Tacho Lycos

2023 NASA Student Launch

Flight Readiness Review

High-Powered Rocketry Club at NC State University
911 Oval Drive
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Common Abbreviations and Nomenclature

AGL = Above Ground Level
APCP = Ammonium Perchlorate Composite Propellant
APRS = Automatic Packet Reporting System
AV = Avionics
BP = Black Powder
CDR = Critical Design Review
CG = Center of Gravity
COTS = Commercial Off The Shelf
CP = Center of Pressure
EIT = Electronics and Information Technology
FAA = Federal Aviation Administration
FMEA = Failure Modes and Effects Analysis
FN = Foreign National
FRR = Flight Readiness Review
HEO = Human Exploration and Operations
HPR = High Power Rocketry
HPRC = High-Powered Rocketry Club
IC = Integrated Circuit
IMU = Inertial Measurement Unit
L3CC = Level 3 Certification Committee (NAR)
LCO = Launch Control Officer
LE = Leading Edge
LRR = Launch Readiness Review
MAE = Mechanical & Aerospace Engineering
MOI = Moment of Inertia
MSDS = Material Safety Data Sheets
MSFC = Marshall Space Flight Center
NAR = National Association of Rocketry
NCSU = North Carolina State University
NFPA = National Fire Protection Association
PDR = Preliminary Design Review
PLAR = Post-Launch Assessment Review
PPE = Personal Protective Equipment
RAFCO= Radio Frequency Command
RF = Radio Frequency
RFP = Request for Proposal
RSO = Range Safety Officer
SBC = Single-board Computer
SL = Student Launch
SLS = Space Launch System
SME = Subject Matter Expert
SMT = Surface Mount Technology
SOCS = Surrounding Optics and Communication System
SOW = Statement of Work
STEM = Science, Technology, Engineering, and Mathematics
SWR = Standing Wave Ratio
TAP = Technical Advisory Panel (TRA)
TE = Trailing Edge
TRA = Tripoli Rocketry Association

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1 Summary of Report

1.1 Team Summary

1.1.1 Team Name and Mailing Address

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

Mailing Address: 911 Oval Drive, Raleigh 27606

Primary Contact: Meredith Patterson, mapatter@ncsu.edu, (919) 448-8001

1.1.2 Final Launch Location

Competition launch will be conducted on April 15th, with a rain date of April 16th, in Huntsville, Alabama.

1.1.3 Mentor Information

Name: Alan Whitmore

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TRA Certification: Level 3, 05945

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TRA Certification: Level 3, 02204

1.1.4 Time Spent on FRR Milestone

The team spent an approximate total of 400 hours working towards completion of FRR milestone.

1.1.5 STEM Engagement Summary

Event/Group	Apex Friendship High School	Joyner Elementary	Science Olympiad	Lacy Elementary	Fred Olds Elementary	NC Museum of Natural Sciences	East Chapel Hill High School	Museum of Life and Science	Ward Elementary	Laurel Park Elementary	Total Direct Engagement Events
Participants	65	100	6	135	44	488	25	142	89	100	1194
Activity Description	Presented, Bottle Rockets	Presented, Straw Rockets	Bottle Rockets	Straw Rockets	Presented, Bottle Rockets	Straw Rockets	Presented, Estes Rockets, Bottle Rockets	Bottle Rockets, Straw Rockets	Presented, Bottle Rockets	Straw Rockets	

1.2 Launch Vehicle Summary

1.2.1 Target Altitude and Motor Selection

The official target apogee is 4500 ft with a final motor selection of an Aerotech L1520-T motor.

1.2.2 Vehicle Size and Mass

Dry Mass	Dry Mass with Ballast	Wet Mass	Burnout Mass	Landing Mass	Launch Rail Size
34.8	38.5	42.5	38.5	38.5	15-15 by 12 ft.

Section	Nose Cone	Main Parachute Bay	AV Bay	Drogue Parachute Bay	Payload Bay	Fin Can	Overall
Length (in)	31	20	2	17	4	31.75	105.75
Weight (lb)	5.31	2.46	3.30	2.07	2.82	6.7	

1.2.3 Recovery System

Two RRC3 Sport altimeters will control deployment events. Fruity Chutes 15 in. Compact Elliptical and 120 in. Iris Ultracompact parachutes will be deployed at apogee and 600 ft. respectively.

1.3 SOCS Payload Summary

The payload has been designated SOCS, Surrounding Optics and Communication System. SOCS consists of a dual antenna RAFCO system and a quad camera system in the launch vehicle's fin can. SOCS will receive RAFCO transmitted using APRS. These camera controls and image editing commands are to be interpreted and carried out by SOCS within 30 seconds of receipt using an on-board camera servo system that is capable of rotating 360° around an axis normal to the ground. After the command sequence has been completed, the resulting image will be saved on the computer for competition review.

2 Changes Since Critical Design Review

2.1 Changes Made to Vehicle Criteria

Several changes have been made to the launch vehicle design since CDR submission. These changes and their justifications are listed in Table 1

Table 1: Changes made to vehicle since CDR submission.

Change	Reason For Change
Increased number of rivets between the payload bay and fin can connection point	After verification testing, the number of rivets at this location was increased in order to ensure the proper factor of safety was met.
Nose cone bulkhead moved 1 in. farther aft.	During construction of the nose cone, the shoulder could not be inserted as far into the nose cone as previously thought. This caused the nose cone bulkhead to be shifted 1 in. aft.
Drogue parachute changed to Fruity Chutes 15 in.	Updated parachute descent rate calculations showed much slower velocities than first expected. This made it acceptable to use a smaller drogue parachute.
Shock cords changed from two 40 ft. cords to a 17 ft. and 23 ft. shock cords.	It was deemed that two 40 ft. shock cords would be excessive. Thus, shorter cords were used to save space inside the parachute bays. The material of the cords remains unchanged.

2.2 Changes Made to Payload Criteria

From data gained from the payload demonstration flight, several changes to the payload system have been made. The changes made and the justifications for these changes are found in Table 2.

Table 2: Changes made to payload since CDR submission.

Change	Reason for Change
Payload sled redesigned to consist of two bulkeads and a sled	Previous payload sled had a sub-optimal usage of space, making assembly complicated
Power distribution board added	Allows for easy powering of servos without wire splicing
CSI to HDMI boards added to cameras	Allows for easy camera rotation
Servo CTRL1 shifted from pin 19 to pin 24	Pin 19 on available Pi is nonfunctioning
4A fuse added to 5V output	Overcurrent caused Pi shortage
USB C connector added to 5V input	USB C header on Pi has a voltage converter, allowing for redundancy in case of buck converter failure
Separate 5V converter added for servos	Servo current draw spike resulted in overcurrent of Pi
Additional connections added to Arducam multicam adapter	I2C connection necessary for functionality

2.3 Changes Made to Project Plan

Since the CDR submission, some changes have been made to the project plan as a result of a better understanding of system components and design criteria. These changes and their justifications are found in Table 3.

Table 3: Changes made to project plan since CDR submission.

Change	Reason for Change
PD 6 was added to the team derived requirements.	The team determined that it was necessary to add further requirements regarding the design of the camera housing such that the camera would have an unobstructed view for each new launch.
Description for PE 1 from CDR was reworded.	After final payload design had been determined, it was concluded that the camera housing could not completely make a water-tight seal, despite mitigations mentioned in the document.
RD 4 was added to the team derived requirements.	The team determined that it was necessary to add further requirments regarding the precautions used to protect each parachute from ejection gases.

3 Vehicle Criteria

3.1 Launch Vehicle Mission Statement and Success Criteria

3.1.1 Mission Statement

The mission of the launch vehicle is to reach the declared apogee of 4500 ft while securely housing all payload electronics and safely delivering them to the ground. The team will work together to design and construct a launch vehicle to accomplish this mission while being in compliance with all NASA and team derived requirements. This year's launch vehicle, "I Don't Care What The Rocket Is Named, Just Pick Something", will be designed around safety, reliability, reusability, and fun.

3.1.2 Success Criteria

The launch vehicle will be declared successful if it accomplishes the mission stated above while also maintaining compliance with all NASA and team-derived requirements. Criteria for the success of the launch vehicle are defined in Table (4) below.

Table 4: Launch vehicle success criteria.

Level of Success	Criteria
Complete Success	- Launch has nominal takeoff and descent - Launch vehicle reaches $\pm$250 ft. of target apogee - Launch vehicle is recovered undamaged - Vehicle could be relaunched the same day - Payload is returned to the ground undamaged
Partial Success	- Successful launch vehicle takeoff and descent - Launch vehicle reaches $\pm$500 ft. of target apogee - Launch vehicle can be repaired at the field - Payload sustains damage but does not loose electronic functions
Inconclusive	- Successful launch vehicle takeoff and descent Launch vehicle apogee is $\pm$750 ft. of target apogee - Launch vehicle can be repaired within a day - Payload can be repaired quickly
Partial Failure	- Successful launch vehicle takeoff and unsuccessful descent - Launch vehicle apogee is below 3000 ft. or above 6000 ft. - Launch vehicle can be repaired within a week - Payload requires extended repairs
Complete Failure	- Launch vehicle is not recovered or unrepairable - Payload is unrepairable

3.2 Launch Vehicle Design Overview

3.2.1 Design Overview

The as-built launch vehicle is 105.75 in. long when fully assembled and 6.17 in. in diameter. This is slightly longer than anticipated due to miscommunication with the manufacturer about the length of the nose cone as well as slight errors in manufacturing the motor tube and tail cone. Other than these errors, the sections of the launch vehicle were manufactured to the planned dimensions within 1/16 of an inch. The launch vehicle was constructed in 6 independent sections which are labeled in Fig. (1) below. The total weight of the assembled launch vehicle (including all electronics and propellant) is 42.5 lb. including 3.7lb of ballast. This quantity of ballast was necessary in order to maintain the required stability at rail exit. Due to a decrease in payload weight below the expected value, more ballast was needed than anticipated during the CDR milestone.

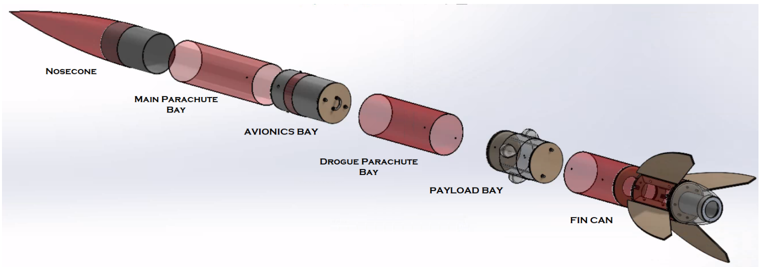

Figure 1: Exploded view CAD of the entire assembled launch vehicle.

The recovery system of the launch vehicle will be controlled by 2 redundant RRC3 altimeters and an Eggtimer Quasar utilized for its GPS tracking capability. At apogee a Fruity Chutes 15 in. elliptical parachute will be deployed followed by a 120 in. Iris Ultra-compact main parachute deployed at 500 ft. AGL.

The payload features 4 clear camera housings which protrude from the surface of the vehicle near the aft end. The housings are oriented such that they lie in between the fins. These housings lie aft of the burnout center of gravity and have been shown to have minimal affects on the stability of the vehicle.

Figure 2: Fully Assembled Launch Vehicle.

3.2.2 Separation Points

During descent the launch vehicle will separate between the nose cone and the main parachute bay as well as between the avionics (AV) bay and the drogue parachute bay. All other sections will be secured together using nylon rivets to ensure that the vehicle does not separate into more than 3 sections during descent. These separation points are shown in Fig. (3) below. Energetics are located on either side of the AV bay attached to the outward facing side of each bulkhead. The launch vehicle will utilize a standard 15-15 launch rail. Rail buttons will be secured to the exterior of the fin can and be mounted such that the rail will pass between the fins and camera housings.

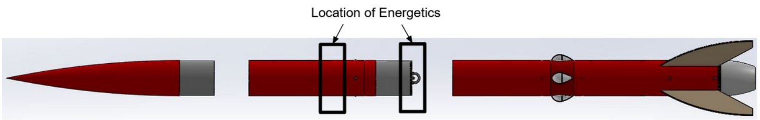

Figure 3: Diagram of separation points and energetic locations.

3.2.3 Changes Since CDR

The overall design of the launch vehicle has not changed since the submission of the CDR milestone. There have been several minor changes made to the vehicle as a result of manufacturing challenges and verification testing. An additional rivet was placed at the point where the payload bay and fin can connect. This was done in response to the rivet shear test in order to increase the factor of safety. The nose cone bulkhead was shifted 1 in. farther aft in the nose cone than was previously designed. This was done because of challenges in inserting the nose cone shoulder far enough into the nose cone. Additionally, the nose cone provided by the manufacturer was 1 in. longer than was originally intended. The orientation of the pull pin switches used to arm the recovery electronics was made such that the switch could not be accidentally depressed due to the acceleration at takeoff. Likewise, the orientation of the batteries on the AV sled were rotated 90 degrees such that the battery connector could not accidentally be removed due to the acceleration of takeoff.

3.2.4 Nose Cone

3.2.4.1 Nose Cone Airframe

The airframe of the nose cone consisted of a G12 fiberglass 5:1 ogive with a metal tip. The nose cone shoulder extends 6 in. from the aft end of the nose cone. The nose cone bulkhead was moved 1 in. farther aft inside the nose cone shoulder than was originally designed. This was done because the shoulder was unable to be inserted as far into the nose cone as previously anticipated. However, the exposed length of the shoulder remains unchanged. A threaded rod was also inserted that runs the entire length of the nose cone. The purpose of this rod is to further support the nose cone bulkhead and to act as an attachment point for ballast. Currently, 3.7 lb. of ballast are attached to the nose cone threaded rod. The total length of the nosecone as built is 31 in. (excluding the length of the shoulder) and the nose cone and bulkhead assembly weigh 5.31 lb. excluding ballast. This length is slightly longer than was anticipated and is due to differences in the manufacturers specifications. The original length was calculated based on the fineness ratio of the nose cone. However, the nose cone received from the manufacturer was slightly longer than this calculated value.

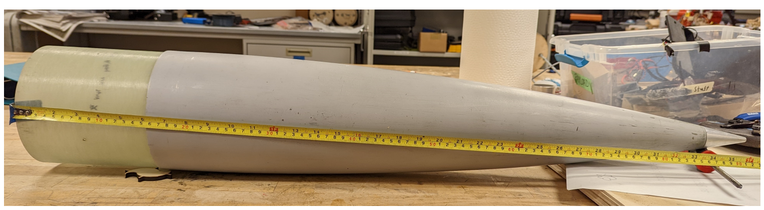

Figure 4: Nose cone.

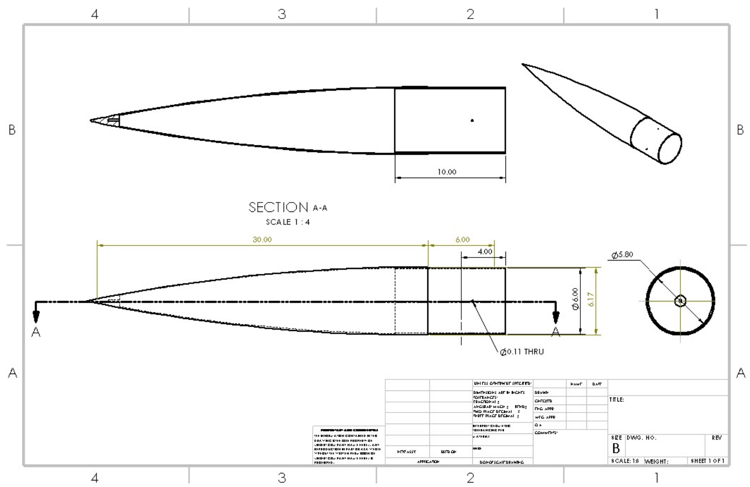

Figure 5: Dimensioned schematic of the as built nose cone.

3.2.4.2 Nose Cone Bulkhead

The design of the nose cone bulkhead remains unchanged. A centering ring is epoxied into the forward end of the nose cone shoulder. Four 1/4-20 T-nuts are attached to the centering ring. The nose cone bulkhead is then bolted to the centering ring. These bolts can be removed in the event that access to the forward face of the bulkhead is needed. A U-bolt is secured to the center of the nose cone bulkhead and serves as the attachment point for the main parachute.

Figure 6: Nose cone bulkhead while installed in the nose cone.

3.2.5 Main Parachute Bay

The main parachute bay will be located between the nose cone and the AV bay. The aft end of the bay will be connected to the AV bay using four ¼ in. nylon rivets and the forward end will be secured to the nose cone using four #4-40 nylon shear pins. Verification testing was performed to ensure that these rivets will be able to support the required loading with an adequate factor of safety. As constructed the main parachute bay is 20 in. long and weighs 2.46 lb. excluding the recovery hardware.

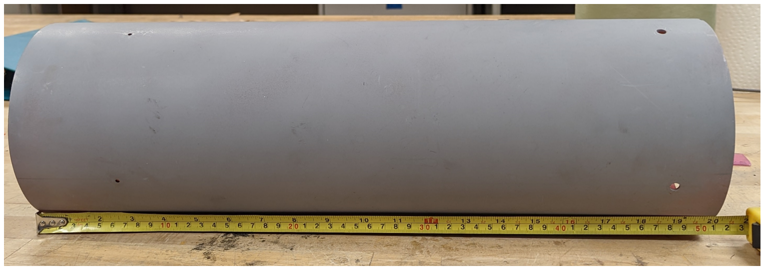

Figure 7: Main Parachute Bay.

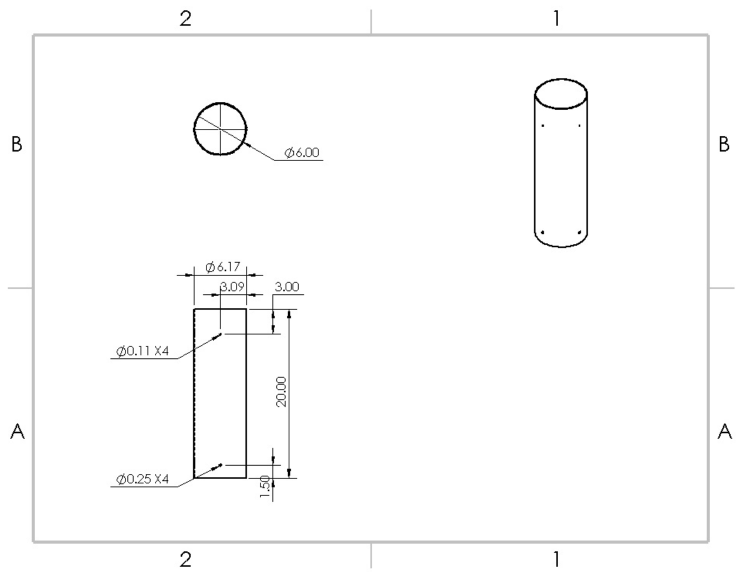

Figure 8: Dimensioned schematic of the as built main parachute bay.

3.2.6 AV Bay

The avionics bay is located between the main and drogue parachute bays and will house all the recovery electronics. The bay is constructed from an 11 in. long coupler section with a 2 in. long band of airframe epoxied 3 in. from the forward end. This makes the exposed lengths of coupler on the forward and aft end of the bay 3 and 6 in. respectively. The weight of the AV bay and its bulkheads, excluding electronics, is 3.30 lb. Four pressure ports are drilled into the airframe bad on the AV bay to provide access to the pull pin switches and allow the altimeters to measure the outside air pressure. The forward end of the bay will be secured to the main parachute bay using nylon rivets and the aft end of the bay will have a shear pin connection to the drogue parachute bay.

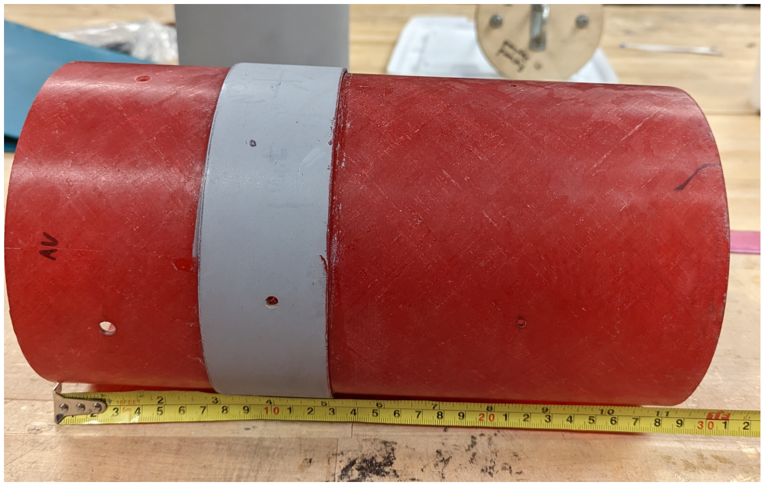

Figure 9: AV bay.

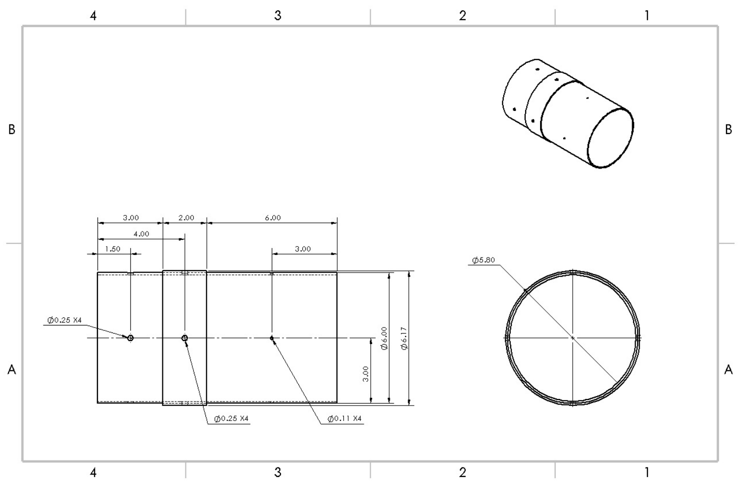

Figure 10: Dimensioned schematic of the as built AV bay.

A bulkhead is secured on each end of the bay and the two bulkheads are connected using two 1/4-20 threaded rods. These threaded rods will also support the AV sled. The AV bay bulkheads underwent verification testing to ensure that the proper factor of safety was met. For this test, a sample av bay was fabricated and subjected to tension using a universal testing machine. The test bulkheads were able to withstand 1000 lb. of loading while showing no signs of deformation or failure. The calculated factor of safety of these bulkheads is 6.4.

Figure 11: AV bay bulkheads.

3.2.7 Drogue Parachute Bay

The drogue parachute bay will house all of the drogue recovery hardware and is located between the AV bay and the payload bay. Shear pins will be used to connect the drogue parachute bay to the AV bay and Nylon rivets will be used to connect the bay to the payload bay. As constructed the drogue parachute bay is 17 in. long and weighs 2.07 lb. excluding the recovery hardware. Additionally, the forward rail button was placed on the drogue parachute bay. This rail button placement was chosen because simulations showed that this location would minimize weathercocking and oscillations at rail exit.

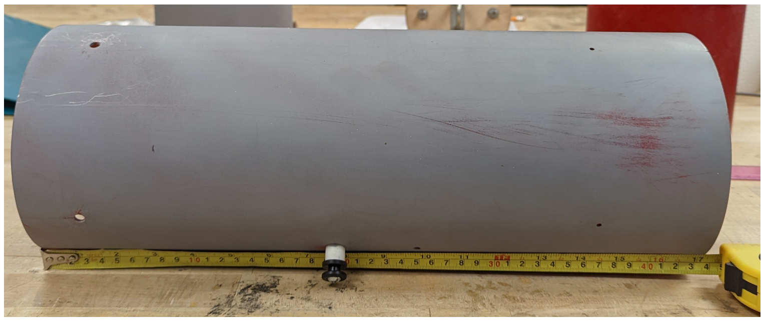

Figure 12: Drogue Parachute Bay.

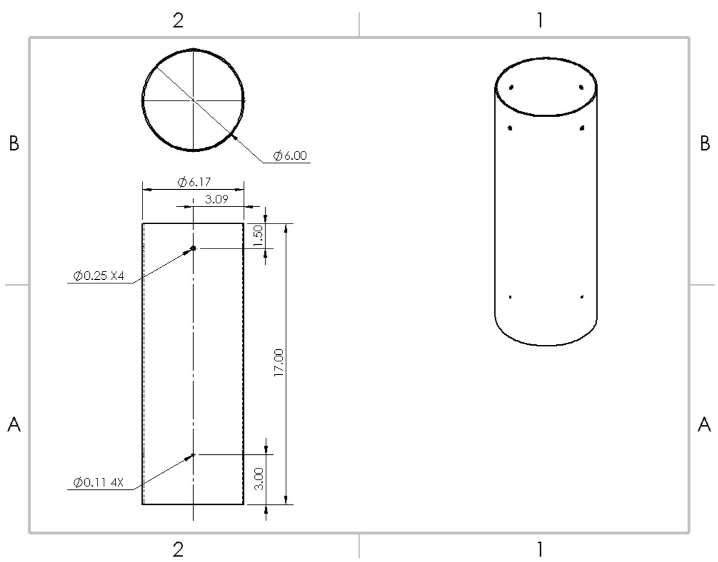

Figure 13: Dimensioned schematic of the as built drogue parachute bay.

3.2.8 Payload Bay

The payload bay will house all of the payload electronics and will be connected to both the drogue parachute bay and the fin can using nylon rivets at each separation point. In response to verification testing, the number of rivets between the payload bay and fin can has been increased to 5 rivets. This connection will experience the most force on the rivets due to the connection to the drogue parachute. The addition of more rivets will ensure that the factor of safety is adequate.

The payload bay as fabricated consists of a 10 in. long coupler section with a 4 in. long airframe band epoxied to the center. Additionally, Four teardrop shaped holes were cut into the airframe band on the payload bay. These holes are evenly spaced around the circumference and will be used to take images of the surroundings upon landing. Each of these holes is covered with a transparent camera housing. The camera housings are held into the bay using four #6-32 machine screws per housing. The payload bay, excluding any payload hardware, weighs 2.82 lb. This assembly is shown in Fig. (14). below.

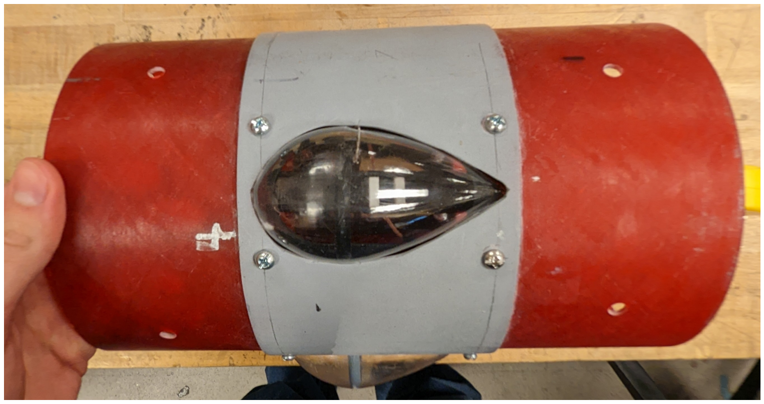

Figure 14: Payload bay with camera housing assembly.

The payload bay will be oriented such that the camera housings lie in the space in between the fins. This is done so that the turbulent flow created by the camera housings does not affect the fin aerodynamics. Two bulkheads sandwich either side of the payload bay. These bulkheads are connected using two 1/4-20 threaded rods. The payload sled will also be supported using these threaded rods. The forward payload bulkhead has a U-bolt for attachment of the drogue parachute. The aft payload bulkhead has 2 holes to allow the antennas to exit the bay.

Figure 15: Payload Bay Bulkheads.

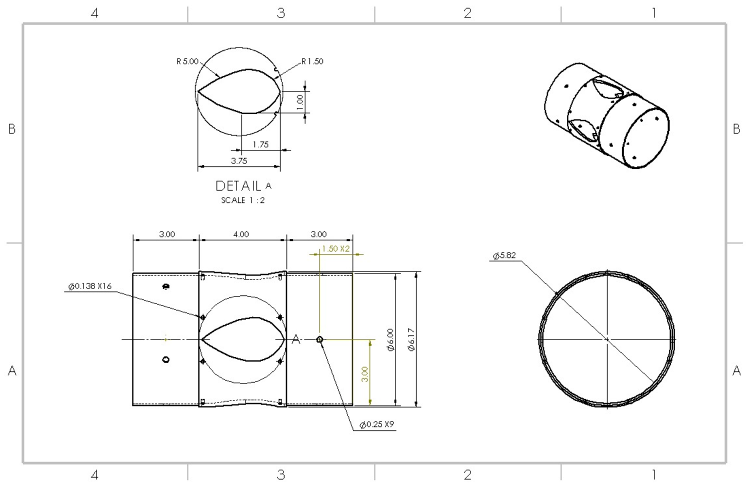

Figure 16: Dimensioned schematic of the payload bay.

3.2.9 Fin Can

3.2.9.1 Airframe

The fin can will hold the fins and the motor for the launch vehicle and is comprised of an airframe section as well as a removable fin assembly. The airframe of the fin can was constructed out of a 25 in. long section of G12 fiberglass. Four 1/4 x 8.5 in. long slots will be cut into the aft end of the fin can to allow the removable fin assembly to slide in and out of the airframe. Eight #8 diameter holes will also be drilled in between the slots in order to connect the removable fin assembly to the airframe. Additionally, the payload antennas will exit the vehicle through two holes in the forward end of the airframe. The location of the antenna holes have changed slightly since CDR submission. The antenna holes are now located several inches farther forward on the fin can. This was done so that as little of the antenna ran behind the fin as possible to reduce any possible interference. The weight of the entire fin can, excluding the motor, is 6.7 lb.

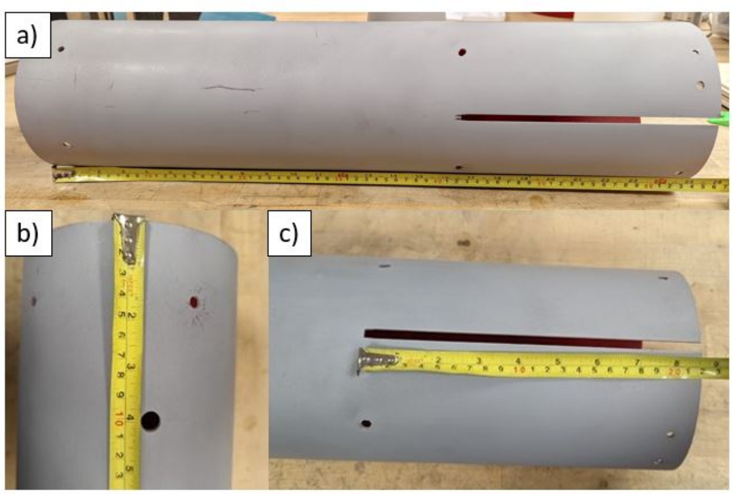

Figure 17: Images of the a) fin can b) antenna holes and c) fin slots as manufactured.

3.2.9.2 Removable Fin Assembly

The removable fin system is constructed out of two centering rings which are connected by plywood runners with a thrust plate and tailcone secured to the aft end. The runners are permanently epoxied to the centering ring with epoxy fillets applied.

The spacing between the runners was larger than was designed. This was due to excess sanding which was required to ensure the runners fit into the slots in the centering rings and to ensure that they were straight. Despite this, the fins are still able to be held securely within the assembly.

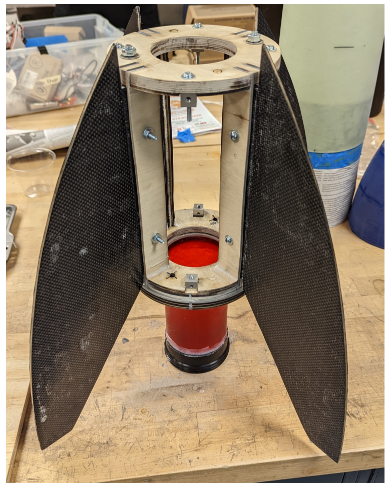

Figure 18: Removable fin assembly.

3.2.9.3 Thrust Plate and Tail Cone

The thrust plate will be constructed out of a combination of 1 ply of 6061 aluminum and 3 plys of plywood. The total thickness of the thrust plate is 1/2 in. The wooden thrust plate plys are used to secure a 5.75 in. long section of motor tube. This length is slightly longer than was originally designed. This was because of error in cutting the motor tube. The body of a 75mm Aeropack retainer was then epoxied to the end of the motor tube. All of the thrust plate plies will be held onto the removable fin assembly using the threaded rods as well as four #8-32 machine screws.

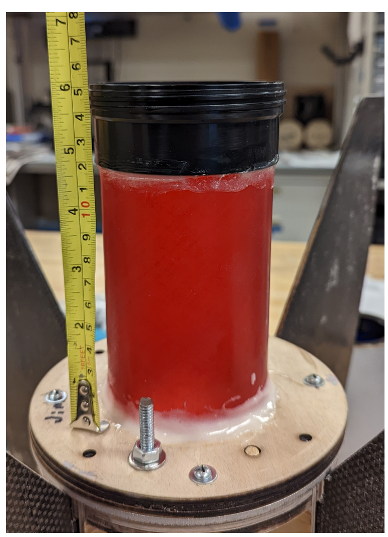

Figure 19: Thrust Plate.

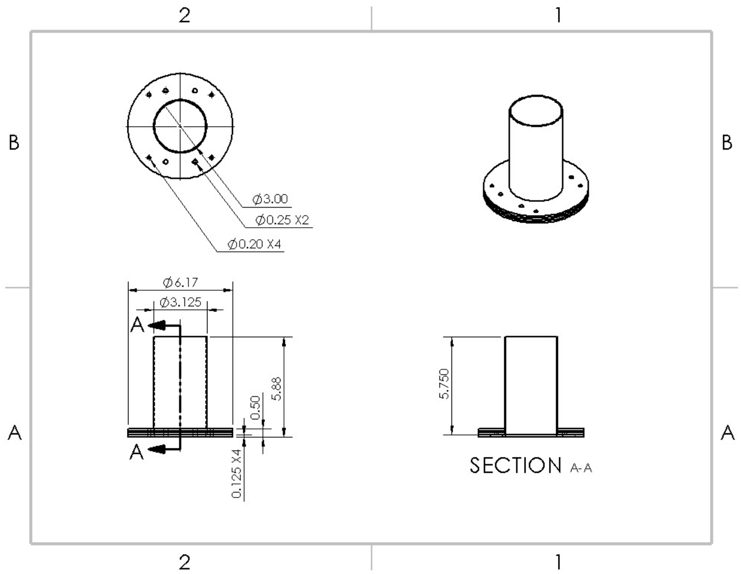

Figure 20: Dimensioned schematic of the thrust plate.

The tail cone was 3D printed in two parts which then had to be epoxied together. This was done because the tail cone was too large to fabricate as a single print. Furthermore, A single layer of fiberglass was applied to the inside of the tail cone to ensure structural stability. The cap of the motor retainer was then epoxied to the tail cone using a strip of cork as insulation. The Tail cone can then be threaded onto the thrust plate assembly. The height of the motor tube was slightly longer than was originally intended. Because of this there is a slight 1/8 in. overhang between the cap of the motor retainer and the tailcone. This resulted in the overall length of the vehicle being slightly increased. However, it does not affect motor retention or vehicle perfromance. Thus, this difference is not of concern.

Figure 21: Tail Cone.

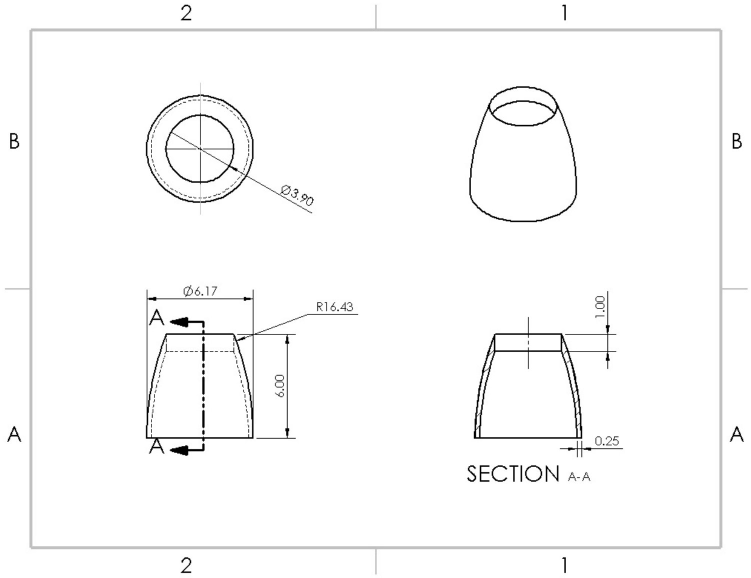

Figure 22: Dimensioned schematic of the as built tail cone.

3.2.9.4 Fins

Fins were constructed out of a carbon fiber sandwich composite. Two layers of 3000K plain weave carbon fiber were layered over each side of a balsa wood core. The dimensions of the fins have not changed since the CDR milestone. Verification testing was also performed on the composite fins in order to ensure that they would not break upon landing. The results of this test are discussed later in this report. There were some challenges in creating a flat surface finish on the fins. However, it was found that wet sanding and several coats of a clear finish provided an adequate surface finish.

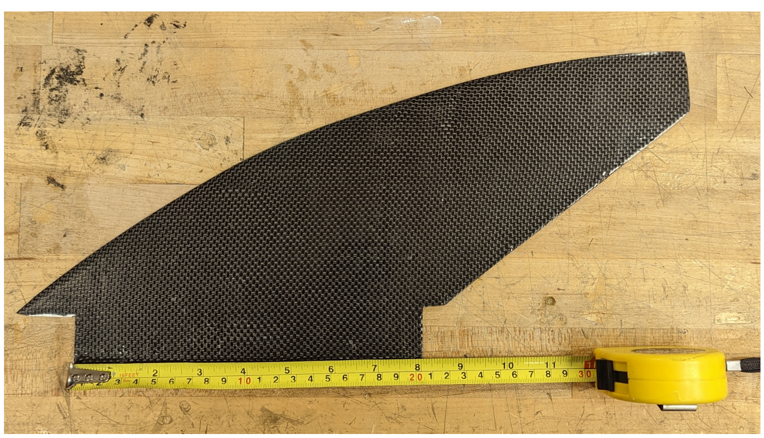

Figure 23: Carbon Fiber Composite Fins.

3.2.10 Test Pieces

Two different test pieces were also constructed prior to the manufacturing of the full scale launch vehicle. These test pieces were intended to verify the strength and factor of safety of the parachute attachment points at the nose cone and AV bay. The nose cone test piece consisted of a nose cone bulkhead assembly which was constructed inside of a piece of fiberglass coupler. At the other end of the coupler, a permanent bulkhead was attached. The AV bay test piece consisted of two AV bay bulkheads which were sandwiched on either end of a section of fiberglass coupler. Images of both of these test pieces are shown in Figures () and () below. Additionally, rivets and shear pins were tested by threading the fastener through two metal plates. These plates could then be pulled apart in order to apply shear to the fastener. Once constructed, a universal testing machine was used to gradually pull on the test pieces until failure occurred or until the maximum load of 1000lb. was reached. Further description and results of structural testing is provided later in this document.

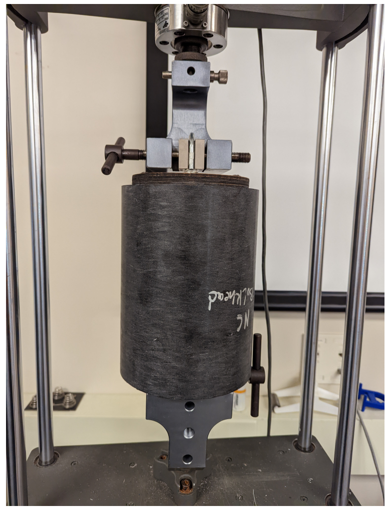

Figure 24: Nose cone bulkhead testing setup.

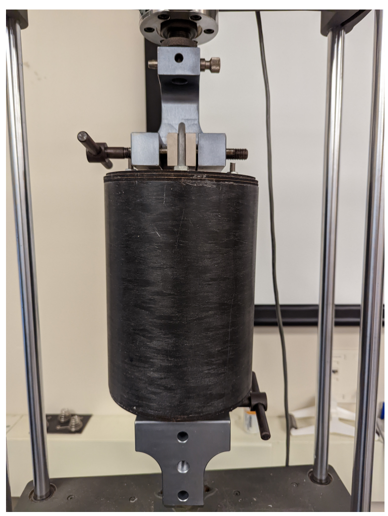

Figure 25: AV bay bulkhead testing setup.

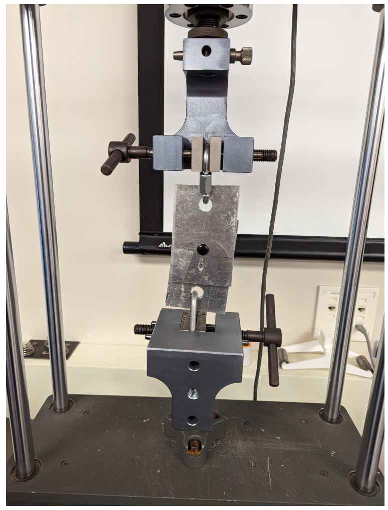

Figure 26: Shear testing setup for rivets and shear pins.

3.3 Flight Reliability

3.3.1 Structural Elements

3.3.1.1 Airframe

The airframe of the launch vehicle is made from G12 fiberglass, which is currently one of the strongest and most damage-resistant materials available in hobby rocketry. This material has proven to withstand all loads accumulated during flight and impacts during landing. Fiberglass is water-resistant which helps to protect the launch vehicle, should it land in water.

3.3.1.2 Fins

The fins are made from a sandwhich composite composed of a balsa wood center between two layers of epoxy-whetted carbon fiber and one layer of epoxy-whetted fiberglass on each side. Each fin is secured using two 1/4 in. bolts securing the fin to the plywood runners on the removable fin assembly. The process is described in more detail in Section 3.4.3. Although the swept-wing design of each fin causes uneven loading along the leading edge, bending moment testing verified that the wing can hold more than 80lbs without deforming. More about the structural testing can be found in Section 7.1.1.5.

3.3.1.3 Bulkheads

Each bulkhead is made by laminating layers of 1/8in. aircraft grade birch plywood. FEA simulations were run for each bulkhead design using ANSYS to ensure that they would have a factor of safety larger than 1.5 as per the requirement LVD 6. Physical tests for the nosecone and AV bay bulkheads were conducted to verify this requirement. These tests resulted in a factor of safety of 6.4 and 16.4 for the AV bay bulkhead and nosecone bulkhead respectively. Further details of the this testing can be found in Sections 7.1.1.6 and 7.1.1.7.

3.3.1.3.1 Epoxy Connection

The forward centering ring in the nosecone is secured using an epoxy connection. All epoxy connections are made from a mixture of West Systems 105 Epoxy Resin and 206 Slow Hardener, with a combined tensile strength of 7,320 psi. This will be more than strong enough to hold the centering ring in place during launch and landing. Fillets were also added to the epoxy connection of the forward centering ring by mixing the epoxy with 406 Colloidal Silica, which helps distribute stress and further increases the strength.

3.3.1.3.2 Bolted Connection

The nosecone bulkhead is attached to the forward centering ring via four 1/4-20 stainless steel bolts. These bolts have a tensile strength of 1,908 lbf, and their shear strength can be estimated as about 60 percent of this value, or 1,145lbf. Structural simulations found that the bolts closest to the U-bolt would only experience 61.12lbf during drogue parachute deployment. This results in a factor of safety of 18.73 which is more than required. Additionally, success in past flights with similar designs gives us confidence in this connection.

3.3.1.3.3 Threaded Rods

The AV Bay and Payload Bay bulkheads are held in place using two 1/4 in. threaded rods. Structural shear tests determined that each threaded rod could be loaded with 1000lbf in shear without deforming. With the highest deployment loading expected at 177.74lbf, giving them a factor of safety of 5.62. Since this load will be split evenly between two threaded rods, they should easily be able to resist deployment forces.

3.3.1.3.4 Attachment Hardware

U-bolts are used on most of the bulkheads in the launch vehicle as mounting points for the shock cord. Washers and plates are used to better distribute the applied loading such that the U-bolts are not ripped out during recovery of the launch vehicle. The U-bolts themselves are 5/16 in. thick with a load capacity of 600 lbf. With the highest deployment loading expected to be 177.74lbf, the U-bolts will have a factor of safety of 3.38 and should be able to resist deployment forces.

3.3.2 Electrical Elements

3.3.2.1 Wiring

All onboard wiring on the launch vehicle is composed of 16-gauge copper wire. While many electrical components use terminal blocks or spaced headers to connect the wiring, their unreliability was proven during the subscale flight. To help prevent this, DuPont to JST-SM cables are manufactured for each daughter board. The DuPont headers are hot glued to the 2.45mm pitch header to create a strong connection and prevent separation during flight. The JST-SM connectors are used to connect all the components together and create a more secure connection than the standard DuPont connectors due to their locking capabilities. More information can be found in Section4.5.4.

3.3.2.2 Switches

Both altimeters in the launch vehicle are armed and disarmed using pull-pin switches due to their simple design and ease of use compared to other methods. Each pull-pin switch is secured to the AV sled using steel M2 screws. To ensure that the altimeter system functions as designed, all wiring connections to the switches are soldered and “Remove Before Flight” tags are attached to the ends of the pins to ensure they are properly removed before launch.

3.3.2.3 Battery Retention

Currently, the launch vehicle houses two standard 9V batteries to power the altimeters and a 7.4V 1500mAh 60 2 cell LiPo battery. Each battery has a 3D printed compartment on the AV sled that is designed to use friction to prevent motion during flight. The sled also includes slots and holes to allow zip ties to further secure each battery. Finally, electrical tape is added around the battery and its respective compartment as an additional precaution. See sections 3.5.6.3 and 4.5.3 for more information on battery retention.

3.3.2.4 Avionics Retention

All avionics electronic components will be bolted to the avionics sled using plastic M3 mounting hardware. The sled is held in place by two 1/4 in. threaded rods that run the length of the AV bay. See Section 3.5.2.2 regarding avionics sled design.

3.4 Launch Vehicle Manufacturing

3.4.1 Airframe Cutting and Bonding

All airframe sections were cut to length using a drop band saw provided by the MAE machine shop. The band saw was operated by machine shop personnel at all times. First, the location of the cut was marked on all airframe sections using a permanent marker. Then the airframe was given to the machine shop personnel who made the cuts at the given location. To ensure that each airframe section was level, the cut pieces were placed on a flat floor and checked using a bubble level. Any sections which were not level were sanded until flat.

Figure 27: Drop band saw used to cut airframe.

To bond cut sections of coupler and airframe material, the sections were first cleaned using isopropyl alcohol in order to remove any grease or surface contaminants. Then the bonding area on each piece was lightly sanded. Next, the surface was once again cleaned in order to remove any dust particles created by sanding. A thin layer of epoxy was then spread over the bonding area. The pieces were then taped or clamped in place and left to cure for 24 hours before further processing. This process is shown in Fig. (28).

Figure 28: Diagram of the process of cutting and bonding of airframe sections.

3.4.2 Bulkhead Construction

Bulkheads were fabricated by laminating layers of 1/8 in. aircraft grade birch plywood (purchased from Aircraft Spruce) to the desired thickness. A diagram of the complete bulkhead fabrication process is shown in Fig. (29) below. A laser cutter was used to cut the desired shape of the bulkhead out of the plywood. First, a single sheet of plywood was inserted into a Universal laser Systems VLS6.60 laser cutter. The individual plys of each bulkhead were then cut.

The individual plys of each bulkhead were then laminated together using West Systems 205 Epoxy Resin. Before gluing, the surface of each ply was lightly sanded. Then 1/4 in. dowels were cut to the thickness of the bulkhead. These dowels were used to align the individual layers of the bulkhead and hold them in place during the layup. Next, a thin layer of epoxy was spread over the surface of each layer. Then, each layer was stacked using the dowels for alignment. Each bulkhead was then wrapped in a layer of peel ply to soak up any excess epoxy that might leak out. Next, a layer of breather material was laid over all of the bulkheads and they were placed in a vacuum bag. A vacuum was created and weights were placed over the vacuum bag. The bulkheads were left to cure for 24 hours before further fabrication. After being removed from the vacuum bag, the edges of each bulkhead were sanded to remove any excess epoxy. Once the bulkheads had been sanded, other hardware such as U-bolts and threaded rods were attached.

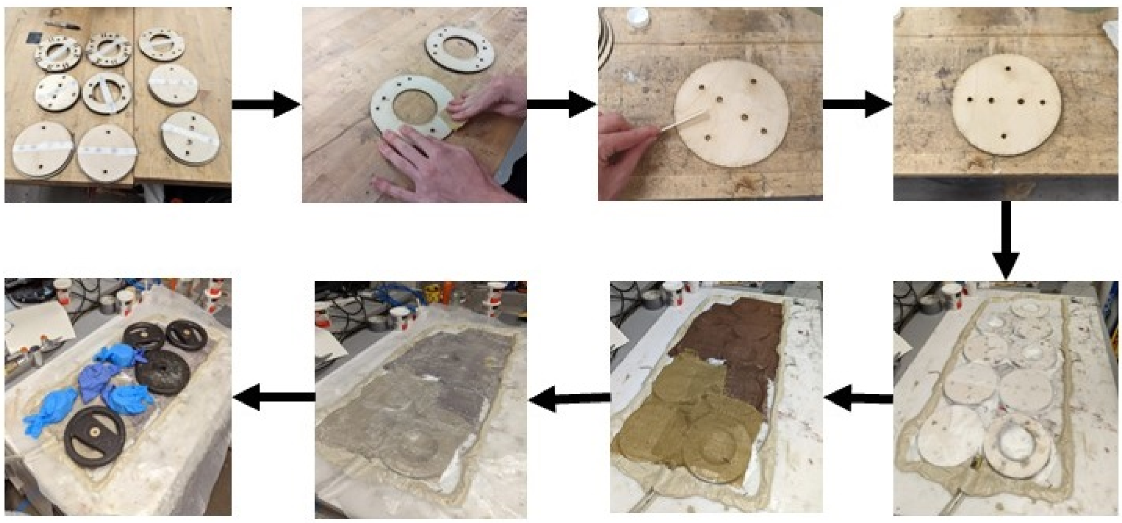

Figure 29: Diagram of the bulkhead manufacturing process.

3.4.3 Fin Construction

The fins were constructed out of a carbon fiber sandwich composite which consisted of two layers of 3K plain weave carbon fiber layered (purchased from Fiberglast) on either side of a balsa wood core. First, the balsa core was cut to shape using a band saw before a thin layer of epoxy was spread over the surface. Two layers of carbon fiber were then laminated over top of the balsa wood. A layer of thin 2 oz. fiberglass was then layered over the carbon fiber. The purpose of the fiberglass layer was to help provide a smoother surface finish. The work piece was flipped to the other side and two more layers of carbon fiber were added. The work piece was then inserted into a vacuum bag and a vacuum was created. Weight was added on top of the layup and it was left to cure for 24 hours. The excess carbon fiber was then cut away and the fins were sanded. Finally, a thin layer of epoxy was spread over the leading edge in order to seal the edge of the wood.

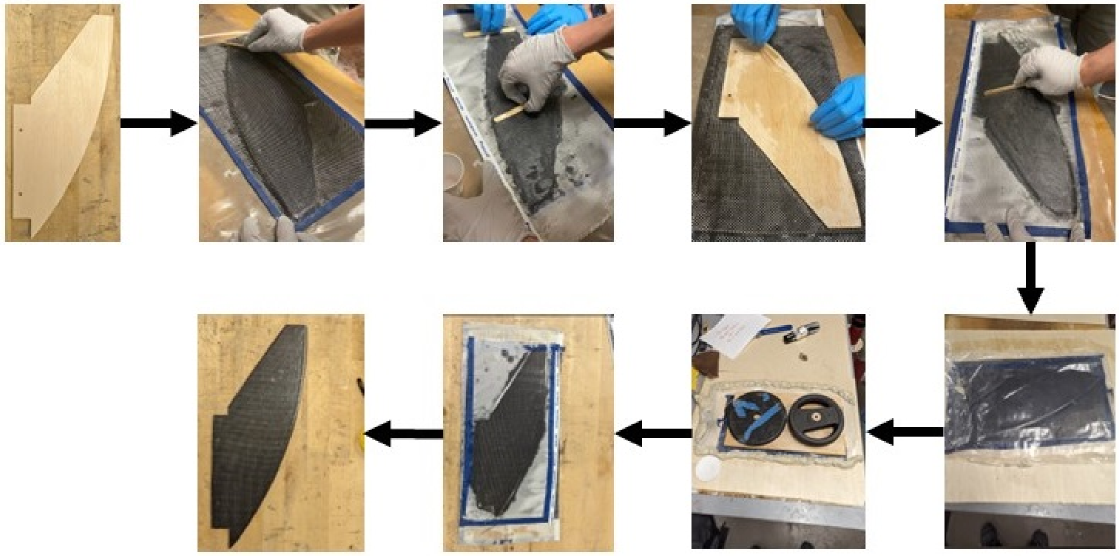

Figure 30: Diagram of the fin manufacturing process.

3.4.4 Nose Cone Construction

The nose cone was constructed of a 5:1 filament wound fiberglass nose cone (purchased from Composite Warehouse) with an anodized aluminium tip. To begin nose cone construction, the bolt holding the aluminum tip was removed and replaced with a 1/4-20 threaded rod which would run the entire length of the nose cone. Additionally, the nose cone bulkhead and centering ring were manufactured according to the procedure described in section 3.4.2 above.

Once the bulkheads were fabricated, four 1/4-20 T-nuts were epoxied to the forward face of the centering ring. The centering ring was then epoxied into the forward end of the nose cone shoulder and a fillet was applied. The nose cone shoulder was then epoxied into the nose cone leaving 6 in. exposed on the aft end. After leaving the epoxy to cure for 24 hours, the nose cone bulkhead was bolted to the nose cone centering ring.

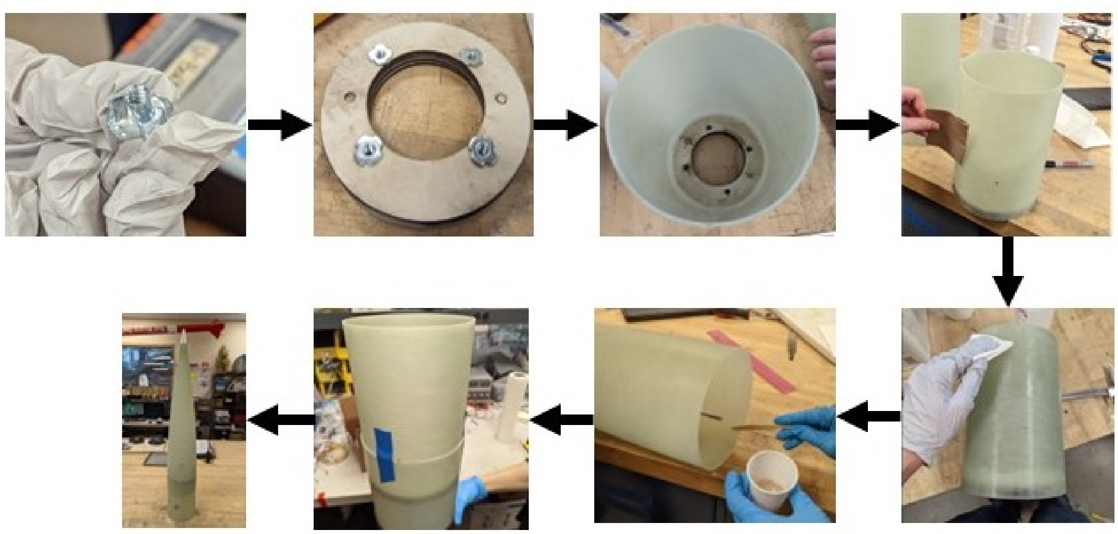

Figure 31: Diagram of the nose cone manufacturing process.

3.4.5 Parachute Bay Construction

Both parachute bays were constructed out of a single section of G12 Fiberglass tube (Purchased from Wildman Rocketry). The tubes were first cut to length using the methods described in section 3.4.1 above. Once cut to length, holes were drilled in both ends of the bays to accommodate the rivets and shear pins used to hold sections together. A pressure relief port was drilled roughly in the center of each bay. The purpose of this pressure port is to equalize the pressure inside of the bay to that of the surrounding atmosphere in order to prevent premature separation. Finally, a 15-15 rail button was attached to the drogue parachute bay.

3.4.6 AV Bay Construction

The AV bay was constructed out of an 11 in. long coupler section and a 2 in. long band of airframe. Both of these sections were cut using the drop band saw described above and then bonded using the procedure described in section 3.4.1.

Once the airframe band was adhered to the coupler, rivet holes were drilled on the forward end of the coupler section for use in joining the AV bay to the main parachute bay. Shear pin holes were then drilled in the aft end of the coupler. Finally, four pressure ports were drilled in the center of the airframe band. The purpose of these ports is to allow the altimeters to read the ambient air pressure as well as providing access to the pull pin switches.

3.4.7 Payload Bay Construction

The payload bay was constructed out of a 10 in. long section of fiberglass coupler and a 4 in. band of airframe. The airframe band was secured to the center of the coupler. Then rivet holes were drilled in both the forward and aft ends of the coupler section. Next, the teardrop shaped holes for the camera housings were cut into the side of the payload bay using a Dremel rotary tool. Finally, the holes for securing the camera housings and camera unit mounts were drilled into the airframe band. At this point the airframe of the payload bay was complete and the necessary payload hardware was secured to the bay.

3.4.8 Fin Can Construction

3.4.8.1 Airframe

The airframe section of the fin can was manufactured from a single section of fiberglass tube which was cut to length using a drop band saw. The location of the fin slots were then marked and fin slots were cut using a milling machine provided by the universities machine shop. The milling machine was operated by the shop personnel at all times.

After fin slots were cut, five evenly spaced holes were drilled into the forward end of the section. These holes would be used to hold rivets used to connect the payload bey to the fin can. Two holes were drilled into the side of the fin can for the antennas to exit the vehicle. Finally, eight holes were drilled in between the fin slots to attache the removable fin assembly

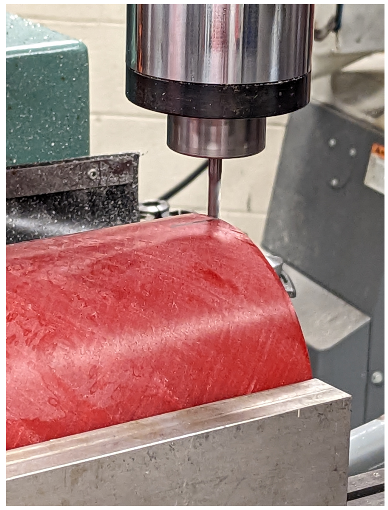

Figure 32: Fin slots being cut on the milling machine.

3.4.8.2 Thrust Plate and Tail Cone

The wooden thrust plate plys were manufactured using the procedure described in section 3.4.2 above. The motor tube was then epoxied to the inside of the wooden thrust plate and a fillet was applied. An Aeropack 75mm motor retainer was used to retain the motor. The body of this retainer was secured to the aft end of the motor tube using West Systems epoxy thickened with 406 Colloidal Silica. Finally, the aluminum thrust plate ply was water jet cut out of 6061 aluminum with 1/8 in. thickness.

The tail cone was 3D printed out of PET-G plastic. Due to the size of the part, the tail cone was printed in 2 separate pieces. These pieces were then bonded together using epoxy. A strip of cork insulation was then attached to the outside of the motor retainer. The retainer and insulation was then epoxied to the tail cone. Once dry, the tail cone could then be screwed onto the thrust plate using the motor retainer.

Figure 33: Diagram of the thrust plate and tail cone manufacturing process.

3.4.8.3 Removable Fin Assembly

To begin construction of the removable fin assembly, the removable centering rings were manufactured in the same manner as the other bulkheads and the plywood runners were laser cut out of 1/8 in. plywood. Once the centering rings had been made, the runners were epoxied into place between the centering rings using two threaded rods for support and alignment. Epoxy Fillets were added to the joint between the runners and centering rings. The aluminum thrust plate ply was then placed over the threaded rods on the end of the assembly followed by the wooden thrust plate. The thrust plate was then secured in place using nuts threaded onto the rods. Aluminum cubes which were tapped with #8-32 through holes on each side were then bolted to the assembly. These cubes would later be used to bolt the entire assembly into the airframe and were custom manufactured by the university machine shop. Fins were then inserted into the slots between the runners and secured in place using two #8-32 machine screws. The entire assembly was then slid into the airframe and secured using eight #8-32 machine screws. The tail cone was then screwed onto the motor retainer.

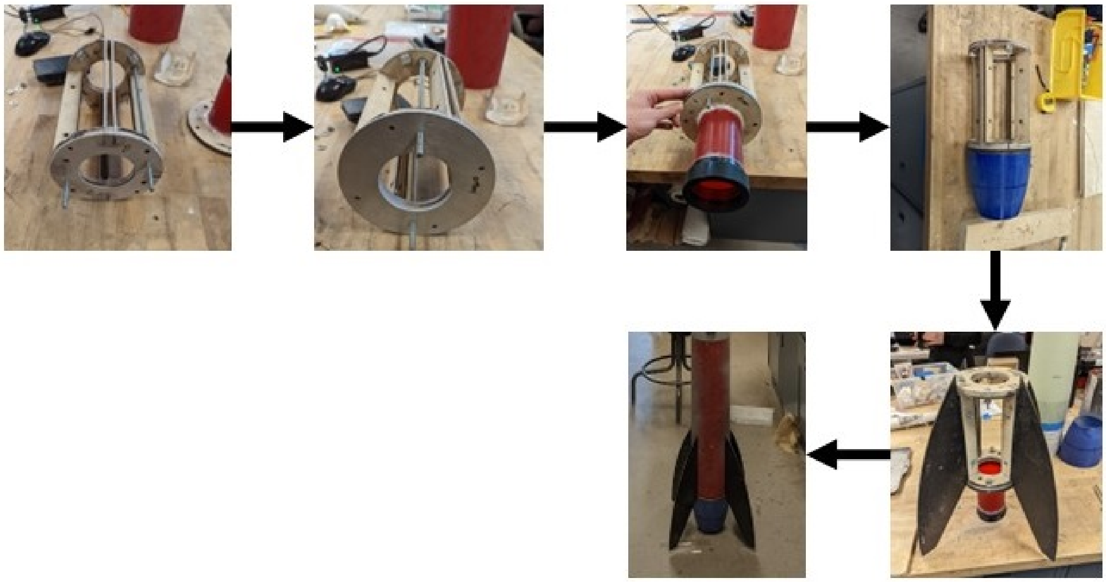

Figure 34: Diagram of the removable fin assembly manufacturing process.

3.5 Recovery Subsystem

3.5.1 Summary

The final recovery subsystem designed for this mission includes all components and equipment necessary for successful descent and recovery of the launch vehicle. This includes the avionics system, the onboard parachutes, the tracking system, and all other components related to these systems. The electronic components will be housed onboard the launch vehicle in the avionics bay section located between the main parachute and drogue parachute bays. Within the AV bay, the electronics will be attached to a 3D printed avionics sled. The electronic components will be bolted to the avionics sled utilizing plastic M3 mounting hardware for the two altimeters and the tracking system, and steel M2 screws for the three pull-pin switches. Batteries will be secured to the sled using zip ties and further reinforced with electrical tape. Prior to launch, the 2 cell LiPo battery that powers the tracking system will be fully charged. The two 9V batteries that power the altimeter will be opened new from a package.

The altimeters that will be utilized for the competition launch are two RRC3 ”Sport” altimeters made by Missle-Works. Each altimeter will be independently wired to a 9V battery, a pull-pin switch, and two black powder ejection charges in order to create two fully independent systems. The ejection charges are housed inside plastic PVC blast caps on the outside of the two bulkheads on either side of the avionics bay. An E-match is threaded from each blast cap through the bulkhead to a terminal block, which in turn is connected to a wire with a quick disconnect connector, and then to the corresponding altimeter port. The bulkheads used to enclose the avionics sled are used as anchor points for both parachutes used in the dual deployment system. A U-bolt is attached on the outside of each bulkhead and a Kevlar shock cord is attached to this U-bolt via a stainless steel quick link. The shock cord connected to the aft AV bay bulkhead will be connected to the drogue parachute via another steel quick link, and finally tethered to a U-bolt on the forward payload bay bulkhead via another quick link. The shock cord connected to the forward AV bay bulkhead will likewise be connected to the main parachute via a quick link and to a U-bolt on the nose cone bulkhead via a quick link.

In order to prevent accidental activation of the recovery system and detonation of the black powder charges, at no point during assembly of the launch vehicle will the altimeters be both armed and connected to the ejection charges. During avionics bay assembly the avionics bay will be armed in order to orient the avionics sled correctly while not connected to the black powder charges. Once oriented the altimeters will be deactivated via the pin switches by simply inserting the pins into their slots. The ejection charges will only be connected to the altimeters after waiting 10 seconds for the capacitors on the altimeter to completely discharge. Subsequent re-arming of the altimeters by removing the pin switches will only occur after the launch vehicle is vertical on the launchpad and before the motor igniter has been inserted.

The tracking system is the Eggtimer Quasar dual altimeter and GPS. The altimeter functionality will not be utilized for this launch. It will be powered on during AV bay assembly, and a connection will be made to the handheld Eggfinder LCD Receiver that will be in possession of the recovery lead for post-launch recovery. It will then be deactivated by placing a pull-pin into its designated switch, and not connected again until the launch vehicle is on the pad.

Immediately following the launch, the altimeters will arm once they register an altitude of 300 ft., approximately 1.5 seconds after launch. Once the primary altimeter detects apogee, it will send a signal to the primary drogue ejection charge in order to release a 15 in. Compact Elliptical Fruity Chutes parachute. One second after the secondary altimeter detects apogee it will similarly send a signal to the redundant secondary drogue ejection charge to ensure drogue parachute deployment. Likewise, following a controlled descent under the drogue parachute, the primary altimeter will trigger the primary main ejection charge at 600 ft. above ground level, and the secondary altimeter will trigger the secondary main ejection charge at 500 feet above ground level, thus releasing a 120 in. Iris UltraCompact Fruity Chutes parachute. Both parachutes will be covered with a nomex cloth in order to protect them from the pressure and temperature of the ejection charges.

The detonation of the drogue ejection charges will separate the launch vehicle into two sections, with the separation point being between the drogue parachute bay and the AV bay, previously held together by four 4-40 nylon shear pins. The subsequent detonation of the main ejection charges will separate the launch vehicle into three sections, with the separation point being between the main parachute bay and the nose cone, also previously held together by four 4-40 nylon shear pins. The ejection charge masses will be calculated to ensure complete separation between sections, and an ejection test will be performed prior to each launch with the entire launch vehicle assembled.

Following the touchdown of the launch vehicle, the Eggfinder LCD handheld receiver will be utilized to locate the launch vehicle on the field. Once located, the detected apogee altitude of both altimeters will be recorded, and the altimeters will subsequently be disarmed by inserting the pin switch into its slot.

The following diagram shows all recovery events.

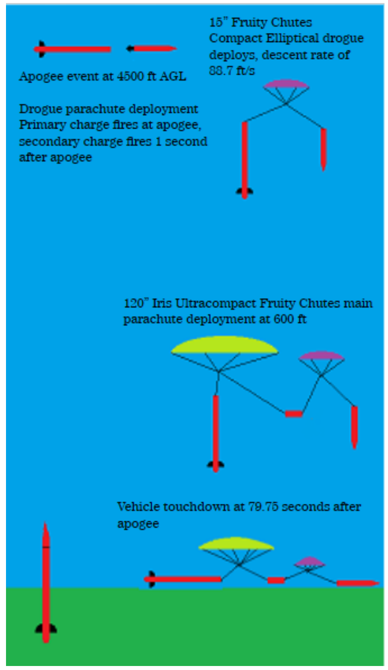

Figure 35: Recovery events drawing

3.5.2 Structural Components

3.5.2.1 AV Bulkheads

The AV bulkheads have two 1/4 in. holes, spaced 4 in. apart, for 1/4 in. threaded metal rods that tighten on both bulkheads. On the outer side of the bulkhead are two blast caps, one for primary and one for secondary black powder charges. On the inner side of the bulkhead are two terminal blocks that will connect the AV bay altimeters to the e-matches. Two holes are also evenly placed to insert a U-bolt that is tightened by nuts and washers on both sides of the bulkhead. Two small 1/8 in. hole are also drilled close to the blast caps for the E-matches to be threaded through. During launch and ejection testing, these holes will be covered with plumbers putty to ensure the safety of all onboard electronics.

3.5.2.2 Avionics Sled

The avionics sled has been fabricated out of PLA 3D printing plastic. Slots have been made in the sled for the two threaded rods that pass through the bulkhead which the sled will sit upon inside the vehicle. There are three compartments for the avionics batteries, two for the 9V batteries that power the altimeters and one for the 2 cell LiPo battery that powers the GPS tracking system. These compartments were designed so that it is possible to secure the batteries with zip ties as well as a strip of electrical tape. There are also through holes made for mounting the two altimeters and the GPS tracking system, as well as the three pull-pin switches that activate the altimeters and GPS tracking system. This mounting hardware is 1/2 in. plastic M3 mounting hardware for the altimeters and GPS tracking system, and metal M2 screws for the pull-pin switches. The pull-pin switches that control the two altimeters are precisely mounted in line with each other so that only one pull-pin would be needed to deactivate both switches. The thickness of the sled, as well as the thickness of all the different compartments and the slots for the threaded rods is 1/8 inch.

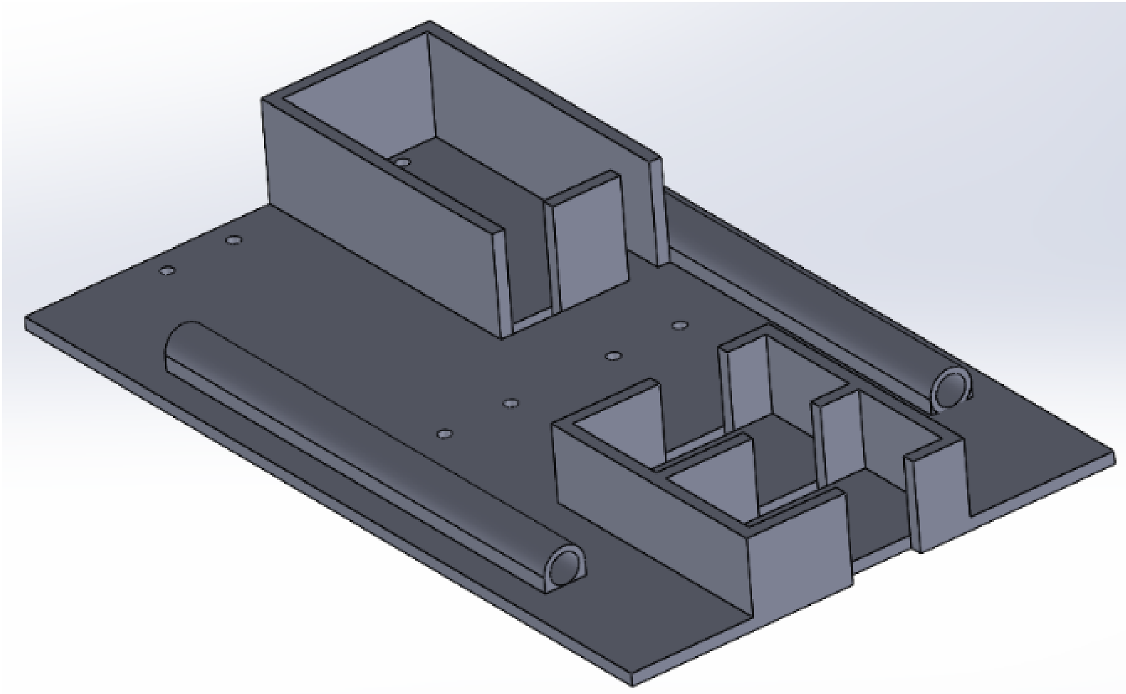

Figure 36: SolidWorks model of final AV sled

Shown above is the SolidWorks model of the avionics sled that was then made into an .stl file and 3D printed. Below are two images of the assembled avionics sled from both sides where hardware is mounted.

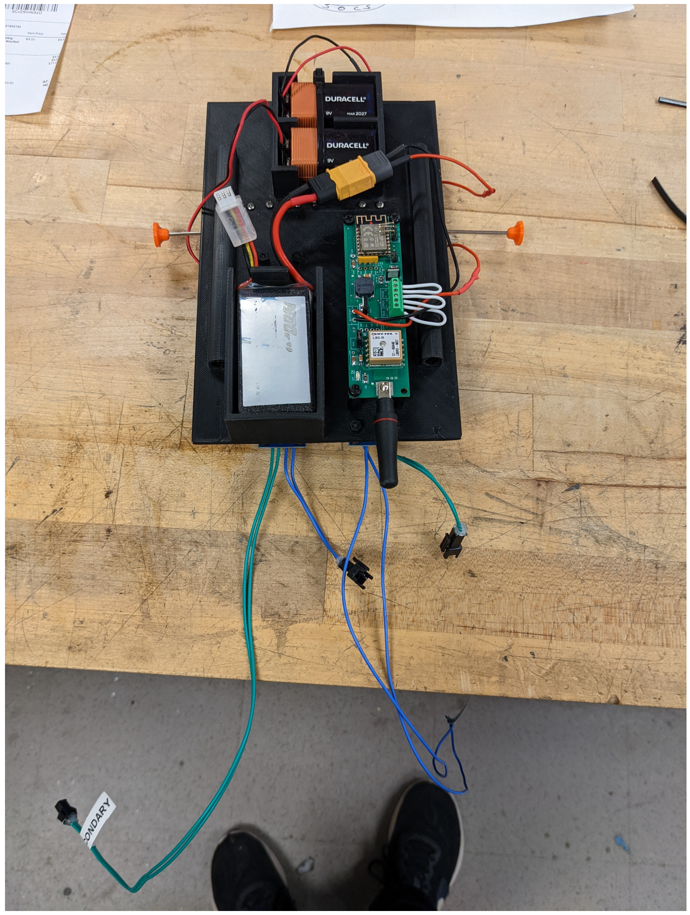

Figure 37: The final assembled AV sled from the top

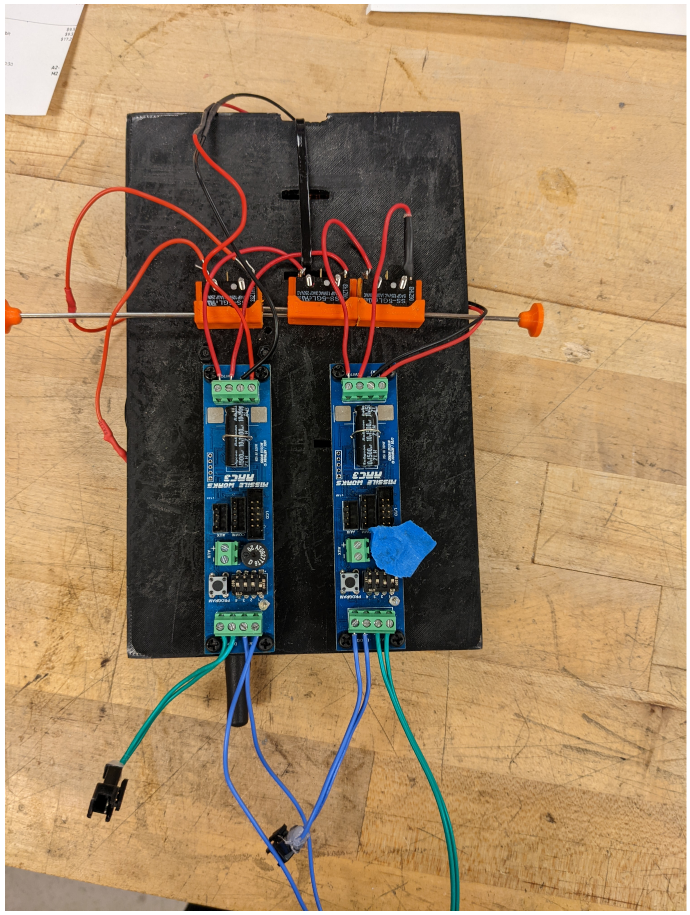

Figure 38: The final assembled AV sled from the bottom

3.5.2.3 Quick Links

5/16 in. quick links are used to connect the recovery harness to the launch vehicle. These steel quick links are rated for upwards of 1200 lbs, and will be fitted through loops at the ends of the shock cord and connect to U-bolts on the nosecone bulkhead, the avionics bay bulkheads, and the payload bay bulkhead. Two more 5/16 in. steel quick links will be used to connect the shock cord itself to both the nomex cloth protecting the parachute and the parachutes themselves.

3.5.2.4 Pressure Sampling Ports

Per MissleWorks' guidelines, four static pressure ports have been drilled into the two in. band of body tube on the AV bay. The size of these holes has been determined by MissleWorks' own formula:

$$D = 2 * \sqrt{\frac{V}{6397.71}} \tag{1}$$

Where D is the minimum diameter of a pressure port when only one is being used. Calculating this value, we see that the minimum diameter of a single port should be .42 in. We then use the following formula to calculate the size of a single port when there are multiple ports in use:

$$D = 2 * \sqrt{\frac{A}{N\pi}} \tag{2}$$

Where D is the minimum port diameter when multiple ports are in use, A is the area of a port when just a single port would be in use, and N is the total number of ports that will be in use. Using this formula, we can calculate the minimum port diameter to be .21 in. Rounding this up, means that using a 1/4 in. hole for the static pressure ports will yield full functionality of the onboard RRC3 altimeters.

The ports themselves will be drilled symmetrically perpendicular from each other, with two of the ports acting as holes for the pull-pin switches before the launch. Because the pull-pin switches activate the altimeters, there is no overlap between the ports being obstructed by the pins and the altimeters' pressure sensing.

3.5.3 Parachute Selection

This year's competition launch vehicle will have a 120 in. Iris Ultracompact Fruity Chutes parachute acting as the main parachute, and a 15 in. Compact Elliptical Fruity Chutes parachute acting as the drogue parachute. These have been chosen as the primary chutes for the launch vehicle due to satisfying all recovery criteria such as descent time, drogue descent rate, drift distance, and impact kinetic energy.

3.5.3.1 Main Parachute

The main parachute bay will be located between the nose cone and the AV bay. The aft end of the bay will be connected to the AV bay using four ¼ in. nylon rivets and the forward end will be secured to the nose cone using two 4-40 nylon shear pins. Nylon rivets were chosen over the previously used bolts because of the increased ease of use. These rivets were used on the subscale launch vehicle with much success. Preliminary shear calculations show that the rivets will be able to withstand the deployment forces with an adequate factor of safety. After completing a shear structural test on the rivets, it was determined that each rivet failed at a load of 130lbs, resulting in a calculated Factor of Safety of 1.64 . The main parachute bay will be 20 in. long and the main parachute is expected to occupy 11 in. along the bay. The remaining volume will be occupied by the shock cord, dog barf insulation, and other deployment hardware. The main parachute bay is expected to weigh 6.51 lbs including all recovery hardware.

3.5.3.2 Drogue Parachute

Since CDR, the drogue parachute has been changed from an 18 in. Fruity Chutes Compact Elliptical parachute to a 15 in. Fruity Chutes Compact Elliptical parachute. This change was made because of updated calculations when calculating drogue descent time, elaborated more on in section 3.6.7. This change is expected to minimally impact the hardware necessary in the drogue recovery system, as the only component that will be changed is the actual parachute itself, as well as some additional dog barf insulation that will be added.

The specifications of this new parachute are outlined in the table below:

Parachute	Canopy Area	Projected Area	Coefficient of Drag (Projected)	Coefficient of Drag (Area Canopy)	Weight
15 Inch Fruity Chutes	2.097 ft^2	1.1781 ft^2	1.5	.8427	1 oz
18 Inch Fruity Chutes	3.0197 ft^2	1.6965 ft^2	1.5	.8427	1.16 oz

With these updated values, as well as the new descent rate formula, the new estimated descent rate under drogue for this launch vehicle is 88.77 ft/s. This value is below the descent rate maximum set as the team derived requirement of 120 ft/s, and so this is acceptable.

3.5.4 Filler

Dog Barf recovery wadding is used to protect the parachutes from the ejection charge, as well as decrease the volume of their respective bays in order to make the ejection charges more effective. Dog Barf insulation is primarily used in rocketry as flame retardant insulation to protect onboard recovery hardware from catching fire and being damaged. This is applicable in our situation as our ejection charges are very large and will heat up the hardware inside the bay to flammable temperatures if not accounted for. It is also useful to reduce the volume of the bay so that the vehicle separates completely and not halfway, which would inhibit intended recovery events from occurring.

The added masses of Dog Barf insulation to the drogue and main parachute bays are 147 grams and 122 grams respectively. These masses were calculated by lightly filling the respective bays to ensure the parachutes and the nomex cloth were protected by a layer of insulation about two in. thick on both sides

3.5.5 Recovery Harness

Figure 39: 5/8 in. Kevlar Shock Cord

The drogue parachute recovery harness is a 23 ft. x 5/8 in. diameter Kevlar shock cord. The main parachute recovery harness is a 17 ft. x 5/8 in. diameter Kevlar shock cord. The 5/8 in. diameter cord is rated for 6000 lbf, which is much more than anything we expect the launch vehicle to endure. For more specifics on the factor of safety on the main parachute opening shock see section 3.6.12. The diagram below shows the recovery harness lengths.

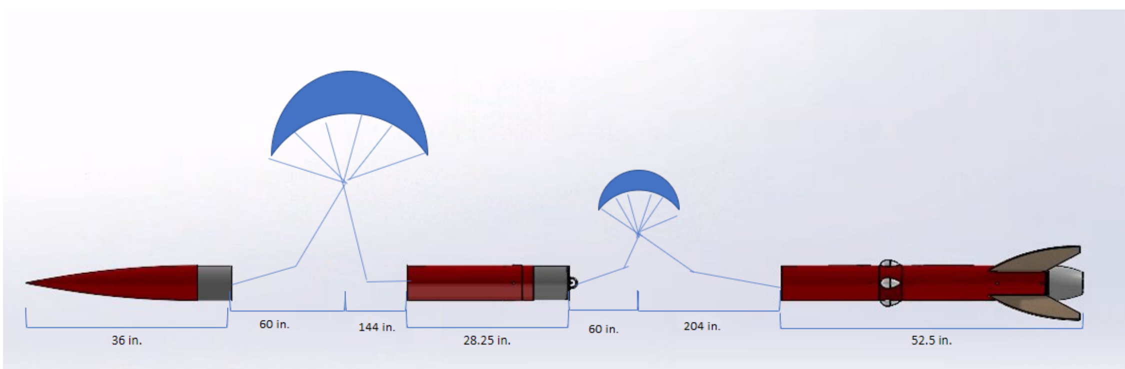

Figure 40: Shock cord lengths

3.5.5.1 Drogue Recovery Harness

The drogue recovery harness has three bowline knots tied on it. Bowline knots were chosen because it is a self-tightening knot that will not come loose under the forces that the launch vehicle will experience. Two knots are tied at each end of the shock cord, intended to attach to the U-bolts on the payload bay bulkhead and the aft AV bulkhead via 5/16 in. quick links. The third knot will be tied 5 ft. from the end of the cord that attaches to the AV bay, and will be attached to the shroud lines of the drogue parachute via another quick link. This separation allows for 5 ft. of separation between the AV bay and the parachute, as well as 8 ft. between the tip of the nose cone and the forward side of the drogue bay during descent. This placement allows for no contact between the sections during drogue descent and ensures that the fin can assembly can not be in contact with the main parachute during its ejection event.

3.5.5.2 Main Recovery Harness

The main recovery harness like the drogue recovery harness has three bowline knots tied on it. Again like the drogue harness, two knots are tied at each end for attachment to the forward AV bulkhead and nosecone bulkhead U-bolts via 5/16 in. quick links, while the third knot will be tied 5 ft. from the end of the cord that attaches to the nose cone bulkhead. This allows for 5 feet of separation between the nosecone and the parachute shroud lines, as well as 5 feet of separation between the tip of the nosecone and the forward part of the main parachute bay. Like the drogue harness, this placement allows for no interaction between sections during descent under the main parachute.

3.5.6 Avionics

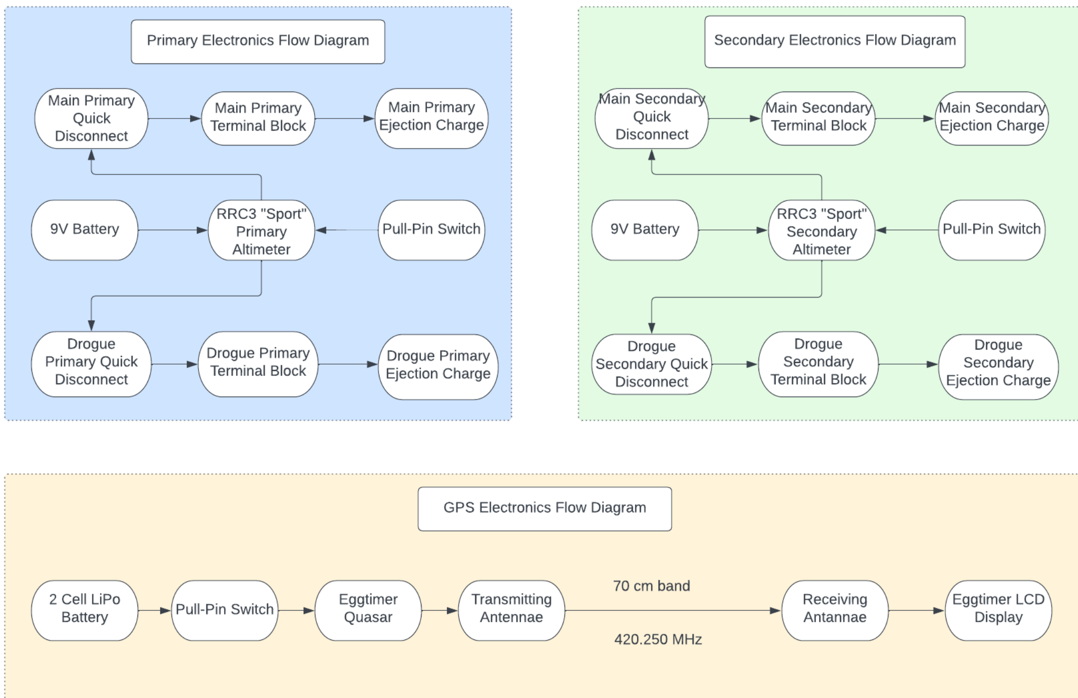

Figure 41: Recovery-Avionics Master Block Diagram

The above block diagram outlines all onboard components of the recovery subsystem, and describes precisely how each is connected. The light blue box on the top left describes the primary altimeter functionality, which will act as the primary competition altimeter as the source of the detected apogee. The power source is a 9V battery that will be fully charged before launch. The battery is wired directly into the altimeter, and a LabRat rocketry pull-pin switch is separately wired into the same altimeter through a designated switch port on the altimeter. The altimeter is then connected to the ejection charges via wires that connect from the altimeter to the terminal blocks on the avionics bay bulkhead through quick-disconnects. E-matches are attached to the terminal blocks and threaded through holes placed in the bulkhead and into blast caps on the opposite side of the bulkhead that contains the ejection charge. This altimeter is set to trigger the primary drogue ejection charge at apogee, and the primary main ejection charge at 600 feet AGL.

The green box on the right describes the exact same process for the secondary altimeter; the only variation between this system and the primary altimeter system is that the ejection charges will be sized differently, and the altimeter itself is set to different deployment conditions. The deployment conditions for drogue are set to one second after detected apogee, and for main at 500 feet AGL. This system serves as an independent redundant backup system for the primary altimeter system. Both systems are capable of recovering the launch vehicle safely.

On launch day this system is armed following a checklist that ensures that at no time the altimeter will be armed during launch vehicle assembly and connected to the ejection charges at the same time. The altimeters are first armed while disconnected from the charges so that the sled can be mounted on the threaded rods that run through the bay, and then disarmed by sliding the pull-pins into their respective switch slots. Only after the LED light on the altimeter has stopped blinking indicating a discharge of the capacitors, then the quick disconnects connecting the altimeters to the terminal blocks on the bulkheads will be reconnected, and the bulkheads will be securely fastened to the bay completing the avionics bay assembly.

The orange box shown below the green and blue boxes in the figure above describes the tracking system functionality. In this case, a 2 cell 1500 MWh LiPo battery provides power to the GPS transmitter, with another LabRat rocketry pull-pin switch wired into the positive side of the circuit. This pull-pin switch, while not necessary to functionality, is intended to preserve the battery life of the GPS transmitter as without it the system would remain active for the entire duration of assembly. The GPS transmitter will then use the 70 cm bandwidth and transmit its location with a frequency of 420.25 MHz to a handheld receiver on the ground.

3.5.6.1 Altimeters

All recovery events are controlled by two onboard RRC3 ”Sport” Missleworks altimeters. Both altimeters are mounted on the AV sled, with one being designated as the primary altimeter and one designated as the secondary altimeter beforehand. The primary altimeter is set to deploy its drogue charge at apogee and its main charge at 600 feet AGL. The primary altimeter also acts as the competition altimeter and accordingly will report the apogee for competition purposes. The secondary altimeter is set to deploy its drogue ejection charge at one second after apogee and its main charge at 500 feet AGL. This delay between the primary and secondary charges is crucial to the integrity of the parachutes and their respective bays, as over-pressurization of the cavities could lead to structural damage, as well as degradation of the parachutes and their Nomex protective cloth.

The RRC3 altimeter was chosen as the onboard altimeter because of its previously tested reliability, accuracy, precision, and ease of programming. The team already owns multiple altimeters as well as the software necessary to program the altimeters. Previous uses of these altimeters have resulted in a difference in altitude between the primary and secondary altimeters as low as one foot. This precision is why the RRC3 was chosen as the onboard altimeter. Additionally, the RRC3 is very user friendly and easy to use.

3.5.6.1.1 Redundancy Features

The recovery electronics contains two entirely separated systems, with each system containing its own separated wires, altimeters, altimeter retention systems, batteries, battery retention systems, terminal blocks, E-matches, and ejection charges. If any of these components fail during flight, the alternate system is designed to operate completely independently but in parallel with the other. In addition, there is further redundancy in the ejection charges that separate the launch vehicle, with the second charge being .5 grams larger than the primary charge. This is in case the first charge goes off as planned but is not strong enough to separate the sections, the second charge will ensure the separation without damaging the structural components of the launch vehicle.

3.5.6.2 Tracking Device

The tracker selected for this year’s competition launch is the Eggtimer Quasar dual altimeter and GPS. This system was selected because it transmits signals on the 70 cm band. The Eggtimer Quasar also has the functionality of an altimeter, however, the altimeter functionality will not be utilized for the competition launch. In order to operate without the altimeter functionality, the designated ports to connect the Quasar to the ejection charges have been connected using scrap wire in order to simulate the continuity of the charges.

The Quasar is WiFi enabled and depends on a WiFi enabled device in order to arm the system. Once the pull-pin that controls the Quasar power is removed and the Quasar is turned on, we are able to make a connection to the Quasar using a normal smartphone using a password that Eggtimer has provided. Once the connection is made, we can navigate to a browser on the smartphone and search for the IP address of the device, thus bringing up the arming screen. Once the Quasar has made a connection to the satellite, we can arm the system, and the Quasar will start transmitting real-time location data to the LCD Receiver.

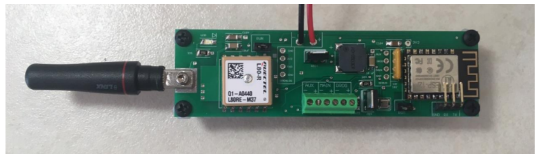

Figure 42: Eggtimer Quasar

This system draws an average of 130 mA during use, typically fluctuating between 100-200 mA. However there are occasions where it might draw up to 300 mA. According to Eggtimer Rocketry, an 800 mAh battery will be able to power it for a few hours. We have paired it with a 1500 mAh battery for redundancy, and are not expecting to have any power problems during launch day. Eggtimer Rocketry also has the range listed as approximately 40,000 ft. for a line of sight signal. The threaded rods and other electronics inside the AV bay are expected to inhibit this range slightly, but Eggtimer assures us that it will only be a small degradation, and as this launch vehicle is expected to drift within 2500 feet, it is well within range.

The Quasar will be paired with a handheld Eggfinder LCD Receiver that will be held by the recovery lead on the ground. After the descent of the vehicle, the Quasar is programmed to transmit its location after it senses five consecutive seconds of no movement of the vehicle. The location of the vehicle will then be transmitted to the receiver until the system is deactivated. The tracker will transmit at a frequency of 420.250 MHz. This frequency falls within amateur radio bands. In order to comply with all FCC regulations, the tracker will be operated by a club member who possesses a HAM radio license.

Figure 43: Eggfinder LCD Receiver in its 3D printed case

The LCD Receiver has been enabled with GPS location sensing, as well as compass directions. Because it itself does not have GPS module attached, it cannot point directly to the coordinates the Quasar transmits, but it can sense the direction the signal is coming from. Therefore, on the LCD screen it can display the relative location of the Quasar after it has been connected using 360 degree compass headings.

3.5.6.3 Batteries

Two standard 9V batteries are used as the power sources for both RRC3 altimeters. Before each launch, two brand new 9V batteries will be opened checked using a multimeter to ensure a charge above 9.0 volts. If the multimeter reads a charge lower than 9.0 volts it will be replaced with another. Once the appropriate charge is ensured, the batteries will be connected to their respective battery connectors that are secured to the altimeters, and placed into the respective compartments. The compartments are specially sized so that the batteries with the battery connector is friction fit, as well as having slots on the sides of the compartment to make it easy to use zipties to secure the batteries in place as added security. They will also be taped over with electrical tape as an additional measure.

The power source for the Eggtimer Quasar is a Zeee 7.4V 1500 mAh 60C 2 cell LiPo battery. This battery is wired directly to the pull pin switch and then onto the Quasar as there is no designated switch port on the Quasar. It is also placed in a friction fit battery compartment on the AV sled, and zip tied and taped over with electrical tape to ensure it does not fall out during flight.

3.5.6.4 Pull-Pin Switches

Pull-pin switches are the method being used to arm and disarm the altimeters. Pull-pin switches were chosen due to their success and ease of use earlier in the year during the subscale vehicle launch. During the assembly of the avionics bay, the altimeters will be activated by plugging in the batteries and removing the pull-pin switches while there are no ejection charges connected. In this state, the avionics sled is able to be safely placed inside of the avionics bay. Once the avionics sled is properly positioned, the pins will be replaced to break the connection to the altimeters. After the connection is broken, the ejection charges will subsequently be connected. After the ejection charges are connected the pins will remain in place until the launch vehicle is upright on the launch pad and all pre-launch checks are finished.

Figure 44: Pull-pin switch that will be used aboard the launch vehicle

Pull-pin switches were selected because of their ease of use and their simplicity when compared to alternative methods. For the purpose of further clarity, ”Remove Before Flight” tags are attached to the ends of the pins to improve visual clarity and assist in the proper removal before launch.

3.5.6.5 Quick Disconnects

Plastic quick disconnect connections are placed at the ends of the wires emanating from the main and drogue ports of both altimeters. The corresponding pair to the connector is placed at end of a wire that is connected to the corresponding port on a terminal block on the correct AV bulkhead. This connection makes it easy, safe, and reliable to connect the altimeters up to the ejection charges.

3.5.7 Ejection Charge Sizing

For determining the necessary mass for a successful ejection, the ideal gas law was used in conjunction with the volume of space that is intended to be pressurized. The volume of these internal compartments was calculated by using a SolidWorks model of the empty compartment and then subtracting the volume of all recovery equipment that would be inside of the respective compartment. After determining the compartmental volume, the necessary pressure for a successful recovery event was calculated by adding the forces necessary to shear all of the shear pins. Since each section is held together by four 4-40 nylon shear pins each rated for 2.5 psi of force, a pressure of 10 psi is required to shear all of the pins and separate the launch vehicle midair. A factor of safety of 2.0 is used to account for unknown skin friction force between the coupler and body tube sections of the launch vehicle, as well as the fact that not all of the black powder will be combusted during the detonation of the charges, as some amount of residue will be left inside of the compartments.

The main primary charge has been calculated to be 4 grams with the main secondary charge being 4.5 grams. The drogue primary charge has been calculated to be 2 grams with the secondary charge being 2.5 grams. The specific calculations are shown in section 3.6.11.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Altitude

The official target apogee is 4,500 ft. AGL. Rocksim, RocketPy simulations, and hand calculations indicate the vehicle will reach this altitude with a strong degree of accuracy.

3.6.2 Updated Flight Profile Simulations

Fig. (45) shows the results of a RockSim launch simulation of the as-built design using the launch conditions given in Table (5). Based on this data, the launch vehicle will reach an apogee of 4,500 ft. approximately 17.24 seconds after launch. Additionally, the velocity and acceleration during the flight are shown in Fig. (46) below. The launch vehicle reaches its maximum velocity shortly after motor burnout. The maximum acceleration experienced by the vehicle is during main parachute deployment. RockSim also predicts descent rates under drogue and main parachutes are approximately 150 and 20 ft/s respectively.

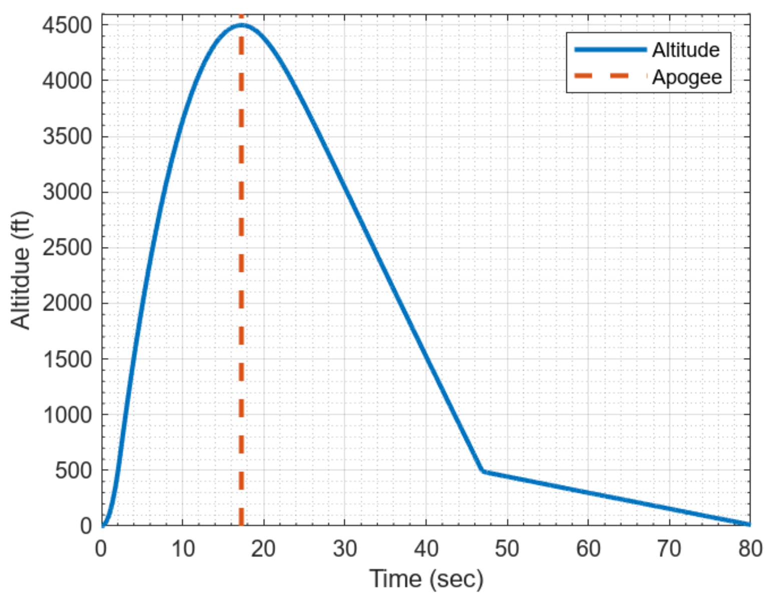

Figure 45: Predicted flight profile of the fullscale launch vehicle.

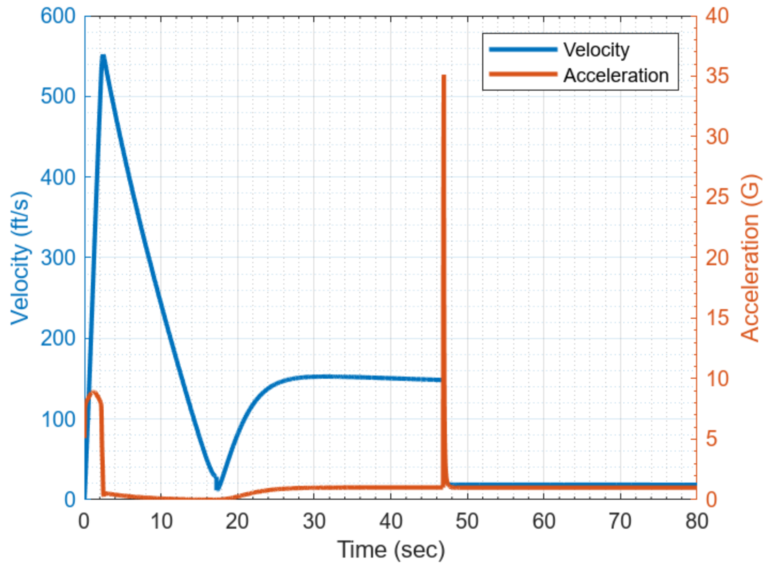

Figure 46: Predicted flight velocity and acceleration.

Table 5: Launch simulation parameters used in Rocksim.

Parameter	Assumption	Justification
Launch Rail Angle	5°	Handbook 1.12
Launch Rail Length	144 in.	Handbook 1.12
Wind Speed	10 mph.	Median Flight Condition
Launch Direction	Into Wind	Standard Procedure

Varying wind speeds will change the resulting apogee due to changes in drag and weathercocking as shown in Table (6). It is important that the launch vehicle can reach the target apogee in both low and high wind conditions. To combat this issue there are several variable ballast configurations that can be used for the purpose of stability and apogee adjustment. These ballast configurations are described in section 3.6.6 below.

Table 6: Apogee at possible wind conditions from RocketPy

Wind Speed (mph)	RocketPy Apogee (ft)
0	4367
5	4357
10	4327
15	4274
20	4206

These RocketPy simulations are utilizing the updated drag curve discussed later in the document and reduce the apogee significantly compared to the RockSim simulations.

3.6.3 Altitude Verification

A calculation of the expected apogee was performed below using Eqns. (3) through (9) to validate RockSim simulation results. Table (7) contains necessary values for the hand calculations and were taken from the geometry of the launch vehicle, L1520T motor reference [4] data, and standard environmental constants.

Table 7: Values used to solve for apogee algebraically

Quantity	Variable	Value	Units
Mass	M	17.5	kg
Frontal Area	A	0.01936	m^2
Gravitational Acceleration	g	9.81	m/s^2
Total Impulse	I	3715	N·m
Average Thrust	T	1567	N
Burn Time	t	2.4	s
Air Density	ρ	1.225	kg/m^3
Drag Coefficient	C_D	0.4627	N/A

The aerodynamic drag is first calculated using equation (3) and is then used to calculate q, and x, which are necessary for determining the maximum velocity.

$$k = \frac{1}{2}\rho C_D A = 0.0055\frac{kg}{m} \tag{3}$$

$$q = \sqrt{\frac{T - Mg}{k}} = 504.29\frac{m^2}{s^2} \tag{4}$$

$$x = \frac{2kq}{M} = 0.3162\frac{m}{s^2} \tag{5}$$

The maximum velocity is then calculated using the results of Eqns. (4) and (5).

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} = 182.67\frac{m}{s} \tag{6}$$

Maximum velocity will be at the point where the motor stops producing thrust. This height is calculated using equation (7).

$$h_{boost} = -\frac{M}{2k}\ln\frac{T - Mg - kv^2}{T - Mg} = 224m \tag{7}$$

Gravity and drag then slow the launch vehicle down during the coast phase of the flight and the height gained is calculated using equation (8).

$$h_{coast} = \frac{M}{2k}\ln\frac{Mg + kv^2}{Mg} = 1158m \tag{8}$$

Finally, by summing the calculated altitudes, the apogee was calculated:

$$h_{total} = h_{boost} + h_{coast} = 1382m \rightarrow 4534ft \tag{9}$$

This apogee is then compared to the altitude given by RockSim. These two calculation methods are strikingly similar despite the variety of factors influencing RockSim's analysis. The less than 1% difference in apogee from the two methods results from RockSim's wind shear and turbulence simulations. However, real-world factors will produce far more variability in the flight than the difference between the simulations calculated.

Table 8: Apogee comparison between RockSim and hand calculations.

Method	Result	Comparison
RockSim	4500	$\%_{diff} = 0.7527\%$
Algebraic	4534	

3.6.4 Stability Margin Simulation

RockSim is utilized for the CP calculation that determines the stability margin of the vehicle. The CP is a dynamic calculation that entirely depends on the surface area facing the direction of motion through the air. When the launch vehicle leaves the rail at 0.27 seconds into the flight, the vehicle weather cocks due to the rail no longer providing a reaction point against the wind. This pitching creates an oscillatory motion which causes slight changes in the CP during flight. Additionally, as the motor burns, the CG of the vehicle is shifted farther forward causing the stability margin to increase. A plot of the CP, CG, and stability is shown in Fig. (47) below.

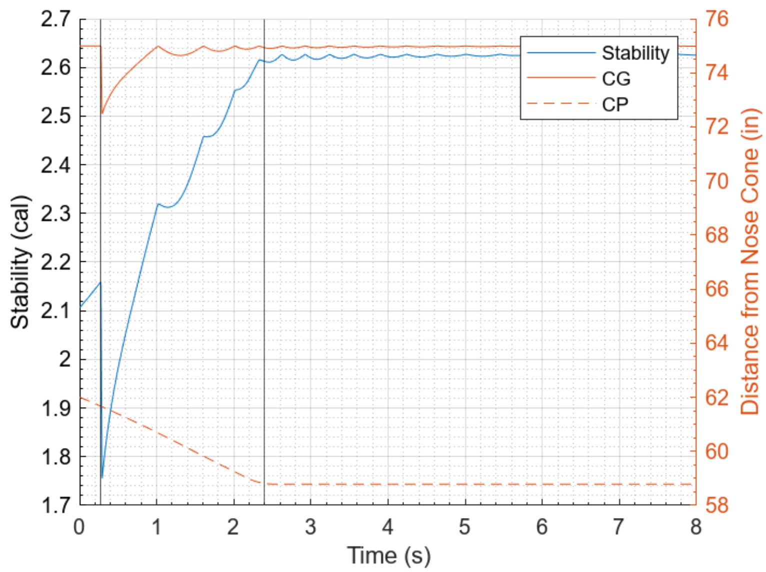

Figure 47: Simulated stability margin of the full scale vehicle.

With the current design, the launch vehicle has the following stability during the flight milestones as shown in Table (9) below. The vertical black lines in Fig. (47) indicate rail exit and motor burnout. The motion due to weather cocking is also visible in the change in the CP with it continuing to dampen during the flight. This motion appears severe in simulations but the flight of the sub-scale vehicle during a light wind indicates less weather cocking than simulations predict. These calculations show that the vehicle will have a stability margin greater than 2.0 upon rail exit which satisfies requirement NASA 2.14.

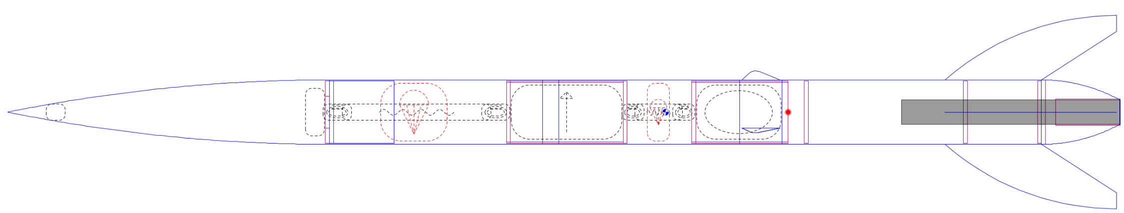

Figure 48: Full Vehicle Diagram with CG and CP labeled.

Fig 48 shows the internal layout of the vehicle with the blue mark indicating the CG at 62 in. from the tip of the nose cone and the CP, marked by the red circle, at 75 in. from the tip of the nose cone.

Table 9: Simulated stability at ascent milestones.

Milestone	Stability	Velocity (ft/s)
Ignition	2.10	0
Rail Exit	2.16	59.8
Motor Burnout	2.62	552

3.6.5 Stability Margin Calculation

RockSim is known to generate accurate CG information, but CP calculation is a more complex process with a variety of methods. To verify the stability margin, the CP of the launch vehicle is calculated using a series of equations. By splitting the launch vehicle into two aerodynamic shapes, the CP can be calculated using Barrowman's method [8].

Barrowman's equations utilize standard trapezoidal fin geometries which are not compatible with the ogive geometry chosen for the launch vehicle. To circumvent the incompatibility, an approximation of the ogive fin is constructed as shown below in Fig. (49). This approximation was chosen because it represents a fin with the same surface area and sweep. Fin area was kept constant between the actual and approximation because CP is largely based on the area of the fins. Additionally, Table (10) contains the variable names and values used for the stability calculations detailed below.

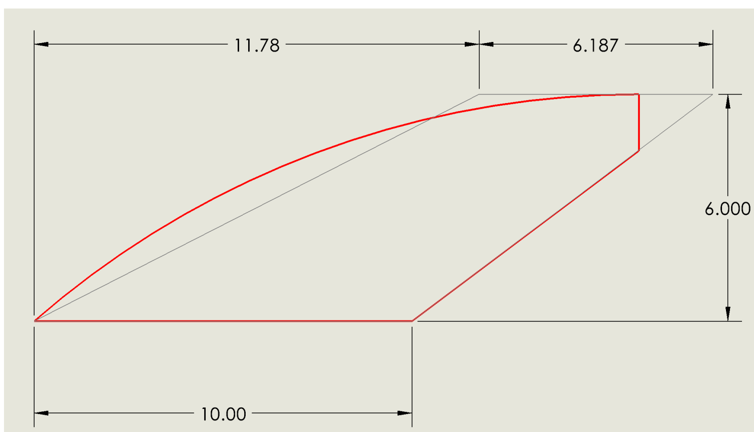

Figure 49: Annotated modification to the ogive fin for Barrowman's equations.

Table 10: Measured values for stability calculations.

Variable	Description	Value	Units
C_N	Nose Cone Coefficient	2	N/A
L_N	Length of Nose Cone	30	In.
R	Radius	3.085	In.
S	Fin Semi-Span Length	6	In.
C_R	Fin Root Chord	10	In.
C_T	Fin Tip Chord	6.19	In.
N	Number of Fins	4	N/A
X_B	Nose Cone Tip to Root Chord LE	88	In.
X_R	Fin Sweep from Root Chord LE to Tip LE	11.78	In.
CG	Center of Gravity from RockSim	61.9	In.

The ogive nose cone used on this vehicle has an understood pressure coefficient of 2 with an arm that is a function of the nose cone length as shown in Eqn. (10).

$$X_n = 0.466 * L_N \tag{10}$$

Finding the fin coefficient and arm length utilizes the basic fin geometry and is calculated using Eqns. 11 and 12.

$$\theta = 90° - tan^{-1}(\frac{S}{X_R}) = 63.01° \tag{11}$$

$$L_F = \sqrt{S^2 + (\frac{1}{2}C_T - \frac{1}{2}C_R + \frac{S}{tan(\theta)})^2} = 6.109in. \tag{12}$$

Eqn. 13 and 14 are calculating the center of the pressure coefficient of the fin and its moment arm.

$$C_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N(\frac{S}{2R})^2}{1 + \sqrt{1 + (\frac{2L_F}{C_R+C_T})^2}}\right] = 8.997 \tag{13}$$

$$X_F = X_B + \frac{X_R}{3}\frac{C_R + 2C_T}{C_R + C_T} + \frac{1}{6}\left[(C_R + C_T - \frac{C_R C_T}{C_R + C_T})\right] = 91.89in. \tag{14}$$

A weighted average of the aerodynamic moment arm from the nose cone and fin geometries is calculated in Eqn. 15.

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} = 77.71in. \tag{15}$$

This simplified CP calculation is then used to calculate the stability of the launch vehicle using Eqn. 16.

$$\frac{X_{CP} - X_{CG}}{2R} = 2.67cal \tag{16}$$

A calculated CP of 77.71 in. is 3.7% different than the 74.9 in. CP RockSim is simulating. This creates a significantly different stability margin shown in Table (11).

Table 11: Calculated stability values.

Variable	Description	Value	Unit
θ	Sweep Angle	63.01	Degrees
L_F	Middle Chord Length Line	6.109	In.
C_F	Fin Coefficient	8.997	N/A
X_F	Fin Arm Length	91.89	In.
X_{CP}	CP Location	77.71	In.

Table 12: Stability margin comparison between RockSim and hand calculations.

Method	Result	Comparison
RockSim	2.15 calibers	$\%_{diff} = 21.58\%$
Barrowman's Method	2.67 calibers	

the hand calculations were understandably different than RockSim calculations. The modification of the fin geometry to fit Barrowman's equations is a likely source of error. Rocksim, unlike Barrowman's method, also factors the camera housing geometry into its center of pressure calculations and treats it as a wide fin. A stability margin of 2.67 calibers is within NASA requirements but may result in unfavorable weather cocking. The actual stability of the launch vehicle is confirmed to be reasonable and is likely much closer to the RockSim calculations than Barrowman's method.

3.6.6 Ballast Placement for Stability and Altitude Tuning

There are two locations for placement of ballast within the launch vehicle: On the threaded rod within the nose cone, and within the removable fin assembly. Both of these locations allow for the ballast to be easily accessible in the event that the quantity of ballast must be changed and are shown in Fig. (50) below. In either location, the ballast will consist of washers sandwiched between nuts on the threaded rods. This form of ballast ensures that it will be securely held in place and does not rely on an epoxy connection. Any ballast at each location will be fully enclosed within a closed section of the launch vehicle so there is no possibility of it becoming loose during flight and falling out of the vehicle. Furthermore, the quantity of ballast can be easily changed by adjusting the number of washers on the threaded rod.

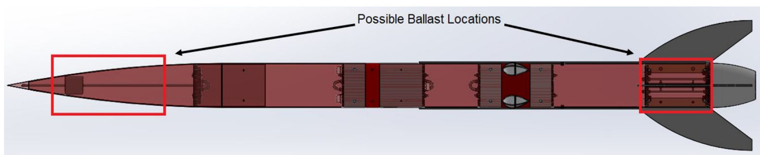

Figure 50: Ballast locations.

In order to move the CG and maintain a 2.0 stability margin, the as-built launch vehicle design uses 3.7 lb of ballast secured to the nose cone threaded rod. A diagram of the location of this ballast is shown in Fig. (51) below. For the purpose of maintaining the desired stability margin, the nose cone ballast can be increased or decreased as desired using the removable system. If the CG needs to be moved forward, weight can be added to this location. Similarly, if the CG needs to move aft to meet the desired stability margin, nose cone ballast can be easily removed.

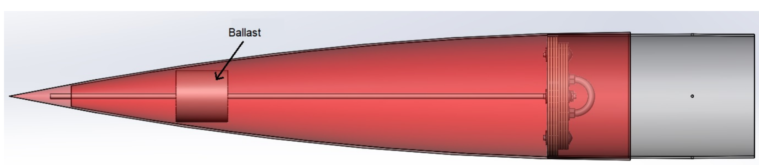

Figure 51: Location of the nose cone ballast.

The as-constructed launch vehicle is predicted to overshoot the target apogee, the altitude of the launch vehicle can be tuned by adjusting the vehicle's overall weight. To increase the weight of the vehicle without impacting the stability, ballast can be added to either side of the CG. Forward of the CG, ballast can be added to the nose cone as previously described. Aft of the CG, ballast can be secured to the removable fin assembly in a similar manner. Based on the changes in payload weight, it is likely that some amount of ballast will need to be included for the purpose of altitude adjustment. However, the total amount of ballast on the launch vehicle shall not exceed 10% of the launch configuration mass in order to satisfy NASA requirement 2.23.7.

3.6.7 Descent Velocity

The descent velocity calculations have been updated since CDR. Previously we calculated descent velocity using the following equation:

$$V = \sqrt{\frac{W}{\frac{1}{2}C_d \rho A}} \tag{17}$$

Where W was the burnout weight of the launch vehicle, C_d was the coefficient of drag of the parachute being used, ρ was the density of the surrounding air, and A was the area of the parachute. We have now updated this formula to account for the drag force caused by the bluff body of the launch vehicle as it descends. The corresponding equation now looks like this:

$$V = \sqrt{\frac{W}{\frac{1}{2}C_{D_1}\rho A_1 + \frac{1}{2}C_{D_2}\rho A_2}} \tag{18}$$

Where C_{D_1} is the coefficient of drag of the parachute, C_{D_2} is the coefficient of drag of the bluff body of the launch vehicle, ρ is the surrounding air density, A_1 is the area of the parachute, and A_2 is the projected area of the bluff body of the launch vehicle. This projected area of the launch vehicle includes the projected area of the main body and the fins, as well as the shock cord and the cupolas extending from the body. This area is estimated to be 6.5 ft2. The bluff body drag coefficient is estimated by taking the burnout coefficient of drag calculated by RockSim, and multiplying 1.5 for drogue descent and 2 for main descent to account for the increased drag associated with the launch vehicle in separation.

Using these updated descent velocities, the decision was made to switch the drogue parachute from an 18 in. Fruity Chutes Classic Elliptical parachute to a 15 in. Fruity Chutes Classic Elliptical parachute. The updated descent velocities are shown in the table below.

3.6.8 Kinetic Energy at Landing

The impact kinetic energy of the launch vehicle is determined by the mass of the section that is hitting the ground, and the velocity that it is traveling at, related by the following formula.

$$E = \frac{1}{2}mV^2 \tag{19}$$

Using this formula, the maximum allowable descent velocities of each section of the launch vehicle under main descent was calculated and are shown in Table (13).

Table 13: Section masses and their desired descent velocities.

Section	Mass of Section	Descent Velocity Necessary to be Awarded Points	Descent Velocity Necessary to be Awarded Bonus Points
Nose Cone	.280 slugs	21.54 ft/s	19.82 ft/s
Main Parachute Bay and Avionics Bay	.210 slugs	24.88 ft/s	22.88 ft/s
Drogue Parachute Bay, Payload Bay, and Fin Can	.445 slugs	17.09 ft/s	15.722 ft/s

Using this data, as well as the descent time and wind drift distance calculations shown in sections 3.6.9 and 3.6.10, the 120 in. Fruity Chutes Iris Ultracompact parachute was chosen to be the main parachute and is further described in section 3.5.3.1. Using equation 18, the descent velocities were calculated for each section and are displayed alongside the impact energies of each section in the table below. It is important to note that the descent velocity of the upper sections during descent will decrease dramatically once a lower section makes ground impact due to the fact that there will be a much lower force pulling down on the parachute. This fact was taken into account while calculating the descent velocities for the main parachute bay and AV bay sections, as well as the nose cone section.

Table 14: Section masses and their corresponding velocities and impact energies.

Section	Mass of Section	Velocity Under Main Parachute	Impact Energy
Nose Cone	.280 slugs	6.85 ft/s	6.57 ft-lbf
Main Parachute Bay And Avionics Bay	.210 slugs	11.42 ft/s	13.70 ft-lbf
Drogue Parachute Bay, Payload Bay, and Fin Can	.445 slugs	14.40 ft/s	46.16 ft-lbf

Thus it is shown that the maximum impact kinetic energy that this launch vehicle will experience is 46.16 ft-lbf of force, almost 20 ft-lbf below the limit necessary to earn bonus points, as set by NASA 3.3.

3.6.8.1 Alternative Kinetic Energy Calculation Method

RocketPy simulations were used as an alternative method to calculate the descent velocity of the launch vehicle under main parachute. The descent velocity predicted by RocketyPy is 13.93 ft/s upon ground impact. This value can then be used in Eqn. 19 along with the maximum weight of an independent section to find the maximum kinetic energy. This method results in a maximum impact kinetic energy of 43.17 ft-lbf which is below the maximum limit set by NASA to earn bonus points. The kinetic energy calculated using RocketPy is different from hand calculations by only 2.99 ft-lbf which validates the accuracy of the hand calculations.

3.6.9 Descent Time

In order for the launch vehicle to not have a large drift distance, the descent time must be sufficiently low. The expected descent times are calculated using the following formula under the assumption that both parachutes deploy exactly when there is a separation event.

$$t = \frac{h_a - h_m}{v_d} + \frac{h_m}{v_m} \tag{20}$$

Where t is the descent time, h_a and h_m are the apogee and main deployment altitudes respectively, and v_d and v_m are the velocity of the launch vehicle descent under drogue and main parachute respectively. The total expected descent time of the launch vehicle was calculated to be 79.78 seconds, within the 80 seconds necessary to earn the bonus points described in NASA requirement 3.11.

3.6.10 Maximum Wind Drift Distance

The maximum wind drift distance calculations assume that the launch vehicle horizontal velocity matches the wind velocity. Because during descent the launch vehicle horizontal velocity will not, so assuming this means that we can overestimate the drift distance, which in turn makes it much less likely that the launch vehicle will exceed the maximum drift distance. In addition, it is assumed that the launch vehicle travels vertically from liftoff to apogee, which is also not the case. However it is not possible to estimate the horizontal distance traveled between launch and apogee without simulations, as described in section 3.6.10.1.

Further assumptions made are that the parachutes are deployed exactly at apogee and 600 ft. above ground level. These are much more concrete assumptions as the time of deployment for both parachutes is relatively short at under .5 seconds. This low deployment time means that a smaller error occurs when making this calculation by hand.

Using the predicted apogee of 4500 ft. and the expected descent time of 79.78 seconds, the maximum drift distances are shown in the table below.

Table 15: Maximum drift distances.

Wind Velocity	Drift Distance
0 mph	0 feet
5 mph	585 feet
10 mph	1170 feet
15 mph	1755 feet
20 mph	2340 feet

3.6.10.1 Alternative Drift Distance and Descent time Calculation Method

Using RocketPy, the horizontal drift due to wind was simulated with maximum wind launch conditions of 20 mph. Using the RocketPy simulation is much more precise as it does not assume that the launch vehicles horizontal velocity is equal to the wind velocity, it rather makes a more accurate guess based on the drag of the parachute and launch vehicle combined. It also takes into account the vehicles drift on its ascent and descent rather than just the descent. This same simulation can be used to simulate the descent time of the vehicle. A graph showing the total horizontal distance from the launchpad over time is shown below.

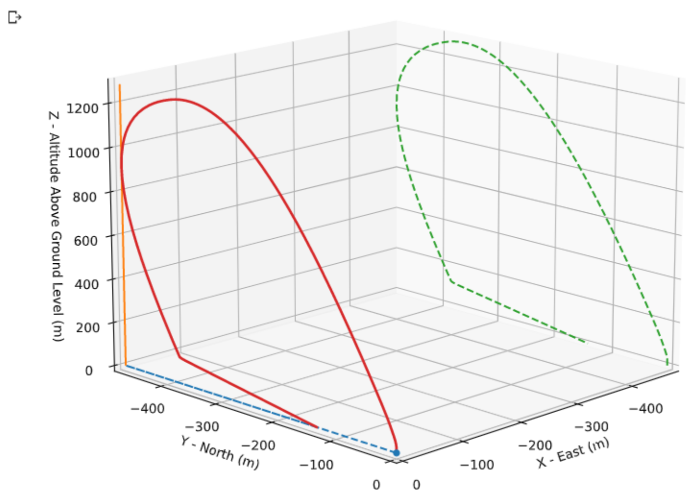

Figure 52: Drift distance due to wind.

Based on this figure, the total descent time of the launch vehicle is 75.94 seconds and the total drift distance is only about 436 ft.

3.6.11 Black Powder Ejection Charge Mass

To calculate the mass necessary for each successful recovery event, the ideal gas law is used. The volume of the internal compartments is calculated by finding the volume of the empty internal compartment via a SolidWorks model and subtracting the volume of all recovery hardware inside each compartment. Next the pressure necessary for a successful recovery event is calculated by adding the forces necessary to shear all shear pins. Since each section will be held together by 4 4-40 nylon shear pins each rated for 2.5 psi of force, a pressure of 10 psi is required to shear all pins and separate the launch vehicle in midair. This pressure is multiplied by a factor of safety of 2.0 in order to account for the unknown skin friction force in between the coupler and body tube sections of the launch vehicle, as well as to account for the fact that not all the black powder will be combusted during the detonation of the charges, as there will be some small amount of residue left inside the compartments. The total masses for the four charges are shown in the table below.

Table 16: Black powder charge sizes

Ejection Charge	Black Powder Masses
Main Primary	4 grams
Main Secondary	4.5 grams
Drogue Primary	2 grams
Drogue Secondary	2.5 grams

These values have been experimentally verified by conducting ejection tests on the ground with a fully assembled launch vehicle. See section 7.1.1.11 for more information.

3.6.12 Parachute Opening Shock Calculations

It is important to know the opening shock force for the main parachute deployment as it is likely the largest force that the launch vehicle will experience during flight. This force is calculated by using W. Ludtke's study that elaborated on how to calculate opening shock forces for cloth parachutes [11]. Using the following two equations we can first solve for the time it takes for the parachute to deploy, and then subsequently use the masses of each individual section to calculate the force that they will experience.

$$t = \frac{8r}{v_d} \tag{21}$$

$$F = \frac{m\Delta v}{t} \tag{22}$$

In these equations, v_d represents the drogue descent velocity, Δv represents the change in velocity between the drogue descent velocity and the main descent velocity, m is the mass of the section, r is the radius of the main parachute, t is the time the parachute takes to unfurl and F is the opening shock force.

The opening shock force will be most important as a factor to see if the U-bolts on the bulkheads that are connected to the parachutes are strong enough to survive the stress, as well as any onboard electronics that might be damaged by the force. The force of each section is shown in the table below.

Table 17: Opening shock force on each section

Launch Vehicle Body Section	Body Section Mass	Main Parachute Opening Shock
Full Launch Vehicle	1.304 slugs	215.219 ft-lbs
Nose Cone	.280 slugs	46.213 ft-lbs
Main Parachute Bay and Avionics Vay	.210 slugs	34.660 ft-lbs
Drogue Parachute Bay, Payload Bay and, Fin Can	.445 slugs	73.445 ft-lbs

3.7 RocketPy Simulation and Optimizations

Figure 53: Official RocketPy logo

RocketPy is an open-source Python library for advanced rocket trajectory simulation in active development by a multi-national team to improve launch simulation capabilities. This tool utilizes nonlinear six-degree-of-freedom simulations using real-time weather forecasts or raw atmospheric data collected by NOAA. A major benefit of RocketPy is its modularity within the code which allows for the fine-tuning optimization of individual aspects of the launch vehicle such as rail button placement and rail exit speed. Randomization of certain flight uncertainties, such as the time the parachute takes to unfurl or nozzle throat radius, will create Monte Carlo Dispersion analysis to show the normal distribution of flight performance characteristics. RocketPy precision and vast feature set create programming difficulty with no GUI or ability to visualize the vehicle being simulated. The following sections will detail the progress in understanding this software and utilizing it to benefit the design.

3.7.1 RocketPy Setup

After installing the required Python libraries, the characteristics of the flight are defined before beginning a simulation. The atmospheric environment of a future flight is defined by the longitude and latitude of the launch site and utilized in a forecast function that gathers atmospheric data from an online database and returns all necessary atmospheric conditions such as wind vectors at various altitudes. Fig. 54 shows a visualization of the forecast for the verification flight with RocketPy. A previous launch's weather data, such as the full-scale verification launch, can be downloaded from the University of Wyoming atmospheric science database. Historical data dating back several years of the day of a launch can be aggregated and analyzed to predict what the average wind speeds for the launch day will be. The historical data coupled with the weather forecast provide maximum predictive capabilities of the launch conditions prior to arriving on the launch day.

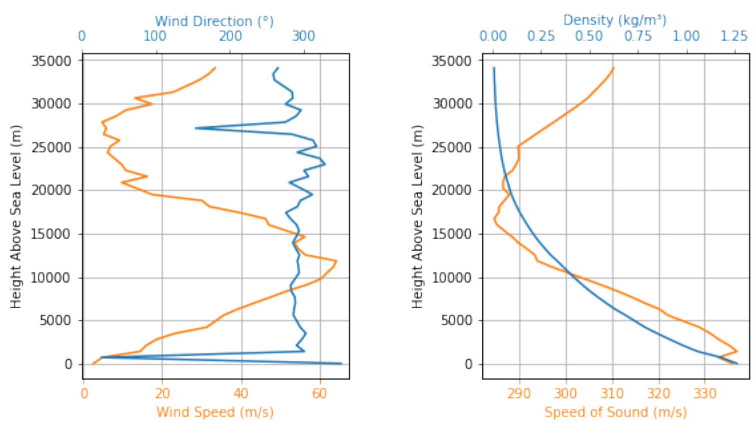

Figure 54: Atmospheric data from Python forecast function.

The solid rocket motor is next defined with all the physical characteristics of the fuel grain and nozzle. The thrust curve of the motor is also required and sourced from validated online data. RocketPy's SolidMotor class uses the dimensions of the motor and contains a set of functions that calculate the performance of the motor such as exhaust velocity and total impulse. The L1520T motor was created in RocketPy from the manufacturer's data sheet with the following parameters in Table (18) that are required to model the motor. The performance of the

Parameter Name	Value	Unit
motor	L1520T	N/A
radius	0.07835	meters
mass	17.23	kg
inertiaI	0.05831	kg m^2
inertiaZ	10.18582488	kg m^2
distanceRocketNozzle	-1.375	meters
distanceRocketPropellant	-0.89	meters
setRailButtons	[-.275, -1.185]	meters

motor varies from online test data as RocketPy does its own simulation and calculations of the burn. RocketPy calculates the L1520T to have an average thrust of 1450 N with an impulse of 3768 Ns. while online testing claims the L1520T has an average thrust of 1568 N and an impulse of 3716 Ns. Impulse is the more important metric of the two and both are within 5% error of each other allowing RocketPy's motor performance calculations to be trusted.

Table 18: L1520T physical properties for RocketPy

Parameter Name	Value	Unit
burnOut	2.4	sec
grainNumber	3	#
grainSeparations	0.0016	meters
grainDensity	1625	kg/m3
grainOuterRadius	0.031661	meters
grainInitalInnerRadius	0.011112	meters
grainInitialHeight	0.1318	meters
nozzleRadius	0.023813	meters
throatRadius	0.0086995	meters
interplationMethod	linear	N/A

After the motor is created, the vehicle is defined with all dimensions originating from the CG. The nose cone, fins, and tail cone are all defined with their dimensions and distance to the CG. The moment of inertia in the axial and perpendicular direction is also required in the definition of the vehicle. Initially, this was calculated assuming the vehicle was a solid cylinder while a more accurate test was created. The moment of inertia test detailed in Section 7.1.1.10 validated the assumption and generated a moment of inertia for the vehicle. RocketPy also utilizes and power on and power off drag curve to define the launch vehicle. RockSim simulations are utilized to produce realistic drag curves that RocketPy can utilize. The placement of the rail buttons was optimized through hundreds of RocketPy simulations detailed below in Section 3.7.3. The parachutes are next defined with a trigger function that governs when each chute will deploy with built-in sampling rates to match the altimeter used. Manufacturer specifications for the drag coefficients of the parachutes are also utilized to define the parachutes. With the large number of inputs required to define the vehicle and the approximations needed, there are many potential error sources.

3.7.2 RocketPy Vehicle Flight Simulation

RocketPy flight simulations are easily executed with a function and run quickly compared to other flight simulation software. The results of the simulations are significantly more detailed with RocketPy utilizing a Matlab plugin to visually display the results as shown. A visual of RocketPy's simulation to predict the flight of the full scale launch vehicle verification flight is shown in fig. 55. Aditionally, RocketPy provides several other calculation results, such as Euler Angles, angular kinematics, and aerodynamic forces, which are not provided by Rocksim and other software previously used.

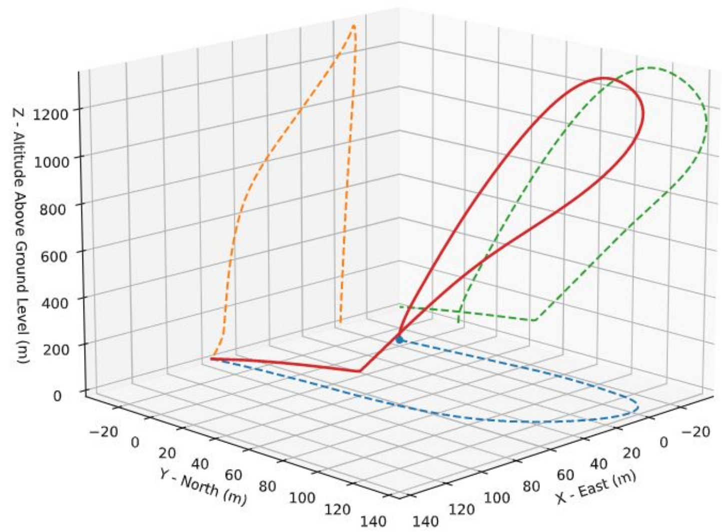

Figure 55: 3D trajectory plot of simulated launch vehicle flight.

RocketPy also has easily exportable csv and kml files for the flight data with the kml files visible on Google Earth to interactively display the flight on the actual launch field where the flight takes place.

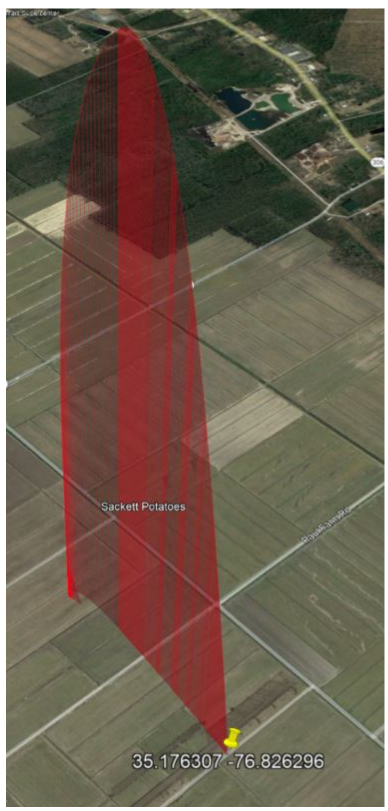

Figure 56: Google Earth plot of launch vehicle flight.

Additionally, RocketPy also calculates the force on the rail buttons during the on-rail portion of the flight. Fig.

57 shows the results for the current design. Once the vehicle leaves the rail, RocketPy is able to calculate the exact amount of weather cocking the vehicle experiences with the period and magnitude of the oscillations.

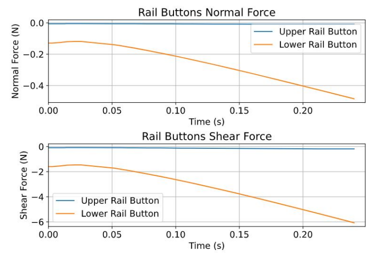

Figure 57: Rail button forces from RocketPy simulation.

3.7.3 RocketPy Rail Button Optimization

As a test of RocketPy's optimization simulations for design purposes, the rail button placement was simulated in a number of possible configurations to understand the rail button placement relationship with weather cocking or any oscillatory movement of the launch vehicle shortly after leaving the launch rail. Any weather cocking or large oscillation will produce large cosine losses in the thrust that will result in inconsistencies in performance. Previously, the rail button placement was designed only to secure the vehicle to the rail without any consideration of its performance impact. RocketPy calculates the forces of the aft rail on the vehicle when the forward rail button leaves the rail which is combined with the pitching forces required to align with the sideslip airstream due to wind. With the proper pitching moment of inertia and aerodynamic profile of the vehicle, RocketPy is able to plot a feedback response of the vehicle's angle of attack. By analyzing the feedback for desirable qualities such as a high dampening coefficient and small displacement area the exact placement of the rail buttons can be optimized.

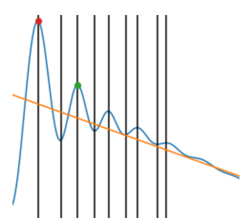

Figure 58: Weather cocking feedback data processed to calculate the dampening coefficient.

The simulation outputs raw signal data of the angle of attack response that is converted to a dampening coefficient through the logarithmic decrement calculations in Eqn. 23 and Eqn. 24 where $x(t)$ is the amplitude of the first peak and $x(t+nT)$ is the amplitude n peaks away from the first one.

$$\delta = \frac{1}{n} \ln \frac{x(t)}{x(t+nT)} \tag{23}$$

$$\zeta = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \tag{24}$$

This value is the only saved value from a simulation allowing a large number of simulations to be run in a reasonable timeframe. RocketPy also allows for the time step and max simulation time to be adjusted to maximize efficiency for a large number of optimization flight simulations needed.

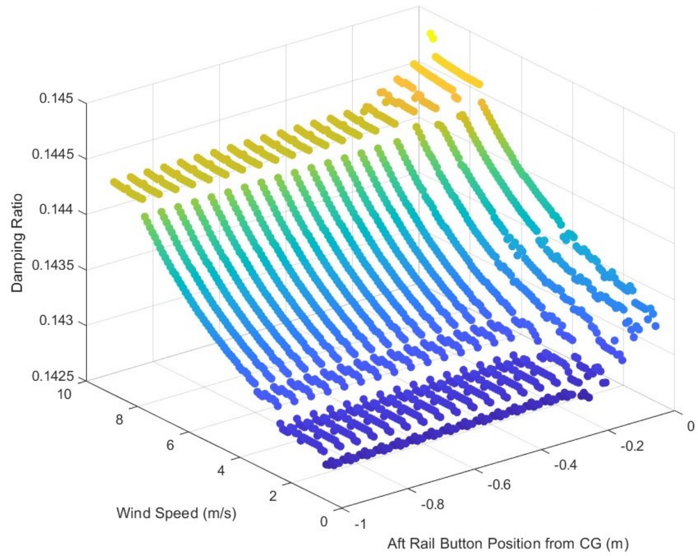

Figure 59: Brute force damping ratio vs variable wind speed and aft rail button placement optimization.

During the initial understanding of the rail button placement dynamics, both the forward and aft rail button placements were altered. The aft rail button did not provide any impact on the dampening coefficient illustrated in fig. 59. For this batch of simulations, the forward rail button was held constant at the CG and the aft was iterated through every possible position and wind condition. The higher temperature of color indicates a higher dampening coefficient with each rail button placement location indicating a consistent color for a given wind speed. The only impact the aft rail button had was when it is located close to the forward one.

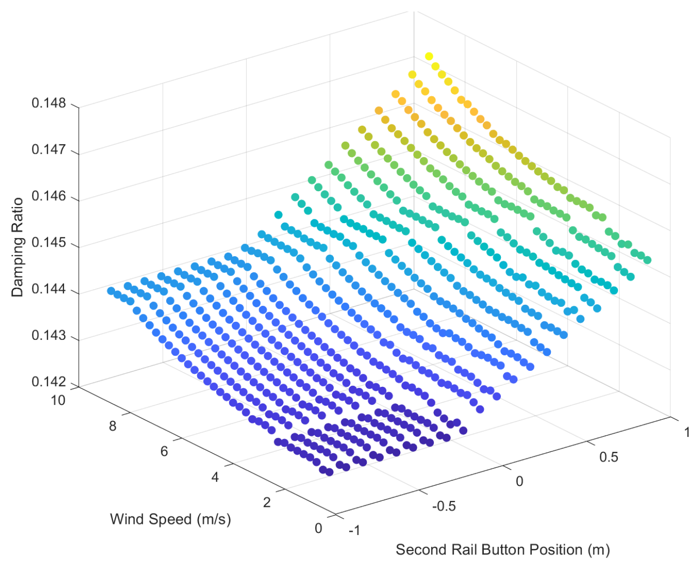

Figure 60: Brute force damping ratio vs variable wind speed and forward rail button placement optimization.

Fig. 60 indicates a much more substantial performance impact of the forward rail button over the aft with a strong indication that the farther forward the rail button is placed the higher the dampening coefficient possible. The RocketPy optimization simulation results were presented to the team and the aft rail button location was decided to be as far aft as possible and the forward rail button was decided to be placed at CG. Fig. 61 is the launch simulation for the full scale verification launch indicating some weathercocking but substantially less than previous designs. The small period of oscillations and the low magnitude are both desirable traits that the simulation predicts. Watching the launch and analyzing footage of the launch there are no perceivable oscillations indicating a successful design decision.

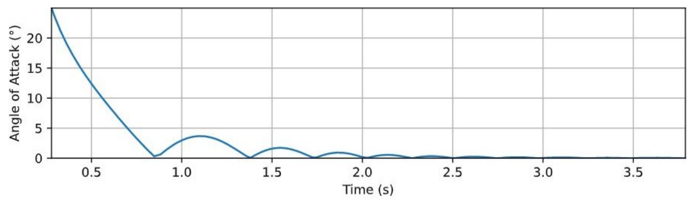

Figure 61: FFV RocketPy simulation of the angle of attack.

3.7.4 RocketPy Historical Weather Forecasting

Another useful data analytic tool of RocketPy is its ability to analyze large sources of historical data for the purposes of predicting wind speed on a launch day. The University of Wyoming stores a large public database of weather-sounding data that RocketPy interfaces with. Large amounts of this weather data can be downloaded and used to generate the wind climate for a launch location. Fig. 62 and fig. 63 are examples of the information gathered for the verification launch location in Bayboro, NC.

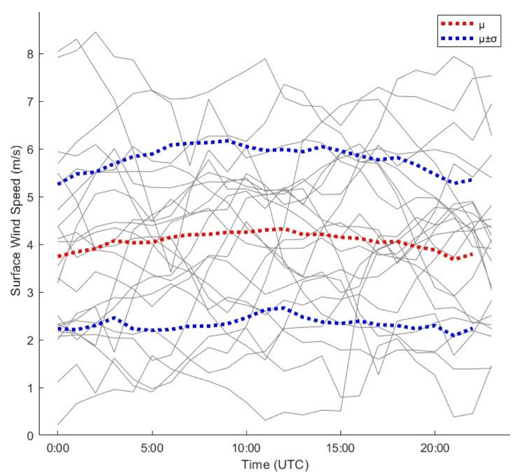

Figure 62: February wind speed historical data.

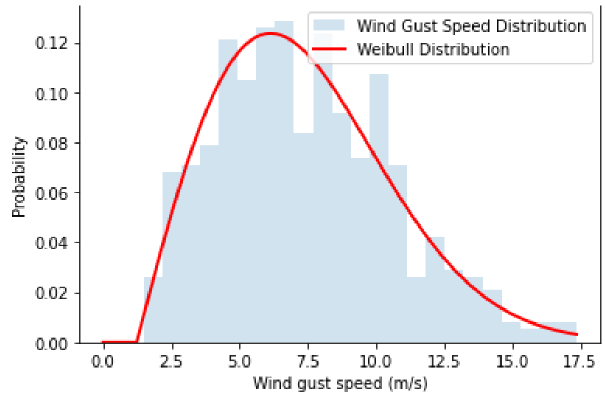

Figure 63: Wind gust distribution

The wind data is used to predict in conjunction with the forecast data what the wind conditions of the launch will be. This method has much better long-term predictive abilities while the forecast becomes more refined closer to the launch day.

3.7.5 RocketPy Monte Carlo Launch Prediction

In addition to specific vehicle characteristic optimization through component-level variation, an entire vehicle analysis can be easily conducted through Rocketpy's Monte Carlo function library. By defining an average and standard deviation value for each vehicle attribute, a randomization operation can be used to holistically define a unique launch vehicle whose characteristics vary from a nominal value by a predetermined envelope. These unique launch vehicles can be launched within the simulated environmental model using numerical methods, and the output variables are logged for post-processing. This process is repeated until a high-fidelity normal distribution is achieved for all datasets. This is a very powerful tool for assessing what characteristics of the design generate the most error in performance and, therefore, can receive additional attention to reduce that error.

Using the most current launch configuration, the Monte Carlo simulation can be used for the previously conducted flight of the launch vehicle to determine the amount of correlation between the analytical simulation and real-world results. Each characteristic of the vehicle and environment was furnished with an operational envelope, and real weather data collected from the launch site was used to generate a one-thousand flight projection of the vehicle's apogee and landing point plotted over satellite imagery of the launch field. From the simulation, it can be observed that the measured landing point was within two standard deviations of the average simulated landing point, further reinforcing RocketPy's simulation ability to match real-world trends.

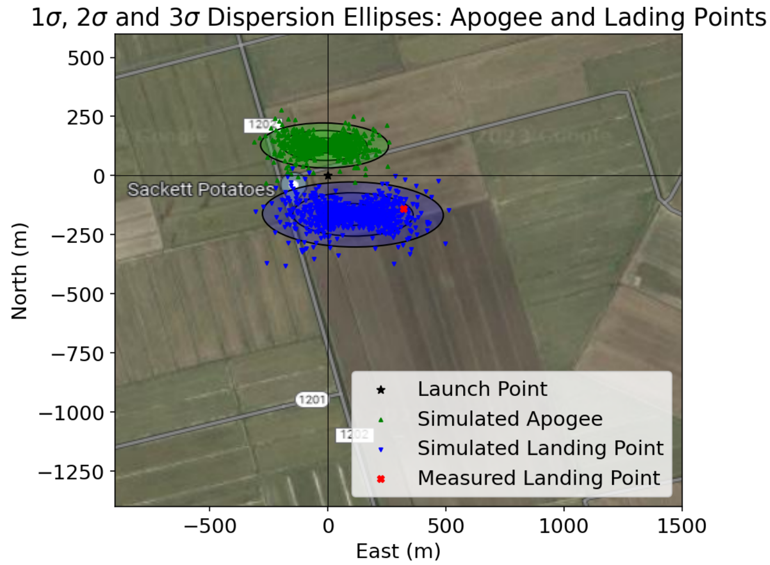

Figure 64: RocketPy Monte Carlo dispersion analysis for Bayboro VDF.

3.7.6 RocketPy Future Usage

RocketPy will continue to be utilized as much as possible with the construction of the full scale vehicle providing clarity on approximations used in the current design. RockSim and RocketPy results will be closely compared to flight results with the current prediction that RocketPy will improve the flight performance predictions over RockSim. Additional work is going into understanding the optimization and randomization aspects of RocketPy with the expectation that the current design can be improved.

4 Payload Criteria

4.1 Mission Statement

The payload mission is the capture of landing site images using a RAFCO controlled camera system. These commands are to be sent over APRS, and the payload is to rotate the operating camera and take pictures as commanded. RAFCO also includes image editing commands, which are to be performed on-board. The captured images are also to be time stamped. Additionally, team derived mission requirements highlight system and operations efficiency, in order to reduce design and construction complexity, and reduce the number of failure nodes while allowing for redundancy.

4.2 Success Criteria

Using requirements and guidelines set by the competition handbook and team-derived requirements, the following mission success criteria were created. Table (19) details mission and personnel outcomes and their corresponding success/failure level.

Table 19: Mission success criteria for SOCS.

Outcome	Mission	Personnel
Total Success	Clear and unobstructed images captured according to RAFCO commands; no damage to essential payload components	No personnel injury
Partial Success	Mildly obscured images captured according to RAFCO commands; minor, reparable damage to essential payload components	No personnel injury; personnel exposure to hazards
Partial Failure	Obscured images captured; RAFCO commands not correctly followed; significant, reparable damage to essential payload components	Personnel injury treatable with on-site first aid
Total Failure	No images captured; significant, irreparable damage to essential payload components	Personnel injury resulting in hospitalization or death

4.3 Changes Since CDR

4.3.1 SOCS Sled Redesign

Immediately prior to the payload demonstration flight, it was found that the payload sled in its horizontal configuration did not fit in the payload bay. Thus, a design change was made that re-arranged SOCS components onto module-like bulkheads, discussed in section 4.5.3 below. This newly designed system has been shown to be reliable, easily used, and cleanly designed.

4.3.2 JST-SM Connectors

DuPont connectors, pictured below in Figure (65), have been used to connect various electronics on SOCS. These connections are not locking and tend to disconnect under acceleration encountered during flight. Thus, JST-SM locking connectors, shown in Figure (90), will replace most instances of DuPont connectors on SOCS. These connections will be reinforced with hot glue to ensure connectivity during flight, while allowing for removable afterwards with the application of isopropyl alcohol.

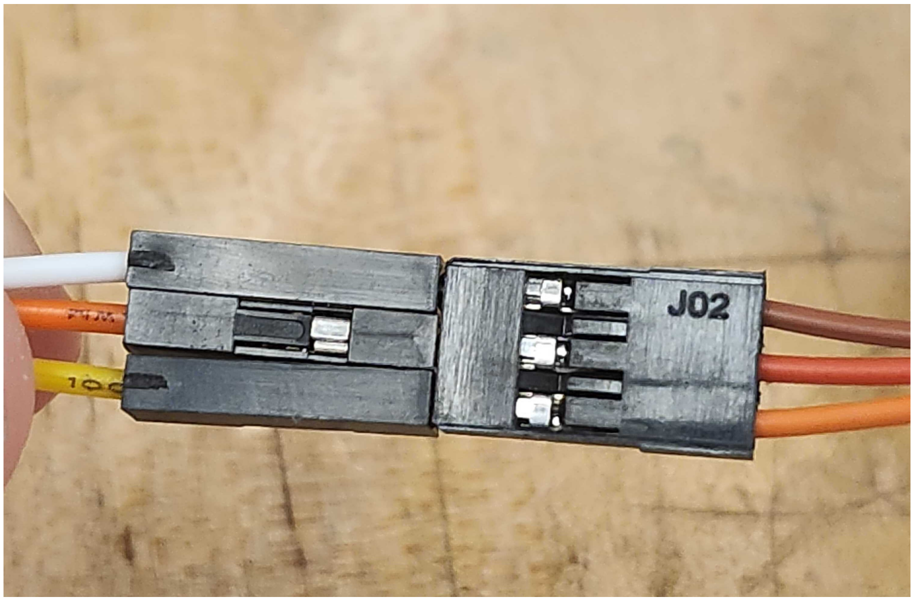

Figure 65: DuPont connectors that are slated to be replaced by JST-SM connectors.

4.3.3 Power System Fail-safes

A fuse was added to protect essential SOCS components from current overload. Five days before PDF, 3.7 A of current at 11.1 V was delivered to the buck converter by connecting the buck converter to the fully assembled SOCS. Because the buck converter's max allowable current was 3 A, the buck converter failed and delivered 11.1 V at high current to the Raspberry Pi. This Pi is no longer functional, and a replacement has been implemented. To reduce the likelihood of electronics damage due to overcurrent, a 4A fuse was added to protect payload components in the event that the buck converter fails. Figure (66) below shows the SOCS fuse.

Figure 66: Fuse for SOCS electronics.

An additional 5V buck converter was added to the power system, which supplies power only to the servos. This isolates them from other components, in the event of another spike in current draw. The power to the Raspberry Pi is also now supplied through the USB-C port, which has its own voltage converter. This supplies an additional fail-safe in the event of a buck converter failure.

4.3.4 CSI to HDMI Adapters

The default connection between the Smraza camera units and the Arducam multi-camera module is a CSI cable. These cables are fragile and easily lose connection under shearing stress and torsional moments. Because the camera units must rotate and therefore place torsional stress on the CSI cables, load-resistant cables are preferred. Thus, HDMI cables will connect cameras to the multi-camera module. Four HDMI to CSI adapters, one for each camera, are added to the SOCS sled to convert the HDMI output of the cameras to CSI input for the Arducam board. An example of this adapter is shown below in Figure (67)

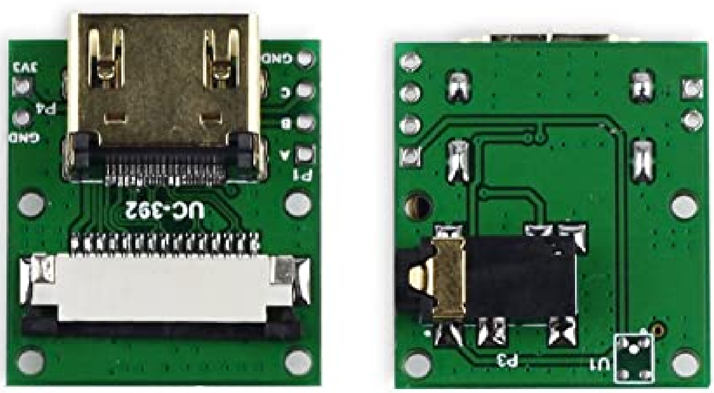

Figure 67: An example of HDMI to CSI adapters for each SOCS camera [1].

4.4 Payload Overview

4.4.1 Electronics

The electronics that power and control SOCS consist of two subsystems: the RAFCO subsystem and the camera positioning and image capture subsystem. Each subsystem controls a different aspect of mission performance. The RAFCO subsystem controls how APRS commands sent by NASA are received and interpreted. Four camera assemblies comprise the camera positioning and image capture subsystem, which receive these interpreted commands and take pictures. These two subsystems are controlled by a Raspberry Pi single-board computer. A Raspberry Pi was selected as the central computer due to its reliability, previous availability, thoroughness of documentation, and component compatibility. Figure 68 shows an example of the computer used.

Figure 68: Raspberry Pi 4 [14]

The power system consists of a 8000mAh 3 Cell lipo battery, which is split into two 5V rails through two different 5V buck converters. The first buck converter, shown in figure 69, is used to supply 5V to the majority of the system, including the Raspberry Pi, logic level shifter, IMU, relay, and Arducam Multicam Adapter. The second buck converter is used to supply 5V power to the servos. This isolation is to prevent overvoltage/current due to current draw spikes from the servos. Additional protection is provided through a 4A fuse on the 5V rail which provides power the the Pi, along with power being inputted through the USB-C connection. This connection has a built in voltage regulator, providing backup in case the buck converter fails. Further clarification on system wiring can be found in figure 78.

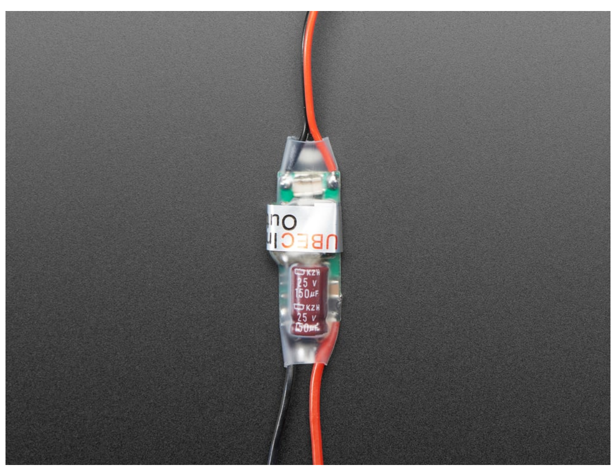

Figure 69: Adafruit UBEC [10]

A power bus is utilized to provide 5V and ground to each of the servos, without the need for wire splices. This bus consists of a piece of stripboard with mounting holes added to it. A 2 by 5 2.54mm pitch header is added to allow for connections, and extra positions were left on to allow for JST-SM connectors as needed. Figure 70 shows the manufactured servo power bus.

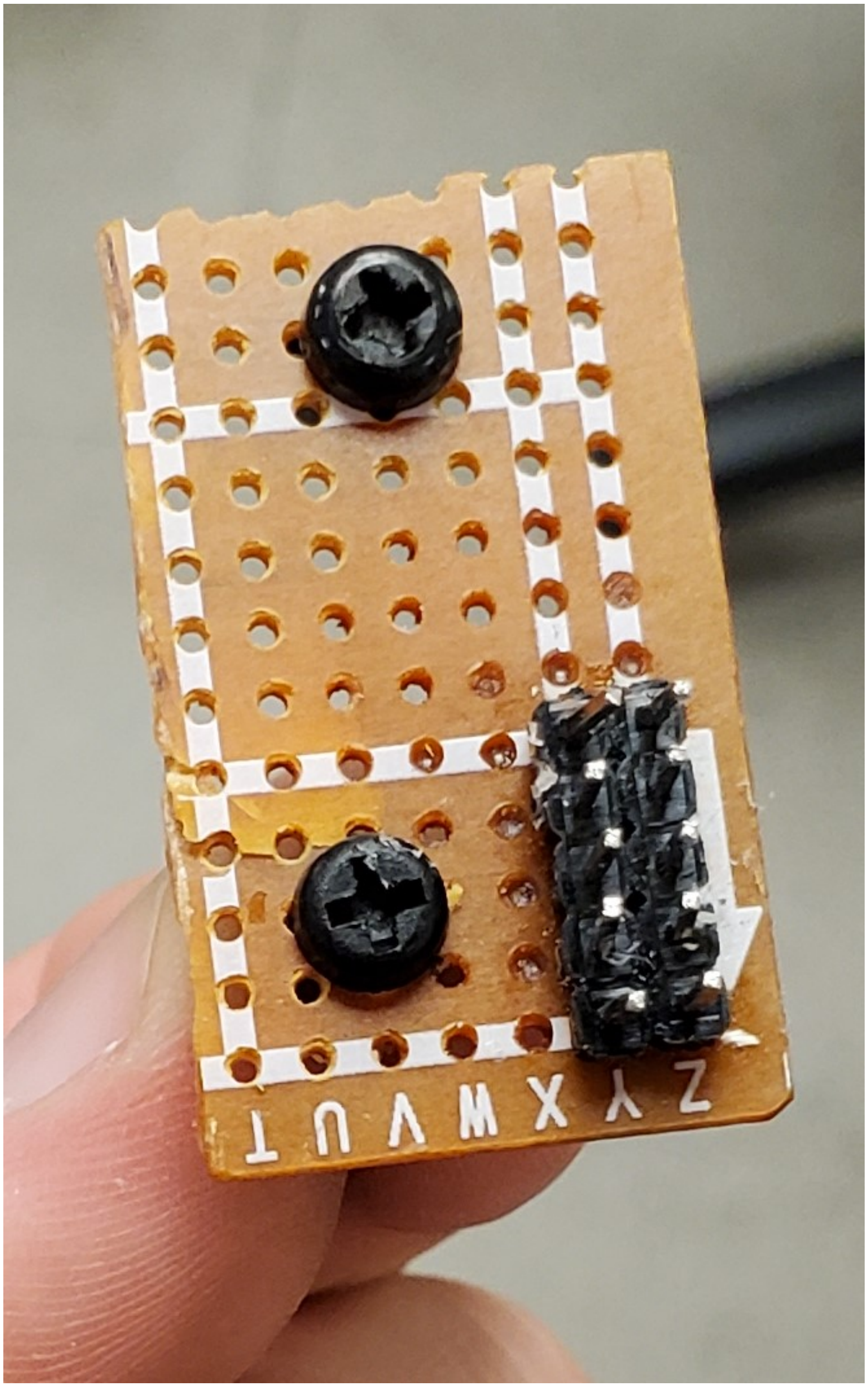

Figure 70: Servo Power Bus

4.4.1.1 RAFCO Subsystem

The selected RAFCO alternatives consist of two half-wave dipole antennas, a SainSmart 2-Channel Relay, a Nooelec NESDR Smart RTL-SDR dongle, and a BNO055 IMU. Half-wave dipole antennas were selected due to their ease of construction and implementation. Since dipole antennas do not require a large perpendicular ground plane, they can easily be mounted to the launch vehicle with minimum supporting architecture. Half-wave dipole antennas are essentially two pieces of wire connected together by an SMA connector, allowing for easy construction and testing. These two antennas will be placed on the outside of the launch vehicle, 180° apart. This means that no matter how the launch vehicle lands, there will always be one antenna facing up.

These two antennas cannot be connected in parallel due to the possibility of signal interference. Thus, the 2-channel relay is used in conjunction with the IMU and Raspberry Pi. The IMU sends orientation data to the Pi, which is then used to determine which antenna is facing upwards at that moment. The Pi makes an antenna selection, and commands the relay as to which antenna to select. The relay must have two channels in order to select both the signal and ground for each antenna, as neither are connected in parallel. Further details regarding orientation determination can be found in Section 4.4.1.2.3, with two 180° sections used for antenna selection, rather than the four 90° sections used for camera selection. Figures 71, 72, and 73 show example images of the off-the-shelf components used in this subsystem.

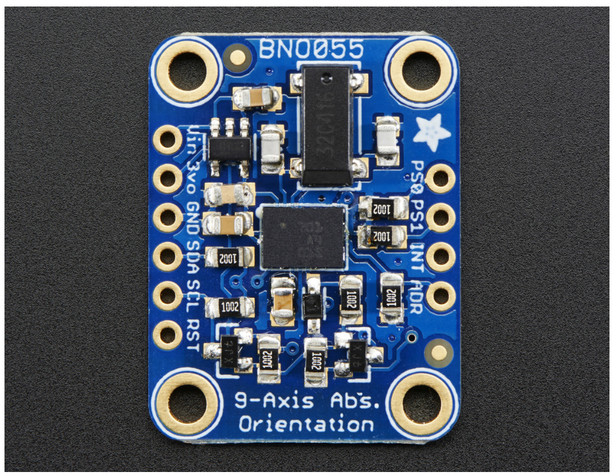

Figure 71: BNO055 IMU [13]

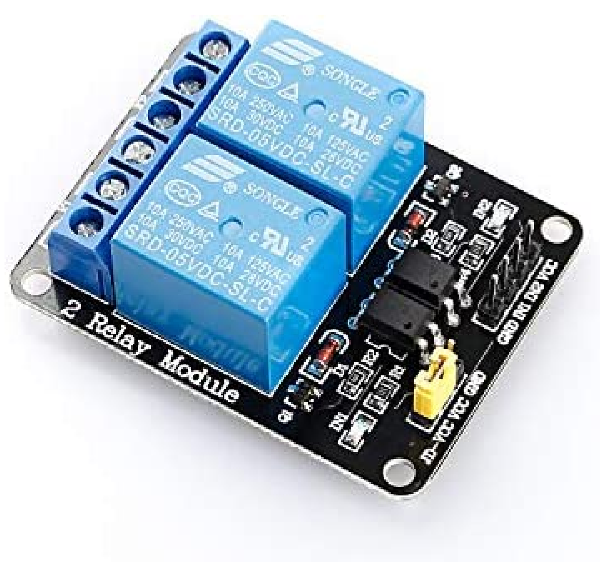

Figure 72: SainSmart 2-Channel Relay [7]

Figure 73: Nooelec NESDR Smart RTL-SDR Dongle [6]

4.4.1.2 Camera Positioning and Image Capture Subsystem

4.4.1.2.1 Fin and Camera Orientation

When the launch vehicle lands, the fin can can land in one of four orientations due to the four fin configuration used (as shown in Figure (74)). Thus, four cameras are used, one for each possible landing orientations. When the vehicle lands in position one, camera one is activated. The same is true for positions and cameras two through four. It can be seen that because the force of gravity acts in a downward direction on the fin can, the positions labeled "unlikely" are not possible on Earth and other bodies in the solar system.

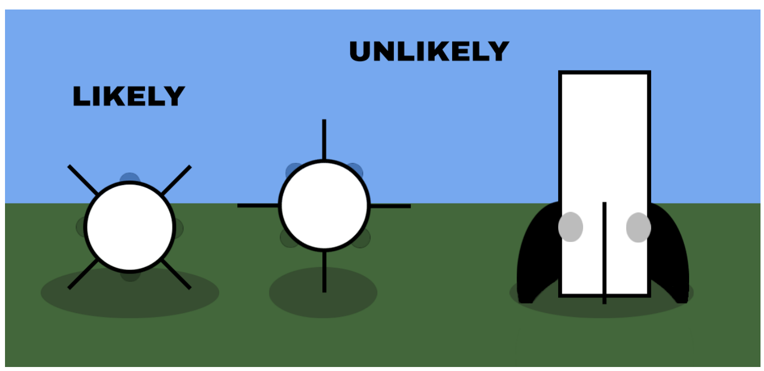

Figure 74: Likely and unlikely landing orientations of the fin can.

4.4.1.2.2 Camera Units

Four camera units are affixed to the airframe, one seated in between each of the four fins. Each camera unit consists of a Feetech FS90R servo that rotates each camera, a Smraza camera module that captures images, a vacuum-formed aerodynamic camera housing that protects the system from debris, a 3D-printed camera mount that secures the camera to the servo, and a 3D-printed camera unit mount that holds the camera assembly and housing to the airframe with plastic rivets.

The Feetech FS90R was chosen because of its low cost and history of use in HPRC. Also in use is the Smraza camera module, of which the team both possesses and has previous experience using.

Of the proposed camera design alternatives, the Raspberry Pi camera module alternative was chosen for these cameras' native ability to integrate with the on-board computer. One camera module is bolted to each servo with a 3D-printed mount, shown in Figure (97).

The Feetech FS90R requires a 5V PWM signal in order to control rotation. The Pi, however, is only able to supply a 3.33V PWM signal. Thus, it is necessary to raise the voltage level of the Pi logic output. This is done using the SN74AHCT125N quad logic-level shifter IC. The SN74AHCT125N is an integrated circuit that is capable of taking low voltage logic and shifting it to 5V logic. With this IC as an interface between the four FS90R servos and the Rapsberry Pi, control of the servos can be done easily. This IC runs off of 5V which is readily available in the system, and is produced in a variety of through-hole and SMT packages.

4.4.1.2.3 Camera Position Determination

Once RAFCO commands are received and parsed, they are directed to the correct camera unit based on orientation data from the BNO055 IMU mounted to the payload sled. Orientation is determined based on the rotation of the gravitational frame to that of the neutral frame of the IMU. For example, a rotation of 0 degrees is when the IMU is sitting level to the ground, with gravity normal to the bottom surface of the IMU. As the launch vehicle and the IMU rotate, the gravity vector (and thus frame) rotate with respect to the frame of the IMU. Only a single axes of rotation is necessary, since only the axial rotation (i.e. along the launch vehicle) is necessary to determine which camera is facing upwards. This plane is divided into 90 degree increments, and a camera assigned to each quadrant. The camera is then selected based on which quadrant the gravitational frame has rotated to. In the case that the IMU does not report that it is in any of the four configurations or it otherwise fails, commands will be sent to all four cameras and the correct images will be chosen manually. Figure 75 shows a visual example of this determination system.

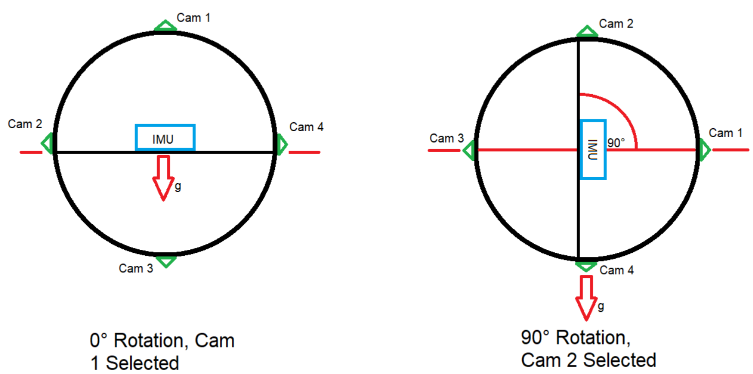

Figure 75: Camera Orientation Determination

Commands are sent to the correct camera using an Arducam Multicam Adapter Board, shown below in Figure (76). This board allows CSI input from one camera at a time as composite video data which is stored as a series of frames on the Raspberry Pi. Additional information regarding this process is discussed in Section 4.6.4.

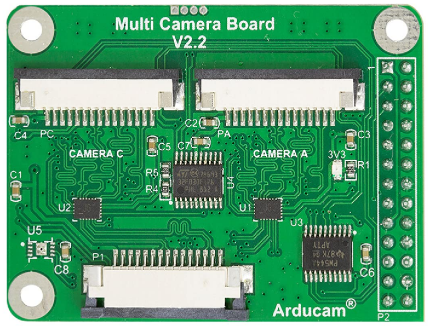

Figure 76: Arducam Multicam Adapter Board [5]

4.4.1.3 Block and Wiring Diagrams

Figure 77 shows the block diagram for payload operations. This includes both software and hardware components. Note that there are four camera leveling systems (i.e. servos) and cameras, although the connection and data path for each are the same. The camera and servo selection is done in software rather than through hardware, as is used for the antennas.

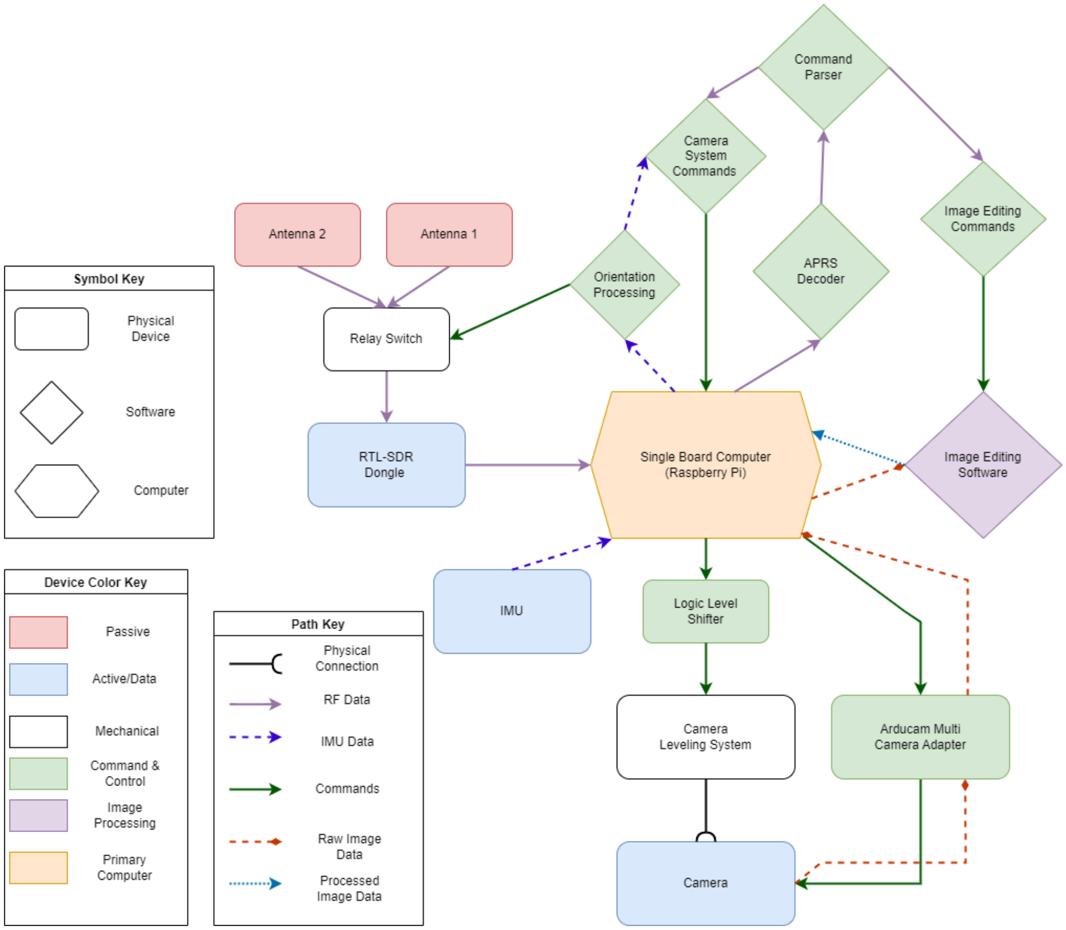

Figure 77: Finalized payload operations block diagram

Figure 78 shows the wiring schematic for the payload. This diagram shows the electrical connections being made, and does not include any of the physical connections, such as that between the servos and the cameras. Connections are color coded so as to best match the wiring present on the physical payload. Wiring made with similar colors will be labeled using the team's label maker in order to distinguish them.

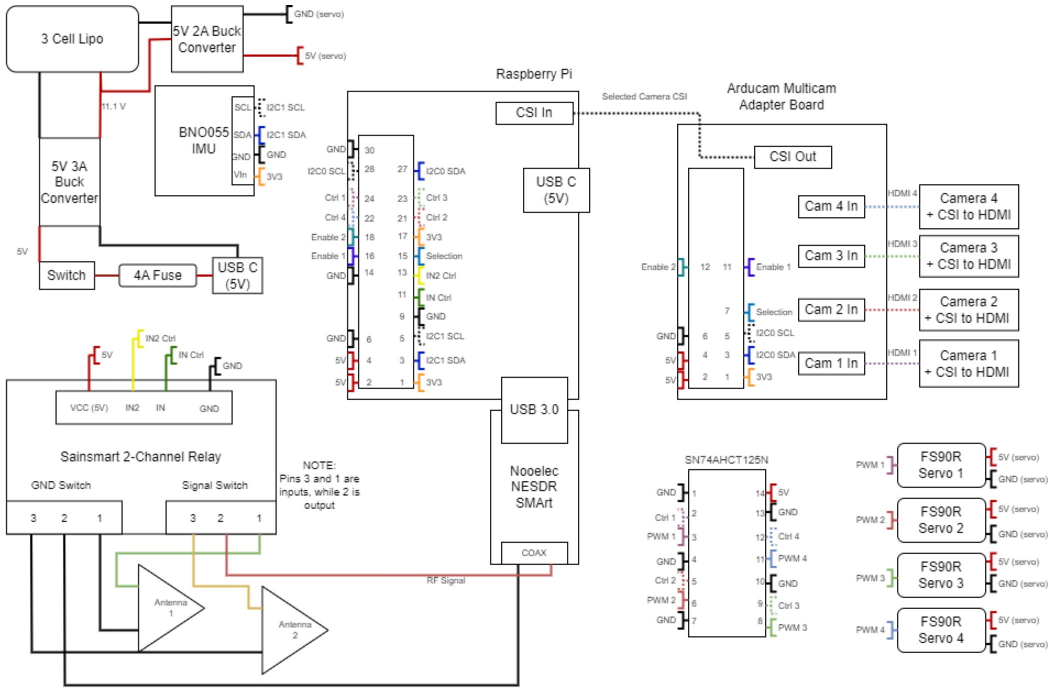

Figure 78: Payload wiring diagram

The SN744HCT125N logic level shifter requires a custom board in order to facilitate integration with the rest of the payload system. Since the selected component is through-hole, a stripboard is used to create this necessary breakout board. Figure 79 shows the layout of the breakout board.

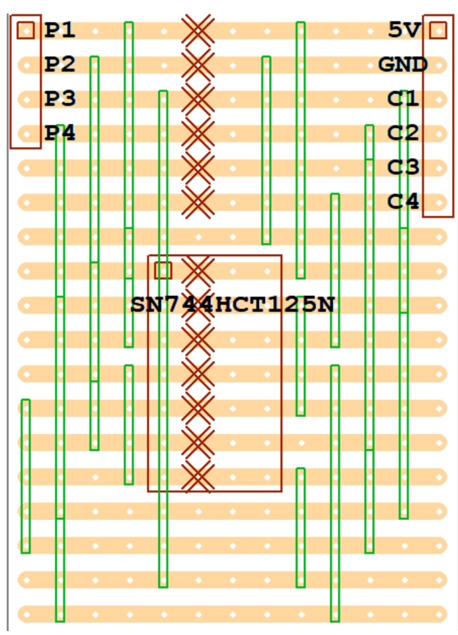

Figure 79: SN744HCT125N Breakout Board

4.4.2 Structure

The final structural design of SOCS is composed of three components: a camera unit mount, an aerodynamic camera housing, and an electronics sled. These parts combine with the camera units, the custom servo-camera mount, and SOCS electronics to create the payload system.

The unit mount is the base of the design and holds the servo, camera and servo-camera mount. This mount is 3D printed entirely with PLA plastic. An additional 3D-printed tab, called the servo support, is sanded and super-glued to the bottom servo slot and acts as a guide to ensure proper camera placement. Each servo slides into the slot on the bottom of the mount and is secured to the mount and the 3D-printed alignment tab using electrical tape. Once the servo is secured, the camera unit (consisting of a camera and a 3D-printed servo-camera mount) is secured to the top of the servo. The servo-camera mount utilized attachments that came with the servo on the bottom and a 3D-printed part which is specially designed to fit the Smraza camera. The servo attachment and the 3D-printed part are attached together using very small screws and are epoxied to ensure connection of each nut and bolt holding the camera mount together. The camera is attached to the servo-camera mount using screws. A picture of the assembled unit mount is shown below.

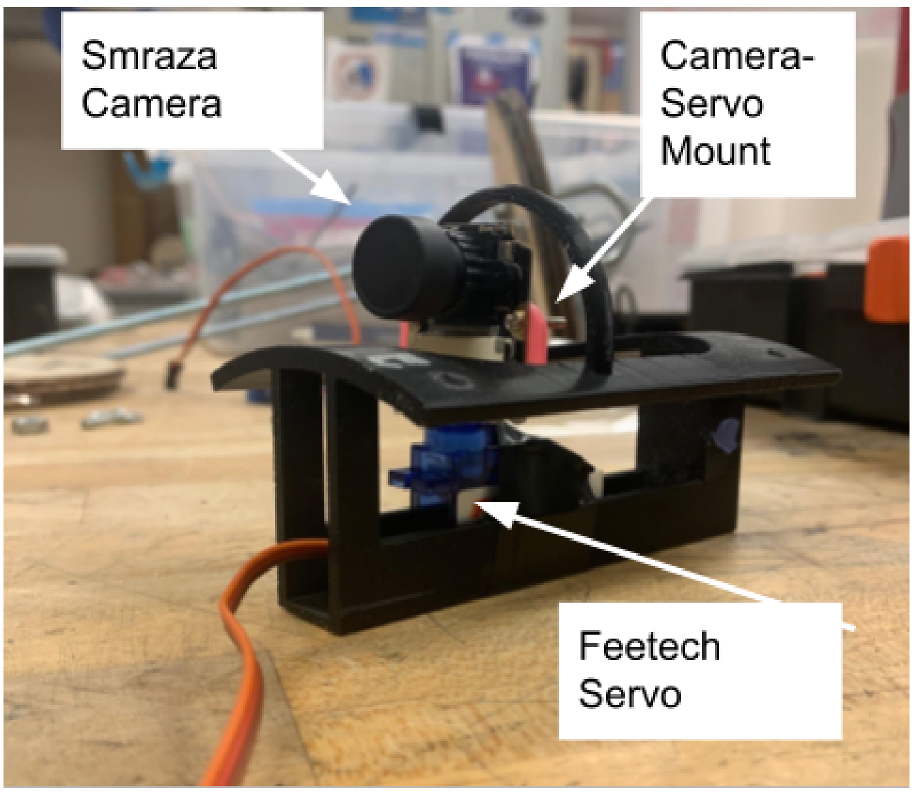

Figure 80: Unit Mount

After the unit mount is assembled, the vacuum-formed camera housings and camera unit mounts are bolted to the airframe with #6-32 machine screws. During launch day assembly, the camera housing's flange will be sealed with removable silicon sealant to prevent electrical damage from moisture contact. An example of the housing on top of the unit mount is shown below.

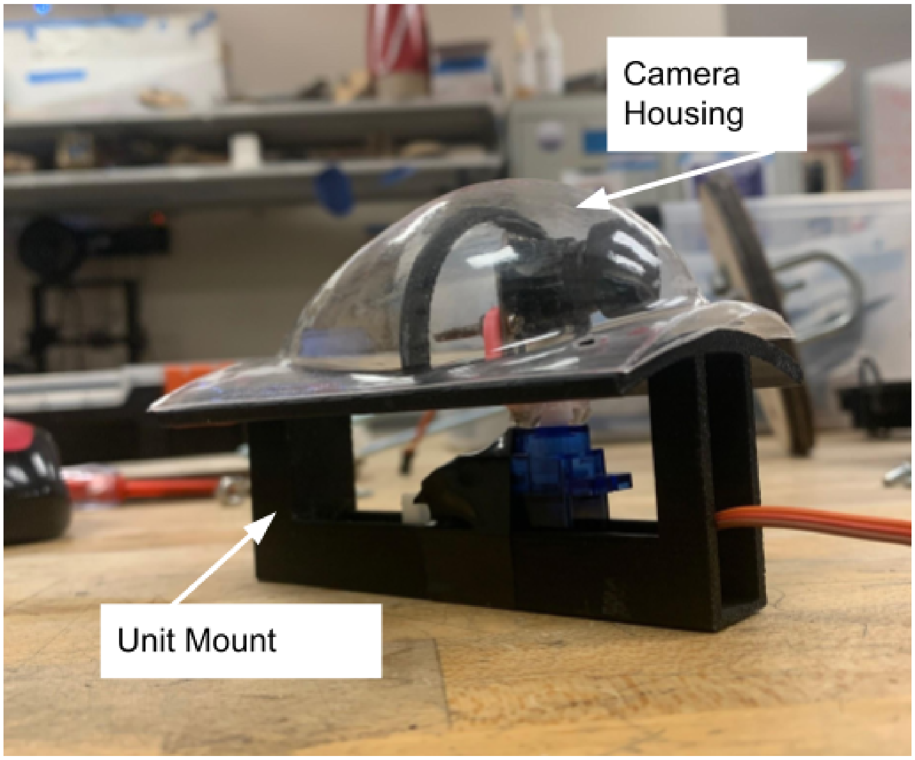

Figure 81: Camera Housing and Unit Mount

The sled is composed of three components: two circular sub-bulkheads and a battery holder. The two circular sub-bulkheads each hold the electronics for the RAFCO and camera subsystems. For the subscale Launch the sub-bulkheads were made from plywood and for the final launch it will be 3D printed.

4.4.2.1 Camera Unit Mount

The unit mount is a 3D-printed structure that houses each servo and camera unit. The final design of the unit mount is composed of 4 components: a curved base plate with an oval-shaped hole in the middle to allow the camera and servo to freely rotate, an arch support above the base plate to protect the camera from forces experienced during landing, a hollow slot underneath the base plate which houses the servo, and two truss-like supports attaching the slot to the base plate to add extra arch support strength. A CAD model of this unit mount is shown below.

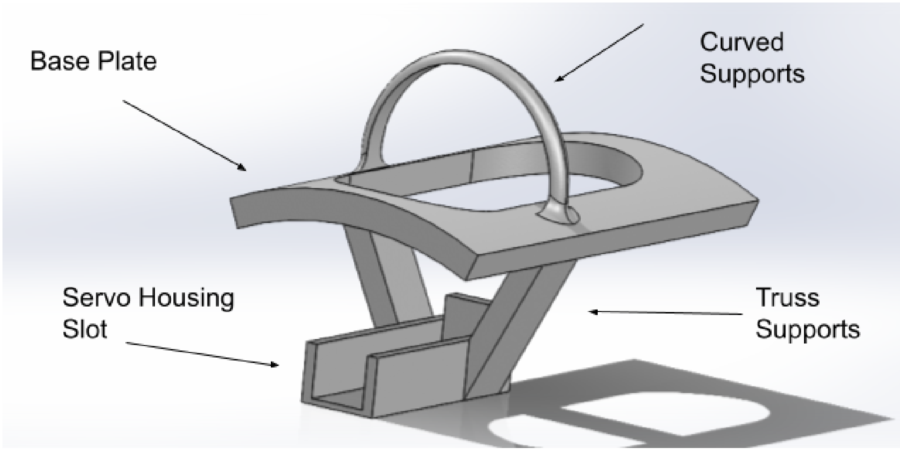

Figure 82: Final Unit Mount Design

The unit mount design used for PDF is different from the one described above. It did not include the truss-like structures and had a longer slot to allow for adjustment of the placement of the servo. A picture of our old unit mount is shown below. When the vehicle landed, the bottom-most unit mount cracked due to the force of the impact with the ground. The new design ensures that unit mounts will survive the landing. The infill of the prints will also be increased from 20 percent to 40 percent as an assurance of structural stability of the part. The design is also streamlined and removes all components that do not protect the camera so that print times are reduced.

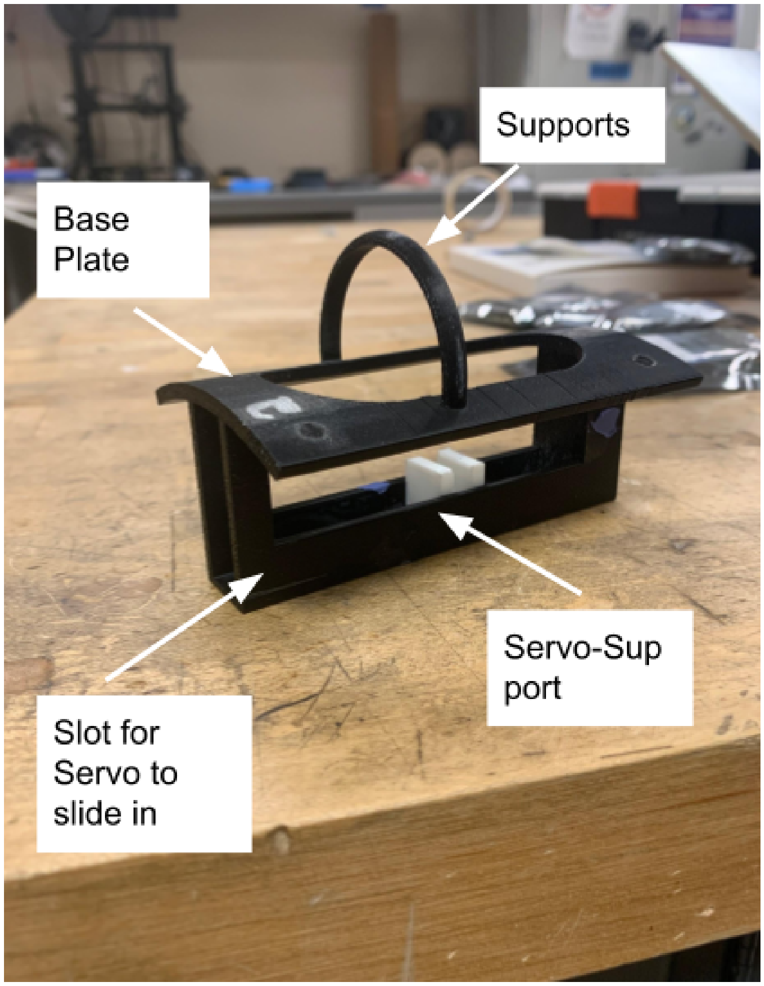

Figure 83: Camera Housing and Unit Mount

4.4.2.2 Aerodynamic Camera Housings

The aerodynamic camera housing is a thin, vacuum-formed component made from PET-G plastic. This housing protects the camera from debris during launch and landing. The housing is completely transparent to allow the camera to capture clear images of the launch field after landing. The housing is composed of a hollow, curved, dome shape in which the camera sits and a skirt that allows the housing to be bolted to the airframe. An example of a camera housing is shown below.

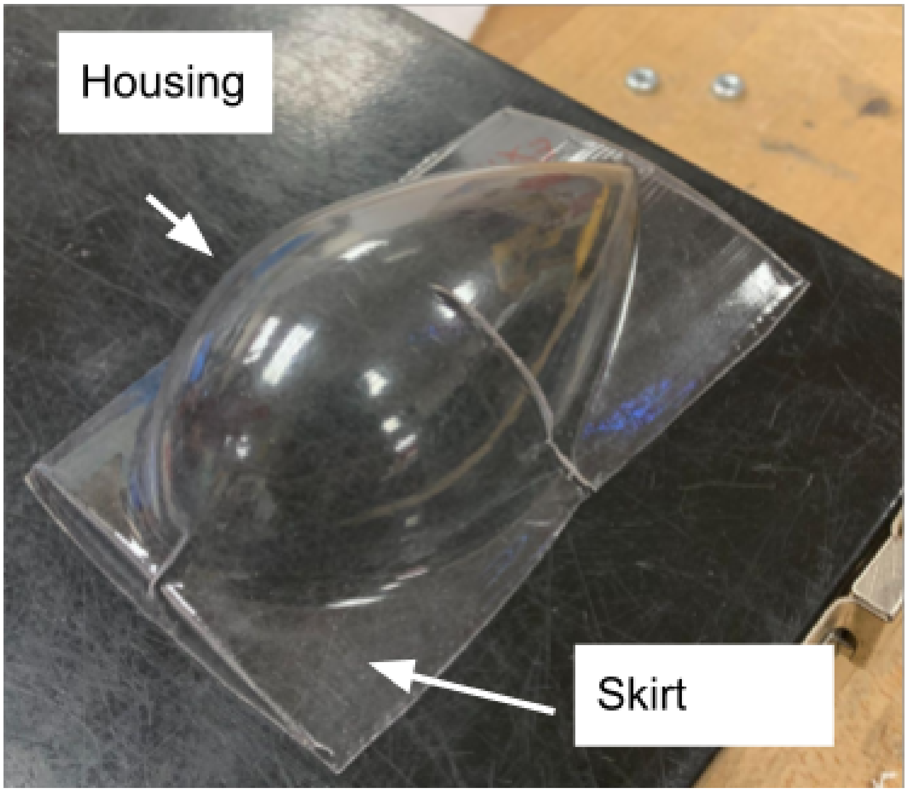

Figure 84: Vacuum Formed Camera Housing

4.5 SOCS Manufacturing

The manufacturing process for each component of SOCS is detailed in the sections below.

4.5.1 Camera Housing

In North Carolina State Univerity's Engineering Garage there is a Mayku Vaccum Former, which is used to create the camera housings. First, a 3D print is made of a positive mold of the camera housing, with a curved base plate to simulate how the housing will sit within the air frame. Then thin sheets of PET-G plastic are placed inside the vacuum forming machine. The machine then heats the plastic until it is stretchy and malleable, at which point the plastic is pressed onto the mold and the built in vacuum is used to perfectly create a hollow housing in the desired shape.

In order to ensure maximum clarity housing, the 3D printed parts were sanded until completely smooth and then washed in isopropyl alcohol. Several identical molds were used to create the housings, as after each use of the mold the heat from the machine caused it to deform slightly. To ensure perfect camera housing, each mold was only used a maximum of 4 times before being switched out.

Once the housing was made, it was aligned with the bolt holes on the air frame and marked out the corresponding positions on the skirt. Holes were then drilled so that bolts could be inserted.

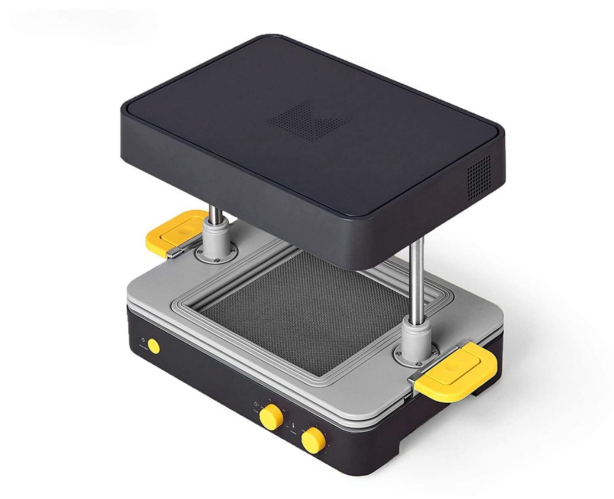

Figure 85: Makyu vacuum former

4.5.2 Camera Unit Mount

In order to make the unit mounts an Ultimaker 3D Printer in the Engineering Garage was utilized. The Ultimakers used PLA plastic filament to construct the design created. A high infill ratio of 40 percent was used to ensure that the structure would be able to withstand the forces experienced during landing. Once the unit mounts were made, they were aligned with the bolt holes made in the air frame, and the position of the bolts on the base plate was marked out. 4 holes were drilled into the base plate where so it could be attached to the air frame.

For the PDF launch, the position of the servos in which the cameras will be comfortably be able to spin around was measured. A small 3D printed rectangle was super glued in, which served as the support on which the servos were tapped onto. In our final design, supports have been incorporated as part of the Unit mount design so super glue is not needed.

Figure 86: Ultimaker S3

4.5.3 Payload Sled

For PDF, the Payload Sled design has changed from having a large flat plate running though the middle of the bay to having a 3D printed battery holder in the middle of the bay, which also houses the IMU, and 2 separate circular sub-bulkheads which were made with plywood. This design ensures that all the electronics used easily fit into the bay without the unit mounts disturbing them. Heat inserts were used on the 3D printed parts to secure the electronics onto them.

The circular plywood bulkheads had holes drilled into it so that the remaining electronic components could be attached. One of the bulkheads houses the RAFCO subsystem electronics and the other houses the camera subsystem components and Raspberry Pi.

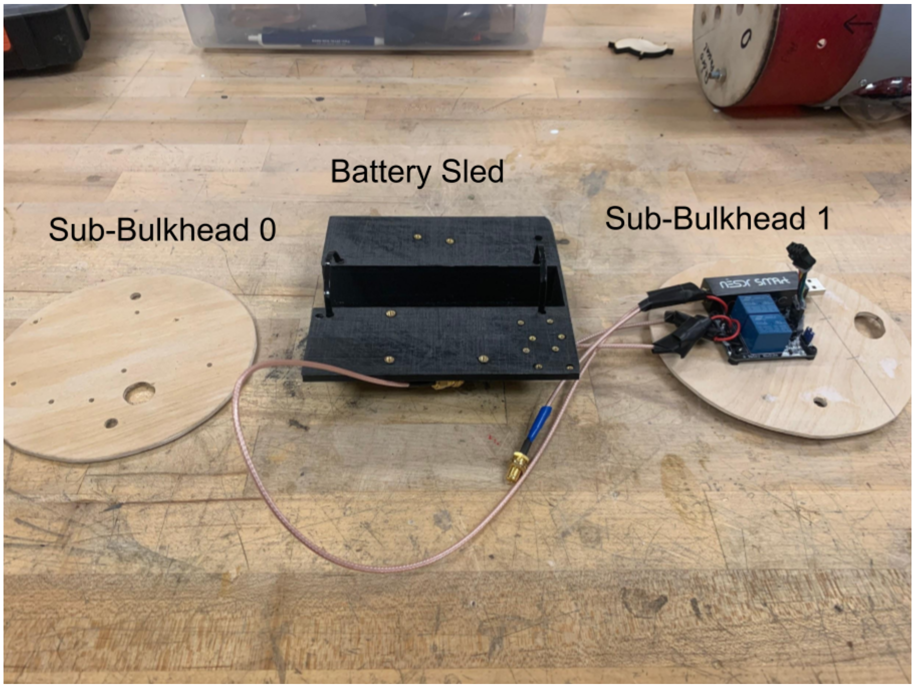

Figure 87: The Sled Assembly

In the final design, the sub-bulkheads will be 3D printed. This allows for M3 and M2 heat set inserts to be added, providing a secure connection between components and bulkheads. These inserts are utilized by first drilling a pilot hole which the tapered end of the insert fits into. Then, a soldering iron is pressed on top of the insert. This causes the insert to heat up, and the surrounding plastic to melt. As pressure is applied, the insert is pushed into the plastic until level with the rest of the bulkhead. The soldering iron is removed, and the insert is left to cool. Once fully cooled, the insert is firmly bonded with the plastic, and provides a threaded mounting point for components to be attached to. An example of these inserts is shown below in figure 88.

Figure 88: M3 Heat Set Inserts [9]

The battery holder will be changed so that the battery can be oriented in a different way which allows for an easier assembly process. A CAD Model of the new battery holder is shown below.

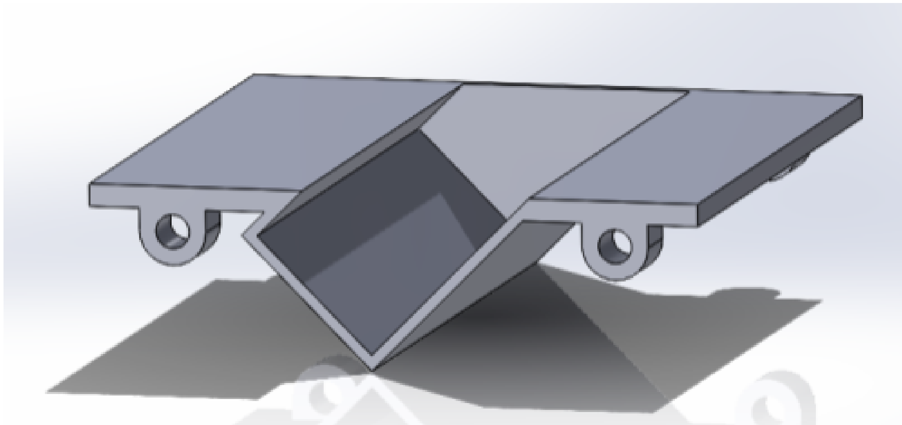

Figure 89: The Final Battery Holder Design

4.5.4 Command and Control Electronics

Many of the off-the-shelf electrical components have either terminal blocks or standard 2.54mm spaced headers. While excellent for rapid prototyping, these connectors are unreliable in high vibration environments. This unreliability was proven during the subscale flight, in which five of the six connections using terminal blocks were sheared off, rendering the prototype payload inoperable. Thus, terminal blocks are always de-soldered and removed. In order to facilitate secure yet removable connections, DuPont to JST-SM cables are manufactured for each of the daughter boards. The DuPont header is hot glued to the standard 2.54mm pitch header, while the JST-SM connectors are used to connect components together. An example of a JST-SM connector can be found in figure 90 Since JST-SM connectors are locking, this allows for a more secure connection than standard DuPont connectors, while still being removable. Hot glue allows for a secure mechanical and electrical connection, while capable of being dissolved with high concentration isopropyl alcohol. Both DuPont and JST-SM connectors are crimped connectors, consisting of a metal connector which is crimped onto the exposed end of a wire, that is then inserted into a plastic housing. These connectors require no soldering. The wires for each component are then covered in a 1/4in braided nylon cable wrap (figure 91), which prevents tangling and allows for easy identification and movement of wire bundles. The Raspberry Pi and daughter boards are attached to the payload sled using M3 and M2 mounting bolts, depending on the size of the mounting holes on each of the boards.

Figure 90: An Example of JST-SM Connectors [3]

Figure 91: 1/4in Braided Nylon Cable Wrap [2]

The SN74AHCT125N quad logic-level shifter does not come with a pre-assembled breakout board. Thus, it is necessary to construct one. A through-hole version of this component was selected, and the breakout board presented in figure 79 was constructed. The connecting wires to the Raspberry Pi were hot glued in place, while the output wires were soldered directly onto the board. Figure 92 shows the finished breakout board, minus the output wires to the individual servos. The SN74AHCT125N was socketed, allowing for easy replacement if the IC fails or is damaged.

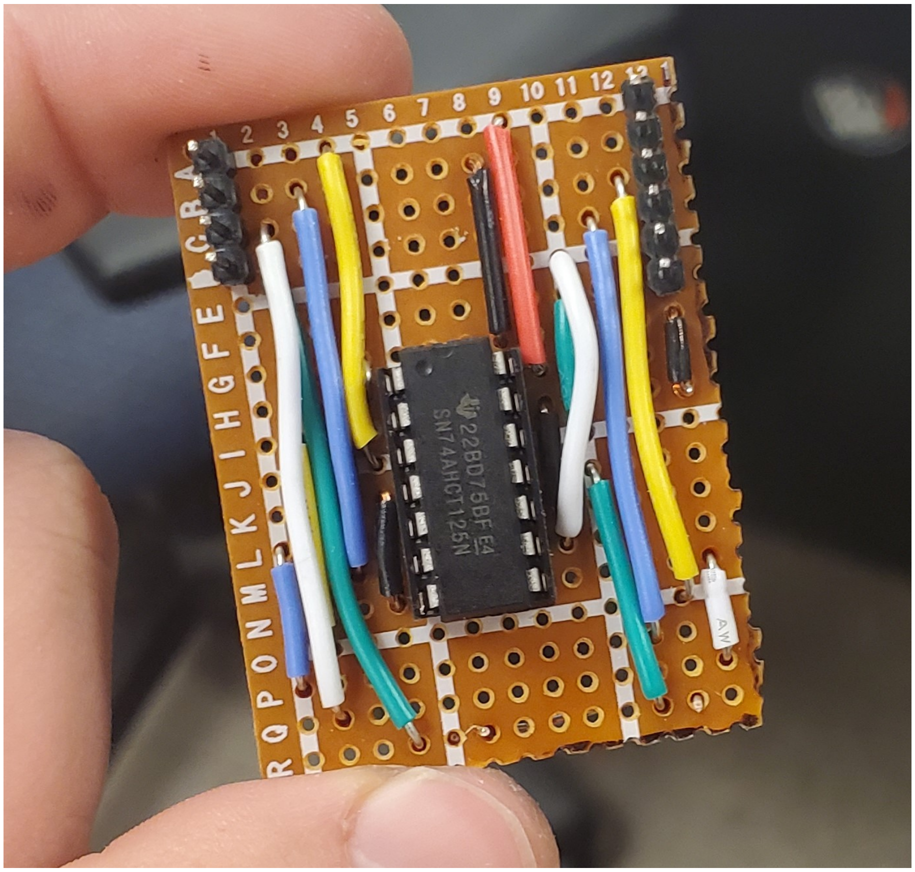

Figure 92: Constructed SN74AHCT125N Breakout Board without Output Wires

In order to streamline connections between the Raspberry Pi and daughter boards, a 2 by 20 DuPont connector is manufactured. This connector allows for all necessary wiring to be attached at once, without the possibility of improper wiring on the field. Since the Pi header is also 2 by 20, this connector is orientation fixed (meaning that it cannot be put in backwards or reversed), and has enough points of contact that accidental removal is unlikely. In order to ensure that this critical piece of hardware does not come undone, hot glue is used to both secure the wires to the connector, and secure the connector the the Raspberry Pi. This partially assembled connector is shown in figure 93

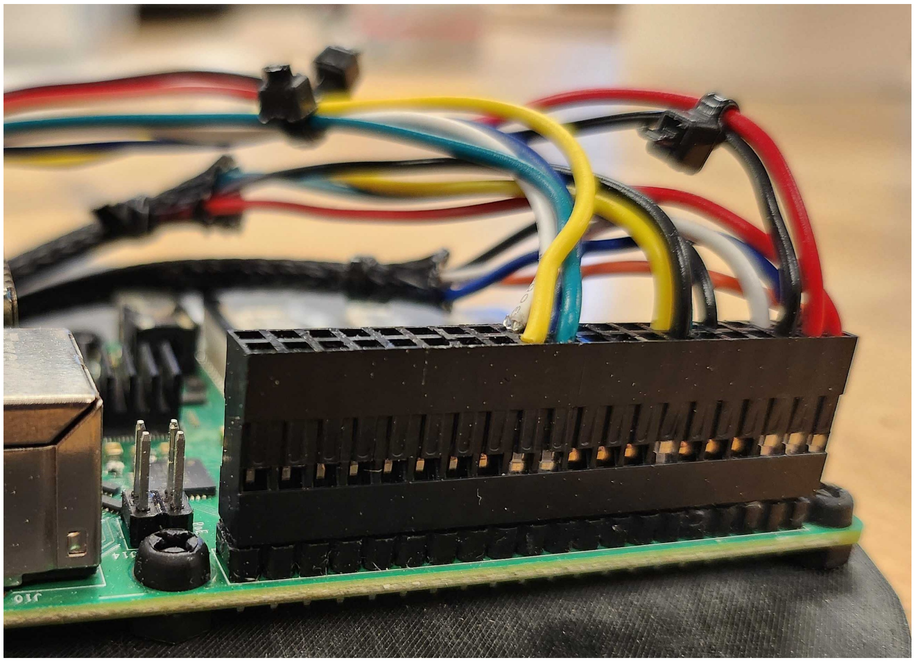

Figure 93: Raspberry Pi Connector

The antennas were constructed using two 50 cm pieces of 16AWG stranded wire, and a leaded SMA connector (figure 94). The wires were soldered onto each lead, and the connection was reinforced with popsicle sticks to ensure antenna survival. This was then covered in electrical tape, to provide further support and insulation. The finished connection point is shown in figure 95.

Figure 94: Leaded SMA Connector [12]

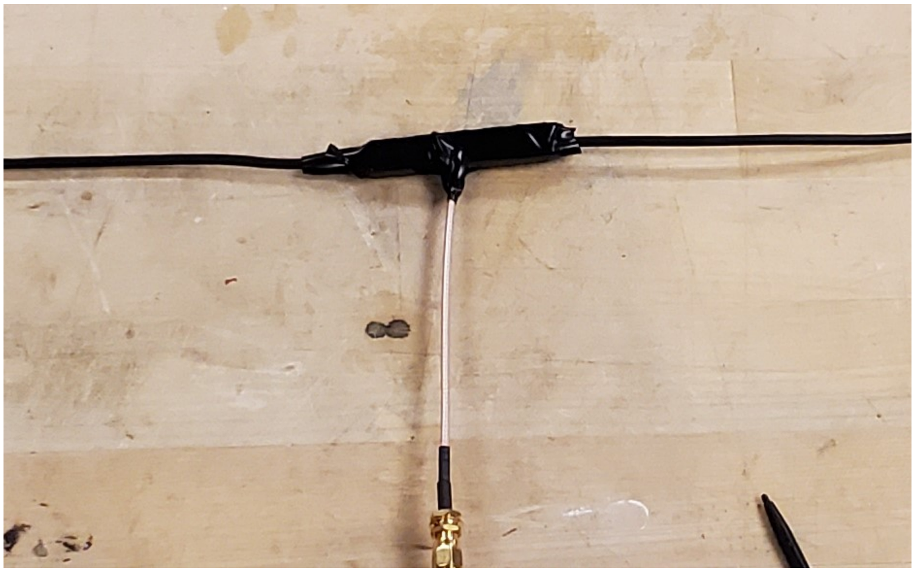

Figure 95: Connection Point on Antenna

4.5.5 Imaging Electronics

Electronics and hardware responsible for imaging and command execution are the four Smraza camera modules, four Feetech FS90R servos, four HDMI cables and HDMI to CSI adapters, the Arducam multi-camera adapter board, and 3D printed mounts holding each component together. The fully assembled system is shown in Figure (96) below.

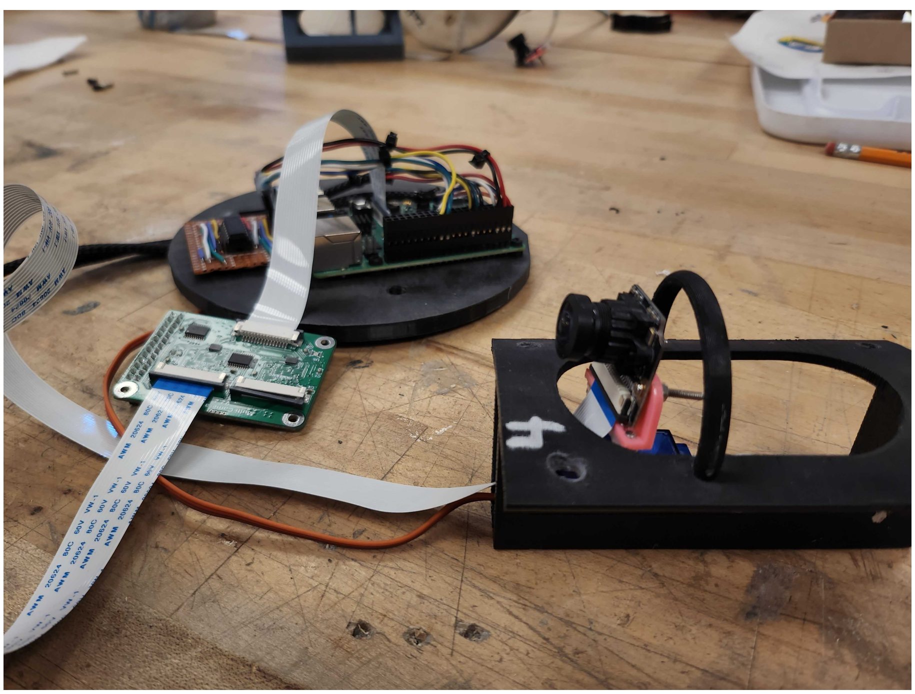

Figure 96: The full imaging and command execution assembly.

Each individual component's manufacturing and assembly procedure is detailed in the sections below.

4.5.5.1 Camera Units

Each camera unit contains a camera board, 3D-printed camera mount, Feetech FS90R servo, and HDMI cable. Camera mounts are 3D-printed using pink PLA plastic and affixed to servo mounts that shipped with each servo. The bottom of the pink mounts are sanded and epoxied to the servo mounts using West Systems 2-part epoxy. This ensures that the camera mounts will stay connected throughout the duration of the flight. Because these are not load-bearing parts, loads and stresses need not be considered.

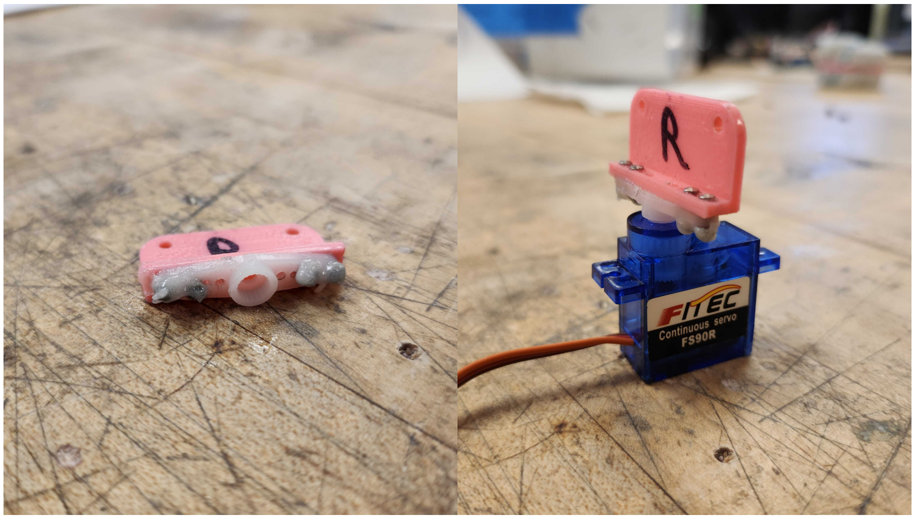

Figure 97: 3D-printed camera mounts are affixed to servos and secured with epoxy.

Machine screws that shipped with each camera mount are used to affix each camera board to the front of the camera mounts and nuts secure the back of the screws such that the cameras stay secured and stable during flight.

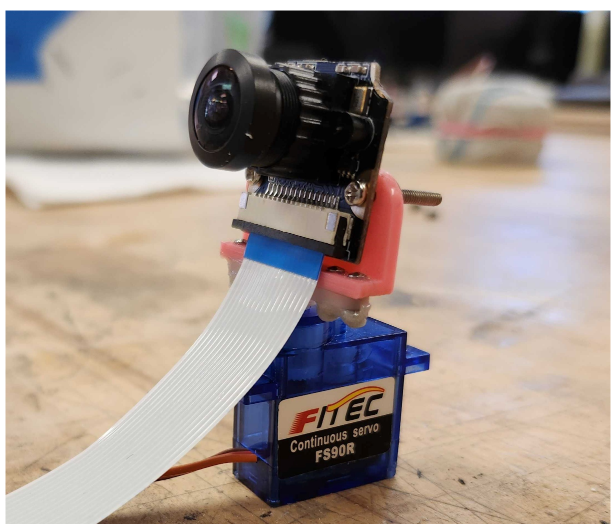

Figure 98: Each SMRaza camera is attached to its camera mount with provided machine screws.

CSI cables will connect to CSI to HDMI adapters affixed to the rear of the camera boards. An example of this configuration is shown in Figure (99) below. extending from the rear of the camera mounts wrap through a hole in the camera unit mounts and connect to one of four HDMI to CSI adapters such that the cameras can connect to the Arducam multi-camera adapter boards.

Figure 99: A CSI to HDMI adapter is affixed to the rear of each camera, allowing HDMI output.

4.5.5.2 Imaging Daughter Boards

The most significant daughter board used in the imaging process is the Arducam mult-adapter board, discussed above in the SOCS overview section. This board converts four channels of CSI input into one channel of CSI output that goes to the Raspberry Pi. To do this, it needs three logic pins, one power pin, one ground pin, and two i2c pins from the Raspberry Pi. These connections are made with the Raspberry Pi header shown in Figure (93). Each connection is reinforced with removable glue that secures the multicam board during launch. This board is connected with M3 screws, standoffs, and heated inserts that fit into sub-bulkhead zero.

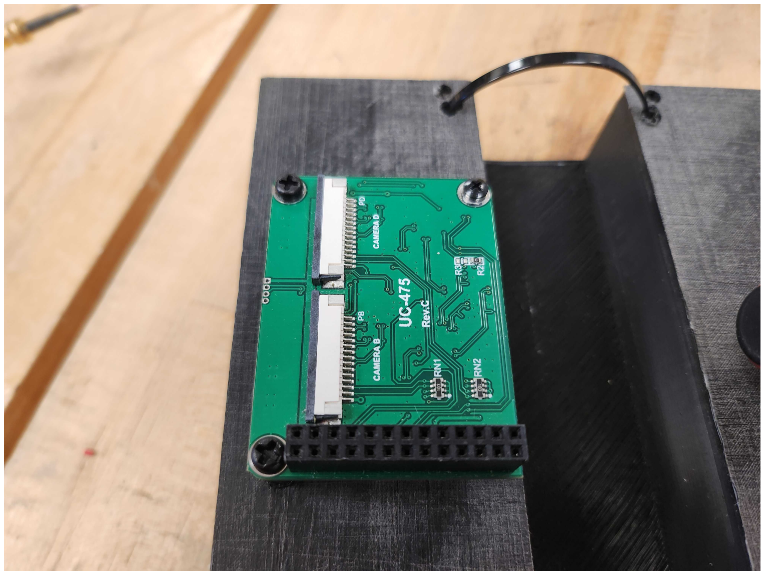

Figure 100: The Arducam board affixed to the sled.

Next, four HDMI to CSI adapters connect HDMI cables extending from each camera unit to the Arducam board which accepts CSI input only. These boards are also affixed to sub-bulkhead zero with M3 screws and heated inserts.

4.6 System Operations

The process of capturing images compliant with requirement NASA 4.2 follows a set list of instructions. The payload system will:

1. Approximate the position and rotation of the fin can relative to the ground and the BNO055 IMU
2. Use this position data to choose an antenna that receives signals and a camera unit that captures images
3. Receive and decode APRS commands using the correct antenna
4. Send decoded commands through the multi-cam adapter board to the correct camera
5. Rotate the camera using a Feetech FS90R servo and capture clear images according to commands
6. Send those images back to the Raspberry Pi to be timestamped, processed, and saved.

Details of each step are described in Sections 4.6.1 through 4.6.4 below.

4.6.1 RAFCO Receipt and APRS Decoding

Initially, the system uses data from the IMU to determine launch and landing, based on changes in acceleration. After landing has been detected, orientation is determined from the direction of gravitational acceleration. Orientation data is then used to determine whether the relay selecting an antenna needs to be switched or not. This antenna selection routine runs during the entire operational period, allowing for an appropriate response to unexpected changes in launch vehicle orientation, and also serving as a fail-safe in case landing was detected early.

A secondary timer is used to ensure that operations proceed even if landing is never detected. This timer will be set to the descent time of a main parachute opening at apogee, plus 20%. This gives a large buffer and assumes the worst-case scenario for recovery configuration. If landing is detected this timer will be ignored.

Once antenna selection has been made, the system is capable of receiving RAFCO. The data recieved by the antenna is outputted as analogue data, which cannot be read by the Pi. An RTL-SDR dongle is used to convert this analogue data to digital data readable by the Raspberry Pi. Direwolf is used by the Pi as a software terminal node controller (TNC), with the raw KISS data output being fed into a TCP port on the Pi. The transmitted commands are then decoded from this data using a python script.

4.6.2 Camera Orientation and Position Determination

In addition to determining which antenna receives signals, orientation data from the IMU is used to select which camera unit is facing upwards. This camera is selected through the Arducam Multicam Adapter Board, with the respective servo being controlled from a single GPIO pin on the Pi. The IMU's absolute position on the sled is secured using four M3 bolts. Its position relative to the airframe and camera mounts is established using alignment marks on the airframe. During assembly, two alignment marks on each side of the payload bay section are used to ensure that the IMU's position data corresponds with the correct camera unit. IMU orientation within the airframe is verified immediately prior to launch according to the payload checklist found in Section 5.4 by powering SOCS on, rotating the payload bay in 90 degree increments, and ensuring that the upward-facing camera is selected in each orientation.

After orientation is determined, the Raspberry Pi then sends the interpreted APRS commands through the Arducam multi-cam adapter board, shown in Figure (76), and to the respective servo's GPIO pin. This board passes the commands to the selected camera, and images are then captured as described below.

4.6.3 Image Capture

Once a camera is selected using IMU positioning data, the script main.py executes a function called takepic() that initializes the multi camera adapter board and the four cameras. takepic() also takes inputs corresponding to the various commands sent by NASA and decoded with the on-board computer. Examples of those commands are found in Table (20) below.

Table 20: APRS commands and their interpretations.

Command	Interpretation
A1	Turn camera 60° to the right
B2	Turn camera 60° to the left
C3	Take picture
D4	Change camera mode from color to grayscale
E5	Change camera mode back from grayscale to color
F6	Rotate image 180° (upside down)
G7	Special effects filter
H8	Remove all filters

Commands A1 and B2 are accomplished by sending commands to the chosen servo motor. This code's ability to control Feetech FS90R servos has been verified through its use in experimental payload launches separate from the competition. Command C3 is accomplished using the PiCamera module in Python. Still images are captured using the camera.capture() function inside of this module. Filters and camera mode switches will be done using a combination of changes to camera inputs and outputs and the Python PILLOW module.

Command G7 is defined in the competition handbook such that SOCS can "apply any filter or image distortion." Upon receipt of command G7 by the communication system, the on-board computer will choose one of the three filter/distortion effects at random to apply to the captured image. These effects were chosen based on popular image distortion and processing techniques used across disciplines.

1. **deeppy Module:** The deeppy module takes a jpeg input and "deep fries" the image. This process involves increasing contrast, sharpness, warmth, and brightness of the image to create a messy effect. This module uses the pillow module, an essential module for image processing in python.

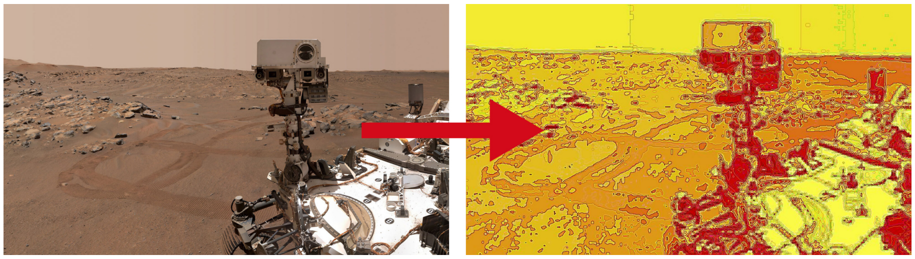

Figure 101: An example image filtered through the deeppy module.

2. **grassless() Function:** This script takes a jpeg input and removes all green values using rgb tuple data. This helps differentiate the launch field (a warm green) and the sky (a cool green).

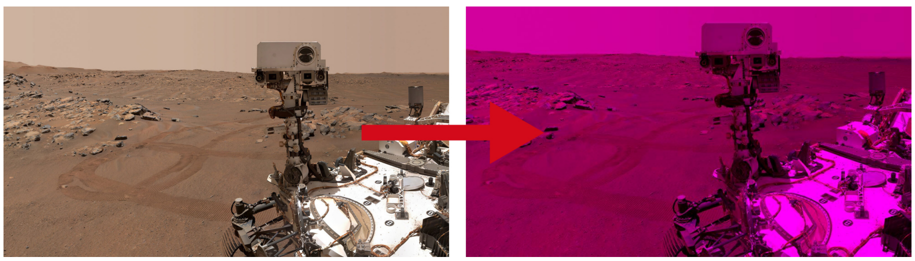

Figure 102: An example image filtered through the grassless function.

3. **meme() Function:** This script takes a jpeg input and randomly generates a string of text for the top and bottom of the image. A key component of space exploration is engagement with the public, and social media is growing increasingly influential in public outreach. "Memes," or easily spreadable images (usually with text), are invaluable ways to both spread awareness of scientific topics and broaden the scope of individuals reached. Through meme.py, SOCS automates this process.

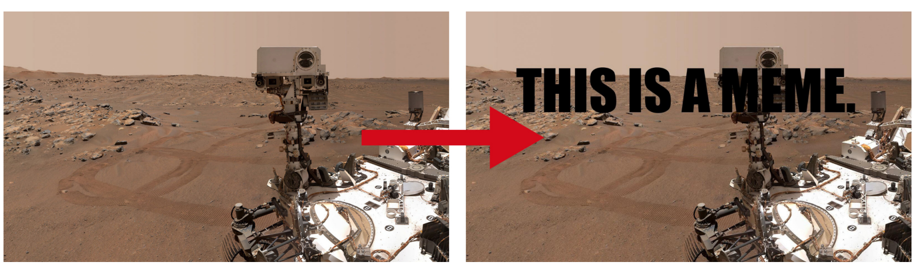

Figure 103: An example image filtered through the meme function.

4.6.4 Data Storage and Post-Processing

4.6.4.1 Image Logging

During initial testing of SOCS components on the subscale vehicle, it was found that the shutdown of payload components during transmission by licensed team members yielded complete loss of received data. Because data logged by SOCS was logged to a file that could only be closed manually, the file was left open upon shutdown of the Raspberry Pi and thus was not saved to the Pi's memory. To combat this, images will be saved and closed immediately after capture so that in the event that the computer loses power, images captured previously are still saved. This testing process is documented in Section 7.1.2.4.

4.6.4.2 Timestamping

Timestamping is accomplished using the pillow and logging Python modules. Logging is used to record the time at which the image is captured, and pillow's ImageDraw function is used to display this day and time in the lower right-hand corner of the screen. An example of a timestamped image is shown below in Figure (104). Additionally, the date and time will be saved in the filename saved on the Raspberry Pi.

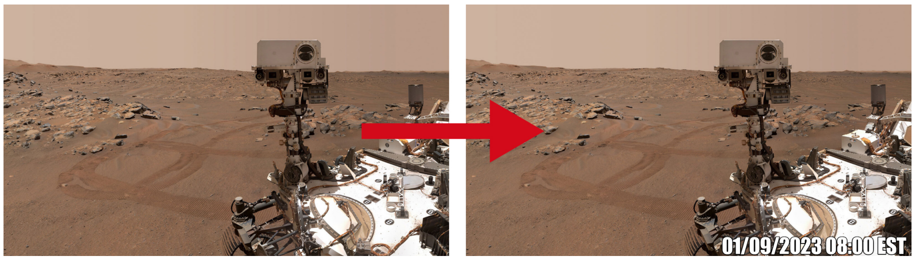

Figure 104: An example image timestamped with an arbitrary date.

4.7 Payload Integration

4.7.1 Retention

Each module of the payload sled is 3D printed out of PLA and held in place with two 1/4-20 threaded rods. The threaded rods run the length of the payload bay and are held in place with two aircraft-grade birch plywood bulk heads on either side of the bay. The aft bulkhead will have two holes that allow wires connecting the antenna to the electronics inside the bay to pass through. A U-bolt on the forward payload bay bulkhead connects the drogue parachute to the aft section of the vehicle (the payload bay and the fin can) Threaded rods are fastened to the bulkheads using 1/4-20 washers and nuts.

The SOCS sled will be oriented at 45 degrees such that it does not block the four camera units. Electronic components housed on the central SOCS sled are held in place with M3 screws and heat-set inserts.

Each 3D printed camera unit mount the vacuum formed camera housing is bolted together on the airframe with four 6-32 bolts. This ensures structural rigidity and stability.

Each antenna will be secured flat along the outside of the launch vehicle to minimize aerodynamic effects and will be held in place using non-conductive electrical tape.

4.7.2 Power Sources

SOCS current and power draw was investigated via a thorough power study that considered each component's current needs. It was found that an 11.1 V, 8000 mAh LiPo battery provides a factor of safety of 1.5 assuming the longest possible pad wait time (2 hours). It is unlikely that SOCS components will be powered for this long, and pull pin switches are used to reduce the amount of time that the system is powered and decrease the load on the battery. These switches are discussed in the next section, Section 4.7.3.

The battery is secured to its slot on the sled using at least two heavy-duty, heat-resistant zip ties. Additionally, the bottom end of the payload sled contains a slot for the battery that prevents lateral and up-and-down motion during flight. Thus, the battery is secured in all three of its axes of motion and is unlikely to move during flight.

LiPo batteries are isolated from moisture and static before flight using LiPo bags. These bags are used to transport batteries to and from launch locations and prevent battery fires inside of the lab. Once batteries are removed from their bags, appropriate precautions are taken to shield the batteries from moisture.

Because no SOCS components operate using 11.1V, a 5V buck converter and a fuse is used to transform this voltage from the 11.1V battery output to the 5V Raspberry Pi input. Several components connected to the Pi operate on 3.3V, and a logic-level shifter is used to convert this voltage and split GPIO outputs as appropriate. Additional details on electronics and schematics can be found in Section 4.4.1.3.

4.7.3 Safety Switches

A singular pull-pin switch mechanically arms and powers SOCS immediately prior to program initialization and vehicle take-off. This omron ss-5gl is rated for 625 W AC (125VAC at 5A). At around 12V, this switch will experience a current of 4A, resulting in approximately 48 W of power being passed through the switch, well within operational tolerances. This switch is located inside of the bay with a small access hole through which the pin is inserted. The switch ensures that SOCS components can be armed at the correct time, the IMU does not prematurely detect launch and landing, and the battery is not discharged prior to flight. When the pin is inserted into the bay, the circuit made by the switch is open and electronics are powered off. When the switch is pulled out of the bay, the circuit is completed and electronics can receive power from the LiPo battery. Discussions of these failure modes are presented in the Payload section of the FMEA tables (Section 5.3).

5 Safety

5.1 Safety Officer

Megan Rink is the 2022-23 HPRC Safety Officer. Megan is responsible for ensuring the safe operation of lab tools and materials, including, but not limited to, drill presses, hand tools, band saws, power tools, flammable items, and hazardous materials. Megan is required to attend all launches and must always be present during the construction of the launch vehicle, payload, and associated components. Additionally, she is responsible for maintaining all lab space and equipment up to and exceeding NASA, MAE, and Environmental Health and Safety standards. This includes, but is not limited to, displaying proper safety information and documentation, maintaining safe operation of a flame and hazardous materials cabinet, keeping lab inventory, and stocking an appropriate first aid kit.

5.2 Hazard Analysis Methods

Safety documentation will continue to be performed through FMEA analysis and Likelihood-Severity (LS) matrices. These matrices detail each hazard and the corresponding causes, effects, and LS, as determined by the matrix. Additionally, mitigation methods for each hazard have been analyzed and the LS after mitigation has been determined.

Verification of safety procedures is checked through various sources, including but not limited to, inspection, Launch Day checklists, NAR Safety Code, TRA Safety Code, and HPRC standards.

Below is the Likelihood-Severity matrix upon which all of the FMEA tables are based. Failure modes are defined as any hazard that is color coded as orange or red. LS ratings both before and after mitigation are analyzed systematically in order to determine the percent likelihood and percent severity of failure for each launch vehicle system. There are additional matrices to better visualize the LS percentages both before and after mitigation for each subsection.

Table 21: LS Matrix Key

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	1A	2A	3A	4A
	B Unlikely	1B	2B	3B	4B
	C Likely	1C	2C	3C	4C
	D Very Likely	1D	2D	3D	4D

5.3 Failure Modes and Effects Analysis (FMEA)

Table 22: Structures PRA and FMEA

Structures Risk Assessment Before Mitigation					
		Level of Severity			
15.00% result in failure modes		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	0%	0%
	B Unlikely	0%	15.38%	0%	7.69%
	C Likely	7.69%	7.69%	15.38%	15.38%
	D Very Likely	15.38%	7.69%	7.69%	0%

Structures Risk Assessment After Mitigation					
		Level of Severity			
0.00% result in failure modes		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	15.38%	15.38%	15.38%	0%
	B Unlikely	15.38%	7.69%	0%	7.69%
	C Likely	0%	0%	15.38%	0%
	D Very Likely	0%	0%	0%	0%

Launch Vehicle Structure							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to and from Bulkheads							
S.B.1	Failure of U-bolts			4A	Distribution of load during construction	4A	(1) Analysis: FEA simulations in Section 3.2.9 of CDR document (2) Test: Structural Testing on Nosecone Bulkheads and U-bolts detailed in FRR 7.1.1.7
S.B.2	Failure of nose cone bulkhead bolts	Excessive deployment force	Ballistic reentry	4A		4A	(1) Analysis: FEA simulations in CDR 3.2.9 (2) Test: Structural Testing on Nosecone Bulkheads and U-bolts detailed in FRR 7.1.1.7
S.B.3	Bulkhead cracking	Excessive stress around bolt connections		3D		3B	Test: Bulkhead stress test detailed in FRR 7.1.1.6-7.1.1.7.
S.B.4	Bulkhead delaination	Excessive axial stress from shock cord connections	Separation of bulkhead from airframe	3D		3B	Test: Bulkhead stress test detailed in FRR 7.1.1.6-7.1.1.7.
S.B.5	Separation of bulkhead from airframe	Softened epoxy Excessive force from latch connections		3D	Load management during construction	3B	Inspection: LVD 1
S.B.6	Exposure of bulkhead to hot ejection gases	Excessive heat from ejection charges or motor	Stabilization of LV is changed	3B	Ensure LV is kept in optimal temperatures	3A	Test: Full-scale ejection testing performed on 2/24/23.
Hazards to and from Removable Fin System							
S.F.1	Failure of #8 bolts securing assembly to airframe	Excessive force from motor, excessive force on landing	CATO or loss of stability, damage to LV components (potentially repairable)	3B		3A	Test: Structural testing on threaded rods and bolts completed on 1/23/23.
S.F.2	Buckling of fin can threaded rods or fin runners		CATO, loss of stability	3B	Bolts and rods are designed to have a high safety factor, as supported by preliminary calculations.	3A	Test: Structural testing on threaded rods and bolts completed on 1/23/23.
S.F.3	Thrust plate failure	Excessive force from motor, excessive force on landing	CATO, damage to airframe	3A	Material decision during design phase	2A	Analysis: FEA simulations in CDR 3.2.9
S.F.4	Fin breaks	Excessive force upon landing, fin flutter	Loss of stability during flight	3B	Fiberglass reinforcement during construction	1C	Test: Fin Bending test performed on 2/24/23. See detailed explanation in FRR 7.1.1.5.

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Launch Vehicle Structure							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
S.F.5	Centering ring cracks or delaminates	Excessive force from motor	Motor is not securely held, CATO, loss of stability	3A	Proper construction techniques	1A	Inspection: LVD 1
S.F.6	Motor retainer comes un-epoxied	Epoxy is weakened by heat	Motor descends separately from the launch vehicle	2B	Ensure epoxy is rated for expected temperatures	1A	Inspection: SDR 1
Hazards to and from Airframe							
S.A.1	Fin can body tube cracking	Hoop stress from internal pressure	Jettison of motor and motor tube, CATO, Inability to relaunch LV	4A	Propellant grains are securely fastened in a motor tube and motor construction is assisted by Tripoli personnel	2A	(1) Analysis: FRR 3.6.11 (2) Test: Full scale Ejection testing detailed in FRR 7.1.1.10.
S.A.2	AV bay body tube cracking	Hoop stress from internal pressure	Inadequate axial force generated by black powder to separate LV sections	3B	Calculations are performed in order to get an accurate measurement for the correct amount of black powder, ejection tests are performed prior to each and every flight	3A	See S.A.1 Verification
S.A.3	Body tube zippering	Excessive forces from shock cord	Airframe rupture	2B	Fiberglass body tube and rigid, appropriately sized couplers are used in the full scale LV to prevent zippering	2A	(1) Inspection: FRR 3.3.1.1 (2) Demonstration: FRR 7.1.1.11.
		Parachute ejection at excessively low altitude					
S.A.4	High-energy impact with ground	Late or no parachute deployment		3B	An appropriate recovery system is used to slow the LV for a safe landing	3A	(1) Inspection: FRR 3.5.1 (2) Demonstration: FRR 6.1
S.A.5	LV section collision	Shock cord of insufficient length		3B		3A	Inspection: FRR 3.5.5
S.A.6	Airframe exposure to water	LV touchdown in wet area of launch field	Airframe disintegration/rupture	2C	The full scale LV airframe is made of waterproof fiberglass	2B	Inspection: FRR 3.3.1.1
		Inclement weather	CATO		The subscale LV is made of blue tube, so it will not be launched in inclement weather conditions		
S.A.7	Airframe exposure to burning black powder	Uncontrolled ejection charges	Airframe disintegration/rupture	1D	The airframes of both the subscale and the full scale LVs are constructed from heat-resistant materials	1C	Test: FRR 7.1.1.11
S.A.8	Body tube abrasion	High energy impact with the ground	Changes in LV center of pressure/stability, irreversible damage to LV	1C	An appropriate recovery system is used to slow the LV for a safe landing	1B	Inspection: FRR 3.5.1
		Parachute re-inflation upon landing, causing the body tube to be dragged			Launches do not occur in high winds	1A	Inspection: FRR 3.5.1

Table 23: Recovery PRA and FMEA

Recovery Risk Assessment Before Mitigation					
41.10% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	0%	10.53%
	B Unlikely	0%	0.00%	10.53%	0.00%
	C Likely	10.53%	10.53%	5.26%	5.26%
	D Very Likely	10.53%	10.53%	21.05%	0%

Recovery Risk Assessment After Mitigation					
15.79% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0.00%	21.05%	5.26%	5.26%
	B Unlikely	10.53%	10.53%	15.79%	5.26%
	C Likely	10.53%	5.26%	10.53%	0%
	D Very Likely	0%	0%	0%	0%

Recovery System							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to/from Parachutes and Shock Cord							
R.C.1		Insufficiently powered altimiters		2D	Altimeter battery checked immediately prior to flight	2A	Inspection: Checklist Section AV Bay Assembly
R.C.2		Insufficient black power charges to seperate LV components		3D	Dual-redundant black powder charges which are tested for efficacy before flight	3B	Test: Fullscale Ejection Testing
R.C.3		Shear pins of an excessive diameter		2D	4-40 shear pins are used	2C	Test: Checklist section FInal Measurements
R.C.4	No parachute deployment	Excessively moist black powder	LV goes ballistic, LV high-energetic touchdown	1D	Black powder is properly stored, no launches occur in inclement weather	1C	Inspection: All energetics are stored in a flame cabinet until launch day.
R.C.5		Parachute contact with hot ejection gases		4C		4B	Inspection: FRR 3.5.1
R.C.6		Parachute contact with motor flame		1C		1B	Test: FRR 7.1.1.11
R.C.7	Parachute rips and tears	Parachute entanglement during seperation/deployment	Poor parachute performance, high-energetic touchdown	2C	Parachutes are wrapped in fireproof Nomex like a burrito in order to insulate them from heat and tension	2B	Demonstration: FRR 6.1
R.C.8	Shock cord disconnection	Loose quick links		3D	Quick links are tested immediately prior to flight	3B	Inspection: 3.5.2.3
R.C.9	Shock cord rip	Excessive flight forces on shock cord		1D	Shock cords are rated for up to 6000 lbf of flight forces	1C	Inspection: FRR 3.5.1
R.C.10	Excessive force on shock cord	Late parachute deployment		3D	Estimated forces on the recovery system are calculated and verified	3C	Analysis: FRR 3.6.8
R.C.11	Parachute falls off	Manufacturing defect	LV goes ballistic, LV high-energetic touchdown	4A	No mitigation possible, manufacturing defect is likely to go unnoticed until the parachute goes through the stresses of flight	4A	(1) Inspection: FRR 3.5.1 (2) All parachutes are inspected for defects before launch and are repaired if any damages are found.
Hazards to/from Avionics and Black Powder							
R.A.1	Main parachute deployed at apogee	Wires for main and drogue parachutes mixed up, wires misrouted	Wind drift LV tree landing Personnel made to walk considerable distances during recovery	3C	Avionics utilize labeled quick-connects to prevent mix-ups	2A	(1) Inspection: FRR 3.5.6 (2) Inspection: FRR Checklist Section AV Bay
R.A.2	Shear pins shear prematurely	Shear pins are of an insufficient diameter	Premature section separation	3B	4-40 shear pins are utilized and have been chosen for their known for their strength	3A	(1) Inspection: FRR Checklist Section AV Bay (2) Test: 7.1.1.8
R.A.3	Premature section separation	Premature black powder detonation	Failure to reach intended apogee	3C	Altimeters are set properly and verified by team leads	3B	(1) Inspection: FRR Checklist Section AV Bay (2) Test: FRR 7.1.1.1
R.A.4	Late section separation	Delayed black powder detonation	Excessive force on shock cords, ballistic landing	3D	Altimeters are set properly and verified by team leads	3C	Demonstration: FRR 3.5.1
R.A.5	Excessive wind drift	Premature parachute deployment	LV tree landing	3B	Avionics utilize labeled quick-connects to prevent mix-ups	2A	Inspection: FRR 3.5.1
R.A.6	Premature black powder detonation	Sympatheticc main/drogue black powder detonation	Parachute damage	1C	AV blast caps face in opposite directions	1B	Inspection: FRR 3.5.1

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Recovery System							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
R.A.7	Abrupt pressure changes in AV bay	LV separates while altimeters are still armed	Black powder detonates while altimeters are being armed	3C	Pull-pin switches are used to arm altimeters, preventing jostling that can occur with screw switches	2B	Inspection: FRR 3.5.6.4
R.A.8	LV flight without armed altimeters	No section separation	Ballistic descent	1D	Recovery checklists are used to ensure altimeters are installed in rockets	1B	Inspection: FRR Checklist Section AV Bay

Table 24: Aerodynamics PRA and FMEA

Aerodynamics Risk Assessment Before Mitigation					
63.63% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	9.09%	0%
	B Unlikely	0%	9.09%	0%	0.00%
	C Likely	18.18%	0.00%	0.00%	9.09%
	D Very Likely	0.00%	27.27%	27.27%	0%

Aerodynamics Risk Assessment After Mitigation					
27.27% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0.00%	18.18%	0.00%	0%
	B Unlikely	18.18%	0.00%	9.09%	9.09%
	C Likely	0%	27.27%	18.18%	0%
	D Very Likely	0%	0.00%	0%	0%

Aerodynamics							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to/from Motor							
Ae.M.1	Uneven pressure buildup in motor tube	Defects in propellant grain	CATO	2D	AeroTech Motors are used for their low likelihood of catastrophic failure	2C	Inspection: CDR 3.2.8.11
Ae.M.2	Motor ejection	Loose motor retainer Centering ring epoxy fail Crack in fin can body tube	CATO	2D	Motor assembly performed under the guidance of certified Tripoli professionals Epoxy is allowed to fully cure Body tubes are made of fiberglass in order to combat alial compression	2C	(1) Inspection: Checklist Section Motor Assembly (2) FRR 3.2.9
Ae.M.3	Premature ignition	Ignition system static discharge	Severe personnel burns, LV flight without armed altimeters	3D	Ignition systems provided by certified NAR/Tripoli professionals	3B	Inspection: Checklist Section Launchpad
Ae.M.4	Cracks in propellant grain	Torsional load applied to grains during assembly	Uneven thrust curve, CATO	3D	Motor assembly performed under the guidance of certified Tripoli professionals	3C	Inspection: Checklist Section Motor Assembly
Hazards to Aerodynamics							
Ae.A.1	bird strike	bird	CATO	4C	The LV has an optimal stability margin calculated in RockSim and measured immediately prior to launch	4B	Analysis: FRR 3.6.4
Ae.A.2	LV weathercocking	Vehicle over-stability	Failure to reach intended apogee	3A	The LV has an optimal stability margin calculated in RockSim and measured immediately prior to launch	2A	Analysis: FRR 3.6.4
Ae.A.3	LV division diverges from expected trajectory	Vehicle instability	Failure to reach intended apogee Ballistic descent	3D	The LV has an optimal stability margin calculated in RockSim and measured immediately prior to launch	3C	Analysis: FRR 3.6.4
Ae.A.4	Fin flutter	Transonic LV speeds	Fin structural damage	1C	The LV will not fly at speeds in the transonic range	1B	Analysis: FRR 3.6.2
Ae.A.5	Centering ring structural failure	Unexpectedly high motor thrust Weak epoxy connections	Motor goes through LV	2D	Fins are made with aircraft-grade epoxy throuh proven construction methods	2C	Demonstration: FRR 6.1
Ae.A.6	Fin damage	Fin flutter	Fin loss Divergence from intended trajectory Vehicle instability	1C	The LV will not fly at speeds in the transonic range	1B	Analysis: FRR 3.6.2
Ae.A.7	Abnormal thrust curves	Propellant grain gaps, cracks, holes, and bubbles	Failure to achieve intended apogee Excessive forve applied to structural bulkheads	2B	AeroTech Motors are used for their low likelihood of catastrophic failure	2A	Analysis: FRR 3.6.2

Table 25: Payload PRA and FMEA

Payload Risk Assessment Before Mitigation					
72.72% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	9.09%	0%
	B Unlikely	0%	0.00%	0%	0.00%
	C Likely	0.00%	9.09%	9.09%	0.00%
	D Very Likely	9.09%	36.36%	27.27%	0%

Payload Risk Assessment After Mitigation					
27.27% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0.00%	9.09%	0.00%	0%
	B Unlikely	0.00%	9.09%	9.09%	0.00%
	C Likely	9.09%	18.18%	9.09%	0%
	D Very Likely	18.18%	18.18%	0%	0%

Payload							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to/from Payload Structures							
Pa.S.1	Scratches on cupula surface	High energy contact between cupola and ground	Blurred or obscured camera image	3C	Triple redundant, top cupola will not be in contact with the ground	3B	See PD 6 verification
Pa.S.2	Structural deformation of cupula		Obscures camera image and damages the structure of the mounted camera	2C	Triple redundant, top cupola will not be in contact with the ground, installing cupolas without epoxy so they are removable	2B	See PD 6 verification
Pa.S.3	Cracking/breaking to the anntenna	High energy impact between the anntenna and the ground	Antenna will no longer be able to recieve commands	2D	Two antenna on different sides of launch vehicle to ensure that one always lands sky-upwards, recovery system in place to drastically slow down LV to minimize force between LV and ground, the whole antenna will be secured with tape and a protective cover will be added on the leading edge of the fin	2C	Inspection: FRR 4.4.1.1
Pa.S.4	Cracking/breaking of camera system	High energy impact between camera and launch vehicle	Camera will no longer be able to execute commands recieved by the antenna	3D	Camera will be fixed in place to the outside of the LV, camera mount designed to prevent movement from the camera upon high energy impact, recovery system in place to minimize force between LV and ground	2D	Inspection: FRR 4.4.1.1
Pa.S.5	Cracking/breaking of payload sled	Impact between the components of the payload sled and the inside of the launch vehicle during launch	Loss of power to payload electronics, loss of communication between the Raspberry Pi and the antenna	1D	Payload sled attached to two 1/4-20 threaded rods which will be secured by at least two nuts per side on a bulkhead that will keep the sled from moving around inside the payload bay, payload sled will be 3D printed so that it can withstand the impact force when the LV comed in contact with the ground	1C	Inspection: FRR 4.4.2
Pa.S.6	Payload electronics cables shear/fraying	Friction due to contact between cables and sled		3D	Payload sled will be designed to secure each cable in place while allowing enough room to not constrict cables	3C	Inspection: FRR 4.4.2
Pa.S.7	Camera obstruction	Payload parachute, fins, fincan, and/or shock cord in line of sight of the camera	Failure of camera to take clear pictures of launch vehicle's surroundings	3A	Each camera will be placed between the fins and near the top of the fin can to minimize fin obstruction, launches not conducted during inclement weather	2A	Inspection: FRR 4.4.1.2.2
Hazards to/from Payload Electronics							
. . . Pa.E.1	Antenna does not have clear view	Landing orientation	Weak/corrupted signals or no reciept of commands	2D	Multiple antennas on different sides of the launch vehicle to ensure that one will always land sky-upwards	2C	Inspection: FRR 4.4.1.1
Pa.E.2	Damage to LiPo bettery connection/low power	LiPo battery is not charged fully Friction due to contact between cable and sled	Loss of power to Raspberry Pi and camera	3D	Voltage of battery measuerd before each launch, all connections and wires are secured to the payload sled	2D	Inspection: FRR 4.5.3

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Payload							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Pa.E.3	Overvoltaging of elctronic components	Voltage from LiPo battery is higher than components can withstand	Electronics get fried and are no longer useable	2D	Use of buck converters to regulate voltage going into components	1D	Inspection: FRR 4.4.1
Pa.E.4	Wires shorting together on circuit board	Wired are too loosely connected and come in to contact with each other	Incorrect voltages are passes through the circuit, excessive current flow, possible fire hazard	2D	All exposed wire is covered in shrink wrap and secured with electrical tape	1D	Inspection: FRR 4.4.1

Table 26: Hazards from Environment PRA and FMEA

Hazards From Environment Risk Assessment Before Mitigation					
53.83% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	0%	15.38%
	B Unlikely	0%	15.38%	0%	15.38%
	C Likely	15.38%	23.08%	15.38%	15.38%
	D Very Likely	7.69%	0.00%	7.69%	0%

Hazards From Environment Risk Assessment After Mitigation					
23.07% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	7.69%	23.08%	7.69%	0%
	B Unlikely	15.38%	7.69%	0%	7.69%
	C Likely	15.38%	0%	15.38%	0%
	D Very Likely	0%	0%	0%	0%

Hazards from Environmental Factors							
Label	**Hazard**	**Cause**	**Effect**	**LS Before**	**Mitigation**	**LS After**	**Verification**
Hazards to LV Structure							
E.S.1	LV contact with water	LV touchdown in irrigation ditch	Airframe structural damage	4C	The full scale LV is made of fiberglass, a water-resistant material	4B	Inspection: FRR Payload 4.4
E.S.2	Contact between LV and birds	Birds flying in proximity to LV flight path	Airframe abrasion/rupture	2B	Airways in the flight path of the LV are confirmed to be clear before flight by the RSO	2A	(1) Inspection: Checklist section Launchpad (2) Inspection: NAR High Power Rocket Safety Code #9
E.S.3	LV landing in tree	Large gusts of wind contributing to wind drift	Inability to recover rocket, mission failure	3D	Launches do not occur if wind at the launch field exceed 20 mph	3C	
Hazards to Personnel							
E.Pe.1	Personnel contact with sunlight and heat	Lack of personal protective equipment and devices Hot launch conditions	Heat stroke, sunburn	4B	Personnel are provided with sunscreen and are highly encouraged to bring sunglasses, a tent is set up for personnel to take shelter	2B	Inspection: Checklist section AV Bay Assembly
E.Pe.2	Personnel slips, trips, and falls	Uneven ground Sharp rocks on the ground Working near/next to irrigation ditches	Bruising, broken bones, concussion	4C	closed toe shoes to launch day activities, only recovery and launch pad personnel are permitted on the launch field itself.	3C	Inspection: Checklist sections Launchpad, Recovery
E.Pe.3	Rain or hail	Inclement weather conditions	Rips, dents, and/or holes in airframe, personnel injury	3C	during inclement weather. If inclement weather rolls in while at the launch field, the launch may be postponed and personnel will take shelter	3A	Inspection: NAR High Power Rocket Safety Code #9
E.Pe.4	Lightning strike			1D		1A	
E.Pe.5	Wet and icy terrain		Personnel slips, trips, and falls	2C		1C	
E.Pe.6	Pollen or other allergens present at launch site	Seasonality	Potentially severe personnel allergic reactions	3B	Personnel are asked to make the Safety Officer aware of any environmental allergies. Antihistamines and other allergy medication is kept in the Launch Day Safety Box.	2B	Inspection: Checklist sections Launchpad, Recovery
Hazards to Payload System							
E.Pa.1	Payload contact with water	LV touchdown in irrigation ditch or other wet area		1C	Mitigation pending	1C	Inspection: FRR 4.4.2
E.Pa.2	Lightning strike	Inclement weather conditions	Payload electronics damage	3C	Launches are not conducted in inclement weather	2A	Inspection: NAR High Power Rocket Safety Code #9
Hazards to Mission Success							
E.M.1	Damp propellant grains	High humidity conditions	No motor ignition, inability of LV to fly	1D	Launches are not conducted in inclement weather	1B	Inspection: NAR High Power Rocket Safety Code #9
E.M.2	Damp black powder grains			2D		1B	
E.M.3	LV flight in proximity to bird flight	Flight path not clear at launch	Diverted flight path, failure of LV to reach intended apogee	2B	Airways in the flight path of the LV are confirmed to be clear before flight by the RSO	2A	Inspection: NAR High Power Rocket Safety Code #9
E.M.4	Unauthorized aircraft in designated airspace	Aircraft knowingly ignores restricted airspace designations	Any and all launches suspended until further notice	1D	RSO has contact with local air traffic controllers in order to	1A	RSO is contacted by air traffic control

Table 27: Hazards to Environment PRA and FMEA

Hazards to Environment Risk Assessment Before Mitigation					
53.84% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	0%	0%	0%
	B Unlikely	0%	15.38%	0%	7.69%
	C Likely	7.69%	7.69%	15.38%	15.38%
	D Very Likely	15.38%	7.69%	7.69%	0%

Hazards to Environment Risk Assessment After Mitigation					
23.08% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	15.38%	15.38%	15.38%	0%
	B Unlikely	15.38%	7.69%	0%	7.69%
	C Likely	0%	0%	15.38%	0%
	D Very Likely	0%	0%	0%	0%

Hazards to Environmental Safety							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Wildlife							
E.W.1		Motor ignition		3D	Ground areas around the launch pad are free of flammable debris, launch rails are fitted with blast plates to deflect exhaust gases away from the ground	3B	
E.W.2		Black powder ignition		2C	Recovery personnel are equipped with a fire extinguisher	1C	
E.W.3	Fire on launch field	Payload battery explosion	Crop damage, wildlife injury, personnel burns	2D		2B	Inspection: NAR Safety Code #7
E.W.4	Payload battery explosion	Puncture of battery leading to contact with moisture Excessive heat surrounding battery	HazMat leakage onto the launch field, water contamination, fire on launch field	3D	Payload batteries are isolated from moisture, abrasion, and heat	3B	Inspection: NASA 2.22
E.W.5	Contact between LV components and birds	Birds flying in proximity to LV flight path	Wildlife injury, wildlife death, bird migration patterns may become obstructed	1C	Airways in the LV flight path are confirmed to be clear by the RSO	1A	Inspection: Checklist Section Launch Pad
E.W.6		Rips and tears in Nomex		2A	Nomex is rated to withstand flight forces and is flame resistant	1A	
E.W.7	Permanent jettisoning of Nomex sheet	Nomex connection breakage	Contamination of wildlife habitats, food, supply, and water supply	1A	Nomex sheets are connected to shick cord by steel quick links, quick links are confirmed to be tight by the safety officer prior to	1A	
E.W.8	Permanent jettisoning of parachute	Quick link is not tightened before parachute is inserted into LV	LV descends at an unsafe speed	1A	Quick links are tightened before parachute is inserted into LV	1A	Inspection: Checklist Section Main/Drogue Recovery Assembly
E.W.9		Battery explosion		2B		2A	
	HazMat deposit in irrigation ditch	Explosion byproducts	Toxic chemicals remain in soybeans by wildlife and humans				
E.W.10	Wildlife consumes toxins	HazMat littering	Wildlife develop digestive issues or incur injury or death	3D	All protective insulation is biodegradable, payload batteries are protected from puncture and heat	3C	Inspection: FRR 3.5.4
E.W.11	CATO	Motor defects	Wildlife incur injury or death, water supply contaminated	2D	AeroTech motors are selected for their low likelihood of catastrophic failure	2C	The team has used and will continue to use AeroTech motors due to their reliability during launch.
E.W.12	LV landing in tree	Premature parachute deployment High wind drift	Destruction of habitats	4C	Recovery systems are tested away from trees	4B	Test: FRR 7.1.1.11
E.W.13	Emission of microplastics	High usage of single-use plastics	Wildlife infertility, bodily inflammation, choking/digestive hazard	4B	Use of reusable containers encourages team-wide	4B	Inspection: Team Safety Briefing Presentations
Hazards to Land							
E.L.1	Forceful impact of LV with ground	Late or no deployment of parachute	Permanent ruts or dips in the launch field, inability for field to be used for future farmin endeavors	3A	Use of altimeters in parachute deployment to ensure accuracy	2A	

Continued on Next Page

Hazards to Environmental Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
E.L.2	Non-recoverable landing in tree	Premature parachute deployment High wind drift	Permanent damage to tree	4C	The recovery system is labeled and documented so that assembly mistakes are unlikely	4B	Inspection: FRR 3.5
E.L.3	Fire at launch field	CATO Motor ignition Black powder detonation Payload battery explosion	Tree destruction, inability for field to be used for future farming endeavors	2D	Ground areas around the launch pad are free of flammable debris, launch rails are fitted with blast plates to deflect exhaust gases away from the ground	2B	
E.L.4	Removable ballast comes dislodged from LV	Excessive forces on LV druing flight	Metal in ballast contaminates farmland at launch sites	3A	Ballast is sufficiently and securely epoxied into LV Any metal is completely encased in epoxy, preventing any contamination	1A	Inspection: NAR High Power Rocket Safety Code #3
Hazards to Air/Water							
E.A.1	Greenhouse gas emissions	Transportation to/from launch field Motor and black powder combustion by-products Use of power-drawing electronics	Air pollution, contribution to climate change	4A	Team members are highly encouraged to carpool to launches and to either take public transportation, bike, or walk to regularly scheduled meetings	4A	(1) Inspection: Aerotech Motor SDS (2) Safety Briefing Presentation Slides
E.A.2	Emission of microplastics	Use of single-use plastics	Air and water contaminiation	4A	Use of single-use plastics will be limited in LV design	4A	(1) The final LV design does not include any single-use plastics. (2) Inspection: FRR 3.2
E.A.3	Chemical off-gassing	Working with HazMats		1B	HazMats that off-gas are only used in well-ventilated areas	1A	Inspection: HPRC Safety Handbook
E.A.4		CATO		2B	AeroTech Motors are used for their low likelihood of catastrophic failure	2A	
E.A.5		Motor ignition		2B	Under nominal circimstances, LV operation produces few combustion byproducts	2A	Demonstration: FRR 7.1.1.11
E.A.6		Black powder detonation		1B		1A	
E.A.7	Smoke emission	Man-made wildfire		2D	Heat sources are not allowed within 25 feet of LV motors	2B	Inspection: NAR High Power Rocket Safety Code #3
E.A.8	Creation of vaporized hydrochloric acid		Air pollution	1B	AeroTech motors do not produce enough by-product to create hydrochloric acid	1B	Insection: Aerotech Motors Safety Data Sheet

Table 28: Hazards to Personnel PRA and FMEA

Personnel Risk Assessment Before Mitigation					
62.52% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	0%	3.13%	6.25%	3.13%
	B Unlikely	6.25%	3.13%	6.25%	6.25%
	C Likely	0.00%	6.25%	9.38%	3.13%
	D Very Likely	3.13%	28.13%	9.38%	6.25%

Personnel Risk Assessment After Mitigation					
21.88% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	15.63%	0%	6.25%	9.38%
	B Unlikely	6.25%	21.88%	6.25%	0.00%
	C Likely	3.13%	21.88%	9.38%	6.25%
	D Very Likely	0%	0%	6.25%	0%

Hazards to Personnel Safety							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Skin and Soft Tissue							
Pe.S.1	Slips, trips, and falls	Material spills around the lab Wet/uneven launch field conditions	Skin abrasion/bruising	3B	After handling of liquid/powder assembly materials, lab floors will be inspected for material spill. Only required recovery personnel are allowed on launch field to recover rocket; closed toe, heavy duty shoes are required.	1B	(1) Inspection: HPRC Safety Handbook (2) Inspection: Checklist Section
Pe.S.2	Personnel fingers caught in bandsaw blade	Bandsaw blade contact with clothes and/or jewelry Personnel misunderstanding of bandsaw operation	Skin and muscle tear/abrasion	2D		2C	
Pe.S.3	Contact with hot soldering iron	Personnel misunderstanding of soldering system	Mild to severe burns	3C	Personnel working with manufacturing equipment are trained in proper use of machinery. Proper PPE is always used.	3B	Inspection: HPRC Safety Handbook
Pe.S.4		Launch rail tipping with assembled LV		2C	Launch rails, provided by TRA personnel, have a locking mechanism that is engaged when the LV is righted.	2B	Inspection: Checklist Section Launch Pad
Pe.S.5		Sideways propulsion from severe instability		2B	The stability margin of the LV is no less than 2.0.	1B	Inspection: NASA 2.14
Pe.S.6	Personnel collision with LV	LV touchdown within close proximity to personnel	Skin and muscle abrasion/tear	1B	The LV is angled 20° away from personnel; personnel are instructed to keep eyes on all falling LVs and keep others aware.	1A	Inspection: NAR Safety Code
Pe.S.7	High load places on personnel muscle	Lifting heavy LV components	Muscle strain/tear	4C	At least two persons carry the LV while it is fully assembled and proper lifting techniques are utilized	4A	Inspection: Checklist Section Launch Pad
Pe.S.8	Bug sting/bite	Prolonged exposure to wildlife during launch day activities	Itchiness, rash, and/or anaplylaxis	4A	Bug spray is provided to team members during launch day and there is appropriate knowledge on the proper use of EpiPens	3A	Inspection: Checklist Section Night Before Checklist
Pe.S.9	Personnel contact with ejection charges	Contact with unknown black powder after touchdown	Mild to severe burns and abrasions	3C	Personnel approaching the LV are provided with Nomex gloves; LV sections are inspected for unblown charges prior to handling.	3B	Inspection: Checklist Section Recovery
Pe.S.10	Contact with large, airborne shrapnel	CATO	Severe skin abrasion/laceration	2D	Personnel are separted from the launch pad according to the minimum distance table. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2B	Inspection: NAR High Power Rocket Safety Code
Pe.S.11	Contact with small, airborne shrapnel	Sanding, cutting, or drilling brittle or granuar materials	Cuts and bruises	3C	Protective eye and face equipment are provided to personnel working with power tools.	2C	
Pe.S.12	Exposure to uncured epoxy fluid	Working with epoxy		3A		2A	
Pe.S.13	Exposure to vaporous chemicals	HazMat off-gassing	Skin rash, skin irritation	2A	Nitrile gloves and other appropriate forms of PPE are provided to personnel working with hazardous liquid/vapor materials.	2A	Inspection: HPRC PPE Cabinet
Pe.S.14	Excessive amount of walking	Far away LV touchdown	Muscle sprain, shin splints	3A	The LV is equipped with a GPS tracker;nif the LV is sufficiently far away from the launch site, recovery personnel are driven to the recovery site.	2A	Inspection: FRR Checklist Section Field Recovery
Hazards to Bones and Joints							

Continued on Next Page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Personnel Safety							
Pe.B.1	Slips, trips, and falls	Material spills around the lab. Wet/uneven launch field conditions	Bone fracture, bone bruise, dislocation	1D	After handling of liquid/powder assembly materials, lab floors will be inspected for material spill. Only required recovery personnel are allowed on launch field to recover rocket; closed toe, heavy duty shoes are required.	1C	Inspection: FRR Checklist Section Field Recovery
Pe.B.2	Excessive amount of walking	Far away LV touchdown	Stress fracture	2D	The LV is equipped with a GPS tracker; the LV is sufficiently far away from the launch site, recovery personnel are driven to the recovery site.	2C	Inspection: FRR Checklist Section Field Recovery
Pe.B.3	Personnel finger caught in bandsaw blade	Bandsaw blade contact with clothes and/or jewelry; Personnel misunderstanding of bandsaw operation	Broken bone	2D	Personnel working with manufacturing equipment are trained in proper use of machinery. Proper PPE is always used.	2C	Inspection: HPRC Safety Handbook
Pe.B.4	Contact with large, airborne shrapnel	CATO	Bone fracture requiring immediate medical attention. Limb loss.	2D	Personnel are instructed by the RSO to stand a minimum distance away from the launch pad. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2C	(1) Personnel are separated from the launch pad according to the minimum distance table. (2) AeroTech motors are chosen for their low likelihood of catastrophic failure.
Hazards to Respiratory System							
Pe.R.1	Exposure to epoxy fumes	Working with epoxy	Difficulty breathing, respiratory irritation.	2C	Personnel wirking with epoxy are provided particle masks. An oxygen sensor in the lab goes off when there is insuffficient oxygen.	2C	Inspection: HPRC PPE Cabinet and HPRC Safety Handbook
Pe.R.2	Exposure to COVID-19	Working in close proximity with infected personnel	Respiratory infection, hospitalization, death, outbreak amongst teammates.	4D	Personnel are highly encouraged to follow University guidelines for COVID-19. Personnel who have been exposed to or are infected with COVID-19 are encouraged to attend meetings virtually.	4C	Inspection: HPRC PPE Cabinet
Pe.R.3	Exposure to carcinogenic particulates	Working with fillet epoxy	Respiratory irritation and/or infection, cancer	4D	Personnel working with fillet epoxy are provided particle masks.	4C	Inspection: HPRC PPE Cabinet
Pe.R.4	Inhalation of aerosolized particulates	Sanding, cutting, and/or drilling		4B	Personnel working with materials prone to particulate production are provided with particle masks.	4A	Inspection: HPRC PPE Cabinet
Pe.R.5	Inhalation of spray paint fumes	Working with spray paint for rocket aesthetics		4B	Personnel in the vicinity of burning chemicals are provided with particle masks. Personnel are instructed by the RSO to stand a minimum distance away from burning motors.	4A	Inspection: HPRC PPE Cabinet
Pe.R.6	Inhalation of cumbustion reactants	Close proximity to LV motors and ejection charges	Respiratory irritation, difficulty breathing.	3B		3A	Personnel are separated from the launch pad according to the minimum distance table.
Hazards to Head							
Pe.H.1	Personnel contact with high-energy LV components	High-energy LV sections are in proximity to personnel at touchdown		2D	The LV has a dual-redundant recovery system. Personnel are instructed by the RSO to stand a minimum distance away from the launch pad.	2C	Inspection: NAR High Power Rocket Safety Code
Pe.H.2	Launch vehicle tipping during assembly	Launch rail assembly		3D	Launch rails, provided by TRA personnel, have a locking mechanism that is engaged when the LV is righted.	3C	Inspection: Checklist Section Launch Pad
Pe.H.3	Slips, trips, and falls	Attempting to jump through/over launch field irrigation ditches.		3D	Personnel members are made aware that jumping over ditches is strictly forbidden.	3D	Inspection: Checklist Section Recovery

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Hazards to Personnel Safety							
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Pe.H.4	Contact with large, airborne, shrapnel	CATO	Concussion, brain damage, memory loss, skull fracture	2D	Personnel are instructed by the RSO to stand a minimum distance away from the launch pad. AeroTech motors are chosen for their low likelihood of catastrophic failure.	2B	Inspection: NAR High Power Safety Code
Hazards to Eyes							
Pe.E.1	Exposure to epoxy fumes	Working with epoxy	Eye irritation, temporary blindness (from tear production), permanent or semi-permanent blindness	3D	Personnel working with epoxy will be provided with safety glasses	3C	Demonstration: HPRC PPE Cabinet
Pe.E.2	Exposure to aerosolized particulates	Working with spray paint; Sanding, cutting, or drilling		2D	Personnel cutting, sanding, or drilling will be provided with safety glasses.	2B	
Pe.E.3	Eye contact with the sun/bright sky	Maintaining eye contact with falling rockets	Temporary blindness, permanent blindness	1B	Personnel maintaining eyes with falling rockets are encouraged to wear sunglasses.	1A	Inspection: Checklist Section Recovery

5.4 Launch Procedures

FULLSCALE: IDCWTRINJPS

Launch Day Checklists

This checklist completed by: Meredith Patterson

On: 2 / 26 / 23

Checklist Legend:

PPE Required

Explosives/Energetics - DANGER!

NOTE: Any completion blocks with a personnel title require that individual either to stamp or their initials to be placed in the completion block.

NOTE: Checklists 1-3 may be completed the night before launch as long as black powder charges in bulkheads can be stored in static bags, in a flame cabinet, and transported by an L3 mentor.

NIGHT BEFORE

1. E-MATCH INSTALLATION

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	MP
Safety Officer	Megan Rink	MR
E-Match Personnel 1		
E-Match Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Bulkhead #4 (Fwd AV)	1	Struct/Recovery Box	✓
Bulkhead #3 (Aft AV)	1	Struct/Recovery Box	✓
Blue tape	1	LD Toolbox (Drawer 1)	✓
E-Match	4	LD Toolbox (Drawer 1)	✓
Scissors	1	LD Toolbox (Drawer 1)	✓
Needle nose Pliers	1	LD Toolbox (Drawer 2)	✓
Wire strippers	1	LD Toolbox (Drawer 2)	✓
Terminal block screwdriver (blue, gray, red, minus head)	1	LD Toolbox (Drawer 2)	✓
Terminal Block Screwdriver (black)	1	LD Toolbox (Drawer 2)	✓

Note: This checklist is to be executed on bulkheads 3 and 4 simultaneously

Bulkhead 4 uses labels **MP** and **MS**, Bulkhead 3 uses labels **DP** and **DS**

Number	Task	Completion
1.1	Unscrew all *UNOCCUPIED* terminal blocks on bulkheads 4 and 3	✓
1.2	Take one e-match (each) and trim the e-match to approximately 6.5 inches in length from the red cap using wire cutters	✓
1.3	Remove red plastic protective e-match cover by sliding it down the e-match wire	✓
1.4	Feed the e-match through the **MP** (Bulkhead 4) or **DP** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps	✓
1.5	Flip bulkhead over and use a fingernail to separate the two e-match wires	✓
1.6	Use wire strippers to strip 1 inch of insulation from end of each e-match wire	✓
1.7	Bend each exposed e-match wire section into a loop	✓
1.8	Place the exposed e-match wires into the **MP** or **DP** terminal block, one into each unoccupied block	✓
1.9	Tighten the screws on the **MP** or **DP** terminal block	✓

1.10	Verify e-match security by lightly tugging on the wires coming out of the **MP** or **DP** terminal block	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.11	Place the e-match head into the **MP** or **DP** blast cap	✓
1.12	Bend the e-match wire such that the head lies flat against the bottom of the blast cap	✓
1.13	Bend the e-match wire such that it is flush to the inner and outer walls of the blast cap	✓
1.14	Confirm the e-match in the **MP** or **DP** blast cap is connected to the **MP** or **DP** terminal block, respectively	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.15	Confirm that all bulkhead and wiring labels are still visible	✓
1.16	Take one e-match (each) and trim the e-match to approximately 6.5 inches in length using wire cutters	✓
1.17	Remove red plastic protective e-match cover by sliding it down the e-match wire	✓
1.18	Feed the e-match through the **MS** (Bulkhead 4) or **DS** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps	✓
1.19	Use a fingernail to separate the two e-match wires	✓
1.20	Use wire strippers to strip 1 inch of insulation from end of each e-match wire	✓
1.21	Bend each exposed e-match wire section into a loop	✓
1.22	Place the exposed e-match wires into the **MS** or **DS** terminal block, one into each unoccupied block	✓
1.23	Tighten the screws on the **MS** or **DS** terminal block	✓
1.24	Verify e-match security by lightly tugging on the wires coming out of the **MS** or **DS** terminal block	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.25	Place the e-match head into the **MS** or **DS** blast cap	✓
1.26	Bend the e-match wire such that the head lies flat against the bottom of the blast cap	✓
1.27	Bend the e-match wire such that it is flush to the inner and outer walls of the blast cap	✓
1.28	Using blue tape, tape the w-match wire to the outside wall of the blast cap	✓
1.29	Using blue tape, tape the e-match wire to the bulkhead surface	✓
1.30	Confirm the e-match in the **MS** or **DS** blast cap is connected to the **MS** or **DS** terminal block, respectively and all labels are still visible	Safety Officer: Safety Officer High-Powered Rocketry NC State

3

NIGHT BEFORE

2. MAIN BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	MP
Safety Officer	Megan Rink	MR
Black Powder Personnel 1		
Black Powder Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Bulkhead #4	1	Struct/Recovery Box	✓
Funnel	1	LD Toolbox (Top)	✓
Paper Towel Roll	1	Struct/Recovery Box	✓
Blue Tape	1	LD Toolbox (Drawer 1)	✓
Plumbers Putty	1	LD Toolbox (Top)	✓
Scissors	1	LD Toolbox (Drawer 1)	✓
Anti-static bag	1	-	✓
Safety Glasses	4	PPE box	✓
Nitrile Gloves	4	PPE box	✓
Heavy Duty Gloves	1	PPE box	✓
Main Primary Charge (4 g)	1	Energetics Box	✓
Main Secondary Charge (4.5 g)	1	Energetics Box	✓

Number	Task	Completion
2.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.3	Place the bottom of the funnel into the **MP** blast cap and carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head. Slowly lift the funnel and tap it so the black powder falls into the blast cap only	✓
2.4	Lift the e-match head so that it rests on top of the black powder	✓
2.5	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓

2.6	Place small 2-3 inch strips of blue tape over the top of the **MP** blast cap to cover the blast cap completely. Do NOT have any overlaps greater than 1mm, but leave no gaps	✓
2.7	Confirm all edges of the **MP** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.8	Wrap blue tape around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap	✓
2.9	Place the bottom of the funnel into the **MS** blast cap and carefully pour the **Main Secondary Charge** of black powder into the **MS** blast cap over the e-match head	✓
2.10	Lift the e-match head so that it rests on top of the black powder	✓
2.11	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓
2.12	Place small 2-3 inch strips of blue tape over the top of the **MS** blast cap to cover the blast cap completely. Do NOT have any major overlaps, but leave no gaps	✓
2.13	Confirm all edges of the **MS** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.14	Wrap blue tape around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap	✓
2.15	Place a sheet of paper towel on the assembly table and turn the bulkhead over above the paper	✓
2.16.1	Confirm that no black powder has leaked onto the copy paper	✓
2.16.2	If black powder has leaked, wipe copy paper clean and repeat checklist items 2.3-2.8 or 2.9-2.14 depending on which charge leaked, then repeat checklist items 2.15-2.16.2	✓
2.17	Use plumber's putty to seal any holes in the bulkhead	✓
2.18	Wrap the entire bulkhead in an anti-static bag and place in flame cabinet or locked energetics box	✓

5

NIGHT BEFORE

3. DROGUE BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	MP
Safety Officer	Megan Rink	MR
Black Powder Personnel 1		
Black Powder Personnel 2		

Required Materials			
Item	Quantity	Location	Completion
Bulkhead #3	1	-	✓
Funnel	1	-	✓
Paper Towel Roll	1	Struct/Recovery Box	✓
Blue Tape	1	LD Toolbox (Drawer 1)	✓
Plumbers Putty	1	LD Toolbox (Top)	✓
Scissors	1	LD Toolbox (Drawer 1)	✓
Safety Glasses	4	PPE box	✓
Nitrile Gloves	4	PPE box	✓
Heavy Duty Gloves	1	PPE box	✓
Drogue Primary Charge (2g)	2	AV HDX Box	✓
Drogue Secondary Charge (2.5 g)	2	AV HDX Box	✓
Anti-static bag	1	-	✓

Number	Task	Completion
3.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
3.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer: Safety Officer High-Powered Rocketry NC State
3.3	Place the bottom of the funnel into the **DP** blast cap and carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head. Slowly lift the funnel and tap it so the black powder falls into the blast cap only	✓
3.4	Lift the e-match head so that it rests on top of the black powder	✓
3.5	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓

3.6	Place small 2-3 inch strips of blue tape over the top of the **DP** blast cap to cover the blast cap completely. Do NOT have any overlaps greater than 1mm, but leave no gaps	✓
3.7	Confirm all edges of the **DP** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
3.8	Wrap blue tape around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap	✓
3.9	Place the bottom of the funnel into the **DS** blast cap and carefully pour the **Drogue Secondary Charge** of black powder into the **DS** blast cap over the e-match head	✓
3.10	Lift the e-match head so that it rests on top of the black powder	✓
3.11	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓
3.12	Place small 2-3 inch strips of blue tape over the top of the **DS** blast cap to cover the blast cap completely. Do NOT have any major overlaps, but leave no gaps	✓
3.13	Confirm all edges of the **DS** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
3.14	Wrap blue tape around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap	✓
3.15	Place a sheet of white copy paper on the assembly table and turn the bulkhead over above the paper	✓
3.16.1	Confirm that no black powder has leaked onto the copy paper	✓
3.16.2	If black powder has leaked, wipe copy paper clean and repeat checklist items 3.3-3.8 or 3.9-3.14 depending on which charge leaked, then repeat checklist items 3.15-3.16.2	✓
3.17	Use plumber's putty to seal any holes in the bulkhead	✓
3.18	Wrap the entire bulkhead in an anti-static bag	✓

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4. AVIONICS BAY ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Recovery Lead	Shaan Stephen	SS
AV Bay Personnel 1	Abhi Kondagunta	AK
AV Bay Personnel 2	Emma McDonald	EM

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Bulkhead #3	1	Struct/Recovery Box	✓
Bulkhead #4	1	Struct/Recovery Box	✓
AV Sled (assembled)	1	Struct/Recovery Box	✓
Secured Pull Pin Switch	2	AV Sled	✓
Secured RRC3 Altimeters	2	AV Sled	✓
AV Bay Airframe	1	-	✓
9V Battery	2	AV HDX Box	✓
Electrical Tape	2	LD Toolbox (Drawer 3)	✓
¼-20 nuts	4	AV HDX Box	✓
¼ -20 washers	2	AV HDX Box	✓
7/16" Wrench	1	LD Toolbox (Drawer 2)	✓
Adjustable Wrench	1	LD Toolbox (Drawer 2)	✓
Multimeter	1	LD Toolbox (Top)	✓
Safety Glasses	1	PPE Toolbox	✓

Number	Task	Completion
4.1	Use multimeter to test voltage of the primary 9V battery	Note Voltage: 9.64
4.2	Use multimeter to test voltage of the secondary 9V battery	Note Voltage: 9.64
4.3	If either battery measures below 9V, replace with a fresh battery and repeat checklist item 1.1 or 1.2	✓
4.4	Connect each battery to its battery clip on the avionics sled	✓
4.5	Place primary and secondary batteries in the avionics sled battery compartments and secure in place with electrical tape	✓
4.6	Connect lipo to GPS	✓
4.7	Turn on receiver	✓
4.8	Wait for 1 min and verify connection on receiver	✓

Number	Task	Completion
4.1	Use multimeter to test voltage of the primary 9V battery	Note Voltage:
4.2	Use multimeter to test voltage of the secondary 9V battery	Note Voltage:
4.3	If either battery measures below 9V, replace with a fresh battery and repeat checklist item 1.1 or 1.2	
4.9	Pull the Pull Pin switch out of the primary altimeter	
4.10	Verify primary altimeter beeps match the expected pattern detailed on the Primary Altimeter Beep Sheet	
4.11	Pull the pull pin switch out of the secondary altimeter	
4.12	Verify secondary altimeter beeps match the expected pattern detailed on the Secondary Altimeter Beep Sheet	
4.13	Confirm all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.14	Remove **Bulkhead #3** from its anti-static bag and ensure security of threaded rods	
4.15	Lightly tug on the wires coming out of the **DP** and **DS** terminal blocks to verify security	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.16	Slide **AV Sled** on to the threaded rods aligning switches with marks on **Bulkhead #3**	
4.17	Slide **AV Bay** over **AV Sled** ensuring the aft bulkhead is on the same side as the aft marks on the **AV Bay**.	
4.18	Replace the pull pins through the holes in the av bay and tape in place with blue tape (label P and S)	
4.19	While pointing the blast caps away from personnel, connect the **DP** and **DS** wires on the avionics sled to the **DP** and **DS** wires on **Bulkhead #3**	
4.20	Lightly tug on the wire connection to verify security and carefully insert wires into **AV Bay**	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.21	Remove **Bulkhead #4** from its anti-static bag	
4.22	Lightly tug on the **MS** and **MP** wires in the terminal blocks on **Bulkhead #4** to verify security.	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.23	While pointing blast caps away from personnel, Attach **MS** and **MP** wires on bulkhead to **MS** and **MP** wires on **AV Sled**	

Number	Task	Completion
4.1	Use multimeter to test voltage of the primary 9V battery	Note Voltage:
4.2	Use multimeter to test voltage of the secondary 9V battery	Note Voltage:
4.3	If either battery measures below 9V, replace with a fresh battery and repeat checklist item 1.1 or 1.2	
4.24	Lightly tug on the wire connection between the avionics sled and **Bulkhead #4** to verify security and carefully insert wires into **AV Bay**	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.25	Align **Bulkhead #4** with terminal blocks facing the battery side of the **AV sled**. (Note: Avoid pinching wires)	✓
4.26	Slide the **Bulkhead #4** on to the threaded rods until the bulkhead is snug with the coupler.	✓
4.27	Secure **Bulkhead #4** to the **Avionics Bay** using one ¼ inch washer and two ¼ hex nuts on each threaded rod, tighten until snug	✓
4.28	Confirm all nuts are snug and **Avionics Bay** is properly aligned	Recovery Lead:
4.29	Confirm a club member with safety glasses and gloves holds the assembled AV bay in the shade at least 6 feet from other members until further use.	Safety Officer: Safety Officer High-Powered Rocketry NC State

5.1 CAMERA HOUSING ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Payload Systems Lead	Frances McBride	FCM
Payload Structures Lead	Ashwin Sivayogan	
Personnel 1	Mason Meyer	MM

Required Materials			
Item	Quantity	Location	Completion
Payload Bay	1	-	✓
Servos	4	Payload HDX Box	✓
Camera Units	4	Payload HDX Box	✓
Camera Unit Mounts	4	Payload HDX Box	✓
Cupolas	4	Payload HDX Box	✓
#6-32 Screws and Nuts	16	Payload HDX Box	✓
Needle Nose Pliers	1	Launch Day Toolbox	✓
Phillips Head screwdriver	1	Payload HDX Box	✓

5.2 PAYLOAD ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Payload Systems Lead	Frances McBride	FM
Payload Electronics Lead	Ben Lewis	BL
Personnel 1	Myers Harbinson	MH
Personnel 2	Matthew Simpson	MSS

Required Materials			
Item	Quantity	Location	Completion
Payload Bay	1	-	✓
Fin Can	1	-	✓
Assembled Payload Sled	1	Payload Box	✓
Servos	4	Payload Box	✓
Camera Units	4	Payload Box	✓
CSI Cables	4	Payload Box	✓
Coax Cables	2	Payload Box	✓
Antennas	2	Payload Box	✓
Rivets	1	Structures HDX	✓
Zip ties	1	LD Toolbox (Top)	✓
Painter's Tape	1	LD Toolbox (Drawer 2)	✓
Multimeter	1	LD Toolbox (Top)	✓
USB-C to USB-A Cable	1	Payload Box	✓
Baofeng radio	1	Payload Box	✓
Radio to Phone Connector	1	Payload Box	✓
Electrical Tape	1	LD ToolBox (Drawer 2)	✓
Mobile Device/Computer	1	-	✓

Number	Task	Completion
5.2.1	Confirm that the long CSI cable is connected to the camera labeled "B."	✓
5.2.2	Connect the free end of the CSI cable connected to camera "B" to the innermost CSI port on the Raspberry Pi. Ensure that the metallic end of the cable is in contact with the metal pins inside of the CSI port.	✓
5.2.3	Connect the USB-C end of the cable to the Raspberry Pi.	✓
5.2.4	Connect the USB-A end to a laptop to read outputs.	✓
5.2.5	Set up a mobile hotspot with Name **HPRC2** using a mobile device.	

Number	Task	Completion
5.1.1	Confirm cameras are secured to pink mounts. Tighten nuts if necessary.	✓
5.1.2	Place a servo into camera unit mount 1 ensuring that the shaft is closer to the forward end of the mount.	✓✓✓✓
5.1.3	Secure into place with electrical tape extending around the entire support.	✓✓✓✓
5.1.4	Secure camera and pink mount onto Servo	✓✓✓✓
5.1.5	Place cupola over camera unit mount	✓✓✓✓
5.1.6	Place camera unit mount 1 into the corresponding labeled slot in the AV bay and push into place until assembly is flush with the inside of the body tube	✓✓✓✓
5.1.7	secure into place with 4 #6-32 Screws and nuts tighten with needle nose pliers	✓✓✓✓
5.1.8	Place pull pin into pull pin switch slot through camera unit mount 1	✓
5.1.9	Repeat steps 5.1.2 through 5.1.7 for the remaining camera assemblies	✓

5.2.6	Connect to the mobile hotspot **HPRC2** with password **tacholycos**	✓
5.2.7	Confirm that the Raspberry Pi is connected to the hotspot by checking the mobile device.	✓
5.2.8	Open the terminal window on the device connected to the Pi.	✓
5.2.9	Type <ssh pi@raspberrypi.local> in the command window.	✓
5.2.10	When prompted, enter the password **raspberry** in the command window. The terminal window should reflect connectivity to the Pi.	✓
5.2.11	Type **cd Payload-2022-2023** in the terminal and press enter.	✓
5.2.12	Type **python3 main.py** in the terminal and press enter to start the script.	✓
5.2.13	Shake the payload sled vertically and confirm that **LIFTOFF DETECTED** is printed to the console.	✓
5.2.14	Wait 100 seconds until **LANDING DETECTED** is printed to the console.	✓
5.2.15	Ensure that when the relay switch is pointed towards the person holding the sled and the pi is pointed away from the person holding the sled, relay switch 2 is active. A red LED should turn on.	✓
5.2.16	Rotate the sled around its central axis clockwise in 90 degree increments and track the sensed changes in orientation.	✓
5.2.17	Ensure that relay switching is functioning correctly by observing active relay LED and comparing to the supposed antenna selection. Payload ECD confirms in the box to the right.	Payload ECD: 0:2 90:2 360:2 180: 1 270: 1
5.2.18	Connect the antennas to their respective coax cables (green to green, yellow to not green).	✓
5.2.19	Transmit a test APRS signal using the Baofeng radio, making sure that the receiving antenna is upright and in the correct orientation.	✓
5.2.20	Ensure both antennas are receiving the test signal and it is being properly decoded and stored on the Pi.	Payload ECD:
5.2.21	Disconnect the antennas from their respective coax cables.	✓
5.2.22	Press **Ctrl+C** in the terminal window on the laptop.	✓
5.2.23	Unplug the USB cable from the Raspberry Pi and laptop.	✓

5.2.24	Slide pi bulkhead onto rails and secure in place with nuts just behind Bulkhead #1	✓
5.2.25	Remove pull pin switch from payload bay	✓
5.2.26	Slide battery sled into payload bay	✓
5.2.27	Insert pull pin	✓
5.2.28	Plug the payload into the flight-ready LiPo and tug lightly to ensure a tight connection.	✓
5.2.29	feed all cables on pi bulkhead through the payload bay from forward to aft	✓
5.2.30	slide threaded rods through the payload bay and battery sled	✓
5.2.31	Connect Imu and hot glue in place	✓
5.2.32	Pull relay cable and and usb cable through hole in antenna bulkhead and slide bulkhead into place on the aft end of the battery sled	✓
5.2.33	Secure antenna bulkhead in place with nuts	✓
5.2.34	plug in relay and dongle cable	✓
5.2.35	Feed **Bulkhead #0** onto threaded rods making sure to pull antenna cables through the hole	✓
5.2.36	tape aft end of antenna to the payload bay. Note that antenna 1 is the antenna with the imu upright labeled with blue electrical tape	✓
5.2.37	Ensure top of **Bulkhead #0** sits between camera's 1 and 2	✓
5.2.38	Slide the payload bay into the fin can.	✓
5.2.39	Attach the payload bay to the fin can using four black, plastic rivets.	✓
5.2.40	Tape both antennas flat to the airframe in line with the fins with a long strips of electrical tape.	✓
5.2.41	Tidy up coax cables to ensure clearance for fin can assembly.	✓
5.2.42	Confirm Payload is assembled correctly.	Payload Systems:

6. FINCAN ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Structures Lead	Mike Pudlo	
Personnel 1	Sofia Antinozzi	SA
Personnel 2	Joseph Alonso	JA

Required Materials			
Item	Quantity	Location	Completion
Fincan	1	-	✓
Payload Bay	1	-	✓
Removable Fin assembly	1	-	✓
Tail cone	2	-	✓
Rail button standoff	1	Structures HDX	✓
Rail button	1	Structures HDX	✓
#8 Screws and washers	7	Structures HDX	✓
Phillips Screwdriver	1	LD Toolbox (Drawer 1)	✓

Number	Task	Completion
6.1	Check that antenna cables are clear from fin can cavity where fin assembly will be placed	✓
6.2	Verify all bolts through removable fin slats are sufficiently tight	Structures Lead:
6.3	Use alignment marks on fin can to slide fin assembly into fin can aligning all L bracket holes with airframe holes	✓
6.4	Find the rail button standoff and slide a long #8 screw through	✓
6.5	insert 7 #8 screws and the rail button standoff screw into the fin can cavity	✓
6.6	Confirm that rail button and screws are sufficiently tight	Structures Lead:
6.7	Lightly screw on the tail cone. This will need to be removed further on to insert the motor.	✓
6.8	Ensure no pinching of antennas	✓
6.9	Pull on the fins to ensure the assembly is secure.	Structures Lead:

7. DROGUE RECOVERY ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Integration Lead	Mike Pudlo	
Personnel 1	Elizabeth Bruner	EB
Personnel 2	Hanna McDaniel	HM

Required Materials			
Item	Quantity	Location	Completion
Fin Can assembly	1	-	✓
Drogue Bay Airframe	1	-	✓
AV bay Assembly (Bring over at step 7.9)	1	-	✓
Safety Glasses	1	PPE Box	✓
Drogue Parachute (18 in)	1	Struct/Recovery Box	✓
Small Nomex Sheet	1	Struct/Recovery Box	✓
Drogue Parachute Shock Cord (Loops #1-3)	1	Struct/Recovery Box	✓
Quicklink (#1-3)	3	Recovery HDX Box	✓
Shear Pins	4	Recovery HDX Box	✓
Blue Tape	1	LD Toolbox (Drawer 1)	✓
Scissors	1	LD Toolbox (Drawer 1)	✓
Plumbers Putty	1	LD Toolbox (Top)	✓
Electrical tape	1	LD Toolbox (Drawer 1)	✓

Number	Task	Completion
7.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
7.2	Fold the length of shock cord between **Loops #1 and 2** accordion-style with 8-inch lengths	✓
7.3	Secure the length of shock cord between **Loops #1 and 2** with a single rubber band. Do not cover any part of a parachute. Two fingers should fit snugly under the rubber band	✓
7.4	Confirm the shock cord is folded accordion-style	Structures Lead:

7.5	Attach the hole in the nomex sheet to **Quicklink #2**. Do not tighten	✓
7.6	Attach **Quicklink #2** to **Drogue Parachute Quicklink #2.** Do not tighten	✓
7.7	Attach **Quicklink #2** to shock cord **Loop #2** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure	Structures Lead:
7.8	Attach **Quicklink #3** to shock cord **Loop #3.** Do not tighten	✓
7.9	Attach **Quicklink# 3** to AV Bay **Bulkhead #3** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure.	✓
7.10	Confirm the shock cord is secured to the **Bulkhead #3** by visual inspection and pulling on shock cord	Structures Lead:
7.11	Slide shock cord and parachute through the drogue parachute bay with **Loop #1** hanging out the aft end of the bay.	✓
7.12	Attach **Quicklink #1** to shock cord **Loop #1**. Do not tighten	✓
7.13	Attach **Quicklink #1** to payload **Bulkhead #2** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure	✓
7.14	Confirm the shock cord is secured to the **Payload Bay** by visual inspection and pulling on shock cord	Structures Lead:
7.15	Slide **Drogue Bay** onto the **Payload Bay** using alignment marks. Secure into place with 4 rivets	✓
7.16	Confirm the drogue parachute is properly folded	Structures Lead:
7.17	Firmly grasp the drogue parachute and remove the rubber band securing the drogue parachute	✓
7.18	Confirm all rubber bands are removed from drogue parachute and shroud lines	✓
7.19	Wrap the nomex cloth around the drogue parachute, like a burrito, continuing to firmly grasp the parachute	✓

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7.20	Carefully insert the shock cord between **Loops #1 and 2** into the drogue bay cavity	✓
7.21	Carefully insert the drogue parachute into the drogue bay with the yellow tag facing the aft end of the vehicle	✓
7.22	Carefully insert the shock cord between **Loops #2 and 3** into the **drogue parachute bay**	✓
7.23	Insert 147 grams of biodegradable insulation into the **drogue parachute bay**	✓
7.24	Slide the **AV Bay** coupler into the drogue bay, using the sharpie marks for alignment	✓
7.25	Insert a #4-40, ½-inch long nylon shear pin into each shear pin hole	✓
7.26	Place a small piece of blue tape over each shear pin head.	✓
7.27	Hold the avionics bay and let the fin can hang free and confirm vehicle holds its own weight	Structures Lead:

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8. MAIN RECOVERY ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	[signature]
Structures Lead	Chris Luzzi	[signature]
Personnel 1	Shyanne Large	[signature]
Personnel 2	Caleb Allman	CCA

Required Materials			
Item	Number	Location	Confirmation
Nosecone	1	-	✓
Main Parachute Bay Airframe	1	-	✓
Fin Can Assembly	1	-	✓
Safety Glasses	5	PPE Box	✓
Main Parachute (120 in)	1	Struct/Recovery Box	✓
Large Nomex	1	Struct/Recovery Box	✓
Main Parachute Shock Cord	1	Struct/Recovery Box	✓
Quicklink (#4-6)	1	Recovery HDX Box	✓
Shear Pin	2	Recovery HDX Box	✓
Blue tape	1	LD Toolbox (Drawer 1)	✓
Plumbers Putty	1	LD Toolbox (Top)	✓

Number			Task	Completion
8.1			Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
8.2			Slide **Loop #4** of the shock cord through the main parachute bay with **Loop #4** hanging out the forward end of the bay	✓
8.3			Attach **Quicklink #4** to shock cord **Loop #4**. Do not tighten.	✓
8.4			Attach **Quicklink #4** to AV bay **bulkhead #4**. Tighten by hand and tape over with electrical tape.	✓
8.5			Slide main parachute bay onto **AV bay** using alignment marks	✓
8.6			Insert 4 rivets to secure **AV bay** to main parachute bay	✓

8.7			Fold the length of shock cord between **Loops #4 and 5** accordion-style with 8-inch lengths	✓
8.8			Secure the length of shock cord between **Loops #4 and 5** with a single rubber band. Two fingers should fit snugly under the rubber band	✓
8.9			Fold the length of shock cord between **Loops #5 and 6** accordion-style with 8-inch lengths	✓
8.10			Secure the length of shock cord between **Loops #5 and 6** with a single rubber band. Do not cover any part of a parachute. Two fingers should fit snugly under the rubber band	✓
8.11			Confirm the shock cord is folded accordion-style	Int Lead: ★
8.12			Attach **Quicklink #5** to the main parachute. Do not tighten	✓
8.13			Attach **Quicklink #5** to the Main Parachute **Nomex sheet**. Do not tighten	✓
8.14			Attach **Quicklink #5** to shock cord **Loop #5** and tighten by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure	Int Lead: ★
8.15			Remove all rubber bands from the main parachute. Hold the parachute securely so that it does not come unfolded and place in center of nomex sheet	✓
8.16			Fold nomex sheet over the main parachute like a burrito so that it is fully covered with swivel aligned with nomex hole	✓
8.17			Firmly grasp the nomex so that parachute does not come unflolded.	✓
8.18			Carefully insert the main parachute completely into the main parachute bay with the yellow loop pointed towards the Nose Cone	✓
8.19			Attach **Quicklink #6** to shock cord **Loop #6**. Do not tighten	✓
8.20			Attach **Quicklink #6** to nose cone **Bulkhead #6** and tighten by hand. Tape over the connection to ensure the shock cord will not unthread the closure.	✓

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8.21			Confirm the shock cord is secured to the **Nose Cone** by visual inspection and pulling on shock cord	Int Lead:
8.22			Insert the length of shock cord between **Loops #4 and 5** into the **Main Parachute Bay.**	✓
8.23			Insert the length of shock cord between **Loops #5 and 6** into the main parachute bay.	✓
8.24			Add 122 grams of biodegradable insulation into the **main parachute bay**.	✓
8.25			Slide the **Main Parachute Bay** over nose cone coupler, being careful not to pinch the shock cord, and using the sharpie marks for alignment	✓
8.26			Insert a #4-40, ½-inch long nylon shear pins into each shear pin hole	✓
8.27			Place a small piece of blue tape over the shear pin heads.	
8.28			Hold the launch vehicle upright by the nose cone and verify the launch vehicle can hold its own weight from shear pins alone	Int Lead:

9. MOTOR ASSEMBLY

Essential Personnel:	Name	Initial
L3 Mentor	Alan Whitmore/Jim Livingston	AW
Aerodynamics Lead	J.W. Mason	JW
Motor Personnel 1	Michael Wax	MW

Required Materials			
Item	Quantity	Location	Completion
Aerotech I135T Reload Kit	1	Energetics Box	✓
Aerotech Phenolic Tube	1	Energetics Box	✓
Aerotech 38/1080 motor casing	1	Energetics Box	✓
Motor Igniter	1	LD Toolbox (Top)	✓
Vaseline	1	LD Toolbox (Top)	✓
Needle nose pliers	1	LD Toolbox (Drawer 2)	✓
Baby Wipes	1	LD Toolbox (Top)	✓
Sharpie Marker	1	LD Toolbox (Top)	✓
Blue Tape	1	LD Toolbox (Drawer 1)	✓
Nitrile Gloves	2	PPE Box	✓
Paper Towels	1	Recovery Box	✓

NOTE: Follow all manufacturer procedures for motor assembly!

Number	Task	Completion
9.1	Gather all materials and L3 mentor at table and receive permission to begin motor assembly from mentor	✓
9.2	Use Vaseline to lightly grease included O-Rings identified by motor manual	✓
9.3	Use Vaseline to lightly grease threads on motor casing	✓
9.4	Install smoke grain into insulator tube with spacer until snug	✓
9.5	Use Vaseline to lightly grease one end of the smoke grain	✓
9.6	Install smoke grain into forward closure, greased side facing forward, until snug	✓
9.7	Install forward seal disk O-Ring on forward seal disk	✓
9.8	Install forward seal disk and O-Ring into one end of motor liner until snug	✓
9.9	Install three propellant grains into motor liner	✓
9.10	Install motor liner into motor casing, holding the liner centered within the casing	✓
9.11	Install forward O-Ring into forward end of motor casing. The O-Ring MUST be seated against the forward end of the forward seal disk assembly	✓

9.12	Install the forward closure with smoke grain assembly onto the forward end of the motor casing, on top of the forward O-Ring. Tighten until finger tight	✓
9.13	Install aft nozzle on the aft end of the motor casing	✓
9.14	Install aft O-Ring onto aft nozzle	✓
9.15	Install aft closure onto aft O-Ring	✓
9.16	Install aft closure assembly into aft end of motor casing. Tighten until finger tight. NOTE: There will be exposed threads when the aft closure is snug	✓
9.17	Install nozzle cap with a corner cut	✓
9.18	Prepare motor ignitor	✓
9.19	Hold ignitor wire along the side of the motor casing	✓
9.20	Designate appropriate length by marking ignitor wire with Sharpie	✓
9.21	Separate ends of ignitor wire	✓
9.22	Strip ends of ignitor wire	✓
9.23	Coil ignitor wire back into original orientation	✓
9.24	Tape ignitor to side of casing	✓
9.25	Thank the mentor for assisting with motor assembly	✓
9.26	Return to launch vehicle assembly location with motor and prepared ignitor. Designate one person to hold the motor. **KEEP MOTOR AWAY FROM PERSONNEL UNTIL CHECKLIST ITEM 10.2**	✓

10. FINAL MEASUREMENTS

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Aerodynamics Lead	J.W. Mason	JM
Personnel 1	Connor Swanson	CNS
Personnel 2	Lauren Scott (Donald or Cameron)	LS

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Fish Scale	1	LD Toolbox (Drawer 3)	✓
Calculator	1	Phone	✓
Tape Measure	1	LD Toolbox (Top)	✓
Rope	1	LD Toolbox (Drawer 3)	✓
Circle Stickers	2	LD Toolbox (Top)	✓
Sharpie	1	LD Toolbox (Top)	✓
Launch Vehicle	1	-	✓
Motor	1	-	✓

Number	Task	Completion
10.1	Unscrew motor retainer	✓
10.2	Slide motor casing into motor tube	✓
10.3	Secure motor casing using motor retainer screw	Safety Officer: Safety Officer High-Powered Rocketry NC State
10.4	Measure the center of pressure of the launch vehicle. This point is 49 inches from the tip of the nose cone. Ensure tape measure is straight/ not following the nose cone curvature	✓
10.5	Use an orange circular sticker or blue tape labeled "CP" to mark the center of pressure of the launch vehicle	✓
10.6	Using the rope and fish scale, locate the center of gravity of the launch vehicle. Tie the rope around the launch vehicle and move the rope until the launch vehicle balances	✓
10.7	Record the weight of the launch vehicle using the fish scale	Record weight here: 42.52
10.8	Use a green circular sticker or blue tape labeled "CG" to mark the center of gravity of the launch vehicle	✓

10.9	Measure the center of gravity's distance from the tip of the nose cone using the tape measure. Ensure the tape measure is straight	Record CG location here: 63
10.10	Calculate the stability margin using the formula (CP-CG)/D. This is (49 - CG)/1. The stability margin must be at least 2.0	Record stability margin here: 2.09 Team Lead: ✓
10.11	Load the field recovery box with the items required by checklist 8	✓
10.12	Proceed to the launch pad!	✓

11. LAUNCH PAD

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	
Recovery Lead	Shaan Stephen	SS
Payload Leads	Ben Lewis, Frances McBride	BL FM
Personnel 1	Craig Abell	CA

Required Materials

Item	Quantity	Location	Completion
Launch Vehicle	1	-	✓
Motor ignitor	1	Field Recovery Box	✓
Vaseline	1	LD Toolbox (Top)	✓
Nitrile Gloves	1	PPE Box	✓
Heavy Duty Gloves	2	PPE Box	✓
Safety Glasses	5	PPE Box	✓
TB Screwdriver	1	LD Toolbox (Drawer 2)	✓
Adjustable Wrench	1	LD Toolbox (Drawer 2)	✓
Rubber Bands	6	Recovery HDX Box	✓
Laptop	1	-	✓
Wire Snips	1	LD Toolbox (Drawer 2)	✓
Wire Strippers	1	LD Toolbox (Drawer 2)	✓
Fire extinguisher	1	Field Recovery Box	✓

Number	Task	Completion
11.0	Pack field recovery box according to checklist 12	✓
11.1	Confirm with RSO that field conditions are safe for launch	✓
11.2	Submit flight card to RSO for review	✓
11.3	Proceed to launch pad	✓
11.4	Record coordinates of launch pad	✓
11.5	Confirm blast deflector is mounted on launch rail	Safety Officer: MR ✓
11.6	Carefully slide the launch vehicle onto the launch rail	✓
11.7	Visually confirm the launch vehicle slides smoothly along rail	Safety Officer: MR

11.8	If there is resistance in sliding remove the launch vehicle, apply Vaseline to the launch rail, then repeat items 11.6 and 11.7	✓
11.9	Rotate launch rail into the upright position and lock into place	✓
11.10	Orient the launch rail such that it is pointed 5 degrees away from spectators	✓
11.11	Confirm the launch rail is locked	Safety Officer: MR
11.12	Take team pictures as necessary	✓
11.13	All non-essential personnel leave the launch pad	✓
11.14	Confirm that all remaining individuals are wearing safety glasses	Safety Officer: MR
	Payload Procedure	
11.15	Pull pin switch out	✓
11.16	Confirm payload is buzzing to ensure activation	✓
11.17	Use **$ ssh pi@raspberrypi.local (password:raspberry)**	✓
11.18	Start tmux session **$ tmux new -s launch**	✓
11.19	Navigate to payload directory **$ cd Payload-2022-2023**	✓
11.20	Start main script **$ python3 main.py**	✓
11.21	Detach from tmux session with **ctrl+b then d**	✓
11.22	Verify tmux session running **$ tmux ls**	✓
	Altimeter arming procedure:	
11.23	Pull pin switch out of primary altimeter slot	✓
11.24	Confirm primary altimeter is programmed correctly using Appendix A – Primary Beep Sheet	✓
11.25	Pull pin switch out of secondary altimeter slot	✓
11.26	Confirm secondary altimeter is programmed correctly using Appendix B – Secondary Beep Sheet	✓
11.27	Confirm both altimeters are powered on with full continuity	Safety Officer: MR
	Ignitor installation procedure:	
11.28	Attach ignitor to wooden dowel	✓
11.29	Insert ignitor fully into the motor	✓
11.30	Tape ignitor into place at the bottom of the launch vehicle, using the mark made in item 8.17.2	✓
11.31	Confirm that launch pad power is turned off	✓
11.32	Connect ignitor wires to launch pad power	✓
11.33	Confirm launch pad continuity, measurement should read between 1.5 and 3.5	
11.34	All personnel navigate to safe location behind the launch table	

11.35	Pass the primary checklist and field recovery toolbox to the Safety Officer	
11.36	Inform the RSO the team is ready for launch	
11.37	Launch	

12. FIELD RECOVERY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	
Recovery Lead	Shaan Stephen	SS
Personnel 1	Braden Rueda	BR
Personnel 2	Andrew Simon	
Personnel 3	Luke Pollard	

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Nitrile Gloves	1	Field Recovery Box	
Heavy Duty Gloves	1	Field Recovery Box	
Safety Glasses	5	Field Recovery Box	
Switch Screwdriver	1	Field Recovery Box	
TB Screwdriver	1	Field Recovery Box	
Adjustable Wrench	1	Field Recovery Box	
Rubber Bands	6	Field Recovery Box	
Phone	1	Field Recovery Box	
Wire Snips	1	Field Recovery Box	
Wire Strippers	1	Field Recovery Box	
Blue Tape	1	Field Recovery Box	
Fire extinguisher	1	Field Recovery Box	

Number	Task	Completion
12.1	Confirm that all personnel are wearing safety glasses	Safety Officer:
12.2	Confirm that all personnel handling the launch vehicle are wearing nitrile gloves	Safety Officer:
12.3	Approach the launch vehicle on foot	
12.4	If a parachute is open and pulling the launch vehicle, follow items 12.5-12.7. Otherwise, proceed to item 11.8	
12.5	Approach the parachute from the billowed side	
12.6	Use hands and body to pull down the parachute by the CANOPY. **Do not grab the shroud lines or shock cord**	

12.7	Repeat for second parachute if necessary	
12.8	If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the flame	
12.9	Use a rubber band to secure the main parachute	
12.10	Use a rubber band to secure the drogue parachute	
12.11	Carefully pick up the forward end of the main parachute bay and inspect the forward AV bulkhead for un-blown black powder charges	
12.12	Inspect the aft AV bulkhead for un-blown black powder charges	
12.13	If there are un-blown charges, follow items 12.14-12.15 then proceed to 12.18. Otherwise, proceed to item 12.16.	
12.14	Equip heavy duty gloves before handling the body tube	Safety Officer:
12.15	Use the switch screwdriver to turn off the primary AND secondary screw switches	
12.16	Listen to the altimeters and record flight data using Appendix C - Post-Flight Beep Sheet	
12.17	Power off both altimeters by turning off both screw switches	
12.18	Record the coordinates of the final resting position of the launch vehicle	
12.19	Record the coordinates of the initial ground impact point	
12.20	Take pictures of any damage to the launch vehicle	
12.21	Inspect for and collect non-biodegradable waste from the landing site	
12.22	Collect each launch vehicle section and return to the launch site	

APPENDIX A – PRIMARY BEEP SHEET

NOTE: There is a quick low beep between each line

The Beeps: What do they mean	Write Beeps Here	Expected Output
long 5 second beep means successful boot up, 4 quick low beeps mean issue during boot up	✓	5 second beep, If 4 beeps remove and replace the pin switch
A two second pause, and then a two- digit number representing the battery voltage in tenths of a volt (9.2 volts would report as 92).	9.2	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, quick low tone, and then a single number corresponding to the main deploy altitude setting x100.	600	IMPORTANT: Should be 6
A two second pause, quick low tone, one-digit number (range of 1 to 3) corresponding to the currently-selected program preset.	1	Should be 1
A pause, and then beeps repeated every few seconds – a single beep means drogue e-match continuity, two beeps means main e-match continuity, three beeps means both have continuity. Repetitive 2 second beeps means no continuity.	3	IMPORTANT: Should be 3

APPENDIX B – SECONDARY BEEP SHEET

The Beeps: What do they mean	Write Beeps Here	Expected Output
long 5 second beep means successful boot up, 4 quick low beeps mean issue during boot up	✓	5 second beep, If 4 beeps remove and replace the pin switch
A two second pause, and then a two- digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).	9.3	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, quick low tone, and then a single number corresponding to the main deploy altitude setting x100.	500	IMPORTANT: Should be 5
A two second pause, quick low tone, one-digit number (range of 1 to 3) corresponding to the currently-selected program preset.	2	Should be 2
A pause, and then beeps repeated every few seconds – a single beep means drogue e-match continuity, two beeps means main e-match continuity, three beeps means both have continuity. Repetitive 2 second beeps means no continuity.	✓	IMPORTANT: Should be 3

APPENDIX C – POST-FLIGHT BEEP SHEET

The Beeps: What do they mean	Primary Beeps	Secondary Beeps	Expected Output
An extra-long tone to indicate the start of the reporting sequence	✓	✓	Ignore, currently not important
A three to six-digit number representing the peak altitude in feet	4312	4314	Should be approximately 4500 ft. Record
If the "siren delay" number is set to a number greater than zero, the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone.	✓	✓	Ignore, currently not important
After a 10 second period of silence, the sequence repeats until power is disconnected.	✓	✓	Ignore, currently not important

APPENDIX D - EMERGENCY PROCEDURES

PREMATURE BLACK POWDER IGNITION

- ALL PERSONS CLEAR THE AREA
- CLEAR FLAMMABLE OBJECTS FROM THE AREA
- USE FIRE EXTINGUISHER TO EXTINGUISH ANY REMAINING FIRE

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

LAUNCH RAIL COLLAPSE AT LAUNCH

- TAKE COVER IF NECESSARY
- CLEAR THE AREA IN DIRECTION OF NOSE CONE TIP
- LISTEN TO RSO INSTRUCTIONS

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

Once Hazard is Clear:

- FOLLOW FIELD RECOVERY CHECKLIST

CATASTROPHE AT TAKE OFF

- LISTEN TO RSO INSTRUCTIONS
- ALL PERSONS CLEAR THE AREA
- DO NOT APPROACH UNTIL CONDITIONS AT THE LAUNCH PAD ARE CLEAR

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

BALLISTIC DESCENT

- LISTEN TO RSO INSTRUCTIONS
- DETERMINE LOCATION OF BALLISTIC DESCENT
- ALL PERSONS MOVE AWAY FROM DESCENT PATH
- MAINTAIN VISUAL CONTACT WITH LAUNCH VEHICLE

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

6 Demonstration Flights

6.1 Vehicle Demonstration Flight

On February 26th, 2023, the team completed their first flight of the full scale launch vehicle in Bayboro, NC. This launch satisfied the requirements for both Vehicle Demonstration Flight and Payload Demonstration Flight. The results of Payload Demonstration Flight are discussed in section 6.2. Table (29) below, shows a summary of flight data from this launch.

Table 29: Demonstration Flight Data for February 26th.

Demonstration Flight Data	
Date	2/26/2023
Location	Paul Farm, Bayboro, NC
Temperature (F)	64
Pressure (mmHg)	30.34
Wind (mph)	7
Motor Flown	L1520T
Ballast Flown (lb)	3.7
Payload Flown	Yes, Powered On
Airbrakes	None
Target Altitude (ft)	4,500
Predicted Altitude (ft)	4,800
Measured Altitude (ft)	4,313

The Bayboro, NC Launch field is a corn field used for official Tripoli Rocketry Association Launches in the off season. The field is a total of 6.5 square miles divided into sections with irrigation ditches. These ditches as well as dead corn stalks make the land difficult to traverse. This is a hazard described in 5.3 of this report and has previously caused launch vehicles and payloads to be submerged in water. This is a hazard we take into consideration when designing the payload bay and launch vehicle for water resistance.

Figure (105) below, shows the field conditions on launch day. The field was somewhat muddy due to the previous day rainstorms, and cloud cover was fairly significant. Wind speeds at the launch field staggered between 6 and 8 mph throughout the day.

Figure 105: Launch Field Conditions on February 26th, 2023

6.1.1 Analysis of Flight

The first flight of the launch vehicle was largely successful. The vehicle had no visible wobbling off the launch rail and demonstrated no weather cocking throughout the flight. After motor burnout, the vehicle began to slowly tip over onto a slightly parabolic path, yielding an apogee within 5 percent of what our simulations predicted. The extra drag produced by the payload section onto to vehicle is the primary reason for the discrepancy between simulated apogee and actual apogee. An image of the launch vehicle's ascent is shown in Figure 106.

Figure 106: Full Scale Launch Vehicle Flight

The launch vehicle landed safely on the field with very minor damage, despite the still deployed main parachute slowly dragging the launch vehicle body along the field until it could be recovered. This dragging resulted in the drogue parachute bay taking in about two pounds of dirt by time of recovery, but this is of no concern due to the bulkhead-sealed payload bay. The vehicle was carefully checked and showed signs of all black powder charges successfully detonated. The recovery harness and parachutes were found mostly free of tangles. The main parachute was slightly damaged due to the black powder charges. Figure (107) below shows a small hole in the parachute which will be patched prior to the next flight.

Figure 107: Deployed Recovery System at Descent and Landing

6.1.2 Altimeter Data and Modified Simulation

The main altimeter data is displayed below after being modified from the original pre-flight predictions. The main change made from the pre-flight simulation was a 3.25% increase in the drag curve to match the apogee of the simulation to the altimeter. Small additional changes were made to the drogue parachutes CdS value to match the decent rate. The following graphs show the exceptional agreement between the flight data and the RocketPy simulation.

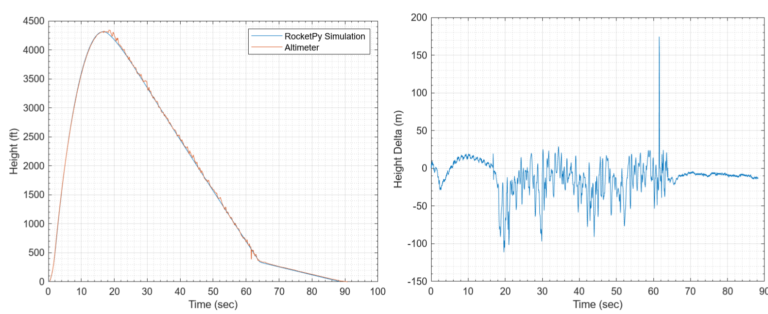

Figure 108: Height of launch vehicle and the difference between RocketPy and Altimeter.

Without looking at the delta graph in fig. 108 it is difficult to see any difference between the RocketPy and altimeter data. These values will be useful for future predictive accuracy.

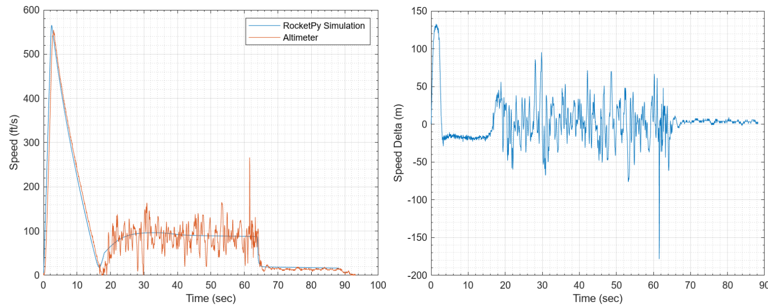

Figure 109: Speed of launch vehicle and the difference between RocketPy and Altimeter.

Speed simulation was in strong agreement with the simulation result with a small offset during the accent which is likely due to a delay in pressure readings from the altimeter.

6.1.3 Sources of Error

The RRC3 flight computers have a 20 Hz sampling rate that is accurate enough for the safe deployment of recovery devices but too low for the accurate positioning of the vehicle during every phase of the flight. With a 2.4-second burn, the altimeter is only collecting around 48 data points during a very dynamic stage of the flight. These devices are also only reading pressure changes so there is likely a small distortion of the reading due to the dynamics of the vent holes in the airframe of that section.

6.1.4 Estimated Drag Coefficient

The RocketPy simulation requires two drag curves, power on and power off, to define the launch vehicle. Rock-Sim simulations were utilized to create the curves prior to the verification flight. This approximation of the drag curve is a good starting point for understanding how the launch vehicle's drag curve changes at different Mach numbers. Post-launch altimeter data was analyzed and compared to the simulated data in fig. 110. The altimeter's data was differentiated to calculate the net acceleration of the vehicle during its coast phase so that the force of gravity could be removed leaving only the force of drag. This drag force was then normalized with velocity and density data also calculated from the altimeter data to generate the power off coefficient of drag for the flight. The Rocksim flight data increased by 3.25% to account for the discrepancy between RocketPy's apogee and the verification flight's apogee.

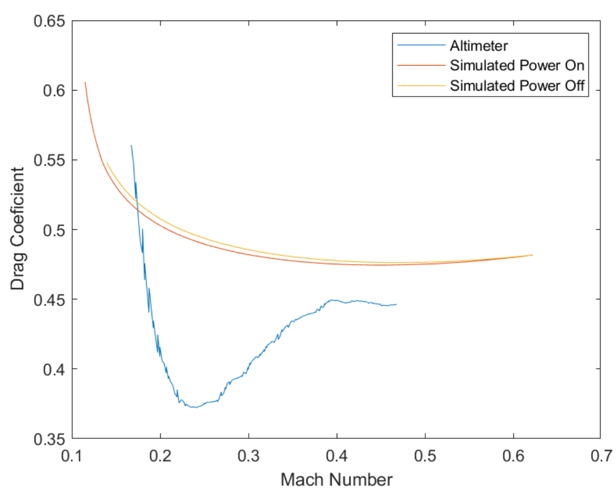

Figure 110: Coefficient of drag curve comparison.

The figure shows a large difference between the corrected RocketPy drag curve and the altimeter drag curve. The large spike in drag coefficient that occurs when the vehicle is traveling at a low Mach number occurs at a higher value for the altimeter data indicating that the vehicle is likely experiencing high amounts of drag at low speeds. The large trough in the altimeter data compared to the simulated drag curve indicates that the vehicle likely produces laminar flow across the surface of the vehicle drastically decreasing the skin friction drag. RocketPy simulations with the altimeter drag curve do not result in an improvement of RocketPy's ability to predict apogee so the corrected RockSim simulation drag curve will be used to predict the apogee of future launch vehicle launches.

6.1.5 Subscale Comparison

Both the subscale and full scale vehicles exhibited successful demonstration flights. The full scale vehicle remained close to vertical after rail exit and exhibited very little yawing or rolling motion. This phenomenon was also observed in the flight of the subscale vehicle. This is was likely observed in both flights because both vehicles have very similar aerodynamic properties and static stability margins. A comparison of the subscale and full scale vehicles is shown in Table (30) below.

Both vehicles reached a target apogee within 5% of the predicted apogee. This verifies the accuracy of the simulation performed on both vehicles and demonstrates that it is feasible to obtain the predicted apogee on launch day. It is also significant to note that both the subscale and full scale vehicles fell short of their predicted apogees. This shows the tendency of our simulations to over-predict the vehicle's apogee. As a result, it may be possible to slightly lower the weight of the full scale vehicle in order to more closely reach the target apogee.

Table 30: Comparison of subscale and full scale characteristics.

Quantity	Subscale	FullScale
Weight	10.2 lb.	42.5 lb.
Length	69 in.	105.75 in.
Stability	1.92	2.09
Takeoff TWR	10.5	8.17
Apogee	2116 ft.	4314 ft.

6.1.6 Lessons Learned

The vehicle performed very well at this launch. Although, there are still some takeaways we took from this launch. The altimeter data from this launch showed the launch vehicle falling at 84 ft/s which is much slower than previously calculated at around 115 ft/s. This lead the team to recognize that the drag of the launch vehicle body was not being added to descent calculations and our calculations needed to be revised.

Also, after achieving an apogee of 4313 ft when predicted to be about 4800 ft, we notice a discrepancy in our Rocksim calculations that is causing an overestimation of the apogee. This discrepancy also aligned with our subscale data. This could be due to weather conditions but also is likely to do with an error in Rocksim estimations. This has brought up the need to reduce the ballast secured in the nose cone at the vehicle demonstration flight for the competition flight.

We also discovered out of date information within our launch day safety checklists which caused the team to spend more time than necessary on the payload assembly checklist, the AV Bay assembly checklist, and the

We also observed some minor damage to the main parachute that was used during the launch. This damage, shown below, is expected to have occurred due to the ejection charges. This in turn means that the nomex cloth protecting the parachute was likely not entirely securely covering the parachute. For the next launch, these holes will be patched over to not negatively affect the recovery, and the nomex cloth will be more securely fastened and completely cover the parachute.

Figure 111: Parachute damage during demonstration flight

6.1.7 Plan of Action

The team's first point of action is looking to refine our drag calculations for our parachutes. This has been done and updated calculations are included in this document. The team also will be reducing the ballast amount from 3.7 lbs to approximately 1.36 lbs. Checklist discrepancies have been noted and are in the update process. Due to the successful result of the payload demonstration flight, detailed below, the team is not required to launch again before the competition flight. Although, in an attempt to secure the payload system stability, the team has decided to launch again in Bayboro, North Carolina on March 25th.

The following image details the mass budget of the vehicle demonstration flight, as well as the adjusted masses in order to reach apogee.

Section	Mass (lbs)
Nose Cone	9.21
Main Parachute Bay	5.48
Avionics Bay	3.90
Drogue Parachute Bay	3.67
Payload Bay	5.42
Fin Can	14.80
Total	42.48

Section	Mass (lbs)
Nose Cone	8.42
Main Parachute Bay	5.38
Avionics Bay	3.90
Drogue Parachute Bay	3.57
Payload Bay	5.42
Fin Can	14.46
Total	41.15

Figure 112: Mass budget of VDF vs next flight

6.2 Payload Demonstration Flight

The launch on February 26th, 2023 satisfied requirements for both the vehicle demonstration flight (VDF) and payload demonstration flight (PDF). This flight satisfied the requirements that the payload must (a) be powered on prior to and during flight and (b) stay inside of the vehicle as expected during launch, flight, and landing. SOCS satisfied both of these requirements, and thus, PDF was successful.

6.2.1 Payload System Performance

The pull-pin switch that controls payload connectivity and power was pulled prior to launch, a secure shell connection was initiated between the Raspberry Pi and a nearby laptop, and a tmux session was started that allowed the Raspberry Pi to continue running python scripts when the secure shell connection was broken. When a secure shell connection was re-initiated after launch, it was seen that the tmux session was still running and the payload remained powered throughout flight and landing.

The payload bay and fin can landed in a favorable orientation for data-gathering as seen in Figure (113) below. Thus, it is demonstrated that the four-fin and four-camera configuration is favorable for gathering data and capturing images at all likely landing configurations.

Figure 113: The fin can and payload bay immediately after landing.

A disconnection between the leaded coax cables and their respective antennas led to no radio signal being received or decoded by the payload. Thus, no images were captured and no servo motion was recorded. Confirmation of antenna connection will be added to checklists to reduce the risk of future flight disconnection of antennas.

Although no data was gathered, this flight is considered successful because the payload was retained within the vehicle and remained powered throughout the flight.

6.2.2 Lessons Learned

Four points of failure were identified after the vehicle was recovered. Firstly, the aerodynamic camera housing that landed face-down (labeled number three) cracked and bent. Because housing number three was not the upwards-facing camera unit, this failure did not impact mission performance and mission success. Additionally, the second failure was a shear in the supporting plastic ring on the camera unit mount, also in position number three. This structural failure also did not impact mission performance, as no internal components were damaged. Both the transparent camera housings and the camera unit mounts are single-use, wearable components. Redesigned camera unit mounts will be 3D printed and new aerodynamic camera housings will be vacuum-formed for subsequent flights.

The next identified point of failure was the lack of water-tightness of the payload bay. This bay houses expensive and difficult-to-replace components, which makes protecting it from moisture imperative. Additional checklist items will be added that instruct the team to add removable silicon sealant to the gaps in the aerodynamic camera housings and plumber's putty to screw holes, pull pin switch holes, and antenna holes.

Lastly, the team will amend all payload checklists to streamline the process of assembly and confirm the connection of essential SOCS components. The antenna connection was not confirmed prior to flight, which led to complete failure of the RAFCO subsystem to detect APRS transmissions. Payload systems lead confirmation boxes will be added to competition checklists that require a system lead to inspect the bay for loose and missing connections.

6.2.3 Plan of Action

In summary, the four major points of failure identified will be mitigated by printing new wearable components for the SOCS bay, adding moisture barriers to holes in the SOCS bay, and adding confirmations to checklists that ensure the bay is checked for loose and missing component connections. These changes will be completed before the team's next launch and will be streamlined and solidified before the competition launch in April.

7 Project Plan

7.1 Testing

7.1.1 Launch Vehicle Test Suite

At the time of Vehicle Demonstration Flight, all vehicle tests were complete and all success criteria has been verified.

Table 31: Launch Vehicle Tests

Test	Requirement Verified	Required Facilities	Required Personnel
Subscale Ejection Test	NASA 3.2	N/A	Recovery Lead, Team Lead
Subscale Demonstration Flight	NASA 2.18, NASA 2.18.1	Paul Farm, Bayboro, NC	Team Lead
GPS Operational Test	NASA 2.23.8 , NASA 2.23.9	Motor Vehicle	Recovery Lead
Altimeter Operational Test	NASA 3.4, NASA 3.5, NASA 3.6	Vacuum Container	Recovery Lead
Composite Fin Structural Test	LVD 1	Universal Testing Machine	Integration Lead
Avionics Bay Tensile Test	LVD 1	Universal Testing Machine	Structures Lead
Nose Cone Bulkhead Tensile Test	LVD 1	Universal Testing Machine	Structures Lead
Shear Pin Shear Loading Test	LVD 1	Universal Testing Machine	Structures Lead
Rivet Shear Loading Test	LVD 1	Universal Testing Machine	Structures Lead
Full Scale Ejection Test	NASA 3.2	N/A	Recovery Lead, Team Lead
Full Scale Demonstration Flight	NASA 2.19.1	Paul Farm, Bayboro, NC	Team Lead

7.1.1.1 Subscale Ejection Test

Test Date: 11/17/2022

Per NASA requirement 3.2, a black powder ejection test will be performed prior to each launch using ejection charges of the same mass in the same assembly configuration as the primary ejection charges to be used during flight. This test confirms that the ejection assembly will function as intended and section separation will occur for parachute deployment. Should the section separation fail to occur, the launch vehicle will enter a ballistic descent state leading to an increased risk to personnel and likely launch vehicle damage beyond repair constituting mission failure. The success criteria for this test are given below in Table (32). If success criteria are not met, the mass of the ejection charges will be increased by 0.2 grams. This task was done before the flight of the subscale vehicle.

The drogue primary charge for aft vehicle separation was calculated to be 0.9 grams. This will be assembled identically to the flight configuration on the aft AV bulkhead. The main primary charge for forward vehicle separation was calculated to be 2.0 grams and will be assembled identically to the flight configuration on the forward AV bulkhead. For this test, the AV bay will be assembled without the AV sled on board to avoid any unplanned continuity between electrical matches and altimeters. Long wire leads with a battery connector at the end will be secured from the terminal blocks on the inside of the AV bay through the pull pin switch holes for attaching the ejection testing trigger. Four #4-40 shear pins will be used to secure the main parachute bay to the AV bay and two shear pins will be used to secure the drogue parachute bay to the AV bay. This test will then be performed on foam board to reduce the possible damage to the launch vehicle and surroundings. The team lead, with safety glasses and fireproof gloves, will stand as far as the wire leads will reach away from the vehicle and ensure all personnel are at least 15 feet from the launch vehicle. To perform the test the team lead will count down, connect the 9V battery to the connector and observe separation. Once the range is deemed safe by the team lead or safety officer, the team lead and recovery lead will move the aft section of the vehicle off of the foam boards and reset the forward section in its place. This replicates the order of recovery events during flight as long as there is no obstructions surrounding the launch vehicle on any side.

Table 32: Subscale ejection test success criteria.

Success Criteria	Met? (Y/N)
Vigorous and complete separation of the AV bay and drogue parachute bay	Y
Vigorous and complete separation of the nose cone and main parachute bay	Y
No damage to launch vehicle	Y
No damage to recovery materials and hardware	Y

7.1.1.1.1 Controllable Variables

- Ejection Charge Size

7.1.1.1.2 Procedure

See Appendix for the field assembly checklist used for launch. The following items are required changes to this procedure for this test.

- The AV sled and electronics mounted thereon are not placed in the AV bay
- Only primary blast caps are filled with black powder
- Long wires are connected to the terminal block input side
- Output wires are fed through screw switch holes in the AV bay to the launch vehicle exterior
- Motor assembly and launch pad procedures are not performed
- Once the launch vehicle is fully assembled, it is placed horizontally on a piece of foam ensuring forward and aft ends are at least 3 feet from any walls
- Any walls directly in front of or behind the vehicle are protected with another piece of foam
- All team members retreat to a safe distance of 15 ft and out of the path of the launch vehicle
- ensure battery is not connected to the battery clip
- One designated team member with safety glasses and fireproof gloves approaches the launch vehicle to secure the ejection test wire to the wires labeled drogue hanging from the vehicle.
- The designated team member retreats to a safe distance
- The team member conducts a verbal countdown
- The team member connects a 9V battery to the connector detonating the drogue ejection charge
- The team member approaches the launch vehicle and the fin can is placed out of the way and the forward section is placed in the center of the foam.
- One designated team member with safety glasses and fireproof gloves approaches the launch vehicle to secure the ejection test wire to the wires labeled main hanging from the vehicle.
- The team member conducts a verbal countdown
- The team member connects a 9V battery to the connector detonating the main ejection charge

7.1.1.1.3 Required Facilities/Equipment/Tools/Software

- HPRC Lab
- All assembly tools identified in Appendix
- Fully assembled subscale launch vehicle
- Safety glasses
- Fireproof gloves

- Fire extinguisher
- Ejection test wires with battery clip
- 9V battery

Figure 114: The subscale vehicle just after ejection test of the drogue deployment.

7.1.1.1.4 Results

The subscale ejection test successfully separated both sections during the first attempt at this test. A picture of the separation is shown above.

7.1.1.2 Subscale Demonstration Flight

Test Date: 11/19/2023

This test ensures that our design functions safely at a smaller scale. Specifically, this test was performed on a 2/3 scale aerodynamically similar vehicle to the full scale design. Additionally, this test confirms the structural design, aerodynamic design, recovery system, and removable fin system perform nominally and do not need to be modified for use in the full scale design. This fulfills NASA requirements 2.18 and 2.18.1. In the event that the subscale vehicle is significantly damaged during the flight a subscale re-flight will be required after full repair of the launch vehicle. Significant damage includes but is not limited to: broken fins, coupler zippering, and loss of a component due to ubolt or bulkhead failure. Reflights requirements are up to the discretion of the NASA and NAR competition leaders. This test was performed at Paul Farms in Bayboro, NC under the supervision of Tripoli Rocketry Association.

Table 33: Subscale Demonstration Flight success criteria.

Success Criteria	Met? (Y/N)
Launch vehicle exits rail traveling vertically until motor burn out	Y
Launch vehicle deployed at least one parachute upon descent	Y
Launch vehicle endures minimal damage to the effect that it would be safe to refly	Y

7.1.1.2.1 Controllable Variables

- Motor Selection
- Ejection Charge Sizing

- Altimeter Selection
- Launch Vehicle Weight

7.1.1.2.2 Procedure

See Appendix for this test procedure.

7.1.1.2.3 Required Facilities/Equipment/Tools/Software

- Tripoli Range Safety Officer and Mentor
- FAA approved launch field
- 10-10 launch rail
- Launch controller
- Assembled launch vehicle
- All tools and hardware identified in Appendix test procedure

Figure 115: The subscale vehicle launching for demonstration flight.

7.1.1.2.4 Results

This test completed the success criteria with the first test attempt. The vehicle flew within 5 percent of the predicted apogee and endured no significant damage. All recovery systems performed nominally with both drogue and main parachute deployment upon descent.

7.1.1.3 Tracking Device Operational Test

Test Date: 2/24/2023

NASA Requirement 2.23 states that all independent sections must have a tracking system which in this scenario only necessitates one system in the launch vehicle. This test is designed to ensure that the GPS device chosen is functioning correctly and presenting accurate coordinates. If the current GPS fails this test and cannot be repaired, it will be replaced. To test the tracking device's accuracy, in this case the Eggfinder Quasar, the device will be driven around a preset route in a team member's personal vehicle. The tracker's record of this data will be compared to the preset course for accuracy.

Table 34: GPS test success criteria.

Success Criteria	Met? (Y/N)
The GPS receiver accurately locates the transmitter within a range of 100 feet	Y
The GPS transmitter/receiver pair stay active and powered on for approximately 1 hour	Y

7.1.1.3.1 Controllable Variables

- Selected GPS tracker
- Selected driving route

7.1.1.3.2 Procedure

1. One team stays in a specified location with the receiver while it is connected to the transmitter.
2. The other team will take the transmitter in a car and drive to various locations on campus. These locations will not be predetermined and the team with the receiver should not know their locations.
3. The team with the transmitter will notify the team with the receiver when they are in a specific location.
4. The team with the transmitter will record their coordinates.
5. The team with the receiver records the coordinates of the transmitter as displayed by the receiver
6. The team with the transmitter will repeat steps 2 and 3 5 times
7. The team with the receiver will record all 5 locations the transmitter is at
8. The team with the transmitter will return to the location of the team with the receiver
9. The two teams will compare the coordinates
10. Both the GPS transmitter and receivers will stay powered on until one of their batteries runs out
11. The time either the transmitter or the receiver takes to run out of battery will be recorded

7.1.1.3.3 Required Facilities/Equipment/Tools/Software

- Eggtimer Quasar
- Eggfinder LCD Receiver
- 2 cell LiPo Battery
- Car
- Phone

Figure 116: The handmade GPS receiver used for testing.

7.1.1.3.4 Results and Conclusions

During the GPS test all desired results were met; The LCD Receiver repeatedly reported the correct location of the Quasar module, as well as stayed active for a full hour. The accuracy of the GPS is higher than expected, frequently accurate to below 20 ft accuracy.

7.1.1.4 Altimeter Test

Test Date: 2/21/2023

This test ensures that both altimeters used onboard the full scale launch vehicle are operating correctly prior to its launch. It also demonstrates that both altimeters are programmed correctly and will deploy their respective charges at the intended times. To accomplish this, the altimeter must both register pressure changes and signal the correct flight events in response to these pressure changes. Should an altimeter fault result in incorrect or missing signals, parachute deployment could fail resulting in ballistic descent of the launch vehicle. Success Criteria are shown in the table below. If success criteria are not met, the altimeter will be examined and replaced with another altimeter that completes this test successfully. In order to test the altimeter functionality, the pressure decrease as altitude increases and following pressure increase as altitude decreases must be replicated usinga vacuum chamber. The altimeters to be tested will have their deployment terminals connected to LED's and powered. When the pressure decreases and then increases it will signal the apogee deployment of the drogue by sending a charge to the LED and lighting it up. The second LED, connected to the main deployment terminal, will light up after a pause when it detects pressure equivalent to 500 or 600 ft in altitude. These visual indicators of the firing signal will be observed through the viewing port of the pressure vessel.

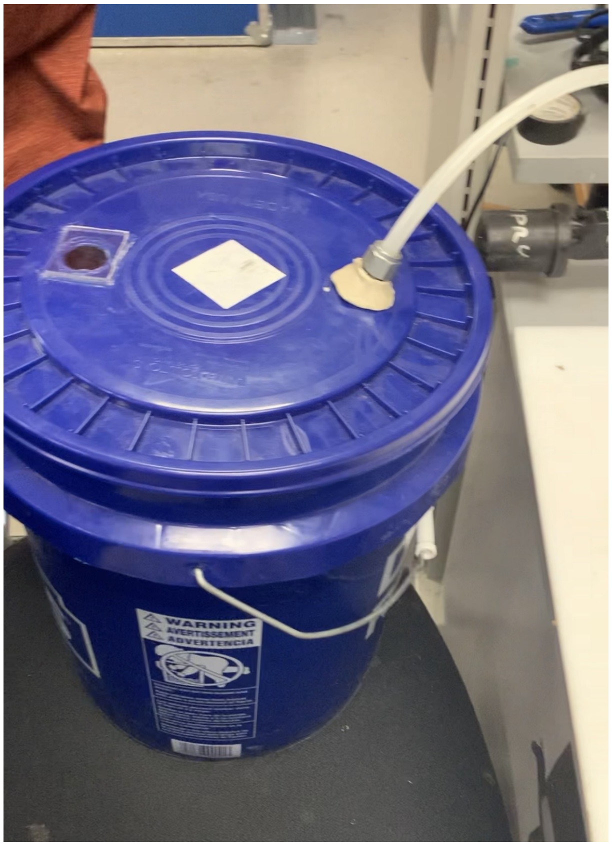

Figure 117: The vacuum chamber for altimeter testing

Table 35: Altimeter test success criteria.

Success Criteria	Met? (Y/N)
Flight data indicates that parachute charges deployed in accordance with NASA and NAR regulations.	Y

7.1.1.4.1 Controllable Variables

- Pressure
- Altimeter Selection

7.1.1.4.2 Procedure

1. Each altimeter is programmed using the MissleWorks mDAC program on the lab computer
2. The primary altimeter is connected to the Handmade Altimeter Test System (HATS)
3. The altimeter and HATS will be placed into the pressure vessel
4. The pressure vessel is sealed
5. The pressure vessel is slowly brought to its maximum vacuum pressure
6. The pressure vessel is slowly brought back down to atmospheric pressure
7. The HATS is observed to ensure that the drogue deployment lights and main deployment lights light up one after another after a reasonable time has passed

8. The altimeter and HATS are removed from the pressure vessel and the secondary altimeter is tested repeating steps 2-7
9. The altimeters are each hooked back up to the lab computer and flight data is ensured to be adequate

7.1.1.4.3 Required Facilities/Equipment/Tools/Software

- RRC3 ”Sport” Altimeter
- Altimeter cable
- Lab computer
- 9V Battery
- HATS
- Vacuum Pump

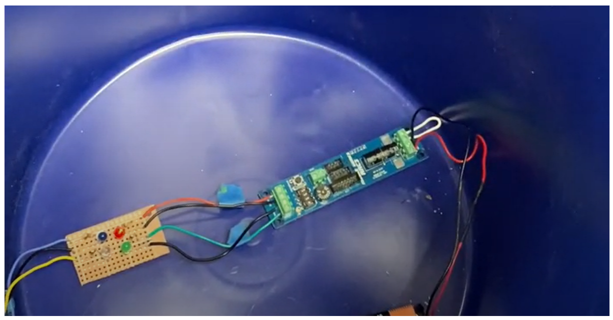

Figure 118: The handmade altimeter testing system wired up to an RRC3 Altimeter used for testing.

7.1.1.4.4 Results and Conclusions

During the altimeter test, all success criteria were met. The LED lights on the HATS system showed a separate drogue and main deployment for the correct pressures, and looking at the altimeter data afterwards again showed correct deployment altitudes for the pressures given.

7.1.1.5 Composite Fin Bending Test

Test Date: 2/24/2023

This test will verify the strength of the composite fins and be used to calculate the factor of safety. Each composite fin is used to stabilize the launch vehicle during flight. In the event the Composite Fin Bending Test results in failure, the thickness of the fiberglass layer will be increased and the test repeated.

Table 36: Composite fin bending test success criteria.

Sucess Criteria	Met? (Y/N)
Composite fin has a calculated factor of safety >2.	Y
The tested fins show no visible damage or deformation under 80 lbf loading.	Y

7.1.1.5.1 Controllable Variables

- Force Applied
- Material Selection
- Layers of fiberglass on each fin

7.1.1.5.2 Procedure

1. Composite fin is placed in the four-point beam testing stand.
2. The Universal testing machine applies a force on the two center rollers, causing the fin the bend.
3. The deflection and strain for the composite structure are measured using the P-3 reader and the 1K materials tester.
4. force applied is increased incrementally and data is recorded until failure

7.1.1.5.3 Required Facilities/Equipment/Tools/Software

- Composite fin test piece
- HPRC lab
- Universal Testing Machine
- Department of Mechanical and Aerospace Engineering structures lab

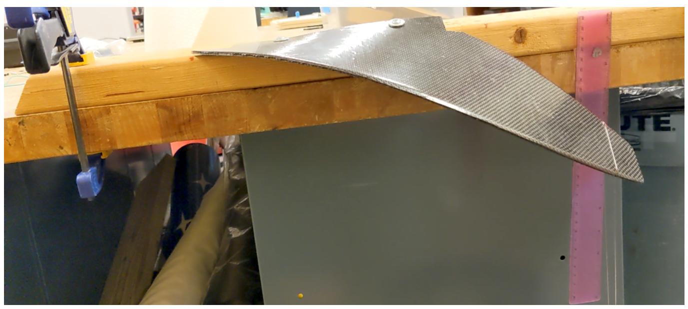

Figure 119: Composite fin testing setup.

7.1.1.5.4 Results and Conclusion

All success criteria were met for the composite fin bending test. The fin successfully withstood 80 lbs of force with no visible damage or deformation. The measured deflection at this load was about 5 in.

7.1.1.6 Avionics Bay Tensile Test

Test Date: 1/23/2023

This test will verify the strength of the AV bay bulkheads and be used to calculate the factor of safety. The maximum force expected on these bulkheads 177 lb and the bulkheads used in this test will have a thickness of 1/2 in. The AV bay bulkheads are used as attachment points for the recovery harness. In the event that a bulkhead should fail, a section of the vehicle may fall without a parachute. In the event the AV bay tensile test is a failure, the thickness of the bulkheads will be increased and the test repeated. For this test, the AV bay test piece will be assembled to be identical to the full scale AV bay. The U-bolts of the test piece will be inserted into the jaws of the universal testing machine and testing will commence.

Table 37: AV bay tensile test success criteria.

Success Criteria	Met? (Y/N)
Bulkhead has a calculated factor of safety >2	Y
Test piece shows no visible signs of damage under 354 lb. loading	Y

7.1.1.6.1 Controllable Variables

- Bulkhead Material

- Bulkhead Thickness
- Location of U-bolt
- Airframe Material
- Force Applied

7.1.1.6.2 Procedure

1. Ensure those observing the test are wearing proper PPE.
2. Place u-bolts of the test sample into the jaws of the universal testing machine. The orientation of the test sample does not matter.
3. Ensure the universal testing machine is tared and reading properly.
4. Begin increasing the load on the test piece in 50lb increments up to 300 lb.
5. Allow the test piece to settle for 5-10 seconds between increasing force.
6. Once 300 lb has been reached, increase the load in increments of 10 lb until failure.
7. Record the failure point and calculate the factor of safety.

7.1.1.6.3 Required Facilities/Equipment/Tools/Software

- AV bay test piece
- Universal Testing Machine
- HPRC lab
- Department of Mechanical and Aerospace Engineering structures lab

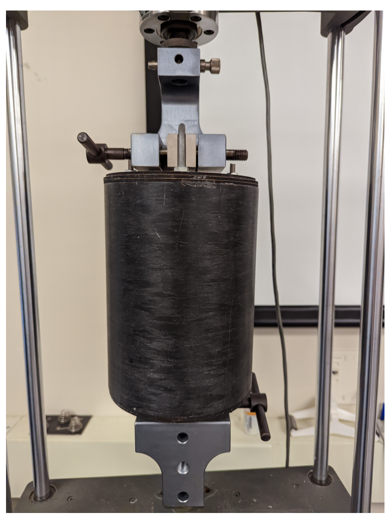

Figure 120: AV bay bulkhead testing setup.

7.1.1.6.4 Results and Conclusion

All success criteria were met for the AV bay bulkhead tensile test. The bulkheads successfully withstood 1000lb. of force with no visible damage or deformation. The calculated factor of safety of the AV bay bulkheads is 5.6 which is well above the minimum required.

7.1.1.7 Nose Cone Bulkhead Tensile Test

Test Date: 1/23/2023

This test will verify the strength of the nose cone bulkhead and be used to calculate its factor of safety. The maximum load expected on the nose cone bulkhead is 61.1 lb. The nose cone bulkhead is used as an attachment point for the main parachute recovery harness. In the event that the bulkhead should fail, the nose cone may fall without a parachute. In the event the Nose Cone Bulkhead Tensile Test is a failure, the thickness of the bulkhead will be increased and the test repeated. For this test, the nose cone bulkhead assembly test piece is constructed to be identical to the full scale design. The bulkhead will be attached to the nose cone centering ring using four 1/4-20 bolts. U-bolts of this test piece are inserted into the jaws of the universal testing machine and testing commences.

Table 38: Nose cone bulkhead tensile test success criteria.

Success Criteria	Met? (Y/N)
Bulkhead has a calculated factor of safety >2	Y
Centering ring has a calculated factor of safety >2	Y
Test piece shows no visible signs of damage under 122 lb. loading	Y

7.1.1.7.1 Controllable Variables

- Bulkhead Material
- Bulkhead Thickness
- Location of U-bolt
- Airframe Material
- Force Applied

7.1.1.7.2 Procedure

1. Ensure those observing the test are wearing proper PPE.
2. Place u-bolts of the test sample into the jaws of the universal testing machine. The orientation of the test sample does not matter.
3. Ensure the universal testing machine is tared and reading properly.
4. Begin increasing the load on the test piece in 50lb increments up to 100 lb.
5. Allow the test piece to settle for 5-10 seconds between increasing force.
6. Once 100 lb has been reached, increase the load in increments of 10 lb until failure.
7. Record the failure point and calculate the factor of safety

7.1.1.7.3 Required Facilities/Equipment/Tools/Software

- Nose cone bulkhead test piece
- Universal Testing Machine
- HPRC lab
- Department of Mechanical and Aerospace Engineering structures lab

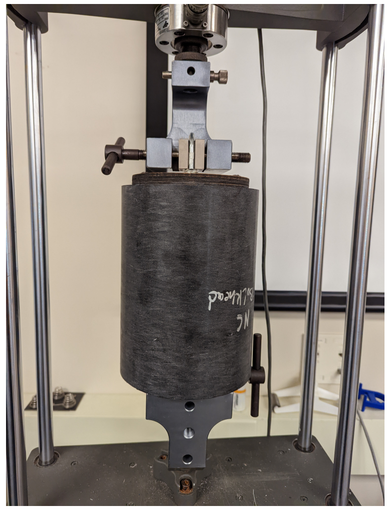

Figure 121: Nose cone bulkhead testing setup.

7.1.1.7.4 Results and Conclusion

All success criteria were met for the nose cone bulkhead tensile test. The bulkhead successfully withstood 1000lb. of force with no visible damage or deformation. The calculated factor of safety of the nose cone bulkhead is 16.4 which is well above the minimum required.

7.1.1.8 Shear Pin Shear Loading Test

Test Date: 1/23/2023

Shear pins are used to hold separating sections together during flight. This test will ensure the shear pins fail under the manufactures specified loading. This will ensure that the black powder charges are adequate to separate the launch vehicle. In the event that the Shear Pin Shear Loading test is a failure, the measured value for the failure point will be used in black powder calculations. for this test, Quick links are inserted through quarter in. holes in metal testing plates. The #4 holes in the testing plates are aligned and a shear pin is inserted through the #4 hole in the metal testing plates. U-bolts are placed in the jaws of the universal testing machine and testing commences.

Table 39: Shear pin loading test success criteria.

Success Criteria	Met? (Y/N)
Shear pins fail at 35 $\pm$ 1 lb.	Y

7.1.1.8.1 Controllable Variables

- Shear Pin Selection
- Force Applied

7.1.1.8.2 Procedure

1. Ensure those observing the test are wearing proper PPE.
2. Insert quick links through the 1/4 in. holes at either end of the metal test plates
3. Align holes in the metal plates and insert a shear pin
4. Place the quick links in the universal testing machine.
5. Begin increasing the load in 5lb increments.

6. decrease the increment to 1lb once within 10lb of the expected failure load.
7. continue to increase the load until failure.
8. Record the failure point.

7.1.1.8.3 Required Facilities/Equipment/Tools/Software

- 4-40 nylon shear pin
- Metal shear loading test plates
- 2x stainless steel quick link
- Universal Testing Machine
- HPRC lab
- Department of Mechanical and Aerospace Engineering structures lab.

Figure 122: Shear pin testing setup.

7.1.1.8.4 Results and Conclusion

The shear pin loading test was repeated three times. The first trial was deemed unsuccessful due to the metal plates not being parallel and causing the shear pin to fail at 27 lb. The second and third tests failed at 36 lb. and 34.5 lb. respectively. Thus, The shear pin test was deemed successful.

Figure 123: Results of shear pin testing.

7.1.1.9 Rivet Shear Loading Test

Test Date: 1/23/2023

Rivets are used to hold non-separating sections of the launch vehicle together during flight. This test will ensure that the rivets used have a desirable factor of safety. In the event that the Rivet Shear Loading Test is a failure, additional rivets will be added to the design to support the required loads. For this test, quick links are inserted through the quarter in. holes in metal testing plates. Rivet holes in the metal testing plates are aligned and rivet is inserted through the hole in the metal testing plates. U-bolts are placed in the jaws of the universal testing machine and testing commences.

Table 40: Rivet shear test success criteria.

Success Criteria	Met? (Y/N)
Rivet calculated factor of safety is >1.5	Y

7.1.1.9.1 Controllable Variables

- Rivet Selection
- Force Applied

7.1.1.9.2 Procedure

1. Ensure those observing the test are wearing proper PPE.
2. Insert quick links through the 1/4 in. holes at either end of the metal test plates
3. Align holes in the metal plates and insert a rivet
4. Place the quick links in the universal testing machine.
5. Begin increasing the load in 10lb increments.
6. Continue to increase the load until failure.
7. Record the failure point and calculate the factor of safety.

7.1.1.9.3 Required Facilities/Equipment/Tools/Software

- Nylon Rivet
- Metal shear loading test plates
- 2x stainless steel quick link
- Universal Testing Machine
- HPRC lab
- Department of Mechanical and Aerospace Engineering structures lab.

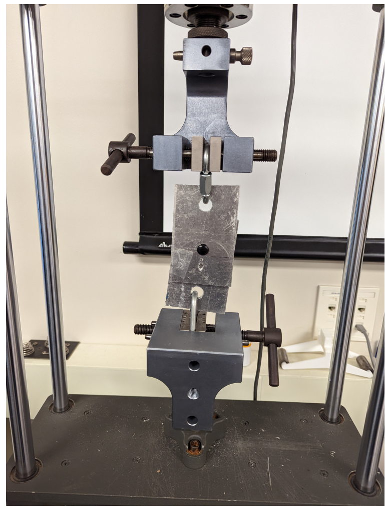

Figure 124: Rivet shear testing setup.

7.1.1.9.4 Results and Conclusion

All success criteria were met for the rivet shear test. The rivet withstood 130 lb. of force with a factor of safety of 1.6. This is very close to the minimum required factor of safety of 1.5. Thus, an additional rivet was added at the connection point between the payload bay and the fin can to ensure that failure would not occur.

7.1.1.10 Bifilar Pendulum

Test Date: 2/23/2023

This test experimentally determines the moment of inertia of the launch vehicle to validate assumptions and refine model predictions. This test will be conducted with a wooden block for calibration and then the fully assembled full scale launch vehicle.

Table 41: Full scale MOI test success criteria.

Success Criteria	Met? (Y/N)
Test setup fully supports the launch vehicle and allows for a swinging motion	Y
Gravity can be experimentally determined from the test setup within 5% error	Y
The MOI of an object with a known MOI can be experimentally determined within 5% error	Y
MOI of the full scale launch vehicle is experimentally determined	Y

7.1.1.10.1 Controllable Variables

- Test setup structure
- Period recording method

7.1.1.10.2 Test Design

Figure 125: Moment of inertia experiment photo.

- A simple saw horse is constructed with a long cross beam to accommodate the length of the full-scale launch vehicle
- String is held in place by two clamps on the cross beam with a loop on the lower part of each string to secure the test object
- A bubble level is utilized to ensure the object under test is level

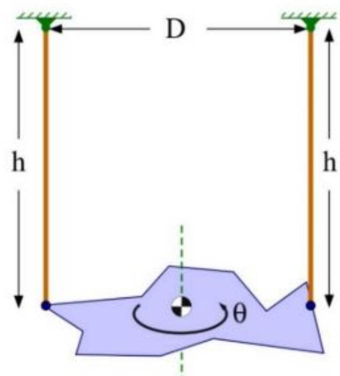

Figure 126: Moment of inertia experimental diagram.

7.1.1.10.3 Procedure

1. To calibrate and validate the test setup a wooden block is weighed and measured
2. The wooden block is attached to the test setup via the loops in the string and the string length is adjusted until the block hangs level
3. Gravity is experimentally determined by swinging the block as a simple pendulum and measuring the period
4. Gravity is calculated with this formula:

$$g = \frac{4 * \pi^2 * h}{T^2} \tag{25}$$

5. To further validate the test setup the MOI of the block is calculated with the formula:

$$I = \frac{m * (b^2 + c^2)}{12} \tag{26}$$

6. The block of wood is rotated around its CG and is oscillating without the CG moving
7. Timing 10 periods with a stopwatch and averaging the results generates an accurate period of time
8. The period is then used in this formula to find MOI:

$$I = \frac{m * g * D^2 * T^2}{16 * \pi^2 * h} \tag{27}$$

9. This inertia measured should match the calculated one validating the setup
10. Now the full scale launch vehicle can be placed under the setup and the previous steps repeated to measure its MOI

7.1.1.10.4 Required Facilities/Equipment/Tools/Software

- HPRC Lab
- Test setup to suspend objects
- Fully assembled full scale launch vehicle
- Level
- Timer
- Measuring tape
- Scale

7.1.1.10.5 Results and Conclusions

The testing setup was successfully calibrated with the simple pendulum measuring gravity within 2% of its actual value and the block's MOI within 5% of the calculated value. Two tests of the full scale launch vehicle were performed and roughly the same period was measured both times. When the MOI equation was applied to the period the results were 6% different than the assumption of using a solid cylinder. There is high confidence the results of this testing generated a MOI with high accuracy.

7.1.1.11 Full Scale Ejection Test

Test Date: 2/24/2023

Per NASA requirement 3.2, a black powder ejection test will be performed prior to each launch using ejection charges of the same mass in the same assembly configuration as the primary ejection charges to be used during full scale flight. This test confirms that the ejection assembly will function as intended and section separation will occur for parachute deployment. Should the section separation fail to occur, the launch vehicle will enter a ballistic descent state leading to an increased risk to personnel and likely launch vehicle damage beyond repair constituting mission failure. The success criteria for this test are given below in Table (42). If success criteria are not met, the mass of the ejection charges will be increased by 0.2 grams. This task was done before the flight of the full scale vehicle.

The drogue primary charge for aft vehicle separation was calculated to be 2 grams. This will be assembled identically to the flight configuration on the aft AV bulkhead. The main primary charge for forward vehicle separation was calculated to be 4 grams and will be assembled identically to the flight configuration on the forward AV bulkhead. For this test, the AV bay will be assembled without the AV sled on board to avoid any unplanned continuity between electrical matches and altimeters. Long wire leads with a battery connector at the end will be secured from the terminal blocks on the inside of the AV bay through the pull pin switch holes for attaching the ejection testing trigger. Four #4-40 shear pins will be used to secure the main parachute bay to the AV bay and two shear pins will be used to secure the drogue parachute bay to the AV bay. This test will then be performed on foam board to reduce the possible damage to the launch vehicle and surroundings. The team lead, with safety glasses and fireproof gloves, will stand as far as the wire leads will reach away from the vehicle and ensure all personnel are at least 15 feet from the launch vehicle. To perform the test the team lead will count down, connect the 9V battery to the connector, and observe separation. Once the range is deemed safe by the team lead or safety officer, the team lead and recovery lead will move the aft section of the vehicle off of the foam boards and reset the forward section in its place. This replicates the order of recovery events during flight as long as there is no obstructions surrounding the launch vehicle on any side.

Table 42: Full scale ejection test success criteria.

Success Criteria	Met? (Y/N)
Vigorous and complete separation of the AV bay and drogue parachute bay	Y
Vigorous and complete separation of the nose cone and main parachute bay	Y
No damage to launch vehicle	Y
No damage to recovery materials and hardware	Y

7.1.1.11.1 Controllable Variables

- Ejection Charge Size

7.1.1.11.2 Procedure

See section 5.4 for the field assembly checklist used for the full scale launch. The following items are required changes to this procedure for this test.

1. The AV sled and electronics mounted thereon are not placed in the AV bay
2. Only primary blast caps are filled with black powder
3. Long wires are connected to the terminal block input side
4. Output wires are fed through screw switch holes in the AV bay to the launch vehicle exterior
5. Motor assembly and launch pad procedures are not performed
6. Once the launch vehicle is fully assembled, it is placed horizontally on a piece of foam ensuring forward and aft ends are at least 3 feet from any walls
7. Any walls directly in front of or behind the vehicle are protected with another piece of foam
8. All team members retreat to a safe distance of 15 ft and out of the path of the launch vehicle
9. ensure battery is not connected to the battery clip
10. One designated team member with safety glasses and fireproof gloves approaches the launch vehicle to secure the ejection test wire to the wires labeled drogue hanging from the vehicle.
11. The designated team member retreats to a safe distance
12. The team member conducts a verbal countdown
13. The team member connects a 9V battery to the connector detonating the drogue ejection charge
14. The team member approaches the launch vehicle and the fin can is placed out of the way and the forward section is placed in the center of the foam.
15. One designated team member with safety glasses and fireproof gloves approaches the launch vehicle to secure the ejection test wire to the wires labeled main hanging from the vehicle.
16. The team member conducts a verbal countdown
17. The team member connects a 9V battery to the connector detonating the main ejection charge

7.1.1.11.3 Required Facilities/Equipment/Tools/Software

- HPRC Lab
- All assembly tools identified in section 5.4
- Fully assembled full scale launch vehicle

- Safety glasses
- Fireproof gloves
- Fire extinguisher
- Ejection test wires with battery clip
- 9V battery

Figure 127: Full scale ejection of the main parachute ejection charge.

7.1.1.11.4 Results

On the first attempt of this test, the vehicle did not meet the success criteria. Upon examination, there were 4 shear pins in the main section when only 2 were necessary and some holes in the AV bay were mistakenly left unplugged. When the shear pins were fixed and holes were plugged for the retest, the test was successful. The test successfully separated both sections fully. An image of the separation is shown above.

7.1.2 Payload Test Suite

Table 43: Payload Tests

Test	Requirement Verified	Required Personnel
Subscale Launch Payload Test	NASA 2.18	Payload Systems Lead
Camera Operation Test	NASA 4.2.1, NASA 4.2.1.4	Payload Systems Lead
Camera Clarity Test	NASA 4.2.1.3	Payload Systems Lead
Camera System Integration Test	PF 1, PF 4	Payload Systems Lead
Camera System RAFCO Test	PF 3	Payload Systems Lead
Camera Housing Structural Test	PD 4	Payload Structures Lead
Camera Unit Mount Test	PF 4	Payload Structures Lead
2-Meter Dipole SWR Test	PF 3, PD 3	Payload ECD Lead
Orientation Detection and Switching Test	PD 3	Payload ECD Lead
APRS Reception and Decoding Test	PF 3	Payload ECD Lead

7.1.2.1 Subscale Launch Payload Test

Test Date: 11/19/2022

A partial payload containing the RAFCO system was used in the subscale launch in order to test system operations. RAFCO was transmitted in competition format over the 70-cm band rather than the 2-meter band used in the competition due to size limitations. Recieved commands were to be saved to a text file that could be retrieved at a later date, along with IMU and antenna selection data.

Table 44: Subscale Launch Payload Test Success Criteria

Success Criteria	Met? (Y/N)
Launch detected correctly	Unknown
IMU correctly determined orientation	Unknown
Correct antenna was selected	Unknown
RAFCO data received properly	Unknown
RAFCO, IMU, and antenna selection saved to .txt file	N

Unfortunately, no data was logged due to the payload being turned off during writing. Thus, the status of most of these criteria is unknown.

7.1.2.1.1 Controllable Variables

- Subscale payload software
- Payload wiring
- Subscale payload electrical hardware
- RAFCO transmission system

7.1.2.1.2 Procedure

1. Setup the RAFCO transmission system, which consists of a Baofeng BF-F8HP connected to a phone running APRSDroid using a Btech Aprs-k1 Cable
2. Following the subscale launch checklist, assemble the payload
3. Test that the payload is recieving commands from the transmission system
4. Test that the payload correctly switches antenna selection when rotated
5. Insert the pin into the pull-pin switch, turning the payload off
6. Attach the payload bay to the fin can
7. At the launch rail, activate the payload by removing the pin
8. SSH into the Pi and start the payload program
9. After landing is confirmed, transmit test packets using the RAFCO transmission system
10. Retrieve launch vehicle
11. SSH into the Pi and open the saved .txt file
12. Compare saved data to transmitted data

7.1.2.1.3 Required Facilities/Equipment/Tools/Software

- Launch Field
- Baofeng BF-F8HP
- Phone capable of generating a hotspot and running APRSDroid
- Btech Aprs-k1 Cable
- Subscale payload system
- Subscale payload bay

- Flush cutters
- Wire strippers
- Portable soldering iron
- Zip ties
- Laptop running VSCode

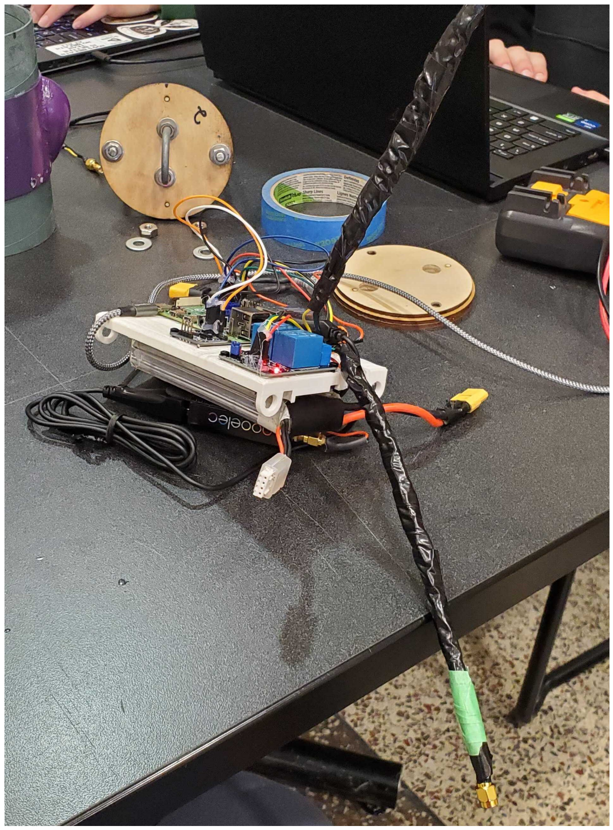

Figure 128: The subscale payload prior to being secured into the payload bay.

7.1.2.1.4 Results

This test was inconclusive. APRS signals were transmitted, but it is unknown if they were received due to the raspberry pi losing power before saving all flight and post flight data.

7.1.2.2 Camera Operation Test

Each camera is tested for its ability to connect to the Raspberry Pi, interface with the multi-camera adapter, and capture and save images.

Table 45: Camera Operation Test Success Criteria

Success Criteria	Met? (Y/N)
Images are captured and saved	Y

7.1.2.2.1 Controllable Variables

- Camera selection

- Camera orientation

7.1.2.2.2 Procedure

1. Connect one camera to the Raspberry Pi using GPIO pins.
2. Insert a micro SD card into the Raspberry Pi.
3. Use a USB cable to connect a laptop to the Rasbperry Pi. Establish an SSH connection between the two.
4. Run commands that capture and save images.
5. Sever the SSH connection between the Pi and the laptop.
6. Insert the micro SD into the laptop and confirm that images are captured and saved.

7.1.2.2.3 Required Facilities/Equipment/Tools/Software

1. Laptop with VSCode
2. Raspberry Pi
3. Micro SD card
4. USB Cable
5. Smraza Pi Camera Module

7.1.2.2.4 Results and Conclusion

Images were captured and saved with each Smraza camera module. Each image had the correct naming scheme and every image was clear.

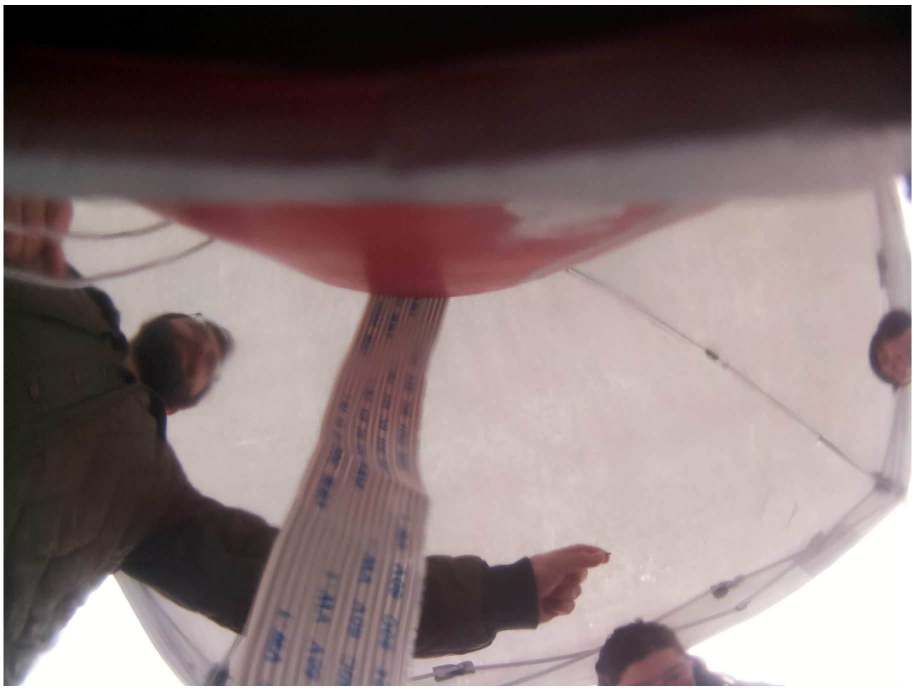

Figure 129: An example of an image captured by each of the cameras.

7.1.2.3 Camera Clarity Test

Test Date: 2/14/2023

The camera unit will be tested for its ability to function inside of the vehicle and capture clear images through the plastic camera housing. One singular camera assembly is connected directly to the Raspberry Pi, bypassing the mutli-camera adapter. Because only one camera is involved in each test, issues related to the adapter can be discounted and control variables can be more closely isolated.

Table 46: Camera Clarity Test Success Criteria

Success Criteria	Met? (Y/N)
Image timestamp corresponds to Pi clock and national clock	Y
Text is legible in captured images	Y

7.1.2.3.1 Controllable Variables

- Camera selection
- Camera orientation
- Distance between paper and camera unit

7.1.2.3.2 Procedure

1. Assemble one camera unit consisting of a camera unit mount, camera, servo, and camera housing. During assembly, insert the assembly into the payload bay. Connect the camera unit assembly to the Raspberry Pi.
2. Print example text on a piece of white, 8.5x11 paper. Place the paper in the line of sight of each camera.
3. Establish an SSH connection between the Pi and the laptop. Ensure that a micro SD card is inserted into the Pi. Run image capture and save commands.
4. Sever the SSH connection and connect the Pi's SD card to the laptop.

7.1.2.3.3 Required Facilities/Equipment/Tools/Software

1. Laptop with VSCode
2. Raspberry Pi
3. Micro SD card
4. USB Cable
5. Smraza Pi Camera Module
6. Camera Unit Mount
7. Camera Housing
8. 8.5x11 Paper
9. Printer

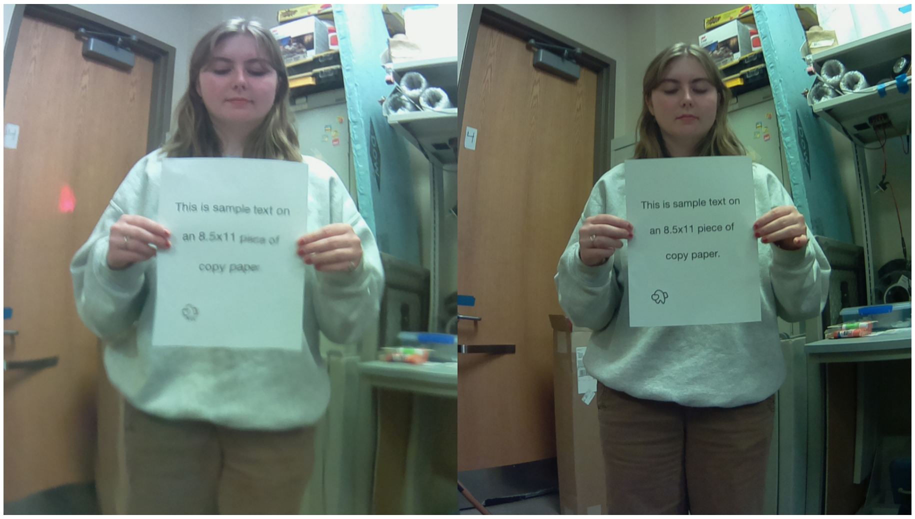

Figure 130: Image captured through camera housing (left) vs. without camera housing (right).

7.1.2.3.4 Results and Conclusion

Clear images were captured when the camera was both obscured and unobscured by the aerodynamic camera housings. Minimal warping and distortion was seen from the camera housings, and the text at two feet and four feet away from the camera was legible in all images.

7.1.2.4 Camera System Integration Test

Test Date: 2/24/2023

The fully assembled payload bay is tested for its ability to toggle between cameras, rotate servos, and capture clear images. Like the previous test, an example text selection is printed on a sheet of printer paper and shown to each camera. If each camera can save a legible capture of the text, the test is considered successful. Additionally, if all four servos can move in series, the test is successful.

Table 47: Camera System Integration Test Success Criteria

Success Criteria	Met? (Y/N)
Image timestamp corresponds to Pi clock and national clock	Y
Text is legible in captured images	Y
Servos move according to instructions	Y
Each camera can be controlled via the multi-camera adapter board	Y

7.1.2.4.1 Controllable Variables

- Camera selection
- Camera orientation
- Distance between paper and camera unit

7.1.2.4.2 Procedure

1. Assemble the entire payload bay minus the battery and RAFCO components according to checklist instructions. Ensure that the cameras are connected to the multi-camera adapter board, and the adapter board and servos are connected to the Pi. Do not connect the battery.

2. Print example text on a piece of white, 8.5x11 paper. Place the paper in the line of sight of one camera.
3. Establish an SSH connection between the Pi and the laptop. Ensure that a micro SD card is inserted into the Pi. Manually toggle between each camera using a python script and capture and save images using each camera.
4. Manually move each servo 60 degrees right and then 60 degrees left.
5. Sever the SSH connection and connect the Pi's SD card to the laptop.
6. Ensure that all text in images is legible and clear.

7.1.2.4.3 Required Facilities/Equipment/Tools/Software

1. Laptop with VSCode
2. Raspberry Pi
3. Micro SD card
4. USB Cable
5. Smraza Pi Camera Module
6. Camera Unit Mount
7. Camera Housing
8. 8.5x11 Paper
9. Printer
10. Payload Bay
11. Multi-Camera Adapter Board

7.1.2.4.4 Results and Conclusion

When connected with the proper i2c bus, the multi-camera adapter board is able to toggle between each camera and capture clear images through each housing. Cameras are free to move when servos move according to hard-coded commands, and captured images are clear.

7.1.2.5 Camera System RAFCO Test

Test Date: 2/25/2023

The final test in the series of camera system tests includes the RAFCO system as well as the camera components. This test ensures functionality of all parts of SOCS. One camera unit is assembled and a test APRS transmission is sent using NASA-given commands. If SOCS can interpret this transmission and execute the commands, the test is considered successful.

Table 48: Camera System RAFCO Test Success Criteria

Success Criteria	Met? (Y/N)
Executed commands match transmitted commands	Y

7.1.2.5.1 Controllable Variables

- Camera selection
- Radio Selection
- Servo Selection

7.1.2.5.2 Procedure

1. Camera 1 is connected to the Pi, which is powered by a USB connection to a laptop.
2. Visual Studio Code is opened, and an SSH connection is established with the Pi.
3. main.py is started on the Pi.
4. Test transmissions are sent using APRSDroid and a Baofeng radio.
5. Servo motion is identified and captured images are saved to the Pi.

7.1.2.5.3 Required Facilities/Equipment/Tools/Software

1. Laptop with VSCode
2. Raspberry Pi
3. Camera Unit Mount
4. USB Cable
5. Camera Housing
6. Baofeng Radio
7. Smartphone with APRSDroid

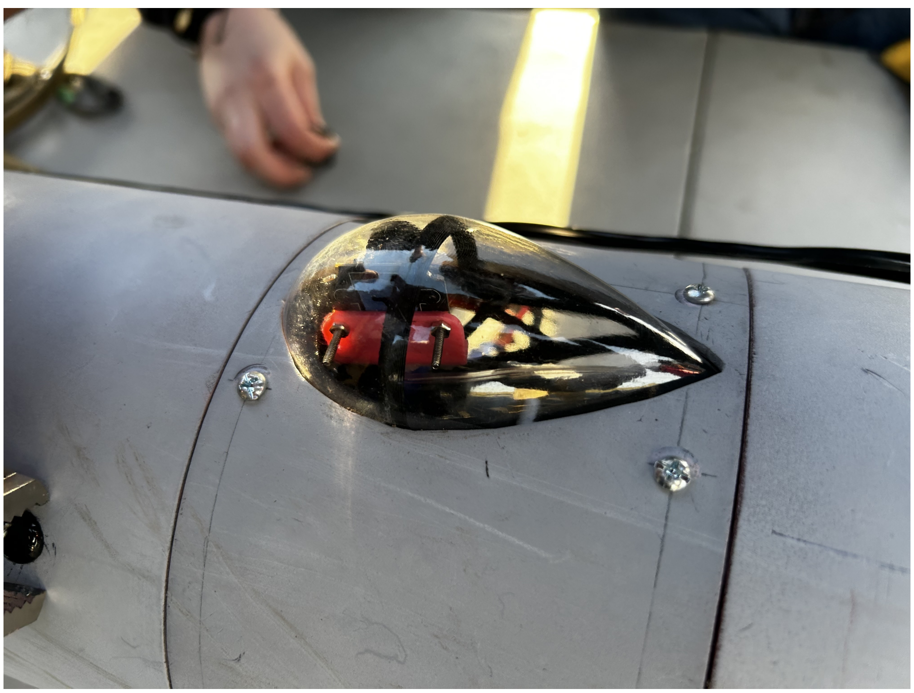

Figure 131: The full camera system assembled to receive APRS commands.

7.1.2.5.4 Results and Conclusion

The RAFCO subsystem is able to correctly receive and interpret APRS commands sent from the Baofeng radio setup. These commands are then processed correctly and sent to the correct camera unit in the payload bay. Captured images are clear and servos move according to commands.

7.1.2.6 Camera Housing Structural Test

Test Date: 2/7/2023

This test makes sure that the Camera Housing system is strong enough to withstand the forces experienced during landing. The maximum amount of force the housing can support before failure will be measured. If that number is higher than the forces it will experience during launch and landing, then the system is successful.

Success Criteria	Met? (Y/N)
Deformation does not exceed .3 in	Y
The max force experienced is greater than max force experienced during launch	Y

7.1.2.6.1 Controllable Variables

- Force Applied
- Camera Housing Material
- Number of Supports

7.1.2.6.2 Procedure

1. An assembled Camera Housing System and camera unit mount will be placed in the Universal testing machine so that force can be applied perpendicular to the supports.
2. apply a force to the the housing and using a ruler measure the amount of deformation caused by the force
3. Incrementally increase the force by 5 lbs until the deformation exceeds .3 in, which is the maximum amount of deformation allowable before the camera is damaged or until the housing system completely fails.

7.1.2.6.3 Required Facilities/Equipment/Tools/Software

- 1x Camera Housing
- 1x Camera Unit Mount
- 4x 6-32 bolts
- Universal Testing Machine
- HPRC Lab
- ECE Makerspace
- NCSU Entrepreneurship Garage

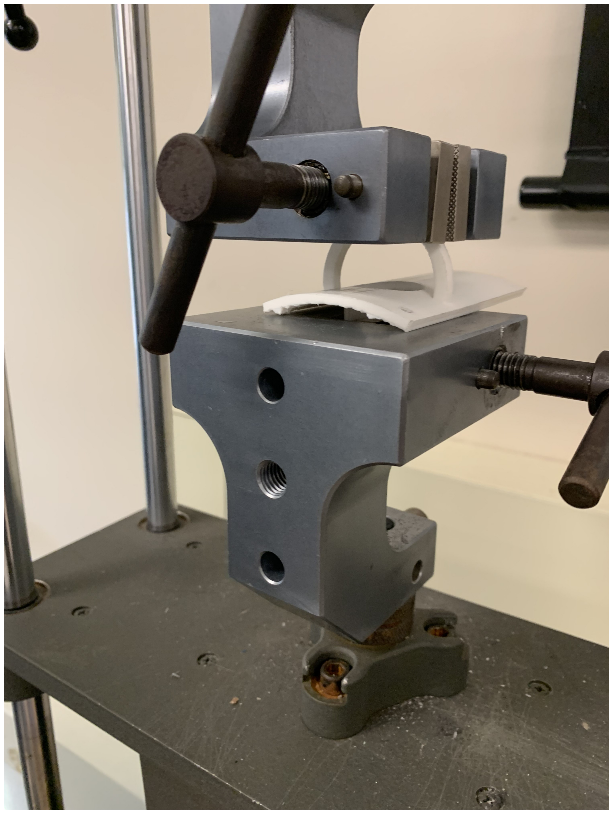

Figure 132: Camera Housing Test taking place in the Universal Testing Machine.

7.1.2.6.4 Results

This test was a success as the Supports withstood a force of 55 lbs which is greater than the 16 lbs of force predicted. There was also no deformation of the supports until failure. This affirms that the supports will be strong enough to survive landing.

7.1.2.7 Camera Unit Mount Test

Test Date:2/7/2023

This test ensures that the bolts used to hold the camera unit mount to the housing to the air frame will be able to withstand the shear forces experienced during launch and landing.

Success Criteria	Met? (Y/N)
The max force experienced by the camera unit mounts are greater than the max for experienced during launch.	Y
The max force experienced by the bolts is greater than max force experienced during launch	Y

7.1.2.7.1 Controllable Variables

- Force Applied
- Mount Material Infill
- Bolt Sizing

7.1.2.7.2 Procedure

1. Overlap 2 camera unit mounts so that the bolt holes on the short side align with each other.
2. Bolt them together and ensure they are secure.
3. Clamp each end of the camera unit mount assembly in the Universal testing Machine, so that compression or lengthening of the clamps will load the bolts
4. Apply 5 lb of force incrementally until failure of the bolts or the camera unit mounts.

7.1.2.7.3 Required Facilities/Equipment/Tools/Software

- 2x Camera Unit Mount
- 4x 6-32 bolts
- Universal Testing Machine
- HPRC Lab
- ECE Makerspace
- NCSU Entrepreneurship Garage

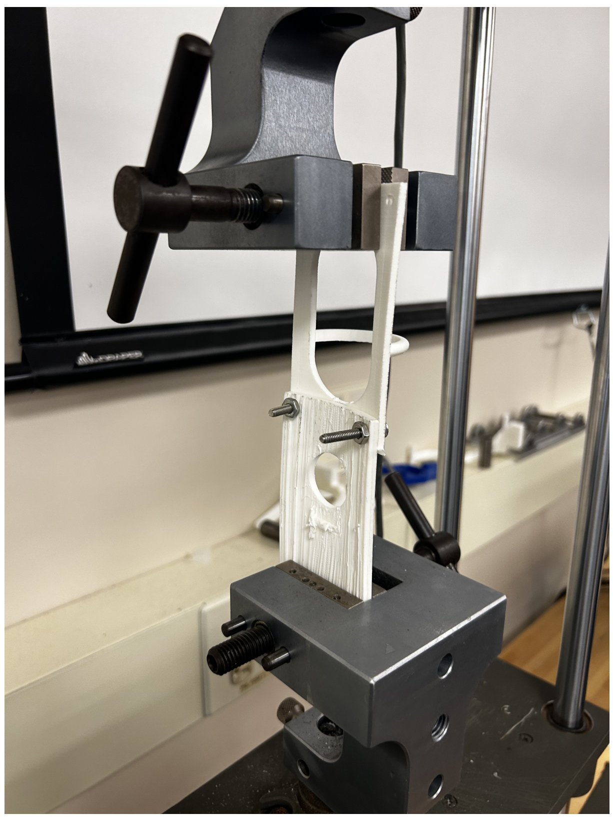

Figure 133: Unit Mount Test taking place in the Universal Testing Machine.

7.1.2.7.4 Results

This test was a success as the Unit Mounts withstood a force of 160 lbs before failure and the bolts did not fail at that time so we can assume it can withstand a force greater than that. The force withstood is greater than the force the mounts would experience so this test is a success

7.1.2.8 2-Meter Dipole SWR Test

Test Date: 1/24/2023

This test confirms that the constructed dipole antennas have a SWR at the competition frequency that provides acceptable gain, i.e. $1 < \text{SWR} < 2.2$. Antennas are constructed longer than needed to allow for trimming in order for proper tuning.

Table 49: 2-Meter Dipole SWR Test Success Criteria

Success Criteria	Met? (Y/N)
After adjusting, antenna SWR is between 1 and 2.2	Y

7.1.2.8.1 Controllable Variables

- Antenna Length

7.1.2.8.2 Test Design

- Antenna male SMA connector is attached to a female SMA to male N adapter
- SMA to N adapter is connected to the antenna 1 female N connector on the SAA-2N
- the SAA-2N is powered on

7.1.2.8.3 Procedure

1. Once antenna and SAA-2N are connected, lay flat on the table
2. Straighten out the antenna
3. Adjust the measurement point on the SAA-2N to the competition frequency ($\sim$145 MHz)
4. Observe the measured SWR
5. If the SWR is above 2.2, trim approximately 1 mm off of each end of the antenna
6. Continue to measure SWR and trim until SWR is within acceptable range

7.1.2.8.4 Required Facilities/Equipment/Tools/Software

- 2-meter Dipole Antenna
- Female SMA to Male N adapter
- SAA-2N
- Flush cutters

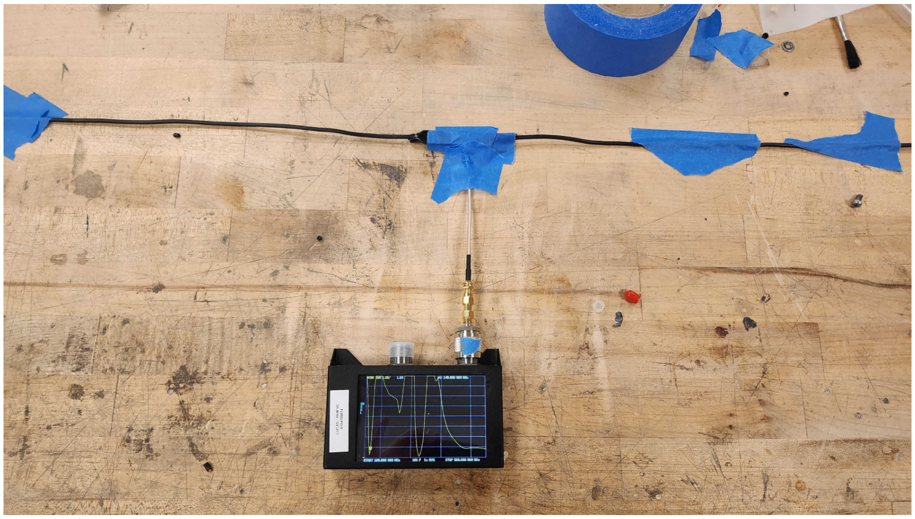

Figure 134: A successful SWR test showing an antenna SWR of 1.75

7.1.2.8.5 Results and Conclusion

Both antenna's SWR were tuned to be within acceptable levels. This process has been shown to be reliably replicated, with subscale antennas, full scale antennas, and backup full scale antennas successfully undergoing tuning.

7.1.2.9 Orientation Detection and Switching Test

Test Date: 2/21/2023

Antenna and Camera selection is done using IMU data, and antenna selection is physically made through a 2-channel relay. This system is mission critical, and thus must be thoroughly tested.

Table 50: Orientation Detection and Switching Test Success Criteria

Success Criteria	Met? (Y/N)
IMU is able to correctly determine orientation	Y
Software makes correct antenna selection	Y
Relay hardware makes correct selection	Y

7.1.2.9.1 Controllable Variables

- Hardware connections
- IMU data processing software
- Relay selection software

7.1.2.9.2 Test Design

- Raspberry Pi running IMU and Relay code
- BNO055 connected to Pi
- 2-channel relay connected to Pi
- Raspberry Pi powered over USB-C
- Computer remote SSH into Pi
- Pi, BNO055, and relay attached to sled or other stable mounting surface that is able to be picked up by hand

7.1.2.9.3 Procedure

1. Ensure wiring between modules is correct
2. Power on the Pi by plugging a USB-C cable into its power port and then into a compatible power supply, such as a computer USB port
3. Remote SSH into the Pi
4. Activate IMU/Relay Program
5. While observing live orientation and relay selection data, rotate the assembly 90 degrees clockwise
6. Ensure that orientation and relay selection is correct
7. Repeat until 360 degree rotation has been completed
8. Stop the program and power off the pi

7.1.2.9.4 Required Facilities/Equipment/Tools/Software

- Wire headers
- Raspberry Pi
- bno055
- 2-channel Relay
- USB-C cable
- Laptop capable of generating a hotspot
- VSCode
- Payload Sled or other secure but rotatable surface

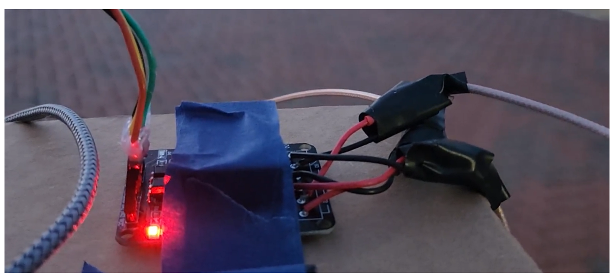

Figure 135: The mechanical switching relay selecting antenna 1.

7.1.2.9.5 Results and Conclusion

This subsystem is arguably the most mature portion of the payload, and has been repeatedly proven to function as intended. Overall system stability has been increased through several design iterations (e.g. the removal of terminal blocks), and the functional reliability of this subsystem is held in high confidence.

7.1.2.10 APRS Reception and Decoding Test

Test Date: 2/21/2023

Using the 2-meter Dipole antennas, reception and decoding of APRS signals transmitted on competition frequency needs to be tested. Testing using 2-m Dipole antennas on the competition frequency has been completed with the full scale launch vehicle, and fulfilled the following success criteria.

Table 51: APRS Reception and Decoding Test Success Criteria

Success Criteria	Met? (Y/N)
Program is able to decode packets at close and far distances	Y
Both antennas are able to receive packets from furthest tested distance	Y

7.1.2.10.1 Controllable Variables

- Antenna Position
- Transmission Strength
- Transmission Location
- Reception Location
- Transmitted Packet Contents

7.1.2.10.2 Test Design

- Raspberry Pi running APRS & IMU/Relay code
- bno055 and 2-channel relay attached to Pi
- coax cables attached to 2-channel relay and 2-meter dipole antennas
- Dipole antennas mounted to wood in order to support them
- APRS transmitting setup consisting of a Baofeng bf-f8hp, APRS cable, and phone running APRSDroid
- Raspberry Pi powered over USB-C
- Computer remote SSH into Pi

7.1.2.10.3 Procedure

1. Ensure wiring between modules is correct
2. Power on the Pi by plugging a USB-C cable into its power port and then into a compatible power supply, such as a computer USB port
3. Remote SSH into the Pi
4. Activate program
5. Raise antenna 1 (i.e. the antenna selected when the Pi is upright)
6. Transmit APRS packet from test setup from 10 ft away
7. confirm reception in terminal
8. move 30 ft further away and re-transmit
9. Continue to transmit and confirm until 460 ft away
10. Rotate pi 180 degrees so antenna 2 is selected
11. Repeat test with antenna 2

7.1.2.10.4 Required Facilities/Equipment/Tools/Software

- Wire headers
- Raspberry Pi
- bno055
- 2-channel Relay

- USB-C cable
- Laptop capable of generating a hotspot
- VSCode
- Payload Sled or other secure but rotatable surface
- Baofeng bf-f8hp
- APRS cable
- Phone with APRSDroid
- 2-meter dipole antennas (x 2)
- wood to mount antennas
- The Oval

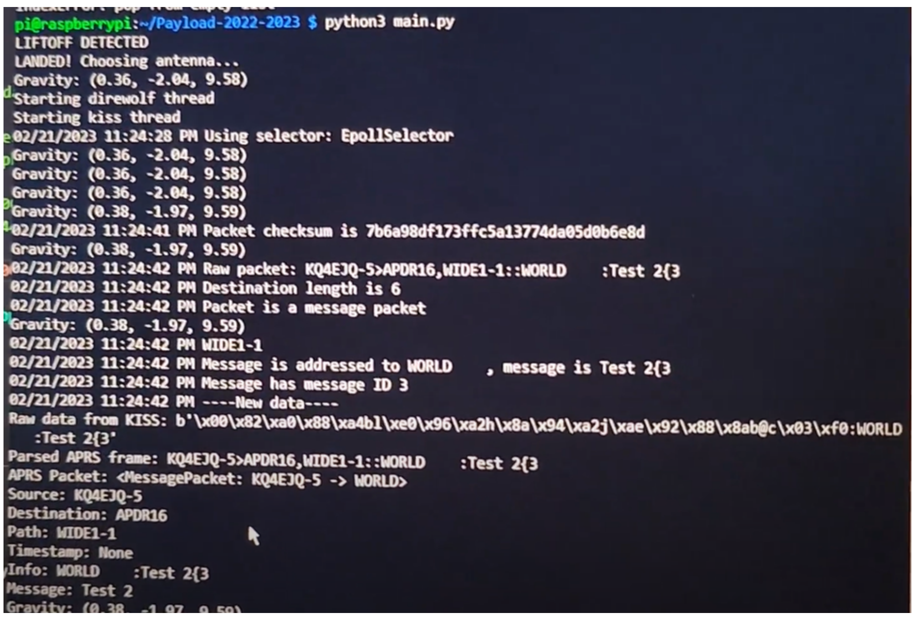

Figure 136: Code detecting launch and logging receipt of APRS command.

7.1.2.10.5 Results and Conclusion

Overall, antenna 1 received and decoded transmitted APRS signals 75% of the time, and antenna 2 70% of the time. Transmissions closer to the antennas were received and decoded almost 100% of the time, with reception rates decreasing the further away transmission occurred. This result is to be expected, and general performance is acceptable. All received signals were properly decoded. It is important to note that the transmission setup used consisted of a 8W transmitter at chest height, which has significantly less reach and power than the 25W raised transmitter that will be used at competition launch. With this difference in mind, the results of this test are extremely promising.

7.2 Requirements Verification

7.2.1 NASA Requirements

Table 52: Requirements given in the 2023 Student Launch handbook.

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
1.1	Students on the team SHALL 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 SHALL submit new work. Excessive use of past work SHALL merit penalties.	The students of the High Powered Rocketry Club at NC State design and construct a solution to the requirements as listed in the Student Launch Handbook using past ideas and methods while also integrating new ideas.	Inspection	Project Management	Verified	Students complete the project using all original work performed only by the students.
1.2	The team SHALL 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.	The project management team, consisting of the team lead, vice president, treasurer, secretary, safety officer, webmaster, and social media lead manage the project planning tasks pertaining to this requirement.	Inspection	Project Management	Verified	See Section 6 for current project plan.
1.3	The team SHALL identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR).	The team lead identifies and reports the team members that attend the launch week by January 9, 2023, with the submission of CDR milestone documentation.	Inspection	Project Management	Verified	The attendance list is provided in the CDR submission packet.
1.3.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team identifies the students that have been actively engaged throughout the year to be invited to launch week activities.	Inspection	Project Management	Verified	All members attending launch week have been actively assisting the senior design members in design and fabrication of the project.
1.3.2	Team members SHALL include one mentor (see requirement 1.1.2).	The team lead invites the mentor listed in Section 1.2 to attend launch week activities.	Inspection	Project Management	Verified	See section 1.1.3 for mentor information.
1.3.3	Team members SHALL include no more than two adult educators.	The team lead invites the adult educator listed in Section 1.2 to attend launch week activities.	Inspection	Project Management	Verified	All adult educators are included in section 1.1.3.
1.4	Teams SHALL engage a minimum of 250 participants in Educational Direct Engagement STEM activities in order to be eligible for STEM Engagement scoring and awards. These activities can be conducted in person or virtually. To satisfy this requirement, all events SHALL occur between project acceptance and the FRR due date. A template of the STEM Engagement Activity Report can be found on pages 39–42.	The outreach lead implements STEM engagement plans with K12 student groups throughout the project lifecycle and submits all STEM Engagement Activity Reports within two weeks of the event's conclusion.	Inspection	Project Management	Verified	See Section 1.1.5.
1.5	The team SHALL establish and maintain a social media presence to inform the public about team activities.	The webmaster and social media officer cooperate to maintain our website and social media platforms to inform the public about all activities and events that the team performs throughout the year. Our social media platforms include, but are not limited to: our club website, Facebook, Instagram, and Twitter.	Inspection	Project Management	Verified	All forms of social media related to team activities have been sent to the NASA project management team.

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
1.6	Teams SHALL 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 SHALL be sufficient. Late submissions of PDR, CDR, FRR milestone documents SHALL be accepted up to 72 hours after the submission deadline. Late submissions SHALL incur an overall penalty. No PDR, CDR, FRR milestone documents SHALL be accepted beyond the 72-hour window. Teams that fail to submit the PDR, CDR, FRR milestone documents SHALL be eliminated from the project.	The team lead sends all deliverables to the NASA project management team prior to each specified deadline.In the event that the deliverable is too large, the webmaster posts the document on the team's website, and the team lead sends the NASA project management team a link to the file.	Inspection	Project Management	Verified	The team emails all deliverables to the NASA project management team by each specified deadline. After submission of FRR document, all deliverables will be completed.
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) SHALL be provided action items needed to be completed following their review and SHALL be required to address action items in a delta review session. After the delta session the NASA management panel SHALL meet to determine the teams' status in the program and the team SHALL be notified shortly thereafter.	Team members complete and submit each milestone review document before the provided deadline. In the event that a document is not satisfactorily completed, the team completes the action items provided and attends the delta review session to maintain their status in the program.	Inspection	Project Management	Verified	The team completes a satisfactory milestone review document and submits before the deadline.
1.8	All deliverables SHALL be in PDF format.	The team lead converts all deliverables to PDF format prior to submission to the NASA project management team.	Inspection	Project Management	Verified	This report is submitted in PDF format.
1.9	In every report, teams SHALL provide a table of contents including major sections and their respective sub-sections.	In every report, teams SHALL provide a table of contents including major sections and their respective sub-sections.	Inspection	Project Management	Verified	See the Table of Contents above.
1.10.	In every report, the team SHALL include the page number at the bottom of the page.	In every report, the team SHALL include the page number at the bottom of the page.	Inspection	Project Management	Verified	The page number has been listed at the bottom of every page in this report.
1.11	The team SHALL 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 a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Each team member participating in the video teleconference obtains the necessary equipment for them to perform a video teleconference with the review panel.	Inspection	Project Management	Verified	The team has and will continue to provide their own equipment to engage in a video teleconference with the review panel.
1.12	All teams attending Launch Week SHALL be required to use the launch pads provided by Student Launch's launch services provider. No custom pads SHALL be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails SHALL be provided. The launch rails SHALL be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant SHALL depend on Launch Day wind conditions.	The aerodynamics lead designs a launch vehicle to be launched from either an 8-foot 1010 rail or a 12 foot 1515 rail. The structures lead fabricates the launch vehicle according to the aforementioned design.	Inspection	Aerodynamics; Structures	Verified	The launch vehicle is designed to be launched from 12- foot 1515 rail. See Section 3.2.1 for final launch vehicle design.

Continued on next page

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
1.13	Each team SHALL identify a "mentor." A mentor is defined as an adult who is included as a team member, who SHALL 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 SHALL 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 SHALL be provided per mentor regardless of the number of teams he or she supports. The stipend SHALL only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The team lead identifies qualified community members to mentor team members throughout the design process.	Inspection	Project Management	Verified	See Section 1.1.3
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The team reports the number of hours spent on each milestone in the associated milestone report.	Inspection	Project Management	Verified	See Section 1.1.4
2.1	The vehicle SHALL deliver the payload to an apogee altitude between 4,000 and 6,000 ft. above ground level (AGL). Teams flying below 3,500 ft. or above 6,500 ft. on their competition launch SHALL receive zero altitude points towards their overall project score and SHALL not be eligible for the Altitude Award.	The aerodynamics lead designs a launch vehicle to reach an apogee between 4,000 and 6,000ft. AGL. The team then constructs the vehicle as designed.	Analysis; Demonstration	Aerodynamics	Verified	See Section 3.6 for mission performance predictions.
2.2	Teams SHALL declare their target altitude goal at the PDR milestone. The declared target altitude SHALL be used to determine the team's altitude score.	The aerodynamics lead reports the eam's target altitude goal in the PDR milestone report, submitted by October 26, 2022.	Inspection	Aerodynamics	Verified	See Section 1.2.1
2.3	The launch vehicle SHALL be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The recovery and structures leads design a recovery harness system that allows the launch vehicle to be recovered upon ground impact with minimal damage.	Demonstration	Recovery; Structures	Verified	See Section 3.5.1 for recovery design.
2.4	The launch vehicle SHALL 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.	The aerodynamics and recovery leads design the vehicle to have a maximum of 4 independent sections.	Inspection	Aerodynamics; Recovery	Verified	See Section 3.2 regarding the launch vehicle design.
2.4.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section).	The aerodynamics lead designs a airframe with couplers at in-flight separation points at least two airframe diameter in length. The structures lead constructs the couplers to the determined lengths.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding the launch vehicle design.

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2.4.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least ½ body diameter in length.	The aerodynamics lead designs the airframe such that nosecone shoulders at in-flight separation points are at least 1/2 body diameter in length.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding the launch vehicle design.
2.5	The launch vehicle SHALL be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The project management and safety teams develop launch day checklists that can be executed in under two (2) hours.	Demonstration	Project Management; Safety	Verified	See Section 3.2 for launch vehicle overview.
2.6	The launch vehicle and payload SHALL 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.	The project management and safety teams monitor the power consumption of each electrical launch vehicle and payload component and verify functionality of each component after two (2) hours.	Demonstration	Project Management; Safety	Verified	See Section 3.2 for launch vehicle overview and Section 4.4 for the Payload overview.
2.7	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system. The firing system SHALL be provided by the NASA-designated launch services provider.	The project management and safety teams choose a motor ignitor that can be ignited from a 12-volt direct current firing system.	Demonstration	Project Management; Safety	Verified	The motor ignitor used can be ignited using a standard 12-volt DC system.
2.8	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The project management and safety teams ensure the launch vehicle is designed such that no external circuitry or ground support equipment is required for launch.	Demonstration	Project Management; Safety	Verified	Currently, there is no plan to use external circuitry which can be seen in Section 3.2.
2.9	Each team SHALL use commercially available ematches or igniters. Hand-dipped igniters SHALL not be permitted.	The project management and safety teams ensure proper purchase and use of commercially available ematches and igniters.	Inspection	Project Management; Safety	Verified	The team currently uses FireWire ematches and igniters which are commercially available.
2.10.	The launch vehicle SHALL 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).	The aerodynamics lead selects a commercially available solid motor propulsion system using APCP that is approved by NAR, TRA, and/or CAR for use in the launch vehicle.	Inspection	Aerodynamics	Verified	See Section 1.2.1 in the FRR document and Section 3.2.11 in the CDR document for the final motor choice.
2.10.1	Final motor choices SHALL be declared by the Critical Design Review (CDR) milestone.	The aerodynamics lead declares the team's final motor choice in the CDR milestone report by January 9, 2023.	Inspection	Aerodynamics	Verified	See Section 1.2.1 for the final motor choice.
2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment SHALL not be approved. A penalty against the team's overall score SHALL be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The project management team requests approval from the NASA RSO for motor changes following submission of the CDR milestone report.	Inspection	Project Management	Verified	No changes have been made to the motor selection since submission of the PDR dcoument.
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The aerodynamics lead designs the launch vehicle such that it only utilizes a single stage.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding the launch vehicle design.
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton-seconds (L-class).	The aerodynamics lead chooses a motor that does not exceed 5,120 Newton-seconds of total impulse.	Inspection	Aerodynamics	Verified	See Section 3.2.11 of the CDR document for the final motor choice.

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2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary information on any onboard pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Verified	There are no pressure vessels in the final launch vehicle design as shown in Section 3.2.
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) is 4:1 with supporting design documentation included in all milestone reviews.	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) is 4:1 with supporting design documentation included in all milestone reviews.	Analysis; Inspection	Structures	Verified	There are no pressure vessels in the final launch vehicle design as shown in Section 3.2.
2.13.2	Each pressure vessel SHALL 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.	The structures lead selects certain onboard pressure vessels such that they include a pressure relief valve that sees the full pressure of the tank and is more than capable of withstanding the maximum pressure and flow rate of the tank.	Analysis; Inspection	Structures	Verified	There are no pressure vessels in the final launch vehicle design as shown in Section 3.2.
2.13.3	The full pedigree of the tank SHALL be described, including the application for which the tank was designed and the history of the tank. This SHALL 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.	The structures lead records the full history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and the name of each person or entity administering the pressure events	Inspection	Structures	Verified	There are no pressure vessels in the final launch vehicle design as shown in Section 3.2.
2.14	The launch vehicle SHALL 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.	The aerodynamics lead designs the launch vehicle such that it has a minimum static stability margin of 2.0 at the point of rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6.4 regarding the projected static stability margin at rail exit.
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5.0 : 1.0.	The aerodynamics lead designs the launch vehicle such that it has a thrust to weight ratio of at least 5.0:1.0.	Analysis; Inspection	Aerodynamics	Verified	See Section 3.2.11 in the CDR document for the final motor choice.
2.16	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity. Camera housings SHALL be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	The aerodynamics lead designs the launch vehicle such that all structural protuberances are located aft of the burnout center of gravity. If any camera housings are included, the aerodynamics lead shows that the housings cause minimal aerodynamic effects on launch vehicle stability.	Analysis; Inspection	Aerodynamics	Verified	See Section 3.2 regarding location of cupulas on the launch vehicle.
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The aerodynamics lead designs the launch vehicle such that a velocity of 52 fps or greater is achieved by the launch vehicle at the rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6.4 regarding the projected velocity of the launch vehicle at rail exit.
2.18	All teams SHALL successfully launch and recover a subscale model of their rocket prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data SHALL be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid-Power motor).	The management team launches a subscale model of the launch vehicle using an impulse motor of E or greater. The management and safety teams successfully recover the subscale model of the launch vehicle. The team reports subscale flight data in the CDR milestone report by January 9, 2023.	Demonstration	Project Management	Verified	See Section 3.3 of the CDR document regarding subscale flight data.

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2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale SHALL not be used as the subscale model.	The aerodynamics lead designs a unique subscale launch vehicle which performs similarly to the full- scale launch vehicle.	Inspection	Aerodynamics	Verified	See Section 3.3 of the CDR document regarding subscale design and performance.
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery lead installs an altimeter in the subscale launch vehicle capable of recording the vehicle's apogee altitude.	Inspection	Recovery	Verified	See Section 3.3 of the CDR document regarding selected subscale altimeter.
2.18.3	The subscale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The team constructs a new subscale launch vehicle, designed to meet the specifications for this year's project.	Inspection	Project Management	Verified	See Section 3.3.1 of the CDR document for subscale design and construction.
2.18.4	Proof of a successful flight SHALL be supplied in the CDR report.	The team includes proof of a successful subscale flight in the CDR milestone report by January 9,2023.	Inspection	Project Management	Verified	See Section 3.3.2 of the CDR document for subscale flight results.
2.18.4.1	Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable.	The recovery lead creates an altimeter flight profile graph that includes all altitudes recorded from liftoff through landing.	Analysis	Recovery	Verified	See Section 3.3.2 of the CDR document regarding altimeter flight profile graph for the subscale vehicle flight.
2.18.4.2	Quality pictures of the as landed configuration of all sections of the launch vehicle SHALL be included in the CDR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	The recovery team takes pictures of the configuration of all sections of the launch vehicle after landing and include them in the CDR report to be submitted before January 9, 2023.	Analysis; Demonstration	Project Management; Recovery	Verified	See Section 3.3.2 of the CDR document for landing configuration of each independent Section of the subscale launch vehicle.
2.18.5	The subscale rocket SHALL not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale SHALL not exceed 3" diameter and 75" in length.	The aerodynamics and structures leads design a subscale launch vehicle such that it does not exceed 75% of the dimensions of the designed full-scale launch vehicle.	Inspection	Aerodynamics; Structures	Verified	See Section 3.3.3 of the CDR document for the scaling factors of the subscale launch vehicle.
2.19.1	Vehicle Demonstration Flight—All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown SHALL be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria SHALL be met during the full-scale demonstration flight:	The team launches and recovers the full-scale launch vehicle in its final flight configuration prior to the FRR milestone.	Demonstration	Project Management	Verified	The VDF was completed. The launch vehicle was successfully launched and recovered on 2/25/22.
2.19.1.1	The vehicle and recovery system SHALL have functioned as designed.	No anomalies are detected in the performance of the launch vehicle and its recovery system.	Demonstration	Project Management	Verified	The launch vehicle and recovery system functioned as designed. See Section 7.1.1.12. for more details.
2.19.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The team constructs a new full-scale launch vehicle that is designed and built according to the specifications for this year's project.	Inspection	Project Management; Aerodynamics	Verified	See Section 3.2 for final launch vehicle design and construction.

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2.19.1.3.1	If the payload is not flown, mass simulators SHALL be used to simulate the payload mass.	If the payload is not flown during the VDF, the structures lead installs mass simulators to simulate intended payload mass.	Inspection	Structures	Verified	See Section 4.4 for the payload flown on VDF.
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the rocket as the missing payload.	If the payload is not flown during the VDF, the structures lead installs mass simulators in the same approximate location on the launch vehicle as the missing payload mass.	Inspection	Structures	Verified	No payload mass simulators were used on VDF.
2.19.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	If the payload changes the external surfaces or manages the total energy of the launch vehicle, the project management team activates those systems during the VDF.	Inspection	Project Management	Verified	See Section 4.4.2 about the camera housings on the launch vehicle for VDF.
2.19.1.5	Teams SHALL fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	The aerodynamics lead installs the Launch Day motor for the VDF.	Inspection	Aerodynamics	Verified	The same motor was used on the VDF as will be used for the competition.
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 SHALL be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	The aerodynamics lead decides on the final ballast configuration. The structures lead installs all required ballast for the VDF.	Inspection	Structures; Aerodynamics	Verified	The launch vehicle flew in its fully ballasted configuration on VDF. See Section 6.1 for more details.
2.19.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	After successful completion of the VDF, the project management team does not allow further modification of the launch vehicle or any of its components without approval from the NASA RSO	Inspection	Project Management	Verified	Currently, there are no plans to change any components after successful VDF.
2.19.1.8	Proof of a successful flight SHALL be supplied in the FRR report.	The project management team provides all proof of successful VDF in the FRR milestone report.	Inspection	Project Management	Verified	See Section 6.1
2.19.1.8.1	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph (s) that are not complete (liftoff through landing) SHALL not be accepted.	The recovery lead includes all altimeter data from the VDF in the FRR milestone report.	Inspection	Recovery	Verified	See Section 3.6.2 for all altimeter flight profile graphs.
2.19.1.8.2	Quality pictures of the as landed configuration of all sections of the launch vehicle SHALL be included in the FRR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	The recovery lead includes all pictures of the landing configuration of the launch vehicle in the FRR milestone report.	Inspection	Recovery	Verified	See Section 6.1.1 for the landing configuration.

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2.19.1.9	Vehicle Demonstration flights SHALL be completed by the FRR submission deadline. No exceptions SHALL be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team completes the VDF by the FRR milestone report submission deadline. If a re-flight is required, the team submits an FRR addendum by the FRR addendum deadline.	Inspection	Project Management	Verified	See Section 6.1 regarding successful VDF.
2.19.2	Payload Demonstration Flight—All teams SHALL successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown SHALL be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria SHALL be met during the Payload Demonstration Flight:	The team successfully launches and recovers the full-scale launch vehicle containing the completed payload prior to the PDF deadline.	Inspection	Project Management	Verified	See Section 6.1 regarding successful PDF.
2.19.2.1	The payload SHALL be fully retained until the intended point of deployment (if applicable), all retention mechanisms SHALL function as designed, and the retention mechanism SHALL not sustain damage requiring repair.	The payload is fully retained until the point of intended deployment, with each retention mechanism functioning as designed and not sustaining damage requiring repair during the PDF.	Inspection	Integration	Verified	See Section 4.4 for the payload flown on VDF.
2.19.2.2	The payload flown SHALL be the final, active version.	The payload flown during the PDF is the final, active version of the payload.	Inspection	Project Management	Verified	The payload flown for VDF and PDF was the final active version..
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.	The project management team ensures all criteria for the VDF are met and submitted before the FRR deadline. In the event that all criteria are not properly met, the team submits the additional flight and FRR addendum required.	Inspection	Project Management	Verified	Due to successful completeion of VDF and PDF on 2/25/23, an FRR addendum will not be submitted.
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline. NO EXTENSIONS SHALL BE GRANTED.	The team completes the PDF by the FRR Addendum deadline.	Inspection	Project Management	Verified	PDF has been completed. See Section 6.2 for further details.
2.20.	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If the team is completing the PDF or a NASA- required VDF re-flight after the submission of the FRR Report, the team lead submits an FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Verified	The team will not need to submit an FRR Addendum due to successful completion of VDF and PDF.
2.20.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline SHALL not be permitted to fly a final competition launch.	The project management team manages the schedule to ensure that a PDF is successfully completed by the FRR Addendum deadline.	Inspection	Project Management	Verified	The team will not need to submit an FRR Addendum due to successful completion of VDF and PDF.

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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 SHALL not be permitted to fly a final competition launch.	The project management team successfully completes VDF and PDF before the FRR Addendum deadline.	Demonstration	Project Management	Verified	Successful VDF and PDF have been completed.
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 SHALL not be granted if the RSO or the Review Panel have any safety concerns.	The project management team petitions the NASA RSO for permissions to fly the payload at launch week in the event that PDF is not fully successful.	Inspection	Project Management	Verified	Successful VDF and PDF have been completed.
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.	The project management team includes the team name and contact information on the launch vehicle such that it can be retrieved without the need to open or separate the vehicle.	Inspection	Project Management	Verified	The team's name and contact info is written on the inside on the AV bay coupler.
2.22	All Lithium Polymer batteries SHALL be sufficiently protected from impact with the ground and SHALL be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	The project management and safety teams clearly mark all lithium polymer batteries as a fire hazard and ensure they are sufficiently protected from impact with the ground.	Analysis; Inspection	Project Management; Safety	Verified	See Section 4.5.3 and 3.5.7 regarding LiPo battery retention system.
2.23.1	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics lead designs the launch vehicle to not utilize forward firing motors.	Inspection	Aerodynamics	Verified	Currently, there are no plans to utilize forward firing motors which can be seen in Section 3.2 for launch vehicle design.
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The aerodynamics lead designs the launch vehicle to not utilize motors that are capable of expelling titanium sponges.	Inspection	Aerodynamics	Verified	See Section 3.2.11 in the CDR document regarding final motor selection.
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics lead designs a launch vehicle that does not utilize hybrid motors.	Inspection	Aerodynamics	Verified	See Section 3.2.11 in the CDR document regarding final motor selection.
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics lead designs a launch vehicle such that it utilizes only one motor.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding launch vehicle design.
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The structures lead designs a motor retention system such that it does not utilize friction fitting to hold the motor in place.	Inspection	Structures	Verified	See Section 3.2.9.3 regarding motor retention.
2.23.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The aerodynamics lead designs the launch vehicle such that it does not exceed Mach 1 at any point during the flight.	Analysis	Aerodynamics	Verified	See Section 3.6.2 regarding vehicle velocity during flight.
2.23.7	Vehicle ballast SHALL 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 40 lbs. On the pad may contain a maximum of 4 lbs. of ballast).	The aerodynamics lead designs the launch vehicle such that the vehicle ballast does not exceed 10% of the total unballasted weight of the launch vehicle.	Analysis; Inspection	Aerodynamics	Verified	See Section 3.6.6 regarding ballast weight calcuations in vehicle design.
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The recovery and payload leads select onboard transmitters that do not exceed 250mW of power for each transmitter.	Analysis	Recovery; Payload	Verified	The Eggfinder GPS Transmitter, shown in Section 3.5.8 was chosen for the recovery system and does not exceed the power requirment.

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2.23.9	Transmitters SHALL not create excessive interference. Teams SHALL utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The recovery and payload leads choose a transmitter that creates minimal interference. The safety lead then enforces the usage of unique frequencies to mitigate interference with other teams.	Analysis; Demonstration	Safety; Recovery; Payload	Verified	See Section 3.5.8 regarding the selected transmitter.
2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the vehicle. Use of lightweight metal SHALL be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The structures lead designs the launch vehicle such that the amount of metal utilized in the construction of the vehicle is minimized.	Inspection	Structures	Verified	See Section 3.2 regarding launch vehicle design.
3.1	The full scale launch vehicle SHALL stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	The recovery lead designs a dual-deployment recovery system.	Demonstration	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.1.1	The main parachute SHALL be deployed no lower than 500ft.	The recovery lead designs a recovery system that deploys the main parachute no lower than 500 ft.	Demonstration	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	The recovery lead designs a recovery system that has an apogee event delay of no more than 2 seconds.	Demonstration	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	The recovery lead designs a recovery system where the motor does not separate from the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.2	Each team SHALL perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	The recovery lead conducts ejection tests prior to each launch confirming electronics function properly.	Demonstration	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by vehicle demonstration flight data, stays under 65 ft-lbf SHALL be awarded bonus points.	The recovery lead designs a recovery system such that the maximum kinetic energy experienced by the heaviest section of the launch vehicle does not exceed 65 ft-lbf.	Analysis	Recovery	Verified	See Section 3.6.8 for kinetic energy calculations.
3.4	The recovery system SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The recovery lead designs a recovery system that utilizes a primary and secondary altimeter, each individually independent from the other.	Inspection	Recovery	Verified	See Section 3.5.6.1 detailing the altimeters system.
3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The recovery lead designs a recovery system that utilizes separate power sources for each altimeter used.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The recovery lead designs a recovery system that utilizes pin switches to activate each altimeter accessible from the exterior of the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.

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3.7	Each arming switch SHALL be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The recovery lead utilizes arming switches that can be locked in the ON position.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.8	The recovery system, GPS and altimeters, electrical circuits SHALL be completely independent of any payload electrical circuits.	The recovery lead designs a recovery system that ensures all recovery electronics are all independent of the payload electronics.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The recovery lead designs a recovery system that utilizes removable shear pins to secure separable sections of the launch vehicle together on the pad.	Inspection	Recovery	Verified	See Section 3.5.1 for recovery system design.
3.10.	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The recovery lead designs a recovery system that prevents the launch vehicle from drifting more than 2,500 ft. radius from the launch pad in launch pad condition.	Analysis; Demonstrati on	Recovery	Verified	See Section 3.6.10 for wind drift calculations.
3.11	Descent time of the launch vehicle SHALL be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds SHALL be awarded bonus points.	The recovery lead designs a recovery system that safely descends the launch vehicle in under 80 seconds.	Analysis; Demonstrati on	Recovery	Verified	See Section 3.6.9 regarding descent time.
3.12	An electronic GPS tracking device SHALL be installed in the launch vehicle and SHALL transmit the position of the tethered vehicle or any independent section to a ground receiver.	The recovery lead designs a recovery system that utilizes a GPS tracking system that transmits the location of the launch vehicle at all points during flight.	Inspection; Demonstrati on	Recovery	Verified	See Section 3.5.8 for tracking system design.
3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic GPS tracking device.	The recovery lead designs a GPS system and implements it on any payload component that lands separate from the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.12.2	The electronic GPS tracking device(s) SHALL be fully functional during the official competition launch.	The recovery lead tests and ensures all GPS devices remain fully functional the day of official competition launch.	Inspection; Demonstrati on	Recovery	Verified	See Section 3.5 for recovery system design.
3.13	The recovery system electronics SHALL not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery lead designs a recovery system that recovery avionics are not affected by any other electronics onboard the launch vehicle.	Inspection; Demonstrati on	Recovery	Verified	See Section 3.5 for recovery system design.
3.13.1	The recovery system altimeters SHALL be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery lead designs an avionics bay that is physically located in a separate compartment than any other radio frequency transmitting or magnetic wave producing devices.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.13.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery lead designs an avionics bay that is shielded from other onboard transmitting devices.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
3.13.3	The recovery system electronics SHALL 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.	The recovery lead designs an avionics bay that is shielded from onboard magnetic wave generating devices.	Inspection	Recovery	Verified	See Section 3.2 and 3.5 for launch vehicle and recovery system design.

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NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
3.13.4	The recovery system electronics SHALL be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery lead designs an avionics bay that is shielded from any other onboard devices that may affect recovery system operations.	Inspection	Recovery	Verified	See Section 3.5 for recovery system design.
4.1	Teams SHALL design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The method(s)/design(s) utilized to complete the payload mission SHALL be at the team's discretion and SHALL be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	Payload team designs a payload system that is capable of receiving and interpreting RF commands and performing tasks with an onboard camera system, while obeying safety, FAA, and legal requirements, and adhering to the intent of the challenge.	Demonstration	Payload Systems; Payload Electronics; Payload Structures Integration; Safety	Verified	See Section 4.4 for payload system design overview.
4.2.1	Launch Vehicle SHALL contain an automated camera system capable of swiveling 360° to take images of the entire surrounding area of the launch vehicle.	Payload system contains a camera system that is able to rotate 360°, take pictures, and is able to take pictures of the entire area surrounding the launch vehicle.	Demonstration	Payload Systems; Payload Electronics; Payload Structures; Integration	Verified	See Section 4.4 for payload system design.
4.2.1.1	The camera SHALL have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane with the sky oriented up and the planetary surface oriented down	Camera system rotational axis is about the described z axis.	Demonstration	Payload Systems; Payload Electronics; Payload Structures	Verified	See Section 4.4.1.2.3 for camera positioning determination.
4.2.1.2	The camera SHALL have a FOV of at least 100° and a maximum FOV of 180°.	Camera used in payload system has a FOV of at least 100° and at most 180°.	Inspection	Payload Electronics	Verified	See Section 4.4.1.2.2 for camera unit description.
4.2.1.3	The camera SHALL time stamp each photo taken. The time stamp SHALL be visible on all photos submitted to NASA in the PLAR.	Payload system adds a time stamp to each photo taken before saving.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.2.4.2.
4.2.1.4	The camera system SHALL execute the string of transmitted commands quickly, with a maximum of 30 seconds between photos taken.	Camera system takes less than 30 seconds to execute commands between photos.	Demonstration	Payload Electronics; Payload Systems; Integration	Verified	See Section 4.6 for payload system operations.
4.2.2	NASA Student Launch Management Team SHALL transmit a RF sequence that SHALL contain a radio call sign followed by a sequence of tasks to be completed.	The payload system is able to determine if the correct call sign is used, and then accept and perform RF commands.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.6 for payload system operations.
4.2.3	The NASA Student Launch Management Panel SHALL transmit the RAFCO using APRS.	The payload system is able to accept RAFCO using APRS.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.6 for payload system operations.
4.2.3.2	The NASA Management Team SHALL transmit the RAFCO every 2 minutes.	The payload system is able to accept RAFCO commands continuously.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.6 for payload system operations.
4.2.3.3	The payload system SHALL not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface.	The payload system is designed such that it does not accept RAFCO until after launch vehicle landing.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.6 for payload system operations.

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NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
4.2.4	The payload SHALL not be jettisoned.	The payload system is designed such that no components are jettisoned.	Inspection	Payload Systems; Payload Electronics; Payload Structures; Integration	Verified	See Section 3.2 regarding launch vehicle design.
4.2.5	The sequence of time-stamped photos taken need not be transmitted back to ground station and SHALL be presented in the correct order in your PLAR.	The sequence of time-stamped photos are presented in correct order in the teams PLAR.	Demonstration	Payload Electronics; Payload Systems	Verified	See Section 4.6.4 regarding data storage and post-processing.
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics SHALL not be permitted for any surface operations.	The payload recovery system is designed such that any energetics are only utilized in flight.	Inspection	Integration	Verified	See Section 3.2 and 4.4 for payload bay design and payload systems overview.
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The safety team verifies payload compliance with all FAA and NAR rules and regulations.	Demonstration	Safety	Verified	See Section 5 regarding all safety rules and regulations.
4.3.6	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	Inspection	Payload Systems	Verified	There are no plans to utilize UAS in the final design for completion of the mission.
5.1	Each team SHALL use a launch and safety checklist. The final checklists SHALL be included in the FRR report and used during the LRR and any Launch Day operations.	Checklists are included in the FRR and are used during LRR and Launch Day activities.	Validation of Records	All subteams	Verified	The final Launch Day checklist is listed in Section 5.4.
5.2	Each team SHALL identify a student safety officer who SHALL be responsible for all items in Section 5.3.	The student safety officer, Megan Rink, upholds all responsibilities detailed in safety requirement 5.3.	Validation of Records	Safety	Verified	See Section 5.1 regarding the declared safety officer.
5.3.1.1	The safety officer SHALL monitor team activities with an emphasis on safety during design of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitors all meetings regarding design of the payload and vehicle.
5.3.1.2	The safety officer SHALL monitor team activities with an emphasis on safety during construction of vehicle and payload components.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration; Validation of Records	Safety	Verified	The safety officer, Megan Rink monitors all construction and assembly events and keeps track of any injuries through the use of incident report sheets (available upon request).
5.3.1.3	The safety officer SHALL monitor team activities with an emphasis on safety during assembly of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitors all construction and assembly events and keeps track of any injuries through the use of incident report sheets (available upon request).
5.3.1.4	The safety officer SHALL monitor team activities with an emphasis on safety during ground testing of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitors all ejection tests and keeps track of any injuries through the use of incident report sheets (available upon request).

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NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
5.3.1.5	The safety officer SHALL monitor team activities with an emphasis on safety during subscale launch test(s).	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques through use of safety checklists.	Validation of Records	Safety	Verified	Completed safety checklists for subscale launch are provided in the CDR. and Appendix of FRR.
5.3.1.6	The safety officer SHALL monitor team activities with an emphasis on safety during full-scale launch test(s).	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitored all assembly events during the VDF on 2/25/23.
5.3.1.7	The safety officer SHALL monitor team activities with an emphasis on safety during competition launch.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Not Verified	TBD
5.3.1.8	The safety officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitored all recovery events during the VDF on 2/25/23.
5.3.1.9	The safety officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety officer, Megan Rink monitored all STEM engagement activities that occured from 10/12/22-1/13/23.
5.3.2	The safety officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety team writes and implements procedures and checklists for assembling, launching, and recovering the launch vehicle.	Demonstration	Safety	Verified	Completed safety checklists for subscale launch are provided in the CDR. Safety checklists for competition launch are provided in Section 5.4 in FRR.
5.3.3	The safety officer SHALL manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The student safety officer manages all safety documentation for the team.	Inspection	Safety	Verified	All safety documentation is included in Section 5 of the CDR.
5.4	During test flights, teams SHALL 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.	The safety team ensures all rules and regulations from the local rocketry club are followed by all team members.	Demonstration	Safety	Verified	See section 5
5.5	Teams SHALL abide by all rules set forth by the FAA.	The safety team ensures all rules from FAA are followed.	Demonstration	All subteams	Verified	See section 5. All FAA rules have been and will continue to be followed by all team members.

7.2.2 Team Derived Requirements

Table 53: Requirements derived by the team.

Safety						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirments						
SDR 1	All epoxy SHALL be left to cure for at least 24 hours before a load is applied.	Uncured epoxy weakens the structural stability of the launch vehicle, which increases the likelihood of structural failure.	Epoxied parts are labeled and remain untouched until the date and time listed on their label.	Inspection	Verified	Current manufacturing procedures specify at least a 24-hour cure period for all epoxied parts. The team has and wil continue to wait 24 hours after every component is epoxied to handle it.
SDR2	Safety glasses SHALL be provided to each personnel working with or around power tools.	Using PPE reduces the risk of skin and eye injury from debris in the air due to power tool operation.	Safety glasses for every working team member of HPRC are contained in the lab's PPE cabinet.	Inspection	Verified	There are 25 pairs of safety glasses in the PPE cabinet which exceeds lab capacity.
SDR 3	Nitrile gloves, safety glasses, and particulate masks SHALL be provided to all personnel working with volatile liquid and/or powder chemicals.	Using PPE reduces the risk of skin and eye injury from debris caused by volatile liquids and/or powders.	Gloves, glasses, and masks for every working team member are contained in the lab's PPE cabinet.	Inspection	Verified	There are 25 glasses, 8 boxes of nitrile gloves, and 3 cases of masks in the lab's PPE cabinet which exceeds lab capacity.
SDR 4	All launch day attendees SHALL maintain a walking pace at all times on the launch field, including during assembly, launch, and recovery of the launch vehicle	Maintaining a steady walking pace decreases the risk of slipping, tripping, and falling	Team members will maintain a walking pace at all times during launch day	Inspection	Not Verified	Team members will be briefed before launch on launch field etiquette.
SDR 5	Hazards identified as orange or red in the risk assessment matrix SHALL be decreased to yellow or green in the CDR through mitigations.	Mitigating potentially dangerous and/or frequent hazards provides a more robust launch vehicle and payload system.	More than 80% of hazards identified in the CDR document will fall in the yellow or green zones after mitigation is applied.	Inspection	Verified	84.7% of current hazards fall in the green or yellow zones.
SDR 6	All hazardous/flammable liquids and/or powder chemicals will be stored in a designated flame cabinet whenever it is not being used.	Storing all hazardous liquids in a fireproof cabinet decreases the risk of injury to students and damage to lab equipment.	All hazardous liquids remain in the flame cabinet until they are used by team members. After use, the liquids are immediately returned.	Inspection	Verified	All hardeners, resins, lubricants, cleaners, aerosol paints, black powder, oxidizers, and igniters used by the team are stored in a JUSTRITE Flammable Liquid Storage Cabinet.

Launch Vehicle						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirments						
LVF 1	The launch vehicle SHALL not exceed a velocity of Mach 0.7.	Exceedingly high speeds and acceleration undergone by the launch vehicle will increase the risk of damage to the payload other structural components inside the launch vehicle.	Simulations are completed in RockSim to calculate the launch vehicle's maximum velocity.	Analysis	Verified	The calculated maximum velocity of the launch vehicle is Mach 0.48. See Section 3.6.2 for mission performance predictions.
LVF 2	The launch vehicle SHALL no exceed an acceleration of 14Gs during its ascent.	Accelerations undergone by the launch vehicle that are higher than 14Gs increase the risk for damage to both the payload and the structural components inside the launch vehicle.	Simulations are completed in RockSim to calculate the launch vehicle's maximum acceleration during its ascent.	Analysis	Verified	The maximum acceleration during flight of the launch vehicle is calculated to be 9Gs. See section 3.6.2 for mission performance predictions.
Design Requirements						
LVD 1	All structural components of the launch vehicle SHALL be designed with a minimum factor of safety of 1.5.	This ensures that the launch vehicle will remain structurally stable during flight despite experiencing higher than expected loads. Additionally, it prevents unexpected failure of the launch vehicle during flight.	The factor of safety of each critical component is reported in the documentation and calculated by structural analysis and testing.	Analysis; Testing	Verified	The factor of safety is calculated through simulations and testing. See Section 7.1.1.6-7.1.1.9 for testing details.
LVD 2	The inner diameter of the launch vehicle SHALL be no larger than 6 in.	Limiting the size of the launch vehicle makes it easier to construct, cuts down on weight and decreases aerodynamic drag.	The inner diameter of the airframe is no larger than 6 in.	Inspection	Verified	See section 3.2 for launch vehicle design.
LVD 3	The launch vehicle SHALL have symmetrical fins.	Ensures that the launch vehicle is aerodynamic. Also ensures that the CG is on the center with equal aerodynamic forces on each side and an equal weight distribution.	Launch vehicle has four fins, equally spaced from each other around the airframe.	Inspection	Verified	See Section 3.2.9 for fin design and configuration.
LVD 4	The launch vehicle SHALL use at least 2 centering rings to support the motor tube.	Ensures that the motor tube has the adequate support to handle the high force caused by the motor during launch.	The launch vehicle has three centering rings to support the motor tube during flight.	Inspection	Verified	See section 3.2.9 for fin can design.
LVD 5	The launch vehicle SHALL have a stability margin between 2 and 2.7 upon rail exit.	To meet the NASA requirement 2.14, a stability margin of 2.0 or greater is required. The maximum value of 2.7 was selected because excessively high stability margins cause undesirable weather cocking of the launch vehicle in high winds.	The calculated launch vehicle's stability margin is calculated to be between 2.0 and 2.7.	Analysis	Verified	See section 3.6.4 for the stability margin analysis of the launch vehicle design.
LVD 6	Each separated section of the launch vehicle SHALL have a connection point for a shock cord capable of sustaining the maximum loads experienced in flight to our defined minimum safety factor of 2.	The nose cone, avionics bay, payload bay, and fin can are all tethered to the launch vehicle and need to withstand loads during flight without completely separating from the launch vehicle.	ANSYS simulations and structural tests are done on the bulkheads and hardware of each section to confirm the factor of safety.	Analysis; Inspection	Verified	See section 3.2.9 in the CDR document for the bulkhead analysis calculations. See Section 7.1.1.5-7.1.1.9 regarding all material strength testing.
LVD 7	The launch vehicle blast caps SHALL be exposed accessible.	Accessible energetics allow for safer and easier installation of black powder charges.	The avionics bay is designed to have blast caps that are easily accessible.	Inspection	Verified	See section 3.2.6 regarding the avionics bay design.
Environmental Requirements						
LVE 1	The airframe of the launch vehicle SHALL be capable of launching in temperatures between 20 and 100 degrees Fahrenheit.	The launch vehicle will be used in a variety of launch fields and seasons, including winter in North Carolina and spring in Alabama.	The airframe material is rated to remain undamaged and undeformed under the stated temperatures.	Inspection; Analysis	Verified	See section 3.3.1.1 for the selected material regarding the launch vehicle design.

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Launch Vehicle						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
LVE 2	The launch vehicle SHALL be water-resistant.	The team's home launch field contains several irrigation ditches that are often filled with water. Having a water resistant airframe will help mitigate any potential damage as a result of the launch vehicle landing in one of the ditches. Additionally, this will help protect the structural integrity of the launch vehicle in situations involving high humidity or rainfall.	The airframe is not damaged nor deformed upon exposure to water.	Inspection; Demonstration	Verified	See section 3.3.1.1 for the selected material regarding the launch vehicle design.

Recovery						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirments						
RF 1	The descent velocity under drogue SHALL be less than 120ft/s.	High descent velocities under drogue parachute lead to a larger load on main parachute when it deploys.	The chosen parachute will have a terminal velocity of less than 120ft/s with the given mass of the rocket.	Analysis	Verified	The selected drogue parachute has a descent velocity of 88.77ft/s. See Section 3.5.3.2 for more details.
RF 2	The secondary black powder charges SHALL be larger than the primary black powder charges.	The secondary black powder charges are used to separate the sections of the launch vehicle should the main charge not generate enough pressure to initially separate the sections. The secondary charges need to be larger than the initial charges to ensure the sections are completely separated during flight.	The amount of black powder added to the secondary blast cap will be greater than the amount added to the primary blast cap.	Inspection	Verified	See section 3.5.9 regarding ejection charge sizing.
RF 3	Fully charged 9V batteries SHALL be used for the altimeters before every flight.	Black powder might not be properly ignited if there is insufficient voltage to the blast cap.	Batteries will be verified to be fully charged at 9 volts before being placed on the AV sled.	Inspection; Analysis	Verified	See section 3.5.1 regarding recovery procedures.
Design Requirments						
RD 1	Only U-Bolts SHALL be used for all shock cord connections.	U-Bolts are designed to provide two points where shock can go through the bulkhead. Dispersing the shock through multiple points increases the bulkhead stability.	U-Bolts are installed in every bulkhead that is used as an anchor point for the recovery harness.	Inspection	Verified	See section 3.5.1 for recovery system design.
RD 2	Threaded quick-links SHALL be used to attach all recovery harnesses to the launch vehicle attachment points.	Threaded quick-links are very unlikely to detach during flight. Due to their design, they are very easy to attach around the U-Bolt.	Quick-links will be used to attach all recovery harnesses to their respective anchor points.	Inspection	Verified	See section 3.5.2.3 for quick link usage in recovery system design.
RD 3	Nomex cloth SHALL be used to protect the main parachute from ejection gases.	Ejection gases will burn/melt the fabric of the main parachute upon exposure, causing the parachute to fail.	The main parachute will be folded and stored inside a Nomex cloth before being attached to the main shock cord inside the main parachute bay.	Inspection	Verified	See section 3.5.1 regarding use of Nomex cloth.
RD 4	Insulation must completely cover Nomex-wrapped parachute with at least 2 in. of insulation between the parachute and the ejection charge.	Ejection gases during flight have been able to damge the parachute despite the nomex barrier.	Insulation will be added to the parachute bays until it is covered completely. The shock cord should just barely be seen.	Inspection	Verified	See section 3.5.4 regarding insulation.
Environmental Requirments						
RE 1	All protective insulation SHALL be biodegradeable.	Insulation protecting the shock cords and parachutes might fall out during/after flight. Since it is hard to prevent all of the insulation from falling out, we require insulation that does not negatively impact the environment.	Insulating used in all parachute bays will be checked to ensure it is biodegradable.	Inspection	Verified	See section 3.5.4 regarding insulation.

Payload						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirments						
PF 1	Each camera SHALL have a field of view greater than 120 degrees and less than 180 degrees.	The camera system must take an image of the launch vehicle's surroundings. Increasing the required minimum field of view mitigates the impact on image quality as a result of unforeseen obstructions.	The cameras used will have a field of view greater than 120 degrees and less than 180 degrees.	Analysis; Demonstration	Verified	The current camera chosen is a Smraza with a FOV of 160 as seen in section 4.4.1.2.2.
PF 2	All electronic components in the launch vehicle SHALL be removable.	Removable electronics allow for easier adjustments to the payload design.	None of the electronic components in the launch vehicle are permanently fixed in place.	Inspection; Testing; Demonstration	Verified	See section 4.4.1 regarding the payload electronics system.
PF 3	The RTL-SDR dongle SHALL only accept RF commands from one antenna.	Antennas that are connected in parallel interfere with each others' signals and decrease signal quality.	When RAFCO commands are being given, a relay switch allows for input from the upward- facing antenna to be sent to the RTL-SDR dongle which is then sent to the Raspberry Pi.	Testing; Demonstration	Verified	See section 4.4.1.1 regarding the RAFCO subsystem operations.
PF 4	Raspberry Pi shall be able to command servos with minimal control circuitry.	The Pi will be used to work with both the antennas, RTL-SDR dongle, and servos to move the camera. Minimal circuitry will condense electronic components needed and decrease load on the Raspberry Pi.	Circuitry on payload sled is efficient and condensed.	Inspection; Demonstration	Verified	See section 4.4.1 regarding the payload electronics system.
Design Requirements						
PD 1	SOCS SHALL have a combined weight of no more than 8 lb.	A weight limit for all of the payload components allows for the launch vehicle to reach the desired altitude.	SOCS has a maximum combined weight of 8 lb.	Inspection	Verified	See section 3.2.8 and 3.6.8 for payload weight calculations
PD 2	SOCS SHALL have 4 symmetrical housings placed equidistant around the launch vehicle and centered at the midpoint between each fin.	Each camera being placed at the midpoint between two fins ensures that one camera will always be facing upward regardless of landing orientation. This design allows mitigates the obstruction of the fins in the camera's field of view.	SOCS will consists of four cameras and housings. Each housing is placed at the midpoint between two fins.	Inspection	Verified	See section 4.4.1.2.2 camera unit placement.
PD 3	The antenna SHALL face upwards upon landing regardless of landing orientation.	An upward-facing antenna prevents structural damage occurring to the antenna as a result of high-energy impact with the ground. Additionally, it mitigates obstructions from the terrain surrounding the launch vehicle that might interfere with receiving RF commands.	Two antennas will be used on the launch vehicle. They will be placed along the outside of the launch vehicle, 180 degrees apart such that regardless of landing orientation, there will always be one antenna upward-facing.	Inspection	Verified	See section 4.4.1.1 regarding the antenna orientation.
PD 4	Each housing SHALL withstand all loads encountered during the flight and landing of the launch vehicle.	Housings are the only structural component protecting the cameras in the SOCS. Each housing must be able to withstand the loads encountered during the flight and landing of the launch vehicle to mitigate any damages to the cameras.	Each housing is designed to withstand the loads encountered during flight and landing of the launch vehicle.	Analysis; Testing	Verified	See section 4.4.2 regarding the camera housing design.
PD 5	Each housing SHALL extrude no more than 1 in. from the launch vehicle.	Housings that extrude further than 1in. from the launch vehicle add unnecessary weight and aerodynamic drag to the launch vehicle.	Each housing is designed such that it does not extrude more than 1in. from the outside of the launch vehicle.	Analysis; Inspection	Verified	See section 4.4.2 regarding SOCS design.
PD 6	Each housing SHALL be easily removable.	During landing, the camera housing will encounter damage such as scratches and dents that will affect the clarity of the pictures taken by each camera. To allow for a clear camera view during future launches, the camera housing should be able to be replaced immediately after each launch.	Each camera housing is designed to be removed and replaced with a new housing after it is damaged.	Inspection; Demonstration	Verified	See section 4.4.2 regarding the camera housing design.

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Payload						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Environmental Requirements						
PE 1	Each housing in SOCS SHALL be water-resistant.	The team's home launch field contains several irrigation ditches that are often filled with water. Having a water resistant housing will help mitigate any potential damage to the cameras as a result of the launch vehicle landing in one of the ditches.	Each camera in SOCS is not damaged as a result of the launch vehicle being exposed to water.	Inspection; Demonstration	Verified	See section 4.4.2 regarding SOCS structural design.

7.3 Budget

Table 54 below details the year-long budget for the 2022-2023 Student Launch Competition.

Table 54: 2022-2023 NASA Student Launch Competition Budget

	Item	Quantity	Price Per Unit	Item Total
Subscale Structure	Plastic 4 in. 4:1 Ogive Nosecone	1	$ 29.80	$ 29.80
	4 in. Blue Tube	2	$ 43.95	$ 87.90
	4 in. Blue Tube Pre-Slotted	1	$ 53.50	$ 53.50
	AeroTech J420R-14 Motor	2	$ 93.08	$ 186.16
	Aero Pack 38mm Retainer	2	$ 29.17	$ 29.17
	AeroTech RMS-38/600 Motor Casing	1	$ 112.34	$ 112.34
	Large Rail Button -1515	1	$ 7.87	$ 7.87
	Standard Rail Button - 1010	2	$ 4.25	$ 8.50
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 611.58**
Full Scale Structure	6 in. nose cone Fiberglass Ogive 4:1	1	$ 149.99	$ 149.99
	6 in. G12 Fiberglass Tube (60 in.)	1	$ 259.00	$ 259.00
	6 in. G12 Fiberglass Tube (48 in.)	1	$ 207.20	$ 207.20
	6 in. G12 Fiberglass Coupler	4	$ 77.50	$ 310.00
	AeroTech High-Power L1390G-P Motor	2	$ 223.54	$ 447.08
	Aero Pack 75mm Retainer	1	$ 59.50	$ 59.50
	AeroTech RMS-75/3840 Motor Casing	1	$ 526.45	$ 526.45
	Large Rail Button -1515	2	$ 4.25	$ 11.40
	U-Bolts	8	$ 1.00	$ 8.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 2021.72**
	FPV Cameras	4	$ 19.99	$ 79.99
	Acrylic Sheets	2	$ 11.22	$ 44.88
	Stepper Motor	2	$ 173.97	$ 347.97
	Raspberry Pi	1	$ 120.00	$ 120.00
	IMU	1	$ 15.30	$ 15.30
	RTL-SDR Dongle	1	$ 39.95	$ 39.95
	Whip Antenna	4	$ 25.00	$ 100.00
	Servo	8	$ 10.00	$ 80.00

	Subtotal:			$ 805.59
Recovery and Avionics	Iris Ultra 120 in. Standard Parachute	1	$ 475.71	$ 475.71
	Iris Ultra 60 in. Standard Parachute	1	$ 212.85	$ 212.85
	18 in. Compact Elliptical Parachute	1	$ 70.95	$ 70.95
	RRC3 Sport Altimeter	4	$ 96.50	$ 386.00
	Eggfinder TX Transmitter	1	$ 70.00	$ 70.00
	6 in. Deployment Bag	1	$ 54.40	$ 54.40
	4 in. Deployment Bag	1	$ 47.30	$ 47.30
	18 in. Nomex Cloth	1	$ 26.40	$ 26.40
	13 in. Nomex Cloth	1	$ 17.60	$ 17.60
	5/8 in. Kevlar Shock Cord (per yard)	25	$ 6.99	$ 174.75
	3/16 in. Stainless Steel Quick Links	16	$ 2.00	$ 32.00
	AeroTech Ejection Charge - 1.4g	24	$ 1.25	$ 30.00
	Subtotal:			$ 1,702.72
Miscellaneous	Paint	12	$ 18.00	$ 216.00
	Domestic Birch Plywood 1/8 in.x2x2	12	$ 14.82	$ 177.84
	West Systems 105 Epoxy Resin	2	$ 109.99	$ 219.98
	West Systems 206 Slow Hardener	2	$ 62.99	$ 125.98
	ABS 3D Printer Filament Spool	1	$ 23.00	$ 23.00
	ClearWeld Quick Dry 2-Part Epoxy	1	$ 20.28	$ 20.28
	Wood Glue	1	$ 7.98	$ 7.98
	Misc. Bolts	1	$ 20.00	$ 20.00
	Misc. Nuts	1	$ 10.00	$ 10.00
	Misc. Washers	1	$ 8.00	$ 8.00
	Tinned Copper Wire Kit	1	$ 25.00	$ 12.00
	Zip Ties Pack	1	$ 6.59	$ 6.59
	Hook and Loop Strips Box	1	$ 10.00	$ 10.00
	9V Battery Pack	1	$ 12.00	$ 12.00
	Misc. Tape	1	$ 20.00	$ 20.00
	Estimated Shipping			$ 1,000.00
	Incidentals (replacement tools, hardware, safety equipment, etc.)			$ 1,500.00
	Subtotal:			$ 3,410.63
Travel	Student Hotel Rooms – 4 nights (# Rooms)	6	$ 898.45	$ 5,390.70
	Mentor Hotel Rooms – 4 nights (# Rooms)	1	$ 1022.03	$ 1,022.03
	NCSU Van Rental (# Vans)	1	$ 798.00	$ 2,394.00
	Subtotal:			$ 8,806.73
Promotion	T-Shirts	40	$ 15.00	$ 600.00
	Polos	15	$ 25.00	$ 375.00
	Stickers	500	$ 0.43	$ 215.00
	Subtotal:			$ 1,190.00
Total Expenses:				$ 18,505.81

As highlighted in Figure 137, our expenses can be divided into different sub-sections with travel funds taking up the majority of our spending for this year.

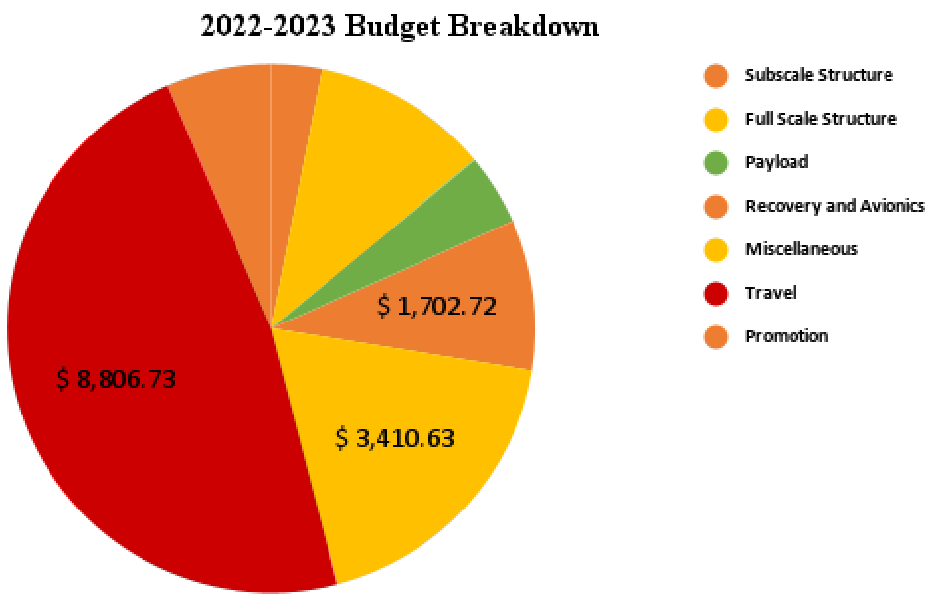

Figure 137: Budget breakdown of the 2022 - 2023 competition year.

7.4 Funding Plan

HPRC receives the majority of funding from a variety of NC State's funding sources, as well as North Carolina Space Grant (NCSG). Below is an in depth breakdown of the team's current funding sources.

NC State's Student Government Association's (SGA) Appropriations Committee is responsible for distributing university funding to nearly 600 different organizations on campus. Each semester the application process persists of a proposal where we outline what we are requesting from SGA, how much money we estimate to receive from other sources, and our anticipated club expenses for the academic year. We then meet with representative from SGA and give a presentation outlining our club activities and how we benefit the university. SGA then collectively allocates money to each organization on campus. In the 2021-2022 academic year, HPRC received $1,766.81 from SGA: $451.81 in the fall semester and $1,315 in the spring semester. For this academic year, $1,103 was received for the fall semester and another $796 was received for the spring semester.

The Educational and Technology Fee (ETF) is an NC State University fund that allocates funding for academic enhancement through student organizations. In the 2021-2022 academic year, we received $3,000 from ETF and the team anticipate to receive $2,500 for this academic year. This funding will be used primarily to pay for the student and team's faculty advisors' travel costs.

Student and mentor travel costs will primarily be funded by the Engineer Your Experience (EYE) program under the direction of NC State's College of Engineering. Funding for EYE comes from a pool of money dedicated to supporting engineering extracurricular activities at NC State. EYE funds are being used to cover lodging costs associated with the travel to Huntsville, AL for the competition, and is estimated to be $5,500.

In addition to funding through NC State organizations, North Carolina Space Grant is a large source of HPRC's funds. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG has reviewed the proposal and has award the club with $5,000 for us to support our acquisition of materials for the construction of our full scale project.

In the past, HPRC has held sponsorships with Collins Aerospace, Jolly Logic, Fruity Chutes, and more. The team is currently seeking out new sponsorships and reaching out to past sponsors. The team has found that companies are more likely to donate gifts in kind rather than provide monetary sponsorship. The team estimates to receive $2,500 in gifts of kind this academic year.

These totals are listed in Table 55 below, which outlines the projected costs and incoming revenue for the 2022-2023 academic year.

Table 55: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$2,500	$2,500
Engineer Your Experience (EYE) Fund	$0	$5,500	$5,500
NC State Student Government	$1,103	$796	$1,899
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$1.000	$1,500	$2,500
Total Funding:			**$17,399.00**
Total Expenses:			**$18,505.81**
Difference:			**$1,106.81**

7.5 Project Timelines

7.5.1 Competition Deliverables Timeline

Table 56: Student Launch competition deadlines.

Event/Task	Start Date	End Date/Submission
Request for Proposal Released	Aug. 17, 2022	N/A
Proposal Submission	Aug. 17, 2022	Sep. 19, 2022, 8:00 a.m. CST
PDR Submission	Oct. 26th, 2022	Oct. 26, 2022, 8:00 am CST
PDR Team Teleconference	Nov. 21, 2022	
Subscale Launch Opportunity	Nov. 19, 2022	Jan. 09, 2023
CDR Submission	Dec. 05, 2022	Jan. 09, 2023, 8:00 am CST
CDR Team Teleconference	(Tentative) Jan. 17 – Feb. 07, 2023	
Full-Scale Launch Opportunity	Feb. 18, 2023	Mar. 06, 2023
Final Launch Vehicle Design RockSim file submission	Dec. 05, 2022	Mar. 06, 2023, 8:00 am CST
FRR Submission	Jan. 26, 2023	Mar. 06, 2023, 8:00 am CST
FRR Team Teleconference	(Tentative) Mar. 13 - 31, 2023	
Payload/Vehicle Demonstration Re-Flight (if needed)	Mar. 13 2023	Apr. 03, 2023
FRR Addendum (if needed)	Mar. 13 2023	Apr. 03, 2023, 8:00 am CST
Team Travel to Huntsville, AL	Apr. 12, 2023	N/A
Launch Readiness Review	Apr. 12, 2023	N/A
NASA Safety Briefing	Apr. 13, 2023	N/A
Rocket Fair and MSFC Tours	Apr. 14, 2023	N/A
Launch Days	Apr. 15, 2023	Apr. 16, 2023
Post-Launch Assessment Review	Apr. 15, 2023	May 01, 2023, 8:00 am CDT

2022-23 Student Launch Competition Gantt Chart

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40
Proposal	1	W03	W07			1	1	1	1	1																																	
Preliminary Design Reviev	2	W08	W12								2	2	2	2	2																												
PDR Teleconference	3	W13	W15													3	3	3																									
Subscale Launch Windov	4	W15	W15															4																									
Critical Design Review	5	W13	W21													5	5	5	5	5	5	5	5	5																			
CDR Teleconference	6	W22	W25																						6	6	6	6															
Flight Readiness Review	7	W22	W29																						7	7	7	7	7	7	7	7											
Fullscale Vehicle Launch Window	8	W28	W28																												8												
Fullscale Payload Launch Window	9	W31	W31																															9									
FRR Teleconference	10	W30	W32																														10	10	10								
Launch Week Activities/Launch	11	W34	W34																																		11						

Figure 138: A Gantt chart containing the official NASA competition deadlines.

7.5.2 Funding Timeline

2022-23 Student Launch Funding Gantt Chart

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40
Spring 2022 Student Gov Appropriations	1	W01	W09	1	1	1	1	1	1	1	1	1																															
Fall 2021 Student Gov Appropriations	2	W10	W26										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2														
Engineering Technology Fund	3	W13	W34													3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
NC Space Grant	4	W13	W36													4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4				
Spring 2023 Student Gov Appropriations	5	W28	W40																												5	5	5	5	5	5	5	5	5	5	5	5	5
College of Engineering EYE Travel Fund	6	W30	W35																														6	6	6	6	6	6					

Figure 139: A Gantt chart detailing when our funding sources are available for use.

7.5.3 Development Timelines

2022-23 Student Launch Competition Development Gantt Chart

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40
Brainstorming	1	W03	W06			1	1	1	1																																		
Vehicle Design	2	W05	W08					2	2	2	2																																
Payload Design	3	W07	W13							3	3	3	3	3	3	3																											
Subscale Parts Ordering	4	W09	W10									4	4																														
Subscale Manufacturing	5	W11	W15											5	5	5	5	5																									
Payload Parts Ordering	6	W14	W17														6	6	6	6																							
Fullscale Parts Ordering	7	W18	W21																		7	7	7	7																			
Fullscale Manufacturing	8	W22	W28																						8	8	8	8	8	8	8												
Payload Manufacturing	9	W18	W26																		9	9	9	9	9	9	9	9	9														
Fullscale Components Testing	10	W23	W28																							10	10	10	10	10	10												
Recovery System Testing	11	W25	W28																									11	11	11	11												
Payload Software Development	12	W20	W27																				12	12	12	12	12	12	12	12													
Payload Testing	13	W21	W30																					13	13	13	13	13	13	13	13	13	13										
Subscale Launch	14	W15	W15															14																									
Full Scale Launch	15	W28	W28																												15												
Competition Launch	16	W34	W34																																		16						

Figure 140: A Gantt chart detailing launch vehicle and payload development schedules.

Table 57: Weekly club schedule.

Monday	4:30-6:30 pm: Vehicle Subteam Meeting- joint meeting for aerodynamics, structures, and recovery subteams
Tuesday	4:30-6:30pm: Payload Subteam Meeting- meeting for development, building, and testing of payload 6:30-7:30 pm: WolfWorks Experimental- Club experimental projects unrelated to student launch, currently working on airbrakes system
Thursday	5:30-6:30pm: Structures Fabrication Meetings 6:30-7:30pm: Club Officer Meetings 7:30-8:30pm: General Body Club Meetings
Friday	10:40am-12:30pm: Senior Design Meeting 2:30-3:30pm: WolfWorks Experimental Meeting 5-8pm: Launch Prep (select weeks)
Saturday	7am-7pm: Launch Day Activities (select weeks)

January						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	1/9	1/10	1/11	1/12	1/13	1/14
	CDR due date - Laser cutting				- Laser cutting - Bulkhead fabrication - 3D print alignment ring	
1/15	1/16	1/17	1/18	1/19	1/20	1/21
	- Fabricate bulkheads for destructive testing				- Attach bulkheads to airframe - Attach hardware to bulkheads	
1/22	1/23	1/24	1/25	1/26	1/27	1/28
	Structures verification testing				- Bulkhead Layups - Prepare for fin layups - 3D print tailcone	
1/29	1/30	1/31				
	- Bulkhead layups - Cut airframe and coupler sections - Composite Fin Layup - Cut aluminium thrust plate					
February						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
			2/1	2/2	2/3	2/4
				- Sand Bulkheads - Epoxy AV bay and Payload Bay couplers - Epoxy T-nuts to nose cone centering ring	- Epoxy tailcone to retainer - Epoxy centering ring to nose cone shoulder - Epoxy motor tube to wood thrust plate plies - Composite Fin Layup	
2/5	2/6	2/7	2/8	2/9	2/10	2/11
	- Epoxy nose cone shoulder to nose cone - Cut camera housing holes into payload bay - Composite Fin Layup			- Fillet motor tube - Epoxy motor retainer - Attach U-bolts and threaded rods to bulkheads	- Composite fin layup - Drill rivet holes and shear pin holes - Epoxy runners and centering rings	
2/12	2/13	2/14	2/15	2/16	2/17	2/18
	- Composite fin layup - Assemble removable fin assembly				- Drill antenna holes in fin can - Composite fin layup - Attach rail buttons	
2/19	2/20	2/21	2/22	2/23	2/24	2/25
	- Secure blast caps and terminal blocks to bulkhead - Drill remaining pressure ports			Ejection Testing	Dry Run	Vehicle Demonstration Flight

Figure 141: Full Scale Build Calendar

TACHO LYCOS

2022-23 Testing Gantt Chart

				Jan				Feb				March			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12
Camera Operation	1	W01	W01	1											
Camera Clarity	2	W01	W01	2											
GPS Operation	3	W02	W02		3										
2-meter Dipole SWR	4	W02	W02		4										
AV Bay Tensile	5	W03	W03			5									
Nose Cone Bulkhead Tensile	6	W03	W03			6									
Camera Unit Mount	7	W03	W03			7									
Composite Fin	8	W04	W04				8								
Camera Housing	9	W04	W04				9								
APRS Reception and Decoding	10	W05	W06					10	10						
Shear Pin	11	W06	W06						11						
Rivet	12	W06	W06						12						
Altimeter	13	W07	W08							13	13				
Orientation Detection and Switching	14	W06	W08						14	14	14				
Ejection Test	15	W08	W08								15				
Full Scale Launch	16	W08	W08								16				
Camera System Integration	17	W07	W10							17	17	17	17		
Camera System RAFCO	18	W07	W10							18	18	18	18		

Figure 142: Testing Gantt Chart

October						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
10/2	10/3	10/4	10/5	10/6	10/7	10/8
	- Cut Body Tubes - Cut Nose Cone Shoulder - AV and payload Bay airframe epoxy			Before Meeting: - Bulkhead Layups (NC, Fin Can) - 3D print alignment ring	Fall Break	Fall Break
10/9	10/10	10/11	10/12	10/13	10/14	10/15
Fall Break	Fall Break	Fall Break		Before Meeting: - Sand Bulkheads - Epoxy T-nuts to NC centering Ring - NC centering Ring Epoxy to NC - Epoxy motor tube to thrust plate - Fillet Coupolas (Ashwin)	- Design and Print Tail Cone	
10/16	10/17	10/18	10/19	10/20	10/21	10/22
	- Epoxy retainer to motor tube - Cut AV threaded rods - Blast caps -Drill shear pin and rivett holes			Before Meeting: - Epoxy tail cone to retainer - Fillet Motor Retainer - File Slots in Fin centering rings - Mark and cut Fin can Slots	PDR soft Deadline	
10/23	10/24	10/25	10/26	10/27	10/28	10/29
	- Payload Bulkhead Layups - Cut Fin can threaded rods - Prepare for fin layups (cut balsa and fiberglass) - Epoxy fin centering rings/runners together		PDR Due	- Composite Fin Layup - Epoxy forward fin can centering ring		
10/30	10/31					
	- Composite Fin Layups - Drill pressure port/switch holes - Rail Buttons					
November						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
		11/1	11/2	11/3	11/4	11/5
				Before Meeting: - Composite Fin Layups (if nessecary) - Ensure all Hardware is mounted to bulkheads		
11/6	11/7	11/8	11/9	11/10	11/11	11/12
	Paint	Paint	Paint	Paint	Paint	
11/13	11/14	11/15	11/16	11/17	11/18	11/19
				Ejection Testing	Dry Run and Packing	Launch

Figure 143: Subscale Build Calendar

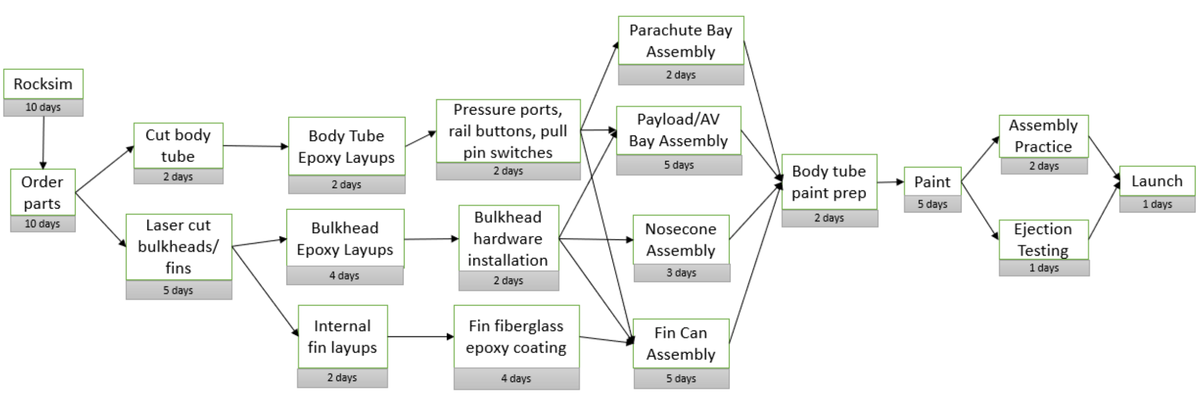

Figure 144: A PERT chart for the construction of the launch vehicle.

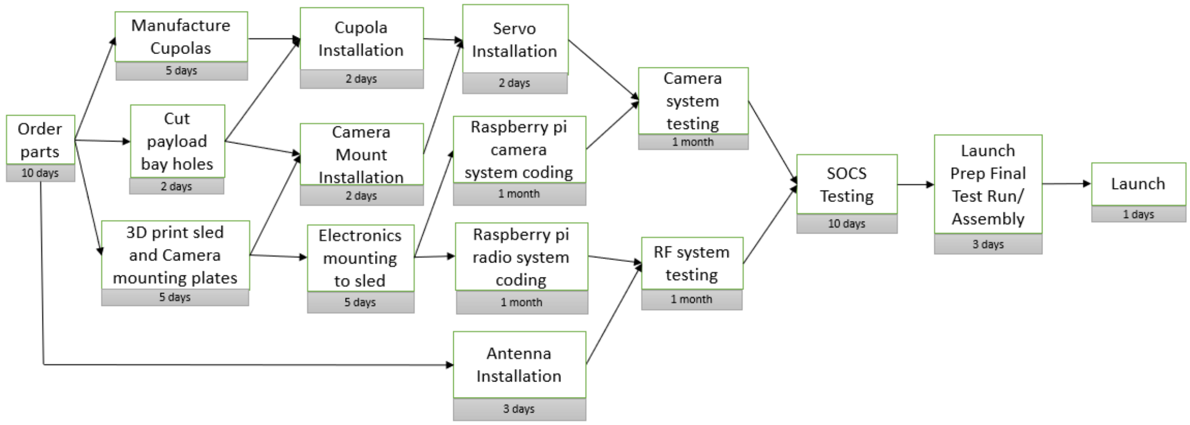

Figure 145: A PERT chart for the construction of the payload.

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Appendix: Subscale Completed Checklists

SUBSCALE
Launch Day Checklists

Safety Officer
High-Powered Rocketry
NC State

Safety Officer
High-Powered Rocketry
NC State

This checklist completed by: Megan Rink

On: 11/19/22

1

1. AVIONICS BAY ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Recovery Lead	Shaan Stephen	SS
AV Bay Personnel 1	Sofia Antinozzi	SA
AV Bay Personnel 2	Donald Gemmel	DG

Required Materials			
Item	Quantity	Location	Completion
Bulkhead #3	1	AV Bulkhead Box	
Bulkhead #4	1	AV Bulkhead Box	
AV Sled (assembled)	1	Recovery Box	✓
Pull Pin Switch	2	AV Sled	✓
RRC3 Altimeters	2	AV Sled	✓
AV Bay	1	-	✓
9V Battery	2	AV HDX Box	✓
#4-40 screw	2	AV Sled	✓
#4-40 nut	2	AV Sled	✓
¼-20 nut	1	Hardware	✓
¼-20 washer	2	Recovery Hardware	✓
7/16" Wrench	1	LD Toolbox (Middle Drawer)	✓
Adjustable Wrench	1	LD Toolbox (Middle Drawer)	✓
Multimeter	1	LD Toolbox (Top Compartment)	✓
Safety Glasses	1	PPE Toolbox	✓

Number	Task	Completion
1.1	Use multimeter to test voltage of the primary 9V battery	Note Voltage: 9.70
1.2	Use multimeter to test voltage of the secondary 9V battery	Note Voltage: 9.70

3

1.3	If either battery measures below 9V, replace with a fresh battery and repeat checklist item 1.1 or 1.2	✓
1.4	Connect each battery to its battery clip in the battery compartment	✓
1.5	Place primary and secondary batteries in the avionics sled battery compartment and secure to sled	✓
1.6	Pull the pull Pin Switch out of the primary altimeter	✓
1.7	Verify primary altimeter beeps match the expected pattern detailed on the Primary Altimeter Beep Sheet	✓
1.8	Pull the pull pin switch out of the secondary altimeter	✓
1.9	Turn the secondary screw switch to the on position	✓
1.10	Verify secondary altimeter beeps match the expected pattern detailed on the Secondary Altimeter Beep Sheet	✓
1.11	Confirm all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.12	Remove **Bulkhead #3** from its anti-static bag	✓
1.13	Lightly tug on the wires coming out of the **MP** and **MS** terminal blocks to verify security	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.14	Slide **AV Sled** on to the threaded rods using pull pin for alignment	✓
1.15	Slide sled over av bay ensuring the aft bulkhead is on the same side as the aft marks on the AV Bay.	✓
1.16	Replace the Pull pin through the hole in the av bay and tape in place with blue tape (label tape P or S)	✓
1.17	While pointing the blast caps away from personnel, connect the **MP** and **MS** wires on the avionics sled to the **MP** and **MS** wires on Bulkhead #4	✓
1.18	Lightly tug on the wire connection between the avionics sled and **Bulkhead #1** to verify security	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.19	Remove **Bulkhead #3** from its anti-static bag	✓
1.20	Double check the **DS** and **DP** wires are secured to the terminal blocks on **Bulkhead #3.**	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.21	While pointing blast caps away from personnel, Attach **DS** and **DP** wires on bulkhead to **DS** and **DP** wires on AV Sled	✓

1.22	Lightly tug on the wire connection between the avionics sled and **Bulkhead 3** to verify security	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.23	Align **Bulkhead #3** with terminal blocks facing the battery side of the **AV sled**. (Note: Avoid pinching wires)	✓
1.24	Slide the **Bulkhead #3** on to the threaded rods until the bulkhead is snug with the coupler.	✓
1.25	Use a small screwdriver to probe the pressure ports on the avionics bay switch band to confirm they are clear	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.26	Secure **Bulkhead #3** to the **Avionics Bay** using one ¼ inch washer and two ¼ hex nuts on each threaded rod, tighten until snug	
1.27	Confirm all nuts are snug and **Avionics Bay** is properly aligned	Recovery Lead: Safety Officer: Safety Officer High-Powered Rocketry NC State

2. PAYLOAD ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Payload Systems Lead	Frances McBride	FM
Payload Electronics Lead	Ben Lewis	BL
Personnel 1	Grayson Amendt	GA
Personnel 2	Audri Clemmons	AC

Required Materials			
Item	Quantity	Location	Completion
Payload Bay	1	-	✓
Fin Can	1	-	✓
Raspberry Pi	1	Payload BOX	✓
IMU	1	Payload BOX	✓
Fully-Charged LiPo Battery	1	Payload BOX	✓
Buck Converter	1	Payload BOX	✓
Coax cables	2	Payload BOX	✓
Antennas	2	Payload BOX	✓
Payload Sled	1	Payload BOX	✓
RTL SDR Dongle	1	Payload BOX	✓
Relay	1	Payload BOX	✓
Pull pin switch	1	Payload BOX	✓
Short M2 Screws	1	Payload BOX	✓
Long M2 Screws	2	Payload BOX	✓
M2 Nuts	1	Payload BOX	✓
Rivets	1	Hardware HDX	✓
Plumber's Putty	1	LD Toolbox	✓
Zip ties	1	LD Toolbox	✓
Painter's Tape	1	LD Toolbox	✓
Multimeter	1	LD Toolbox	✓
USB-C to USB-A Cable	1	Payload Box	✓
baofeng radio	1	Payload Box	✓
APRS Cable	1	Payload Box	✓
Electrical Tape	1	LD ToolBox	✓

Frances's laptop ✓
mobile phone ✓

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Number	Task	Completion
2.1	Connect the USB-C end of the cable to the Raspberry Pi.	✓
2.2	Connect the USB-A end to a laptop to read outputs.	✓
2.3	Set up a mobile hotspot with Name **HPRC** using a mobile device.	✓
2.4	Connect to the mobile hotspot **HPRC** with password **tacholycos**	✓
2.5	Confirm that the Raspberry Pi is connected to the hotspot by checking the mobile device.	✓
2.6	Open VS Code on the laptop connected to the Pi.	✓
2.7	Click the green lightning bolt icon in the lower left corner of the window.	✓
2.8	Select **Connect Current Window to Host** from the dropdown menu.	✓
2.9	Select **raspberrypi.local** from the dropdown menu.	✓
2.10	If prompted, select **Linux** from the dropdown menu.	—
2.11	If prompted, hit **Continue**.	—
2.12	Enter the password **raspberry** into the dialogue box and press enter.	✓
2.13	Press **ctrl+j** in the terminal window.	✓
2.14	Type **cd Payload-2022-2023/** in the terminal and press enter.	✓
2.15	Type **python3 main.py** in the terminal and press enter to start the script.	✓
2.16	Shake the payload sled vertically and confirm that **LIFTOFF DETECTED** is printed to the console.	✓
2.17	Wait 100 seconds until **LANDING DETECTED** is printed to the console.	✓
2.18	Ensure that when the relay switch is pointed towards the person holding the sled and the pi is pointed away from the person holding the sled, relay switch 2 is active. A red LED should turn on.	✓
2.19	Rotate the sled around its central axis clockwise in 90 degree increments and track the sensed changes in orientation.	✓

BRING A FACE SHIELD

2.20	Ensure that relay switching is functioning correctly by observing active relay LED and comparing to the supposed antenna selection. Payload ECD confirm in the box to the right.	Payload ECD Confirm: 0:2 ✓ 90:2 ✓ 360:2 ✓ 180: 1 ✓ 270: 1 ✓
2.21	Connect the antennas to their respective coax cables (green to green, yellow to not green).	✓
2.22	Transmit a test APRS signal using the Baofeng radio, making sure that the receiving antenna is upright and in the correct orientation.	✓
2.23	Ensure both antennas are receiving the test signal and it is being properly decoded and stored on the Pi.	Payload ECD Confirm: ★
2.24	Disconnect the antennas from their respective coax cables.	✓
2.25	Press **Ctrl+C** in the terminal window on the laptop.	✓
2.26	Unplug the USB cable from the Raspberry Pi and laptop.	✓
2.27	Plug the payload into the flight-ready LiPo and tug lightly to ensure a tight connection.	✓
2.28	Fold down, tape, and zip tie any remaining loose components onto the payload sled.	✓
2.29	Remove the pin from the switch, and ensure that the payload powers on.	✓
2.30	Slide the payload sled onto the threaded rods with **Bulkhead #2**, ensuring that the side of the sled with the Pi is facing **Bulkhead #2.**	✓
2.31	Slide the payload sled into the payload bay and align using the pull-pin switch hole.	✓
2.32	Slide the pull-pin into the switch through the payload bay and tape the switch to the airframe with a two-inch long strip of blue tape.	✓
2.33	Hook up both coax cables to the relay on the payload sled through **Bulkhead #1.**	✓
2.34	Slide each coax cable connected to the sled through the holes in the fincan airframe.	✓

2.35	Connect each antenna cable to each coax cables ensuring not green to yellow and green to green connection through holes in the fin can airframe.	✓
2.36	Slide the payload bay into the fin can.	✓
2.37	Attach the payload bay to the fin can using four black, plastic rivets.	✓
2.38	Tape both antennas flat to the airframe in line with the fins with a long strip of electrical tape.	✓
2.39	Tidy up coax cables to ensure clearance for fin can assembly.	✓
2.40	Confirm Payload is assembled correctly.	Payload Systems Confirm: ★

3. FINCAN ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Structures Lead	Mike Pudlo	[illegible]
Personnel 1	Cameron Brown	[illegible]
Personnel 2	Katelyn Yount	[illegible]

Required Materials			
Item	Quantity	Location	Completion
Fincan	1	-	✓
Payload Bay	1	-	✓
Removable Fin assembly	1	-	✓
Tail cone	2	-	✓
Rail button stand off	1	Hardware HDX	✓
#8 Screws and washers	~~7~~ 8	Hardware HDX	✓
Phillips Screwdriver	1	LD Toolbox	✓

Number	Task	Completion
3.1	Check that antenna cables are clear from fin can cavity where fin assembly will be placed	✓
3.2	Verify all bolts through removable fin slats are sufficiently tight	Structures Lead Confirm: ★
3.3	Use alignment marks on fin can to slide fin assembly into fin can aligning all L bracket holes with airframe holes	✓
3.4	Find the rail button standoff and slide a long #8 screw through	✓
3.5	insert 7 #8 screws and the rail button standoff screw into the fin can cavity	✓
3.6	Confirm that rail button and screws are sufficiently tight	Structures Lead Confirm: ★
3.7	Lightly screw on the tail cone. This will need to be removed further on to insert the motor.	✓
3.8	Ensure no pinching of antennas	✓

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3.9	Pull on the fins to ensure the assembly is secure.	Structures Lead Confirm:

4. DROGUE RECOVERY ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Payload Structures Lead	Chris Luzzi	CL
Personnel 1	Hanna McDaniel	HM
Personnel 2	Braden Rueda	BR

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Fin Can assembly	1	-	✓
AV bay Assembly	1	-	✓
Safety Glasses	1	PPE Toolbox	✓
Drogue Parachute (15 in)	1	Recovery Box	✓
Small Nomex Sheet	1	Recovery Box	✓
Drogue Parachute Shock Cord (1-3)	1	Recovery Box	✓
Quicklink (#1-3)	3	Recovery Hardware HDX	✓
Shear Pin	~~1~~ 2	Recovery Hardware HDX	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓
~~Duct~~ E Tape Tape	1	LD Toolbox (Top Compartment)	✓

Number	Task	Completion
4.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
4.2	Fold the length of shock cord between **Loops 1 and 2** accordion-style with 8-inch lengths	✓

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4.3	Secure the length of shock cord between **Loops 1 and 2** with a single rubber band. Do not cover any part of a parachute. Two fingers should fit snugly under the rubber band	✓
4.4	Confirm the shock cord is folded accordion-style	Int Lead Confirm:
4.5	Attach the hole in the nomex sheet to **Quicklink 2**. Do not tighten	✓
4.6	Attach **Quicklink 2** to **Drogue Parachute Quicklink 2.** Do not tighten	✓
4.7	Attach **Quicklink 2** to shock cord **Loop 2** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure	Int Lead Confirm:
4.8	Attach **Quicklink 3** to shock cord **Loop 3.** Do not tighten	✓
4.9	Attach **Quicklink 3** to AV bay **Bulkhead #3** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure.	✓
4.10	Confirm the shock cord is secured to the AV bay by visual inspection and pulling on shock cord	Int Lead:
4.11	Slide shock cord and parachute through the drogue parachute bay with **Loop 1** hanging out the aft end of the bay.	✓
4.12	Attach **Quicklink 1** to shock cord **Loop 1**. Do not tighten	✓
4.13	Attach **Quicklink 1** to payload **Bulkhead #2** and tighten by hand until secure. Duct tape over the connection to ensure the shock cord will not unthread the closure	✓
4.14	Confirm the shock cord is secured to the fin can by visual inspection and pulling on shock cord	Int Lead:

4.15	Slide drogue bay onto payload bay using alignment marks. Secure into place with 4 rivets	✓
4.16	Confirm the drogue parachute is properly folded	Int Lead:
4.17	Firmly grasp the drogue parachute and remove the rubber band securing the drogue parachute	✓
4.18	Confirm all rubber bands are removed from drogue parachute and shroud lines	✓
4.19	Wrap the nomex cloth around the drogue parachute, like a burrito, continuing to firmly grasp the parachute	✓
4.20	Carefully insert the shock cord between **Loops 1 and 2** into the drogue bay cavity	✓
4.21	Carefully insert the drogue parachute into the drogue bay with the yellow tag facing the aft end of the vehicle	✓
4.22	Carefully insert the shock cord between **Loops 2 and 3** into the drogue bay	✓
~~4.23~~	~~Place a handful of dog barf into the drogue bay~~	
4.24	Slide the avionics bay coupler into the drogue bay, using the sharpie marks for alignment	✓
4.25	Insert a #4-40, ½-inch long nylon shear pin into 2 opposing shear pin holes	✓ ✓
4.26	Place a small piece of blue tape over each shear pin head.	
4.27	Hold the avionics bay and let the fin can hang free and confirm vehicle holds its own weight	Int Lead:

5. MAIN RECOVERY ASSEMBLY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Structures Lead	Mike Pudlo	MP
Personnel 1	Sebasian Perna	SP
Personnel 2	Trey Richardson	TR

Required Materials

Item	Number	Location	Confirmation
Nosecone Assembly	1	-	✓
Fin Can Assembly	1	-	✓
Safety Glasses	5	PPE Toolbox	✓
Main Parachute (48 in)	1	Recovery Box	✓
Large Nomex	1	Recovery Box	✓
Main Parachute Shock Cord	1	Recovery Box	✓
Quicklink (#4-6)	1	Recovery Hardware Box	✓
Shear Pin	2	Recovery Hardware Box	✓
Blue tape /duct tape	1	AV HDX Box	✓
	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓

Number	Task	Completion
5.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
5.2	Slide **loop 4** of the shock cord through the main parachute bay with **loop 4** hanging out the aft end of the bay	✓
5.3	Attach **quicklink 4** to shock cord **loop 4**. Do not tighten.	✓
5.4	Attach **quicklink 4** to AV bay **bulkhead 4**. Tighten by hand.	✓
5.5	Slide main parachute bay onto AV bay using alignment marks	✓
5.6	Insert 4 rivets to secure AV bay to main parachute bay	✓
5.7	Fold the length of shock cord between **Loops 4 and 5** accordion-style with 8-inch lengths	

★ Revise checklist & add tape over quicklinks

5.8	Secure the length of shock cord between **Loops 4 and 5** with a single rubber band. Two fingers should fit snugly under the rubber band	✓
5.9	Fold the length of shock cord between **Loops 5 and 6** accordion-style with 8-inch lengths	✓
5.10	Secure the length of shock cord between **Loops 5 and 6** with a single rubber band. Do not cover any part of a parachute. Two fingers should fit snugly under the rubber band	✓
5.11	Confirm the shock cord is folded accordion-style	Structures Lead:
5.12	Attach **Quicklink 5** to the main parachute. Do not tighten	✓
5.13	Attach **Quicklink 5** to the Main Parachute **Nomex sheet**. Do not tighten	✓
5.14	Attach **Quicklink 5** to shock cord **Loop 5** and tighten by hand until secure. Tape over the connection to ensure the shock cord will not unthread the closure	Structures Lead:
5.15	Attach **Quicklink 6** to shock cord **Loop 6**. Do not tighten	✓
5.16	Attach **Quicklink 6** to nose cone **bulkhead 6** and tighten by hand Tape over the connection to ensure the shock cord will not unthread the closure	✓
5.17	Confirm the shock cord is secured to the nose cone by visual inspection and pulling on shock cord	Structures Lead:
5.18	Insert the length of shock cord between loops 4 and 5 into the main parachute bay.	✓
5.19	Remove all rubber bands from the main parachute and shock cords. Hold the parachute securely so that it does not come unfolded.	✓
5.20	Fold nomex sheet over the main parachute like a burrito so that it is covered.	✓

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5.21	Carefully insert the main parachute completely into the main parachute bay with the yellow loop pointed towards the nose cone	✓
5.22	Insert the length of shock cord between loops 5 and 6 into the main parachute bay.	✓
5.23	Slide the main parachute bay over nose cone coupler, being careful not to pinch the shock cord, and using the marks for alignment	✓
5.24	Insert 2 #4-40, ½-inch long nylon shear pins into two opposing shear pin holes	✓
5.25	Place a small piece of blue tape over the shear pin heads.	✓
5.26	Hold the launch vehicle upright by the nose cone and verify the launch vehicle can hold its own weight from shear pins alone	Structures Lead:

All confirmations Checklist

6. MOTOR ASSEMBLY

Essential Personnel:

Role	Name	Initial
L3 Mentor	Alan Whitmore/Jim Livingston	AW
Aerodynamics Lead	J.W. Mason	JWM
Motor Personnel 1	Craig Abell	CA

Required Materials

Item	Quantity	Location	Completion
Aerotech I135T Reload Kit	1	Motor Box	✓
Aerotech Phenolic Tube	1	Motor Box	✓
Aerotech RMS 38/1080 motor casing	1	Motor Box	✓
Motor Igniter	1	LD Toolbox (Top Drawer)	✓
Vaseline	1	LD Toolbox (Top Compartment)	✓
Needle nose pliers	1	LD Toolbox (Middle Drawer)	✓
Baby Wipes	1	LD Toolbox (Top Compartment)	✓
Sharpie Marker	1	LD Toolbox (Top Compartment)	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Nitrile Gloves	2	PPE Toolbox	✓
Paper Towels	1	Recovery Box	✓

NOTE: Follow all manufacturer procedures for assembling the motor!

Number	Task	Completion
6.1	Gather all materials and L3 mentor at table and receive permission to begin motor assembly from mentor	✓
6.2	Use Vaseline to lightly grease included O-Rings identified by motor manual	✓
6.3	Use Vaseline to lightly grease threads on motor casing	✓
6.4	Install smoke grain into insulator tube with spacer until snug	✓
6.5	Use Vaseline to lightly grease one end of the smoke grain	✓

6.6	Install smoke grain into forward closure, greased side facing forward, until snug	✓
6.7	Install forward seal disk O-Ring on forward seal disk	✓
6.8	Install forward seal disk and O-Ring into one end of motor liner until snug	✓
6.9	Install three propellant grains into motor liner	✓
6.10	Install motor liner into motor casing, holding the liner centered within the casing	✓
6.11	Install forward O-Ring into forward end of motor casing. The O-Ring MUST be seated against the forward end of the forward seal disk assembly	✓
6.12	Install the forward closure with smoke grain assembly onto the forward end of the motor casing, on top of the forward O-Ring. Tighten until finger tight	✓
6.13	Install aft nozzle on the aft end of the motor casing	✓
6.14	Install aft O-Ring onto aft nozzle	✓
6.15	Install aft closure onto aft O-Ring	✓
6.16	Install aft closure assembly into aft end of motor casing. Tighten until finger tight. NOTE: There will be exposed threads when the aft closure is snug	✓
6.17	Install nozzle cap with a corner cut	✓
6.18	Prepare motor ignitor	✓
6.19	Hold ignitor wire along the side of the motor casing	✓
6.20	Designate appropriate length by marking ignitor wire with Sharpie	✓
6.21	Separate ends of ignitor wire	✓
6.22	Strip ends of ignitor wire	✓
6.23	Coil ignitor wire back into original orientation	✓
6.24	Tape ignitor to side of casing	✓
6.25	Thank the mentor for assisting with motor assembly	✓
6.26	Return to launch vehicle assembly location with motor and prepared ignitor. Designate one person to hold the motor. **KEEP MOTOR AWAY FROM OTHER PERSONNEL UNTIL CHECKLIST ITEM 9.2**	✓

7. FINAL MEASUREMENTS

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Integration Lead	Chris Luzzi	CL
Personnel 1	Luke Pollard	LP
Personnel 2	Trent Couse	TC
Personnel 3	Caleb	CA

Required Materials

Item	Quantity	Location	Completion
Fish Scale	1	LD Toolbox (Bottom Drawer)	✓
Calculator	1	Phone	✓
Rope	1	LD Toolbox (Bottom Drawer)	✓
Circle Stickers	2	LD Toolbox (Top Compartment)	✓
Sharpie	1	LD Toolbox (Top Compartment)	✓
Launch Vehicle (assembled)	1	-	✓
Motor (assembled)	1	-	✓

add tape measure →

Number	Task	Completion
7.1	Unscrew motor retainer	✓
7.2	Slide motor casing into motor tube	✓
7.3	Secure motor casing using motor retainer screw	Safety Officer High-Power Safety Officer/ NC State
7.4	Measure the center of pressure of the launch vehicle. This point is 49 inches from the tip of the nose cone. Ensure tape measure is straight and not following the curvature of the nose cone	✓
7.5	Use an orange circular sticker or blue tape labeled "CP" to mark the center of pressure of the launch vehicle	✓
7.6	Using the rope and fish scale, locate the center of gravity of the launch vehicle. Tie the rope around the launch vehicle and move the rope until the launch vehicle balances	✓

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7.7	Record the weight of the launch vehicle using the fish scale	Record weight here: 10.25Lb
7.8	Use a green circular sticker or blue tape labeled "CG" to mark the center of gravity of the launch vehicle	✓
7.9	Measure the center of gravity's distance from the tip of the nose cone using the tape measure. Ensure the tape measure is straight	Record CG location here: 41.3
7.10	Calculate the stability margin using the formula (CP-CG)/D. This is (49 - CG)/1. The stability margin must be at least 2.0	Record stability margin here: 1.92 Team Lead:
7.11	Load the field recovery box with the items required by checklist 8	✓
7.12	Proceed to the launch pad!	✓

8. LAUNCH PAD

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Recovery Lead	Shaan Stephen	SS
Payload Lead	Ben Lewis	BL
Personnel 1	Mason Meyer	MM

Required Materials			
Item	Quantity	Location	Completion
Launch Vehicle (assembled)	1	-	✓
Motor ignitor	1	Field Recovery Box	✓
Vaseline	1	LD Toolbox (Top Compartment)	✓
Nitrile Gloves	1	PPE Box	✓
Heavy Duty Gloves	2	PPE Box	✓
Safety Glasses	1	PPE Box	✓
Switch Screwdriver	1	LD Toolbox (Middle Drawer)	✓
TB Screwdriver	1	LD Toolbox (Middle Drawer)	✓
Adjustable Wrench	1	LD Toolbox (Middle Drawer)	✓
Rubber Bands	6	Recovery Hardware Box	✓
Phone	1	-	✓
Laptop	1	-	✓
Wire Snips	1	LD Toolbox (Middle Drawer)	✓
Wire Strippers	1	LD Toolbox (Middle Drawer)	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Fire extinguisher	1	Field Recovery Box	✓

Number	Task	Completion

8.1	Confirm with RSO that field conditions are safe for launch	✓
8.2	Submit flight card to RSO for review	✓
8.3	Proceed to launch pad	✓
8.4	Record coordinates of launch pad 35.1788481 -76.828238	✓
8.5	Confirm blast deflector is mounted on launch rail	Safety Officer: Safety Officer High-Powered Rocketry NC State
8.6	Carefully slide the launch vehicle onto the launch rail	✓
8.7	Visually confirm the launch vehicle slides smoothly along the rail	Safety Officer: Safety Officer High-Powered R
8.8	If there is resistance in sliding along the rail, remove the launch vehicle, apply Vaseline to the launch rail, then repeat items 10.6 and 10.7.1	✓
8.9	Rotate launch rail into the upright position and lock into place	✓
8.10	Orient the launch rail such that it is pointed 5 degrees away from spectators	✓
8.11	Confirm the launch rail is locked	Safety Officer: Safety Officer High-Powered Rocketry NC State
8.12	Take team pictures as necessary	✓
8.13	All non-essential personnel leave the launch pad	✓
8.14	Confirm that all remaining individuals are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
	Payload Procedure	✓
8.15	Pull pin switch out	n/a
8.16	Confirm payload is buzzing to ensure activation	✓
8.17	Use $ ssh pi@raspberrypi.local (password:raspberry)	✓
8.18	Start tmux session	✓

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	$ tmux new -s launch	✓
8.19	Navigate to payload directory $ cd Payload-2022-2023	✓
8.20	Start main script $ python3 main.py > data.txt	✓
8.21	Detach from tmux session with ctrl+b then d	✓
8.22	Verify tmux session running $ tmux ls	✓
	Altimeter arming procedure:	
8.23	Pull pin switch out of primary altimeter slot	✓
8.24	Confirm primary altimeter is programmed correctly using Appendix A – Primary Beep Sheet 9.5v, 6, 1,	
8.25	Pull pin switch out of secondary altimeter slot 9.5v, 5, 2,	
8.26	Confirm secondary altimeter is programmed correctly using Appendix B – Secondary Beep Sheet	
8.27	Confirm both altimeters are powered on with full continuity	Safety Officer: Safety Officer High-Powered Rocketry NC State
8.28	Ignitor installation procedure:	✓
8.29	Attach ignitor to wooden dowel	✓
8.30	Insert ignitor fully into the motor	✓
8.31	Tape ignitor into place at the bottom of the launch vehicle, using the mark made in item 8.17.2	✓
8.32	Confirm that launch pad power is turned off	✓
8.33	Connect ignitor wires to launch pad power	✓
8.34	Confirm launch pad continuity, measurement should read between 1.5 and 3.5	✓
8.35	All personnel navigate to safe location behind the launch table	✓
8.37	Pass the primary checklist and field recovery toolbox to the Safety Officer	✓
8.38	Inform the RSO the team is ready for launch	✓
8.39	Launch	✓

9. FIELD RECOVERY

Essential Personnel:

Role	Name	Initial
Safety Officer	Megan Rink	MR
Team Lead	Meredith Patterson	MP
Recovery Lead	Shaan Stephen	SS
Payload Systems Lead	Frances McBride	FM
Personnel 1	Connor Swanson	CS
Personnel 2	Michael Wax	MW

Required Materials			
Item	Quantity	Location	Completion
Nitrile Gloves	1	Field Recovery Box	✓
Heavy Duty Gloves	1	Field Recovery Box	✓
Safety Glasses	5	Field Recovery Box	✓
Switch Screwdriver	1	Field Recovery Box	✓
TB Screwdriver	1	Field Recovery Box	✓
Adjustable Wrench	1	Field Recovery Box	✓
Rubber Bands	6	Field Recovery Box	✓
Phone	1	Field Recovery Box	✓
Wire Snips	1	Field Recovery Box	✓
Wire Strippers	1	Field Recovery Box	✓
Blue Tape	1	Field Recovery Box	✓
Fire extinguisher	1	Field Recovery Box	✓

Number	Task	Completion
9.1	Confirm that all personnel are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.2	Confirm that all personnel handling the launch vehicle are wearing nitrile gloves	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.3	Approach the launch vehicle on foot	✓
9.4	If a parachute is open and pulling the launch vehicle, follow items 11.5.1-11.5.3. Otherwise, proceed to item 11.6	✓
9.5	Approach the parachute from the billowed side	✓

9.6	Use hands and body to pull down the parachute by the CANOPY. **Do not grab the shroud lines or shock cord**	✓
9.7	Repeat for second parachute if necessary	✓
9.8	If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the flame	✓
9.9	Use a rubber band to secure the main parachute	✓
9.10	Use a rubber band to secure the drogue parachute	✓
9.11	Carefully pick up the forward end of the main parachute bay and inspect the forward AV bulkhead for un-blown black powder charges	✓
9.12	Inspect the aft AV bulkhead for un-blown black powder charges	✓
9.13	If there are un-blown charges, follow items 11.12.1-11.12.2. Otherwise, proceed to item 11.13	✓
9.14	Equip heavy duty gloves before handling the body tube	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.15	Use the switch screwdriver to turn off the primary AND secondary screw switches	✓
9.16	Listen to the altimeters and record flight data using Appendix C - Post-Flight Beep Sheet	✓
9.17	Power off both altimeters by turning off both screw switches	✓
9.18	Record the coordinates of the final resting position of the launch vehicle	✓
9.19	Record the coordinates of the initial ground impact point	✓
9.20	Take pictures of any damage to the launch vehicle	✓
9.21	Inspect for and collect non-biodegradable waste from the landing site	✓
9.22	Collect each launch vehicle section and return to the launch site	✓

Alt 2111
2116

APPENDIX A – PRIMARY BEEP SHEET

NOTE: There is a quick low beep between each line

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.	N/A	Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).	9.5	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	6	IMPORTANT: Should be 6~~00~~
(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a ***five second continuous tone*** *to warn you that your apogee firing is set to be delayed.*	N/A	IMPORTANT: SHOULD NOT SOUND
A one-digit number (range of 1 to 3) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue and main have good continuity.	3	IMPORTANT: Should be 3

APPENDIX B – SECONDARY BEEP SHEET

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.	N/A	Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).	9.5	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	5	IMPORTANT: Should be 600
*(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a **five second continuous tone** to warn you that your apogee firing is set to be delayed.*	N/A	IMPORTANT: SHOULD NOT SOUND
A one-digit number (range of 1 to 3) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue and main have good continuity.	3	IMPORTANT: Should be 3

APPENDIX C – POST-FLIGHT BEEP SHEET

The Beeps: What do they mean	Primary Beeps	Secondary Beeps	Expected Output
An extra-long tone to indicate the start of the reporting sequence			Ignore, currently not important
A three to six-digit number representing the peak altitude in feet	2111	2116	Should be approximately 2000 ft. Record
A long separator tone followed by a two to five-digit number representing the maximum velocity during the flight in miles per hour			Record
If the "siren delay" number is set to a number greater than zero, the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone.			Ignore, currently not important
After a 10 second period of silence, the sequence repeats until power is disconnected.			Ignore, currently not important