NC STATE UNIVERSITY

Tacho Lycos

2023 NASA Student Launch

Critical Design Review

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27606

January 9, 2023

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
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 Mentor Information

Name: Alan Whitmore

Email: acwhit@nc.rr.com, (919)-929-5552

TRA Certification: Level 3, 05945

Name: Jim Livingston

Contact: livingston@ec.rr.com, (910)-612-5858

TRA Certification: Level 3, 02204

1.1.3 Time Spent on CDR Milestone

The team spent an approximate total of 300 hours working towards completion of CDR milestone.

1.1.4 Launch Week Plans

Thirty club members will be traveling to Huntsville, AL to participate in the expected launch on April 15th, 2023.

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

The length of the launch vehicle is 104.5 in. with a 6.17 in. diameter and launch pad weight of 40.71 lb.

Table 1: Vehicle Sizing and Weight

Dry Mass	Dry Mass with Ballast	Wet Mass	Burnout Mass	Landing Mass
35.87	36.62	40.71	36.62	36.62

Section	Nose Cone	Main Parachute Bay	AV Bay	Drogue Parachute Bay	Payload Bay	Fin Can	Overall
Length (in)	30	20	2	17	4	31.5	104.5
Weight (lb)	6.85	2.64	3.25	2.24	3.2	5.89	

1.2.3 Recovery System

Two RRC3 Sport altimeters will control deployment events. Fruity Chutes 18 in. Compact Elliptical and 120 in. Iris Ultracompact parachutes will be deployed at apogee and 600 ft. respectively.

1.2.4 Rail Size

The launch vehicle will use a 15-15 launch rail that is 12 ft. in length.

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 Last Document

2.1 Changes Made to Vehicle Criteria

Several changes have been made to the launch vehicle design since PDR submission. These changes and their justifications are listed in Table 2

Table 2: Changes made to the launch vehicle since PDR submission.

Change	Reason For Change
Removed forward fin can centering ring	After discussion with the NASA Panel and Tripoli mentors, it was determined that the motor was already being sufficiently held within the airframe by the aft two centering rings. Thus, the forward centering ring provided no additional benefit and was removed.
AV Bay threaded rods decreased from 5/16 to 1/4 in.	Further estimations of the forces endured by the AV bay and FEA simulations show that 1/4 in. rods are sufficient. Additionally, this allows for all threaded rods on the vehicle to be the same diameter and thread designation allowing for parts to be interchangeable.
Plastic rivets used to secure non-separating sections during flight.	Plastic fasteners were utilized on the subscale vehicle to hold sections together during flight. Because of the increased ease of use they will be utilized on the full scale vehicle as well.
Switched from fiberglass to carbon fiber composite fins	Subscale fins were constructed using fiberglass and were able to bend considerably. Due to the increased size and forces of the full scale fins Tripoli mentors recommended using carbon fiber for composite fin construction.
GPS changed to operate on the 70cm band	After discussion with the NASA panel after the team's PDR presentation, the GPS was changed to operate on the 70cm band in order to avoid interference with other teams who may be using the 900 MHz band.
Addition of threaded rod to the nose cone	A threaded rod was added that runs the entire length of the nose cone in order to further secure the nose cone bulkhead as well as to act as a method of securing an adjustable ballast system.

2.2 Changes Made to Payload Criteria

From data gained from the subscale vehicle launch, several changes to the payload system have been made. The changes made and the justifications for these changes are found in Table 3.

Table 3: Changes made to payload since PDR submission.

Change	Reason for Change
Addition of a logic-level shifter IC between the Raspberry Pi and the servos	Pi GPIO pins can only output a maximum of 3.3V, while the servos require 5V. This IC shifts the signals from 3.3V to 5V.
Antenna mounting along the launch vehicle no longer has a portion running along the fins	Antenna was ran along the fins in order to ensure that the antenna would fit entirely along the body of the launch vehicle. The aft section of the launch vehicle is long enough to lay the antenna along without bending it, with several inches of margin. Thus, it is not necessary to curve the antenna.
Added bracket for servo mounting to camera mount	Bracket needed to ensure that servo body remains fixed while head rotates
Changed camera from the Arducam IMX219 to the Smraza camera module 5	The Smraza modules offer similar performance at a smaller size, allowing for smaller camera housings. These cameras are also already in club possession.
Added supports to the camera mount for the camera housing	Provides extra rigidity and prevents camera housing deformation

2.3 Changes Made to Project Plan

Since the PDR 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 4.

Table 4: Changes made to project plan since PDR submission.

Change	Reason for Change
Success criteria for SDR 5 from PDR was reworded.	After mitigations were applied, it was clear that not every hazard could be reduced to yellow or green so 80% was deemed sufficient.
PF 4 was added to the team derived requirements.	The team determined it was necessary to add further requirements regarding the design of the payload sled such that the Raspberry Pi is able to effectively complete all commands.
Success criteria for PD 3 was reworded.	Since PDR, the vehicle and payload teams changed the antenna placement to along the length of the fin can instead of along the leading edge of the fin.

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. The launch vehicle 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 to all NASA and team derived requirements. Criteria for success of the launch vehicle are defined in Table (5) below.

Table 5: Launch vehicle success criteria.

Level of Success	Criteria
Complete Success	- Launch has nominal takeoff and descent - Launch vehicle reaches ±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 ±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 ±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 Vehicle Design

3.2.1 Design Overview

When fully assembled the launch vehicle will be 104.5 in. long with a maximum outside diameter of 6.17 in. The launch vehicle will be constructed in 6 independent sections which are labeled in Fig. (1) below. The total weight of the launch vehicle is predicted to be 40.71 lb. including 0.75 lb. of ballast. 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. 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.

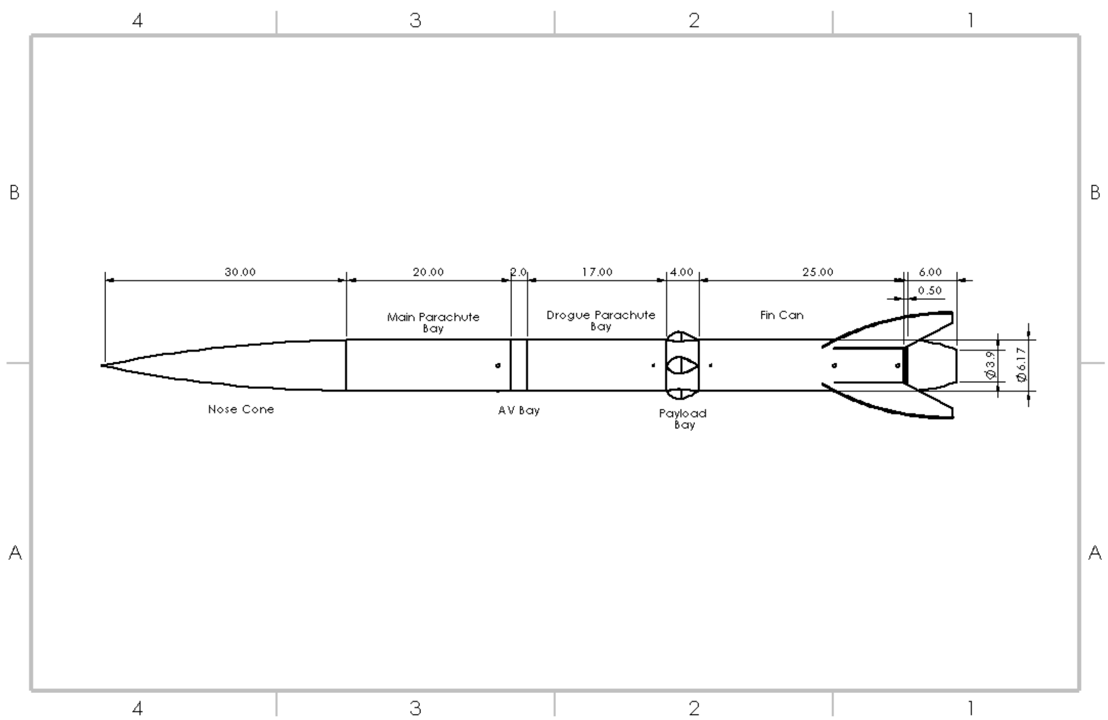

Figure 1: Overall dimensions of the assembled launch vehicle

Figure 2: CAD rendering of the assembled launch vehicle.

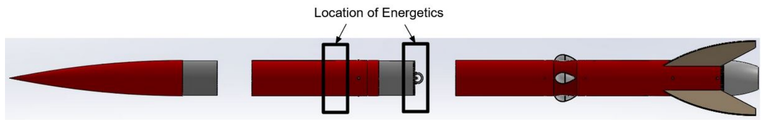

Figure 3: Diagram of separation points and energetic locations.

3.2.2 Material Selection

3.2.2.1 Airframe Material

G12 fiberglass has been selected as the material for both the airframe and the nose cone. Fiberglass is a common material choice in hobby rocketry as well as having significant legacy use within the club. The material is fabricated by winding filaments with angles between 30-45 degrees giving it the required strength to resist loads from all directions. Additionally, G12 fiberglass is waterproof which provides a benefit over the other materials that were considered.

3.2.2.2 Fin Material

The fins will be constructed from a balsa wood/carbon fiber sandwich composite. This design was chosen over the solid plywood alternative as it provides reduced weight. Balsa wood was chosen as the core material because it is lightweight and inexpensive. Carbon fiber was chosen to re-enforce the balsa wood because it provided a higher strength and bending resistance that fiberglass although it does come at an increased price. This increased bending resistance is important because the fins will likely be subjected to large forces upon landing.

3.2.2.3 Bulkhead Material

Bulkheads will be constructed by laminating layers of 1/8 in. aircraft grade birch plywood using West Systems 105 epoxy resin and 206 slow hardener. Further details on the manufacturing of bulkheads is provided in section 3.4.3 below. Birch plywood is a lightweight material that will allow for the construction of bulkheads that are easily manufactured. Additionally, bulkhead thickness can be varied based on the applied loading. Bulkheads will be used for the attachment of hardware such as U-bolts and threaded rods which are necessary for securing the recovery hardware. Stainless steel components will be used for all load bearing bulkhead hardware.

3.2.3 Nose Cone

The nose cone will be a 5:1 Ogive shape constructed out of G12 fiberglass with an anodized aluminum tip. This shape was chosen as it offered acceptable aerodynamic performance and an increase in stability from the 4:1 alternative. Additionally, Ogive nose cones are commercially available making them easy to purchase and avoiding the cost and complexity of custom manufactured nose cones. The nose cone will be constructed with a removable bulkhead. This design was chosen because it allows for access to the inside of the nose cone in order to adjust ballast. The dimension of the nose cone and the removable bulkhead assembly are shown in Figures (4) and (5) below. Additionally, a 1/4-20 threaded rod will run the entire length of the nose cone. This rod will be secured to the threaded insert of the aluminum tip on the forward end and by a nut on the other side of the nose cone bulkhead. The purpose of this rod is to further support the attachment of the removable bulkhead as well as act as an attachment point for a ballast box. In the event that ballast is needed to stabilize the launch vehicle, it will be attached to the threaded rod and secured with nuts. This creates a system that does not rely on an epoxy bond in order to secure ballast. Furthermore, it allows for the location of the ballast to be moved along the length of the nose cone.

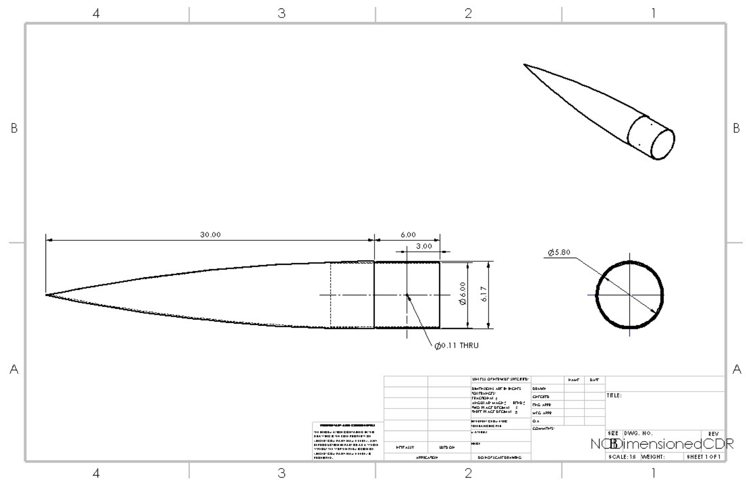

Figure 4: Dimensioned drawing of the nose cone with the shoulder.

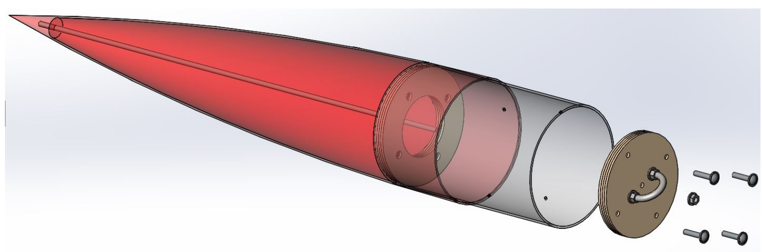

Figure 5: Exploded view of the nose cone and removable bulkhead assembly.

The nose cone bulkhead assembly is comprised of two parts. First, a centering ring is permanently epoxied into the forward end of the nose cone shoulder. This centering ring will have 4 symmetrically spaced holes for the insertion of 1/4-20 T-nuts. A removable bulkhead will then be bolted to the centering ring using four 1/4-20 stainless steel bolts. Dimensions of both the bulkhead and centering ring are shown in Fig. (6) below. A U-bolt will be attached to the center of the bulkhead to act as the attachment point for the main parachute. To verify that the attachment points and bulkhead thickness meet the required factor of safety, destructive testing will be performed as is described in section 6.1.1 below. Excluding any ballast, the nose cone and bulkhead assembly is expected to weight 6.85 lb.

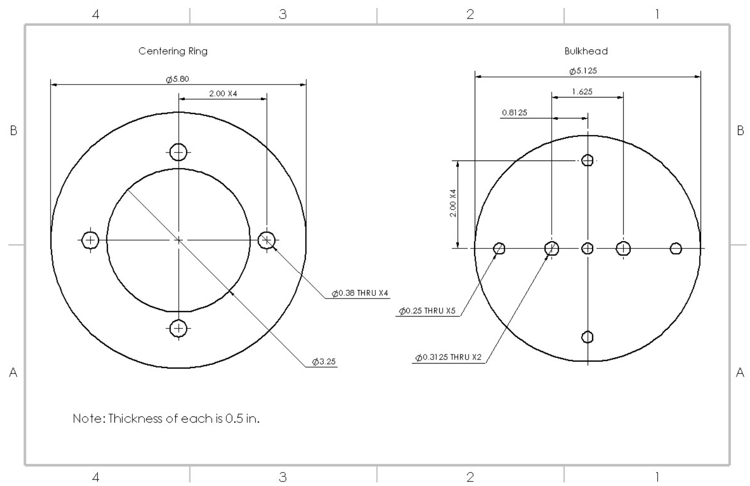

Figure 6: Dimensioned drawing of the nose cone bulkhead and centering ring.

3.2.4 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 inch nylon rivets and the forward end will be secured to the nose cone using four #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; However, additional testing will be done to verify this. 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 and other deployment hardware. Excluding the recovery hardware, the main parachute bay is expected to weigh 2.64 lb.

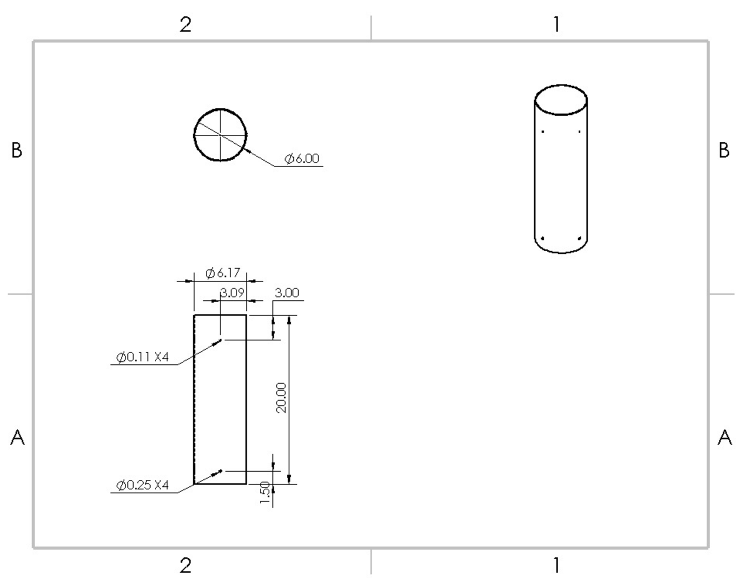

Figure 7: Dimensioned drawing of the nose cone bulkhead and centering ring.

3.2.5 Avionics Bay

The avionics bay is located between the main and drogue parachute bays and will house all the recovery electronics. The bay will be constructed using a modular design that allows for it to be separated from the rest of the launch vehicle allowing for easy access to blast caps as well as the AV sled. Additionally, this design will allow the AV bay to be assembled in parallel with other sections of the launch vehicle. An assembled view of the AV bay with its internal components is shown in Fig. (8).

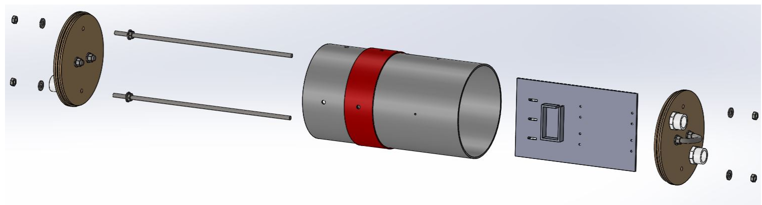

Figure 8: Exploded view of the AV bay with bulkheads and internal components.

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. 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 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. Each bulkhead will be ½ in. thick and have a U-bolt for attaching shock cords as well as two blast caps. The bulkheads will feature a stepped diameter design which allows them to slot into the coupler section of the AV bay. Dimensioned drawings of the airframe and bulkheads are shown in Figures (9) and (10) below. The weight of the bay, excluding the AV sled and electronics, is expected to be 3.25 lb.

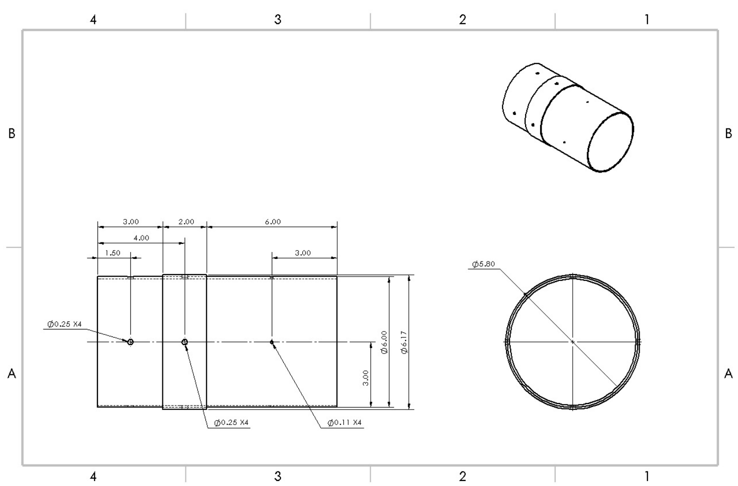

Figure 9: Dimensioned drawing of the avionics bay airframe.

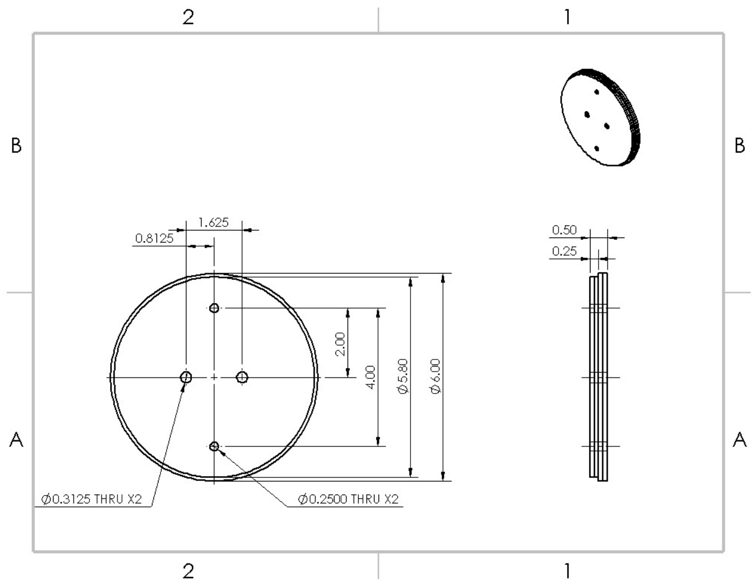

Figure 10: Dimensioned drawing of the avionics bay bulkheads.

3.2.6 Drogue Parachute Bay

The drogue parachute bay will be 17 in. long and is located between the AV bay and the payload bay. The drogue parachute is expected to occupy 4 inches along the length with the rest of the volume being taken up by shock cords and other recovery hardware. 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. A dimensioned drawing of the drogue parachute bay is shown in Fig. (11). The drogue parachute bay is expected to weigh 2.24 lb. not including recovery hardware.

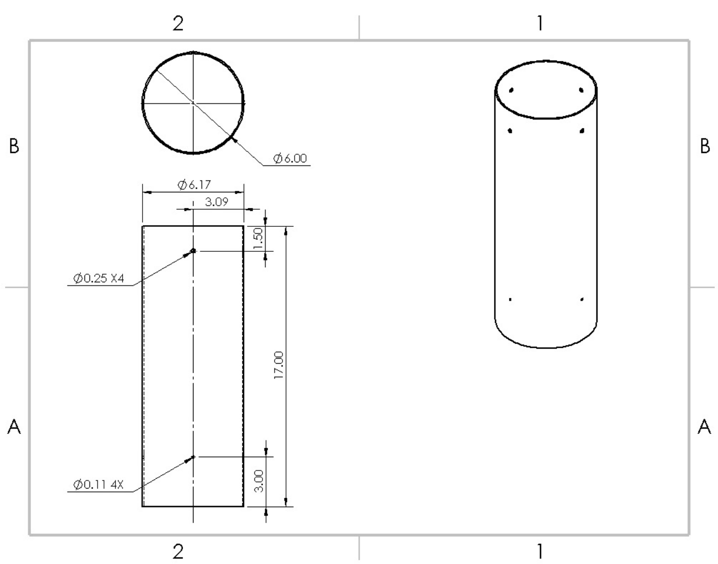

Figure 11: Dimensioned drawing of the avionics bay bulkheads.

3.2.7 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 four 1/4 in nylon rivets at each separation point. The payload bay will be constructed in a similar manner as the AV bay. It will be fabricated using a 10 in. long coupler section with a 4 in. long band of airframe material epoxied in the center. Four teardrop shaped holes will be cut into the airframe band on the payload bay. These holes will be evenly spaced around the circumference and will be used to take images of the surroundings upon landing. Each of these holes will be covered with a transparent camera housing. The design and fabrication of these camera housings is further discussed in Sections 4.3.2.2 and 4.4.1 later in the document. Additionally, 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 will not affect the fin aerodynamics. Two bulkheads will 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. An exploded view diagram of all payload bay structural components is shown in Fig. (12) below.

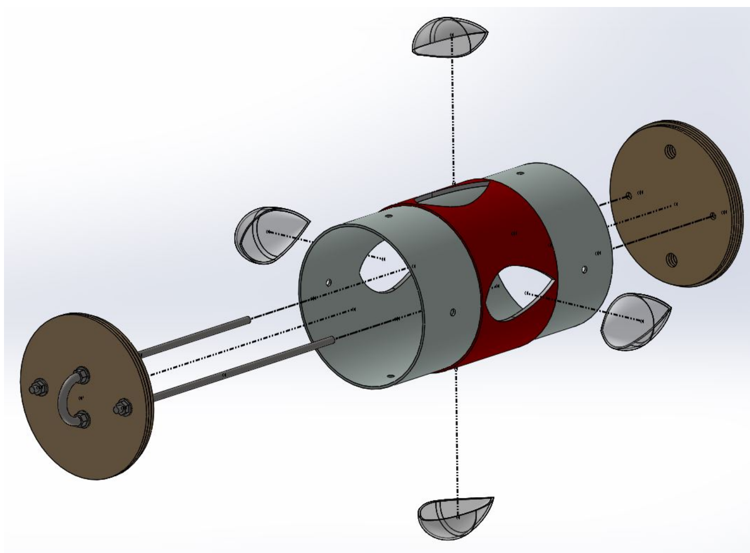

Figure 12: Exploded view of the payload bay and its components

The forward payload bulkhead will be identical to the AV bay bulkheads in size and shape, however, there will be no blast cap on the forward payload bay bulkhead. The aft payload bay bulkhead will have 2 hole which will be used to connect the payload electronics to the antenna via coaxial cables. There will be no other hardware mounted to the aft payload bulkhead. Dimensioned drawings of the payload bay airframe and aft bulkhead are shown in Figures (13) and (14). The payload bay and its bulkheads are expected to weigh 3.2 lb. not including the weight of the payload electronics. Further details on the construction of the payload bay and mounting of camera housings is described in section 4.6

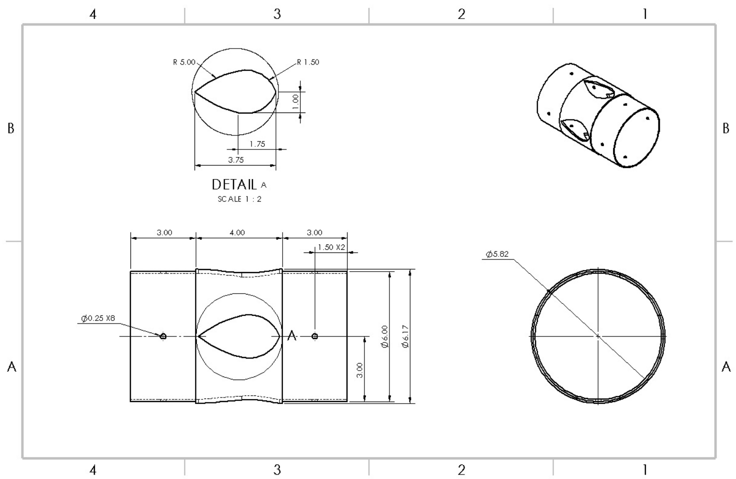

Figure 13: Dimensioned drawing of the payload bay airframe.

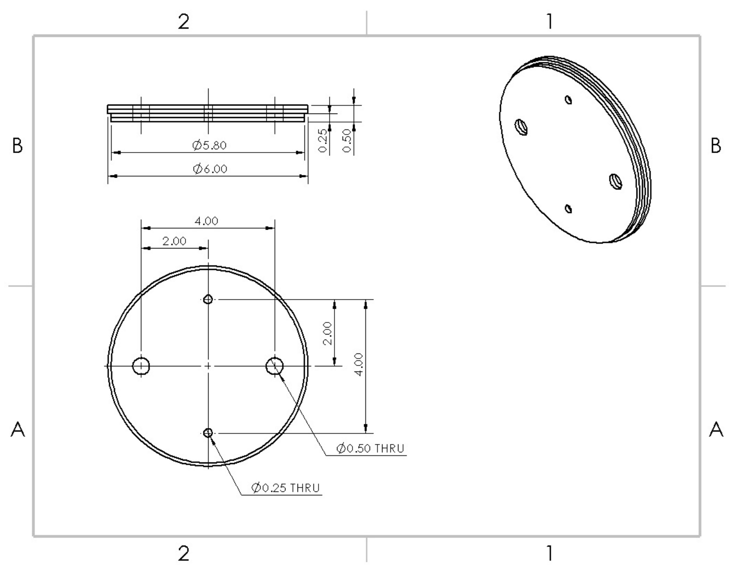

Figure 14: Dimensioned drawing of the payload bay aft bulkhead.

3.2.8 Fin Can

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 will be 25 in. long and is secured to the payload bay using four 1/4 in. nylon rivets. 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. Rail buttons will also be secured onto the exterior of the fin can. These rail buttons will be placed such that the launch rail passes in between the fins and camera housings. To ensure that the launch rail does not make contact with the camera housings the rail buttons will be held 1/2 in. off of the surface of the airframe using spacers. A dimensioned drawing of the airframe section as well as the overall assembly is shown in Fig. (15) and (16) below. The fin can including the removable fin assembly, thrust plate, and tailcone is expected to be 5.89 lb.

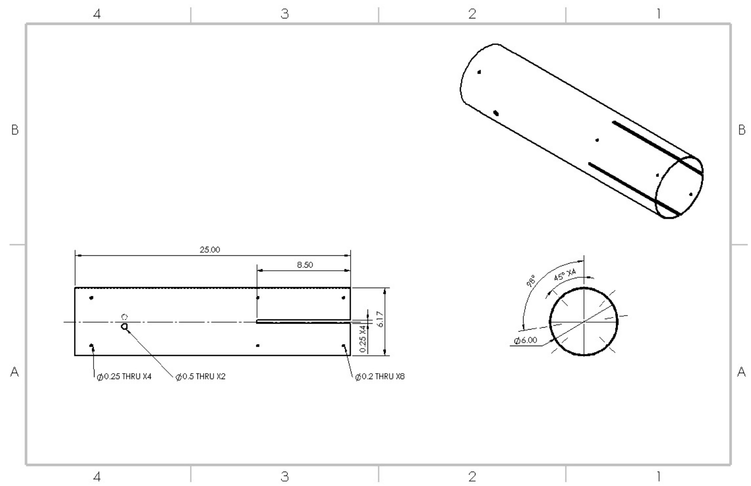

Figure 15: Dimensioned drawing of the airframe of the fin can.

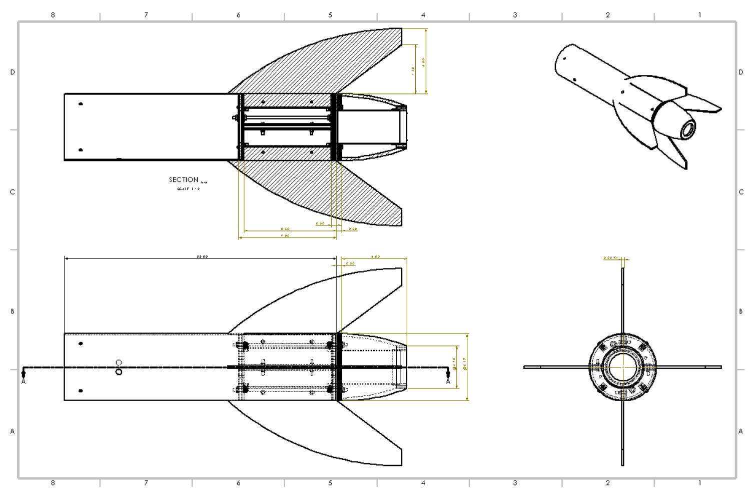

Figure 16: Dimensioned drawing of the assembled fin can with all components.

3.2.8.1 Fin Configuration

The launch vehicle will use a four-fin configuration. This was chosen in order to create two axes of symmetry in order to support the payload design. Additionally, the four fin configuration serves to move the center of pressure aft in order to ensure that the stability margin will be 2.0 at rail exit.

The fins will have a large amount of sweep, extending as far back as the end of the tail cone, and an Ogive leading edge profile. The large sweep moves a portion of the surface area well behind the fin can which aids in moving the center of pressure farther aft. Additionally, CFD simulations showed that the curved leading edge provided significant drag reduction over a traditional trapezoidal design of the same area. These simulations were discussed in depth in the PDR document. Overall, the fins will have an area of 52.27 in^2 with a root chord of 10 in. and extending 6 in. away from the airframe. The full dimensions of the fins are provided in Fig. (17) below.

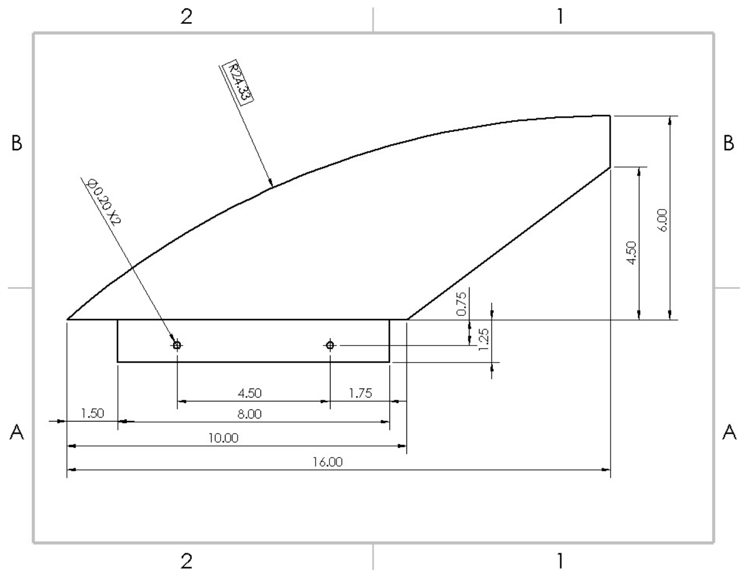

Figure 17: Dimensioned drawing of the planform area of the fin.

The fins will be constructed using a balsa wood/carbon fiber sandwich composite. Two layers of 3000K plain weave fiberglass will be laminated on each side of the fin. A single layer of 2 $\frac{oz}{yd^3}$ fiberglass will then be layered on each side. The purpose of this thin fiberglass layer is to aid in creating a smooth surface finish. A diagram of this layup is shown in Fig. (18) below Carbon fiber was chosen in lieu of fiberglass at the recommendation of the team's Tripoli mentors and because of its much higher strength. This layup is different from the fiberglass composite used on the subscale fins. The reason for these changes is discussed further in section 3.3.4 later in the document.

Figure 18: Layup diagram for the construction of composite fins.

3.2.8.2 Removable Fin System

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 will be permanently epoxied into slots in the centering rings. An epoxy fillet will then be applied to the joint between the runners and the centering rings in order to resist any torsional loads that may be supplied to the system. Dimensioned drawings of the removable centering rings and runners are shown in Figures (19) and (20). The fins will then be bolted to the runners using two #8-32 machine screws per fin. Additionally, two 1/4-20 threaded rods will run through the entire length of the assembly. These threaded rods will add structural rigidity to the assembly and will be used in order secure the thrust plate to the removable fin assembly. Additionally, ballast can be secured to these threaded rods for the purpose of apogee adjustment if required.

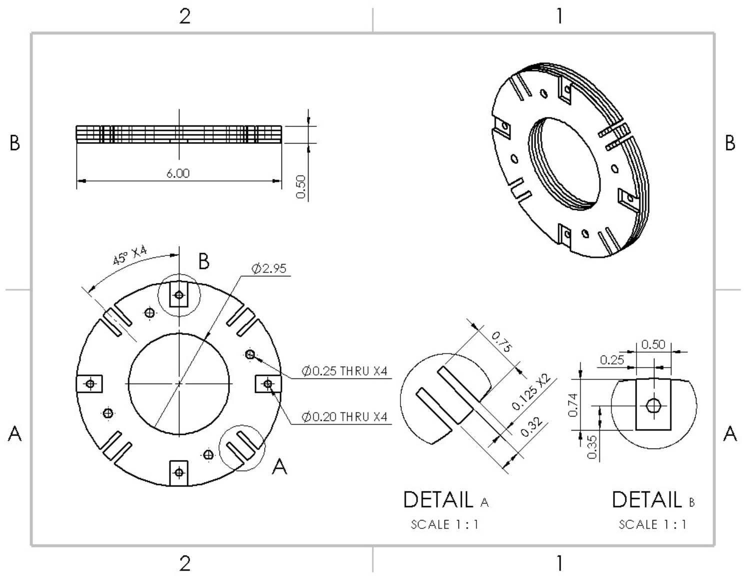

Figure 19: Dimensioned drawing of the removable centering ring.

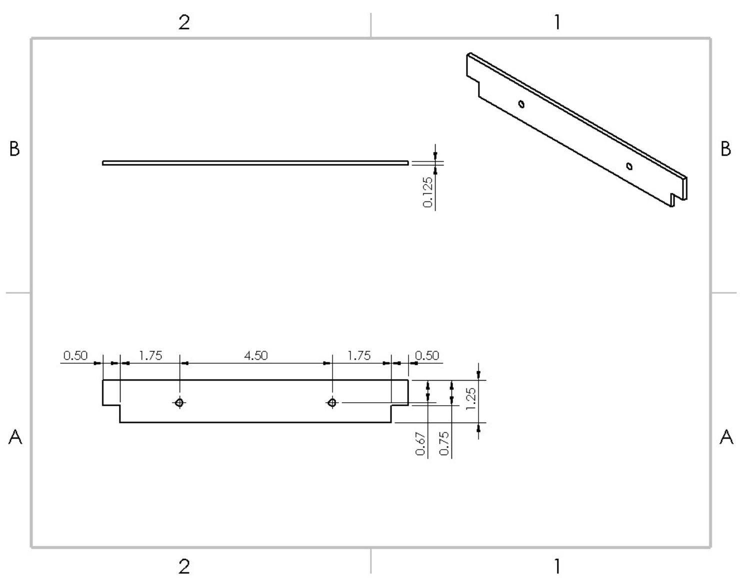

Figure 20: Dimensioned drawing of the runners connecting the centering rings.

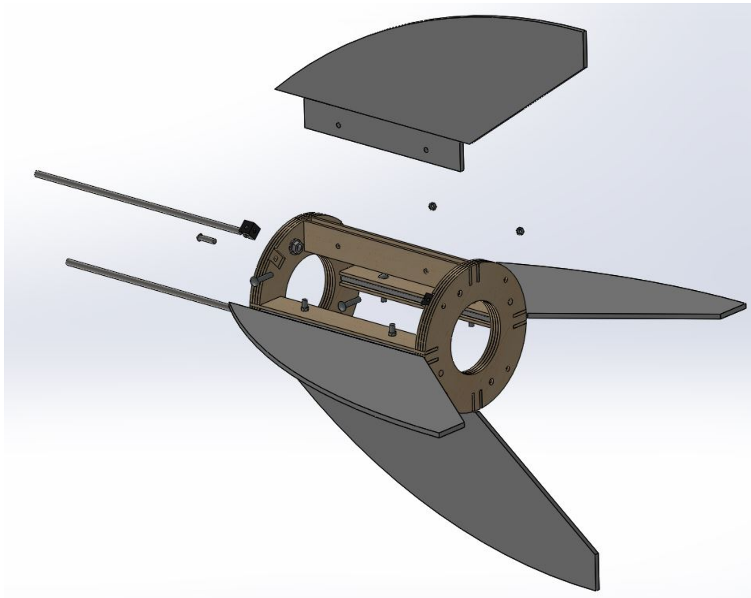

Figure 21: Exploded view of the removable fin system.

The thrust plate is designed to transfer the force of the motor directly to the airframe. This removes any of the force from the centering rings and ensures that the fiberglass airframe bears the full force from the motor. This is beneficial because the fiberglass is the strongest part of the launch vehicle. A section view of the thrust plate design is shown in Fig. (22) below. The thrust plate will be constructed out of a combination of 1 ply of 6061 aluminum and 3 plys of plywood. Both the aluminium and wood plies will be 1/8 in. thick making the total thickness of the thrust plate 1/2 in. The aluminum ply will make direct contact with the airframe. Aluminum was chosen for this ply because it is much stronger than plywood and, unlike plywood, will not compress under the given loads. The plywood plies will then be used to secure a short section of motor tube. All the plies will be held onto the removable fin assembly using the threaded rods as well as four #8-32 machine screws. The entire removable fin assembly will then be secured to the airframe using eight #8-32 machine screws.

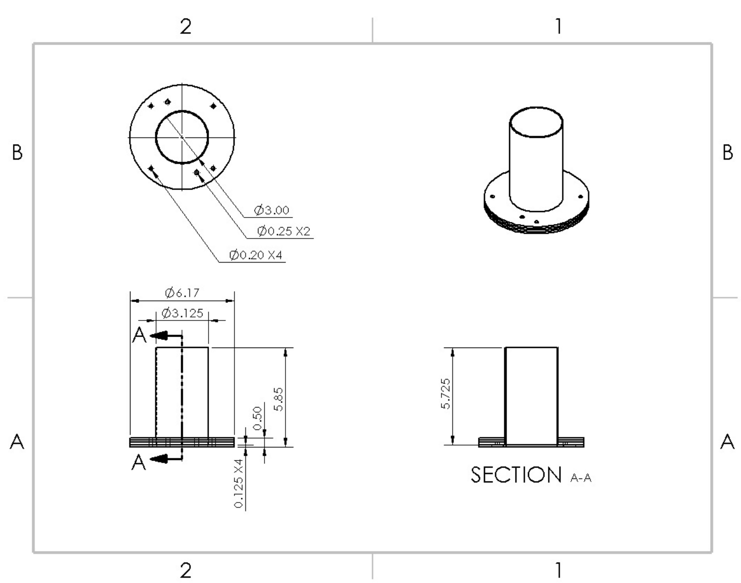

Figure 22: Section view of the thrust plate.

The tail cone will be manufactured using 3D printing with PETG plastic. A dimensioned drawing of the tailcone is shown in Fig. (23) below. PETG was chosen because it has a higher melting point than other 3D printer filaments. The tailcone will then be epoxied onto the outside of the motor retainer, this allows it to be easily removable and does not support structural loads and only acts as aerodynamic improvement. Because of the proximity to the motor, the tail cone will be insulated from the retainer using 1/8 cork insulation. Cork has a low thermal conductivity of 0.04 $\frac{W}{m-K}$ and is also inexpensive, flexible, and easy to cut. This provides insulation that is also easy to manufacture.

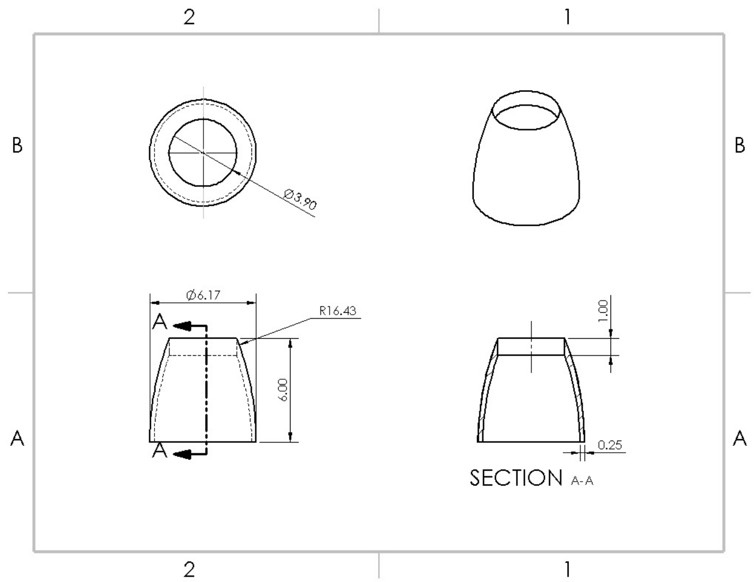

Figure 23: Dimensioned drawing of the 3D printed tailcone.

3.2.8.3 Motor Retention

The motor will be retained using a 75mm Aeropack motor retainer shown in Fig. (24) below. These retainers are commercially available and machined out of aluminum. The body of the retainer will be secured to the motor tube using epoxy. A layer of cork insulation will be epoxied to the outside circumference of the retainer cap. The tailcone will then be epoxied to the layer of insulation. The entire tailcone will then be able to screw onto the motor tube and secure the motor. An exploded view diagram of this system is shown in Fig. (25) below.

Figure 24: 75mm Aeropack retainer [1].

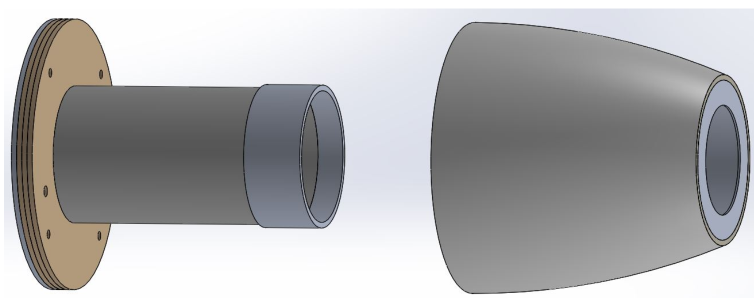

Figure 25: Exploded view of the tailcone and motor retention system.

3.2.9 Finite Element Analysis

Finite element analysis was performed on certain bulkheads in order to verify that they are strong enough to meet to required factor of safety. The maximum principle stresses on each load bearing bulkhead was found using static structural simulations performed in ANSYS Workbench.

All metal components were assigned a material of stainless steel which has a yield stress of 31,200 psi [3]. The material properties of the birch plywood used was not available as a default setting within ANSYS and had to be manually entered. The mechanical properties of aircraft grade birch plywood are shown in Table (6) below [8].

Table 6: Material properties of birch plywood.

Property	Value
Density (lb/ft^3)	39.33
Elastic modulus (psi)	$1.11\text{x}10^6$
Ultimate Compressive Strength (psi)	3307
Ultimate Tensile Strength (psi)	4757
Poisson Ratio	0.3

3.2.9.1 Nose Cone Bulkhead FEA

The nose cone bulkhead is expected to experience 61.12 lb. of force during main parachute deployment. This loading will be applied directly to the U-bolt secured in the center of the bulkhead. Fixed supports were added along the outer surface of the centering ring in order to simulate its position inside the nose cone shoulder. The results of this simulation are shown in Fig. (26) below.

The largest stress concentrations occur around the attachment point of the U-bolt. The maximum and minimum principal stresses occur on the U-bolt and are 2381.8 and -139.72 psi respectively. These stresses are well within the range of values that stainless steel is able to handle. The maximum stress the plywood bulkhead is subjected to is 456.52 psi which gives the bulkhead a factor of safety of 10.4.

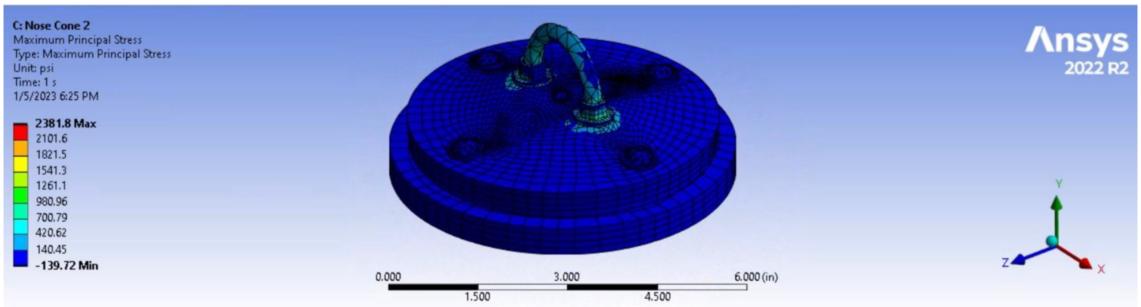

Figure 26: FEA simulation of the nose cone bulkhead assembly.

3.2.9.2 AV Bay and Payload Bay Bulkheads FEA

The attachment points for the recovery hardware at the AV bay and payload bay are identical. Thus, one simulation was conducted to verify the strength of both the AV and payload bay bulkheads. These bulkheads are expected to withstand a parachute deployment force of 177.74 lb. This force was applied directly to the top of the U-bolt. Fixed supports were added at the end of the threaded rods to simulate being held in place by the opposing bulkhead. The results of this simulation are shown in Fig. (27) below.

The largest stress concentrations occur at the U-bolt connection points and around the threaded rods. Based on this simulation, the maximum stress the bulkhead is expected to endure is 1839.6 psi which gives a factor of safety of 2.6.

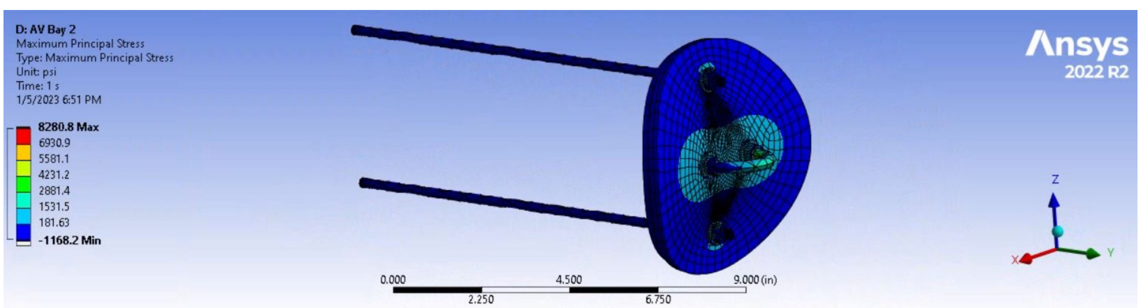

Figure 27: FEA simulation of the payload and AV bulkheads.

3.2.9.3 Removable Fin Assembly FEA

Finite element analysis was performed on the entire removable fins assembly as one unit. The maximum thrust of 396.86 lb. created by the L1520T was applied axially to the end of the motor tube. The bottom edge of the thrust plate was treated as a fixed support because it will be in contact with the airframe. Likewise, compression only supports were applied to the outside surface of each centering ring. The results of this simulation are shown in Figures (28) and (29) below.

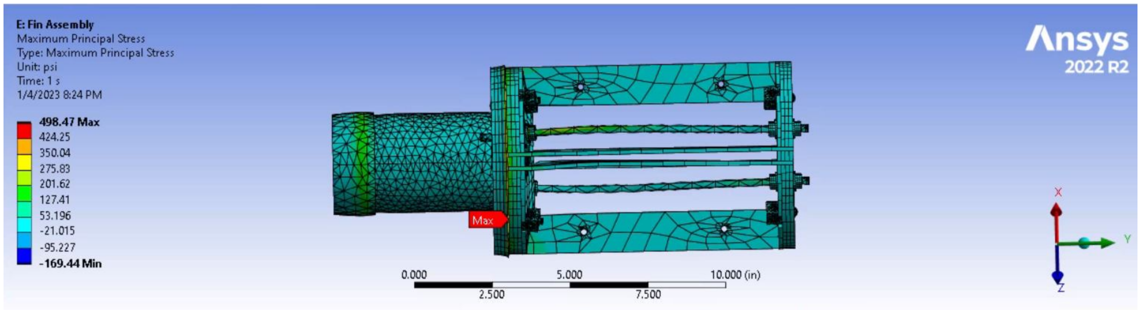

Figure 28: FEA simulation of the entire removable fin assembly.

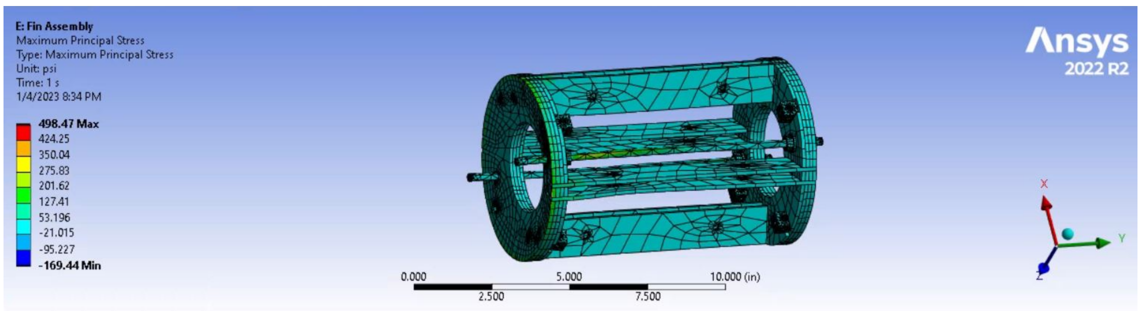

Figure 29: FEA simulation of the centering rings within the removable fin assembly.

The highest stress concentrations occur at the interface between the thrust plate and the airframe. This was expected as the purpose of the thrust plate is to transfer the force of the motor directly to the airframe. Figure (28) shows the maximum and minimum principal stresses as 487.47 psi and -169.44 psi respectively. Both of these stresses occur on the aluminium ply of the thrust plate. The maximum stress any plywood component undergoes is 235.66 psi with most components reaching values much lower than the maximum. Based on this data, the thrust plate and removable centering rings were determined to have factors of safety of 80.2 and 20.2 respectively.

3.2.10 Vehicle Weight Breakdown

The current weight of the launch vehicle is 40.71 lb which includes 0.75 lb of ballast secured inside the nose cone. A detailed breakdown of the weight of each section is shown in Table (7) below. The current estimate of vehicle weight is 2.51 lb. lighter than the estimate obtained during the PDR milestone. The reason for this change is that the expected payload mass decreased by approximately 2 lb. and the nose cone ballast was decreased to adjust the stability margin accordingly. This decrease in weight will affect the apogee of the launch vehicle. In order to adjust the vehicle's apogee additional ballast can be added to both the nose cone and fin can in order to fine tune the final mass of the launch vehicle. Ballast is further discussed in section 3.6.6 later in the document.

Table 7: Weight breakdown of the complete vehicle.

Avionics Bay		Drogue Parachute Bay		Payload bay	
Component	Weight (lb)	Component	Weight (lb)	Component	Weight (lb)
Sled	0.18	Airframe	2.24	Airframe	0.52
Bulkheads	0.8	Drogue Parachute	0.07	Coupler	1.33
Threaded Rods, U-bolts	0.55	Shock Cord	0.45	Payload with Bulkheads	4
Airframe	0.26	Quick Links	0.14	U-Bolt	0.15
Coupler	1.46	Nomex	0.140625	Quick Link	0.07
Total	**3.25**		**3.04**		**6.07**
Nose Cone		**Main Parachute bay**		**Fin Can**	
Component	**Weight (lb)**	**Component**	**Weight (lb)**	**Component**	**Weight (lb)**
Nose Cone	4.6	Airframe	2.64	Airframe	3.3
Coupler	1.2	Main Parachute	1.375	Motor Tube	0.3
Bulkhead	0.34375	Shock Cord	0.45	Fins	0.75
Centering Ring	0.25	Quick Links	0.14	Thrust Plate, Tailcone, and Retainer	0.5
Threaded Rod	0.232	Deployment Bag	0.25	Motor Casing, Propellant	10
Ballast	0.75			Centering Rings	0.625
U Bolt and Quick Links	0.22			Threaded Rods, Misc. Hardware	0.42
Total	**7.60**		**4.86**		**15.90**
Total Vehicle Weight (lb)	**40.71**				

3.2.11 Motor Selection

Aerotech RMS-75/3840 and RMS-75/5120 reloadable motor casings have been purchased previously and support several suitable motor candidates. Due to substantial previous launch experience with no reports of unreliability or failures, the L-1390G and L-1520T are favored over other options. The L-1150R was used on a previous launch vehicle and was found to have unreliable performance characteristics. Reports of other motor failures have also encouraged the use of motors known to the team to be entirely reliable with consistent burns. Simulation using a high-fidelity mass estimation has also generated three potential motor choices; the L-1390G, L-1420R, and L-1520T.

Weather cocking when the launch vehicle leaves the launch rail can be mitigated with a motor that accelerates the vehicle quickly to achieve a higher speed at rail exit. Sharp peaks in a motor's thrust will cause unnecessary loading of the launch vehicle and its contents and motors with smooth consistent burn profiles are preferred. For these reasons, the motor selected will have a high, flat average thrust profile. Additionally, a motor that burns quickly will remove more mass from the aft end of the vehicle and push the stability margin forward when the vehicle leaves the rail.

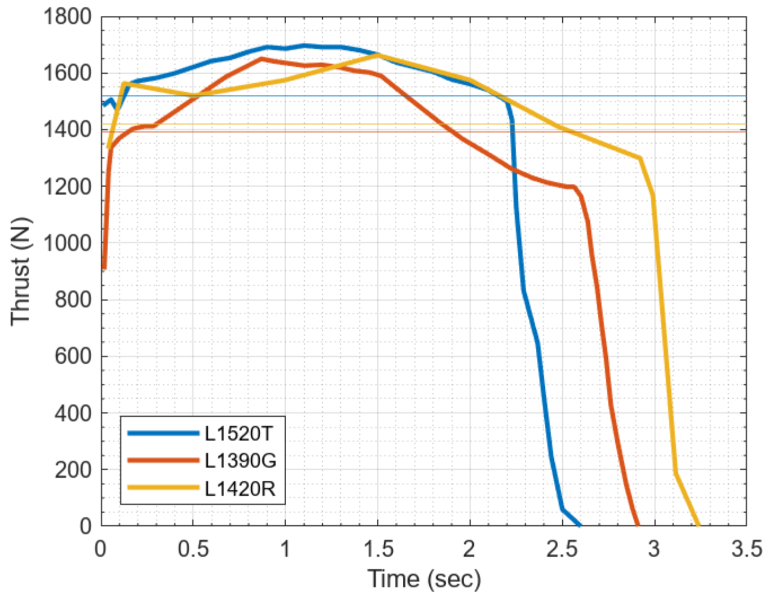

Figure 30: Thrust Profiles of potential motor options.

As shown in Fig. (30) all three potential options have high consistent thrust profiles as desired for the use case. Table (8) shows the weight and performance that the thrust profiles don't show.

Table 8: Potential motor performance characteristics.

Motor	Total Weight (g)	Total Impulse (Ns)	Burn Time (sec)
L-1520T	3651	3716	2.4
L-1390G	3879	3949	2.6
L-1420R	4562	4603	3.2

The L-1420R contains substantially more propellant and therefore more specific impulse. This motor will boost substantially more mass to the target apogee of 4,500 ft than the other motor options and was selected as a preliminary option in the event that vehicle mass increased substantially from initial estimates. As the design has matured the mass has not increased for this motor to be needed and is therefore eliminated from the motor selection.

The L-1520T has a higher average thrust and a quicker burn time giving it an advantage over the L-1390G. The simulations below also show that L-1520T has an apogee close to the target with the current design and mass breakdown.

The Aerotech L-1520T has been selected, due to the reasons above, as the motor to propel the launch vehicle to the target apogee. This motor will provide an initial thrust to weight ratio of 8.35.

3.3 Subscale Flight Results

3.3.1 Design and Flight Predictions

The subscale launch vehicle was designed to be aerodynamically similar to the fullscale vehicle in order to evaluate the stability of the fullscale design. All airframe sections of the vehicle were constructed out of 4 in. diameter blue tube. The overall length and weight of the subscale rocket was 69 in. long and 10.2 lb. Additionally, a test payload was flown on the subscale rocket. This payload consisted of a RAFCO system to receive, interpret, and save APRS signals. After the vehicle had landed, several commands were transmitted to the payload in order to test the ability of a Raspberry Pi to receive commands and ensure that this system would function on the fullscale vehicle. A CAD rendering of the subscale vehicle as well as the as built vehicle is shown in Fig. (31) below. Two RRC3 sport altimeters were used to control the parachute deployment. An 18 in. drogue parachute was deployed at apogee followed by a 48 in. main parachute deployed at 600 ft. The chosen motor for the subscale launch vehicle was an Aerotech J-420R. This motor was selected for its relatively flat and consistent burn which are also characteristics of the L-1520T the fullscale launch vehicle will utilize. The motor thrust curve is shown in Fig (32) below.

Figure 31: CAD rendering and as built subscale launch vehicle.

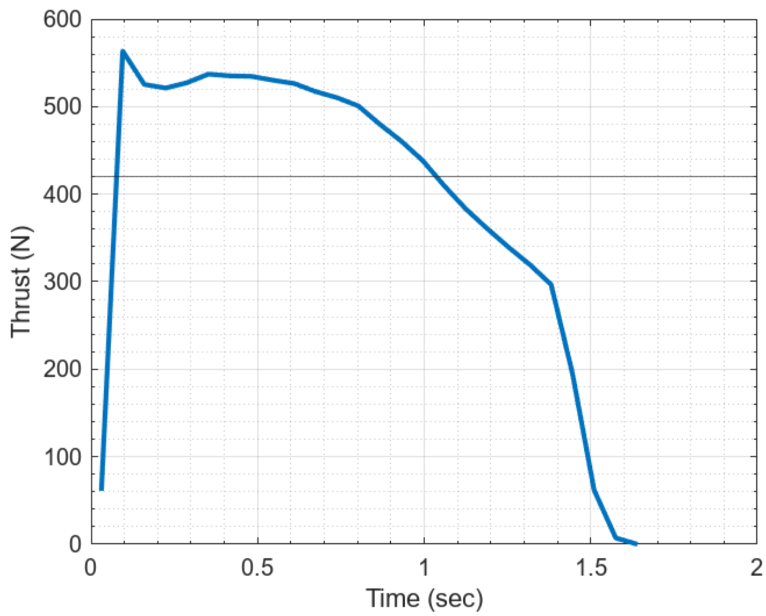

Figure 32: Thrust Curve of an Aerotech J-420R

After the construction of the vehicle, weight measurements were taken in order to verify stability and adjust ballast as needed. Rocksim simulations were then performed based on the measured values and atmospheric conditions at the field. The subscale launch was performed At the team's home launch field in Bayboro, NC on November 19. The wind was low (5-10 mph) with clear skys and a temperature of 53.0 degrees Fahrenheit at the time of launch.

Based on these conditions, the predicted apogee of the subscale launch vehicle was 2,269 ft. A complete graph of the expected flight profile is shown in Fig. (33). Additionally, the stability margin of the vehicle during powered flight and coast was evaluated and is presented in Fig. (34). At rail exit, there is are spikes in the value for center of pressure which in turn causes the values of stability to be affected. These values are likely caused by oscillations in the vehicle at rail exit and were treated as outliers. From this data, it can be seen that the stability margin gradually increases to a value of 2.3 at motor burnout. The averaged drag coefficient of the launch vehicle during the coasting phase of flight is predicted to be 0.55.

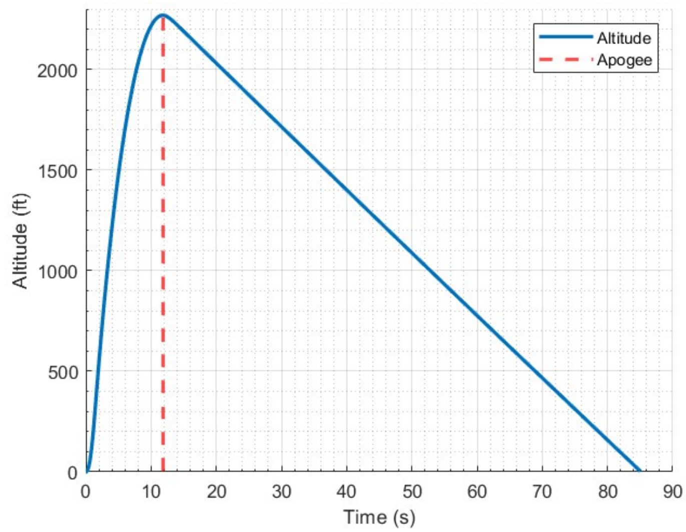

Figure 33: Predicted flight profile of the subscale launch vehicle.

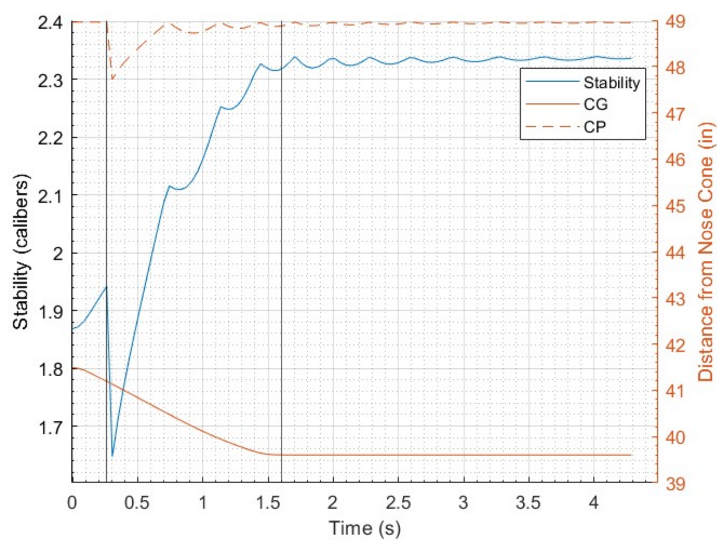

Figure 34: Simulated stability margin of the subscale vehicle.

3.3.2 Flight Results

The subscale launch vehicle reached an apogee of 2116 ft. which differed from the simulation by only 153 ft. A full profile of the altimeter flight data is shown in Fig. (35). This reduction in altitude was likely caused by variations in wind speed and atmospheric conditions above 500 ft. Large gusts of wind would cause disturbances which lower altitude. Additionally, it is possible that there were errors in modeling the drag created by the camera housings in Rocksim which caused a higher apogee to be predicted.

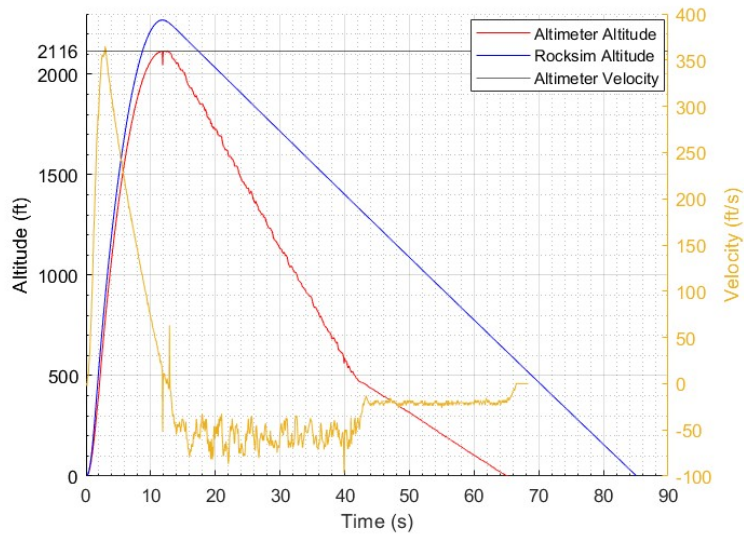

Figure 35: Altimeter data collected during the subscale vehicle flight.

The altimeters on board the launch vehicle are also capable of measuring the velocity of the launch vehicle over the duration of the flight. This data can be used in order to estimate the drag coefficient of the launch vehicle. The drag coefficient is given by:

$$C_d = \frac{2F_d}{\rho u^2 A} \tag{1}$$

Where the drag coefficient, C_D, can be found based on the drag force acting on the launch vehicle, F_d, the air density, ρ, the cross sectional area of the vehicle, A, as well as the velocity, V, as measured by the altimeter. The air density and vehicle cross sectional area are known quantities. The force of drag during the coasting phase of launch vehicle flight can be found by considering the forces acting on the launch vehicle.

$$F_d = -mg - ma \tag{2}$$

The force of drag was found by subtracting the weight of the vehicle by the overall mass times its acceleration. The acceleration of the vehicle was found by differentiating the velocity curve provided by the altimeter. Using this method, the coefficient of drag of the launch vehicle as found to be 0.58. This value is slightly higher than predicted by rocksim. This is likely due to differences in turbulence and skin friction drag which rocksim was unable to account for. Additionally, errors in the way in which the camera housings were modeled in rocksim could have contributed to the difference in the predicted and calculated values.

From analysis of video taken during launch, it was seen that the launch vehicle exhibited very little weather-cocking during the powered stages of flight. Several consecutive frames of a video of the vehicles takeoff are shown in Fig. (36) below. The subscale launch vehicle remained very close to vertical during powered ascent and exhibited very little yaw or rolling motion. This is beneficial to the flight as weathercocking is known to greatly reduce the apogee of high-power launch vehicles. Finally, the stability margin measured on the launch field was 1.92 which increased to above 2 at motor burnout. The differences in simulated and actual stability is likely due to different parachute and recovery hardware weights. Rocksim simulates parachute weights as discrete components with fixed volume and shape. In reality, the packed parachute and shock cords will have slightly different volumes and weight distributions which could have caused slight changes to the CG and shift the stability margin.

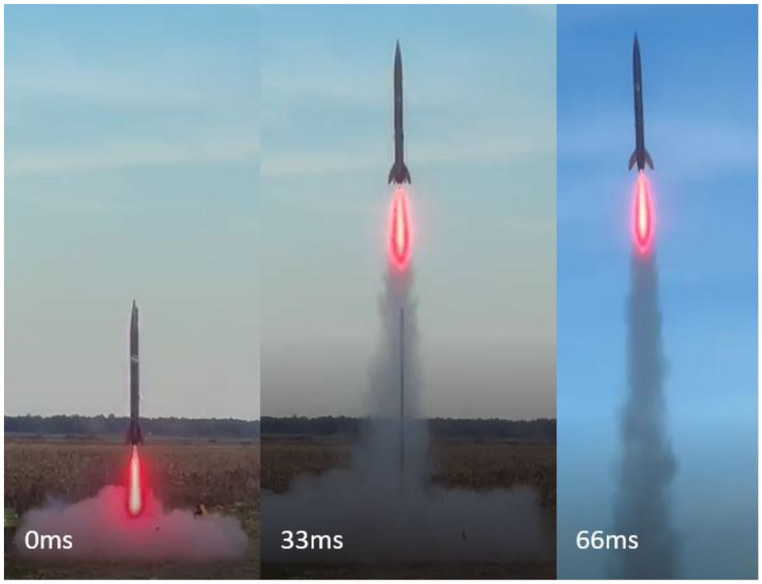

Figure 36: Several frames of video from the subscale launch vehicle takeoff.

The subscale recovery system functioned nominally. The drogue parachute successfully deployed at apogee and the launch vehicle descended at 56.8 ft/s. At 600 ft. AGL the primary ejection charges fired and the main parachute fully deployed and the launch vehicle descended to the ground at 21.1 ft/s. The launch vehicle sustained no damage during landing. Figure (37) shows each section of the launch vehicle as it landed. No parachutes or shock cords were tangled on deployment. Based on the vehicle success criteria described above, the subscale vehicle flight would be classified as a complete success.

Figure 37: Landing configuration of each independent section of the launch vehicle.

3.3.3 Scaling Factors

A scaling factor of 2/3 was implemented on the subscale launch vehicle. Launch vehicle length and diameter were the primary factors considered in determining this factor. These parameters were chosen because the length and cross sectional area are commonly used in order to determine aerodynamic coefficients. Likewise, it was important to properly scale the fin span and root chord in order to ensure that the subscale is aerodynamically similar. Blue tube is commercially available in 4in. diameter making this scaling factor easy to apply. All other airframe dimensions were multiplied by the scaling factor in order to reach the desired overall length. Bulkhead thickness was not scaled according to the chosen scaling factor. This is because the thickness of the bulkheads were determined based on the forces they were expected to withstand. A table of all measurements used to determine the scaling factor is shown in Table (9) below.

Table 9: Scaling factors used in subscale design.

Parameter	Fullscale Value	Subscale Value	Scaling Factor
Length (in)	104.5	69.0	66.0%
Diameter (in)	6.17	4.0	64.8%
CP (in)	74.9	49.0	65.4%
CG (in)	61.2	41.3	67.5%
Fin Root Chord (in)	10.0	6.0	60.0%
Fin Span (in)	6.0	4.0	66.7%
Stability (cal)	2.10	1.92	–

3.3.4 Subscale Influence on Fullscale Design

The removable fin system performed nominally. All the fins were securely held in place during flight and landing. No damage was sustained to either the centering rings or runners. Upon post flight inspection, no damage was noted to any components. The design was able to sufficiently withstand the forces of flight which verifies that this design is appropriate for use on the fullscale vehicle.

The composite fins were able to reduce the weight of the fins by 33% as compared to the plywood alternative. The fins showed slight damage on the leading edge which was likely caused by impact with the ground during descent. An image of this damage is shown in Fig. (38). This damage is only minor dents and scratches. No cracks or delaminations were noted which would prevent the vehicle from flying again. Furthermore, the fiberglass fins were able to bend considerably. Because of these considerations, the team's Tripoli mentors suggested the use of carbon fiber for the fullscale fins. Carbon fiber will provide an increase in strength and resistance to bending. The fullscale fins will be subjected to greater moments due to the increased size. Thus, the increased strength of carbon fiber is desired. Aerodynamically, the size and shape of the fins proved to be adequate. The vehicle exhibited and exceptionally stable flight with minimal weathercocking. Thus, no changes to fin shape are necessary.

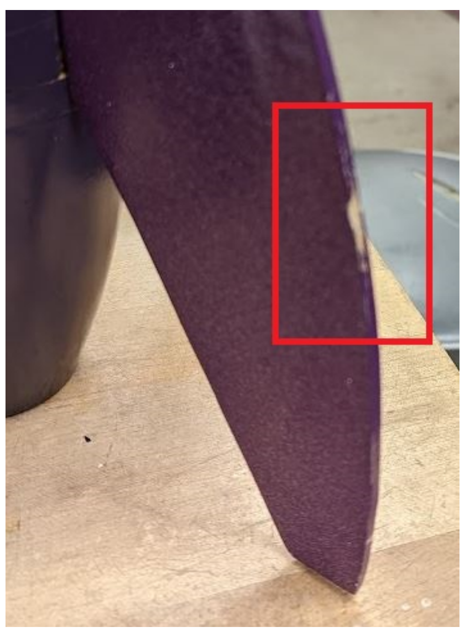

Figure 38: Damage on the leading edge of the fin sustained during landing.

The tail cone was successfully 3D printed out of PETG plastic. The Ogive shape did not show any distortion or difficulty printing showing that the manufacturing of the fullscale tailcone with this method is feasible. One concern the team had with the subscale design was the thermal insulation of the tail cone. A single layer of cork insulation was used in order to insulate the tailcone from the heat of the motor retainer. On inspection post-flight, no evidence of warping or melting was observed showing that the thermal insulation was adequate.

The subscale payload electronics were not damaged by the flight. Upon landing several commands were successfully sent to the payload. However, due to an error in the code, any recorded data was lost when the Raspberry Pi was turned off. Several changes will be made to the fullscale payload based on these resluts. First, better antennas must be constructed to ensure the SWR and other performance values are optimal. Additionally, some cables located in the fin can were secured with hot glue connections. Due to the heat of the motor and vibrations of launch, these connections were loosened. Better cables have been purchased for the full scale payload which will prevent these issues from re-occurring. Finally, the terminal blocks will be removed from the relay which will aid in creating orderly wiring within the payload.

3.4 Construction Methods

3.4.1 Airframe and Coupler Cutting

The team has access to a machine shop within the Mechanical and Aerospace Engineering Department. Airframe will be measured and marked in the team's lab and then delivered to the machine shop where it will be cut using a drop band saw to be operated by the machine shop's personnel.

3.4.2 Bonding Airframe and Coupler Sections

After airframe and coupler sections have been cut, sections will need to be joined. The tubes will be cut by the procedure detailed in section 3.4.1. After cutting the location where the tubes must be joined should be marked along the entire circumference of the coupler. The following procedure will be followed to join airframe and coupler sections:

1. Mark the location which the tubes must be bonded on the coupler section.
2. Clean the bonding surface of each piece using isopropyl alcohol in order to remove and contaminants.
3. Lightly sand the area of each surface that is to be bonded.
4. Clean the freshly sanded surface with isopropyl alcohol to remove any dust.
5. Apply a thin layer of epoxy over the area that is to be bonded.
6. Slide the airframe material over the coupler until it reaches the desired location, rotating the airframe slightly to ensure epoxy is evenly spread over the surface.
7. Apply tape or a clamp to hold the airframe in place and let dry for 24 hr.

3.4.3 Bulkhead Fabrication

All bulkheads will be fabricated by laminating layers of 1/8 in. aircraft grade plywood purchased from Aircraft Spruce. The diameter and hole locations for each bulkhead will vary, however, each one will contain two ¼ in. holes to insert alignment dowels during the layup process. These dowels will ensure that the layers do no shift during the manufacturing process. The shape of each ply will be cut out of a larger sheet using a laser cutter. Then the plies will be laminated using the following procedure:

1. Sand the surface of each ply to promote bonding.
2. Cut ¼ in. dowels to match the thickness of the bulkhead.
3. Apply a thin layer of epoxy to the surface of the bottom ply and place it on the work surface.
4. Place the dowels through the alignment holes in the bottom ply.
5. Spread a thin layer of epoxy on the bottom of the next ply.

6. Place the next ply on top of the previous one.
7. Repeat until all plies of the bulkhead have been assembled.
8. Wrap the assembled bulkhead in peel ply.
9. Place the bulkhead in a vacuum bag and maintain a vacuum for 24 hr.
10. Place weights on top of the bulkhead to ensure the layers are pressed together and the assembly remains flat.

3.4.4 Fin Fabrication

The fins of the launch vehicle will be fabricated using 1/8 in. balsa wood sheets purchased from amazon, West Systems 105 epoxy with 206 slow hardener purchased from West Systems, and 2 $\frac{oz}{yd^2}$ fiberglass and 3000K plain weave carbon fiber fabric purchased from Fiberglast. Before beginning construction of composite fins ensure all team members present are wearing appropriate PPE. First the profile of the fins will be cut out of the balsa wood sheets and the fiberglass and carbon fiber will be cut into rectangles larger than the fin shape. Next a layup will be performed based on the following procedure:

1. Place the balsa wood core on the work surface and spread a layer of epoxy over the surface.
2. Lay a sheet of carbon fiber over the core and wet the fabric using more epoxy if necessary.
3. Spread an additional thin layer of epoxy over the first carbon fiber sheet.
4. Place a second sheet of carbon fiber onto the layup and wet the fabric, using additional epoxy if necessary.
5. Place a sheet of fiberglass over the layup and wet the fabric using additional epoxy if necessary.
6. Flip the fin over on the work surface.
7. Repeat steps 2-5 for the second side of the fin.
8. Place the fin in a vacuum bag and maintain under vacuum for at least 24 hr.
9. Add weights on top of the layup to ensure the work piece remains flat as necessary.
10. After 24 hr. remove the fin from the vacuum bad and trim the excess material from the edges.

3.4.5 Nose Cone With Removable Bulkhead

The current nose cone with bulkhead design is complete and ready to manufacture. The 5:1 tangent ogive is commonly stocked in most online stores and will be constructed out of fiberglass with an anodized aluminum tip. After purchase of the nose cone, a permanent centering ring and removable bulkhead will be attached to the aft end of the nose cone using the following procedure:

1. Bulkhead is assembled as per the bulkhead fabrication process seen in section 3.4.3.
2. The centering ring is fabricated to 1/2 in. thickness and have a 3 in. hole in the center.
3. Epoxy four 1/4-20 T-nuts to the forward face of the centering ring.
4. Epoxy the centering ring into the forward end of the nose cone shoulder.
5. epoxy the nose cone shoulder into the nose cone using the procedure described in section 3.4.2 above
6. Mount U-bolt into center of bulkhead and secure using 1/4-20 hex nuts.
7. Secure bulkhead to the centering ring in the nose cone shoulder using four 1/4-20 bolts.

3.4.6 Avionics Bay

The avionics bay is designed to endure high loads during launch and recovery of the launch vehicle. U-bolts will be attached to bulkheads on each end of the avionics bay with threaded rods running along the length of the avionics bay to bear the loads. The avionics bay will be constructed using the following procedure:

1. Cut an 11 in. long coupler section and a 2 in. long airframe section using the methods detailed in section 3.4.1.
2. Drill four equidistant holes in the forward and aft sections of the coupler for nylon rivets and shear pins.
3. Assemble two bulkheads as per the bulkhead fabrication process seen in section 3.4.3.
4. Secure the airframe section 3 in. from the forward end of the coupler using the procedure described in section 3.4.2.
5. Secure a U-bolt to each bulkhead using 1/4 in. hex nuts.
6. Secure two blast caps to each bulkhead via screws.
7. Secure threaded rods to one bulkhead using four 1/4-20 nuts. Two on either side of the bulkhead.
8. Slot fully constructed avionics sled onto the threaded rods.
9. Slot the threaded rods and AV sled through the airframe section.
10. Secure second bulkhead on the opposite end of the avionics bay using two 1/4 in. nuts.

3.4.7 Payload Bay

The payload bay will be constructed in a similar manner to the avionics bay. It is designed to house all of the payload electronics and will accommodate four cupolas and camera systems. Four 1/4 in. nylon rivets will be used to connect the payload bay with the drogue bay and the fin can. The payload bay will be constructed using the following procedure:

1. Cut a 10 in. long coupler section and a 4 in. long airframe section using the methods detailed in section 3.4.1.
2. Drill four 1/4 in. equidistant holes in the forward and aft sections of the coupler for nylon rivets.
3. Epoxy the 4 in. long band of airframe material in the center of the coupler following the procedure detailed in section 3.4.2.
4. Cut four equidistant teardrop-shaped holes in the airframe band with the rounded edge facing the forward end of the coupler.
5. Assemble two bulkheads as per the bulkhead fabrication process seen in section 3.4.3.
6. Secure a U-bolt to the forwards bulkhead.
7. Insert the two 1/4 in. threaded rods into the forward bulkhead and secure using nuts.
8. Slot fully constructed payload sled onto the threaded rods and ensure each camera unit is able to extend fully outside of the airframe through the teardrop-shaped holes.
9. Secure second bulkhead on the opposite end of the payload bay using two 1/4 in. T-nuts.

3.4.8 Fin Can

The fin can is designed to hold the motor, fins, and removable fin assembly. The fin can will be secured to the payload bay using four 1/4 in. nylon rivets and the removable fin assembly is held in the airframe using eight #8-32 machine screws. The fin can will be constructed using the following procedure:

1. Cut a 25 in. long airframe section using the methods detailed in section 3.4.1.
2. Drill four 1/4 in. equidistant holes in the forward section of the airframe for nylon rivets.
3. Cut four equidistant 1/4 x 8.5 in. long slots in the aft end of the fin can.
4. Drill eight # 8 diameter holes between the slots.
5. Drill two holes 180 °apart in the forward end of the airframe for the antennas.

6. Construct four composite fins using the methods in section 3.4.4.
7. Fabricate two centering rings with 1/2 in. thickness and a 3 in. diameter hole in the center following the procedure from section 3.4.3.
8. fabricate the wooden portion of the thrust plate using the methods described in section 3.4.3.
9. fabricate the aluminum thrust plate using a water jet cutter.
10. Cut eight runners our of 1/8 thick aircraft grade birch plywood.
11. Epoxy a plywood runner to the slots in each centering ring and secure the assembly until the epoxy fully dries.
12. Run the two 1/4-20 threaded rods through the 1/4 in. holes in the centering rings and secure with nuts.
13. Secure each composite fin to each pair of runners via a #8-32 bolts and hex nuts.
14. Cut a 5.725 in. long section of motor tube using the methods detailed in section 3.4.1.
15. Epoxy the motor tube to the wooden portion of the thrust plate.
16. Epoxy the body of the motor retainer to the aft end of the motor tube.
17. Slot the epoxied thrust plate and airframe assembly to the threaded rods, making sure the thrust plate contacts the aft centering ring.
18. Secure the thrust plate to the fin assembly via two 1/4 in. hex nuts.
19. Insert the removable fin assembly into the slots in the fin can.
20. Secure the removable fin assembly using eight #8-32 bolts.
21. 3D print the tailcone using PETG filament.
22. cut a strip of cork insulation long enough to run around the circumference of the motor retainer.
23. epoxy the 3D printed tailcone and the cork insulation to the outside of the motor retainer.
24. Screw on the tailcone to the thrust plate assembly.

3.5 Recovery Subsystem

3.5.1 Final Recovery Subsystem Design

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 avionics sled is described in more detail in section 3.5.1.1. The electronic components will be bolted to the avionics sled utilizing 4-40 screws for the two altimeters and the tracking system, and M3 screws for the two pin switches. Batteries will secured to the sled using electrical tape and further reinforced with zip ties. 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 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 ematch is threaded from each blast cap to a terminal block, which in turn is connected to a wire that is threaded through the corresponding bulkhead and connected to the correct altimeter. 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 the outside of each bulkhead and a Kevlar shock cord is attached to this U-bolt via a stainless steel quicklink. The shock cord connected to the aft AV bay bulkhead will be connected to the dogue parachute via another steel quicklink, and finally tethered to a U-bolt on the forward payload bay bulkhead via another quicklink. The shock cord connected to the forward AV bay bulkhead will likewise be connected to the main parachute via a quicklink and to a U-bolt on the nose cone bulkhead via a quicklink.

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 will be 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.

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 an 18 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 in 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 in 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 RX 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.

A diagram showing the full recovery overview is shown below.

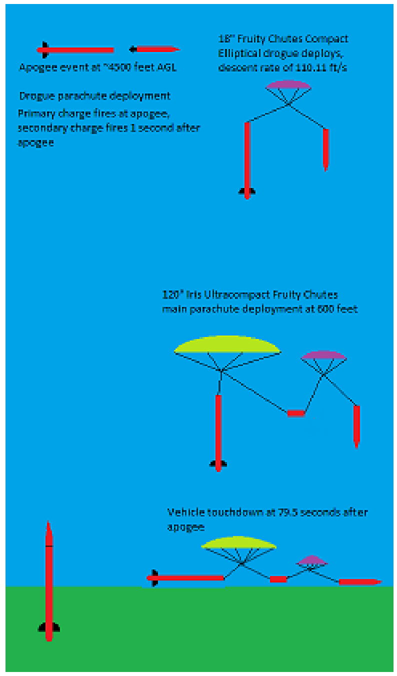

Figure 39: Recovery Overview

3.5.1.1 Avionics Sled

All recovery electronics will be held within the vehicle on the avionics sled. A SolidWorks 3D rendering of the AV sled is shown in Fig. (40 below. The sled will be rectangular in shape and 8.5 by 5 in. On one side of the sled, recovery electronics will be mounted using either 4-40 or M3 circuit board standoffs. The other side of the sled will have 3 battery compartments as well as two tubes which will allow the sled to slide onto the threaded rods which run the length of the AV bay. The avionics sled will be fabricated using an Ender Pro 3 3D printer in the club's lab. It will be fabricated with PETG 3D printing filament, which is strong enough to withstand all forces experienced by the launch vehicle during flight. 3D printing was chosen as the method of fabrication as it is simpler than manufacturing a wooden AV sled. Additionally, PETG filament was chosen over other alternatives because it tends to have higher strength.

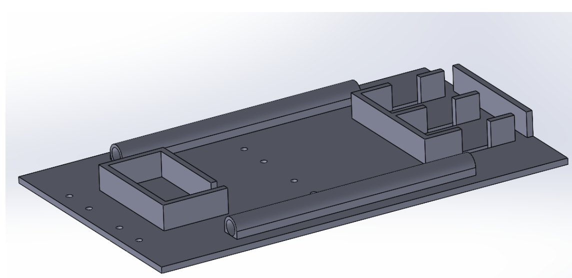

Figure 40: Fullscale AV Sled SolidWorks Render

The AV sled will be 3D printed as a single part in order to simplify its construction. Holes for mounting altimeters as well as battery compartments will be printed into the design of the sled in order to avoid the need for post processing. However, holes for the pull-pin switches and Eggfinder GPS transmitter will be drilled after the sled has been printed. This is to allow the exact location of these holes to be changed in order to align the switches with the external holes in the airframe of the AV bay. The complete flow diagram of all recovery electronics, including redundancy and separation of systems, is shown in Fig. (41) below.

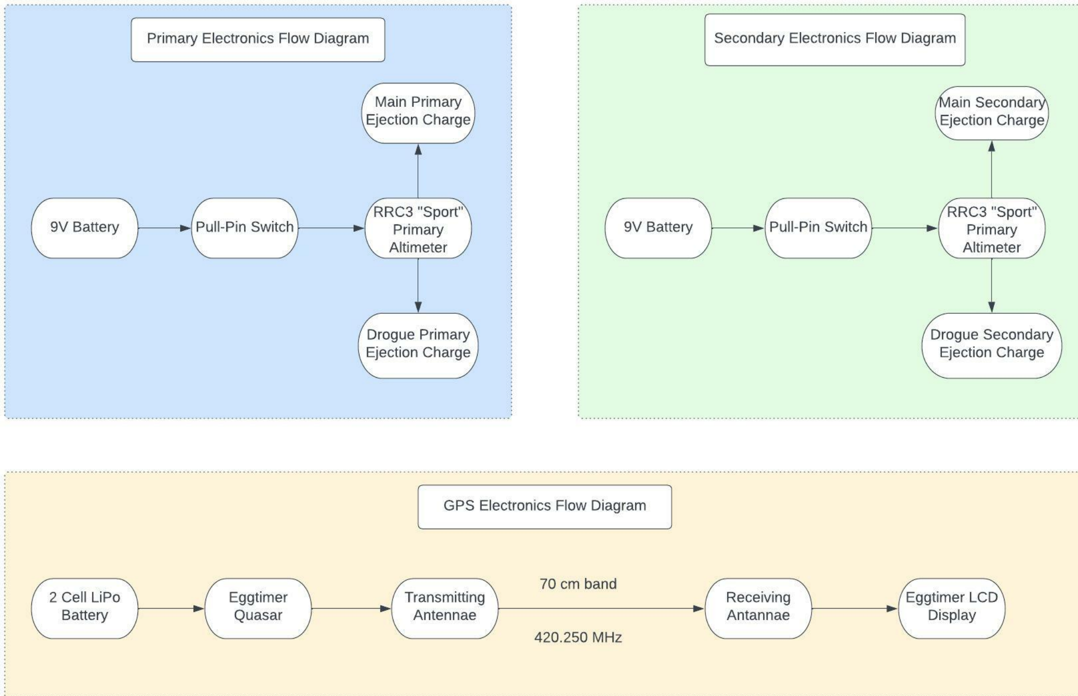

Figure 41: Flow Diagram of all Recovery Electronic Systems and their Components

3.5.1.2 Altimeter System

The two onboard altimeters that will be utilized during the competition launch are two RRC3 ”Sport” Altimeters. These two altimeters will control all the recovery events occurring during launch vehicle flight. Each altimeter can be individually programmed to act as either a primary or secondary altimeter, and can control both main and drogue charges at the same time. Therefore, one altimeter will act as the primary and will be connected to one primary drogue ejection charge and one primary main ejection charge, while the second altimeter will be connected to one secondary drogue ejection charge and one secondary main ejection charge. Because the altimeters communicate information in short beeps, the secondary altimeter will be set to make a much higher pitched beep than the primary altimeter to avoid confusion. The primary altimeter will be used for the purpose of reporting competition altitude.

The RRC3 altimeter was chosen as the onboard altimeter because of its previously tested reliability, accuracy, precision, and easy 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.

3.5.1.2.1 Altimeter Arming

Pull-pin switches will be used to arm and disarm the altimeters. Pull pin switches were chosen over other switches due to their ease of use as well as their proven success aboard this year’s subscale launch vehicle. The assembly of the avionics bay will involve activating the altimeters by plugging in the batteries and removing the pins while no ejection charges are connected. The avionics sled can then be correctly positioned inside the bay, and the pin is subsequently replaced to break the connection to the altimeters. Only then will the ejection charges be connected. The pins will not be removed until the launch vehicle is upright on the launchpad after all pre-launch checks are complete.

Pull-pin switches were chosen for the altimeter arming method as they provide much more consistency than any alternative. A ”Remove Before Flight” tag will be attached to the end of each pin to make the location of the pin even more clear, and to make removal much easier.

3.5.1.3 Tracking System

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. 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 transmit 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.

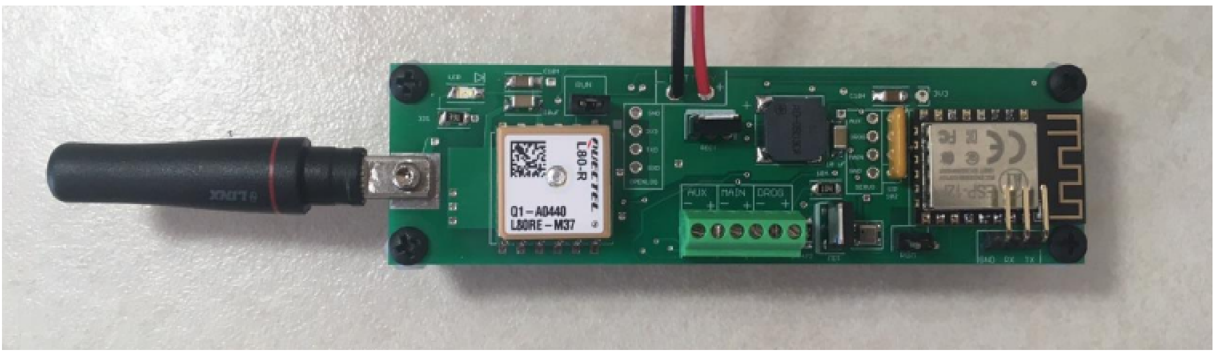

Figure 42: Eggtimer Quasar

The Quasar comes as an unassembled kit. It will be correctly assembled and tested in our lab prior to the first launch.

3.5.1.4 Parachute

The drogue parachute selected for this year's competition launch is an 18 in. Fruity Chutes classic elliptical parachute. This parachute will be deployed at apogee by the primary drogue ejection charge, and the launch vehicle will descend using only this parachute until it reaches 600 ft. above ground level. The burnout weight of the launch vehicle is expected to be 36.38 lb., and using this drogue parachute the descent velocity is expected to be 110.1 ft/s, under the team derived maximum limit of 120 ft/s. Once the launch vehicle reaches 600 ft. above ground level, the main parachute will be deployed with the primary main ejection charge. The main parachute selected for this year's competition launch is a 120 in. Fruity Chute Iris Ultracompact parachute. This parachute was selected because it is the only chute commercially available that fits the wind drift distance, impact kinetic energy, and descent time requirements required to achieve the bonus points in the recovery section. The overall wind drift distance under both drogue and main parachute is expected to be 2332 ft. under maximum wind conditions of 20 mph, the impact kinetic energy is expected to be 55.69 ft-lbs, and the total descent time of the launch vehicle is expected to be 79.5 seconds.

Since there is no payload ejection from the launch vehicle, there are no more parachutes necessary to provide safe descent for this launch vehicle.

3.5.1.5 Shock Cord and Attachment Point Selection

The shock cords used in this year's competition launch vehicle are two 40 ft. long 5/8 in. tubular Kevlar shock cords. Kevlar shock cords were chosen because they are much stronger than nylon alternatives while also being resistant to tears and abrasion. A diagram of the complete shock cord and parachute arrangement is shown in Fig. (43) below. After the first recovery event at apogee, the launch vehicle will separate into two sections, with a separation point between the avionics bay and the drogue parachute bay. The shock cord will attach to the parachute approximately 6 ft. from one end of the cord, using a bowline knot to secure the parachute in place and to ensure the selected attachment point does not move or adjust. The shorter end of the shock cord will attach to a U-bolt on the aft end of the avionics bay, and the longer end will attach to a U-bolt on the forward end of the payload bay. This arrangement will allow the launch vehicle to descent under the drogue parachute separated into these two sections without the two sections clashing with each other on descent as there will be approximately six feet of vertical separation between the two sections on descent. Additionally, this configuration puts the main parachute bay above the fin can to ensure that the main parachute does not get tangles in the fin can upon deployment.

After the second recovery event at 600 ft. above ground level, the section containing the avionics bay, the main parachute bay, and the nose cone will separate into two sections between the main parachute bay and the nose cone. The main parachute will be attached to another 40 ft. long shock cord. The main parachute will be secured 8 ft. from one end using a bowline knot. The shorter end of the shock cord will attach to a U-bolt on the nose cone bulkhead, and the other end of the shock cord will attach to a U-bolt on the forward end of the avionics bay. This arrangement will allow the launch vehicle to descend under main parachute with all sections separated by at least 5 feet to avoid clashing during descent.

During flight the launch vehicle will be held together at the separation points by four 4-40 nylon shear pins at each separation point. Each shear pin is rated for 2.5 psi of force, which has been experimentally verified by our team. This is enough to hold the launch vehicle together while it experiences any forces during flight that are not related to the recovery events, while being weak enough to shear to separate the launch vehicle into the desired sections during the recovery events.

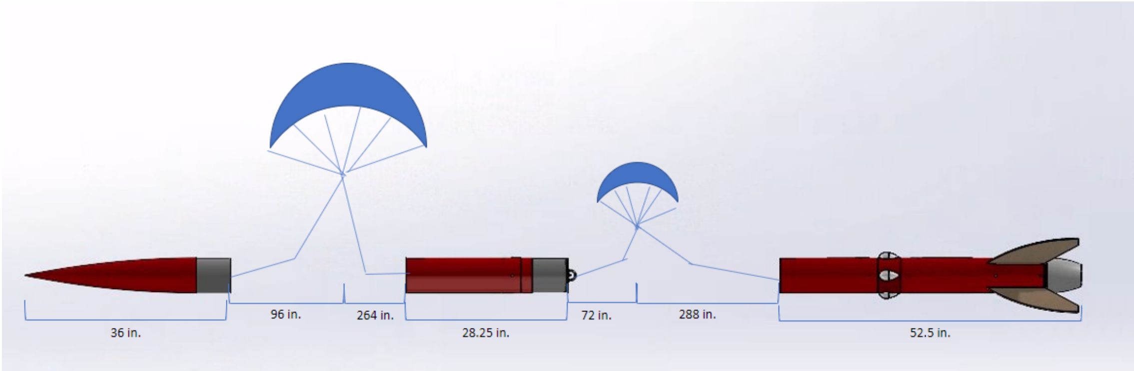

Figure 43: Parachute attachment locations

3.5.1.6 Ejection Charges

The ejection charges necessary to separate the launch vehicle during the recovery events have been selected to be 777 grade FFF black powder. This grade of black powder was chosen because the fineness of the grain leads to a quicker combustion than larger grain sizes. In turn, this creates a more rapid pressurization of the bay and a cleaner separation event. Two primary and two redundant secondary charges will be housed in PVC blast caps on the outer surface of the avionics bay bulkheads.

The required mass for the ejection charges is determined by the volume of the bay the charge is pressurizing as well as the magnitude of the pressure required to separate the vehicle. The volume of the bay is determined by taking the empty space within the bay and subtracting the volume of the parachute and other recovery hardware. The shear pins used on the vehicle are rated for 2.5 psi. Thus, a pressure of at least 10 psi is required to to separate the vehicle. Due to the presence of friction as well as variation in the shear pins, a factor of safety of 2 is applied to the ejection charge pressure, making the required pressure to perform recovery events 20 psi.

To ensure that separation occurs, the mass of the secondary ejection charge will be increased by .5 grams from the primary charge. Detailed calculations of ejection charge sizing are performed in section 3.6.10. 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.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Altitude

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

3.6.2 Updated Flight Profile Simulations

Fig. (44) shows the results of a RockSim launch simulation of the latest design using the launch conditions given in Table (10). 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. (45) below. The launch vehicle reaches its maximum velocity shortly after motor burnout. The maximum acceleration experienced by the vehicle is during main parachute deployment. Descent rates under drogue and main parachutes are also able to be calculated from this data and are approximately 150 and 20 ft/s respectively.

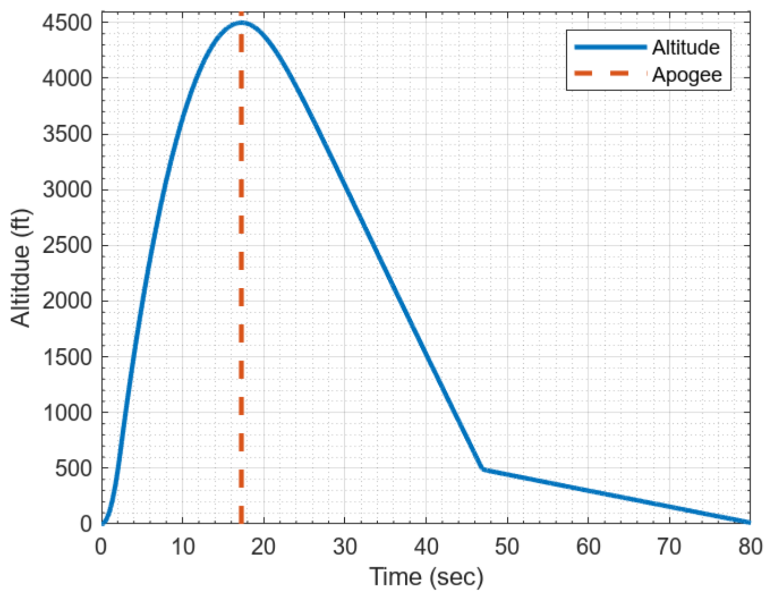

Figure 44: Predicted flight profile of the fullscale launch vehicle.

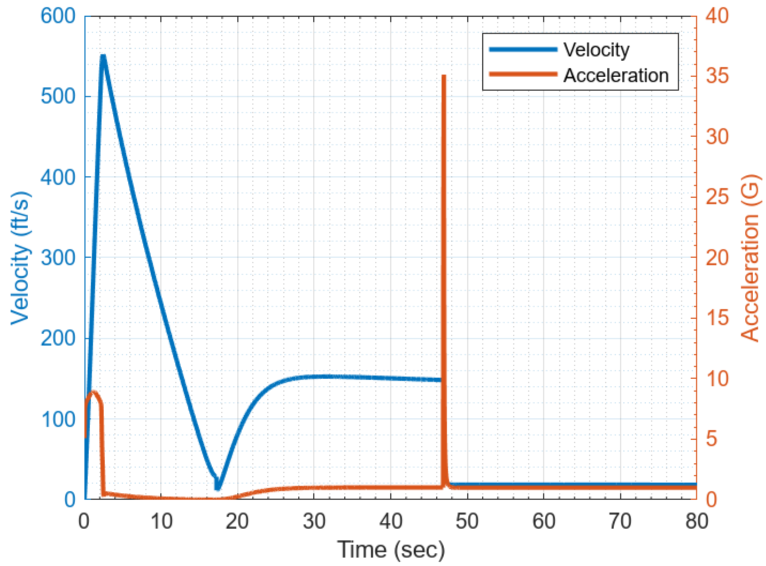

Figure 45: Predicted flight velocity and acceleration.

Table 10: 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. It is important that the launch vehicle can reach the target apogee in both low and high wind conditions. in order 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.

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 (11) contains necessary values for the hand calculations and were taken from the geometry of the launch vehicle, L1520T motor reference [2] data and standard environmental constants.

Table 11: Values used to algebraically solve for apogee

Quantity	Variable	Value	Units
Mass	M	18.5	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	0.2469	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.

$$k = \frac{1}{2}\rho C_D A = 0.002928\frac{kg}{m} \tag{3}$$

$$q = \sqrt{\frac{T - Mg}{k}} = 685.3\frac{m^2}{s^2} \tag{4}$$

$$x = \frac{2kq}{M} = 0.2047\frac{m}{s^2} \tag{5}$$

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

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} = 165.1\frac{m}{s} \tag{6}$$

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

$$h_{boost} = -\frac{M}{2k}\ln\frac{T - Mg - kv^2}{T - Mg} = 200m \tag{7}$$

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).

$$h_{coast} = \frac{M}{2k}\ln\frac{Mg + kv^2}{Mg} = 1161m \tag{8}$$

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

$$h_{total} = h_{boost} + h_{coast} = 1361m \rightarrow 4455ft \tag{9}$$

This apogee is then compared to the altitude given by RockSim. These two calculation methods are strikingly similar despite the variety of factors influencing the RockSim's analysis. The 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 12: Apogee comparison between RockSim and hand calculations.

Method	Result	Comparison
RockSim	4500	$\%_{diff} = 1.005\%$
Algebraic	4455	

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. (46) below.

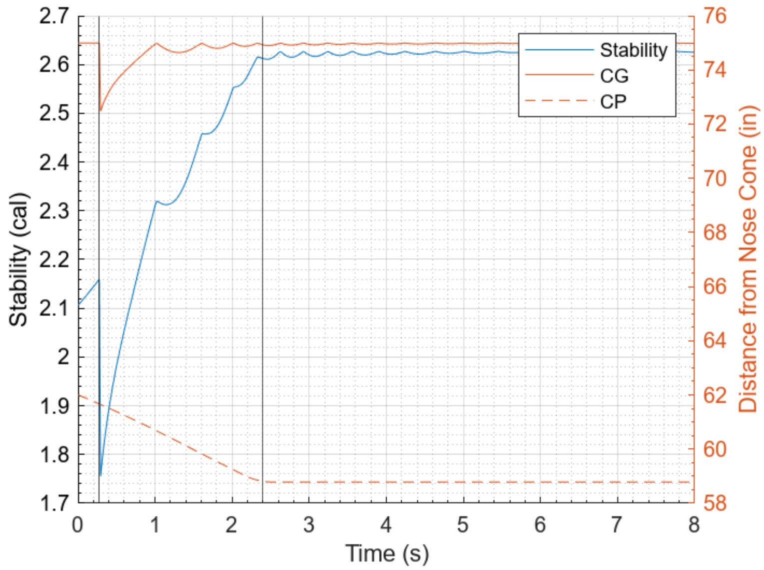

Figure 46: Simulated stability margin of the fullscale vehicle.

With the current design, the launch vehicle has the following stability during the flight milestones as shown in Table (13) below. The vertical black lines in Fig. (46) 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.

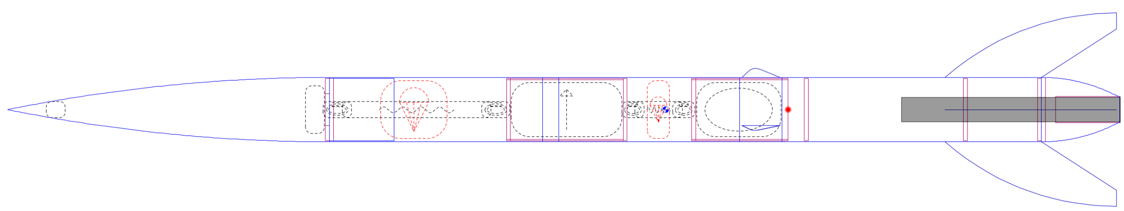

Figure 47: Full Vehicle Diagram with CG and CP labeled.

Fig 47 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 13: 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 [7].

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. (48). 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 (14) contains the variable names and values used for the stability calculations detailed below.

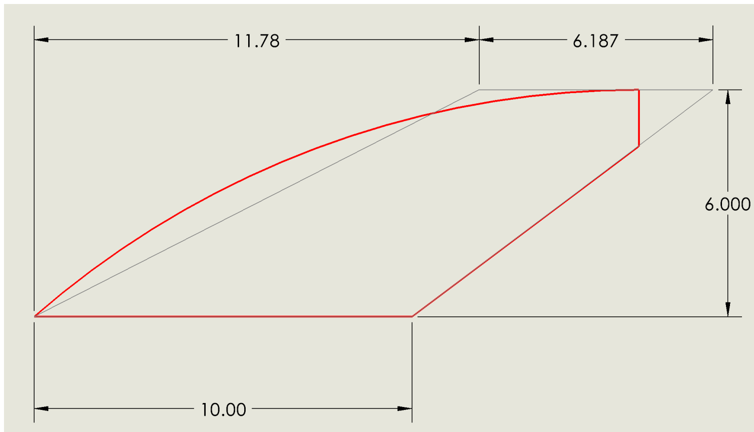

Figure 48: Annotated modification to the ogive fin for Barrowman's equations.

Table 14: Measured values for stability calculations.

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

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.

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

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

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

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

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

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

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

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 (15).

Table 15: Calculated stability values.

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

Table 16: 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 the 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 the 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, 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. (49) 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.

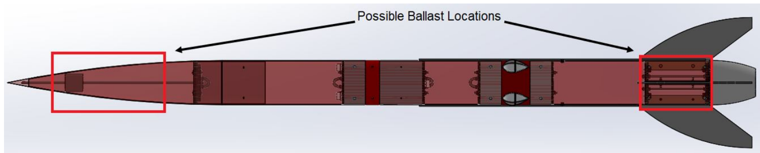

Figure 49: Possible ballast locations.

In order to move the CG and maintain a 2.0 stability margin, the current launch vehicle design uses 0.75 lb of ballast secured to the nose cone threaded rod. A diagram of the location of this ballast is shown in Fig. (50) below. For the purpose of maintaining the desired stability margin, the nose cone ballast can be increased to as much as 2 lbs. 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.

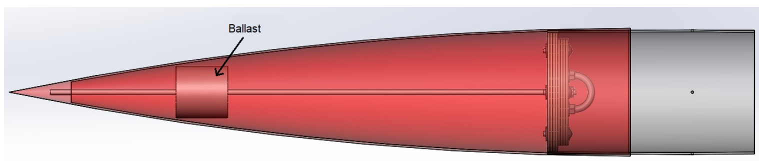

Figure 50: Location of the nose cone ballast.

In the event that the as constructed launch vehicle is predicted to overshoot the target apogee, the altitude of the launch vehicle can be tuned by adjusting the overall weight of the vehicle. 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 4 lb. in order to satisfy NASA requirement 2.23.7.

3.6.7 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.

$$E = \frac{1}{2}mV^2 \tag{17}$$

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 (17).

Table 17: 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	.207 slugs	26.92 ft/s	25.06 ft/s
Main Parachute Bay and Avionics Bay	.220 slugs	26.11 ft/s	24.31 ft/s
Drogue Parachute Bay, Payload Bay, and Fin Can	.632 slugs	15.4 ft/s	14.34 ft/s

Using this data, as well as the descent time and wind drift distance calculations shown in sections 3.6.8 and 3.6.9, the 120" Fruity Chutes Iris Ultracompact parachute was chosen to be the main parachute and is further described in section 3.5.1.4. Using the known mass, area, and drag coefficient of this parachute the descent velocities and impact kinetic energies were calculated using the following formula.

$$V = \sqrt{\frac{2gm}{AC_D\rho}} \tag{18}$$

The descent velocities and impact kinetic energies for each section are shown 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 18: Section masses and their corresponding velocities and impact energies.

Section	Mass of Section	Velocity Under Main Parachute	Impact Energy
Nose Cone	.207 slugs	6.11 ft/s	4.247 ft-lbf
Main Parachute Bay And Avionics Bay	.220 slugs	9.16 ft/s	9.230 ft-lbf
Drogue Parachute Bay, Payload Bay, and Fin Can	.6014 slugs	13.61 ft/s	55.69 ft-lbf

Thus it is shown that the maximum impact kinetic energy that this launch vehicle will experience is 55.69 ft-lbf of force, almost 10 ft-lbf below the limit necessary to earn bonus points, as set by NASA 3.3.

3.6.7.1 Alternative Kinetic Energy Calculation Method

RockSim simulations were used as an alternative method to calculate the descent velocity of the launch vehicle under main parachute. The descent velocity predicted by RockSim is 13.58 ft/s upon ground impact. This value can then be used in Eqn. 17 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 58.27 ft-lbf which is below the maximum limit set by NASA to earn bonus points. The kinetic energy calculated using RockSim is different from hand calculations by only 2.58 ft-lbf which validates the accuracy of the hand calculations.

3.6.8 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.

$$t = \frac{h_a - h_m}{v_d} + \frac{h_m}{v_m} \quad (19)$$

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 79.5 seconds, within the 80 seconds necessary to earn the bonus points described in NASA requirement 3.11.

3.6.9 Wind Drift Distance

The wind drift distance calculations rely on the assumption that the launch vehicle horizontal velocity matches the wind velocity. In reality it will be slightly slower than the wind velocity, 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 3.6.9.1.

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 79.5 seconds, the expected drift distances are shown in the table below.

Wind Velocity	Drift Distance
0 mph	0 feet
5 mph	583 feet
10 mph	1166 feet
15 mph	1749 feet
20 mph	2332 feet

3.6.9.1 Alternative Drift Distance Calculation Method

Using RockSim, the horizontal drift due to wind was simulated with maximum wind launch conditions of 20 mph. Using the RockSim simulation is much more precise as it does not assume that the launch vehicles horizontal velcoity 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.

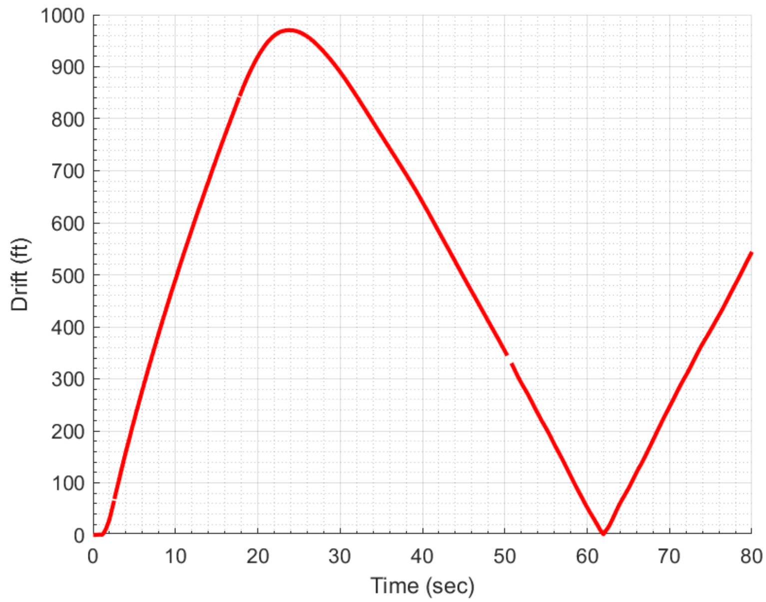

Figure 51: Drift distance due to wind.

Based on this figure, the total descent time of the launch vehicle is 68.38 seconds and the total drift distance is only about 530 ft.

3.6.10 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.

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

3.6.11 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 [9]. 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.

$$t = \frac{8r}{v_d} \tag{20}$$

$$F = \frac{m\Delta v}{t} \tag{21}$$

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.

Launch Vehicle Body Section	Body Section Mass	Main Parachute Opening Shock
Full Launch Vehicle	1.255 slugs	370.54 ft-lbs
Nose Cone	.207 slugs	61.117 ft-lbs
Main Parachute Bay and Avionics Vay	.225 slugs	66.431 ft-lbs
Drogue Parachute Bay, Payload Bay and, Fin Can	.602 slugs	177.740 ft-lbs

3.7 RocketPy Simulation

RocketPy is an open-source Python library for advanced rocket trajectory simulation. This tool has nonlinear six-degree-of-freedom simulations using real-time weather forecasts or raw atmospheric data collected by NOAA. A huge benefit of RocketPy is its modularity within the code which allows for the 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, can create Monte Carlo Dispersion analysis to show the normal distribution of flight performance characteristics. RocketPy precision and features 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, numerous characteristics are defined before beginning a simulation. The atmospheric environment to be used is defined by the longitude and latitude of the launch site and utilized in a forecast function that returns all necessary atmospheric conditions such as wind vectors at various altitudes. Fig. 52 shows a visualization of the forecast output possible with RocketPy.

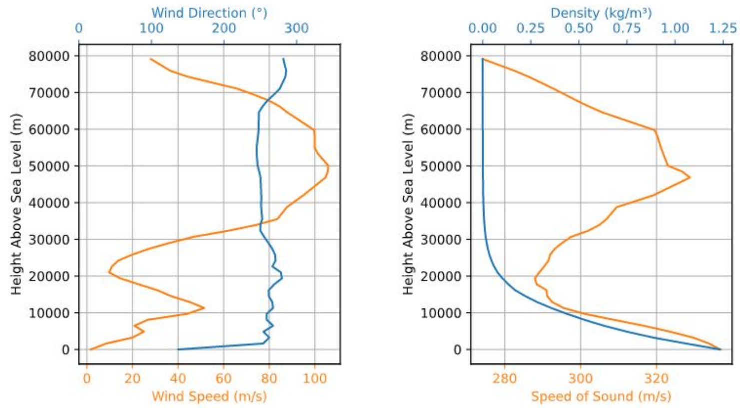

Figure 52: Atmospheric data from Python forecast function.

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 available online data. RocketPy takes the dimensions of the motor and has a function that calculates the performance of the motor such as exhaust velocity and total impulse. After the motor is defined the vehicle can begin to be defined with all dimensions originating from the CM. The moment of inertia in the axial and perpendicular direction is also required in the definition of the vehicle. RocketPy also utilizes and power on and power off drag curve to define the launch vehicle. The nose, fins, tail cone, and rail buttons are individually defined with the physical dimensions. 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.

The L1520T motor was created in RocketPy in conjunction with the current vehicle design. Approximations for the moments of inertia and the drag curves were necessary without having the vehicle built and tested. 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 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 in fig. 53. RocketPy provides several pieces of data, such as Euler Angles, angular kinematics, and aerodynamic forces, which are not provided by Rocksim and other software.

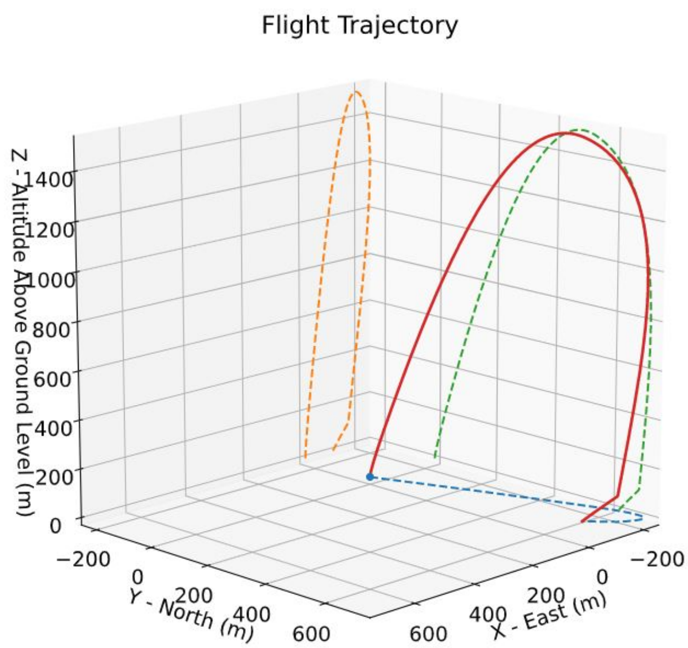

Figure 53: 3D trajectory plot of launch vehicle flight.

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

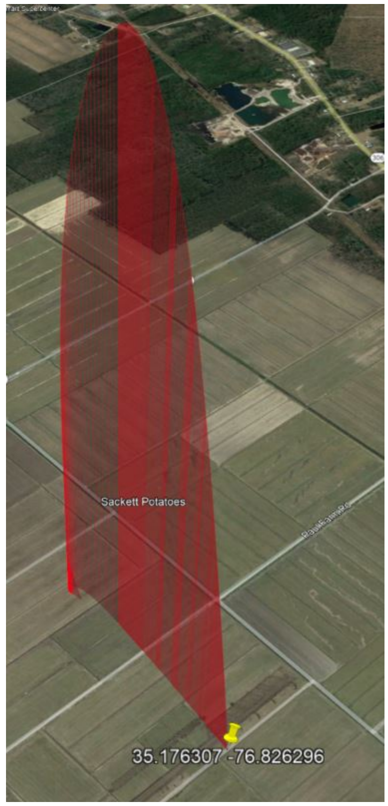

Figure 54: Google Earth plot of launch vehicle flight.

Additionally, RocketPy also calculates the force on the rail buttons during the on-rail portion of the flight. Fig. 55 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.

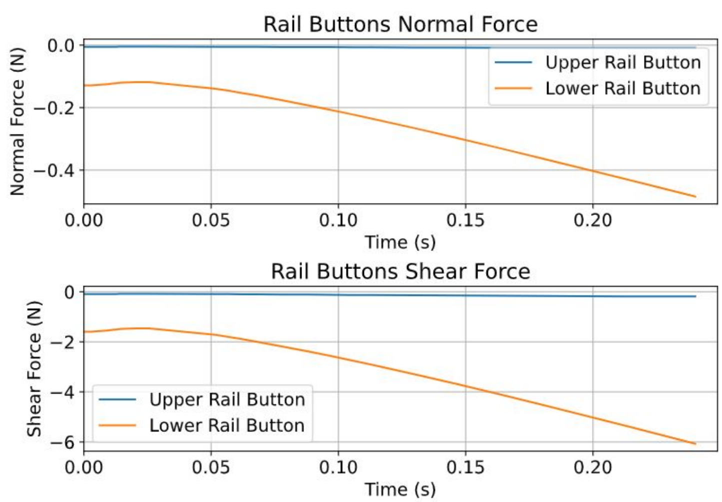

Figure 55: Rail button forces from RocketPy simulation.

3.7.3 RocketPy Optimizations

The current design doesn't utilize RocketPy's optimization calculations with an additional understanding of this program required. The following are examples of possible calculations that can be performed for the current design to better understand its performance. Fig. 56 demonstrates how RocketPy can sweep through the launch vehicle's potential mass to calculate the resulting rail exit performance.

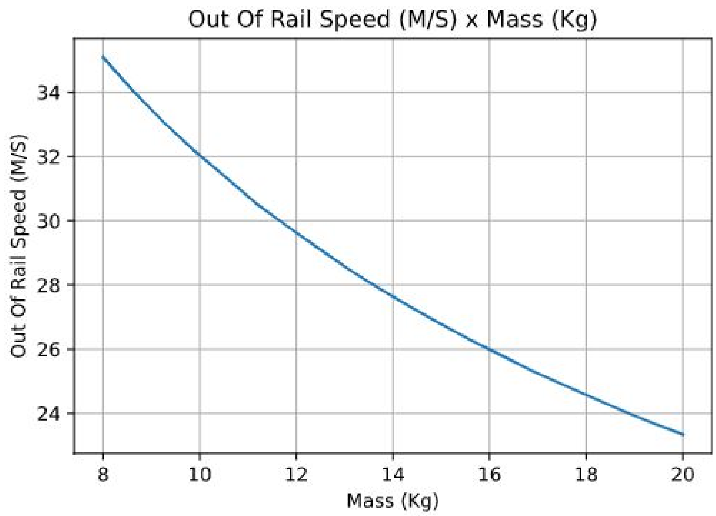

Figure 56: Example of RocketPy optimization calculation.

Additional to optimization in specific performance through variability in a singular characteristic, Monte Carlo dispersion analysis can be performed by providing the software with an error range for characteristics of the design and performing thousands of simulations where the exact inputs into the simulation vary based on the errors provided. This results in a normal distribution of results where the performance of the vehicle can be assessed through statistical analysis with the mean and potential error possible in the performance. 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. Fig. 57 overlays the results of an example simulation with a scale photo of a launch field to visually display where the example launch landed in relation to what RocketPy predicted.

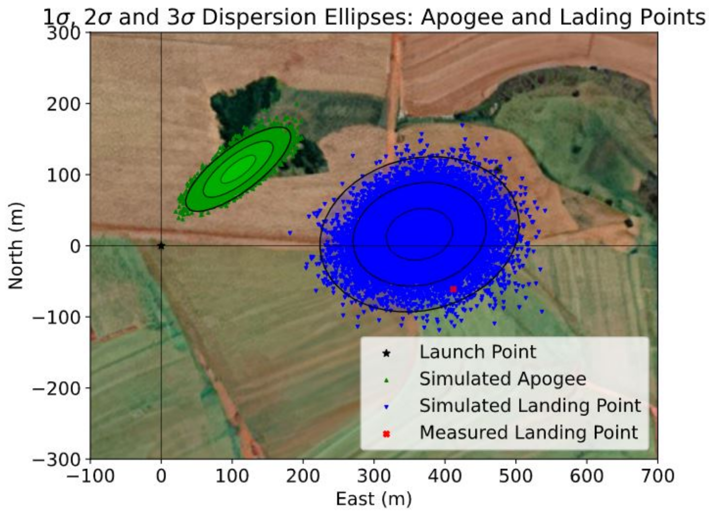

Figure 57: Example of RocketPy Monte Carlo dispersion analysis.

3.7.4 RocketPy Future Usage

RocketPy will continue to be utilized as much as possible with the construction of the fullscale 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 SOCS Final Design Overview

Several design alternatives were presented in the PDR document, and those alternatives are refined below to produce the final SOCS design. Table (20) shows chosen design alternatives and the justifications behind these choices.

Table 20: Chosen design alternatives and their corresponding justifications.

Component	Justification for Choice
Smraza Pi camera	Small, reliable, FOV that meets requirements, native integration with Raspberry Pi.
Feetech FS90R servo	Low-cost, low power draw, reliable.
Vacuum-formed housing	Low-cost, easily replaceable, thin-walled to minimize distortions.
Teardrop-shaped housing	Aerodynamic, space-efficient.
Dipole antenna	Easily manufactured, no ground plane necessity.
Antenna mounting along fin can	Simple, aerodynamic, accessible.
Pull-pin switch	Reliable, low-cost, accessible.
SainSmart 2-Channel Relay	Well documented, Pi compatible
BNO055 IMU	Versitility, compact, previous experience
Nooelec NESDR Smart RTL-SDR Dongle	Compact, rugged, Pi compatible

4.3.1 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 58 shows an example of the computer used.

Figure 58: Raspberry Pi 4 [12]

4.3.1.1 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 4.3.1.2.3, with two 180° sections used for antenna selection, rather than the four 90° sections used for camera selection.

The particular relay used was selected due to its known ability to interface with the Pi and the documentation available, which clearly explains its use and operational paradigm. The BNO055 was selected as the IMU due to the large amount of measurements available in a small package, its well documented implementation with the Raspberry Pi, and its use by the club in previous years. Since only four 90° zones need to be determined, a high-fidelity IMU with little drift is unnecessary. The BNO055 is already owned by the club, is compact, well documented, and has the necessary fidelity and drift characteristics for this particular use-case. The Nooelec NESDR was chosen as the implemented RTL-SDR dongle due to its rugged aluminum construction, compact size, Raspberry Pi compatibility, and part availability. Figures 59, 60, and 61 show example images of the off-the-shelf components used in this subsystem.

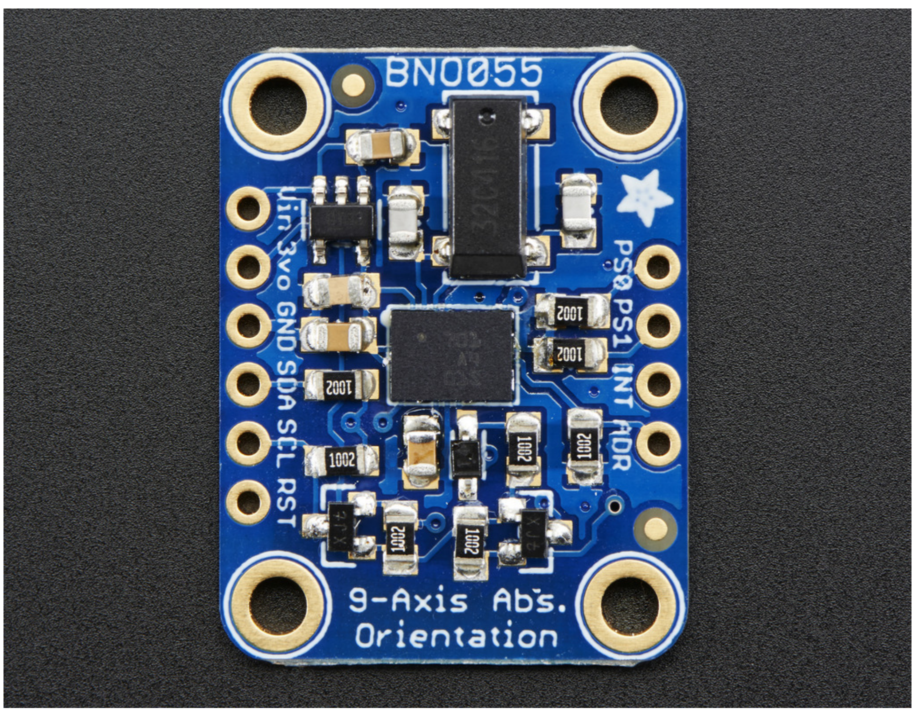

Figure 59: BNO055 IMU [11]

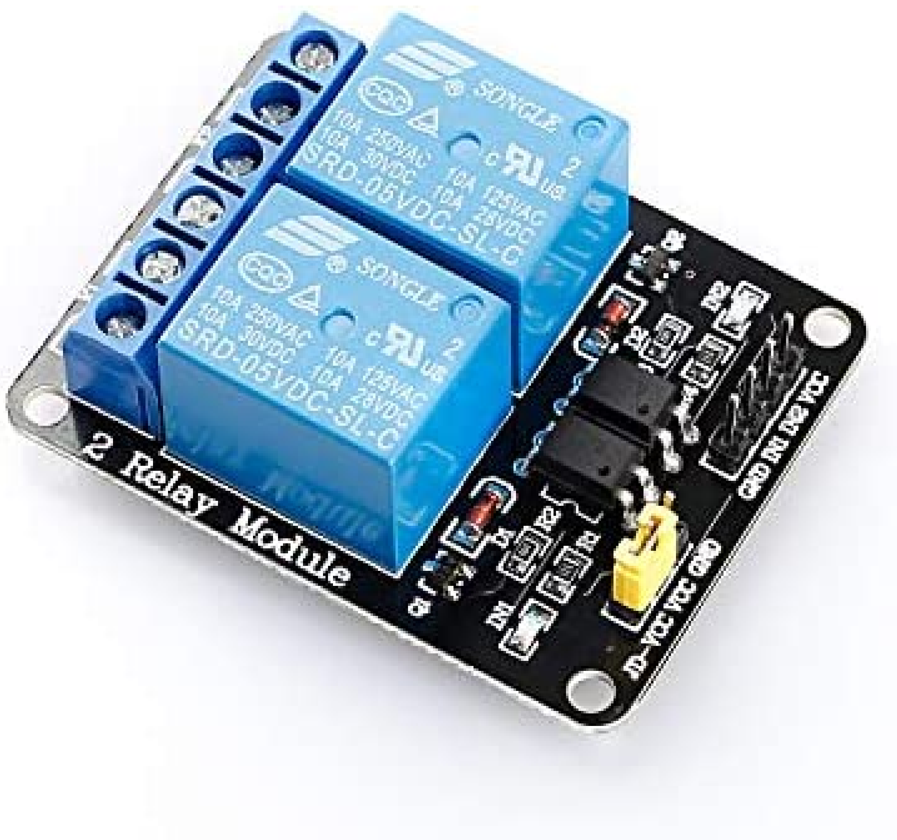

Figure 60: SainSmart 2-Channel Relay [6]

Figure 61: Nooelec NESDR Smart RTL-SDR Dongle [5]

4.3.1.2 Camera Positioning and Image Capture Subsystem

4.3.1.2.1 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 (62)). 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.

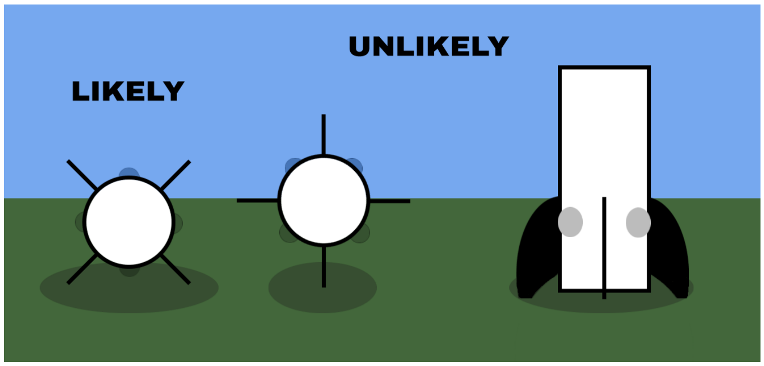

Figure 62: Likely and unlikely landing orientations of the fin can.

4.3.1.2.2 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. Table (20) shows design justifications for additional components on SOCS and each camera unit.

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 (63) below.

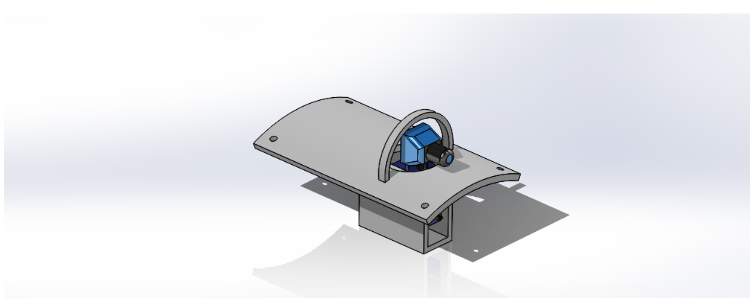

Figure 63: A 3D model showing the 3D-printed camera mount attached to a servo.

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.

4.3.1.2.3 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 64 shows a visual example of this determination system.

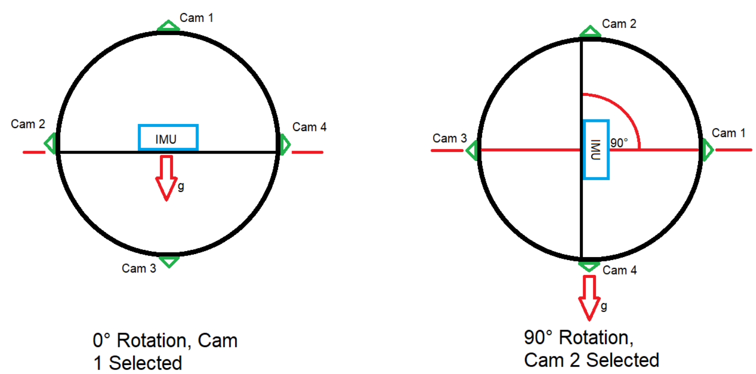

Figure 64: Camera Orientation Determination

Commands are sent to the correct camera using an Arducam Multicam Adapter Board, shown below in Figure (65). 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 4.5.4.

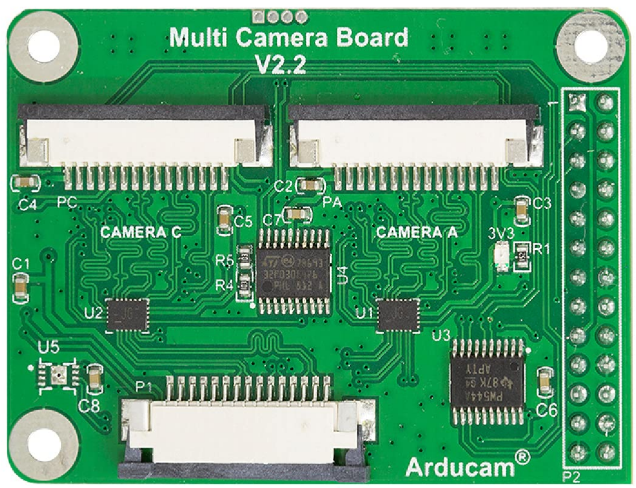

Figure 65: Arducam Multicam Adapter Board [4]

4.3.1.3 Block and Wiring Diagrams

Figure 66 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.

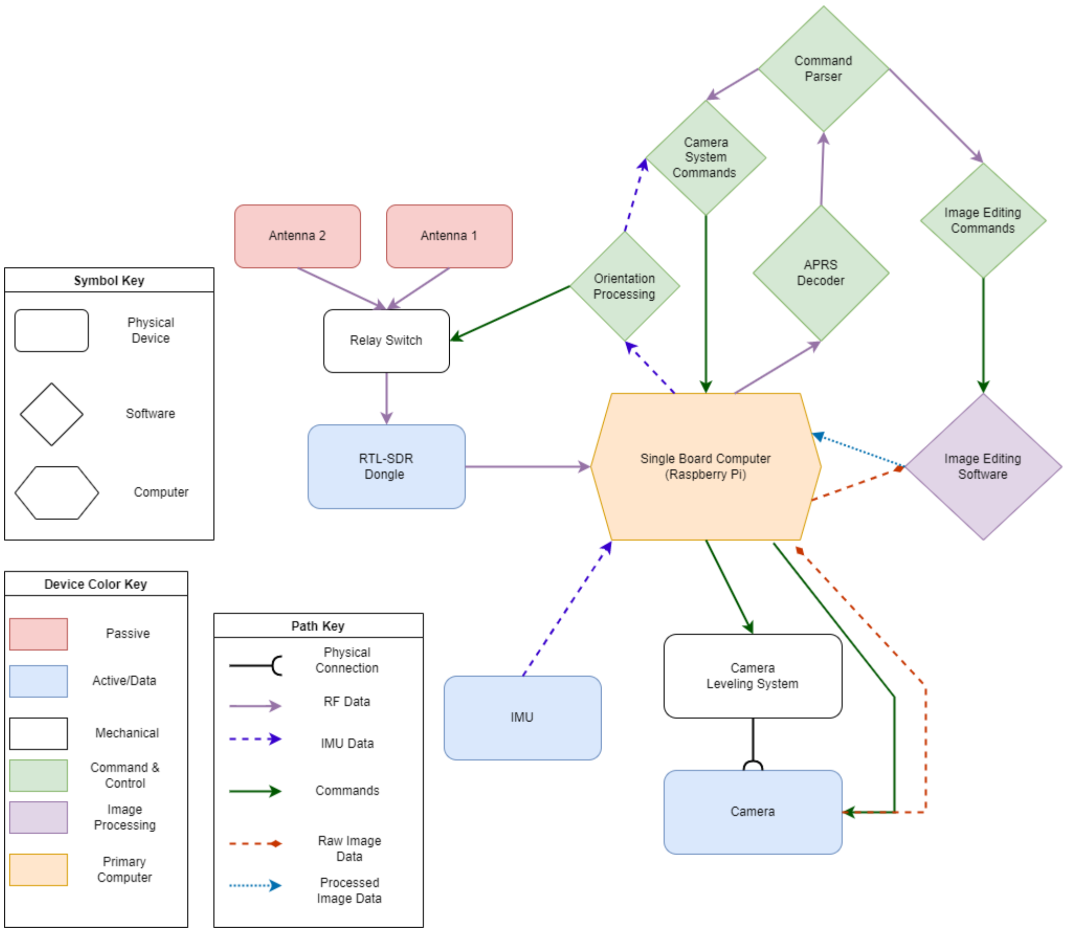

Figure 66: Finalized payload operations block diagram

Figure 67 shows the wiring schematic for the payload. It is important to note that the CSI connections are flexible ribbon cables, rather than the 22 AWG wire used with the rest of 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.

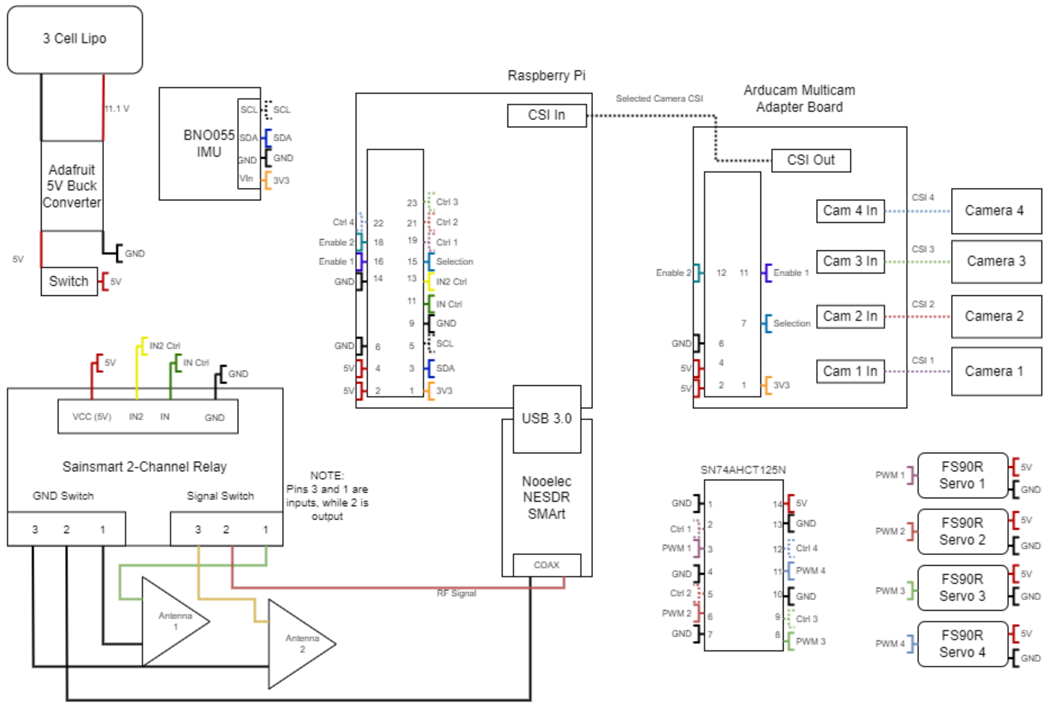

Figure 67: Payload wiring diagram

4.3.2 Structure

SOCS's structure is composed of two parts, the camera unit mount and the camera housing. The camera unit mount is a 3D printed structural component whose purpose is to hold the camera unit (camera, servo, and camera mount) in the correct position so that captured images are unobstructed and clear. The camera unit mount also protects internal electronics from damage due to in-flight motion of camera components. The camera housing is a curved, vacuum-formed dome that sits over the camera unit and protects internal electronics from debris experienced during flight. Further information on these components is detailed in the following sections.

There are 3 pieces that are used to assemble the payload structure: the camera housing, camera unit mount, and the airframe. The camera housing is be sandwiched in between the camera unit mount and the airframe so that the domed portion of the camera housing protrudes through the hole in the airframe. Four, 6-32 bolts will be used to secure the assembly to the airframe. A exploded and assembled model of this is shown in Figures 68 and 69 respectively.

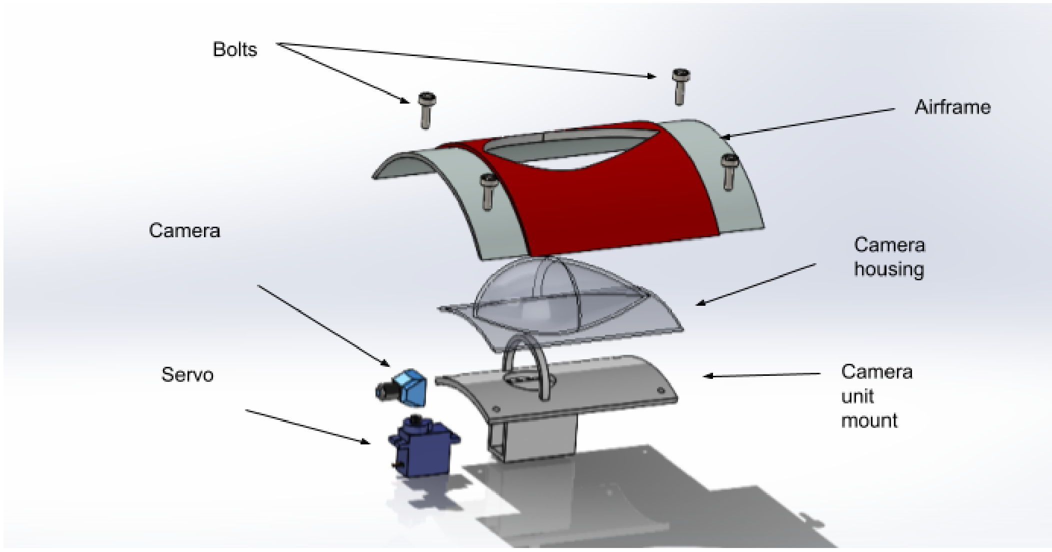

Figure 68: Exploded payload assembly

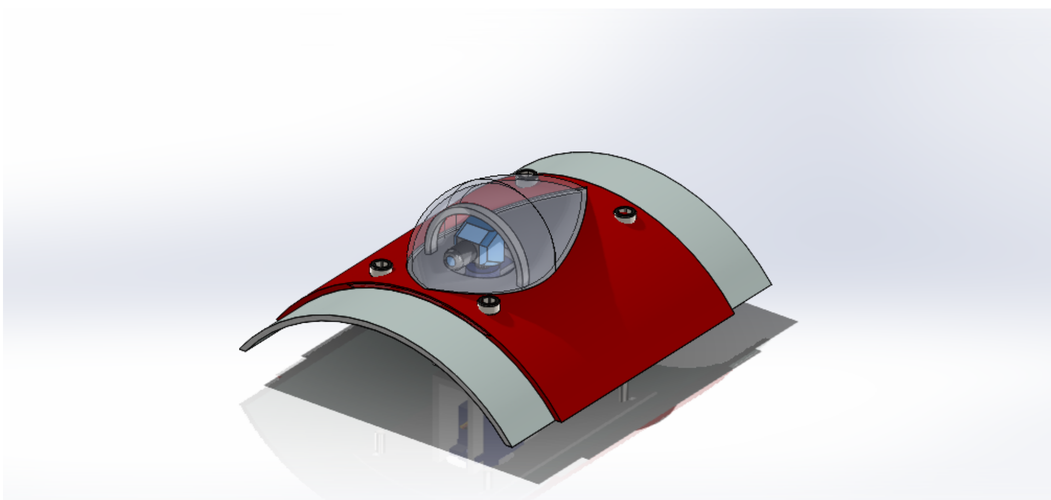

Figure 69: CAD model of the assembled payload

4.3.2.1 Camera Unit Mount

The camera unit mount is a structure made up of three components, which can be seen in Figure (70). The first component is the servo housing, which is a hollow cube that keeps each servo stationary during flight. The housing has an open face, allowing a path for each servo's wires to attach to the Raspberry Pi.

The second component is a curved base plate. The base plate attaches to the airframe and holds the entire camera structure in place. A one-inch hole at the top of the plate allows the servo and camera to peer through the plate and capture a clear image.

The final component is a support structure. Because vacuum-formed components tend to deform under loading, arch support is necessary to prevent the aerodynamic camera housings from deforming upon landing and damaging sensitive internal components. Figure (70) shows a CAD model of the entire assembly and Figure (71) shows the corresponding dimensioned drawing.

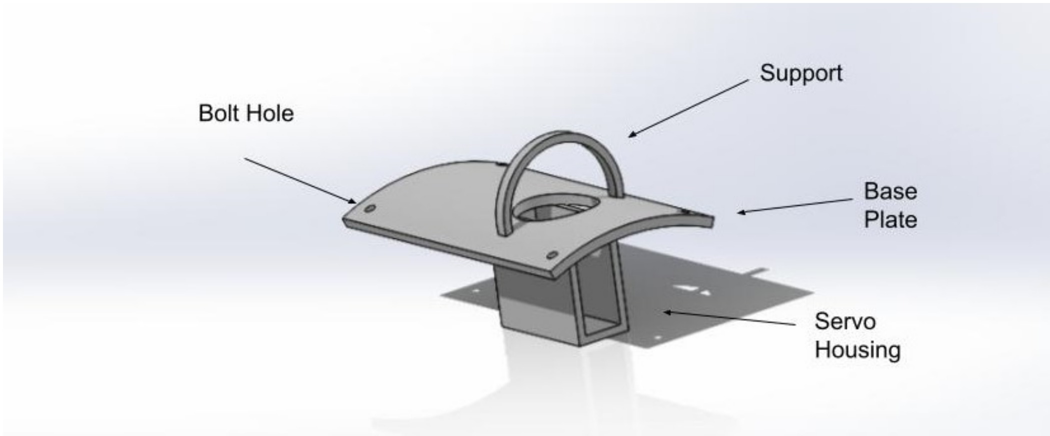

Figure 70: CAD model of the camera unit mount

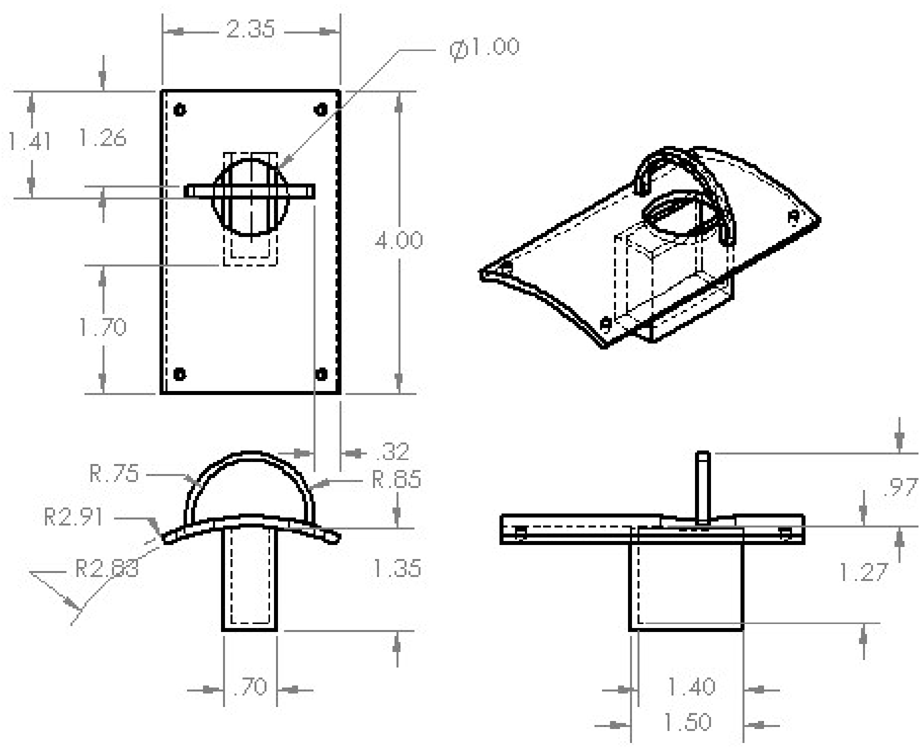

Figure 71: Dimensioned drawing of the camera unit mount

4.3.2.2 Aerodynamic Camera Housings

The camera housings are designed to protect internal SOCS components while minimizing drag on the vehicle during flight. They will have a hollow, curved structure with a skirt that allows them to be attached to the vehicle with rivets. The hollow domed portion will house the camera system. The skirt is used to attach the camera housing to the camera unit mount and the airframe. A CAD Model and dimensioned drawing of the camera housing is provided below.

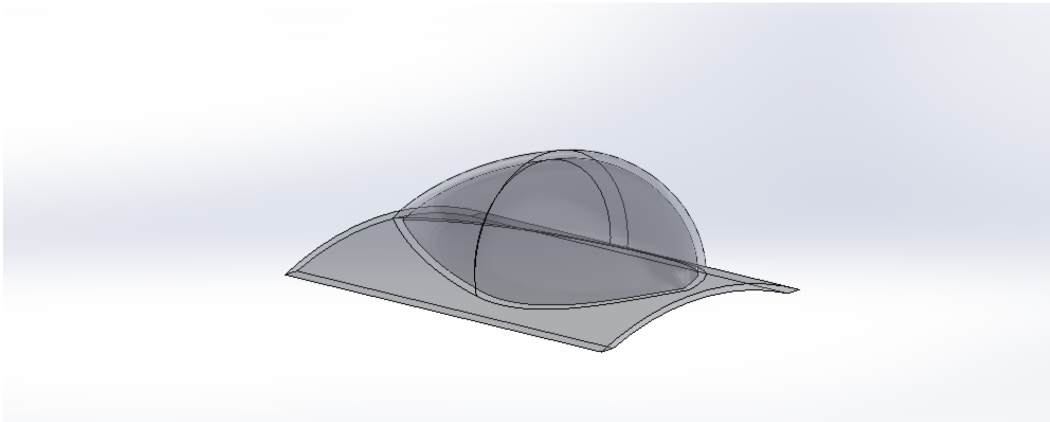

Figure 72: CAD model of the camera housing.

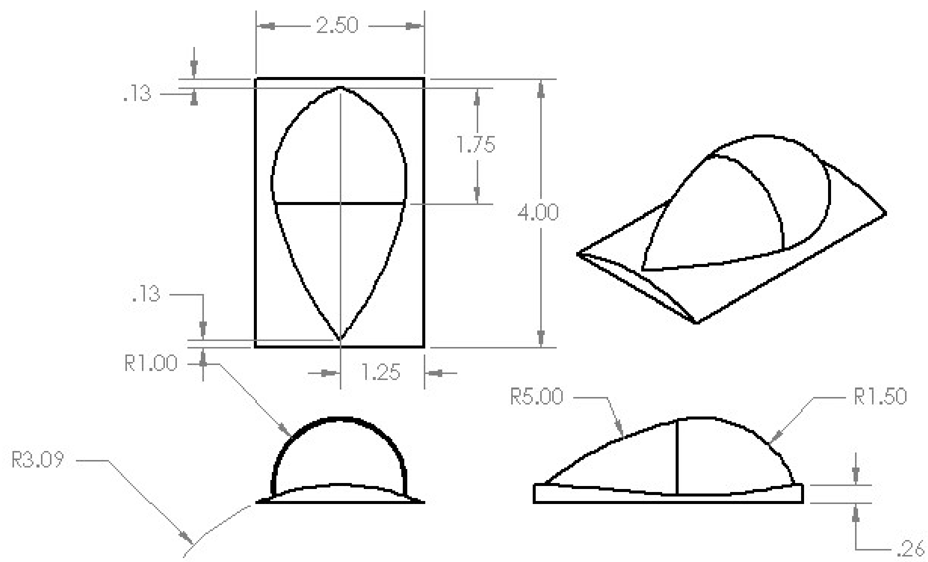

Figure 73: Dimensioned drawing of the camera housing.

4.4 SOCS Manufacturing

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

4.4.1 Camera Housing

A Mayku Vacuum Former (shown in Figure (74) below) will be used to manufacture camera housings. PET-G plastic, a thin and transparent material, will be used so that clear pictures of the launch field can be obtained.

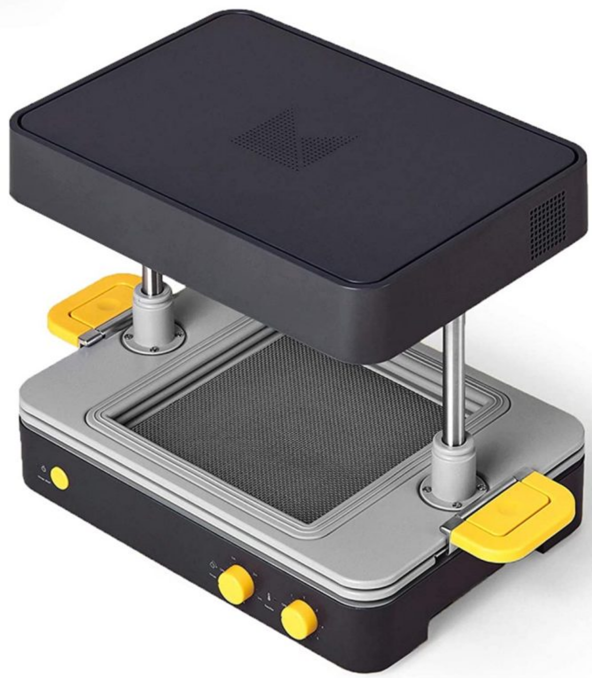

Figure 74: Makyu vacuum former

A positive mold of the aerodynamic camera housing is necessary for the vacuum forming process. The mold will consist of a 3D-printed, smaller version of the camera housing attached to a smaller version of the airframe so that when the plastic forms onto it, the housing will be the desired thickness and dimensions shown in Figure (73). The mold will be 3D printed out of PLA. A CAD Model of the mold and a dimensioned drawing is shown below in Figures (75) and (76).

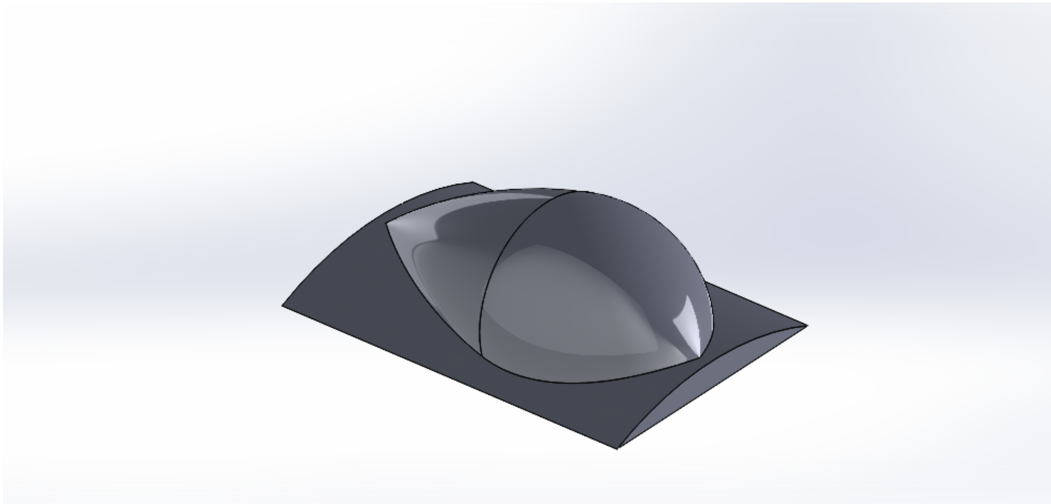

Figure 75: CAD Model of the Camera Housing Mold

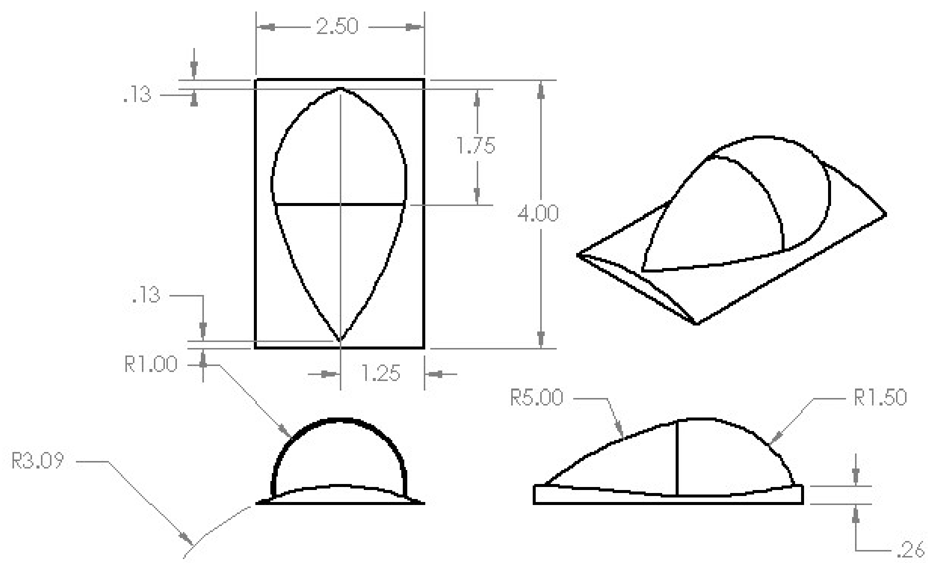

Figure 76: Dimensional Drawing of the Camera Housing Mold

4.4.2 Camera Unit Mount

The camera unit mount will also be printed using an Ultimaker S3 printer (shown in Figure (77) below). This printer is located in the NCSU Entrepreneurship Garage.

Figure 77: Ultimaker S3

Two types of filament will be used to ensure print quality and structural integrity. The part will be printed with PLA filament which is very strong when used with a high infill. Print supports will be printed using a natural PVA filament which is easy to remove without damaging the printed object.

4.4.3 Payload Sled

The payload sled will also be 3D Printed using the Ultimaker S3 shown in Figure (77). The same PLA and PVA combination will be used for this print. Two 1/4-20 threaded rods are used to secure the sled to the bay.

4.4.4 Electronics

Many of the off-the-shelf electrical components have either terminal blocks (of which a stand-alone example can be found in figure 78) 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, and pin headers are when practical. The pin headers on the Raspberry Pi are not removed. Instead, a large female header is created, to which jumper wires are attached and hot glued down. This allows for a secure mechanical and electrical connection, with the hot glue capable of being dissolved with high concentration isopropyl alcohol.

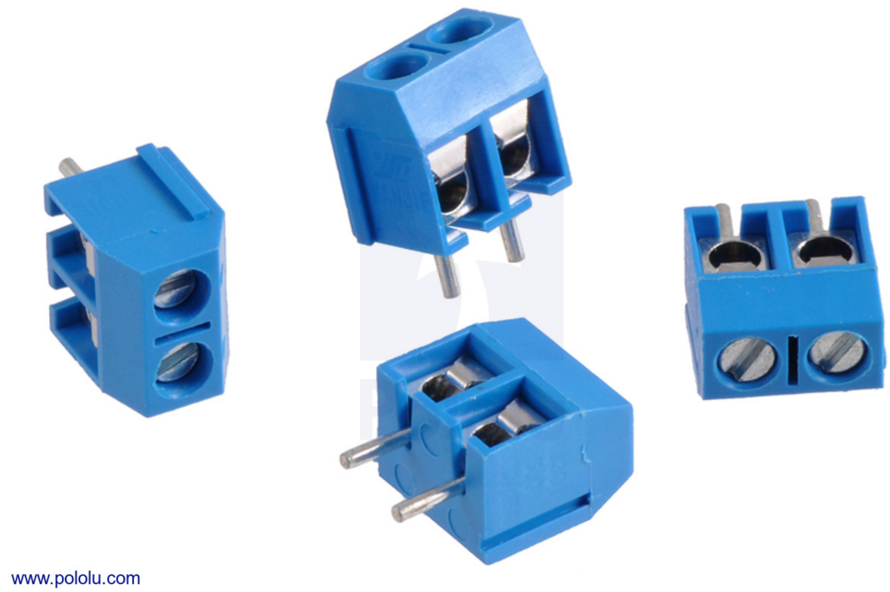

Figure 78: Terminal Blocks [10]

22 Awg jumper wires are soldered to the necessary connections on the daughter boards. If other removable connections are necessary, JST-SM connectors are used to make sturdy, vibration resistant connections while still allowing for separation. The Raspberry Pi and daughter boards are attached to the payload sled using M3, M2.5, and M2 mounting bolts, depending on the size of the mounting holes on each of the boards.

Some necessary components do not come on pre-made breakout boards, specifically the SN74AHCT125N quad logic-level shifter. When possible, through-hole components are selected, and a breakout board is constructed using stripboard. Both through-hole and SMT versions of this component are available, with no appreciable cost or operational differences between the different packages. A through-hole solution is preferred due to the ease of constructing a breakout board for this package. However, if supply issues arise the SMT version may be used with a breakout board. The wide variety of SMT packages in which this chip are available enable the use of off-the-shelf footprint adapter boards. This chip requires no supporting architecture, meaning that this commercially available adapter board is the ideal solution if the necessity arises.

4.5 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 4.5.1 through 4.5.4 below.

4.5.1 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 5%. 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.

4.5.2 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 is mounted to the payload sled shown in the 3D model in Figure (79).

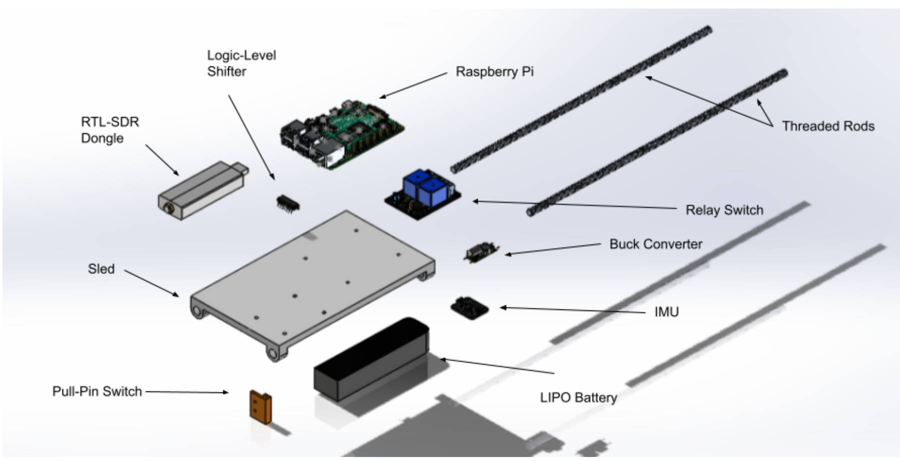

Figure 79: 3D rendering of the exploded payload sled.

The IMU's absolute position on the sled is secured using four M2 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 (65), 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.

4.5.3 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 (21) below.

Table 21: 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.

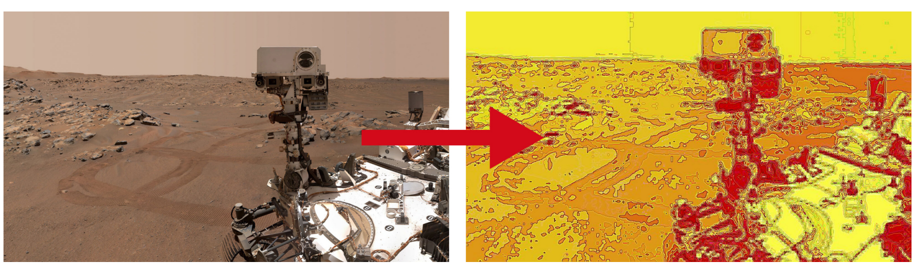

Figure 80: An example image filtered through the deeppy module.

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).

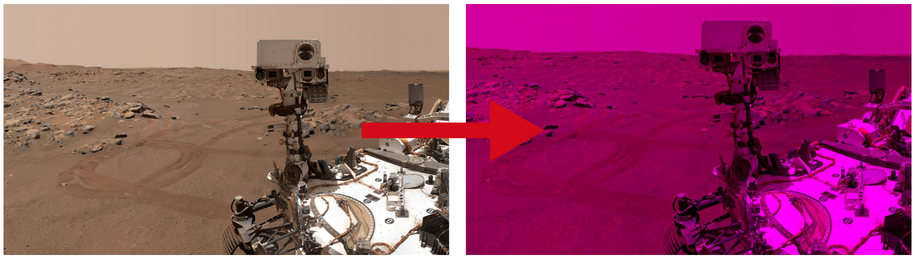

Figure 81: An example image filtered through the grassless function.

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.

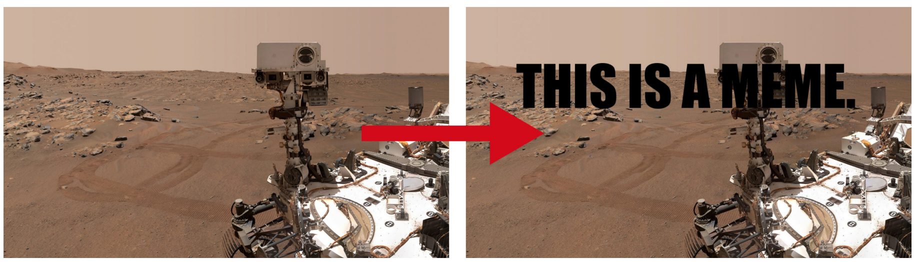

Figure 82: An example image filtered through the meme function.

4.5.4 Data Storage and Post-Processing

4.5.4.1 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 6.1.2.4.

4.5.4.2 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 (83). Additionally, the date and time will be saved in the filename saved on the Raspberry Pi.

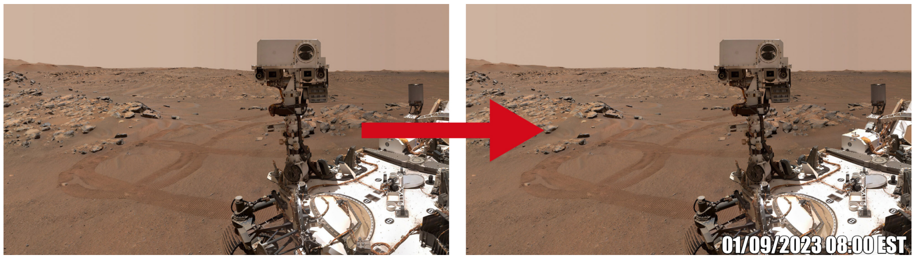

Figure 83: An example image timestamped with an arbitrary date.

4.6 Payload Integration

4.6.1 Retention

The Payload Sled is 3D printed out of PLA and held in place with 2, 1/4-20 threaded rods. The threaded rods run the length of the payload bay and are held in place with 2 bulk heads on either side of the bay. The aft bulkhead will have 2 holes in order to connect the antenna to the electronics inside the bay. The forward bulkhead will also have a u bolt on the outside. The Threaded rods are fastened to the bulkheads using washers and nuts.

The Payload sled will be oriented such that it doesn't interfere with the 4 camera housing units. The electronic components are held in place using tape, hot glue, and bolts.

The Camera subsystem will have the 3D printed camera unit mount and the vacuum formed camera housing bolted together with the air frame with 4, 6-32 bolts. Each of the the 4 camera housing will be secured to the air frame in this way in order to ensure structural stability.

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

4.6.2 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 4.6.3.

The battery is secured to the sled using two strips of heavy-duty velcro tape along the central axis of the vehicle. 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 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 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 the Raspberry Pi is capable of converting 5V to this voltage internally. Additional details on electronics and schematics can be found in Section 4.3.1.3.

4.6.3 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 22: 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 23: Structures PRA and FMEA

Structures Risk Assessment Before Mitigation					
15.00% 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%

Structures Risk Assessment After Mitigation					
0.00% 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%

Launch Vehicle Structure						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
Hazards to and from Bulkheads						
S.B.1	Failure of U-bolts			4A	Distribution of load during construction	4A
S.B.2	Failure of nose cone bulkhead bolts	Excessive deployment force	Ballistic reentry	4A		4A
S.B.3	Bulkhead cracking	Excessive stress around bolt connections		3D		3B
S.B.4	Bulkhead delaination	Excessive axial stress from shock cord connections	Separation of bulkhead from airframe	3D		3B
S.B.5	Separation of bulkhead from airframe	Softened epoxy		3D		3B
		Excessive force from latch connections			Load management during construction	
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
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
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
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
S.F.4	Fin breaks	Excessive force upon landing, fin flutter	Loss of stability during flight	3B	Fiberglass reinforcement during construction	1C
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
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
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

Continued on Next Page

Launch Vehicle Structure						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
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
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
		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
S.A.5	LV section collision	Shock cord of insufficient length		3B		3A
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
		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
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
		Parachute re-inflation upon landing, causing the body tube to be dragged			Launches do not occur in high winds	1A

Table 24: 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
Hazards to/from Parachutes and Shock Cord						
R.C.1		Insufficiently powered altimiters		2D	Altimeter battery checked immediately prior to flight	2A
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
R.C.3		Shear pins of an excessive diameter		2D	4-40 shear pins are used	2C
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
R.C.5		Parachute contact with hot ejection gases		4C		4B
R.C.6		Parachute contact with motor flame		1C		1B
R.C.7	Parachute rips and tears	Parachute entanglement during seperation/deploy ment	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
R.C.8	Shock cord disconnection	Loose quick links		3D	Quick links are tested immediately prior to flight	3B
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
R.C.10	Excessive force on shock cord	Late parachute deployment		3D	Estimated forces on the recovery system are calculated and verified	3C
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
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
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
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
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

Continued on Next Page

Recovery System						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
R.A.5	Excessive wind drift	Premature parachute deployment	LV tree landing	3B	Avionics utilize labeled quick-connects to prevent mix-ups	2A
R.A.6	Premature black powder detonation	Sympatheticc main/drogue black powder detonation	Parachute damage	1C	AV blast caps face in opposite directions	1B
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
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

Table 25: 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
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
Ae.M.2	Motor ejection	Loose motor retainer		2D	Motor assembly performed under the guidance of certified Tripoli professionals	2C
		Centering ring epoxy fail			Epoxy is allowed to fully cure	
		Crack in fin can body tube			Body tubes are made of fiberglass in order to combat alial compression	
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
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
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
Ae.A.2	LV weathercocking	Vehicle over-stability	Failure to reach intended apogee	3A		2A
Ae.A.3	LV divereges from expected trajectory	Vehicle instability	Ballistic descent	3D		3C
Ae.A.4	Fin flutter	Transonic LV speeds	Fin structural damage	1C	The LV will not fly at speeds in the transonic range	1B
Ae.A.5	Centering ring structural failure	Unexpectedly high motor thrust	Motor goes through LV	2D	Fins are made with aircraft-grade epoxy throuh proven construction methods	2C
		Weak epoxy connections				
Ae.A.6	Fin damage	Fin flutter	Fin loss	1C	The LV will not fly at speeds in the transonic range	1B
			Divergence from intended trajectory			
			Vehicle instability			
Ae.A.7	Abnormal thrust curves	Propellant grain gaps, cracks, holes, and bubbles	Failure to achieve intended apogee	2B	AeroTech Motors are used for their low likelihood of catastrophic failure	2A
			Excessive forve applied to structural bulkheads			

Table 26: 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
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
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
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
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
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
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
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
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
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

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Payload						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
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
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

Table 27: 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**
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
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
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
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	Personnel are required to wear closed toe shoes to launch day activities, only recovery and launch pad personnel are permitted on the launch field itself.	3C
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
E.Pe.4	Lightning strike			1D		1A
E.Pe.5	Wet and icy terrain		Personnel slips, trips, and falls	2C		1C
Hazards to Payload System						
E.Pa.1	Payload contact with water	LV touchdown in irrigation ditch or other wet area		1C	Mitigation pending	1C
E.Pa.2	Lightning strike	Inclement weather conditions	Payload electronics damage	3C	Launches are not conducted in inclement weather	2A
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
E.M.2	Damp black powder grains			2D		1B
E.M.3	LV flight in proximity to bird flight		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

Table 28: Hazards to Environment PRA and FMEA

Hazards to Environment Risk Assessment Before Mitigation					
		Level of Severity			
53.84% 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%

Hazards to Environment Risk Assessment After Mitigation					
		Level of Severity			
23.08% 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%

Hazards to Environmental Safety						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
Hazards to Wildlife						
E.W.1	Fire on launch field	Motor ignition	Crop damage, wildlife injury, personnel burns	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		Payload battery explosion		2D	Payload batteries are isolated from moisture, abrasion, and heat	2B
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		3B
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
E.W.6	Permanent jettisoning of Nomex sheet	Rips and tears in Nomex	Contamination of wildlife habitats, food, supply, and water supply	2A	Nomex is rated to withstand flight forces and is flame resistant	1A
E.W.7		Nomex connection breakage		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 flight	1A
E.W.8	HazMat deposit in irrigation ditch	Battery explosion	Toxic chemicals remain in soybeans by wildlife and humans	2B	All protective insulation is biodegradable, payload batteries are protected from puncture and heat	2A
E.W.9		Explosion byproducts		3D		3C
	Wildlife consumes toxins	HazMat littering	Wildlife develop digestive issues or incur injury or death			
E.W.10	CATO	Motor defects	Wildlife incur injury or death, water supply contaminated	2D	AeroTech motors are selected for their low likelihood of catastrophic failure	2C
E.W.11	LV landing in tree	Premature parachute deployment; High wind drift	Destruction of habitats	4C	Recovery systems are tested away from trees	4B
E.W.12	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
Hazards to Land						

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Hazards to Environmental Safety						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
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
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
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
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
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
E.A.3	Chemical off-gassing	Working with HazMats		1B	HazMats that off-gas are only used in well-ventilated areas	1A
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
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
E.A.8	Creation of vaporized hydrochloric acid		Air pollution	1B	AeroTech motors do not produce enough by-product to create hydrochloric acid	1B

Table 29: 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
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
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	Personnel working with manufacturing equipment are trained in proper use of machinery. Proper PPE is always used.	2C
Pe.S.3	Contact with hot soldering iron	Personnel misunderstanding of soldering system	Mild to severe burns	3C		3B
Pe.S.4	Personnel collision with LV	Launch rail tipping with assembled LV	Skin and muscle abrasion/tear	2C	Launch rails, provided by TRA personnel, have a locking mechanism that is engaged when the LV is righted.	2B
Pe.S.5		Sideways propulsion from severe instability		2B	The stability margin of the LV is no less than 2.0.	1B
Pe.S.6		LV touchdown within close proximity to personnel		1B	The LV is angled 20° away from personnel; personnel are instructed to keep eyes on all falling LVs and keep others aware.	1A
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
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
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
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
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	Nitrile gloves and other appropriate forms of PPE are	2A

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Hazards to Personnel Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
Pe.S.13	Exposure to vaporous chemicals	HazMat off-gassing	Skin rash, skin irritation	2A	provided to personnel working with hazardous liquid/vapor materials.	2A
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
Hazards to Bones and Joints						
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
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
Pe.B.3	Personnel finger caught in bandsaw blade	Bandsaw blade contact with clothes and/or jewelry	Broken bone	2D	Personnel working with manufacturing equipment are trained in proper use of machinery. Proper PPE is always used.	2C
		Personnel misunderstanding of bandsaw operation				
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
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
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
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
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
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
Pe.R.6	Inhalation of cumbustion reactants	Close proximity to LV motors and ejection charges	Respiratory irritation, difficulty breathing.	3B		3A
Hazards to Head						

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Hazards to Personnel Safety						
Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After
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
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
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
Pe.H.4	Contact with large, airborne, shrapnel	CATO		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
Pe.H.5	Impact with ballistic lander	Premature lander ejection from LV	Concussion, brain damage, memory loss, skull fracture	2D	The latch release system will be tested for its ability to withstand flight forces prior to launch.	2B
Hazards to Eyes						
Pe.E.1	Exposure to epoxy fumes	Working with epoxy	temporary blindness (from tear production), permanent or semi-permanent blindness	3D	Personnel working with epoxy will be provided with safety glasses	3C
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

5.4 Launch Procedures

FULLSCALE

Launch Day Checklists

This checklist completed by: ______________________________

On: __ / __ / __

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.

1. E-MATCH INSTALLATION

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	
Safety Officer	Megan Rink	
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:
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:
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:
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:

2. MAIN BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	
Safety Officer	Megan Rink	
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:
2.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer:
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:
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:
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	

3. DROGUE BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Meredith Patterson	
Safety Officer	Megan Rink	
Black Powder Personnel 1	Myers Harbinson	
Black Powder Personnel 2	Abhi Kondagunta	

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:
3.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer:
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:
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:
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	

4. AVIONICS BAY ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	Megan Rink	
Team Lead	Meredith Patterson	
Recovery Lead	Shaan Stephen	
AV Bay Personnel 1		
AV Bay Personnel 2		

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:
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	
4.4	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	
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:
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:
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:
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:
4.23	While pointing blast caps away from personnel, Attach **MS** and **MP** wires on bulkhead to **MS** and **MP** wires on **AV Sled**	
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:
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:

5. PAYLOAD ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	**Megan Rink**	
Payload Systems Lead	**Frances McBride**	
Payload Electronics Lead	**Ben Lewis**	
Personnel 1		
Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Payload Bay	1	-	
Fin Can	1	-	
Assembled Payload Sled	1	Payload BOX	
Camera Unit Mounts	4	Payload BOX	
Servos	4	Payload BOX	
Cameras	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	
APRS Cable	1	Payload Box	
Electrical Tape	1	LD ToolBox (Drawer 2)	
Mobile Device/Computer	1	-	

Number	Task	Completion
5.1	Connect the USB-C end of the cable to the Raspberry Pi.	
5.2	Connect the USB-A end to a laptop to read outputs.	
5.3	Set up a mobile hotspot with Name **HPRC** using a mobile device.	
5.4	Connect to the mobile hotspot **HPRC** with password **tacholycos**	
5.5	Confirm that the Raspberry Pi is connected to the hotspot by checking the mobile device.	
5.6	Open VS Code on the laptop connected to the Pi.	
5.7	Click the green lightning bolt icon in the lower left corner of the window.	
5.8	Select **Connect Current Window to Host** from the dropdown menu.	
5.9	Select **raspberrypi.local** from the dropdown menu.	
5.10	If prompted, select **Linux** from the dropdown menu.	
5.11	If prompted, hit **Continue**.	
5.12	Enter the password **raspberry** into the dialogue box and press enter.	
5.13	Press **ctrl+j** in the terminal window.	
5.14	Type **cd Payload-2022-2023/** in the terminal and press enter.	
5.15	Type **python3 main.py** in the terminal and press enter to start the script.	
5.16	Shake the payload sled vertically and confirm that **LIFTOFF DETECTED** is printed to the console.	
5.17	Wait 100 seconds until **LANDING DETECTED** is printed to the console.	
5.18	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.	
5.19	Rotate the sled around its central axis clockwise in 90 degree increments and track the sensed changes in orientation.	
5.20	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
5.21	Connect the antennas to their respective coax cables (green to green, yellow to not green).	

5.22	Transmit a test APRS signal using the Baofeng radio, making sure that the receiving antenna is upright and in the correct orientation.	
5.23	Ensure both antennas are receiving the test signal and it is being properly decoded and stored on the Pi.	Payload ECD:
5.24	Disconnect the antennas from their respective coax cables.	
5.25	Press **Ctrl+C** in the terminal window on the laptop.	
5.26	Unplug the USB cable from the Raspberry Pi and laptop.	
5.27	Plug the payload into the flight-ready LiPo and tug lightly to ensure a tight connection.	
5.28	Fold down, tape, and zip tie any remaining loose components onto the payload sled.	
5.29	Remove the pin from the switch, and ensure that the payload powers on.	
5.30	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.**	
5.31	Slide the payload sled into the payload bay and align using the pull-pin switch hole.	
5.32	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.	
5.33	Hook up both coax cables to the relay on the payload sled through **Bulkhead #1.**	
5.34	Slide each coax cable connected to the sled through the holes in the fincan airframe.	
5.35	Connect each antenna cable to each coax cable ensuring green to green connection through holes in the fin can airframe.	
5.36	Slide the payload bay into the fin can.	
5.37	Attach the payload bay to the fin can using four black, plastic rivets.	
5.38	Tape both antennas flat to the airframe in line with the fins with a long strip of electrical tape.	
5.39	Tidy up coax cables to ensure clearance for fin can assembly.	
5.40	Confirm Payload is assembled correctly.	Payload Systems:

6. FINCAN ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	**Megan Rink**	
Team Lead	**Meredith Patterson**	
Structures Lead	**Mike Pudlo**	
Personnel 1		
Personnel 2		

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	
Team Lead	Meredith Patterson	
Integration Lead	Chris Luzzi	
Personnel 1		
Personnel 2		

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:
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	Int 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	Int 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	Int 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 **Fin Can** by visual inspection and pulling on shock cord	Int 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	Int 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	
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 bay	

7.23	Slide the **AV Bay** coupler into the drogue bay, using the sharpie marks for alignment	
7.24	Insert a #4-40, ½-inch long nylon shear pin into each shear pin hole	
7.25	Place a small piece of blue tape over each shear pin head.	
7.26	Hold the avionics bay and let the fin can hang free and confirm vehicle holds its own weight	Int Lead:

8. MAIN RECOVERY ASSEMBLY

Essential Personnel	Name	Initial
Safety Officer	**Megan Rink**	
Team Lead	**Meredith Patterson**	
Structures Lead	**Mike Pudlo**	
Personnel 1		
Personnel 2		

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:
8.2	Slide **Loop #4** of the shock cord through the main parachute bay with **Loop #4** hanging out the aft 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	Structures 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	Structures Lead:
8.15	Attach **Quicklink #6** to shock cord **Loop #6**. Do not tighten	
8.16	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.	
8.17	Confirm the shock cord is secured to the **Nose Cone** by visual inspection and pulling on shock cord	Structures Lead:
8.18	Insert the length of shock cord between **Loops #4 and 5** into the **Main Parachute Bay.**	
8.19	Remove all rubber bands from the main parachute and shock cords. Hold the parachute securely so that it does not come unfolded.	
8.20	Fold nomex sheet over the main parachute like a burrito so that it is fully covered with swivel aligned with nomex hole	
8.21	Carefully insert the main parachute completely into the main parachute bay with the yellow loop pointed towards the Nose Cone	
8.22	Insert the length of shock cord between **Loops #5 and 6** into the main parachute bay.	

8.23	Slide the **Main Parachute Bay** over nose cone coupler, being careful not to pinch the shock cord, and using the sharpie marks for alignment	
8.24	Insert a #4-40, ½-inch long nylon shear pins into each shear pin hole	
8.25	Place a small piece of blue tape over the shear pin heads.	
8.26	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:

9. MOTOR ASSEMBLY

Essential Personnel:	Name	Initial
L3 Mentor	**Alan Whitmore/Jim Livingston**	
Aerodynamics Lead	**J.W. Mason**	
Motor Personnel 1		

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**	
Team Lead	**Meredith Patterson**	
Aerodynamics Lead	**J.W. Mason**	
Personnel 1		
Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Fish Scale	1	LD Toolbox (Drawer 3)	
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:
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:
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:
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: Team Lead:
10.11	Load the field recovery box with the items required	
10.12	Proceed to the launch pad!	

11. LAUNCH PAD

Essential Personnel	Name	Initial
Safety Officer	**Megan Rink**	
Team Lead	**Meredith Patterson**	
Recovery Lead	**Shaan Stephen**	
Payload Lead	**Ben Lewis**	
Personnel 1		

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
11.1	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:
11.6	Carefully slide the launch vehicle onto the launch rail	
11.7	Visually confirm the launch vehicle slides smoothly along rail	Safety Officer:
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	Set launch rail pointed 5 degrees away from spectators	
11.11	Confirm the launch rail is locked	Safety Officer:
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:
	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:
	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**	
Team Lead	**Meredith Patterson**	
Recovery Lead	**Shaan Stephen**	
Payload Structures Lead	**Ashwin Sivayogan**	
Personnel 1		
Personnel 2		

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).		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.		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.		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.		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).		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.		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.		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			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

FAILED MOTOR IGNITION

- LISTEN TO RSO INSTRUCTIONS
- WAIT UNTIL RSO APPROVED APPROACH
- EXPECT POSSIBLE MOTOR IGNITION
- APPROACH LAUNCH PAD WITH PPE
- INSPECT IGNITOR AND WIRING
- CONSULT RSO FOR FURTHER ACTION

NO IGNITOR CONTINUITY

- LISTEN TO RSO INSTRUCTIONS
- DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD WITH PPE
- CHECK IF ALLIGATOR CLIPS ARE PROPERLY ATTACHED TO IGNITOR AND ENSURE BOX IS WIRED TO CORRECT LAUNCH PAD

If No Continuity Persists:

- SEEK RSO DIRECTION
- CHANGE LAUNCH PAD

BLACK POWDER SPILL

- ALL NON-DESIGNATED PERSONS CLEAR THE AREA
- EQUIP PPE FOR HANDLING BLACK POWDER
- ACQUIRE FUNNEL AND EMPTY PLASTIC CONTAINER
- BRUSH/FUNNEL AS MUCH OF THE SPILLED BLACK POWDER AS POSSIBLE INTO THE CONTAINER USING GLOVED HANDS
- DISPOSE OF REMAINING BLACK POWDER
- USE WET WIPES TO CLEAN REMAINING BLACK POWDER

MISSING REQUIRED TOOL

- ASK TEAM MEMBERS FOR PERSONAL TOOLS
- ASK OTHER LAUNCH PATRONS
- ACQUIRE NEW TOOL FROM HARDWARE STORE IF POSSIBLE

If Unable to Resolve:

- ABORT LAUNCH PROCEDURE
- FIRST REMOVE ANY ENERGETICS FROM LAUNCH VEHICLE
- PACKAGE ENERGETICS IN STATIC BAGS
- PLACE BAGS IN LOCKED ENERGETICS BOX OR FLAME CABINET
- DISASSEMBLE REMAINDER OF VEHICLE

RAPID WEATHER CHANGE AT LAUNCH

- LISTEN TO RSO INSTRUCTIONS
- REMOVE VEHICLE FROM LAUNCH RAIL
- REMOVE ANY ENERGETICS FROM LAUNCH VEHICLE
- PACKAGE UNUSED ENERGETICS IN STATIC BAGS
- PLACE BAGS IN LOCKED ENERGETICS BOX OR FLAME CABINET
- DISASSEMBLE REMAINDER OF VEHICLE

PARACHUTE UNFOLDS DURING ASSEMBLY

- DISCONNECT PARACHUTE FROM QUICK LINK
- REFOLD PARACHUTE
- REATTACH PARACHUTE TO QUICK LINK
- GRASP PARACHUTE FOR FURTHER ASSEMBLY
- RESUME RECOVERY ASSEMBLY CHECKLIST AT NOMEX INSTALLATION CHECKLIST ITEM

HARDWARE DAMAGE POST-LANDING

- REPLACE HARDWARE FOR FUTURE LAUNCHES
- NASA REQUIRES RE-FLIGHT ON NEW HARDWARE
- NASA REQUIRES RE-FLIGHT IF DATA LOST

6 Project Plan

6.1 Testing

6.1.1 Launch Vehicle Test Suite

Table 30: 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	Wolfline Bus	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

6.1.1.1 Subscale Ejection Test

This test ensures that the calculated values of black powder are sufficient to separate the vehicle for parachute deployment. This will demonstrate the vehicles safe recovery capability with a fully assembled launch vehicle.

Table 31: 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

6.1.1.1.1 Controllable Variables

- Ejection Charge Size

6.1.1.1.2 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 horizontal 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 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

6.1.1.1.3 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

6.1.1.2 Subscale Demonstration Flight

This test ensures that our design functions safely at a smaller scale. Additionally, this test confirms the structural integrity, aerodynamic design, and recovery system are successful and do not need to be modified for use in the full scale design.

Table 32: Subscale Demonstration Flight success criteria.

Success Criteria	Met? (Y/N)
Launch vehicle exits rail travelling 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

6.1.1.2.1 Controllable Variables

- Motor Selection
- Ejection Charge Sizing
- Altimeter Selection
- Launch Vehicle Weight

6.1.1.2.2 Procedure

See Appendix for this test procedure.

6.1.1.2.3 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

6.1.1.3 GPS Test

This test ensures that the GPS is functioning correctly and the team will be able to successfully locate the launch vehicle on launch day after the launch.

Table 33: GPS test success criteria.

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

6.1.1.3.1 Controllable Variables

- Selected GPS tracker
- Selected driving route

6.1.1.3.2 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

6.1.1.3.3 Required Facilities/Equipment/Tools/Software

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

6.1.1.4 Altimeter Test

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.

Table 34: Altimeter test success criteria.

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

6.1.1.4.1 Controllable Variables

- Pressure
- Altimeter Selection

6.1.1.4.2 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

6.1.1.4.3 Required Facilities/Equipment/Tools/Software

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

6.1.1.5 Composite Fin Bending Test

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 35: Composite fin bending test success criteria.

Sucess Criteria	Met? (Y/N)
Composite fin has a calculated factor of safety >2.	TBA
The tested fins show no visible damage or deformation under 122 lbf loading.	TBA

6.1.1.5.1 Controllable Variables

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

6.1.1.5.2 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 is measured using the P-3 reader and the 1K materials tester.
4. force applied is increased incrementally and data recorded until failure

6.1.1.5.3 Required Facilities/Equipment/Tools/Software

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

6.1.1.6 Avionics Bay Tensile Test

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 rocket 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.

Table 36: AV bay tensile test success criteria.

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

6.1.1.6.1 Controllable Variables

- Bulkhead Material
- Bulkhead Thickness

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

6.1.1.6.2 Test Design

- AV bay test piece is assembled to be identical to the full scale AV bay.
- U-bolts of the test piece are inserted into the jaws of the universal testing machine.

6.1.1.6.3 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.

6.1.1.6.4 Required Facilities/Equipment/Tools/Software

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

6.1.1.7 Nose Cone Bulkhead Tensile Test

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.

Table 37: Nose cone bulkhead tensile test success criteria.

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

6.1.1.7.1 Controllable Variables

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

6.1.1.7.2 Test Design

- Nose cone bulkhead assembly test piece is constructed to be identical to the full scale design.
- Nose cone bulkhead is attached to the centering ring using four 1/4-20 bolts.
- U-bolts of the test piece are inserted into the jaws of the universal testing machine.

6.1.1.7.3 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

6.1.1.7.4 Required Facilities/Equipment/Tools/Software

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

6.1.1.8 Shear Pin Shear Loading Test

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.

Table 38: Shear pin loading test success criteria.

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

6.1.1.8.1 Controllable Variables

- Shear Pin Selection
- Force Applied

6.1.1.8.2 Test Design

- Quick links are inserted through 1/4 in. holes in metal testing plates
- #4 holes in the metal testing plates are aligned
- 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

6.1.1.8.3 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.

6.1.1.8.4 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.

6.1.1.9 Rivet Shear Loading Test

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.

Table 39: Rivet shear test success criteria.

Success Criteria	Met? (Y/N)
Rivet calculated factor of safety is >2	TBA

6.1.1.9.1 Controllable Variables

- Rivet Selection
- Force Applied

6.1.1.9.2 Test Design

- Quick links are inserted through 1/4 in. holes in metal testing plates
- Rivet holes in the metal testing plates are aligned
- Rivet is inserted through the rivet hole in the metal testing plates
- U-bolts are placed in the jaws of the universal testing machine

6.1.1.9.3 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.

6.1.1.9.4 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.

6.1.1.10 Full Scale Ejection Test

This test ensures that the calculated values of black powder are sufficient to separate the full scale vehicle for parachute deployment. This will demonstrate the vehicles safe recovery capability with a fully assembled full scale launch vehicle.

Table 40: Full scale ejection test success criteria.

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

6.1.1.10.1 Controllable Variables

- Ejection Charge Size

6.1.1.10.2 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 horizontal 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 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

6.1.1.10.3 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

6.1.1.11 Full Scale Demonstration Flight

This test ensures that our design functions safely for launch day. Additionally, this test confirms the structural integrity, aerodynamic design, and recovery system are successful and do not need to be modified for use during the competition launch day.

Table 41: Full scale demonstration flight success criteria.

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

6.1.1.11.1 Controllable Variables

- Motor Selection
- Ejection Charge Sizing
- Altimeter Selection
- Launch Vehicle Weight

6.1.1.11.2 Procedure

See section 5.4 for this test procedure.

6.1.1.11.3 Required Facilities/Equipment/Tools/Software

- Tripoli Range Safety Officer and Mentor
- FAA approved launch field
- Launch controller

- Assembled launch vehicle
- All tools and hardware identified in section 5.4 test procedure

6.1.2 Payload Test Suite

Table 42: 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

6.1.2.1 Subscale Launch Payload Test

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 43: 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.

6.1.2.1.1 Controllable Variables

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

6.1.2.1.2 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

6.1.2.1.3 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

6.1.2.2 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 44: Camera Operation Test Success Criteria

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

6.1.2.2.1 Controllable Variables

- Camera selection
- Camera orientation

6.1.2.2.2 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.

6.1.2.2.3 Required Facilities/Equipment/Tools/Software

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

6.1.2.3 Camera Clarity Test

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 45: Camera Clarity Test Success Criteria

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

6.1.2.3.1 Controllable Variables

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

6.1.2.3.2 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.

6.1.2.3.3 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

6.1.2.4 Camera System Integration Test

The fully assembled payload bay is tested for its abilty 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 46: Camera System Integration Test Success Criteria

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

6.1.2.4.1 Controllable Variables

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

6.1.2.4.2 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.

6.1.2.4.3 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

6.1.2.5 Camera System RAFCO Test

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 47: Camera System RAFCO Test Success Criteria

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

6.1.2.5.1 Controllable Variables

- Camera selection
- Radio Selection
- Servo Selection

6.1.2.5.2 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.

6.1.2.5.3 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

6.1.2.6 Camera Housing Structural Test

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	TBA
The max force experienced is greater than max force experienced during launch	TBA

6.1.2.6.1 Controllable Variables

- Force Applied
- Camera Housing Material
- Number of Supports

6.1.2.6.2 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.

6.1.2.6.3 Required Facilities/Equipment/Tools/Software

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

6.1.2.7 Camera Unit Mount Test

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.	TBA
The max force experienced by the bolts is greater than max force experienced during launch	TBA

6.1.2.7.1 Controllable Variables

- Force Applied
- Mount Material Infill
- Bolt Sizing

6.1.2.7.2 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.

6.1.2.7.3 Required Facilities/Equipment/Tools/Software

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

6.1.2.8 2-Meter Dipole SWR Test

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 48: 2-Meter Dipole SWR Test Success Criteria

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

6.1.2.8.1 Controllable Variables

- Antenna Length

6.1.2.8.2 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

6.1.2.8.3 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

6.1.2.8.4 Required Facilities/Equipment/Tools/Software

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

- Flush cutters

6.1.2.9 Orientation Detection and Switching Test

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 49: 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

6.1.2.9.1 Controllable Variables

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

6.1.2.9.2 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

6.1.2.9.3 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

6.1.2.9.4 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

6.1.2.10 APRS Reception and Decoding Test

Using the 2-meter Dipole antennas, reception and decoding of APRS signals transmitted on competition frequency needs to be tested. Testing using 70-cm Dipole antennas on non-competition frequency has been completed with the subscale launch vehicle, and fulfilled the following success criteria.

Table 50: APRS Reception and Decoding Test Success Criteria

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

6.1.2.10.1 Controllable Variables

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

6.1.2.10.2 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

6.1.2.10.3 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

6.1.2.10.4 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

6.2 Requirements Verification

6.2.1 NASA Requirements

Table 51: 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 1.1.2 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 1.1.2.
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	Not Verified	Through the events that have been held so far, the minimum number of participants has not yet been reached.
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.

Continued on next page

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	Not Verified	The team emails all deliverables to the NASA project management team by each specified deadline.
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	Not 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	Not Verified	The team plans to use all provided equipment for Launch Day.

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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 1.1.2
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 1.1.3
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 3.7 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 3.6.1 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	Not Verified	TBD
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	Not Verified	Launch day checklists have not been created yet.
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	Not Verified	TBD
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	Not Verified	TBD
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 3.2.11 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 3.2.11 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	Not Verified	No motor change is expected.
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 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	Not Verified	See section 3.2 regarding the launch vehicle design.
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	Not Verified	See section 3.2 regarding the launch vehicle design.
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	Not Verified	See section 3.2 regarding the launch vehicle design.
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	Not Verified	See section 3.2 regarding the launch vehicle design.
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 3.7.4 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 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 3.7.4 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 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 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 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 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 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 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 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 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	Not Verified	See section 6.5 for project timeline regarding planned VDF date.
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	Not Verified	The launch vehicle has not currently been constructed or launched.
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	Not Verified	The launch vehicle has not currently been constructed.

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NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
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	Not Verified	The payload has not currently been constructed.
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	Not Verified	The payload has not currently been constructed.
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	Not Verified	The payload has not currently been constructed.
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD

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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	Not Verified	TBD
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	Not Verified	See section 6.5.1 for the project timeline regarding PDF deadline.
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	Not Verified	TBD
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	Not Verified	The payload has not currently been constructed.
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	Not Verified	TBD
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	Not Verified	See section 6.5 for project timeline regarding PDF.
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	Not Verified	TBD
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	Not Verified	TBD

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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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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 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 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 3.2.8.3 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 3.7.2 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 3.7.6 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 3.6.1.1 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 3.6.1.1 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 3.6.1 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 3.6.1 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 3.6.1 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 3.6.1 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 3.6.1 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 3.7.7 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 3.6.1.2 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 3.6 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 3.6 for recovery system design.

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NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
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 3.6 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 3.6 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 3.6.1 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; Demonstration	Recovery	Verified	See section 3.7.9 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; Demonstration	Recovery	Verified	See section 3.7.8 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; Demonstration	Recovery	Verified	See section 3.6.1.3 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 3.6 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; Demonstration	Recovery	Not Verified	See section 3.6 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; Demonstration	Recovery	Verified	See section 3.6 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 3.6 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 3.6 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 3.6 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 3.6 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 4.3 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 4.3 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 4.3.1.2.3 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 4.3.1.2.2 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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	See section 4.5 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	Not Verified	See section 4.5 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	Not Verified	See section 4.5 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	Not Verified	See section 4.5 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	Not Verified	TBD
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 4.3 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	Not 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	Not Verified	Currently, there are no plans to utilize UAS for the 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	Current launch and safety checklists are included in section 5.4. A final checklist for Launch day will be included in the FRR report.
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	Not 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.
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	TBD
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	Not Verified	Completed safety checklists for subscale launch are provided in the CDR. Safety checklists for full-scale launches and competition launch will provided in future documentation.
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	Not Verified	TBD
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	TBD

6.2.2 Team Derived Requirements

Table 52: 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	Not Verified	Current manufacturing procedures specify at least a 24-hour cure period for all epoxied parts.
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 0.49. See section 3.7.2 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 3.7.2 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 3.2.9 for the simulation details. Future documentation will include additional simulations and testing.
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 3.2.8.1 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 3.2.8 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 3.7.4 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 for the bulkhead analysis calculations. Additional testing and analysis will be presented in future documentation.
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 3.2.5 regarding the avionics bay design.
Environmental Requirements						

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Launch Vehicle						
ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
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 3.2.2 for the selected material regarding the launch vehicle design.
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 3.2.2 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 111. 6ft/s.
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 3.6.1.6 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 3.6.1 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 3.6.1 for launch vehicle 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 3.6.1 regarding 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 3.6.1 regarding use of Nomex cloth.
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 3.6.1 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 4.3.1.2.2.
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 4.3.1 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 4.3.1.1 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 4.3.1 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 3.2.10 for payload weight estimations.
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 4.3.1.2.2 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 4.3.1.1 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 4.3.2.1 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 4.3.2.2 regarding SOCS 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-tight.	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 4.3.2 regarding SOCS structural design.

6.3 Budget

Table 53 below details the year-long budget for the 2022-2023 Student Launch Competition.

Table 53: 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

Payload	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)	8	$ 898.45	$ 7,187.60
	Mentor Hotel Rooms – 4 nights (# Rooms)	2	$ 1022.03	$ 2,044.06
	NCSU Van Rental (# Vans)	1	$ 798.00	$ 2,394.00
	Subtotal:			**$ 11,625.66**
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:				**$ 21,356.86**

As highlighted in Figure 84, our expenses can be divided into different sub-sections with travel funds taking up the majority of our spending for this year.

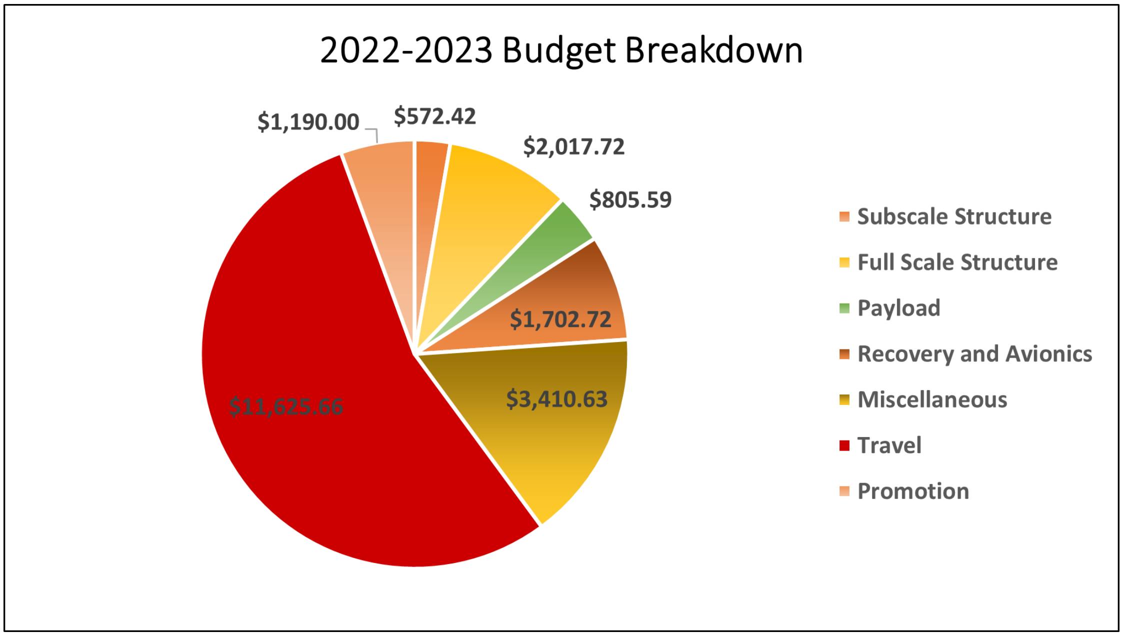

Figure 84: Budget breakdown of the 2022 - 2023 competition year.

6.4 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, a request of $2,000 was submitted for the fall semester and another $2,000 request will be submitted in the spring semester, assuming SGA regulations and budget will remain the same.

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 covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurricular activities at NC State. Based on the 2021-2022 academic year, it is estimated we will receive $7,500.

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 will review the proposal and inform the club of the amount awarded. In previous academic years, this has been the maximum amount of $5,000, which will be available for use starting November 2022.

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 54 below, which outlines the projected costs and incoming revenue for the 2021-2022 academic year.

Table 54: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$2,500	$2,500
Engineering Enhancement Fund	$0	$7,500	$7,500
NC State Student Government	$2,000	$2,000	$4,000
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$1.000	$1,500	$2,500
Total Funding:			**$21,500.00**
Total Expenses:			**$21,317.70**
Difference:			**$182.30**

6.5 Project Timelines

6.5.1 Competition Deliverables Timeline

Table 55: 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

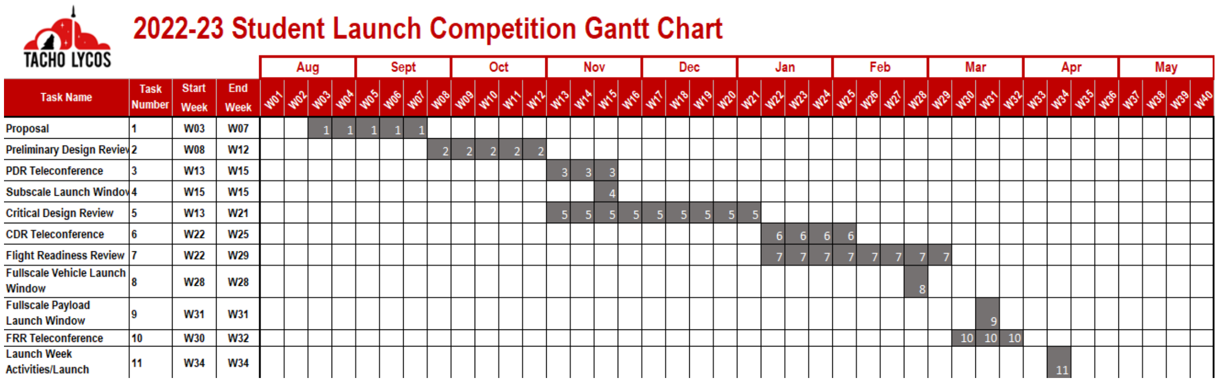

Figure 85: A Gantt chart containing the official NASA competition deadlines.

Table 56: Outreach Event Schedule

Event Name	Date	Estimated Participants
Apex Friendship High School	12-Oct	65
Joyner Elementary Science Go Round	9-Nov	100
Science Olympiad Group	5-Dec	6
Lacy Elementary STEM Night	10-Jan	50
Fred Olds Elementary	11-Jan and 13-Jan	50
Astronomy Days at NC Museum of Natural Sciences	28-Jan and 29-Jan	125
Engineers Day at the Museum of Life and Science	4-Mar	50
Laurel Park Elementary STEAM Night	9-Mar	50
NSBE Jr. Chapter of RTP	February	25
	TOTAL PARTICIPANTS:	521

6.5.2 Funding Timeline

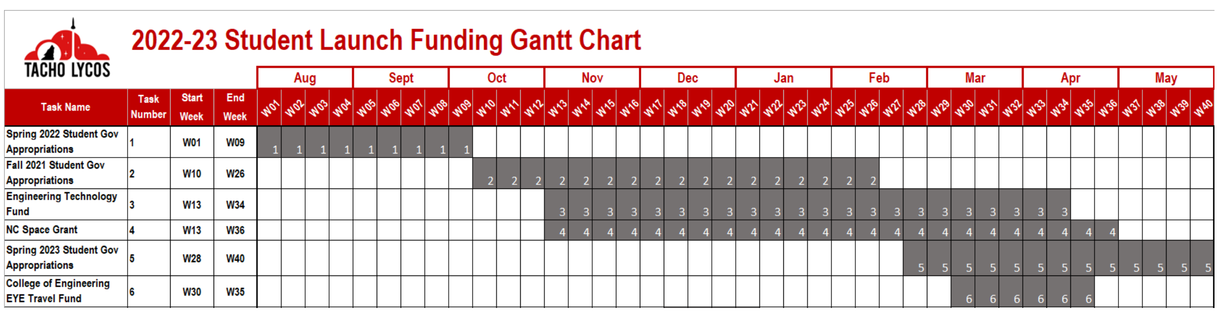

Figure 86: A Gantt chart detailing when our funding sources are available for use.

6.5.3 Development Timelines

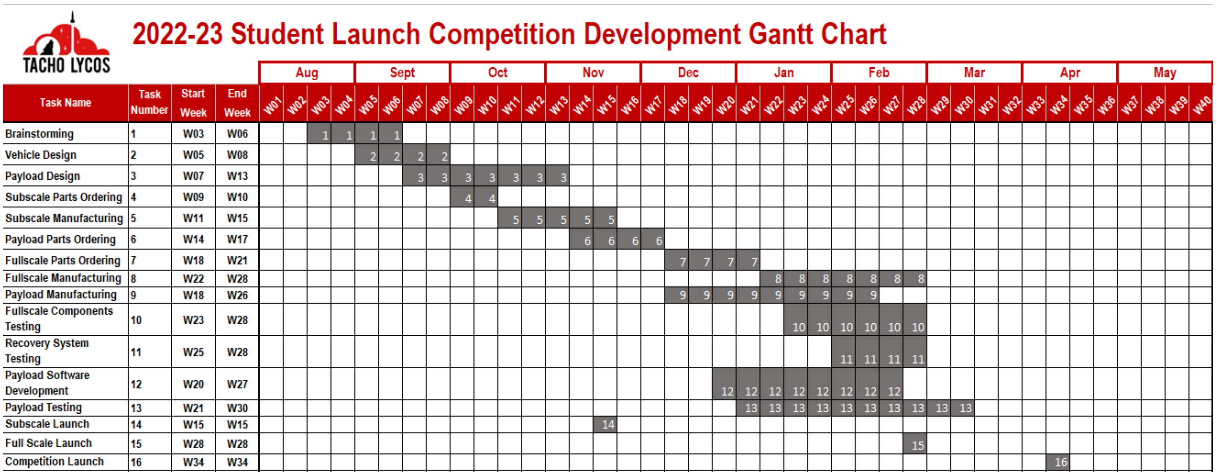

Figure 87: A Gantt chart detailing launch vehicle and payload development schedules.

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 88: 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 89: 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 90: Subscale Build Calendar

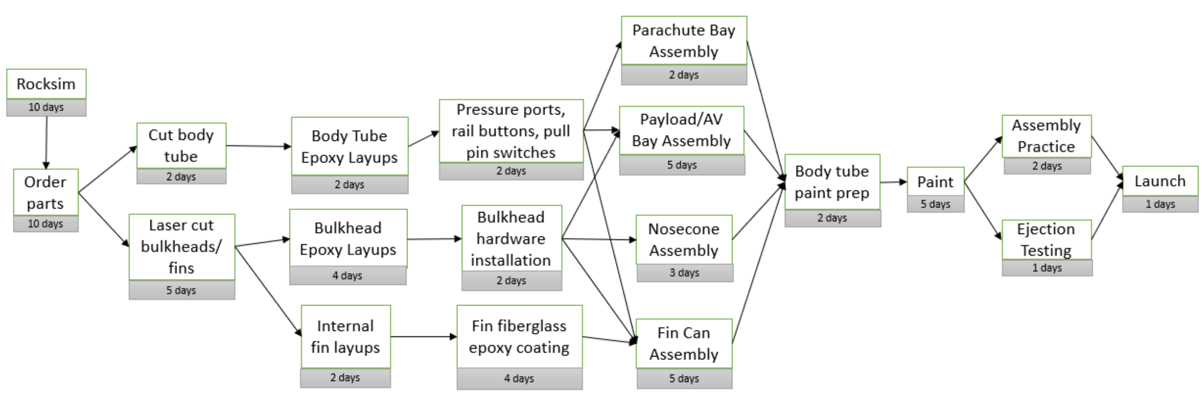

Figure 91: A PERT chart for the construction of the launch vehicle.

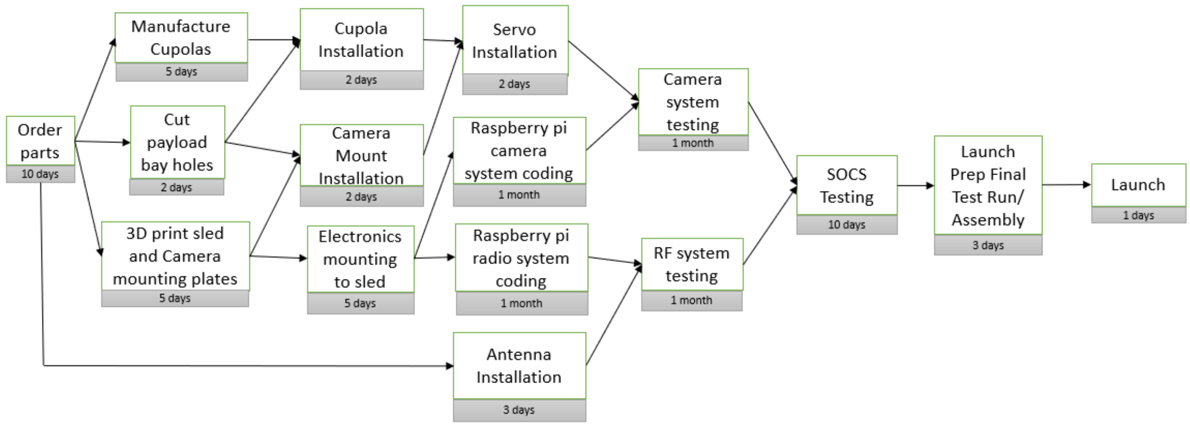

Figure 92: A PERT chart for the construction of the payload.

References

[1] URL: https://www.csrocketry.com/building-supplies/aeropack/retainer-assembly/75mm-p.html.

[2] AeroTech L1520T. URL: https://www.thrustcurve.org/motors/AeroTech/L1520T/.

[3] AISI Type 304 Stainless Steel. URL: https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=mq304a.

[4] Amazon.com: Arducam Multi Camera Adapter Module V2.2 for Raspberry Pi 4 ... URL: https://www.amazon.com/Arducam-Camera-Adapter-Raspberry-Cameras/dp/B07TYL36MC.

[5] Amazon.com: Nooelec RTL-SDR V5 bundle - NESDR smart HF/VHF/UHF (100kHz ... URL: https://www.amazon.com/NooElec-NESDR-Smart-Bundle-R820T2-Based/dp/B01GDN1T4S.

[6] Amazon.com: Sunfounder 2 channel DC 5V relay module with Optocoupler ... URL: https://www.amazon.com/SunFounder-Channel-Optocoupler-Expansion-Raspberry/dp/B00E0NTPP4.

[7] Barrowman Equations. Aug. 2008. URL: http://www.rocketmime.com/rockets/Barrowman.html.

[8] Handbook of Finnish Plywood. 2002. URL: https://%20www.koskisen.com/file/handbook-of-finnish-plywood/.

[9] W. LUDTKE. "A technique for the calculation of the opening-shock forces for several types of solid cloth parachutes". In: 4th Aerodynamic Deceleration Systems Conference (1973). DOI: 10.2514/6.1973-477.

[10] Pololu - screw terminal block: 2-pin, 5 mm pitch, side entry (4-pack). URL: https://www.pololu.com/product/2440.

[11] Kevin Townsend. Adafruit BNO055 absolute orientation sensor. URL: https://learn.adafruit.com/adafruit-bno055-absolute-orientation-sensor.

[12] Eben Upton. Raspberry pi 4 on sale now from $35. June 2019. URL: https://www.raspberrypi.com/news/raspberry-pi-4-on-sale-now-from-35/.

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

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 ✓

6

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	
Team Lead	Meredith Patterson	
Structures Lead	Mike Pudlo	
Personnel 1	Cameron Brown	
Personnel 2	Katelyn Yount	

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	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	[illegible]
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 [redacted] 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

add tape measure →

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	-	✓

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	✓
8.16	Confirm payload is buzzing to ensure activation	n/a
8.17	Use $ ssh pi@raspberrypi.local (password:raspberry)	✓
8.18	Start tmux session	✓

	$ 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

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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~~ 500
(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

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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