration in recovery drift distance. 3. Landing outside of designated launch field recovery area. 4. Heavy swinging of ANVIL. 5. Blurry images due to excessive swinging during recovery. 6. SO delays or cancels launch. 7. Payload section and booster sections of vehicle collide. 8. Not meeting goal altitude.	3A	1. Vehicle will be designed to have a minimum static stability margin of 2. 2. The team will calculate and run simulations on the effect of wind speeds of 0, 5, 10, 15, and 20 mph for the vehicle and recovery. 3. SO will monitor weather forecasts and wind speeds throughout the day. 4. In accordance with *NAR High Power Rocket Safety Code* the SO will cancel any launch from proceeding if crosswinds exceed 20 mph. 5. The payload section has been designed to descend faster than the booster section to avoid a midair collision of the two sections.	Design, Analysis, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints,Adverse weather conditions for this launch are described as: crosswinds in excess of 20mph, lightning storms within a 5 mile radius of the launch field, heavy rain, visibility under 5 miles, or any other scenario that is deemed unsafe by the primary, secondary, or range safety officer. 2. FRR 3.2 Launch Vehicle Design and Construction, Overview: pre-burn stability margin of 3.16 and post-burn stability margin 3.80 3. FRR 3.4.3 OpenRocket Flight Profile Simulations, The flight paths of the launch vehicle with varying wind speeds are shown below in Figure 46: OpenRocket Simulations in Varying Wind Conditions. 4. FRR 3.3.1 Recovery Procedure: Due to the lower coefficient of drag of the streamer, the payload section of the vehicle will descend at a faster rate than the booster section. 5. FRR 3.4.3 OpenRocket Flight Profile Simulations, Table 26: Open Rocket Apogee Simulation Data 6. FRR 3.3.2 Parachutes: Drogue Parachute coefficient of drag 1.5, Payload Section: Streamer coefficient of drag 0.08 7. FRR 8.4.2 NAR High Power Rocket Safety Code: 9. Flight Safety. I will not launch my rockets if wind speeds exceed 20 miles per hour. 8. FRR 7.1 Vehicle Testing: VT3, VT4, VT5, VT12, VT13

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Inclement weather	Storm font brings rain or snow.	1. Electronics become damaged by water. 2. Launch must be delayed or cancelled. 3. Metal components become damaged due to rust. 4. Data from launch lost.	3A	1. SO will monitor weather forecasts to ensure launch day weather requirements are met. 2. A pop-up canopy will be brought to every launch to provide weather coverage. 3. All electronics will be kept in waterproof containers prior to their installation. 4. SO will call off launch if lighting storms, heavy rain, or snow storms are within a 5 mile radius of the launch field. 5. When possible, launches will be scheduled over a several day period. 6. All components will be discarded and replaced in the event of water exposure to avoid future failures.	Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Tent 2. FRR 6.3.1 Full-scale Safety Checklist: Constraints, If at any time the weather conditions are deemed unsafe the launch will be called off. 3. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspection, (PFI.1) Inspect all the following components and place an "X" in the box if the component has damages:
Launch field is wet or damp	1. Recently rained at launch field. 2. The crops at the launch field have been recently watered. 3. Landing in drainage ditch	1. Electronics become damaged by water. 2. Possible loss of flight and payload data. 3. Metal components become rusted. 4. Possible mission failure. 5. Batteries or electronics catch fire.	3A	1. All electronics will be kept in waterproof containers prior to their installation. 2. All components will be discarded and replaced in the event of water exposure to avoid future failures. 3. Vehicle electronics will be housed in the altimeter bay which will remained seat in effort from to reduce water exposure even during recovery.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, All exposed electronics shall be stored in resealable bags until ready for installation. 2. FRR 6.3.1 Full-scale Safety Checklist: Constraints, If at any time the weather conditions are deemed unsafe the launch will be called off.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Frigid temperatures	Snow, cold front, winter launches	Batteries life is affected and batteries under preform, mission failure	2A	1. All batteries will be stored in LiPo safe battery bags until assembly. 2. The team will bring spare batteries for all components. 3. All batteries will be inspected using a multimeter in accordance with the safety checklist. 4. Batteries will exceed the power requirements calculated in the battery budget with a buffer of at least 20 %.	Design, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, (PRE.1) All batteries for (Any signs of damage such as cuts, punctures, etc., and test power using multimeter). 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Batteries are to be placed in LiPo safe battery bags during transportation. 3. FRR 4.9.3 Power Budget: In order to ensure all electrical components are supplied sufficient current for the duration of the mission, an additional 20% buffer is added to the total energy. 4. FRR 4.9.3 Power Budget: A 11.1V, 3000 mAh, three-cell, LiPo battery was chosen for the battery of the payload.
Electronics overheat	High temperatures	Electronics fail, batteries overheat, mission failure	2A	1. All batteries will be stored in LiPo safe battery bags until assembly. 2. The team will bring a pop-up tent to provide shade during assembly. 3. All batteries will be inspected using a multimeter in accordance with the safety checklist. 4. All electronics will be stored in there labeled containers until ready for installation.	Design, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, (PRE.1) All batteries for (Any signs of damage such as cuts, punctures, etc., and test power using multimeter). 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Batteries are to be placed in LiPo safe battery bags during transportation. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, All exposed electronics shall be stored in resealable bags until ready for installation. 4. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Tools, Tent 5. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note, Keep the launch vehicle andpayload in the shade during assembly to avoid overheating and possible heat expansion.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
High humidity	High temperatures causes high water vapor levels in air.	1. Buildup of water vapor or sweat damages electronic components. 2. Inadequate motor burn. 3. E-match or ignitor failure.	3B	1. SO will monitor weather condition leading up to and during launches to ensure launch day conditions are safe. 2. Assembly will be conducted under the pop-up tent and team personnel will not allow any kind of moisture buildup.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, If at any time the weather conditions are deemed unsafe the launch will be called off. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Tent, Shop towels, All exposed electronics shall be stored in resealable bags until ready for installation.
Low humidity	Weather pattern causes cold air.	Increase of static electricity buildup.	3B	1. SO will monitor weather condition leading up and during launches. 2. Personnel must ground themselves when working with electrical components.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, If at any time the weather conditions are deemed unsafe the launch will be called off. 2. FRR 6.3.1 Full-scale Safety Checklist: ***CAUTION* Ensure personnel is grounded when**  **symbol is present for a task.**
Wireless signal impedance	Heavy cloud cover, large obstacles, conflicting signals	Transmissions between home base and payload fail.	3B	1. An omnidirectional antenna will be used and the wireless signal connection will be verified prior to launch. 2. Wireless transmission system will be thoroughly tested prior to launch tests.	Design, Testing, Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Ground Base Antenna, **Constraints**, If at any time the weather conditions are deemed unsafe the launch will be called off. 2. FRR 7.2 Payload Testing: PT1, Near Ground Range Test, The purpose of this test is to validate the use a turnstile antenna near the ground.
Poor visibility	Fog or heavy cloud cover.	1. Inability to visually track vehicle during recovery. 2. Camera inability to locate grid positions. 3. SO delays or cancels launch. 4. Possible failure in mission.	3B	1. SO will cancel any launch if visibility is under 5 miles. 2. Inaccordance with *NAR High Power Rocket Safety Code* the rocket will not be launched into clouds.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Adverse weather conditions for this launch are described as: crosswinds in excess of 20mph, lightning storms within a 5 mile radius of the launch field, heavy rain,visibility under 5miles, or any other scenario that is deemed unsafe by the primary, secondary, or range safety officer. 2. FRR 8.4.2 NAR High Power Rocket Safety Code: 9. Flight Safety. I will not launch my rocket into clouds.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Dirt and mud debris	During landing the launch vehicle collects or is covered in dirt and/or mud.	1. Electronics become damaged by mud. 2. Vehicle components lose functionality. 3. Dirt and mud debris restrict components from moving or fitting properly.	3B	1. All components will be discarded and replaced in the event of water exposure to avoid future failures. 2. Vehicle electronics will be housed in the AV bays which will remained sealed to reduce exposure to mud and dirt during recovery. 3. All components will be inspected prior to and after all launches in accordance with the safety checklist. 4. The launch vehicle and all its components will be cleaned after every launch in accordance with the safety checklist.	Design, Testing, Procedure, Safety Plan	3D	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection,(PRE.1) An inspection of the following components shall be completed 2. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections,(PFI.3) Note all damaged components that need to be replaced, if any are identified in step (PFI.1) and (PFI.2) 3. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections,(PFI.1) - (PFI.2) Inspect all the following vehicle components and place an ”X” in the box if the component has damage: 4. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections, (PFI.5) Use shop towels to clean out all black powder residue created by the separation charges. 5. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections, (PFI.6) Use shop towels to clean out all dirt and mud on and/or in the launch vehicle from landing.
Prolonged UV exposure	leaving the vehicle out in direct sunlight for a prolonged amount of time	1. Thermal expansion of the airframe causes sections not to fit together 2. Electronics overheat	3B	1. The airframe will be made of carbon fiber which has a very low coefficient of thermal expansion. 2. During assembly of the rocket on launch days the vehicle and its components will be kept in the shade to avoid prolonged UV exposure. 3. The team will bring a pop-up tent to provide shade during assembly.	Design, Procedures, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Tools, Tent 2. FRR 3.2.2 Material Summary: The launch vehicles airframe is made of carbon fiber, Table 8: Launch Vehicle Subsystem Material Selections

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Launch field obstacles	Crowd, irrigation system, equipment, or trees	Payload or vehicle sections become stuck, wet, damaged or lost	3B	1. Several tracking device will be use on both vehicle and payload sections to ensure recovery is possible. 2. The vehicle has been designed to land within the 2,500 ft radius of the launch rail.	Design, Testing	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Payload Tracking System Assembly 2. FRR 6.3.1 Full-scale Safety Checklist: Booster Tracking System Assembly 3. FRR 6.3.1 Full-scale Safety Checklist: Payload Steamer Preparations (PSP.9) Attach a RCHP tracker to the shock cord and tether the nomex cloth to the shock cord, (PSP.10) Note which RCHP tracker channel was selected and verify functionality. 4. FRR 6.3.1 Full-scale Safety Checklist: Payload Parachute Preparations (PPP.10)-(PPP.11), Booster Parachute Preparations (BPP.11)-(BPP-12) 5. FRR 3.3.2 Parachutes: With correct parachute selection, the sections of the vehicle shall descend in under 90 seconds, drift less than 2,500ft, and land under 75 ft-lbs of kinetic energy.
Impact with hard object during recovery landing	Vehicle impacts rock or irrigation system.	Possible vehicle or payload damage.	2C	1. Vehicle will be made of carbon fiber for the high strength. 2. Recovery system will ensure that the maximum kinetic energy of any section of the vehicle is 75 ft-lb$_f$ at landing.	Design, Testing	1C	1. FRR 3.2.2 Material Summary: The launch vehicles airframe is made of carbon fiber, Table 8: Launch Vehicle Subsystem Material Selections 2. FRR 3.4.6 Kinetic Energy at Landing, Table 29 Landing Kinetic Energy of Components Under Main Parachute 3. FRR 3.3.2 Parachutes: With correct parachute selection, the sections of the vehicle shall descend in under 90 seconds, drift less than 2,500ft, and land under 75 ft-lbs of kinetic energy.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Bird Strike	Bird fly near launch pad or flight path of the launch vehicle	1. Collision with bird damages launch vehicle subsystems. 2. Vehicle trajectory change. 3. Declared altitude not met. 4. Light damage to launch vehicle.	2C	The team will verify that the airspace is visually free of birds and confirm with the RSO that the airspace is clear.	Procedure, Safety checklist	1C	1. FRR 6.3.1 Full-scale Safety Checklist: Launch Pad Setup, (LPS.9) Visually inspect the airspace for birds and other flying objects, and confirm with the RSO that airspace is clear. 2. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections,(PFI.3) Note all damaged components that need to be replaced, if any are identified in step (PFI.1) and (PFI.2) 3. FRR 6.3.1 Full-scale Safety Checklist: Post-flight Inspections,(PFI.1) - (PFI.2) Inspect all the following vehicle components and place an ”X” in the box if the component has damage:

Table 77: Vehicle Affect on Environment

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Air pollution	1. Burning of rocket motor propellant. 2. Burning of black powder. 3. Driving to launch Field.	Release of Hydrogen Chloride, Carbon Monoxide, and Barium Chloride gases, smoke	5A	1. The team will used Aerotech Motor for their high reliability. 2. The team will carpool to all launches to reduce greenhouse gases.	Design	2A	1. FRR 3 Launch Vehicle Summary, Final Motor Choice: Aerotech L1390-G. 2. FRR 6.3.1 Full-scale Safety Checklist: The team will carpool whenever possible to reduce the emission of greenhouse gases.
Lead contam-ination	1. Lead falling into soil and/or water. 2. Lead being used in the construction of the vehicle.	lead poisoning to water and soil organisms, contamination of food chains and freshwater sources	5A	1. The team will not use the toxic metal lead for any portion of the project. 2. The mass element for the launch vehicle will be made up of the less toxic metal tungsten.	Design	1D	1. FRR 3.2.2 Material Summary: Table 8: Launch Vehicle Subsystem Material Selections, There is no lead used in the construction of the vehicle.
High velocity impact of vehicle with ground	Recovery system failure	1. Rocket debris scattered across field 2. Loss of vehicle and payload 3. Batteries punctured or damaged causing fire	4A	1. The safety checklist will be used for all launches as procedure to ensure every step necessary for a successful recovery is preformed prior to launch. 2. All recovery preparation will be conducted by the recovery officer under the supervision of the safety officer. 3. The recovery system will be thoroughly ground tested prior to any test flight.	Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Booster Parachute Preparation (BPP.8) and (BPP.M.8), Payload Streamer Preparation (PSP.7), Payload Parachute Preparation (PPP.8) 2. FRR 6.3.1 Full-scale Safety Checklist: Payload Avionics Bay Assembly, (PAVB.1)-(PAVB.20), Booster Avionics Bay Assembly, (BAVB.1)-(BAVB.20) 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1)
Non-reusable plastic parts	The 3D printed parts such as ABS, PLA, TPU, PEI and PETG with one time use designs.	1. Solid waste pollution 2. Local wildlife and habits become damaged or injured, fines	3A	All 3D printed components will be designed to be reusable for multiple launches.	Design	1A	1. FRR 3.2.2 Material Summary: Table 8: Launch Vehicle Subsystem Material Selections, The launch vehicle's fins, boattail, fin block and nose cone are all 3D printed and reusable. 2. FRR 4.7 ANVIL Mechanical Overview: ANVIL and all its 3D printed components are designed to be reusable.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Rocket strikes bystander or car	1. Strong winds 2. Loose launch rail 3. Unstable launch of vehicle 4. Inattention during launch and recovery 5. Failure of recovery system	1. Injury to bystander 2. Damage to car 3. Damage to surrounding equipment 4. Debris scatter on field 5. Damage to rocket	3A	1. SO will monitor wind speed to ensure that conditions are safety to launch. 2. Launch vehicle will be designed to have a minimum static stability of 2 that will be confirmed on launch days. 3. The safety checklist will be used to verify the stability of the vehicle and launch rail prior to launch. 4. Crowd will be made aware to focus attention because the launch of the vehicle is imminent.	Design, Testing, Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, **Constraints**, If at any time the weather conditions are deemed unsafe the launch will be called off. 2. FRR 3.2 Launch Vehicle Design and Construction, Overview: pre-burn stability margin of 3.16 and post-burn stability margin 3.80 3. FRR 7.1 Vehicle Testing: VT3, VT4, VT5, VT12, VT13
Hazardous liquid material spillage	1. Careless use of material 2. Failing to store hazardous material in HazMat container	Damage to equipment, facilities, and wildlife habitat, loss of wildlife	3A	1. Team members will ensure to store all Hazardous material in the HazMat container and not to leave open containers while not being used. 2. In the event of spillage, clean up will be done in accordance with the SDS of the specific material.	Procedure, Safety Plan	1A	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Safety Handbook
Solid waste pollution	1. Littering on launch days 2. Improper disposal of solid waste throughout the duration of the project 3. Not providing solid waste containers throughout the duration of the project	1. Local wildlife and habits become damaged or injured. 2. Cluttering of waste on launch field and team facilities.	4B	1. Disposal containers will be provide for the team at all time for solid waste and recyclable material. 2. The team will be held responsible for ensuring that all facilities and launch fields are maintained free of waste.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Trash Container, Safety Handbook
Bird Strike	Bird fly near launch pad or flight path of the launch vehicle	1. Collision with bird injures bird. 2. Wildlife loss of life.	2A	The team will verify that the airspace is visually free of birds and confirm with the RSO that the airspace is clear.	Procedure, Safety checklist	1A	FRR 6.3.1 Full-scale Safety Checklist: Launch Pad Setup, (LPS.9) Visually inspect the airspace for birds and other flying objects, and confirm with the RSO that airspace is clear.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Mid flight explosion	1. Motor failure 2. Airframe structural failure due to over pressurization 3. Batteries overheat and explode 4. Not following checklist	1. Falling debris hits animals or vehicle 2. Falling debris is scattered over the launch field 3. Solid and Hazardous waste pollution 4. Potential for batteries to course fire	3B	1. The team will conduct inspections of all component prior to and after launches in accordance with the safety checklist. 2. The team will being waste containers to collect and discard all waste. 3. Black powder separation charges will be calculated prior to testing. 4. Separation demonstrations will be conducted to verify that over pressurization wont occur. 5. The team will being fire fighting equipment to all launches.	Design, Testing, Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-Flight Inspection, Inspection Form (PRE.1), Post-flight Inspections, (PFI.1) 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Trash Container, PPE, Fire extinguisher 3. FRR 3.3.4 Ejection Charges Equation 1 Ideal Gas law used to calculate the amount of black powder. 4. FRR 3.3.4 Ejection Charges Table 19: Separation Charge Masses 5. FRR 7.1 Vehicle Testing: VT2, VT10 vehicle separation tests.
LiPo battery ignites	LiPo battery is damaged by overcharging, excessive heat exposure, or sharp object.	Battery bursts into flames, causes fire, hazardous smoke and materials	3B	1. All LiPo batteries will be charged in accordance with the manufactures specification. 2. During travel and prior to installation all batteries will be kept in LiPo safe bags that are flame proof. 3. LiPo batteries will be brightly colored with tape and marked as fire hazards. 4. LiPo Batteries will be significantly protected from impact.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Batteries are to be placed in LiPo safe battery bags during transportation. 2. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references.
Hazardous waste pollution	1. Hazardous liquid spillage cleanup 2. Not following SDS disposal requirements of hazardous waste 3. Not following state and local laws on hazardous waste disposal 4. Not providing hazardous waste disposal containers	Local wildlife and habits become damaged or injured, fines	3B	1. Disposal containers will be provide for the team at all time for hazardous waste. 2. Disposal of hazardous waste will be done in accordance with the SDS, state, and local laws. 3. All team members will be held responsible for ensuring that hazardous waste is properly disposed of at facilities and launch fields.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Trash Container, Safety Handbook

Hazard	Cause	Effect	Pre-RAC	Mitigation	Mitigation Type	Post-RAC	Verification
Fire	1. Batteries and electronics overheat or exposed to water. 2. Rocket motor or black powder is ignited. 3. CATO	1. Flames damage equipment, vehicle, payload, and launch site. 2. Personnel or bystanders become injured. 3. Fire becomes uncontrollable and spreads. 4. Destruction of local wildlife habit. 5. Air pollution.	3B	1. All electronics will be kept in waterproof containers and in the shade prior to their installation. 2. All flammable material will be kept in a controlled area know as the blaze zone. 3. A fire extinguisher will be brought to all launches in case of small fire.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Batteries are to be placed in LiPo safe battery bags during transportation. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, All exposed electronics shall be stored in resealable bags until ready for installation. 3. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, PPE, Fire extinguisher, Safety Handbook
Liquid waste pollution	1. Liquid hazardous material spillage 2. Not following SDS disposal requirements of liquid hazardous materials 3. Not providing liquid waste disposal containers	Local wildlife and habits become damaged or injured, fines	3B	1. Disposal containers will be provide for the team at all time for liquid waste. 2. Disposal of liquid hazardous waste will be done in accordance with the specific SDS that can be found in the team's safety handbook. 3. The team will be held responsible for ensure that all facilities and launch fields are maintained free of waste.	Procedure, Safety Plan	1B	1. FRR 6.3.1 Full-scale Safety Checklist: Constraints, Note: Safety Data Sheets will be provided at all times during the launch for team references. 2. FRR 6.3.1 Full-scale Safety Checklist: Pre-launch Packing List, Trash Container, Safety Handbook
Noise pollution	1. Burning of rocket motor propellant during launch. 2. Burning of black power during separation.	Disturbing wildlife habitats and residential areas	3B	1. All launches will be conducted at NAR certified sites. 2. All launches will be conducted during the day. 3. The team will use a rocket motor with a rapid burn time to reduce the amount of time of noise pollution.	Design, Procedure, Safety Plan	1B	1. FRR 3 Launch Vehicle Summary, Final Motor Choice: Aerotech L1390-G. 2. FRR 3.4.1 Simulated Motor Thrust Curve, Figure 42: Thrust Curve Comparison, The Aerotech L1390-G motor has a burn time of just 2.6 seconds.

6.3 Launch Safety Checklist

Launch day Safety Checklists will be used as a procedural checklist for the assembly of the different systems that make up the team's rocket (i.e. recovery, payload, vehicle). The goal for the Safety Checklist is to minimize the hazards that team personnel face during launches, while also maximizing the efficiency of the assembly process. Checklists are important for verifying that assembly of critical systems are done in accordance with the intended design to reduce possible sources of error. For launches, multiple checklists will be available for ease of reference. The full-scale safety checklist has been updated since its first iteration in the CDR to include new critical procedures learned from previous launches.

The Safety Checklists requires that the SO be present to witness and verify that each step of the assembly process is properly followed. Once a section of steps has been completed, the SO and personnel preforming the tasks will sign off on the section. If a task inherently has a hazard attached to it a safety icon will be present prior to the step to identify PPE, or to identify the hazard. The task will also require the SO to sign off on the specific step. The list of all the safety icons used for the safety checklist can be found in Table 78.

Table 78: Safety Icons

Icon	Meaning
	Indication of electrostatic sensitive devices
	Indication of a possible pinch point hazard
	Indication that Nitrile gloves are required
	Indication that safety glasses are required
	Indication that grounding of personnel is required

6.3.1 Full-scale Safety Checklist

Personnel

NAR Certified Mentor: Dr. Jerry Dahlberg
Safety Officer: Daniel Naveira
Backup SO: Caden Pyne
Recovery Officer: Corey Drummond
Integration Officer/Backup Recovery: John Allman
Range Safety Officer: RSO
Team Lead: Chase Atherton
Vehicle Team Personnel: Caitlin Bunce, Connor Thomas, Jason Ellisor, Corey Drummond
Payload Team Personnel: Joseph Petite, Sarah Vitarisi, Caden Pyne, Wilson Yates, Brandon Kepley

Pre-launch Packing List

To ensure everything necessary to complete the full-scale launch is brought to the launch site, the team will verify that everything on the following checklist has been accounted for. All the items listed below must be stored in the proper labeled containers prior to the departure of the team. Batteries are to be placed in LiPo safe battery bags during transportation. All exposed electronics shall be stored in resealable bags until ready for installation. The team will carpool whenever possible to reduce the emission of greenhouse gases.

Vehicle

- ☐ Nosecone
- ☐ Heat Set Inserts(x4)
- ☐ Booster Section
- ☐ Booster Recovery Section
- ☐ Payload Recovery Section
- ☐ Payload Section
- ☐ Motor Tube
- ☐ Aft Cap
- ☐ Motor Casing
- ☐ Motor
- ☐ Forward Closure
- ☐ Rail Buttons (x4)
- ☐ Centering Rings
- ☐ Fin Guide
- ☐ Modular Fins (x6)
- ☐ Fin Block (x2)
- ☐ Boattail (x2)
- ☐ Hex Nuts (x4)
- ☐ Wooden Dowel
- ☐ Radio
- ☐ Radio Battery
- ☐ Forward sealing disk

Recovery

- ☐ 84 *inch* Booster Main Parachute
- ☐ 12.5 *inch* Booster Drogue Parachute
- ☐ 72 *inch* Payload Main Parachute
- ☐ 29 *ft* Streamer/blanket
- ☐ 9V Batteries (x8)
- ☐ Nomex Blankets (x6)
- ☐ RCHP Trackers (x6)
- ☐ CR2032 Battery (x6)
- ☐ RRC3 (x8)
- ☐ Electric Matches (x16)
- ☐ Shock Cord (x4)
- ☐ Pack of Shear Pins
- ☐ Packing Wadding
- ☐ Quick Links (x16)
- ☐ FingerTech switch (x8)
- ☐ Payload AV Bay (Assembled)
- ☐ Booster AV Bay (Assembled)
- ☐ ABS Spacers (x8)
- ☐ ABS Electronics sled (x2)
- ☐ Featherweight GPS Trackers (x2)
- ☐ Featherweight GPS Capsule (x2)
- ☐ 400 mAH 7.4V 2s LiPo (x2)
- ☐ AV Bay gasket (x2)
- ☐ AV Bay Push Rod
- ☐ Teensy 3.6
- ☐ Adafruit ADXL326
- ☐ 950 mAh LiPo

Payload

- ☐ Upper Payload Housing
- ☐ Lower Payload Housing
- ☐ Raspberry Pi HQ Camera
- ☐ Carabiners (x4)
- ☐ Eye Bolts (x2)
- ☐ 4 ft Shock Cord (x2)
- ☐ Payload Doors (x2)
- ☐ Raspberry Pi 4
- ☐ FingerTech (x2)
- ☐ XBee
- ☐ Pre-Assembled Gimbal
- ☐ Trinket M0
- ☐ Adafruit ADXL326 3-AXIS
- ☐ BMP280 Pressure Sensor
- ☐ Antenna
- ☐ Primary PCB board
- ☐ Secondary PCB
- ☐ 3000 mAh 7.4V LiPo (x2)
- ☐ HS-788HB Servo motor
- ☐ 25 - tooth gear
- ☐ 5.5” steal rack
- ☐ Hex nuts (x4)
- ☐ 4-40 Screws (x4)
- ☐ 1/4-20 Screws (x6)
- ☐ 1/4-20 Nut (x2)
- ☐ M4.5 Screw (x4)
- ☐ M4.5 Nut (x4)
- ☐ 2-25 Screw (x4)
- ☐ 2-25 Nut (x4)
- ☐ Rubber O-rings
- ☐ Rubber Washer (x4)
- ☐ Blast Protection Plate
- ☐ Assembly Rods (x4)
- ☐ Payload Door pins (x2)
- ☐ Ribbon Cables
- ☐ HDMI Cable
- ☐ Pi Screen

Tools

- ☐ Work table (x2)
- ☐ Rubber Hammer
- ☐ Zip ties
- ☐ Philips Head Screwdriver
- ☐ Power Drill
- ☐ Aluminum Tape
- ☐ Packing Wad
- ☐ Trash Container
- ☐ Laptop
- ☐ Allen Wrenches/Keys
- ☐ FingerTech Allen Key
- ☐ Featherweight Allen key
- ☐ Digital Scale
- ☐ Scissors
- ☐ Tent
- ☐ Grease
- ☐ Shop towels
- ☐ Electrical Tape
- ☐ Wire Strippers
- ☐ Soldering Iron and Solder
- ☐ Needle Nose Piers
- ☐ Tracker Gun
- ☐ Anemometer
- ☐ Electrical Wires
- ☐ Multimeter
- ☐ Tweezers
- ☐ Sandpaper
- ☐ File
- ☐ Hot Glue Gun and Glue
- ☐ Chairs
- ☐ RRC3 Screwdriver
- ☐ Flashlight
- ☐ Ground Base Antenna
- ☐ Clay/Putty
- ☐ Ladder
- ☐ Small flat head
- ☐ Graphite
- ☐ Safety Handbook
- ☐ Calipers

PPE

- ☐ Safety Glasses
- ☐ Nitrile Gloves
- ☐ Masks
- ☐ First Aid Kit
- ☐ Sunscreen
- ☐ Water
- ☐ Epipen (x2)
- ☐ Fire Extinguisher
- ☐ Bug Spray

Hazardous Materials

- ☐ Black Powder
- ☐ Hot Glue
- ☐ Quick Dry Epoxy
- ☐ Super Glue
- ☐ E-matches
- ☐ Aerotech L1390-G

Constraints

Time: The team must be able to assemble the launch vehicle and be prepared to launch within 120 minutes.

Location:__________ The procedures that follow will be performed outdoors and in clear safe weather conditions. Adverse weather conditions for this launch are described as: crosswinds in excess of 20 *mph*, lightning storms within a 5 *mile* radius of the launch field, heavy rain, visibility under 5 *miles*, or any other scenario that is deemed unsafe by the primary, secondary, or range safety officer. If at any time the weather conditions are deemed unsafe, the launch will be called off.

System Configuration: The procedures outlined in this manual require that the booster sections and payload sections have been assembled previously and tested for safe operation where possible. This also means that all recovery electronics and components have been installed within the proper assemblies and have been inspected for proper functionalities. Altimeters have been tested and verified for operation and accuracy. All the black powder charges have been measured and tested for proper ability to separate the intended section. All batteries have been properly charged with the voltages verified and stored in the proper FAA approved LiPo bags. In addition the E-matches will be cut down to the proper measured lengths and color coordinated using electrical tape.

Altimeter Settings:
Upper Booster Section Drogue: Apogee (primary) and Apogee + 1 *s* (secondary)
Lower Booster Section Main: 600 *feet* (primary) and 500 *feet* (secondary)
Upper Payload Section Streamer: Apogee + 1 *s* (Primary) and Apogee + 2 *s* (Secondary)
Lower Payload Section Main: 600 *feet* (Primary) and 500 *feet* (Secondary)

Note: The critical tasks on the checklist are items that have the potential to cause harm to the personnel preforming the task. Critical tasks shall be denoted from other tasks by having a line that is designated for the initials from the Safety Officer and/or the secondary Safety Officer. A Safety Officer must be present for supervisions of all critical task and must sign off on the task with their initials once the task has successfully been completed. Safety Data Sheets will be provided at all times during the launch for team references. Safety glasses  will be worn at all times while preforming tasks on the checklist. All team personal must wear closed toe shoes for launch days. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers. Keep the launch vehicle and payload in the shade during assembly to avoid overheating and possible heat expansion.

Table 79: Safety Icons

Icon	Meaning
	Indication of electrostatic sensitive devices
	Indication of a possible pinch point hazard
	Indication that Nitrile gloves are required
	Indication that safety glasses are required
	Indication that grounding of personnel is required

Pre-Flight Inspection

Inspection Form

NOTE:
The component inspection form must be completed and signed for each of the following components and then submitted to the Safety Officer (Daniel Naveira) for approval prior to launch.

CAUTION
Failure to complete component inspection guidelines may result in failure of the mission.

☐ (PRE.1) An inspection of the following components shall be completed: SO:___

- ☐ Motor retention (Fracture, cracks, gas porosity)
- ☐ Fin block (Stress/spider/cracks around press fit area, burns, melting material)
- ☐ Fin guide (Stress/spider/cracks around press fit area, burns, melting material)
- ☐ Modular fins (Stress areas, fractures, cracks, scratches, melting, defects)
- ☐ Booster section airframe (Pressure fractures, stress/spider/cracks around bolt points, unintended holes)
- ☐ Payload section airframe (Pressure fractures, stress/spider/cracks around bolt points, unintended holes)
- ☐ Bulkheads (Pressure fractures, stress/spider/cracks around bolt points, unintended holes, signs of epoxy failure)
- ☐ Nosecone (Impact fractures, burns/melted material, ensure eyebolt is not loose inside)
- ☐ Main and drogue parachutes (Burns, holes, discoloration, fray)
- ☐ Streamer (Burns, holes, discoloration, fray)
- ☐ Shock cords (Burns, holes, discoloration, fray)
- ☐ Altimeter bays (Physical damage to bulkheads and mounting hardware, damage to altimeters, ensure eyebolt is not loose inside)
- ☐ Payload housing and rails (Physical damage to bulkheads and mounting hardware, ensure eyebolt is not loose inside, rail system)
- ☐ Payload gimbal (Physical damage to arms and mounting hardware, joint movement)
- ☐ Payload electronics (Physical damage to mounting hardware, ensure electronics turn on and function as intended)
- ☐ Payload gimbal retraction system (Physical damage to mounting, hardware, rack, servo motor, ensure electronics turn on and function as intended)
- ☐ All batteries for (Any signs of damage such as cuts, punctures, etc. test power using multimeter)
- ☐ Payload and AV bays for any loose wire.
- ☐ Inspect rail buttons for damage and ensure they are not fastened too tightly.

☐ (PRE.2) Safety Officer reviewed verification and approval of the inspection form. SO:___

Work Done By:	______________	______________	______________
	Print Name	Sign Name	Date
Safety Officer:	______________	______________	______________
	Print Name	Sign Name	Date

Recovery Preparation - Payload Section

Payload Streamer Preparation

NOTE
Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all the recovery preparations. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers.

CAUTION
During the preparation and installations of the steamer ensure all shock cord remains free of unintended knots and tangles throughout. **Failure to follow the proper preparation guidelines may result in the failure of the recovery system.**

- ☐ (PSP.1) Inspect 29 ft streamer for burns, holes, tears, etc. SO:____
- ☐ (PSP.2) Inspect shock cord for damage such as burns, frays, cuts, and other damage. SO:____
- ☐ (PSP.3) Attach quick links to all mounting points of the shock cord.
- ☐ (PSP.4) Spread the 29 ft drogue streamer on a flat surface. SO:____
- ☐ (PSP.5) Begin to fold the streamer accordion style every half inch for roughly 80 percent of the streamer.
- ☐ (PSP.6) Roll up the accordion fold portion of the streamer in the remaining portion of the streamer.
- ☐ (PSP.7) Roll the streamer within its kevlar liner and set aside.
- ☐ (PSP.8) Attach the streamer to the designated shock cord ensuring it does not become unrolled. SO:____

Payload Parachute Preparation

NOTE
Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all the parachute preparations. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers.

CAUTION
During the preparation and installations of the parachutes ensure all shroud lines remain free of knots and tangles throughout. **Failure to follow the proper preparation guidelines may result in the failure of the recovery system.**

- ☐ (PPP.1) Inspect 72 inch main parachutes for burns, holes, tears, discoloration, etc. SO:____
- ☐ (PPP.2) Inspect the shock cord for burns, frays, cuts, and other damage. SO:____
- ☐ (PPP.3) Attach all quick links to the shock cord mounting points. SO:____
- ☐ (PPP.4) Spread the 72 inch main parachute out on a flat surface and separate shroud lines into three equal but separate groups (left, center, right) and then insert groups into 3D printed guide. SO:____
- ☐ (PPP.5) Fold the 72 inch main parachute accordion style so that half of the gores lie on either side of the vertical axis.
- ☐ (PPP.6) Fold each set of gores in half twice along the vertical axis and then remove shroud lines from the 3D printed guide.
- ☐ (PPP.7) Z-fold the gores and roll tightly along the horizontal axis.
- ☐ (PPP.8) Cover the 72 inch main parachute and shroud lines using a nomex blanket. SO:____
- ☐ (PPP.9) Attach main parachutes to shock cords.
- ☐ (PPP.10) Attach a RCHP tracker to the shock cord and tether the nomex cloth to the shock cord.
- ☐ (PPP.11) Use the RCHP tracker marked with the 64 sticker that matches its channel and verify functionality. SO:____

Work Done By: ____________ Print Name ____________ Sign Name ____________ Date

Safety Officer: ____________ Print Name ____________ Sign Name ____________ Date

Payload Avionics Bay Assembly

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all AV bay preparations.

CAUTION

Ensure personnel is grounded when symbol is present for a task. Failure to follow the proper preparation guidelines may result in the failure of the recovery system.

****WARNING****

All nonessential personnel must withdraw at least 15 *feet* at this time.

- ☐ (PAVB.1) Ensure that all Dip Switches are in the off position. SO:____
- ☐ (PAVB.2) Confirm that the altimeter has the correct setting and that it has been calibrated for launch day conditions. SO:____
  - ☐ Payload Steamer: Apogee + 1 *s* (Primary) and Apogee + 2 *s* (Secondary)
  - ☐ Payload Main: 600 *feet* (Primary) and 500 *feet* (Secondary)
- ☐ (PAVB.3) Measure out 1.93 g of black powder for the payload streamer separation main charge and place in plastic vial labeled **(SM)**. SO:____
- ☐ (PAVB.4) Measure out 2.31 g of black powder for the payload streamer separation backup charge and place in plastic vial labeled **(SB)**. SO:____
- ☐ (PAVB.5) Measure out 2.71 g of black powder for the payload main parachute separation main charge and place in plastic vial labeled **(PM)**. SO:____
- ☐ (PAVB.6) Measure out 3.26 g of black powder for the payload main parachute separation backup charge and place in plastic vial labeled **(PB)**. SO:____
- ☐ (PAVB.7) Ensure that batteries have been disconnected from RRC3's and that FingerTech switches have been turned to the off position. SO:____
- ☐ (PAVB.8) Place one E-match in each of the charge wells ensuring to match the color coordination by feeding it through the designated hole in the bulkheads and/or sleds and cover the bulkhead holes with electrical tape and fill with hot glue. SO:____
  - ☐ Payload Streamer: Yellow **(SM)** and Green **(SB)**
  - ☐ Payload Main: Red **(PM)** and Blue **(PB)**
- ☐ (PAVB.9) Ensure that each E-match has been connected to the proper location on the RRC3's designated by the corresponding colors and labels on the RRC3's and charge wells. SO:____
- ☐ (PAVB.10) Pour the 1.93 g of black powder into the steamer main charge well designated by the label **(SM)** and yellow tape, pack down tightly with paper wadding and then seal with aluminum tape. SO:____
- ☐ (PAVB.11) Pour the 2.31 g of black powder into the steamer backup charge well designated by the label **(SB)** and green tape, pack down tightly with paper wadding and then seal with aluminum tape. SO:____
- ☐ (PAVB.12) Pour the 2.71 g of black powder into the payload main parachute main charge well designated by the label **(PM)** and red tape, pack down tightly with paper wadding and then seal with aluminum tape. SO:____
- ☐ (PAVB.13) Pour the 3.26 g of black powder into the payload main parachute backup charge well designated by the label **(PB)** and blue tape, pack down tightly with paper wadding and then seal with aluminum tape. SO:____

☐	(PAVB.14)	Ensure that the altimeters are screwed in and the batteries have been zip tied down to the AV bay sled with proper polarity and are not loose.	SO:____
☐	(PAVB.15)	Ensure E-matches are secured to the RRC3 altimeters and no wires are touching.	SO:____
☐	(PAVB.16)	Attach the 9V battery and the 950 mAh LiPo to the RRC3 altimeters.	SO:____
☐	(PAVB.17)	Place the gasket onto the AV bay top steamer bulkhead.	
☐	(PAVB.18)	Slide payload AV bay into place ensuring that the streamer separation charges are facing the nosecone section.	SO:____
☐	(PAVB.19)	Secure the AV bay bulkheads together by screwing the two nuts into place.	SO:____
☐	(PAVB.20)	Place clay/putty in the open space between the bulkheads to add additional sealing to the AV bay.	SO:____

Work Done By: ____________________ ____________________ ____________________

Print Name Sign Name Date

Safety Officer: ____________________ ____________________ ____________________

Print Name Sign Name Date

Payload Tracking System Assembly

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all AV bay preparations.

CAUTION

Failure to follow the proper preparation guidelines may result in the loss of the payload section and a failure of recovery.

☐	(PTSA.1)	Inspect the Featherweight capsule, Featherweight GPS, and 400 mAH 7.4V 2S LiPo for any signs of damage.	SO:____
☐	(PTSA.2)	Tug on the eye bolt to verify it is tightly secured in place on the Featherweight capsule.	SO:____
☐	(PTSA.3)	Attach the battery and Featherweight GPS inside the Featherweight capsule.	
☐	(PTSA.4)	Connect the battery to the Featherweight GPS and verify that the Featherweight is transmitting. If transmissions are not received reference Troubleshooting Table 93: Situation Identifiers.	SO:____
☐	(PTSA.5)	Secure the Featherweight capsule door by screwing all four screws down.	
☐	(PTSA.6)	Attach the Featherweight capsule to the payload section streamer shock cord using the eye bolt and a quick link.	SO:____

Work Done By: ____________________ ____________________ ____________________

Print Name Sign Name Date

Safety Officer: ____________________ ____________________ ____________________

Print Name Sign Name Date

Recovery Preparation - Booster Section

Booster Parachute Preparation

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all the parachute preparations. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers.

CAUTION

During the preparation and installations of the parachutes ensure all shroud lines remain free of knots and tangles throughout. **Failure to follow the proper preparation guidelines may result in the failure of the recovery system.**

- ☐ (BPP.1) Inspect 84 *inch* main and 12.5 *inch* parachutes for burns, holes, tears, discoloration, etc. SO:____
- ☐ (BPP.2) Inspect the shock cord for burns, frays, cuts, and other damage. SO:____
- ☐ (BPP.3) Attach all quick links to the shock cord mounting points. SO:____
- ☐ (BPP.4) Spread the 12.5 *inch* drogue parachute out on a flat surface and separate shroud lines into three equal but separate groups (left, center, right) and then insert groups into 3D printed guide. SO:____
- ☐ (BPP.5) Fold the 12.5 *inch* drogue parachute accordion style so that half of the gores lie on either side of the vertical axis.
- ☐ (BPP.6) Fold each set of gores in half twice along the vertical axis and then remove shroud lines from the 3D printed guide.
- ☐ (BPP.7) Z-fold the gores and roll tightly along the horizontal axis.
- ☐ (BPP.8) Cover the 12.5 *inch* drogue parachute and shroud lines using a nomex blanket. SO:____
- ☐ (BPP.9) Repeat the steps (BPP.4-8) for the 84 *inch* main parachute. SO:____
  - ☐ (BPP.M.4)
  - ☐ (BPP.M.5)
  - ☐ (BPP.M.6)
  - ☐ (BPP.M.7)
  - ☐ (BPP.M.8)
- ☐ (BPP.10) Attach drogue and main parachutes to shock cords.
- ☐ (BPP.11) Attach a RCHP tracker to the shock cord and tether the nomex cloth to the shock cord.
- ☐ (BPP.12) Use the RCHP tracker marked with the 98 sticker that matches its channel and verify functionality. SO:____

Work Done By:	____________ Print Name	____________ Sign Name	____________ Date
Safety Officer:	____________ Print Name	____________ Sign Name	____________ Date

Booster Avionics Bay Assembly

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all AV bay preparations.

CAUTION

Ensure personnel is grounded when  **symbol is present for a task. Failure to follow the proper preparation guidelines may result in the failure of the recovery system.**

****WARNING****

All nonessential personnel must withdraw at least 15 *feet* at this time.

☐	(BAVB.1)	Ensure that all Dip Switches are in the off position.	SO:___
☐	(BAVB.2)	Confirm that the altimeter has the correct setting and that it has been calibrated for launch day conditions. • ☐ Booster Drogue: Apogee (Primary) and Apogee + 1 *s* (Secondary) • ☐ Booster Main: 600 *feet* (Primary) and 500 *feet* (Secondary)	SO:___
☐	(BAVB.3)	Measure out 1.56 g of black powder for the booster section drogue separation main charge and place in plastic vial labeled **(DM)**.	SO:___
☐	(BAVB.4)	Measure out 1.87 g of black powder for the booster section drogue separation backup charge and place in plastic vial labeled **(DB)**.	SO:___
☐	(BAVB.5)	Measure out 2.04 g of black powder for the booster section main parachute separation main charge and place in plastic vial labeled **(BM)**.	SO:___
☐	(BAVB.6)	Measure out 2.45 g of black powder for the booster main parachute separation backup charge and place in plastic vial labeled **(BB)**.	SO:___
☐	(BAVB.7)	Ensure that batteries have been disconnected from RRC3's and that FingerTech switches have been turned to the off position.	SO:___
☐	(BAVB.8)	Place one E-match in each of the charge wells ensuring to match the color coordination by feeding it through the designated hole in the bulkheads and/or sleds and cover the bulkhead holes with electrical tape and fill with hot glue. • ☐ Booster Drogue: Yellow **(DM)** and Green **(DB)** • ☐ Booster Main: Red **(BM)** and Blue **(BB)**	SO:___
☐	(BAVB.9)	Ensure that each E-match has been connected to the proper location on the RRC3's designated by the corresponding colors and labels on the RRC3's and charge wells.	SO:___
☐	(BAVB.10)	Pour the 1.56 g of black powder into the main drogue charge well designated by the label **(DM)** and yellow tape, pack down tightly with paper wadding and then seal with aluminum tape.	SO:___
☐	(BAVB.11)	Pour the 1.87 g of black powder into the backup drogue charge well designated by the label **(DB)** and green tape, pack down tightly with paper wadding and then seal with aluminum tape.	SO:___
☐	(BAVB.12)	Pour the 2.04 g of black powder into the booster main parachute main charge well designated by the label **(BM)** red tape, pack down tightly with paper wadding and then seal with aluminum tape.	SO:___
☐	(BAVB.13)	Pour the 2.45 g of black powder into the booster backup main parachute charge well designated by the label **(BB)** blue tape, pack down tightly with paper wadding and then seal with aluminum tape.	SO:___
☐	(BAVB.14)	Ensure that the altimeters are screwed in and the batteries have been zip tied down to the AV bay sled with proper polarity and are not loose.	SO:___
☐	(BAVB.15)	Ensure E-matches are secured to the RRC3 altimeters and no wires are touching.	SO:___
☐	(BAVB.16)	Attach the 9V batteries to the RRC3 altimeters.	SO:___
☐	(BAVB.17)	Place the gasket onto the AV bay top drogue bulkhead.	
☐	(BAVB.18)	Slide booster AV bay into place ensuring that the drogue separation charges are facing the payload section.	SO:___
☐	(BAVB.19)	Secure the AV bay bulkheads together by screwing the two nuts into place.	SO:___
☐	(BAVB.20)	Place clay/putty in the open space between the bulkheads to add additional sealing to the AV bay.	SO:___

Work Done By: ______________ ______________ ______________

Print Name | Sign Name | Date

Safety Officer: ______________ ______________ ______________

Print Name | Sign Name | Date

Booster Tracking System Assembly

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all AV bay preparations.

CAUTION

Failure to follow the proper preparation guidelines may result in the loss of the booster section and a failure of recovery.

- ☐ (BTSA.1) Inspect the Featherweight capsule, Featherweight GPS, and 400 mAH 7.4V 2S LiPo for any signs of damage. SO:____
- ☐ (BTSA.2) Tug on the eye bolt to verify it is tightly secured in place on the Featherweight capsule. SO:____
- ☐ (BTSA.3) Attach the battery and Featherweight GPS inside the Featherweight capsule.
- ☐ (BTSA.4) Connect the battery to the Featherweight GPS and verify that the Featherweight is transmitting. If transmissions are not received reference Troubleshooting Table 93: Situation Identifiers. SO:____
- ☐ (BTSA.5) Secure the Featherweight capsule door by screwing all four screws down.
- ☐ (BTSA.6) Attach the Featherweight capsule to the booster section main parachute shock cord using the eye bolt and a quick link. SO:____

Work Done By: ______________ ______________ ______________

Print Name | Sign Name | Date

Safety Officer: ______________ ______________ ______________

Print Name | Sign Name | Date

Payload Preparation

ANVIL Assembly

NOTE

Under the supervision of the Safety Officer (Daniel Naveira) and Payload lead (Joseph Petite) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct all preparations. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers.

CAUTION

During the preparation and installations of the steamer ensure all shock cord remains free of unintended knots and tangles throughout. **Failure to follow the proper preparation guidelines may result in the failure of the recovery system and/or payload mission.**

- ☐ (AA.1) Inspect ANVIL upper and lower housing sections for unintended holes, fractures, cracks, and any signs of damage. SO:____
- ☐ (AA.2) Inspect the fiberglass plate on the upper housing section of ANVIL for unintended holes, fractures, cracks, and any signs of damage. SO:____
- ☐ (AA.3) Ensure that both eye bolts on ANVIL are secured tightly by tugging on them. SO:____
- ☐ (AA.4) Inspect shock cord for damage such as burns, frays, cuts, and other damage. SO:____
- ☐ (AA.5) Inspect ANVIL electronics for any signs of damage. SO:____

☐ (AA.6) Inspect ANVIL gimbal retraction system for any signs of damage to the servo, gear and rack and pinion. SO:____

☐ (AA.7) Inspect ANVIL gimbal system for any signs of damage to the wires, frame, and arms. SO:____

☐ (AA.8) Inspect the wires for the electronics are free of damage and the wires are not shorting the circuit. SO:____

☐ (AA.9) Verify that all electronics have been secured to the payload doors. SO:____

☐ (AA.10) Calibrate the payload altimeter for the location to ensure data is accurate.

☐ (AA.11) Insert and secure gimbal into the lower housing.

☐ (AA.12) Place the payload doors onto the lower housing and insert door pins.

☐ (AA.13) Secure the battery to the other payload door.

☐ (AA.14) Lift both the battery door and electronics door of the payload electronics bay to the vertical position until they hit the inner door stop and insert all connections between the PBC's.

☐ (AA.15) Secure all connections in the payload housing.

☐ (AA.16) Connect the the battery to the electronic systems.

☐ (AA.17) Verify functionality of the payload system by turning the FingerTech switch to the on position, once verified turn system off with the switch. SO:____

☐ (AA.18) Place the upper payload housing section on top of the lower housing section ensuring the screw holes line up.

☐ (AA.19) Secure the upper and lower payload housing sections together by sliding the four vertical connecting rods through, and threading the four hex nuts into place.

☐ (AA.20) Secure payload doors to the upper payload housing using 4-40 screws.

☐ (AA.21) Attach quick links to all mounting points on both of the 4 ft shock cord. SO:____

☐ (AA.22) Use the quick links to attach both 4 ft shock cords to separate eye bolts on ANVIL to the lower payload sections bulkhead.

☐ (AA.23) Place ANVIL aside in a shaded area under the tent.

☐ (AA.24) Remove the payload camera lens cap. SO:____

	______________	______________	______________
Work Done By:	Print Name	Sign Name	Date
Safety Officer:	Print Name	Sign Name	Date

Motor Preparation

NOTE:
The following procedures will be completed strictly by the 49er Rocketry Team NAR mentor (Jerry Dahlburg) or certified NAR personnel (Caitlin Bunce). Motor preparations will be done in direct accordance with manufacturer's assembly guidelines for the Aerotech L1390-G

NOTE:
The Safety Officer (Daniel Naveira) will supervise the motor preparations.

CAUTION

Ensure personnel is grounded prior to motor preparation .

****WARNING****
All nonessential personnel must withdraw a minimum distance of 15 *feet* at this time.

Only sign off below after the motor has been prepared per the instructions located on the manufacturers' preparation guidelines.

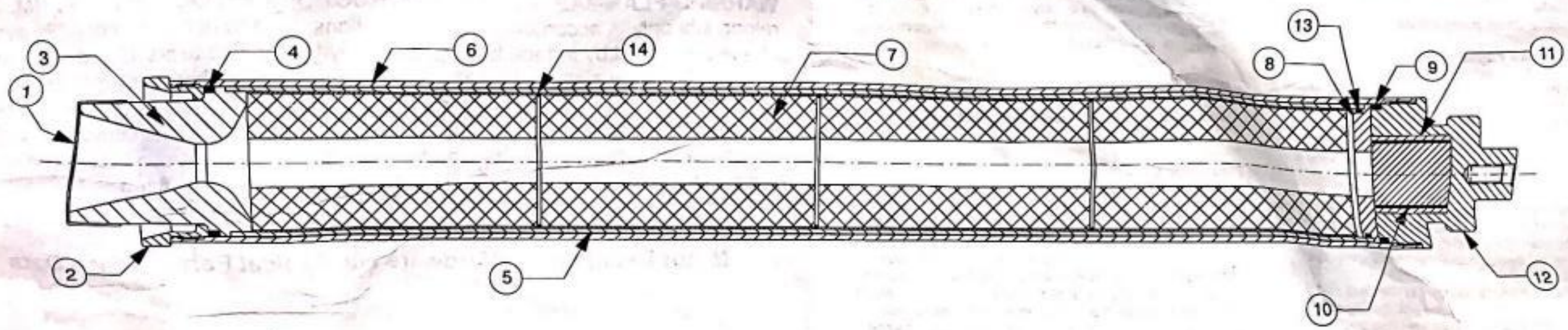
Work Done By:	________________ Print Name	________________ Sign Name	________________ Date
Safety Officer:	________________ Print Name	________________ Sign Name	________________ Date

AEROTECH CONSUMER AEROSPACE

RMS-75/1280-10240 Assembly Drawing and Instructions

NOTE: THE DRAWING SHOWN BELOW MAY BE A GENERIC REPRESENTATION OF THE ACTUAL MOTOR. NOZZLE SHAPE, NUMBER AND SIZE OF PROPELLANT GRAINS MAY BE DIFFERENT. FOR A DETAILED ASSEMBLY DRAWING OF THIS MOTOR PLEASE VISIT THE AEROTECH WEBSITE AT WWW.AEROTECH-ROCKETRY.COM

ITEM	DESCRIPTION	QTY	ITEM	DESCRIPTION	QTY
1	NOZZLE CAP	1	10	SMOKE GRAIN	1
2	AFT CLOSURE	1	11	SMOKE GRAIN INSULATOR	1
3	NOZZLE	1	12	FORWARD CLOSURE	1
4	AFT O-RING	1	13	FORWARD SEAL DISC O-RING	1
5	LINER	1	14	GRAIN SPACER O-RINGS	VARIES
6	CASE	1			
7	PROPELLANT GRAINS	VARIES			
8	FORWARD SEAL DISK	1			
9	FORWARD O-RING	1			



Assembly Instructions (numbers refer to item numbers on drawing):

1. Lightly grease forward, aft and forward seal disk o-rings (4, 9 & 13) and case threads (6).
2. Assemble smoke grain (10) and smoke insulator (11) as shown.
3. Apply a layer of grease to one end of the smoke grain and then push step 2 smoke assembly into forward closure (12), greased end first.
4. Install forward seal disk o-ring (13) on groove in forward seal disk (8) and insert this assembly into one end of liner (5) until seated.
5. Insert propellant grains (7) into liner (5) with a grain spacer o-ring (14) between each grain, then push liner assembly into case (6) until recessed equally from both ends of case.
6. Install forward o-ring (9) into (forward) end of case (6) with the forward seal disk (8)
7. Thread forward closure (12) into the (forward) end of the case (6) with the forward o-ring (9) until seated.
8. Assemble nozzle (3), aft o-ring (4), and aft closure (2) into open (aft) end of case (6) until seated.

Launch Vehicle Assembly

NOTE
Under the supervision of the Safety Officer (Daniel Naveira) the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) will conduct the following preparations. If any inspection or verification fails reference Troubleshooting Table 93: Situation Identifiers.

CAUTION
Failure to follow the proper preparation guidelines may result in the failure of the recovery system.

****WARNING****
If parachutes and steamers have been pre-packed ensure to remove rubber bands.

- ☐ (LVA.1) Inspect the carbon fiber airframe of the booster section for unintended holes, fractures, cracks, and any irregularities. SO:____
- ☐ (LVA.2) Inspect the carbon fiber airframe of the payload section for unintended holes, fractures, cracks, and any irregularities. SO:____
- ☐ (LVA.3) Inspect and verify booster section recovery system has correctly been assembled. SO:____
- ☐ (LVA.4) Inspect and verify payload section recovery system has correctly been assembled. SO:____
- ☐ (LVA.5) Inspect and verify that the precautionary GPS system is secure inside the nosecone. SO:____
- ☐ (LVA.6) Inspect and verify the proper assembly and functionality of ANVIL. SO:____
- ☐ (LVA.7) Inspect the four fin, fin block and boattail for any signs of damage. SO:____
- ☐ (LVA.8) Attach the 29 ft streamer shock cord from the nosecone to the upper part of payload section AV bay using the eye bolts and quick links.
- ☐ (LVA.9) ⚠ Slide the nosecone and upper payload section together with the 29 ft streamer, feather weight, and shock cord in the space between and secure using 2 nylon shear pins.
- ☐ (LVA.10) Attach the payload 72 inch main parachute from the bottom part of the payload AV bay to the lower payload section bulkhead using the eye bolts and quick links.
- ☐ (LVA.11) ⚠ Slide the upper and lower payload sections together with the payload 72 inch main parachute and its shock cord in between and secure using 3 nylon shear pins.
- ☐ (LVA.12) Attach shock cord between ANVIL and the lower payload section using the eye bolts.
- ☐ (LVA.13) ⚠ Place ANVIL on the T-track rail inside the payload section and slide it into place.
- ☐ (LVA.14) Ensure ANVIL slides freely and set the payload section of the launch vehicle aside.
- ☐ (LVA.15) Attach booster section 84 inch main parachute shock cord to the bottom of the AV bay bulkhead and the lower booster section.
- ☐ (LVA.16) ⚠ Slide the upper and lower booster sections together with the booster 84 inch main parachute and its shock cord in between and secure using 2 nylon shear pins.
- ☐ (LVA.17) Attach the booster section 12.5 inch drogue parachute shock cord to the top bulkhead of the booster section AV bay.
- ☐ (LVA.18) Attach the booster section 12.5 inch drogue parachute shock cord to the blast protection carbon fiber plate.
- ☐ (LVA.19) Place the booster section 12.5 inch drogue parachute and its shock cord into the upper booster section on top of the AV bay bulkhead.

☐ (LVA.20) Place the carbon fiber blast protection plate on top of the wedges inside the coupler.

☐ (LVA.21) Join the booster and payload sections of the airframe by sliding them together, ensuring that ANVIL's O-ring has been epoxied to the blast protection plate, and secure using 2 nylon shear pins.

☐ (LVA.22) Slide four modular fins into the fin slots on the lower booster section of the airframe.

☐ (LVA.23) Insert the fin block and use four set screws to secure into place.

☐ (LVA.24) Insert the Aerotech L1390-G motor that has been pre-installed in its motor casing into the aft of the booster section. SO:____

☐ (LVA.25) Thread the boattail onto the base of the motor retainer.

Work Done By: ________________ ________________ ________________
Print Name Sign Name Date

Safety Officer: ________________ ________________ ________________
Print Name Sign Name Date

Launch Procedures

Launch Pad Setup

NOTE:
The team must receive an inspection and approval from the RSO prior to the commencement of the setup.

NOTE:
The following procedures will be completed by the Recovery Officer (Corey Drummond) under the supervision of the NAR certified personnel and the Safety Officer (Daniel Naveira). **Ensure to bring the FingerTech allen wrench.**

CAUTION
Ensure to short circuit the igniter by twisting the ends together and tape it to the launch vehicle prior to the RSO inspection.

****WARNING****
All nonessential personnel must withdraw a minimum distance of 300 *feet* at this time.

☐ (LPS.1) Transport the vehicle to the launch pad that was assigned by the RSO.

☐ (LPS.2) Lower the launch rail by removing the cotter pin from the rail and slowly lowering the rail.

☐ (LPS.3) Inspect launch rail to ensure it is free of FOD (foreign object debris).

☐ (LPS.4) Using a shop towel wipe down the launch rail.

☐ (LPS.5) Inspect the Launch rail to ensure that a rail stop is present.

☐ (LPS.6) Place the launch vehicle onto the launch rail by aligning the rail buttons with the launch rail and gently sliding the vehicle down the rail.

☐ (LPS.7) Slowly raise the launch rail with the launch vehicle back into the vertical position and secure the launch rail by reinserting the cotter pin.

☐ (LPS.8) Arm the recovery altimeters by screwing the FingerTech switches to the on position and verify there is an audible tone for all four altimeters. SO:____

☐	(LPS.9)	Drop a pin location using a smart phone to mark the location of the launch pad being used by the launch vehicle.	SO:___
☐	(LPS.10)	Visually inspect the airspace for birds and other flying objects, and confirm with the RSO that airspace is clear.	SO:___
☐	(LPS.11)	Using the anemometer record the wind speed **Average:**_____*mph* and **Max:**_____*mph*.	SO:___

Igniter Installation

NOTE:

The following procedures will be completed by the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) under the supervision of the NAR certified personnel and Safety Officer (Daniel Naveira). **Cut a small piece off of the red end cap to reduce chance of over pressurization.**

CAUTION

Ensure personnel is grounded prior to the commencement of igniter installation.

****WARNING****

All nonessential personnel must withdraw a minimum distance of 300 *feet* at this time.

****WARNING****

The igniter installation procedures will only be conducted once all other steps of the checklist have been completed.

☐	(IGN.1)	Remove igniter from the side of the launch vehicle and untwist the ends.	
☐	(IGN.2)	Separate the igniter leads by untwisting them and then pull back the insulation to expose about *1 inch* of copper wire.	
☐	(IGN.3)	Touch the alligator clips together to ensure that there is no power being supplied.	
☐	(IGN.4)	Inspect launch terminal, if corrosion is present clean off with a wire brush.	
☐	(IGN.5)	Remove the red end cap from the nozzle of the motor.	
☐	(IGN.6)	Insert the combustion end of the igniter into the motor until no more can be fed in, which will also be indicated by a piece of tape.	
☐	(IGN.7)	Secure the igniter within the motor by reinstalling the motor end cap.	
☐	(IGN.8)	Secure alligator clips to launch pad by looping wire to the launch pad.	
☐	(IGN.9)	Connect the firing module by using the alligator clips to clamp the exposed igniter leads and twisting the leads around the alligator clips to secure in place.	
☐	(IGN.10)	Ensure that the alligator clips do not touch.	
☐	(IGN.11)	Check for continuity by following the leads to the launch control input box and press the button that corresponds to the launch pad and verify there is an audible tone.	SO:___
☐	(IGN.12)	Ensure that all personnel clear the flight line and withdraw a minimum distance of *300 Feet*.	

Work Done By:	______________	______________	______________
	Print Name	Sign Name	Date
Safety Officer:	______________	______________	______________
	Print Name	Sign Name	Date

Post-Flight Recovery

NOTE:

The team must wait and receive approval from the RSO that the launch pads are clear and it is safe prior to the commencement of the setup.

NOTE:

The following procedures will be completed by the Recovery Officer (Corey Drummond) under the supervision of the NAR certified personnel and the Safety Officer (Daniel Naveira). **Ensure to bring the FingerTech allen wrench, RCHP tracking gun, and**

the featherweight tracker.

CAUTION
All personnel must walk not run to recover the launch vehicle and payload. Failure to follow there these procedure may result in injury to personnel.

****WARNING****
All nonessential personnel must stay a minimum distance of 15 *feet* until the rocket has been disarmed and the SO gives the all clear.

- ☐ (PFR.1) Once the RSO has given the all clear and the pads are safe, the team may proceed to retrieve the launch vehicle and payload. SO:____
- ☐ (PFR.2) Take pictures of the launch vehicle and payload from a distance prior to touching anything.
- ☐ (PFR.3) Announce "Disarming" and screw the FingerTech switch counterclockwise to the off position for both avionics bays trying not to alter the landing site.
- ☐ (PFR.4) Wait 30 *s* and verify there is no longer an audible tone coming from the altimeters. SO:____
- ☐ (PFR.5) Verify that all 8 separation chargers went off and there is no longer black power. SO:____
- ☐ (PFR.6) If all 8 separation charges are clear announce "ALL CLEAR" and allow nonessential personnel to approach and help. If the charges are not clear do not allow nonessential personnel to approach and follow Disarm steps (DIS.10) - (DIS.20). SO:____
- ☐ (PFR.7) Power off ANVIL electronics by screwing the FingerTech switch counterclockwise to the off position.
- ☐ (PFR.8) Take pictures of the launch vehicle and payload landing site before moving anything.
- ☐ (PFR.9) Drop a pin location using a smart phone to make where the payload section of the launch vehicle landed. SO:____

Work Done By: ____________ ____________ ____________
Print Name — Sign Name — Date

Safety Officer: ____________ ____________ ____________
Print Name — Sign Name — Date

Troubleshooting

Table 93: Situation Identifiers

Situation	Identifier	Solution
E-match has no continuity	When connected to a digital multimeter there is not a infinite resistance readout.	Replace the E-match.
Featherweight not transmitting	No transmissions received from Featherweight	Ensure Featherweight receiver is set to the correct channel. Test the battery of the Featherweight using multimeter to ensure it has power, if not replace battery and re-due steps (PTSA.1)-(PTSA.4) or (BTSA.1)-(BTSA.4).
Electronics not powering on	Active power lights on electronics don't turn on.	Test batteries with multimeter, if there isn't enough power replace batteries. If there is power inspect wires for damage, if damaged replace wires. If wires are not damage replace electronic component with the backup component.

Situation	Identifier	Solution
Parachute or streamer will not fit inside airframe	The parachute or streamer cover with a nomex blanket does not easily slide into airframe of the launch vehicle.	Remove the parachute from the nomex blanket and repack the parachute following the parachute prep guidelines until it easily slide into the airframe.
Payload not transmitting	No transmissions received from Xbee	Verify both Xbees are active, if they are not both on, activate to ON and wait 5 seconds. Inspect antennas for any signs of damage, if present replace antenna. For further troubleshooting reference XBee user manual that can be found in the safety handbook.
Launch pad module shows no continuity for the igniter	1. Alligator clips have corrosion 2. Defective igniter	Disconnect the alligator clips and inspect for damage and debris. Clean off clips if there is debris and reconnect. If the igniter leads are damaged replace the igniter.
Modular fin does not fit or is damaged	1. During pre-flight inspection damage to fin is identified 2. During assembly fin does not fit	1. Discard fin and replace with spare modular fin 2. If fin does not fit mark for later sanding and replace with spare modular fin
FingerTech switch comes loose or breaks	FingerTech switch cannot be activated	Return the launch vehicle to the ground station and remove the AV bay. Inspect the FingerTech switch for signs of damage, if no damage use quick dry epoxy to fix the FingerTech back in place and wait for it to set. If damaged replace the FingerTech switch use quick dry epoxy to fix in place and solder back to altimeter.
No audible tone after activating altimeter with FingerTech switch.	1. Altimeter circuit lacks continuity 2. Altimeter circuit is shorted	Turn off the altimeters using the FingerTech switches and remove the AV bay. Inspect the altimeter's wires for fraying, loose, touches and electronic contact points.
Shear pin holes don't line up	1. Shear pin holes don't line up horizontally 2. Shear pin holes don't line up vertically 3. Can not locate shear pin holes	1. If the shear pin holes are misaligned horizontally twist the airframe until the marks on the outside of the airframe line up. 2. If the shear pin holes are misaligned vertically push the two sections of airframe together by applying pressure. If they are still misaligned verify nothing is obstructing the coupler by repacking the parachute or streamer and the shock cord. 3. If the shear pin holes can not be located take the two sections apart and verify that the shear pin holes are not cover by an old shear pin.

Situation	Identifier	Solution
FingerTech switches holes misaligned	1. FingerTech hole don't line up horizontally 2. FingerTech hole don't line up vertically	1. If the FingerTech hole is misaligned horizontally detach the AV bay or payload and rotate 180 degrees and resecure inside airframe. 2. If the FingerTech hole is misaligned vertically tighten the screw down further. If it is still misaligned remove the AV bay and clean out any debris and re-assemble.
Rail buttons are binding with the launch rail	The launch vehicle does not smoothly slide down the launch rail.	Verify that the rail buttons are the correct size for the assigned launch rail. If correctly size ensure the rail buttons on the vehicle are aligned properly and ensure that the rail buttons have not been tightened too much.
Misfiring of Motor	After multiple firing cycles the motor still does not ignite.	Disconnect the alligator clips and remove the igniter from the motor. Inspect the igniter to see if it ignited. If it did not ignite follow IGN.2 - IGN.12 steps again. If the igniter did ignite replace the igniter with a new one and ensure that the pressure relief hole was cut into the red end cap and follow IGN.2 - IGN.12 steps again.
AV Bays do not slide in all the way	After multiple tries the AV bay will not easily slid into place.	Remove the AV bay from the airframe and ensure that the AV bay is properly assembled and no wires or tap are sticking out and getting snagged. Ensure the inside of the airframe is clean. Reinsert the AV bay and ensure it is aligned with the slot in the bulkhead. If still stuck use the AV bay push rod to apply a slight localized pressure on the bay.

Immediate Action Procedures

NOTE:
The following procedures will be completed by the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) under the supervision of the Safety Officer (Daniel Naveira).

****WARNING****
Due to hang fires the launch vehicle may still launch after the power has been removed. Prematurely approaching the launch vehicle could result in personnel becoming injured.

☐ (IAP.1) Wait for the power to be removed and the audible confirmation that the range is clear by the RSO. SO:____

☐ (IAP.2) All personnel must wait 5 *mins* incase of hang fire. SO:____

☐ (IAP.3) Remove the alligator clips from the igniter and take it out of the launch vehicle. SO:____

☐ (IAP.4) Use the situation identifier table below to determine the problem and a solution.

Disarm

NOTE:
The following procedures will be completed by the Recovery Officer (Corey Drummond) and/or Secondary Recovery Officer (John Allman) under the supervision of the Safety Officer (Daniel Naveira).

NOTE:
In the event of that a launch must be aborted due to weather or other safety concerns, the following step will be used to safely disarm the launch vehicle and allow for it to be removed from the launch rail and field.

A **maximum of three** personnel will preform the following list of procedures.

☐ (DIS.1) Verify that the RSO has cut the power to the launch control module. SO:____

☐ (DIS.2) All personnel must wait 5 *mins* incase of hang fire. SO:____

☐ (DIS.3) Remove the alligator clips from the igniter and take it out of the launch vehicle. SO:____

☐ (DIS.4) Once removed from the motor, short the igniter by twisting its leads together. SO:____

☐ (DIS.5) Announce ”Disarming altimeters”. SO:____

☐ (DIS.5) Screw the FingerTech switch counterclockwise to the off position for both avionics bay. SO:____

☐ (DIS.6) Wait 30 *s* and verify there is no longer an audible tone coming from the altimeters. SO:____

☐ (DIS.7) Power off ANVIL electronics by screwing the FingerTech switch counterclockwise to the off position. SO:____

☐ (DIS.8) Remove the pin from base of launch rail that holds it in the vertical position.

☐ (DIS.9) Slowly lower the launch rail to the horizontal position and slide the vehicle off the rail.

☐ (DIS.10) Ensure all personnel clear the launch area and transport the vehicle to the teams setup area. SO:____

☐ (DIS.11) Remove the booster section AV bays from the launch vehicle.

☐ (DIS.12) Disconnect the 9 *V* batteries on the AV bays. SO:____

☐ (DIS.13) Unscrew and disconnect the E-matches from altimeters and place in their appropriate container.

☐ (DIS.14) Remove the aluminum tape from main parachute charge well and pour the black powder back into the black powder storage container. SO:____

☐ (DIS.15) Remove the aluminum tape from drogue parachute charge well and pour the black powder back into the black powder storage container. SO:____

☐ (DIS.16) Remove the payload section AV bays from the launch vehicle.

☐ (DIS.17) Disconnect the 9 V batteries on the AV bays. SO:____

☐ (DIS.18) Unscrew and disconnect the E-matches from altimeters and place in their appropriate container.

☐ (DIS.19) Remove the aluminum tape from main parachute charge well and pour the black powder back into the black powder storage container. SO:____

☐ (DIS.20) Remove the aluminum tape from streamer charge well and pour the black powder back into the black powder storage container. SO:____

☐ (DIS.21) Verify that all nonessential personal have withdrawn from the area. SO:____

☐ (DIS.22) Remove the motor casing and pre-installed motor out of the launch vehicle. SO:____

☐ (DIS.23) Carefully remove the motor from the motor casing. SO:____

☐ (DIS.24) Degrease the motor parts and place back into the original container. SO:____

Work Done By:	Print Name	Sign Name	Date
Safety Officer:	Print Name	Sign Name	Date

Post-flight Inspections

NOTE:
During the following procedures take copious amounts of picture of anything that was damaged and always take picture of critical components to verify they were assembled correctly. This includes the AV bays inside the vehicle to ensure it was facing the correct direction and after removal to verify all the wiring was done correctly.

**** WARNING****
Personnel must follow Disarm Procedures and ensure all energetics have been removed prior to completing the following items.

☐ (PFI.1) Inspect all the following vehicle components and place an "X" in the box if the component has damage: SO:____

- ☐ Motor retention (Fracture, cracks, gas porosity)
- ☐ Fin block (Stress/spider/cracks around press fit area, burns, melting material)
- ☐ Fin guide (Stress/spider/cracks around press fit area, burns, melting material)
- ☐ Modular fins (Stress areas, fractures, cracks, scratches, melting, defects)
- ☐ Booster section airframe (Pressure fractures, stress/spider/cracks around bolt points, unintended holes)
- ☐ Payload section airframe (Pressure fractures, stress/spider/cracks around bolt points, unintended holes)
- ☐ Bulkheads (Pressure fractures, stress/spider/cracks around bolt points, unintended holes, signs of epoxy failure)
- ☐ Nosecone (Impact fractures, burns/melted material, ensure eyebolt is not loose inside)
- ☐ Main and drogue parachutes (Burns, holes, discoloration, fray)
- ☐ Streamer (Burns, holes, discoloration, fray)
- ☐ Shock cords (Burns, holes, discoloration, fray)
- ☐ Altimeter bays (Physical damage to bulkheads and mounting hardware, damage to altimeters, ensure eyebolt is not loose inside)
- ☐ Inspect rail buttons for damage.

☐ (PFI.2) Inspect all the following payload components and place an "X" in the box if the component has damage: SO:____

- ☐ Payload housing (Physical damage to bulkheads and mounting hardware, ensure eyebolt is not loose inside, rail system)
- ☐ Payload gimbal (Physical damage to arms and mounting hardware, joint movement)
- ☐ Payload electronics (Physical damage to mounting hardware, ensure electronics turn on and function as intended)
- ☐ Payload gimbal retraction system (Physical damage to mounting, hardware, rack, servo motor, ensure electronics turn on and function as intended)
- ☐ Payload shock cords (Any signs of damage such as cuts, tearing, burning etc.)
- ☐ Payload rails and eye bolts (Any signs of damage such as cracks, fracture, loosening etc.)
- ☐ All batteries (Any signs of damage such as cuts, punctures, etc.)
- ☐ Payload and AV bays for any loose wire.

☐ (PFI.3) Note all damaged components that need to be replaced, if any are identified in step (PFI.1) and (PFI.2) SO:____

☐ (PFI.4) Using a laptop, download and save all flight data from all altimeters:

- Booster Section Altimeter 1: ________
- Booster Section Altimeter 2: ________
- Payload Section Altimeter 1: ________
- Payload Section Altimeter 2: ________
- **Scoring Altimeter:** ________

☐ (PFI.5) Use shop towels to clean out all black powder residue created by the separation charges.

☐ (PFI.6) Use shop towels to clean out all dirt and mud on and/or in the launch vehicle from landing.

Work Done By:	____________________	____________________	____________________
	Print Name	Sign Name	Date
Safety Officer:	____________________	____________________	____________________
	Print Name	Sign Name	Date

7 Project Plan

Testing is preformed to verify design decisions prior to a final design. Testing involves the collection of data from different variables and comparing the results to expected values. These expected values may be from calculations or other credible sources. Verification by analysis is an in-depth evaluation of a certain system or subsystem. Finite Element Analysis (FEA) is an example of such verification method. Verification by inspection is a thorough investigation of a system or subsystem and its current circumstances. An example of inspection is reviewing parachutes for damage. Verification by demonstration is a testament to a system or subsystem's capability to preform under certain conditions. Demonstrations are preformed by "showing" how a system would work. An example of this is a black powder separation demonstration. Vehicle verifications are listed in Table 7.1, while the payload verifications are listed in Table 7.2. Each section includes the following sub-sections:

- **Objective:**
  The objective describes the goal of the verification.
- **Justification:**
  The justification describes why it is necessary to preform the verification method.
- **Testing Variables:**
  The testing variables lists each qualitative aspect of the test to be studied.
- **Equipment:**
  The equipment section lists all required components to complete the verification method.
- **Safety Precautions:**
  The safety precautions section lists all dangers to personnel or the environment that may arise during verifications.
- **Procedure:**
  The procedures section is a list of all steps preformed by team members who completed or will complete the verification method. It

is enumerated to aid those who wish to replicate the verification method.

- **Success Criteria:**
  The success criteria section is a list of requirements for the verification method to be considered successful. Verifications that have been completed are labeled with either a "pass" or "fail". In order for a test to be considered a success, all requirements must passed.

- **Results:**
  The results section provides an overview and the importance of the outcome of the verification method. Quantitative results are shown in this section if applicable.

- **Impact on final design:**
  The impact on final design section pertains to the importance of the results section. Should a verification method be considered a failure, the tested component would have to be redesigned to function as intended.

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.

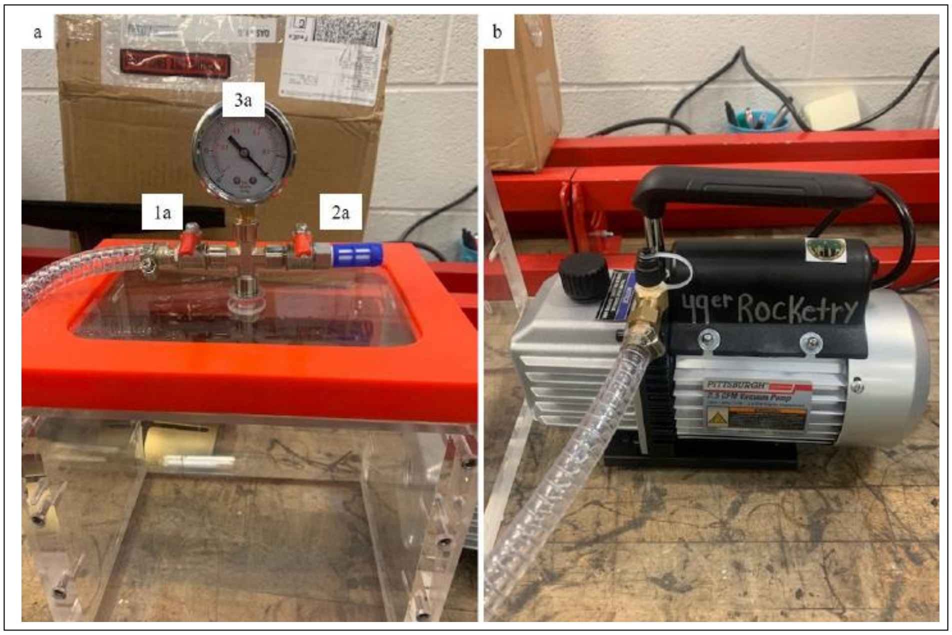


Figure 105: Vacuum Test Chamber and Pump

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.

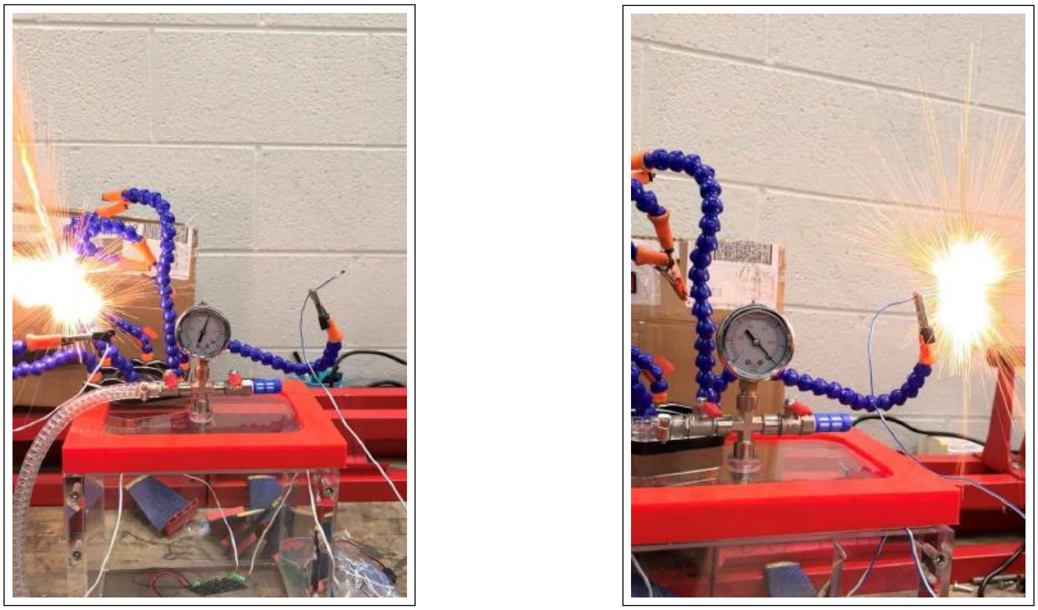
Success Criteria:

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:

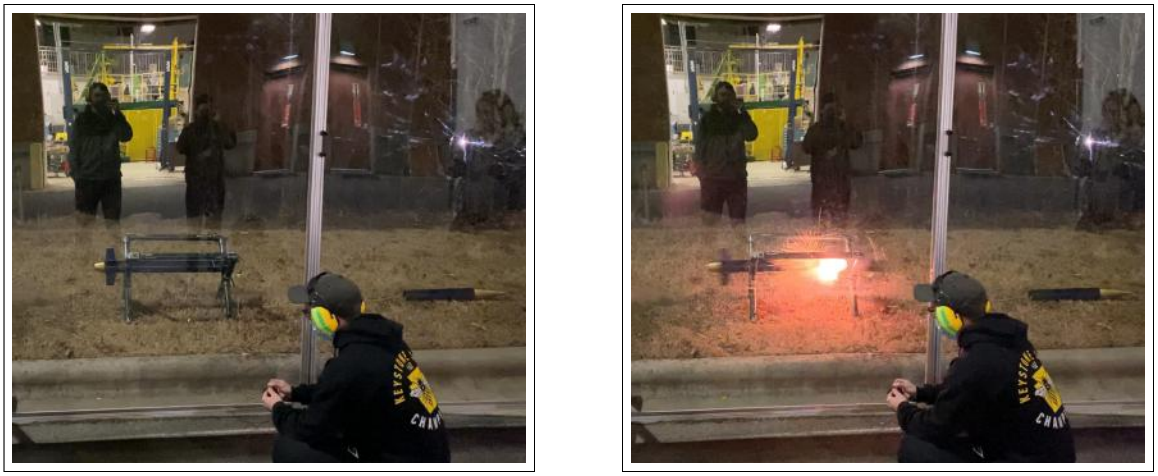
The sub-scale successfully ejected the drogue and main parachutes with the theoretically calculated black powder charges. The drogue and main parachutes were completely ejected with all of their shock cords taught. No damage was suffered by any components during the ejection process.

(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.

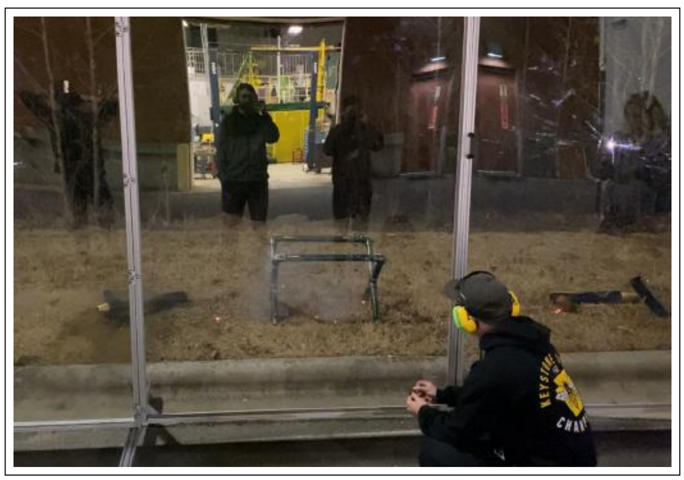


Figure 109: Main Parachute Deployed

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.

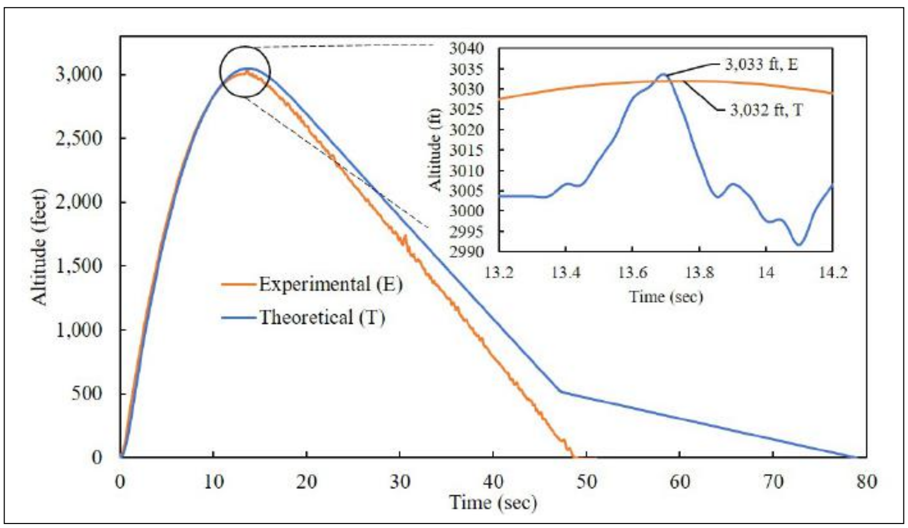


Figure 111: Sub-Scale Flight 2 Apogee Results

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.

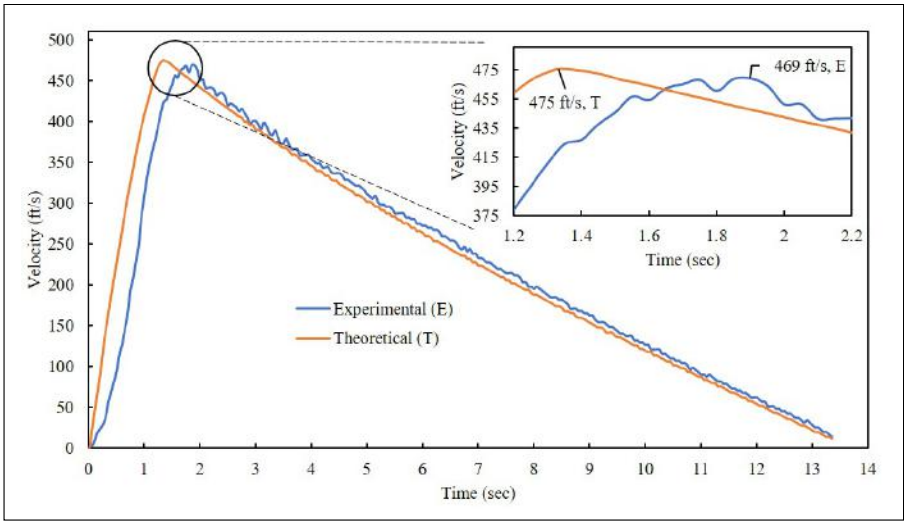


Figure 112: Sub-Scale Flight 2 Velocity Profile

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.

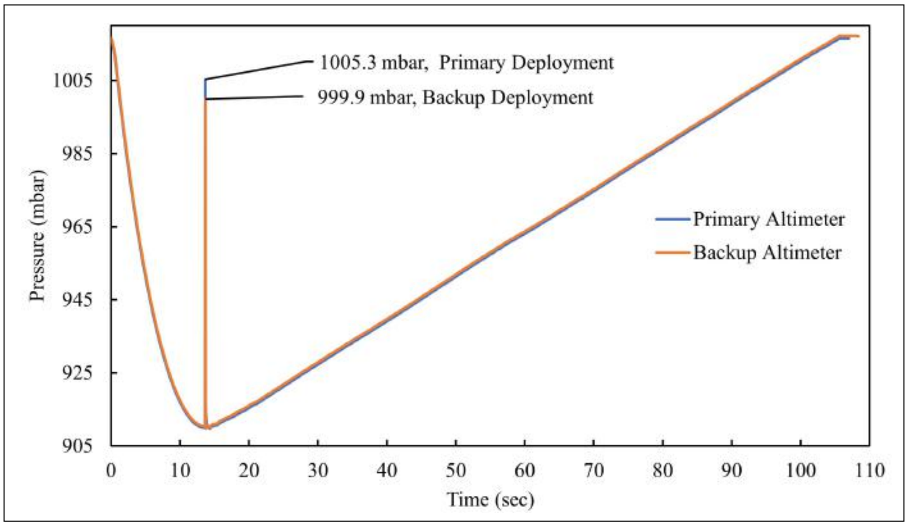


Figure 113: Sub-Scale Flight 3 Pressure Results

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.

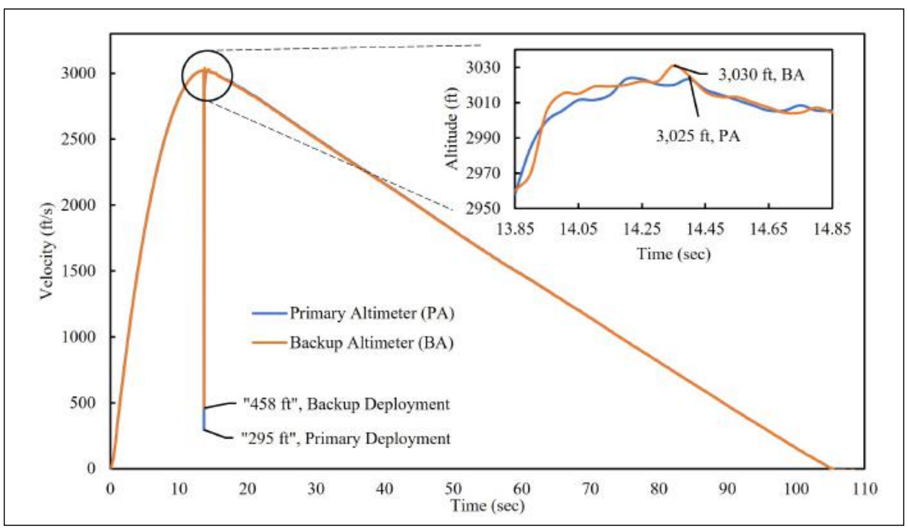


Figure 114: Sub-Scale Flight 3 Altitude Results

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.

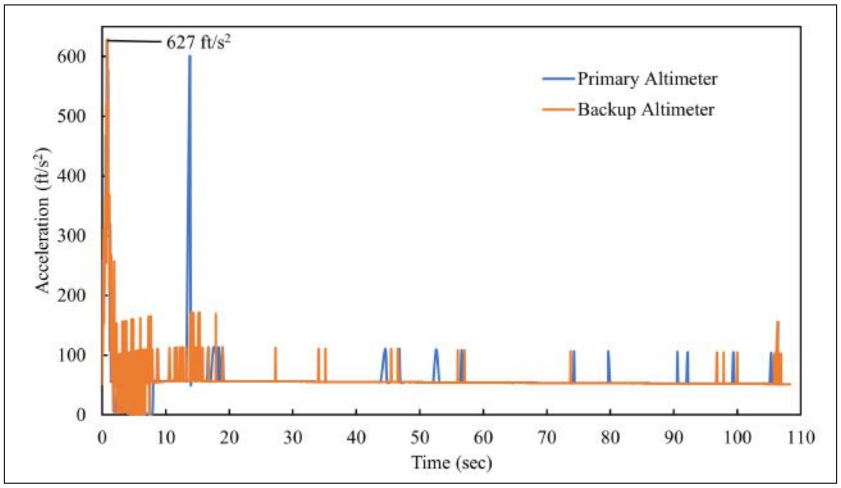


Figure 115: Sub-Scale Flight 3 Acceleration Results

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.

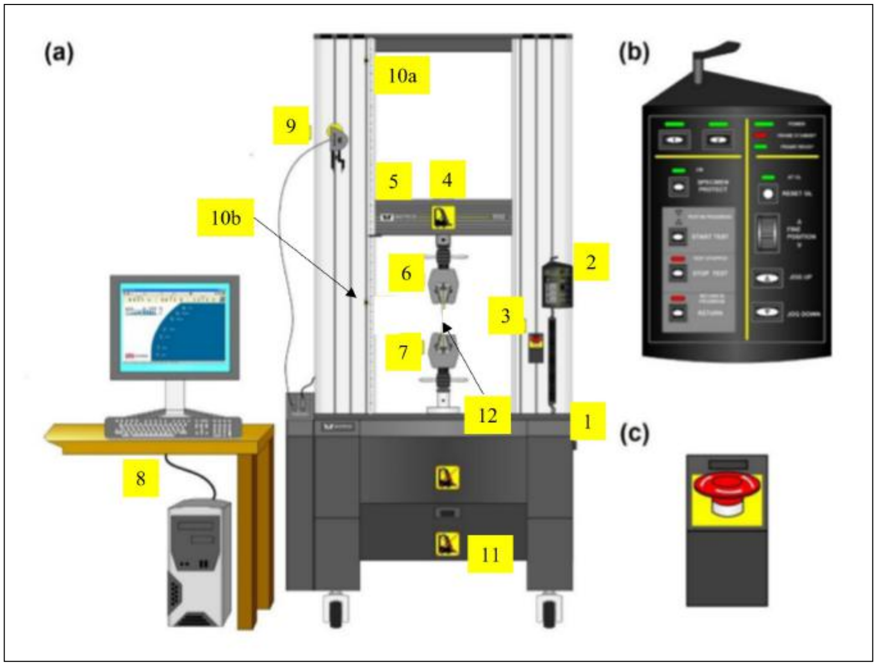


Figure 116: Instron 5582 Universal Testing Machine

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.

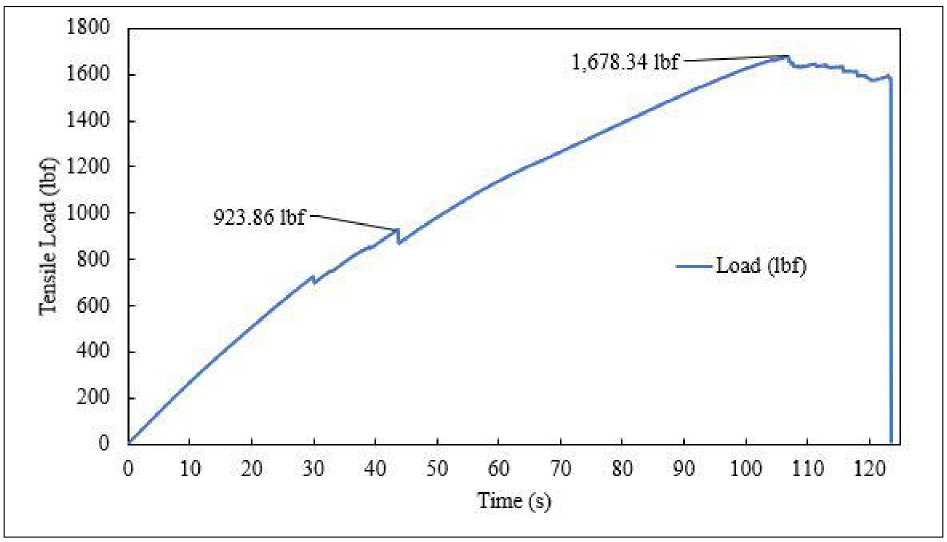


Figure 117: Bulkhead Pull-to-Failure Tensile Test

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:

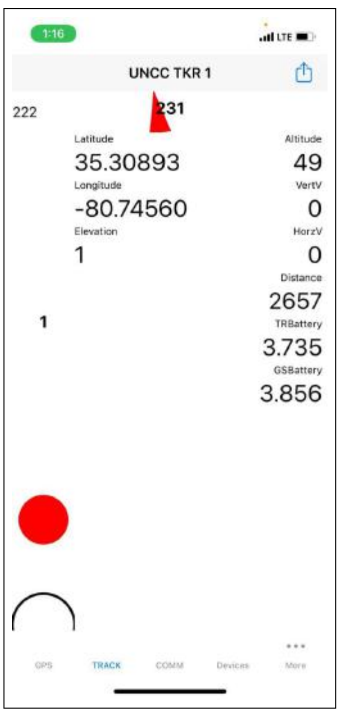
Figure 128 displays the locations of the transmitter and receiver for the FeatherWeight GPS trackers. The red circle in the center of image 128a is the location of the team member with the FeatherWeight GPS receiver.

(a) Transmitter POV

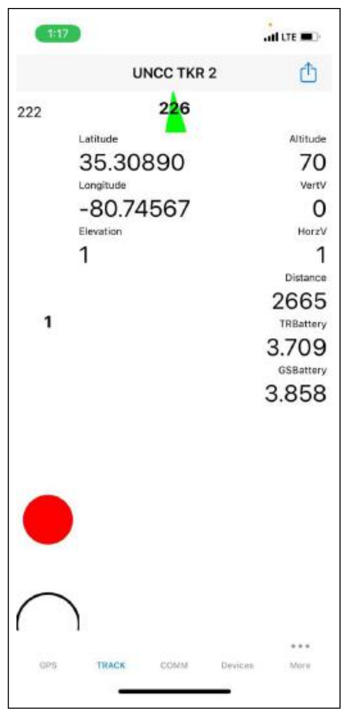
(b) Receiver POV

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.

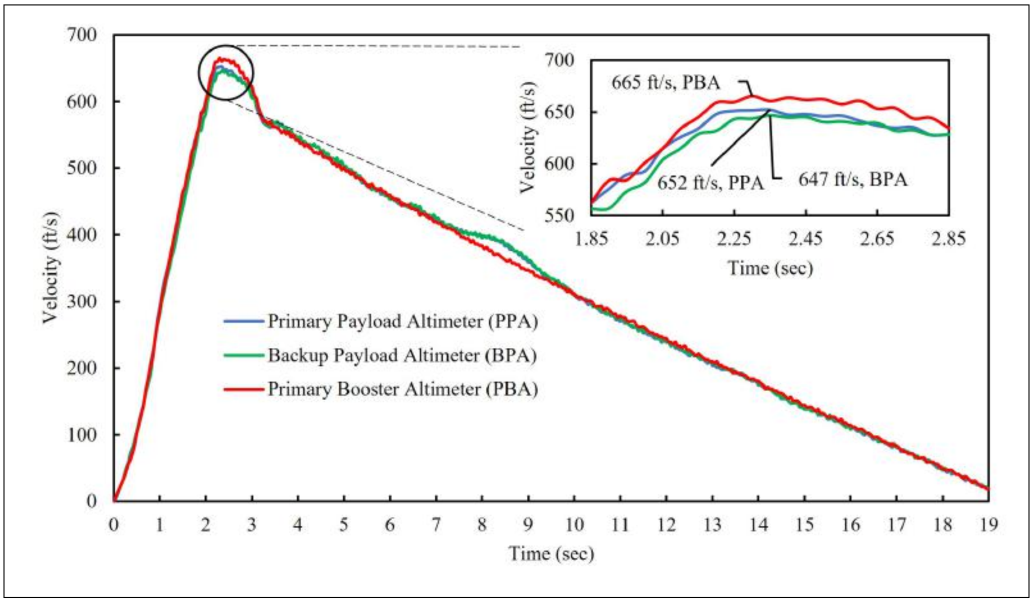


Figure 130: Full-Scale Velocity Profile During Ascent

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.

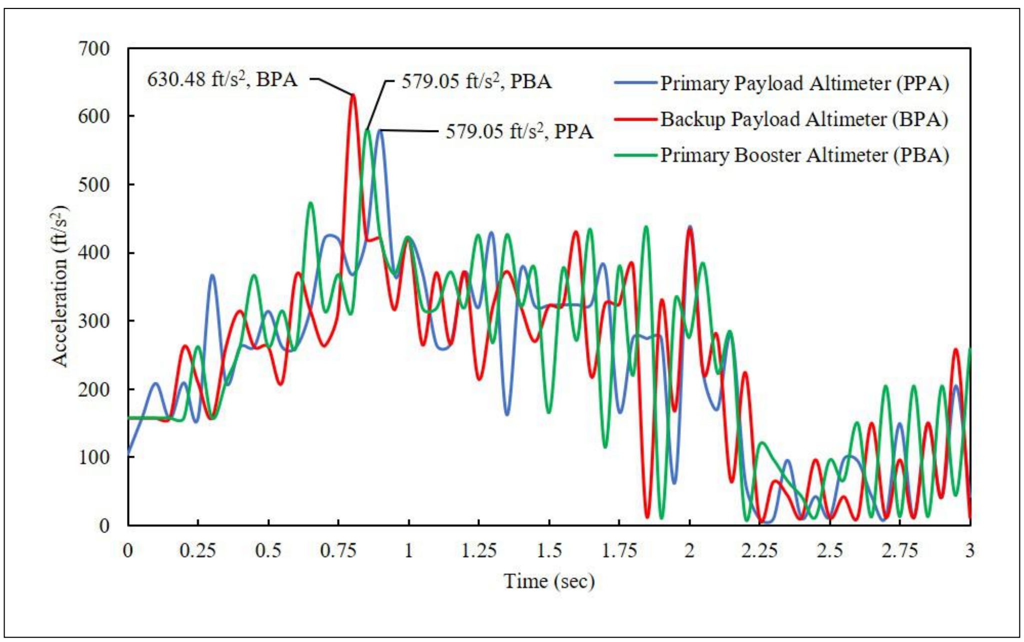


Figure 131: Full-Scale Acceleration Profile

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.

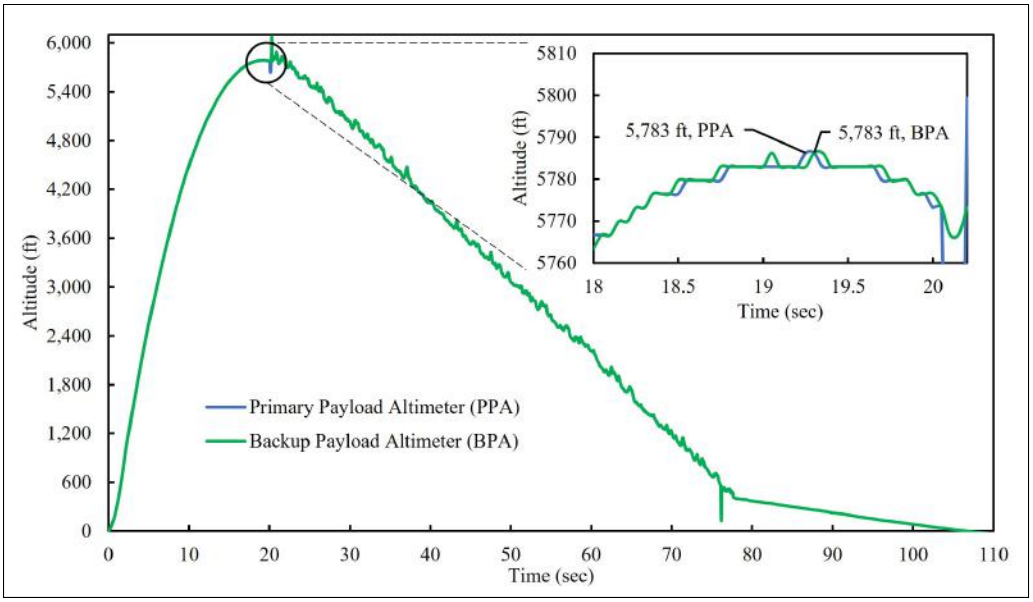


Figure 132: Full-Scale Payload Altimeter Data

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$_\text{f}$. The RRC3 data from the booster section is shown in Figure 133.

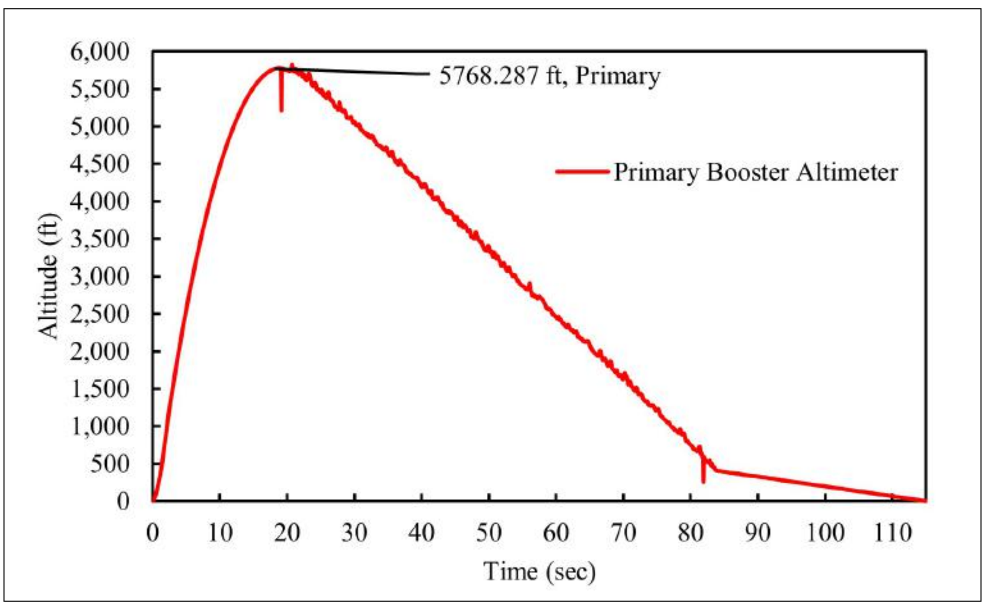


Figure 133: Full-Scale Booster Altimeter Data

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$_\text{f}$.

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.

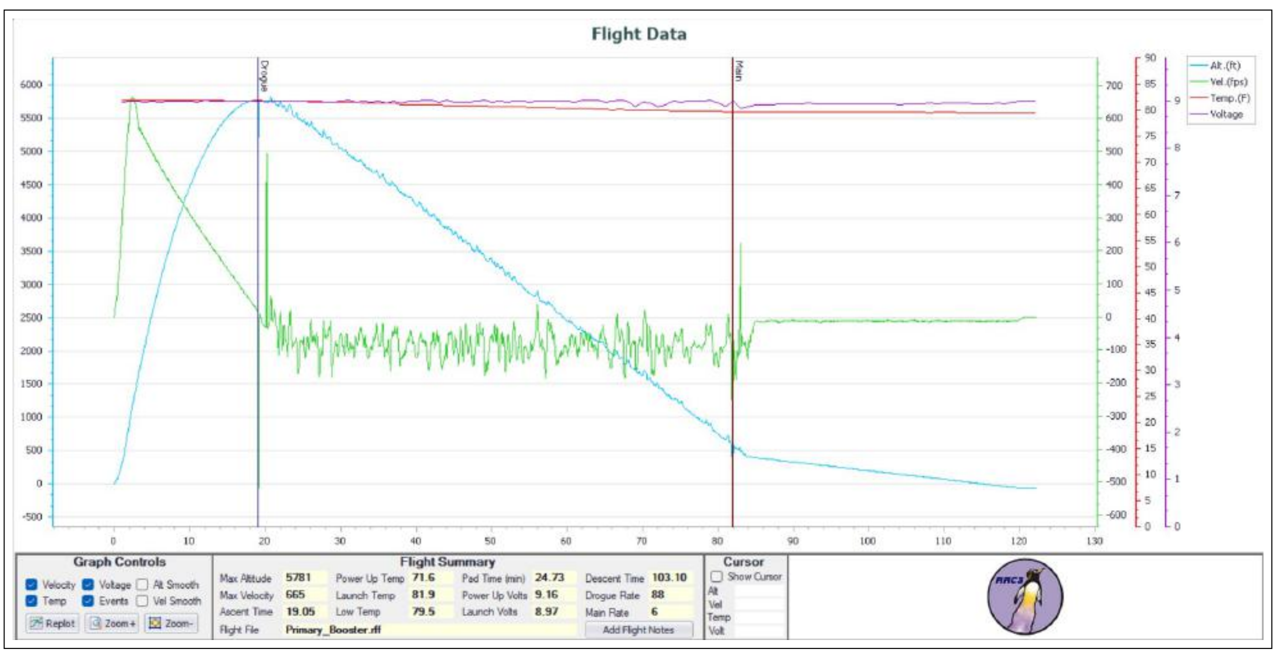


Figure 135: Raw Primary Booster RRC3 Data

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

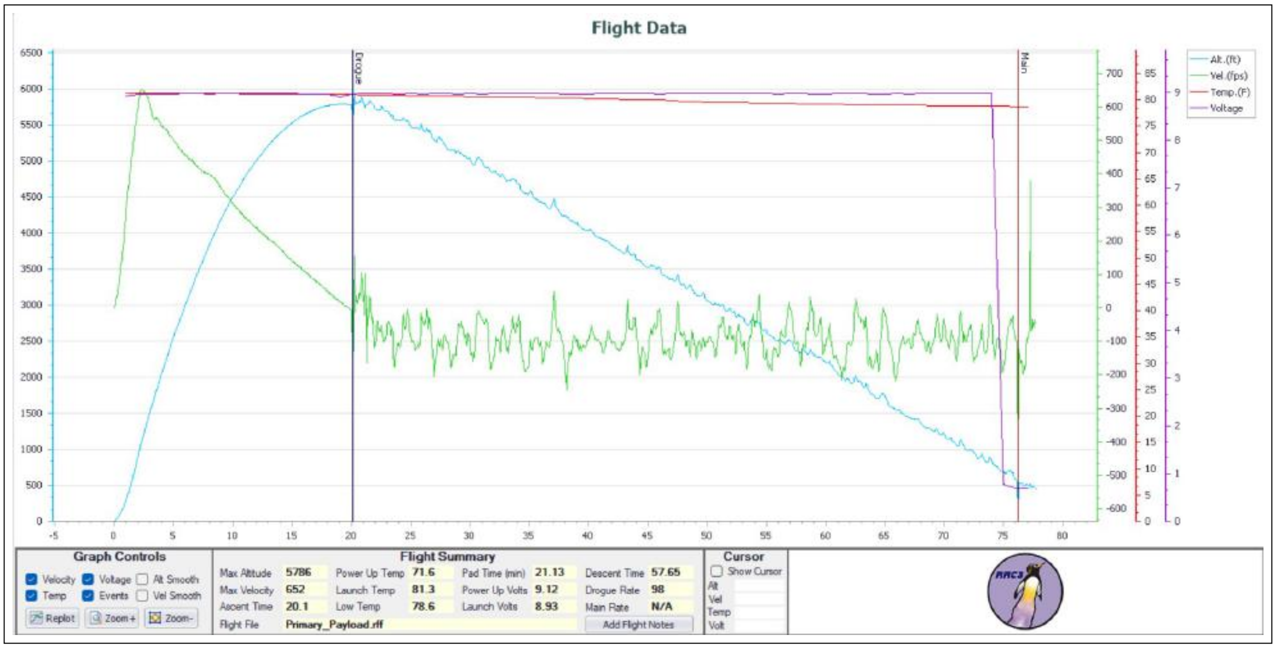


Figure 136: Raw Primary Payload RRC3 Data

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

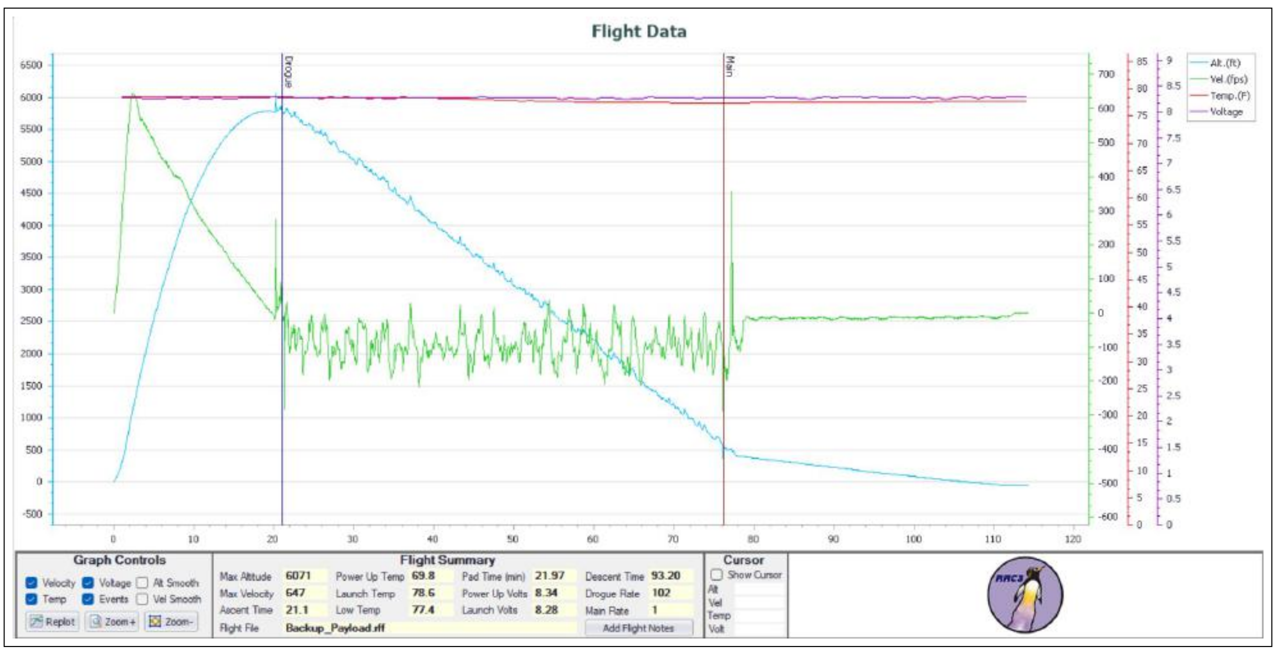


Figure 137: Raw Backup Payload RRC3 Data

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.

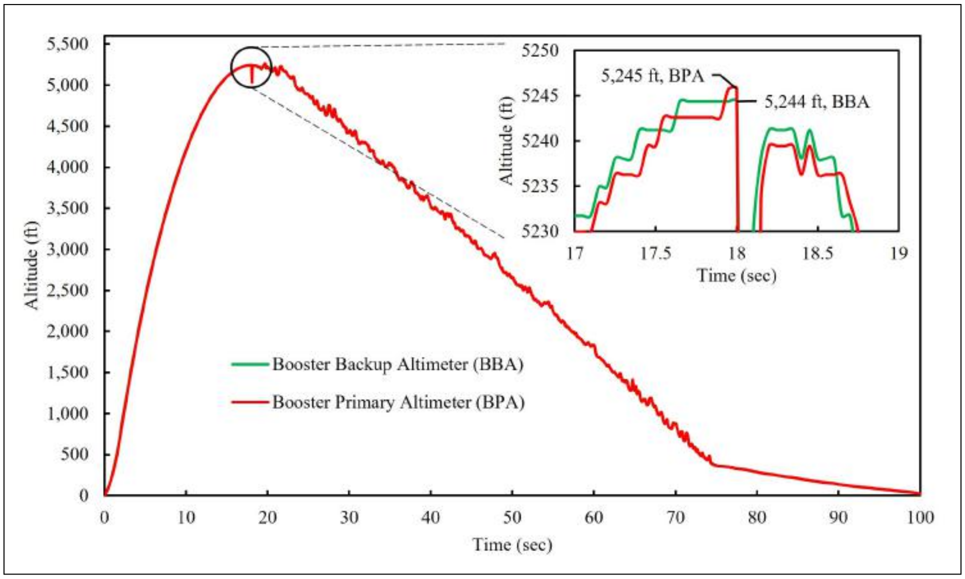


Figure 138: Vehicle Flight Test Booster Altimeter Data

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.

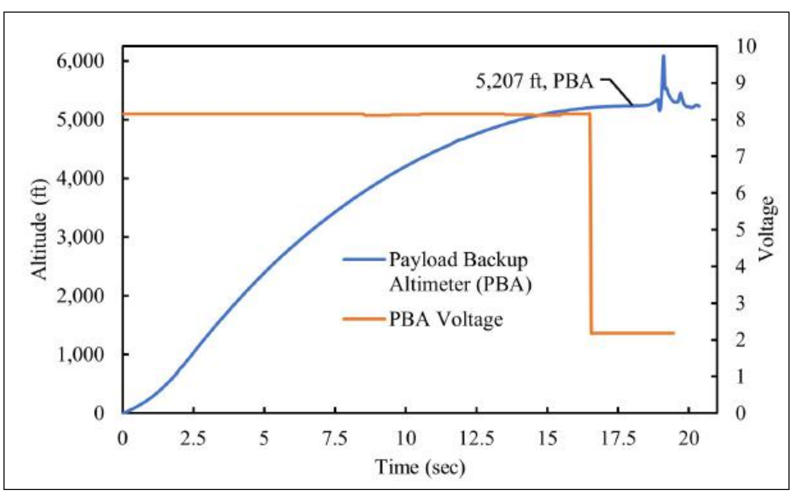


Figure 139: Vehicle Flight Test Payload Altimeter Data

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.

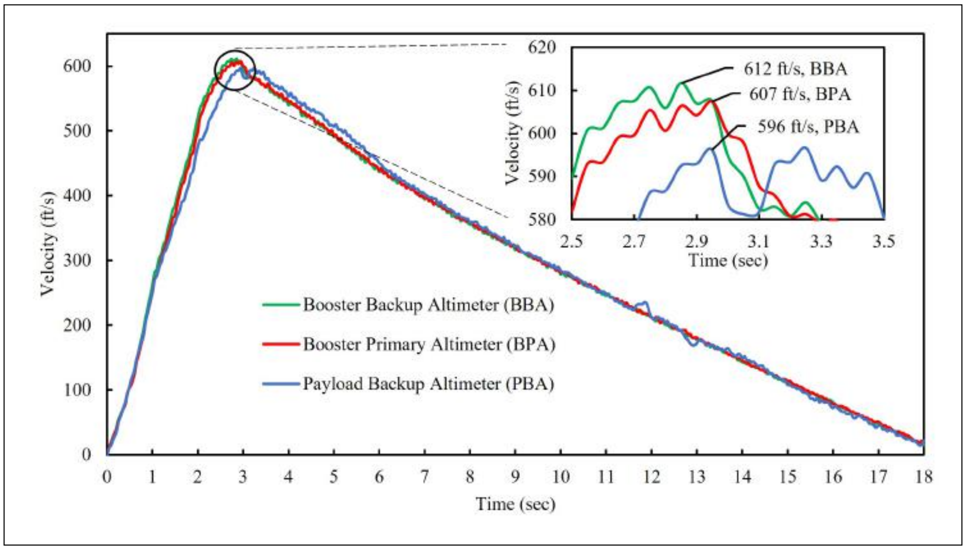


Figure 140: Vehicle Flight Test Ascent Velocity Profile

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.

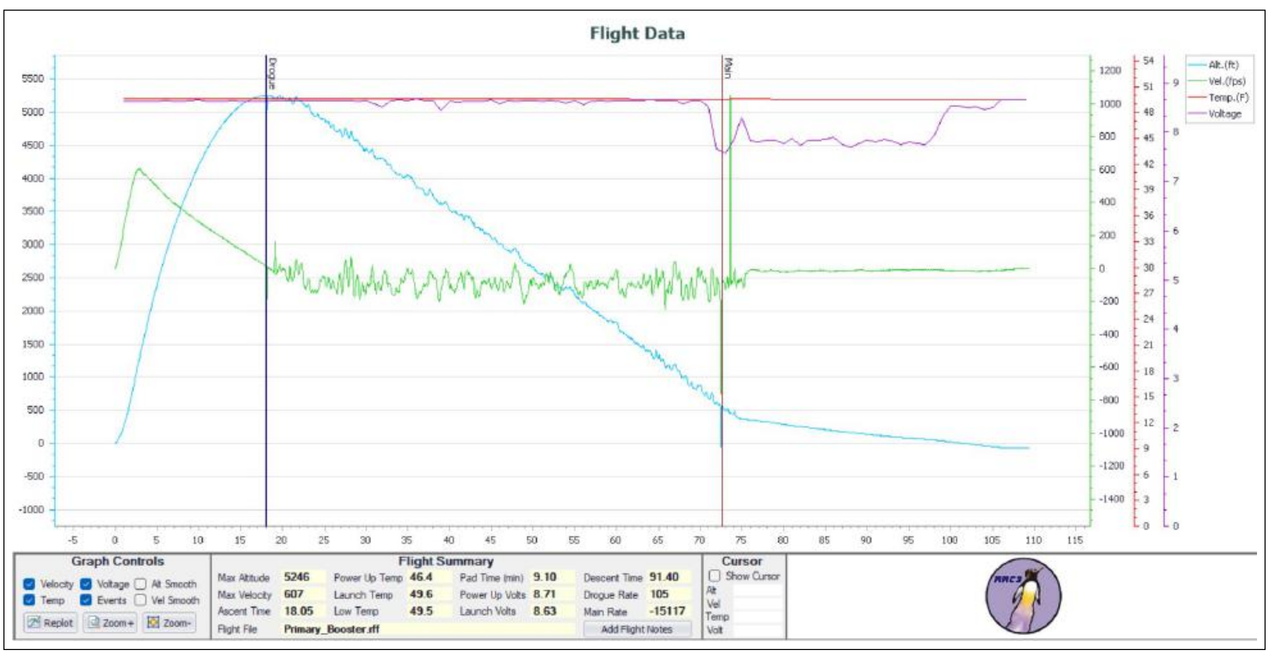


Figure 141: Raw Primary Booster RRC3 Data

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

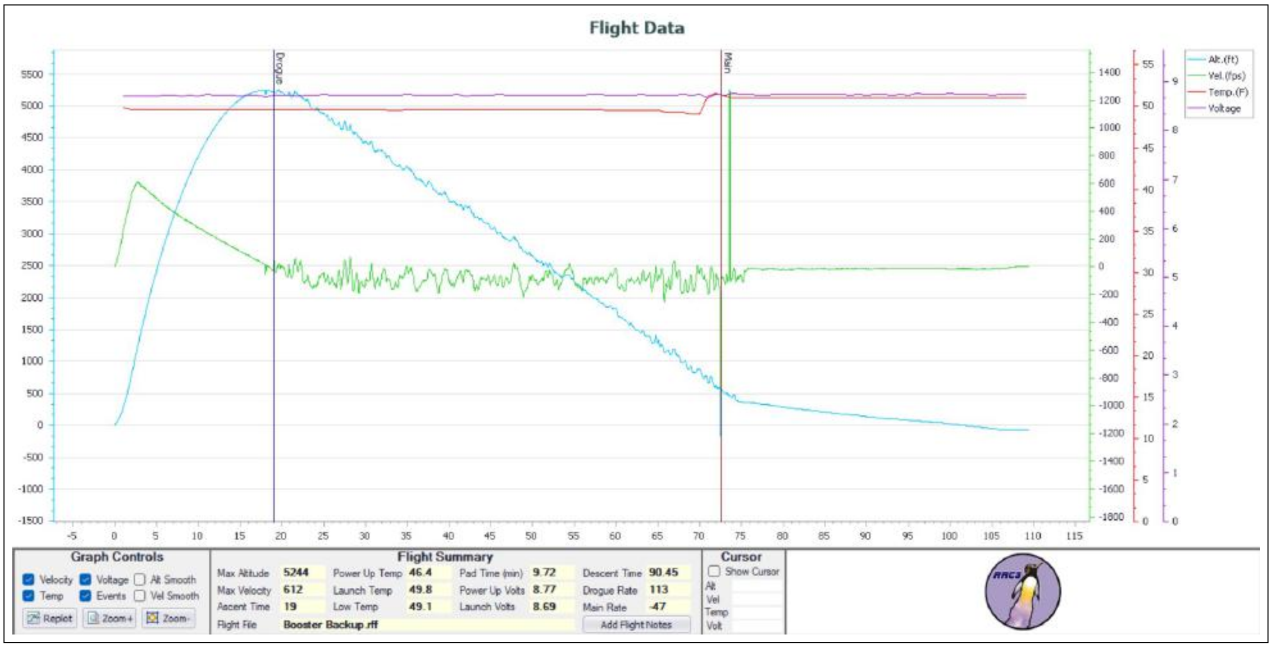


Figure 142: Raw Backup Booster RRC3 Data

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

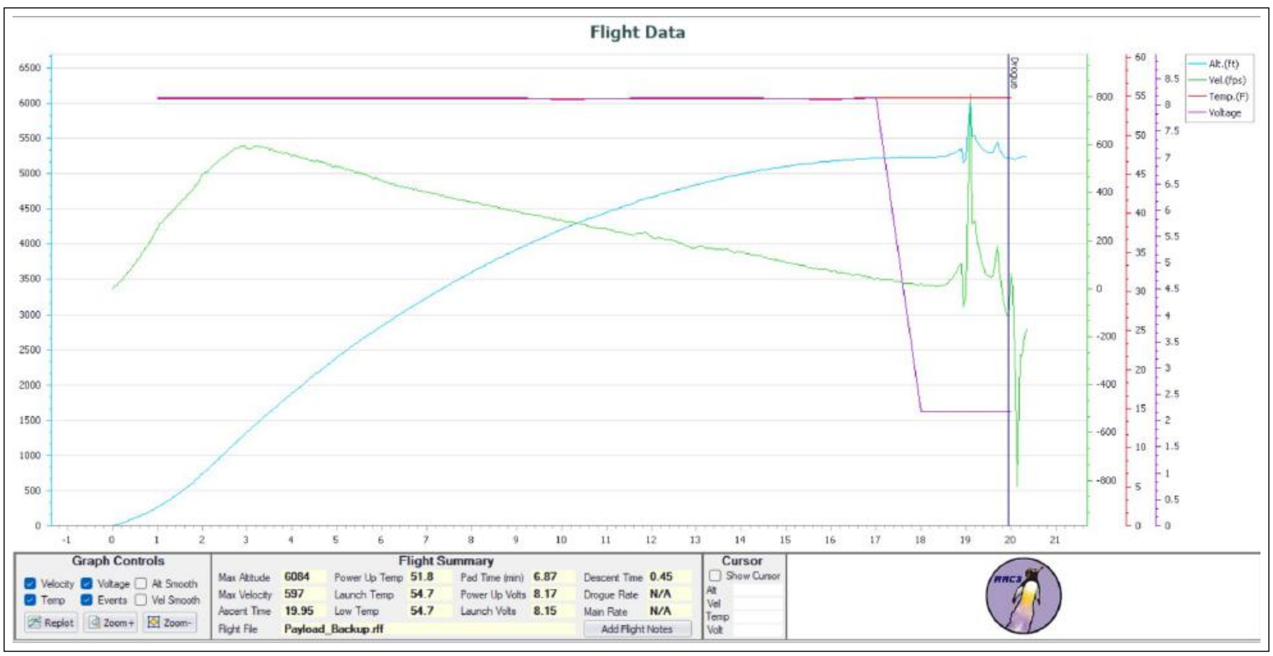


Figure 143: Raw Backup Payload RRC3 Data

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.

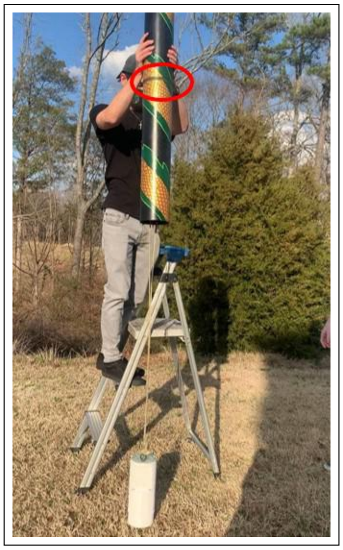
Success Criteria:

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.

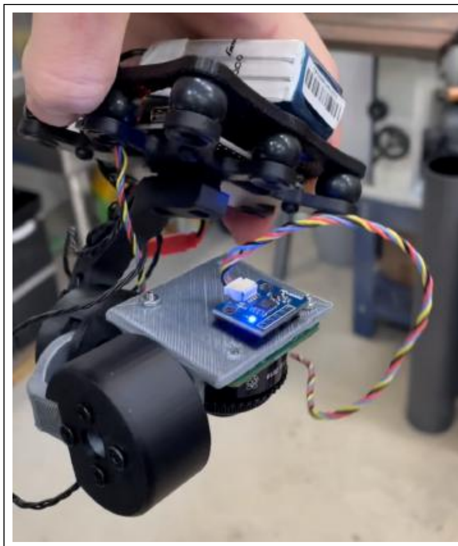


Figure 146: Gimbal Orientation Calibration Test

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.

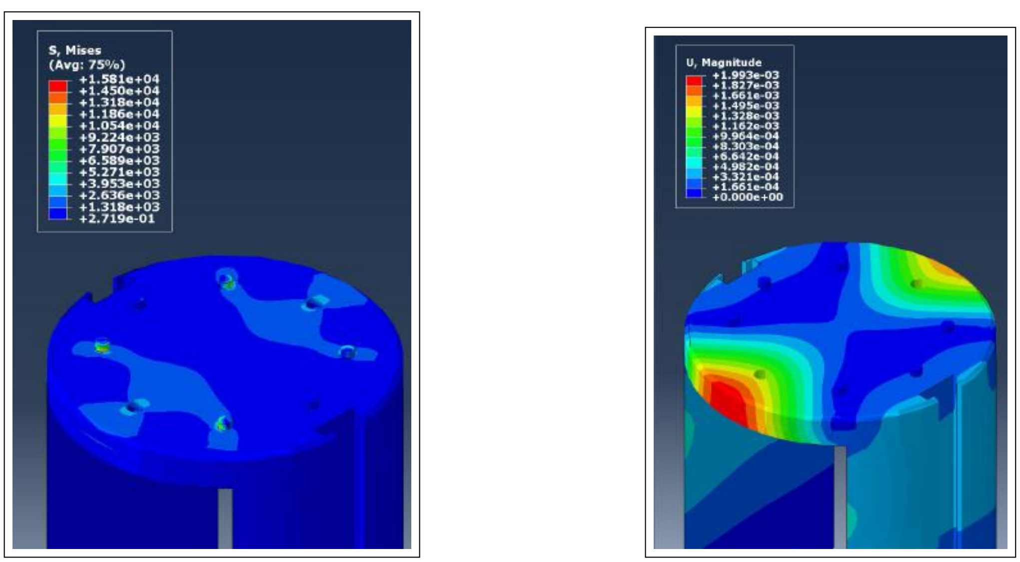
Success Criteria:

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.

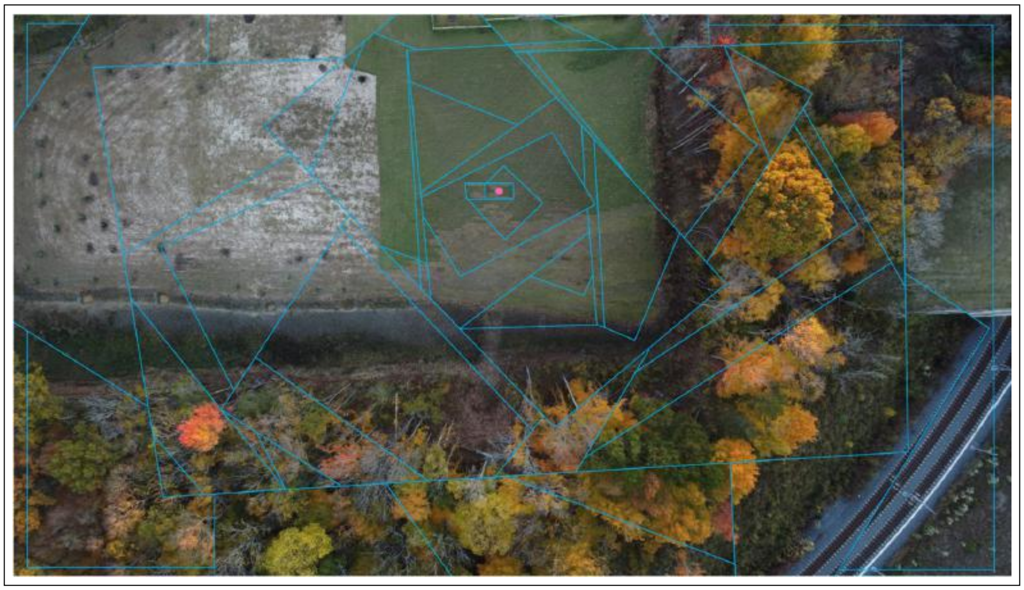


Figure 148: Algorithm Path Using Drone Images

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.

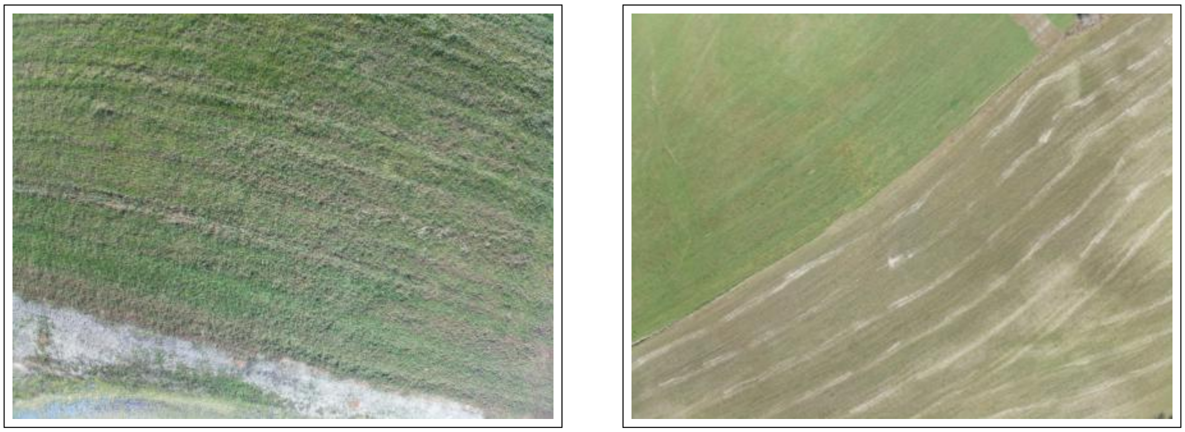
Success Criteria:

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.

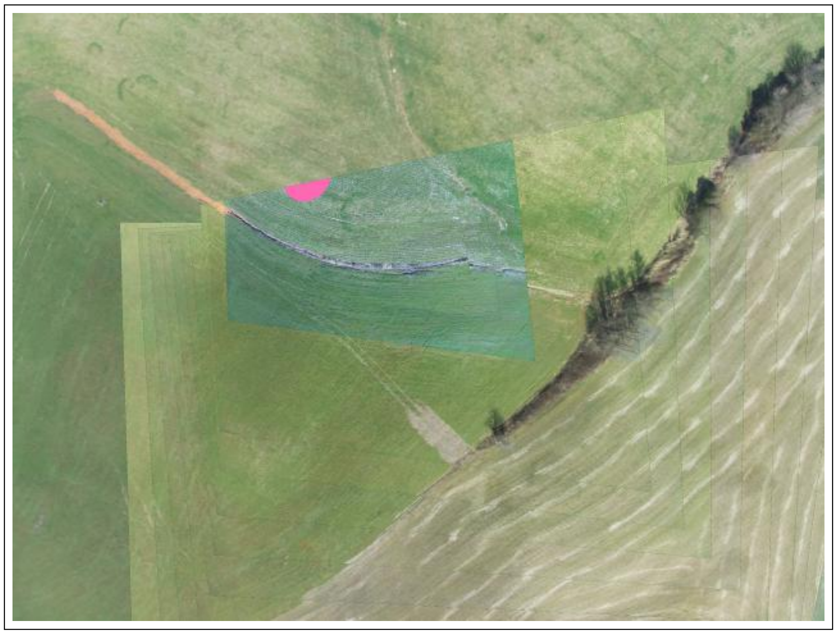


Figure 150: Image Registration Test Result

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 $\text{ft} - \text{lb}_\text{f}$ impact energy.	Inspection	**Status: Complete** The booster section as designed will experience 65.2 $\text{ft} - \text{lb}_\text{f}$ 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 $\text{ft} - \text{lb}_\text{f}$. 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

7.4 Budgeting and Timeline

A high-level budget summary is shown in Table 141 with line item budgets for the Full-scale Vehicle and ANVIL being covered in Sections 7.4.3 and 7.4.4. With the full-scale vehicle and the payload being fully constructed, this table provides a better insight on where the funding has been expended throughout the competition thus far. The full-scale vehicle has stayed under budget by $416.60, with the payload being $101.72 under budget. Travel expenses are also under budget. This is due to the over-estimation of the hotel room rates. With the travel expenses being less than the projected $9,000, as well as several other sub-sections of the project, the team is on track to have at least $18,500 left over for next year's team. The testing budget does not have any expenses under that category, this is due to the fact that there is a significant amount of cross-over between the vehicle/payload budget and the testing budget. The testing category will remain in the budget summary to help with any further expenses to other categories.

Table 141: Budget Summary

Category	Projected Total Cost	Actual Cost to Date	Differences
Full-Scale Vehicle	$7,000.00	$6,583.40	$416.60
Sub-Scale Vehicle	$3,000.00	$2,920.28	$79.72
ANVIL	$2,500.00	$2,398.28	$101.72
Testing	$1,150.00	N/A	N/A
Outreach	$450.00	$378.92	$71.08
Travel	$9,000.00	$6,657.07	$2,342.93
Total	**$23,100.00**	**$18,937.95**	**$3,012.05**

The budget for travel has not changed, even with the modification of the Huntsville Launch Week. The team still plans on traveling to Huntsville the same dates that the competition was initially. This will allow the team to have plenty of time to prepare for the competition dates, as well as have meetings in person with the team's mentor and a group of past rocketry team alumni from UNCC. Taking the team's current spending into account, it is expected that the team will come in under budget with $18,500 in excess funds. The remaining funds are to be used for any spare parts needed for either sub-team. A detailed travel plan for Huntsville can be seen in Section 7.4.5.

7.4.1 Funding Sources

The funding for the team has had only one addition since CDR submission. The team was sponsored by Averna. A rocketry team alum contacted the team early this year looking to create a connection between his company and the 49er Rocketry Team. The partnership between the two entities was as follows: Averna will provide the team with a $2,000 sponsorship, whilst also providing opportunities for rocketry club members to obtain co-ops or internships over the summer. This partnership is beneficial to the team due to Averna potentially providing funding support to future teams. The Averna sponsorship will be used as reserve funding in the event one of the budget categories requires additional funding outside of the preliminary budget restriction. As stated in previous documentation, the remaining funding sources are from: 2020-2021 rollover funding, 2020-2021 1st place award funds, NC space Grant, and the UNCC Crowdfunding campaign. Table 142 shows the team's total funding, with the assumption that the team hits $10,000 on the crowdfunding campaign. The crowdfunding campaign can be found at: `https://crowdfund.charlotte.edu/project/27297` . More details on the NC Space Grant can be found at: `https://ncspacegrant.ncsu.edu/2021/12/02/2021-2022-team-experience-award-winners/`. Details about Averna can be found at their website: `https://www.averna.com/en/home`.

Table 142: Funding Sources

Funding Source	Amount
20-21 Total Roll Over	$21,600.00
20-21 1st Place Award Funds	$5,000.00
NC Space Grant	$5,000.00
Crowdfunding	$10,000.00
Averna Sponsorship	$2,000.00
Total	**$43,600.00**

- **2020-2021 Total Roll Over Funds**
  Amount: $21,600

The 2020-2021 49er Rocketry Team was not given the opportunity to travel to Huntsville due to COVID-19 guidelines. Due to this, the team saved money on their travel budget. This, paired with a low expense sub-scale vehicle, resulted in these funds being carried over to this year's team. This funding was considered the base amount the team started the competition with.

- **2020-2021 1st Place Award Funds**
  Amount: $5,000

  The 2020-2021 49er Rocketry team was able to bring home a 1st place win in last year's competition. This funding was given to this year's team to aid in purchasing the required components for construction.

- **NC Space Grant**
  Amount: $5,000

  The NC Space Grant is a financial grant that is awarded to student teams to aid in their respective competitions. The team mentor wrote up a proposal on behalf of the team to send to the personnel facilitating this grant. Once this grant was approved, the team received the funding provided by it. The team was awarded the full amount of the grant, this being $5,000.

- **UNCC Crowdfunding Campaign**
  Amount: $10,000

  The crowdfunding campaign is run through the university's crowdfunding portal, where donors can access the team's crowdfunding page and see different donation tiers. The team worked with a campus official to set up this portal as well as the donation tiers within it. One benefit to this platform is that the team can post updates onto the platform, which will send an update email to every person who has donated. This ensures that the team's donors are being consistently updated throughout the duration for the competition.

- **Averna Sponsorship**
  Amount: $2,000

  Averna is a Test and Quality Engineering Systems Integrator company that strives to provide new and innovative solutions across the entire product lifecycle. The team spoke with a rocketry team alum who is part of the company and came to a partnership between the team and Averna. This partnership included a $2,000 sponsorship of the team. This money is being used as reserve funding for any expenditures that go over their preliminary budget restriction.

7.4.2 Material Acquisition

The material acquisition has remained the same since CDR submission. A brief run through of the steps for purchasing are as follows: the Project Lead locates the materials that are in need of being purchased, materials are input into an Excel purchase request sheet, the sheet is sent to the team mentor, upon approval it will be sent to the purchasing representative and ordered, and finally it arrives at the team's work space. These purchase requests must be a new sheet per vendor as well as per order. The Project Lead is held accountable for saving every purchase sheet to provide an accurate budget table for each sub-section of the project. The only issue that the team has run into with this ordering process is when the team attempts to order from a non verified vendor. For example, Copterlab was not a verified vendor in the university's system, so the team had some issues allowing the components from said vendor to be purchased. Once the team has ordered from a non verified vendor once, they are then input into the system of the university, allowing for easier purchasing from that vendor.

7.4.3 Full-Scale Budget

Table 143 shows a line item budget of the full-scale vehicle. The team has spent a total of $6,583.40 on the full-scale vehicle, which, as stated in Section 7.4, came under budget by $416.60. The remaining funding will be used to ensure there are backup components for varying parts of the full-scale vehicle.

Table 143: Full-scale Vehicle Purchases

Item	Vendor	Quantity	Cost	Tax	Total Cost
AeroTech L-1390G	Wildman Rocketry	4	$247.99	$69.44	$1,061.40
AeroTech 75/3840 Casing	Chris' Rocket Supply	1	$347.99	$24.36	$372.35
Aeropack 75mm Motor Retainer	Chris' Rocket Supply	2	$51.00	$7.14	$109.14
5.00" ID x 60" Carbon Fiber	Rock West Composites	2	$727.99	$101.92	$1,557.90
4.99" OD x 29.5" Carbon Fiber	Rock West Composites	2	$568.99	$79.66	$1,217.64
0.25" Bulkheads	UNCC	14	$1.25	N/A	$17.50
ABS Fins	UNCC RPL	8	$25.00	N/A	$200.00
ABS Nose Cone	UNCC RPL	1	$70.00	N/A	$70.00
ABS Fin Guide	UNCC RPL	1	$14.00	N/A	$14.00
ABS Fin Block	UNCC RPL	1	$18.62	N/A	$18.62
ABS Altimeter Plate	UNCC RPL	2	$25.00	N/A	$50.00
ULTEM Boattail	UNCC RPL	1	$72.80	N/A	$72.80
Iris Ultra 72" Parachute	Fruity Chutes	1	$225.75	$15.80	$241.55
Iris Ultra 84" Parachute	Fruity Chutes	1	$296.96	$20.79	$317.75
300" Streamer	Rocketman	1	$45.50	$3.18	$48.68
Featherweight GPS 3-unit System	Featherweight Altimeters	1	$520.00	$36.40	$556.40
Firewire Electric Match	Chris' Rocket Supply	80	$0.75	$4.20	$64.20
RRC3 Sport	Chris' Rocket Supply	2	$74.95	$10.49	$160.39
2/56 Shear Pins (100 pack)	Chris' Rocket Supply	2	$5.50	$0.77	$11.77
M2.5 x 20mm Screws (100 pack)	Amazon	1	$6.00	$0.42	$6.42
1/4-20 x 3/8" Set Screw (25 pack)	Amazon	1	$5.42	$0.38	$5.81
950mAh Battery	Amazon	1	$14.59	$1.02	$15.61
21" Nomex Blanket	Fruity Chutes	2	$29.70	$4.16	$63.56
5V, 5.5A Voltage Regulator	Pololu	3	$19.95	$4.19	$64.04
RRC3 Sport	Mac Performance	2	$74.95	$10.49	$160.39
5mm Green LED (100 pack)	Amazon	1	$6.63	$0.46	$7.09
Tungsten Powder	Amazon	1	$55.99	$3.92	$59.91
Featherweight GPS Battery Charger	Featherweight Altimeter	1	$17.00	$1.19	$18.19
18-8 Stainless Steel Screw 1/4" (100 pack)	McMaster	1	$5.09	$0.36	$5.45
2-56 Heat Set Insert (100 pack)	McMaster	1	$13.87	$0.97	$14.84
				Total money spent	**$6,583.40**

7.4.4 ANVIL Budget

Table 144 shows the line item budget for the payload. The team has spent a total of $2,398.28 on the payload. The payload sub-team has $79.72 before going over budget, which is where the Averna sponsorship will come in.

Table 144: ANVIL Purchases

Item	Vendor	Quantity	Cost	Tax	Total Cost
Gimbal System	Copterlab	1	$285.00	$19.95	$304.95
Teensy 4.0	Digi-Key	2	$21.88	$3.06	$46.82
Trinket M0	Digi-Key	4	$8.95	$2.51	$38.31
3-Axis Accelerometer	Digi-Key	3	$17.95	$3.77	$57.62
Barometric Pressure Sensor	Digi-Key	5	$4.05	$1.42	$21.67
Buck Switching Regulator	Digi-Key	10	$1.95	$1.37	$20.87
Raspberry Pi 4	Pi-Shop	2	$55.00	$7.70	$117.70
Raspberry Pi HQ Camera	Pi-Shop	2	$50.00	$7.00	$107.00
Camera Lens	Amazon	1	$20.00	$1.40	$21.40
Breadboard Jumper Wires (120 pcs)	Amazon	1	$6.49	$0.45	$6.94
USB C Cable (2 pack)	Amazon	1	$6.99	$0.49	$7.48
Phantom Omni Antenna	Digi-Key	2	$43.78	$6.13	$93.69
Antenna Adapter	Data-Alliance	2	$3.29	$0.46	$7.04

Table 144: ANVIL Purchases

Item	Vendor	Quantity	Cost	Tax	Total Cost
Duck Antenna	Robotshop	2	$7.95	$1.11	$17.01
XBee-Pro Transceiver	Digi-Key	3	$75.93	$15.94	$243.74
2200mAh Lipo	rcbattery	2	$7.49	$1.05	$16.03
ABS Gimbal Bay (prototype)	UNCC RPL	1	$190.00	N/A	$190.00
ABS Component Bay (prototype)	UNCC RPL	1	$120.23	N/A	$120.23
BMP280	Digi-Key	6	$9.95	$4.18	$63.88
3000mAh Lipo (2 pack)	Amazon	1	$41.99	$2.94	$44.93
4.5" O-Ring (10 pack)	Amazon	1	$7.39	$0.52	$7.91
Alexmos 32bit Gimbal Controller	Aliexpress	2	$59.80	$8.37	$127.97
HS-785HB	Servocity	2	$54.99	$7.70	$117.68
Servo Mount Gear	Servocity	1	$9.99	$0.70	$10.69
Gear Rack	McMaster	1	$16.91	$1.18	$18.09
5V, 5.5A Step-Down Regulator	Pololu	4	$19.95	$5.59	$85.39
MOSFET Slide Switch	Pololu	2	$3.49	$0.49	$7.47
90 Degree Wide-Angle Lens	Chicago Dist.	1	$19.99	$1.40	$21.39
Ribbon Cable Pack	Amazon	2	$9.99	$1.40	$21.38
0.1 Pitch Female Header (5 pack)	Adafruit	2	$2.95	$0.41	$6.31
2mm Pitch Female Header (2 pack)	Adafruit	3	$0.95	$0.20	$3.05
Term Block STR 5.08mm	Digi-Key	4	$5.14	$1.44	$22.00
Term Block Vert. 5.08mm	Digi-Key	4	$1.84	$0.52	$7.88
2pos STR 5mm	Digi-Key	4	$2.08	$0.58	$8.90
2pos Vert. 5mm	Digi-Key	4	$0.76	$0.21	$3.25
3pos STR 5.08mm	Digi-Key	2	$3.12	$0.44	$6.68
3pos Vert. 5.08mm	Digi-Key	2	$1.24	$0.17	$2.65
Right Angle Adapter	Digi-Key	2	$4.86	$0.68	$10.40
4-40 Heat Set Insert (100 pack)	McMaster	1	$13.41	$0.94	$14.35
4-40 1" Screw (50 pack)	McMaster	1	$6.51	$0.46	$6.97
1/4-20 x 1.25" Screw (10 pack)	McMaster	1	$9.62	$0.67	$10.29
316 Stainless Steel Screw (10 pack)	McMaster	2	$10.63	$1.49	$22.75
18-8 Stainless Steel Washer (100 pack)	McMaster	1	$4.58	$0.32	$4.90
2000 Series 5-turn Servo	Servocity	2	$42.49	$5.95	$90.93
Servo Mount Gear	Servocity	2	$8.49	$1.19	$18.17
Trinket m0	Digi-Key	2	$8.95	$1.25	$19.15
1ft HDMI Cable	Amazon	1	$8.88	$0.62	$9.50
CSI to HDMI Module	Amazon	2	$13.99	$1.96	$29.94
Arducam CSI to HDMI Board	Amazon	2	$15.99	$2.24	$34.22
18-8 Stainless Steel Screw 35mm (5 pack)	McMaster	1	$18.27	$1.28	$19.55
18-8 Stainless Steel Screw 20mm (25 pack)	McMaster	1	$10.13	$0.71	$10.84
100T Brushless Gimbal Motor	Copterlab	6	$12.94	$5.43	$83.07
Main PCB	JLCPCB	5	$0.40	$0.14	$2.14
Raspberry Pi PCB	JLCPCB	5	$0.80	$0.28	$4.28
				Total money spent	**$2,398.28**

7.4.5 Travel Plan and Expenses

A travel plan for the team's trip to Huntsville, AL is shown in Table 145. Due to the change in the in-person launch week, the team has modified the travel plan. The team still plans on traveling to Huntsville on the same dates as the original launch week dates with the extra days being used for tours and preparation for the competition days.

Table 145: Travel Plan

Date	Activity
April 19th	Pick up Rental Van
	Pick up U-Haul Trailer
	Travel to Huntsville and Check into Hotel
April 20th	Meet with Mentor
	Tour UTSI Campus
April 21st	Tour Davidson Center for Space Exploration
	Explore Huntsville
April 22nd	Attend LRR
	Prepare for Launch Day
April 23rd	Launch Day
	Pack to Travel Back to Charlotte
April 24th	Backup Launch Date
	Travel Back to Charlotte
April 25th	Return Rental Van
	Return U-Haul Trailer

The travel expenses can be seen in Table 146. The team plans on renting a 15 passengers van from Enterprise to transport the team members to and from the competition. To transport the full-scale vehicle as well as all supplies required for launch, the team plans on renting a U-Haul trailer and attaching it to one of the team member's trucks. This helps limit the amount of cars needed for the team to travel to competition. The hotel rooms have been booked as of February 23rd, with the team staying at the hotel from April 19th to the 24th. Part of the travel plan includes meal allowances to the team members for each day the team is in Huntsville. Team members will receive $50 per day for food, with a team of 12 people that becomes the most expensive section of the travel budget. The travel expenses will still remain under budget due to over-estimation of the hotel rates.

Table 146: Travel Expenses

Category	Cost
15 Passenger Van	$1,220.42
U-Haul Trailer	$188.65
4 Hotel Rooms	$2,248.00
Food for Members	$3,000.00
Total	**$6,657.07**

7.4.6 Vehicle and Payload Testing Schedule

This section serves as a timeline for the team's vehicle and payload testing. Table 147 shows the complete launch schedule for the sub-scale and full-scale vehicle. The final flight of the full-scale vehicle will take place at Bragg Farms for the competition launch. Table 148 lays out the payload test plan with dates of completion. Most of these plans are complete, with the remaining tests being fulfilled by the next full-scale flight. For more details on the test plans, please refer to Section 7.2.

Table 147: Vehicle Testing Schedule

Test	Location	Launch Date	Status
Sub-Scale Attempt 1	Dalzell, SC	November 13th, 2021	CATO
Sub-Scale Attempt 2	Midland, NC	November 20th, 2021	Recovery Failure
Sub-Scale Attempt 3	Bayboro, NC	December 18th, 2021	Successful Launch
Full-Scale Attempt 1	Dalzell, SC	February 12th, 2022	Successful Launch
Full-Scale Attempt 2	Bayboro, NC	February 26th/27th, 2022	Recovery Failure
Full-Scale Attempt 3	Dalzell, SC	March 12th/13th, 2022	-

Table 148: High-Level Payload Testing Schedule

Test	Completion Date
Time Intensive Test for Processing Length and Image Scaling	November 27th, 2021
Raspberry Pi Camera Imaging Demonstration	November 29th, 2022
Imaging Algorithm Demonstration	December 1st, 2021
Gimbal Orientation Calibration Demonstration	December 6th, 2021
Near Ground Range Test	December 22nd, 2021
ANVIL Retention Mechanism Analysis	December 30th, 2021
Payload Integrated Vehicle Flight Test	January 22nd/23rd, 2022
Incorporated Gimbal Camera Test	February 4th, 2022
Gimbal Retraction Test	February 5th, 2022
Full Payload Assembly Test	Incomplete

7.4.7 Educational STEM Engagement

The team has scheduled new outreach events from CDR to FRR. With the addition of these new outreach events, the team will have 877 indirect engagements and 290 direct engagements. All of the outreach events are shown in Table 149 with notable additions of events with Springfield Elementary School and the MEGR 1202 Presentation. A brief explanation of each of the recent outreach events follows the table.

Table 149: Outreach Dates

Event	Indirect Engagements	Direct Engagements	Completion Date
Rocketry Club Outreach	-	25	October 6, 2021
Saturday Academy	-	20	October 9, 2021
Explore Charlotte	291	-	October 16, 2021
Engineering Freshman Learning Community	96	-	October 26, 2021
Fall Festival	89	-	November 12, 2021
Rocketry Club Outreach	-	27	January 26, 2022
Girl Scouts - Meck 13	22	-	January 29, 2022
VEX IQ Winecoff Elementary School Qualifiers	112	79	February 5, 2022
MEGR 1202 Presentation	154	-	February 11, 2022
Rocketry Club Outreach	-	16	February 16, 2022
VEX IQ Elementary States	-	-	Cancelled
Springfield Elementary School	-	130	March 2, 2022
VEX IQ Middle School States	120	-	March 5, 2022

A list of descriptions for each of the recent outreach events can be seen below.

- **VEX IQ Winecoff Elementary School Qualifier - Robotics Judges/Rocketry Activity**
  Engagement Count: 112 Indirect - Educational — 79 Direct - Educational — Duration: 7 hours

  This event takes place at a VEX competition qualifiers for the Elementary School level. The team had a member run a rocketry team booth at this event where the students learned about and tested the effects of different propeller sizes on helicopters. The other members of the team were judges for the competition. Further details can be found in the STEM Engagement Report.

- **MEGR 1202 Presentation - Rocketry Presentation**
  Engagement Count: 154 Direct - Outreach — Duration: 1 hours
  Several members from the team attended an MEGR 1202 lecture, which is first year mechanical engineering students, and spoke about the project as a whole. The vehicle lead and payload lead spoke about each sub-team as well as showing the students the final products, these being the full-scale vehicle and the payload. Following the presentation the students came down to the front for a hands on look at the vehicle and payload.

- **Rocketry Club Outreach - Launch Workshop**
  Engagement Count: 16 Direct - Educational — Duration: 1 hours

  Following the first full-scale launch, the team attended the next rocketry club meeting to hold a launch workshop. During this workshop the team gave students different positions for a simulated launch day assembly. They were then walked through each step of the assembly process with the safety officer, going through the safety checklist just as the team would at the launch field. Further details on this event can be seen in the respective STEM Engagement Report.

- **Girl Scouts - Meck 13 - Rocketry Activity**
  Engagement Count: 22 Direct - Outreach — Duration: 2 hours

  A Girl Scouts troop that is competing in the American Rocketry Challenge came to the team's workshop for a tour of the facility. The team spoke with the parents and students about rocketry and the NASA USLI competition, as well as speaking with the students about their competition. The team plans on meeting with them again once they are close to the end of their competition.

- **Springfield Elementary School - Kit Rockets**
  Engagement Count: 130 Direct - Educational — Duration: 4 hours
  The team traveled to Springfield Elementary school to build and launch small kit rockets with 2nd graders. The team broke up into 6 groups, with 2 members per classroom. Prior to construction, the team members taught the students the basics of rocketry and what each component of the rocket does to the performance of the flight. 24 kit rockets were built and flown with this group of 2nd graders.

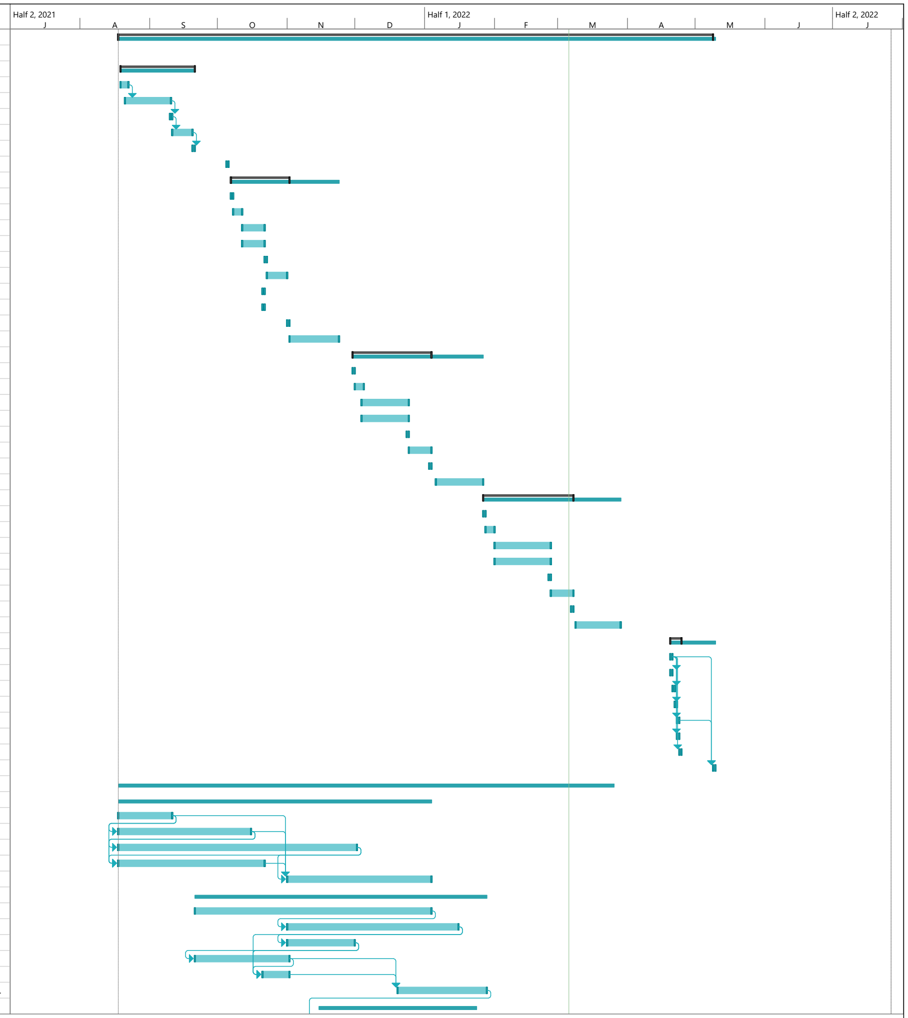
- **VEX IQ Middle School States - Robotics Judges**
  Engagement Count: 120 Indirect - Educational — Duration: 7 hours

  This event will be identical to that of the VEX IQ Elementary States but will be for the middle school level. The team will be judges for this event as well as running a STEM/rocketry hands on activity.

8 Appendix

8.1 Appendix A: Project Timeline

ID	Task Mode	Task Name	Duration	Start
1		**NASA Student Launch Timeline**	**264 days**	**Wed 8/18/21**
2		RFP Available		
3		**Proposal/ Statement of Work**	**33 days**	**Thu 8/19/21**
4		Research Proposal Requirements	3.13 days	Thu 8/19/21
5		Begin Writing Proposal	20.75 days	Sat 8/21/21
6		Submit To Alumni	1 day	Fri 9/10/21
7		Review/ Edit Proposal	9.5 days	Sat 9/11/21
8		Submit Proposal	1 day	Mon 9/20/21
9		Awarded Proposals Announced	1 day	Tue 10/5/21
10		**Preliminary Design Review**	**26 days**	**Thu 10/7/21**
11		Kickoff and PDR Q&A	1 day	Thu 10/7/21
12		Research PDR Requirements	4 days	Fri 10/8/21
13		Begin Writing PDR	10 days	Tue 10/12/21
14		Build PDR Presentation	10 days	Tue 10/12/21
15		Send to Alumni	1 day	Fri 10/22/21
16		Review and Edit PDR Report and Presentation	9.13 days	Sat 10/23/21
17		Update/ Establish Web Presence	1 day	Thu 10/21/21
18		Send Website URL to NASA	1 day	Thu 10/21/21
19		Upload PDR Report, Presentation and Fly Sheet to Website	1 day	Mon 11/1/21
20		PDR Video Teleconferences	22 days	Tue 11/2/21
21		**Critical Design Review**	**35 days**	**Tue 11/30/21**
22		CDR Q&A	1 day	Tue 11/30/21
23		Research CDR Requirements	3.63 days	Wed 12/1/21
24		Begin Writing CDR	21.5 days	Sat 12/4/21
25		Begin CDR Presentation	21.5 days	Sat 12/4/21
26		Send to Alumni	1 day	Fri 12/24/21
27		Review and Edit CDR Report and Presentation	10.5 days	Sat 12/25/21
28		CDR Report, Presentation and Flysheet on Website	1 day	Mon 1/3/22
29		CDR Video Teleconferences	21 days	Thu 1/6/22
30		**Flight Readiness Review**	**40 days**	**Thu 1/27/22**
31		FRR Q&A	1 day	Thu 1/27/22
32		Research FRR Requirements	4 days	Fri 1/28/22
33		Begin Writing FRR	25 days	Tue 2/1/22
34		Begin FRR Presentation	25 days	Tue 2/1/22
35		Send to Alumni	1 day	Fri 2/25/22
36		Review and Edit FRR Report and Presentation	10.5 days	Sat 2/26/22
37		Upload FRR Report, Presentation and Flysheet on Website	1 day	Mon 3/7/22
38		FRR Video Teleconferences	20 days	Wed 3/9/22
39		**Competition Launch**	**4.63 days**	**Wed 4/20/22**
40		Team Travels to Huntsville, AL	1 day	Wed 4/20/22
41		Launch Readiness Reviews	1 day	Wed 4/20/22
42		Official Launch Week Kickoff, LRRs, Launch Week Activities	1 day	Thu 4/21/22
43		Launch Week Activities	1 day	Fri 4/22/22
44		Launch Day	1.13 days	Sat 4/23/22
45		Award Ceremony	1.13 days	Sat 4/23/22
46		Backup Launch Day	1.13 days	Sun 4/24/22
47		Post-Launch Assessment Review uploaded to website	1 day	Mon 5/9/22
48		**Payload Timeline**		
49		**Payload Design**		
50		Conceptual Design	24 days	Wed 8/18/21
51		Research Payload Design Alternatives	59 days	Wed 8/18/21
52		Payload Design Decision	106 days	Wed 8/18/21
53		Generate Preliminary CAD Model	65 days	Wed 8/18/21
54		Conceptual Design Review	64 days	Mon 11/1/21
55		**Payload Build**		
56		Payload Design Analysis	105 days	Tue 9/21/21
57		Initial Testing	75.63 days	Mon 11/1/21
58		Prototype Design	30 days	Mon 11/1/21
59		Full Scale Design of Payload	42 days	Tue 9/21/21
60		Provide Detailed CAD Model	12 days	Thu 10/21/21
61		Final Assembly of Payload	39.63 days	Mon 12/20/21
62		**Payload Testing/Launch**		



Project: USLI_C
Date: Sun 3/6/

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

Page 1

ID	Task Mode	Task Name	Duration	Start
63		Prototype Payload Testing	19.63 days	Mon 11/15/21
64		Full Scale Payload Testing	19.63 days	Mon 12/20/21
65		Launch Day	2.13 days	Sat 1/22/22
66		**Vehicle Timeline**		
67		**Vehicle Design**		
68		Conceptual Design	24 days	Wed 8/18/21
69		Research Carbon Fiber Machining Methods	14 days	Mon 9/20/21
70		Research 3D Printed Material Properties	13.63 days	Mon 9/20/21
71		Vehicle Design Decision	38 days	Mon 11/1/21
72		Conceptual Design Review	53 days	Mon 11/1/21
73		**Vehicle Build**		
74		Sub scale construction	20 days	Fri 10/22/21
75		Initial Testing	2 days	Wed 11/10/21
76		Vehicle Design Analysis		
77		Subscale Design	32 days	Tue 9/21/21
78		Full Scale Design	56 days	Tue 9/21/21
79		Full Scale Assembly	45.63 days	Wed 12/1/21
80		**Vehicle Testing/Launch**	**88 days**	**Fri 12/10/21**
81		Subscale Testing	3.63 days	Thu 11/11/21
82		Full Scale Testing	97 days	Wed 12/1/21
83		Full Scale Launch	52.5 days	Sat 1/15/22
84		Outreach	152 days	Thu 10/7/21
85		Matlab Work		
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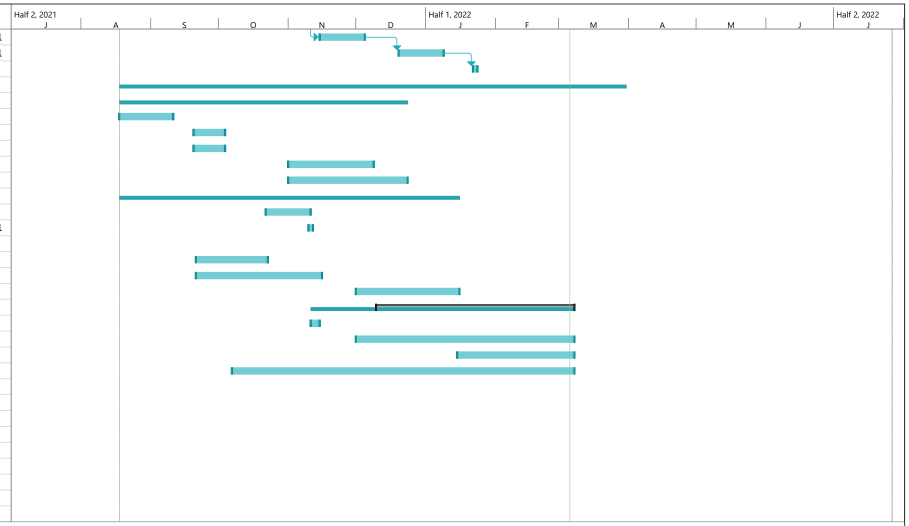

Project: USLI_C
Date: Sun 3/6/

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

8.2 Appendix B: Lab Safety Guidelines

8.2.1 Mechanical Engineering Technology Lab Safety

MACHINING SAFETY

- Always wear safety glasses in the shop, even if you are not running a machine.
- Long hair must be tied back.
- No open toes shoes are permitted in the lab (sandals, "flip-flops", etc.).
- No loose fitting clothing such as baggy sweaters or sweatshirts – tuck in shirttails, roll up or button long sleeves.
- Remove bracelets or other loose jewelry.
- NEVER use gloves around rotating machinery.
- Use cutting oil sparingly.
- If you see oil or water spills on the floor, clean them up.
- DO NOT attempt to work in the lab after having consumed drugs or alcoholic beverages. You will be asked to leave. If you are on prescribed medication, notify the instructor. Focus is essential in the shop.
- Never leave a chuck key or chuck wrench in an unattended machine.
- Do not leave a machine running unattended.
- Always stop any machine before attempting to measure a part.
- Listen to your machine when it is running. If something doesn't sound right, stop and ask the instructor to check the machine or set-up.
- In a machine shop it is important to listen to the sound of your machine. Therefore, students should not wear iPods, CD players, or any personal listening devices when in the Machining Lab.
- Always dispose of used shop rags in an approved container.
- Every machine and shop area must be cleaned before leaving the shop. Disposable rags are available in the shop.
- Return all tools and supplies to their proper place before leaving the lab.
- All safety features of the machinery should be properly utilized.
- Exercise extreme caution when using compressed air to blow chips from machines. DO NOT use compressed air to blow off clothing or skin.
- Do not attempt to use CNC machines without an instructor present.
- Do not grind aluminum, brass, wood, or plastic on pedestal grinders. Only grind ferrous metals. Belt or disc sanders may be used on nonferrous materials.
- Only grind on the periphery (outside) of a grinding wheel.
- Do not force material being cut through a saw blade.
- Do not stop a spindle by hand. Let it coast to a stop, or on a lathe use the brake.
- Remove stringy chips with pliers while the spindle is off.
- Do not use a milling cutter (end mill) in a drill chuck.
- Social distancing is enforced and face coverings are worn at all times.
- BE CONSCIOUS OF WHERE YOU ARE AND WHAT IS GOING ON AROUND YOU.

WELDING SAFETY

- Always wear gloves and body protection when welding.
- Before welding, verify that ground clamp is attached to welding bench.
- Never drape cables over your body when welding.
- Turn off all power and gases when finished.
- Avoid breathing welding fumes.
- Never weld on coated (painted or plated) metals without removing the coating.
- NEVER strike an arc without your eye protection shield in place.
- When opening gas cylinders, open the valve CCW very slowly and turn your head away from the valve while opening it.
- Always wear long pants and closed toe shoes when welding. No cuffs on pants.
- Remove matches and lighters from pockets before welding. If other persons are in the welding area, alert them before striking an arc.
- If you have a pacemaker or a history of heart problems, notify the lab instructor.

8.2.2 Mechanical Engineering Lab Safety

Use of the Duke Centennial Hall machine shop is as follows:

- Undergraduates: Must have finished MEGR 2156, have a signed release form and pass the written safety test.
- Graduate Students: Either demonstrate competency on machines or go through training that is given during semester break, have a signed release form and pass the written safety test.
- Visiting Researchers: Either demonstrate competency on machines or go through training that is given during semester break, have a signed release form and pass the written safety test.
- Faculty: Either demonstrate competency on machines or go through training that is given during semester break, have a signed release form and pass the written safety test.
- Staff: Either demonstrate competency on machines or go through training that is given during semester break, have a signed release form and pass the written safety test.

Upon completion of the above, access will be granted with one of the following badges:

- Normal Access (Green): An individual will be awarded a green badge indicating he/she has completed safety checks on all machines and has also been briefed on the current policies concerning lab operations. Prior approval of jobs is not required but drawings or sketches must be present at the work area.
- Kulwicki Motorsports Access (Pink): An individual is awarded a pink badge after passing the pink badge safety exam. The exam consists of safety questions for both Kulwicki and MSRL. If rules are being broken both building access and pink badge can be taken.

General Safety

- Safety glasses must be worn at all times while in the shop area.
- Long sleeved shirts or loose clothing should not be worn while running machinery. Moving parts of machinery can catch them.
- Never wear gloves while operating machinery.
- Never use rags to hold parts while machining.
- If you have long hair, you must tie your hair back to keep it out of the way of moving machinery parts.
- Before you operate a machine make sure that the floor area is clean and dry, make sure the work is securely held, and remove all tools and other items from the machine.

- It is okay to use shop air to blow off parts and machines, if you use extreme caution. Never use shop air to blow chips or dirt off clothing or hands.
- Replace or sharpen any tool that becomes dull or chipped.
- Keep flammable liquids and material away from machines. Flammable liquids and materials should be kept in the explosion proof cabinets when not in use.
- Always clean chips and dirt off of parts/devises that are going to be mounted together.
- Cutting oil is for cutting. Lube oil is for lubricating. There is a difference.
- If you spill oil on the floor, clean it up.
- Do not attempt to repair the machines. If the machine does not run properly, turn it off and contact the shop supervisor.
- Social distancing is enforced and face coverings are worn at all times.

Grinders/Sander Safety

- Do not grind aluminum, brass, wood or plastic on the pedestal grinder. Grind only steel or iron on the pedestal grinder
- Aluminum, brass, wood, plastic, and steel may be sanded on the belt sander.
- Quench parts that may become hot in water. DO NOT use gloves or rags to hold parts while grinding or sanding.
- The tool rest on the pedestal grinder should never be more then 1/8" away from the wheel.

Saw Safety

- Use coolant when running the horizontal saw unless you are cutting wood or other porous material.
- The adjustable saw guide for the vertical saw should be as close to the work piece as possible.
- When sawing steel and thin materials (under 1/8"), use a fine toothed blade.
- When sawing aluminum or thick material (over 1/8"), use a course tooth blade.
- When sawing round material on the vertical saw, use a vise to hold the work piece.
- When sawing thin material, use a piece of scrap wood under the piece being cut.
- Use a pusher block on work pieces that are small.
- NEVER put your fingers close to the blade while the machine is running.

Lathe Safety

- Turn cams on the cam lock spindle clockwise when mounting chucks.
- Never leave a chuck wrench in the chuck. Do not take your hand off the chuck wrench until the wrench is out of the chuck.
- Do not stop the spindle by hand. Let the chuck coast to a stop or use the brake.
- Always wipe off chips and dirt from mating surfaces when you change chucks, collets, drill chucks, centers, tool holders or any other mating parts. Mounting tooling with chips present can cause permanent damage.
- When removing chucks from the lathe, place a board across the ways. This prevents possible damage to the ways. If the chuck is stuck after loosing the cams, rap briskly with a SOFT FACE hammer.
- Before turning on the spindle, make note of all pinch points, remove tools from working area and disengage power feeds.
- While sanding or filing in the lathe, keep your left hand toward you and your right hand to the back of the machine. Never sand or file with your body over the spinning chuck.
- Remove stringy chips with pliers while the spindle is off. Never remove stringy chips while the spindle is rotating. Never remove stringy chips with your hands. Chips can have razor-sharp edges.

- DO NOT use parting tools as turning tools.

Mill/Drill Press Safety

- Make note of all pinch points before tuning on the spindle.
- Never stop the spindle by hand. Let it coast to a stop or use the brake.
- Never take your hand off the draw bar wrench until the wrench is removed from the draw bar. NEVER LEAVE THE WRENCH ON THE DRAW BAR.
- Never leave a drill chuck key in the chuck in the tightening position. Always remove the chuck key after tightening the chuck. When storing the chuck, place the handle of the key in the chuck.
- Most of the time the spindle will be run clockwise (looking down from the top). Because some tools were made to run counter-clockwise, spindle rotation will be determined by the cutter design.
- Clean dirt and chips from mating parts when changing cutters, collets, drill chucks, vises, rotary tables, or any other devise.
- DO NOT mill with a milling cutter in the Drill Chuck.

8.2.3 Electrical and Computer Engineering Lab Safety

These safety rules must be followed at all times:

- Drinking, eating and smoking are prohibited in the laboratories.
- You must wear clothes that can protect you from against scratches and falling objects.
- ANSI approved safety glasses and closed toe shoes must be worn at all times in rooms 2130/32, 2140, 2142, 2148 and 2236
- Social distancing is enforced and face coverings are worn at all times.

These additional safety rules must be followed when working on experimental set-ups, projects and when operating lab equipment:

- Locate the Yellow Emergency Power Shutoff Switch closest to your work area.
- Do not work alone in the laboratories; have at least one partner.
- Students performing experiments in rooms 2140 and 2142 for ECE lab courses (ECGR 2155, 2156, 2255, 3155, or 3156) must be supervised (by a TA, faculty or staff member) at all times.
- Carefully follow all written and verbal instructions. If you do not clearly understand or remember a procedure, ask your instructor or the laboratory staff before proceeding with the experiment/project.
- Before energizing an experimental circuit.
  - Lay out your circuit to avoid reaching over un-insulated conductors/component to adjust or read instruments.
  - Check your circuit. For ECE lab courses have your instructor check/approve your circuit.
  - The person operating the power switch must make sure that everyone is standing clear of the equipment and warn other group members that the circuit is going live.
- Power must be switched off in an experimental circuit whenever
  - The circuit is left unattended.
  - The circuit is being constructed or disassembled.
  - Any circuit changes must be made.
- If measurements must be made on live circuits, use well-insulated meter probes and work with only one hand at a time.
- Keep your work area clean and tidy. Student should make sure all tools, equipment, and supplies are returned to their proper storage (including electronic components back to drawers), and the equipment is shut down after their experiment is concluded.

8.3 Appendix D: COVID-19 Guidelines

8.3.1 Mecklenburg County Guidelines

- Mecklenburg County Public Health urges everyone 12 years of age and older to get vaccinated.
- Everyone should continue to wash their hands often with soap and water.
- Use hand sanitizer if soap and water aren't available.

8.3.2 UNCC Guidelines

- Masks must be worn at all times while inside a campus building.
- Limited gathering size in small lab rooms.
- Hand sanitizer stations are placed around the buildings entrances and exits.
- Non vaccinated individuals must get tested weekly
- Vaccinated individuals must get a COVID-19 booster shot or get tested weekly

8.3.3 ISL Guidelines

Safety Plan for the Industrial Solutions Lab's Senior Design Workspaces

The following rules must be adhered to while working in the Industrial Solutions Lab's Senior Design workspaces. Failure to follow these rules will result in the loss of space for the entire team. For questions, please contact G.T. Hobday at gthobday@uncc.edu.

Lab Identification

- There are four lab spaces dedicated to Engineering Senior Design. These labs are EPIC 1128, Cameron 171, Duke 219 and the senior design space in the CAB building known as the CAB lab.

Social Distancing

- Students must work to maximize the distance between teammates when at the workstation and try to maintain 6 feet of spacing. Students will be required to wear masks at all times when at their workstations.
- A maximum of two (2) students per workstation will be allowed.

Sanitization Protocols

- Hand sanitizer will be located at the entrance of each lab and at each workstation. Students will be directed to sanitize their hands upon entry.
- Sanitizing wipes will be available in the labs and students will be directed to wipe down their space when they leave. Two sanitizing wipe packages will be maintained at each workstation. Contact the lab manager when running low to resupply the sanitizing wipes.

Personal Protective Equipment

- Safety glasses are located at the entrance of the labs and students are required to wear safety glasses while in the labs. Safety glasses will be left in a "used" container upon exiting the lab. The glasses will then be sanitized after use and placed in a "clean" container before being reused.
- Face masks are located at the entrance of the labs and students are required to wear face masks while in the labs.
- Two types of gloves are provided in the labs: Nitrile and Leather. Depending on the activity, students are required to wear the appropriate gloves to keep their hands protected.

Contactless Part Delivery in Labs

- ISL Staff purchase parts that students build into their projects. Normally, students come to the ISL offices to pick-up the parts. To provide a contactless process, ISL will deliver the parts to the student's stations when the students are not there. Students will sign for the parts and leave the paperwork in a location for ISL to pick-up when the students are not there.

Monitoring

- The highest capacity lab is the CAB lab and this is where the majority of the projects will be assigned. ISL will have a lab manager stationed at this lab to monitor compliance with these protocols. The lab manager will maintain all supplies referenced.
- Duke 219 has a full-time lab manager who will monitor this lab for compliance to the plan and maintain supplies.
- EPIC team assignments will be for ECE projects only. ISL will maintain supplies, but ECE will monitor the labs for compliance using graduate students.
- Cameron team assignments will be for ET projects only. ISL will maintain supplies, but ET will monitor the labs for compliance using graduate students.
- ISL will provide a log for each lab and we will request that students record the date and time that they are in the lab so this data is available if needed for contact tracing.

Student Lab Use

- If a student does not want to go into a lab, the Faculty Mentor for the team will seek a solution that will allow the students participation in the class without having to enter the labs.

8.4 Appendix D: Safety Codes

8.4.1 NAR Model Rocket Safety Code

1. **Materials.** I will use only lightweight, non-metal parts for the nose, body, and fins of my rocket.

2. **Motors.** I will use only certified, commercially-made model rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.

3. **Ignition System.** I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch, and will use a launch switch that returns to the "off" position when released.

4. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

5. **Launch Safety.** I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance. When conducting a simultaneous launch of more than ten rockets I will observe a safe distance of 1.5 times the maximum expected altitude of any launched rocket.

6. **Launcher.** I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of the rod when it is not in use.

7. **Size.** My model rocket will not weigh more than 1,500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320 N-sec (71.9 pound-seconds) of total impulse.

8. **Flight Safety.** I will not launch my rocket at targets, into clouds, or near airplanes, and will not put any flammable or explosive payload in my rocket.

9. **Launch Site.** I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.

10. **Recovery System.** I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

11. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.

8.4.2 NAR High Power Rocket Safety Code

1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position..

5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. **Launch Safety.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the **appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.**

12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

MINIMUM DISTANCE TABLE

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

8.5 Appendix E: Written Safety Agreement

49er Rocketry Written Safety Statement

I understand and agree to abide by the NAR High Power Rocket Safety Code and adhere to all direction set forth by formally established procedures. Prior to the initiation of any procedure, I will consult the team Safety Officer to ensure a proper and full understanding of said procedure. I shall wear all required personal protective equipment while handling hazardous materials and/or utilizing machining facilities/equipment/tools. I will ensure that all proper safety data sheets have been thoroughly reviewed prior to the handling of any hazardous material. It is understood that if I am witness to any individual failing to adhere to the content of the written safety agreement I shall immediately intervene, inform the individual of their action, and report the violation to the primary (Daniel Naveira) and/or secondary Safety Officer (Caden Pyne). I understand and agree to follow any and all guidelines set forth by any laboratory space or machine shop of UNCC. I acknowledge that the team Safety Officer has the authority to stop and intervene in any activity that is deemed unsafe or could have the potential to cause harm to personnel and that failure to comply with directions from the Safety Officer will result in the immediate ejection from the work space. Repeated offenses, egregious violations, and/or blatant disregard to any safety regulation will subject me to the possibility of removal from the project. I understand that any information conveyed by the designated RSO of NAR/TRA during scheduled launches takes precedence over any information conveyed by designated team Safety Officers. In order to promote a safe work environment, I agree to the following statements:

1. I will review safety data sheets before handling hazardous materials.
2. I will have a working knowledge, or required training, of equipment or tools being used.
3. I will assess the surroundings for fire, electrical and environmental hazards.
4. I will participate in a briefing on hazard recognition and accident avoidance.
5. I will follow all rules and regulations laid out in the safety briefings prior to construction and launch.
6. I will learn to identify hazards within the work area.

I am aware of, and will follow, the following regulations stated in the NASA USLI Handbook. They are as follows:

1. Range safety inspections of each launch vehicle before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The RSO has the final say on all launch vehicle safety issues; therefore, the RSO has the right to deny the launch of any launch vehicle for safety reasons.
3. The team mentor is ultimately responsible for the safe flight and recovery of the team's launch vehicle; therefore, a team will not fly a launch vehicle until the mentor has reviewed the design, examined the build and is satisfied the launch vehicle meets established amateur rocketry design and safety guidelines.
4. Any team that does not comply with the safety requirements will not be allowed to launch their launch vehicle.

8.6 Appendix F: ANVIL Electrical Schematics

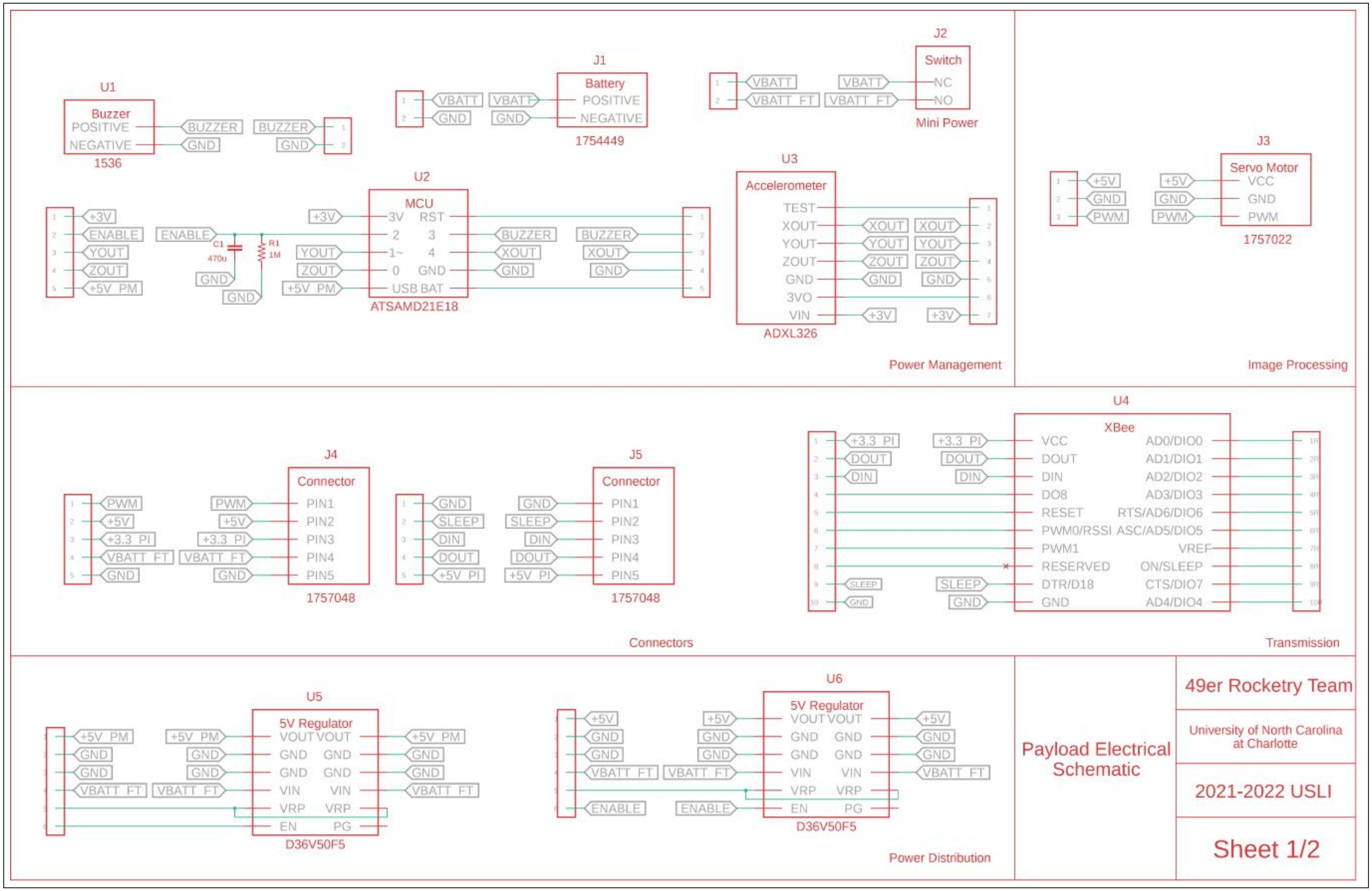

Figure 151: ANVIL Primary Electrical Schematic

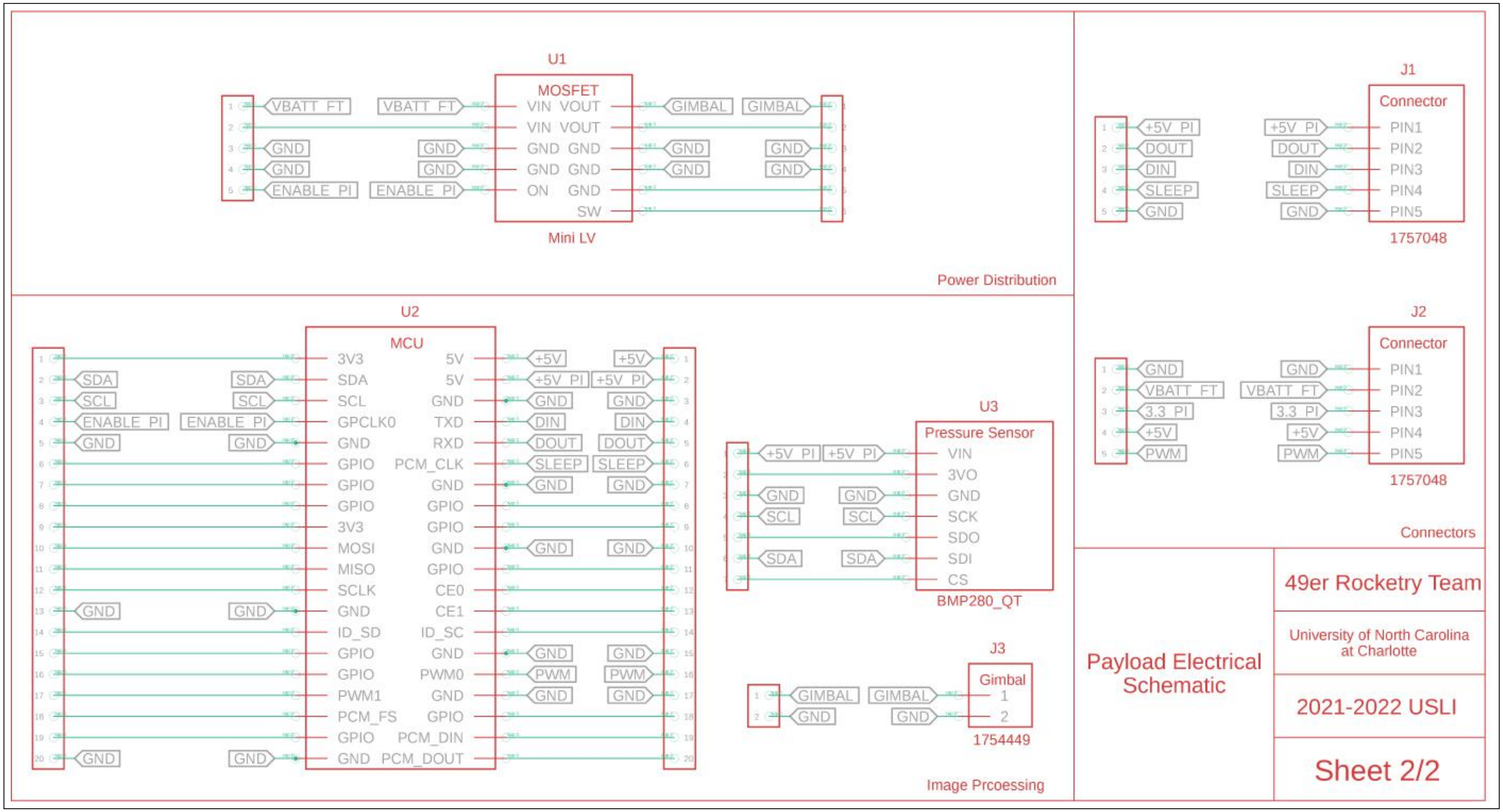

Figure 152: ANVIL Secondary Electrical Schematic