NC STATE UNIVERSITY

Tacho Lycos
2021 NASA Student Launch
Flight Readiness Review

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27695

March 8, 2021

Common Abbreviations & Nomenclature

AGL = above ground level
APCP = ammonium perchlorate composite propellant
ARRD = advanced retention and release device
AV = avionics
BP = black powder
CDR = Critical Design Review
CG = center of gravity
CP = center of pressure
DÁVÍD = Device for Assisting in Validation of Integration and Deployment
EIT = electronics and information technology
FAA = Federal Aviation Administration
FMEA = failure modes and effects analysis
FN = foreign national
FoS = factor of safety
FRR = Flight Readiness Review
HEO = Human Exploration and Operations
HPR = High Power Rocketry
HPRC = High-Powered Rocketry Club
L3CC = Level 3 Certification Committee (NAR)
LCO = Launch Control Officer
LOPSIDED = Lander for Observation of Planetary Surface Inclination, Details, and Environment Data
LRR = Launch Readiness Review
MAE = Mechanical & Aerospace Engineering Department
MSDS = Material Safety Data Sheet
MSFC = Marshall Space Flight Center
NAR = National Association of Rocketry
NCSU = North Carolina State University
NFPA = National Fire Protection Association
PDF = Payload Demonstration Flight
PDR = Preliminary Design Review
PLAR = Post-Launch Assessment Review
POS = Planetary Observation System
PPE = personal protective equipment
RFP = Request for Proposal
RSO = Range Safety Officer
SL = Student Launch
SME = subject matter expert
SOW = statement of work
SSTV = Slow-Scant Television
STEM = Science, Technology, Engineering, and Mathematics
TAP = Technical Advisory Panel (TRA)
TRA = Tripoli Rocketry Association
VDF = Vehicle Demonstration Flight

Table of Contents

List of Tables

List of Figures

1. Summary of FRR 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, NC 27695
Primary Contact: Evan Waldron, emwaldro@ncsu.edu, (919)-448-1396

1.1.2 Mentor Information

Name: Alan Whitmore
Email: acwhit@nc.rr.com
Phone: (919)-929-5552
TRA Certification: Level 3, 05945

Name: Jim Livingston
Email: livingston@ec.rr.com
Phone: (910)-612-5858
TRA Certification: Level 3, 02204

1.1.3 Time Spent on FRR Milestone

The team spent a total of 240 hours working towards completion of the FRR milestone.

1.2 Launch Vehicle Summary

1.2.1 Official Target Altitude

The team's official target altitude is 4473 feet. See section 3.5.1 for justification.

1.2.2 Final Motor Choice

The team's final motor selection is the Aerotech L1520T. See section 3.5.3 for justification.

1.2.3 Launch Vehicle Size and Mass

The as-built launch vehicle is 110.25 inches long with a diameter of 6.17 inches. The fully loaded mass of the launch vehicle with the final motor onboard is 49.3 lbs. See section 3.1 for additional launch vehicle size discussion.

1.2.4 Recovery System

The recovery system design is a dual-deployment system controlled by two independent PerfectFlite Stratologger CF altimeters. An 18-inch drogue parachute will be deployed at apogee, and a 120-inch main parachute will be deployed at 700 feet AGL. See section 3.4.1 for discussion of the recovery system.

1.3 Payload Summary

The lander has been designated the Lander for Observation of Planetary Surface Inclination, Details, and Environment Data, abbreviated to LOPSIDED. The imaging system contained within LOPSIDED is designated the Planetary Observation System, abbreviated as POS. During the descent of the launch vehicle, the LOPSIDED-POS system will be removed from the payload bay by the main parachute recovery harness. The LOPSIDED-POS will then detach itself from the recovery harness by means of an Advanced Retention Release Device (ARRD). The LOPSIDED-POS will descend under its own parachute. After landing, LOPSIDED will record its angle relative to vertical, then disengage four solenoid latches, allowing gravity to rotate two concentric rings such that LOPSIDED is oriented vertically with respect to gravity. LOPSIDED will then record its final orientation. The POS will then capture an image from each of the four onboard cameras. The POS will then transmit these images over slow-scan television to a laptop located in the team's prep area. The laptop will then be used to combine these separate images into a single 360-degree panoramic image.

2. Changes Made Since CDR

2.1 Changes Made to Launch Vehicle

Table 2-1 below lists all changes made to the launch vehicle since CDR, along with justification of these changes.

Table 2-1 Changes to Launch Vehicle Since CDR

Description of Change	Justification of Change
The main parachute bay has been lengthened from 17 inches to 19 inches.	Additional space is required to pack the main parachute and its associated hardware. This change has been approved by the Student Launch team.
The forward AV bay coupler has been shortened from 6 inches to 2 inches.	Additional space is required to pack the main parachute and its associated hardware. This reduction is deemed acceptable since the forward AV coupler is not an in-flight separation point. This change has been approved by the Student Launch team.
The main parachute will now be packed behind the piston in the main parachute bay.	This allows for all hardware to fit within the payload coupler and main parachute bay. When the main parachute previously resided in the payload coupler, there was not sufficient room to join all sections of the launch vehicle.
The forward rail button has been moved from the middle centering ring to the engine block.	This reduces the risk of the rail buttons binding on the launch rail due to the forward CG of the launch vehicle.
The exposed section of the nose cone is 26 inches long instead of 24 inches.	Due to a misinterpretation of manufacturer dimensions, the nose cone is 2 inches longer than predicted. The nose cone is still a 4:1 ogive geometry, as these extra 2 inches are a straight section at the base of the nose cone.
The payload parachute has been changed from a Fruity Chutes 60” Iris Ultra Compact to a Fruity Chutes 48” Classic Elliptical.	The LOPSIDED-POS weight as built was lower than designed resulting in the LOPSIDED-POS exceeding wind drift limits with the larger parachute selected at the CDR level design, so a smaller parachute was selected.

2.2 Changes Made to Payload

Table 2-2 below lists all changes made to the payload since CDR, along with justification of these changes.

Table 2-2 Changes to Payload Since CDR

Description of Change	Justification of Change
An Arduino Nano is now used in addition to a Stratologger CF altimeter for control of the payload retention latch.	Continuous current must be provided to the retention latch to keep it unlocked. The altimeter alone is only capable of instantaneous current, so an Arduino controller is necessary.
SSTV will now be used for image transmission instead of digital SSTV (DSSTV).	DSSTV is much more difficult to implement, and documentation is limited compared to SSTV.
The metal brackets connecting the LOPSIDED landing legs to the leveling system rings are now straight instead of curved.	Limited manufacturing capabilities available to the team made curved brackets not feasible. There is no appreciable difference in strength between the curved and straight brackets.
The LOPSIDED electronics sled is now offset from the center of the LOPSIDED lower compartment.	This offset places the battery as close to the center of LOPSIDED's vertical axis as possible, improving the leveling accuracy of LOPSIDED.

2.3 Changes Made to Project Plan

Table 2-3 below lists all changes made to the project plan since CDR, along with justification of these changes.

Table 2-3 Changes to Project Plan Since CDR

Description of Change	Justification of Change
The Payload Demonstration Flight will now be conducted separately from the Vehicle Demonstration Flight. The PDF is scheduled for March 20, 2021.	The payload was not ready in time for the VDF, so a mass simulator was flown in its place. A separate PDF is now necessary.
The maximum transmission range required by TDR 4.14 has been reduced from 4500 ft to 2500 ft.	Since the team will be launching at the team's home field in Bayboro, NC, the team is able to locate its ground station closer to the launch pad than at the Huntsville launch site. The payload will land within 2500 ft of the launch pad.

3. Vehicle Criteria

3.1 Launch Vehicle Design

3.1.1 Full Assembly

When fully assembled, the launch vehicle is 110.25 inches long with a launch weight of 49.3 lbf and empty weight of 43.6 lbf. The nose cone design has changed based on a misunderstanding with dimensions given by the manufacturer, which is explained in more detail in Section 3.1.2. The dimensions of the AV bay and main parachute bay have been adjusted to give more space for the recovery system. The launch vehicle will separate between the payload bay and main parachute bay and between the AV bay and fin can. Black powder will be in blast caps on either end of the AV bay and in the ARRD on the payload.

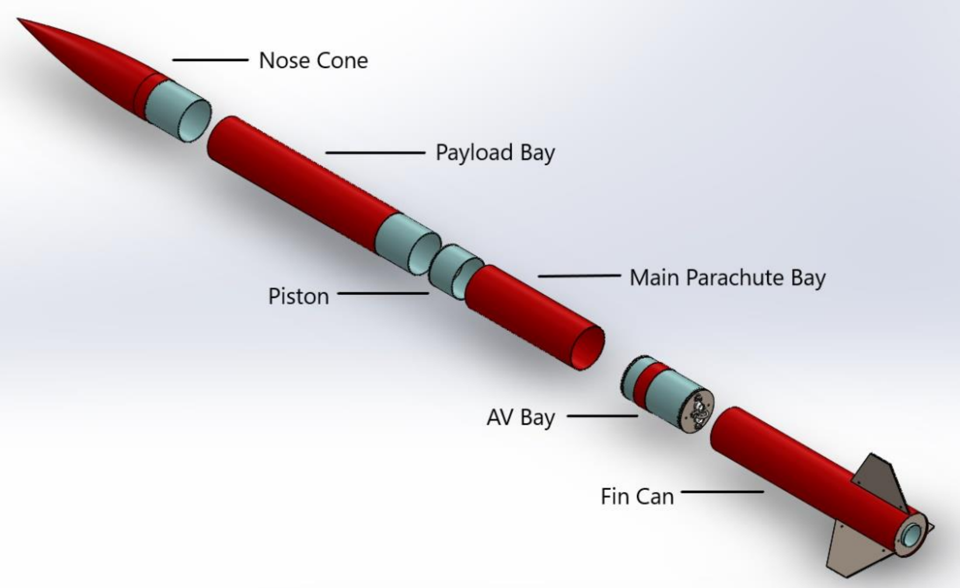


Figure 3-1 Launch Vehicle Sections

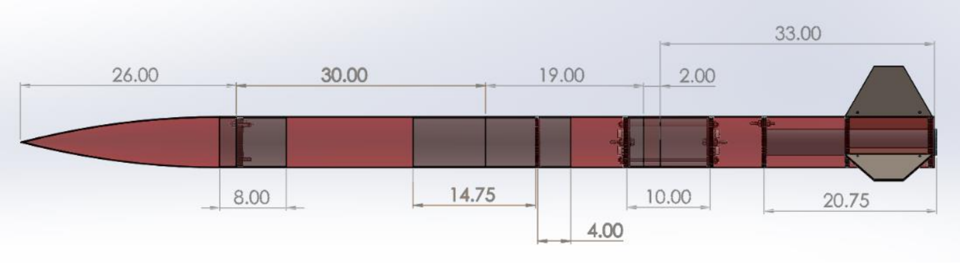


Figure 3-2 Launch Vehicle Dimensions

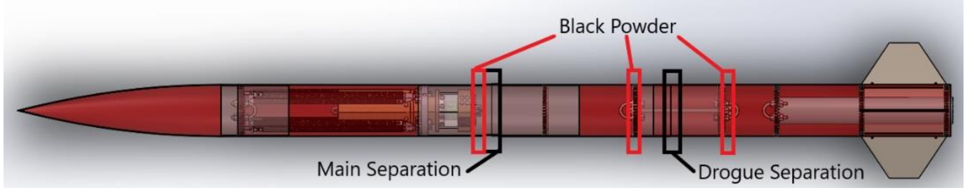


Figure 3-3 Launch Vehicle Points of Separation and Energetic Materials

3.1.2 Nose Cone

The nose cone design changed due to a misunderstanding with the manufacturer. It was expected that the nose cone would be a 24-inch-long 4:1 ogive with an integrated coupler. However, the part we received was 26 inches long and came with the coupler as a separate part. The extra 2 inches were completely straight to allow for a coupler to be inserted. The nose cone bulkhead is still positioned in the same place with respect to the aft edge of the nose cone.

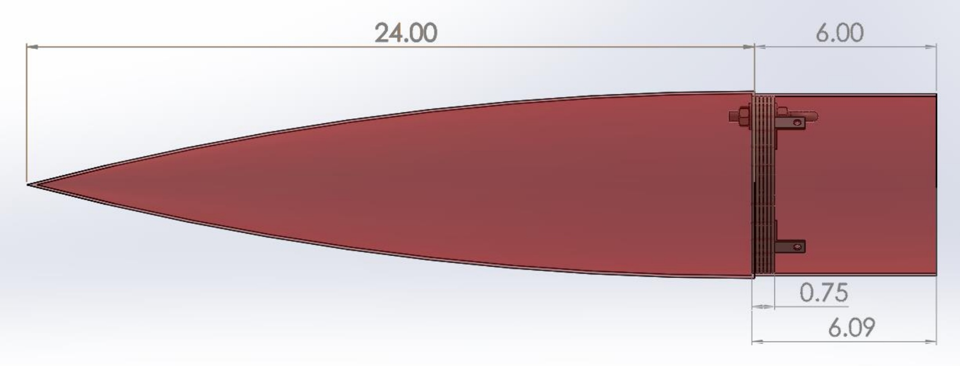


Figure 3-4 CDR Expected Nose Cone Dimensions

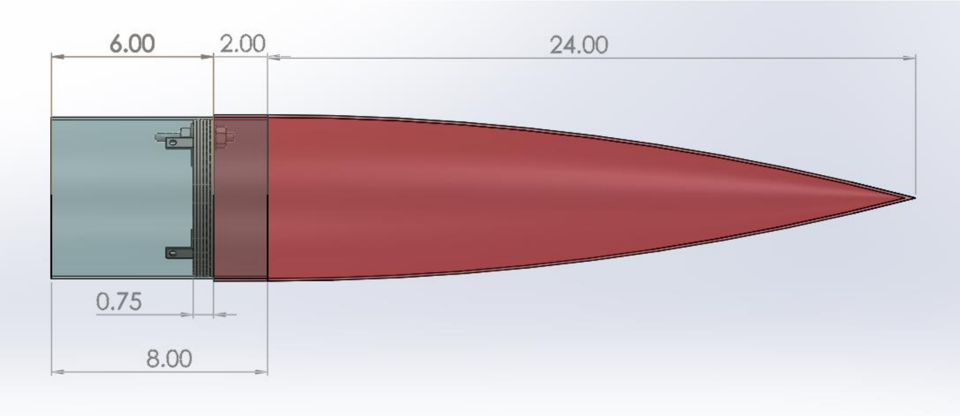


Figure 3-5 Actual Nose Cone Dimensions

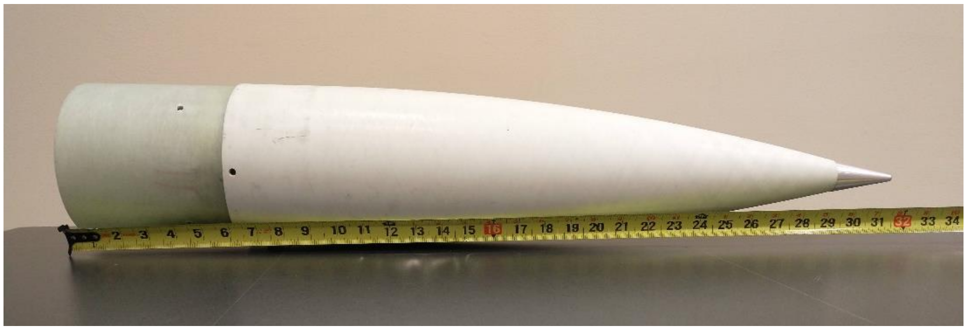


Figure 3-6 Nose Cone

3.1.2.1 Nose Cone Bulkhead

The basic design of the nose cone bulkhead is unchanged since CDR. The latch and associated electronics that have since been added are discussed in Section 4.6.1.2.

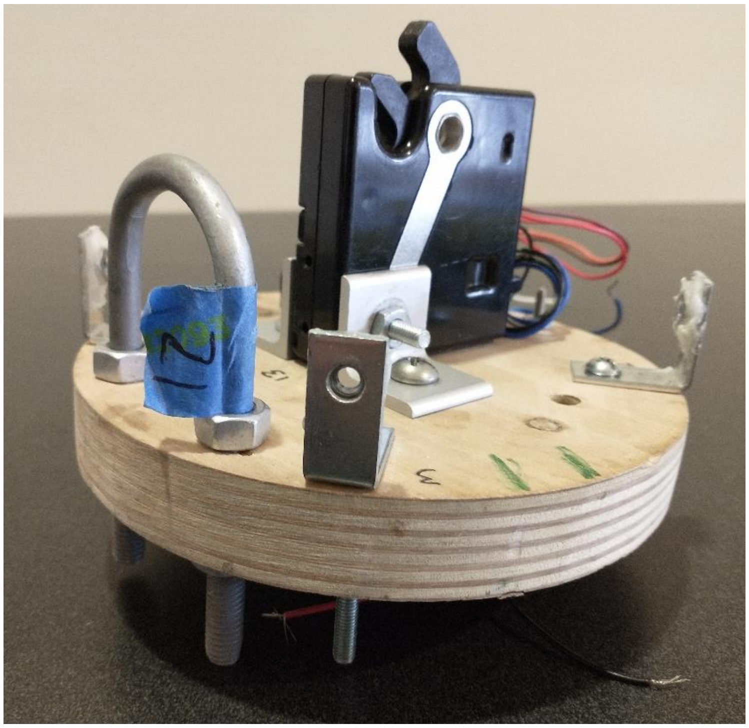


Figure 3-7 Nose Cone Bulkhead

3.1.3 Payload Bay

The dimensions of the payload bay itself are unchanged since CDR, but the coupler section has had a slight modification. The team realized that the location of the payload ring was to be more than 6 inches from the aft end of the payload bay. It was intended that the payload ring would sit inside the coupler section so upon deployment it would not get caught on the transition from body tube to coupler. To remedy this, an additional 2.75 inches of coupler section were added inside the payload bay where the payload ring could be secured.

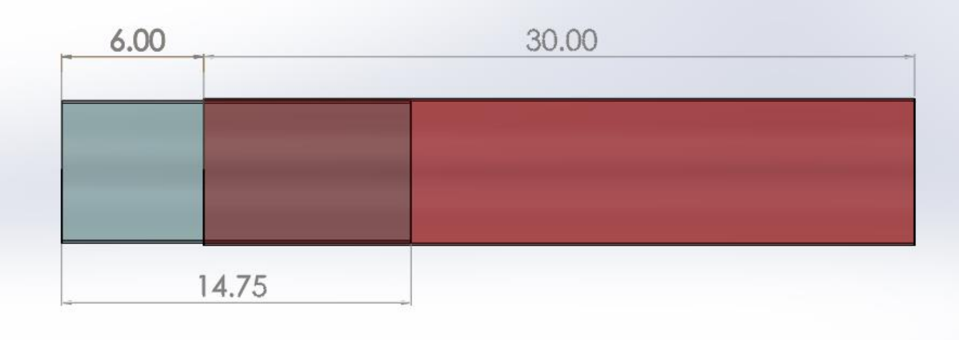


Figure 3-8 Payload Bay Dimensions

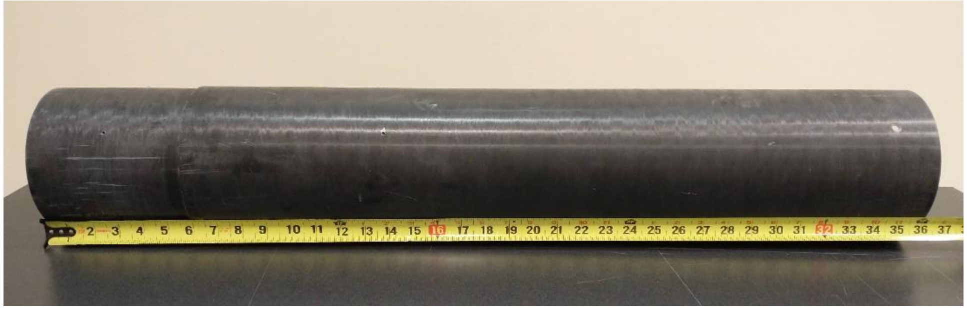


Figure 3-9 Payload Bay

3.1.4 Main Parachute Bay

The main parachute bay has been lengthened to 19 inches to accommodate extra space for parachutes and shock cord, but the piston remains unchanged.

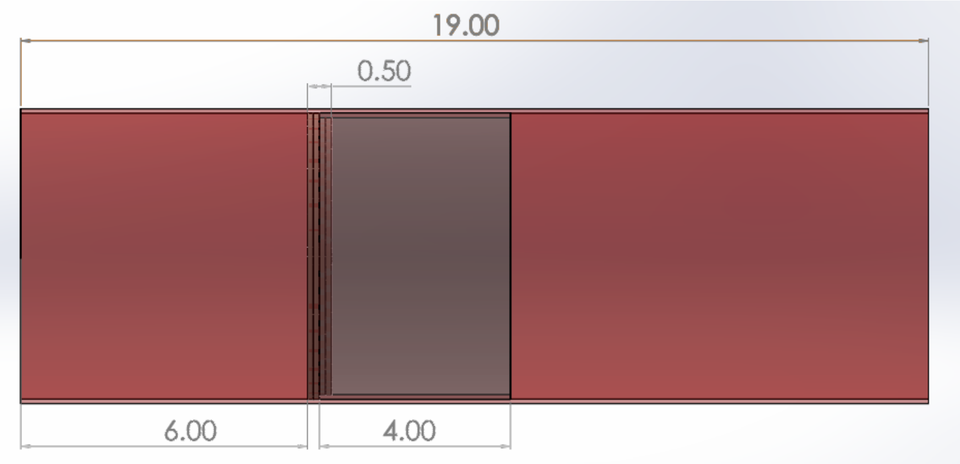


Figure 3-10 Main Parachute Bay Dimensions

Figure 3-11 Main Parachute Bay

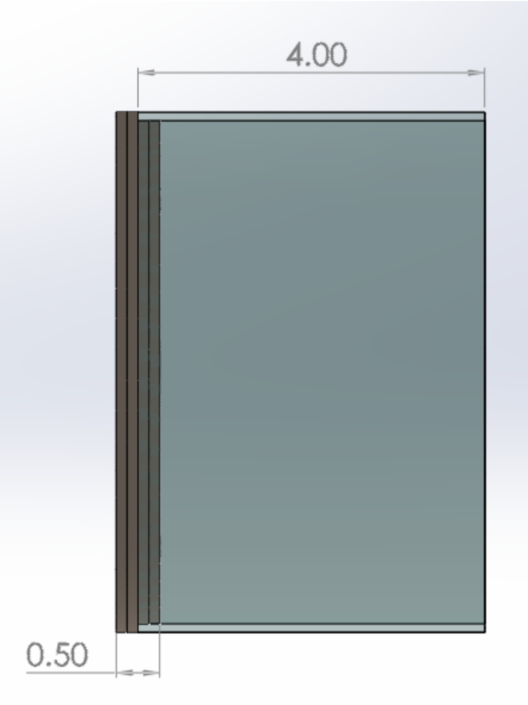


Figure 3-12 Piston Dimensions

Figure 3-13 Piston

3.1.5 AV Bay

The basic design of the AV Bay and bulkheads are unchanged since CDR, but the dimensions have been altered slightly. Due to some issues with packing parachutes and other recovery materials, the team decided to shorten the forward end of the AV coupler by 4 inches to accommodate extra space for the parachutes.

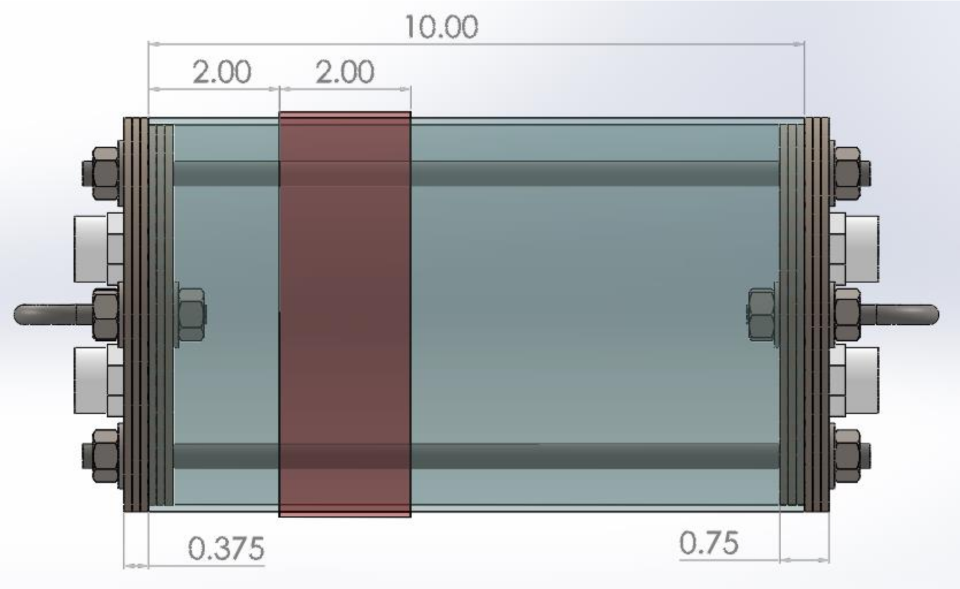


Figure 3-14 AV Bay Dimensions

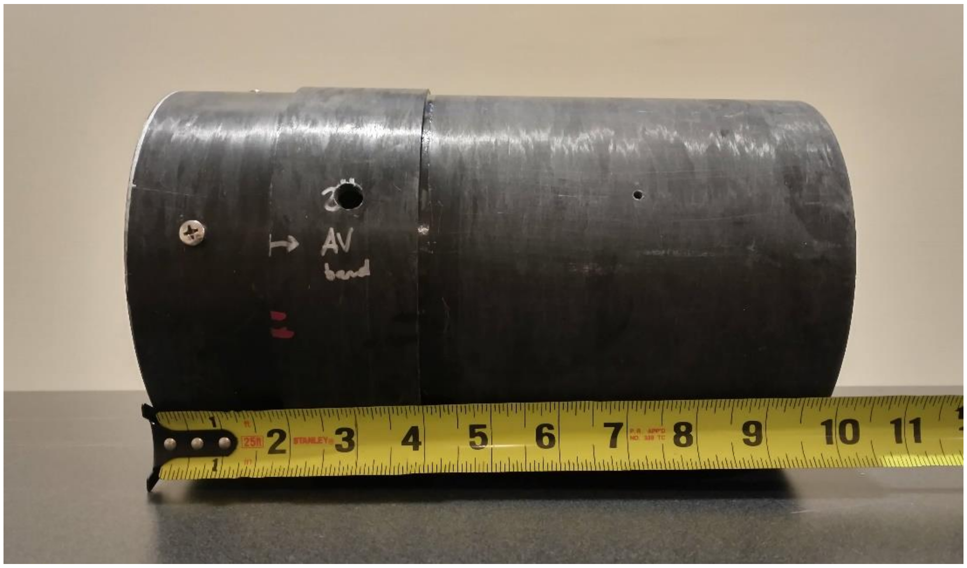


Figure 3-15 AV Bay

3.1.6 Fin Can

The fin can dimensions remain unchanged since CDR.

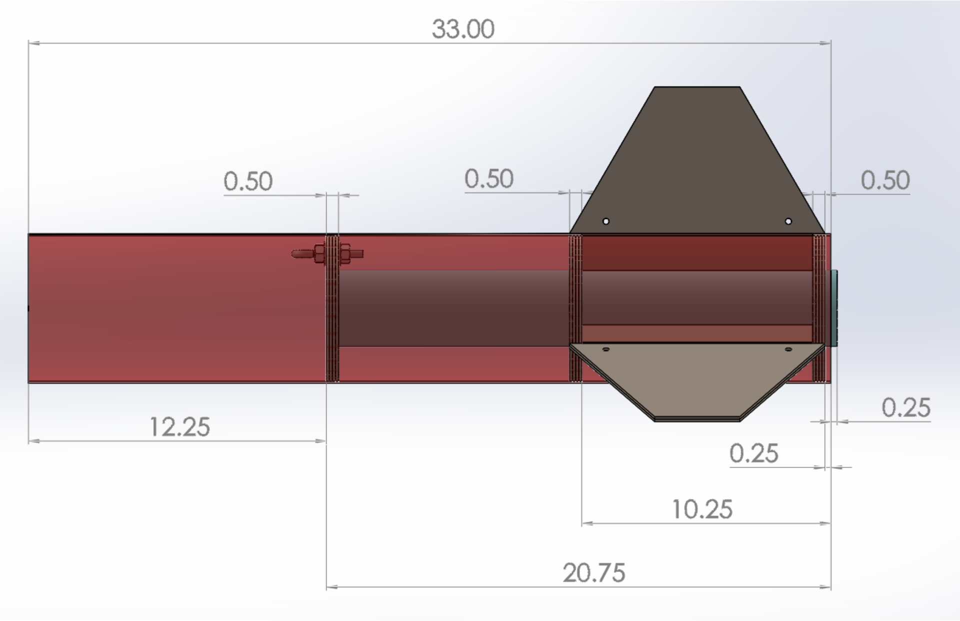


Figure 3-16 Fin Can Dimensions

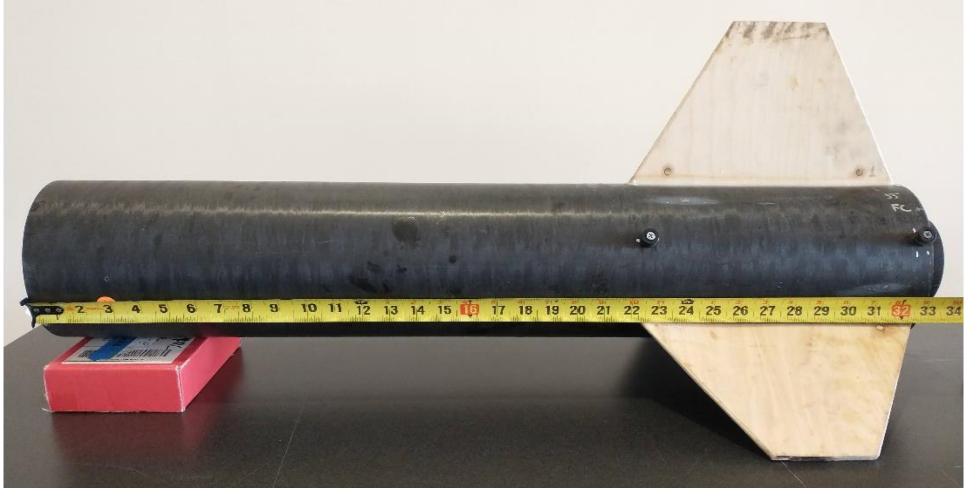


Figure 3-17 Fin Can

3.1.7 Payload Mass Simulator

Since the final payload was not ready in time for the vehicle demonstration flight, a payload mass simulator was built to take its place. The mass simulator was designated the Device for Assisting in Validation of Integration and Deployment, or the DÁVÍD. The DÁVÍD was made to be approximately the same size and weight of the payload, as well as have its center of gravity in the same location in the rocket.

The body of the DÁVÍD was adapted from the body of the payload and measured 17 inches not including external hardware. An ARRD was mounted to the aft end to separate from the main shock cord along with two U-bolts that hooked into the payload parachute. Another U-bolt was attached to the forward end which attached to the latch on the nose cone bulkhead via quick links.

To reach the estimated 9 lbf payload mass, additional weight needed to be added to the DÁVÍD in the form of lead pellets and epoxy. 3D printed spacers were added inside the DÁVÍD to help place the correct volume of lead pellets at the desired center of gravity location. The additional space past the spacers was used to mount an altimeter used to control the ARRD and hinges were added to one of the side panels for easy access. Before the lead pellets and epoxy were poured in, a small metal tube was inserted through the spacers to route wires from the altimeter to the ARRD. As a last touch, a 1/2-inch plywood ring was slid over the DÁVÍD so it could be held in the payload coupler with 4-40 nylon shear pins. A small portion was cut from the ring so the parachute shock cord could pass through.

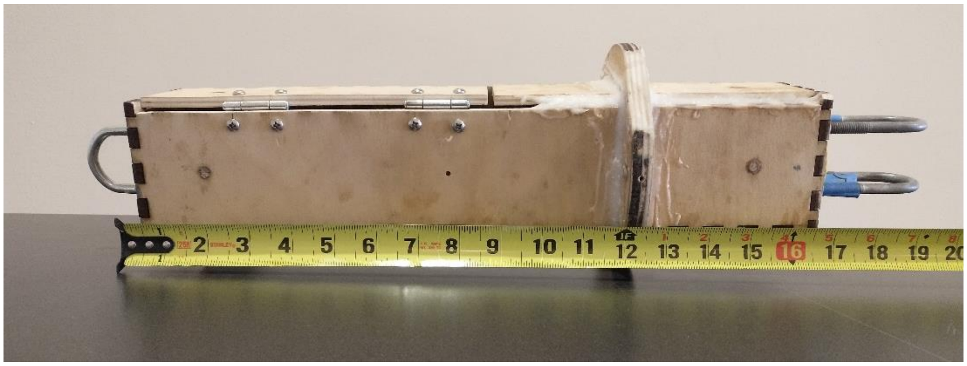


Figure 3-18 DÁVÍD Side View

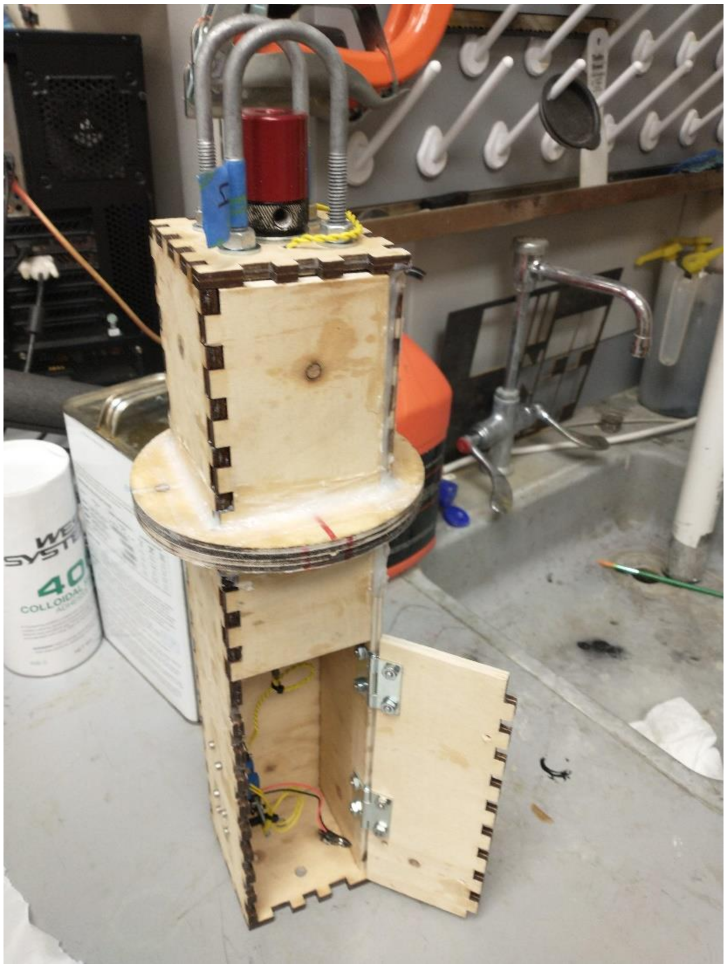


Figure 3-19 DÁVÍD Standing Vertical

3.1.8 Test Pieces

Two test pieces were built alongside the launch vehicle that were meant to test the structural integrity of the nose cone bulkhead and the AV bulkheads. The design has identical bulkheads mounted on either side of a short piece of coupler section and U-bolts on each bulkhead that are connected to a universal testing machine. The tensile machine would increase the tensile loading until either the plywood, the nose cone bolts, or the AV threaded rods failed. These pieces would help to confirm the validity of the ANSYS simulations and that our parts had a sufficient factor of safety per requirement TDR 2.2. Additionally, to shear test the nose cone bolts and shear pins, holes were made in two small pieces of steel so they could be mounted in the universal testing machine as shown in Figure 3-24.

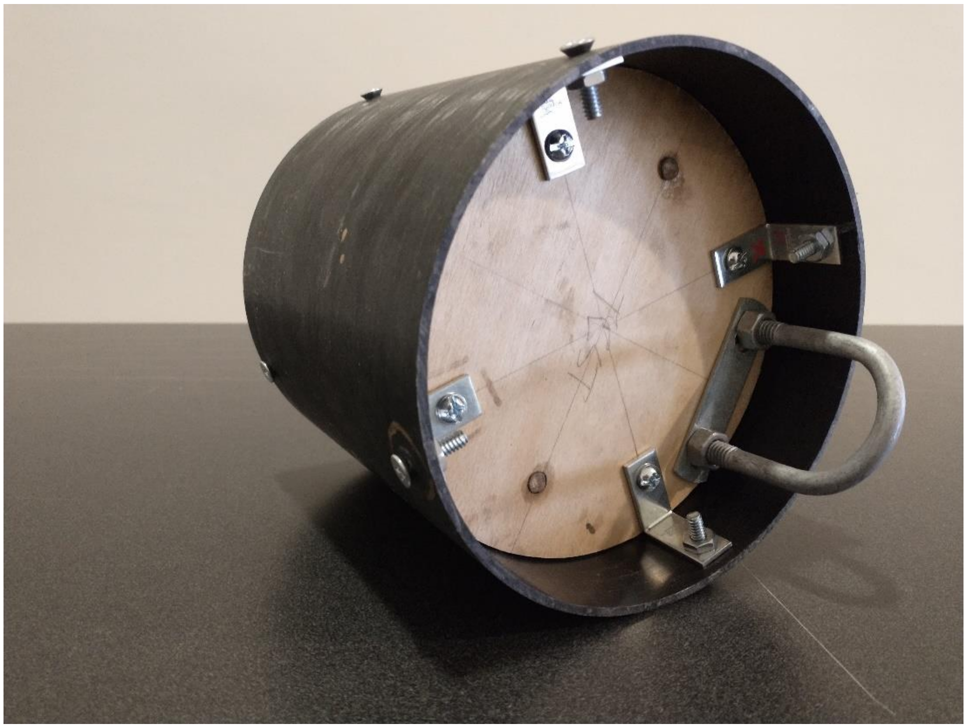


Figure 3-20 Nose Cone Bulkhead Test Piece

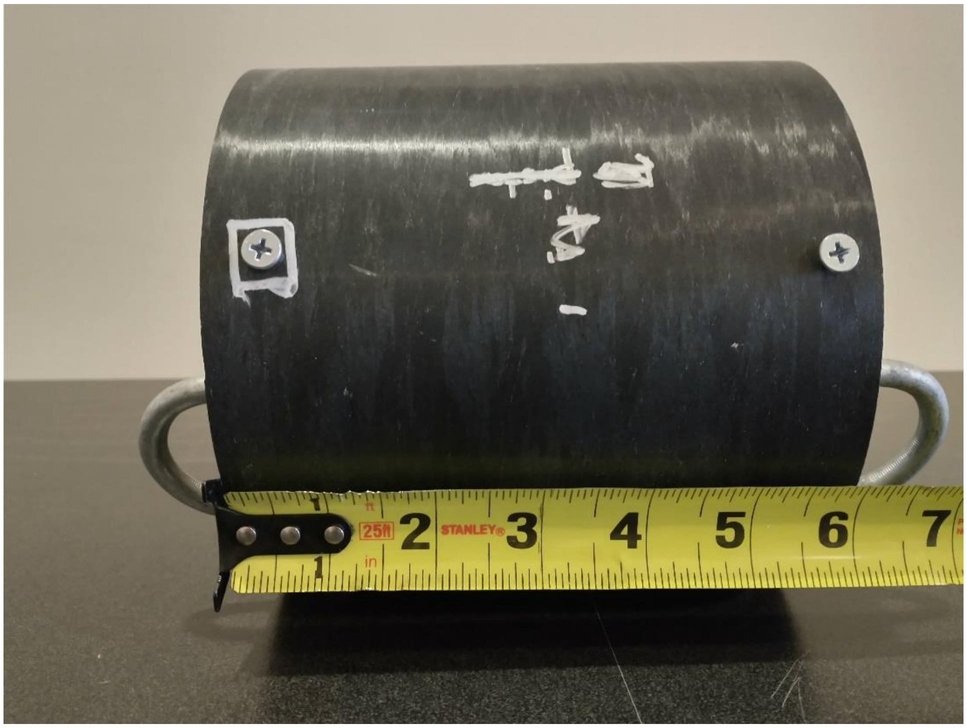


Figure 3-21 Nose Cone Bulkhead Test Piece Dimensions

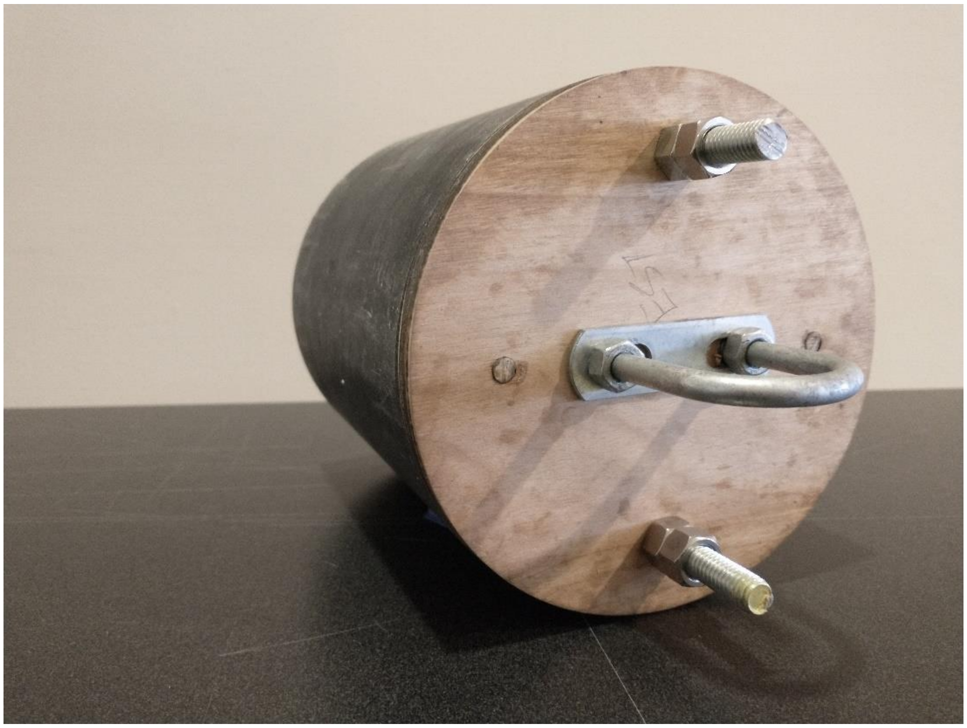


Figure 3-22 AV Bulkhead Test Piece

Figure 3-23 AV Bulkhead Test Piece Dimensions

Figure 3-24 Shear Testing Plates

3.2 Flight Reliability

3.2.1 Structural Elements

3.2.1.1 Airframe

The airframe of the launch vehicle is made from G12 fiberglass which is one of the strongest available materials for hobby rocketry due to its durability and damage resistance. As proven by many previous launches, this material can easily resist in-flight loads as well as any impacts upon landing. Another important feature is its water resistance, which will prevent damage to the airframe should it land in water. These characteristics will allow the launch vehicle to be launched and recovered safely.

3.2.1.2 Fins

Each fin is made of two layers of 1/8-inch aircraft grade birch plywood for greater strength. The fins are secured with epoxy connections to the motor tube, middle centering ring, and fin slots. These connections are then filleted to distribute stress more evenly. The process is described in more detail in Section 3.3.3.2. While the fins do not experience extremely high loadings, these connections prevent undesired movement during flight or damage upon landing.

3.2.1.3 Bulkheads

All the bulkheads in the launch vehicle are made of layers of 1/8-inch thick aircraft-grade birch plywood which is stronger than typical plywood. The designs for each bulkhead were tested using ANSYS to ensure they would have a high enough factor of safety under expected loading as per requirement TDR 2.2. Physical tests of the nose cone and AV bulkheads are scheduled to occur the week after the FRR document is due to COVID-19-related delays in lab access. Based on success in past years using similar designs and the same material, the team can be confident in the reliability of these parts. An example of the FEA analysis is shown in the Figure 3-25 below. Table 3-1 below gives the expected maximum loading and factor of safety for each part. The maximum deployment force on each of the bulkheads has changed since CDR, these changes are reflected in Table 3-2.

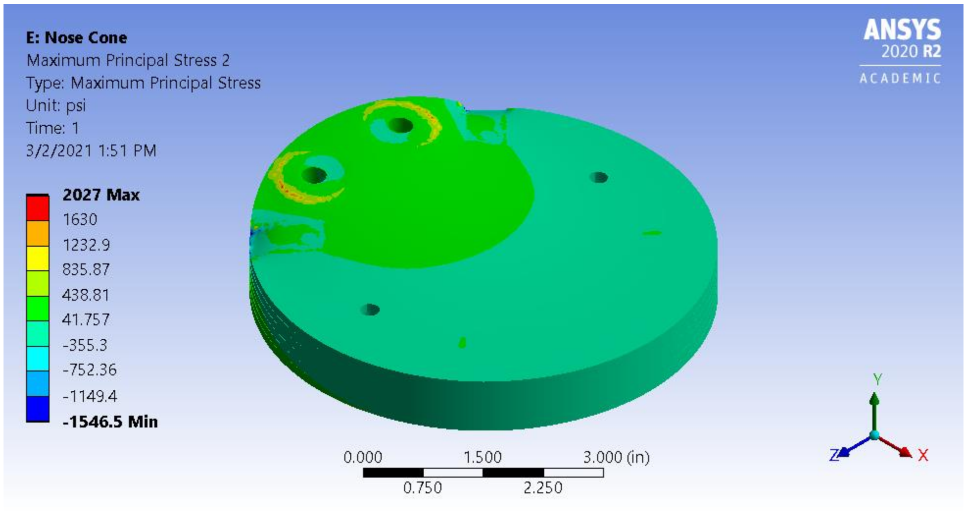


Figure 3-25 Maximum Principle Stress on Nose Cone Bulkhead

Table 3-1 Maximum Stress and FoS for Each Bulkhead

BULKHEAD	MAX FORCE (lbf)	MAX STRESS (psi)	F.o.S.
Nose Cone	206	1600	2.81
AV Bay	343	2200	2.05
Engine Block	106	488	9.23
Aft Centering Ring	397	427	10.5

3.2.1.3(a) Epoxy Connection

The centering rings and engine block in the fin can are secured with an epoxy connection. The mixture of West Systems 105 Epoxy Resin and 206 Slow Hardener has a tensile strength of 7,320 psi, which is more than strong enough to hold the bulkheads in place considering the loading they experience. Fillets are also added to the connection by mixing the epoxy with 406 Colloidal Silica, which helps distribute stress and further increases the strength.

3.2.1.3(b) Bolted Connection

The nose cone bulkhead is held in place by 4 10-24 machine screws which go through the body tube and the L-brackets mounted to the bulkhead. Structural simulations found that the bolts closest to the U-bolt only experience 100 lbf of loading. These screws have a tensile strength of about 1000 lbf, and their shear strength can be estimated as about 60% of this value, or 600 lbf. This gives a factor of safety of 6 which is more than required. Sections of the body tube are bolted together in a similar fashion, described in more detail in Section 3.3.2.3. Shear testing will be done to find the exact strength of the bolts, but success in past flights with similar designs gives confidence in the connection.

3.2.1.3(c) Threaded Rods

The AV bulkheads are held in place by 3/8-inch-thick threaded rods. These rods have a load capacity of 600 lbf. With the highest deployment loading expected at 343 lbf, this gives the threaded rods a factor of safety of 3.5 since the force is split between the two of them, so they should easily resist deployment forces.

3.2.1.3(d) Attachment Hardware

U-bolts are used on most of the bulkheads as mounting points for shock cord. Structural simulations show that the maximum deployment forces will not be enough to damage the bulkheads to the point that the U-bolts are ripped out. Washers and plates are also used to better distribute the applied loading. The U-bolts themselves are 5/16-inches thick with a load capacity of 600 lbf. The yield strength of the U-bolts is likely higher than the capacity. With the highest deployment loading expected at 343 lbf, the U-bolts should have a factor of safety greater than 2 and should be able to resist deployment forces.

3.2.2 Electrical Elements

3.2.2.1 Wiring

All onboard wiring is comprised of 16-gauge copper wire. Quick disconnects are used for all portions of the wiring harness running between different sections of the launch vehicle, for example between the AV sled and AV bulkheads. Wires are secured to fixed portions of the launch vehicle (i.e. bulkheads, AV sled) using zip ties.

3.2.2.2 Switches

All four altimeter arming switches and the GPS arming switch are Missile Works 6-32 screw switches. These are secured to laser cut frames using 4-40 nylon standoffs and bolts. The laser cut frames are epoxied to a secure portion of the launch vehicle or LOPSIDED-POS. All wiring harness connections to the switches are soldered and remove before flight tags are used to prevent premature contact being made by the screw switch on all switches used to arm energetic materials.

3.2.2.3 Battery Retention

All onboard batteries are contained on the AV sled, nosecone bulkhead, or onboard the LOPSIDED-POS. On the AV sled are two 9V batteries powering the altimeter and a 7.4V LiPo battery used to power the GPS tracker. All three of these batteries are mounted inside laser cut boxes, held closed by four 4-40 machine screws. The nosecone contains an additional 9V battery and a 12V battery powering the payload retention altimeter and the rotary latch, respectively. The 12V battery is mounted in an off the shelf battery holder epoxied to the nosecone bulkhead. The 9V battery controlling the payload ascent retention setup is contained in a 3D printed PLA plastic housing, through bolted to the nosecone bulkhead using two 6-32 machine screws.

3.2.2.4 Avionics Retention

All avionics components are mounted using 4-40 machine screws and nylon standoffs. These fasteners are through bolted to robust structural components such as bulkheads or the AV sled.

3.3 Launch Vehicle Construction

3.3.1 Bulkhead Assembly

3.3.1.1 Laser Cutting

The bulkheads were designed in Solidworks with laser cutting in mind, so the parts already had the necessary holes for any hardware needed. The CAD files for the bulkhead layers, the fins, and some of the AV sled parts were exported so they could be read by the VLS6.60 laser cutter. Some issues were encountered using the laser cutter, but all parts were able to be cut in one visit.

Figure 3-26 Laser Cutting in Progress

3.3.1.2 Layups

To prepare for layups, all the layers were sanded to promote adhesion. A 1/4-inch dowel rod was cut into short pieces to go through the bulkheads and help keep the layers aligned while the epoxy cured. With the dowel rod cut, two-part epoxy was mixed and applied in a thin layer between each of the contacting faces. To prevent excess epoxy from leaking out of the bulkheads as they cured, which would require extra sanding, the team was careful to use only the necessary amount of epoxy. With all the bulkheads and fins properly coated in epoxy and assembled, they were each wrapped in a layer of peel ply to prevent the epoxy from sticking to anything. They were then wrapped again in a layer of burlap breather material to ensure vacuum would be applied evenly. A sheet of vinyl was used in conjunction with plumber's putty to create a seal around the parts and then a vacuum line was inserted and turned on. Weights were placed atop each of the parts to add extra compression. The epoxy only takes 10-15 hours to cure, but the parts were left to cure for 24 hours as a precaution and as specified by TDR 1.1.

Figure 3-27 Bulkhead Layups

3.3.1.3 Hardware

Once the epoxy had cured, the bulkheads and fins were removed. A small amount of excess epoxy had leaked out the sides and into the pre-cut holes, so the parts were sanded and filed until a good fit was achieved. With this done, U-bolts were added to the nose cone bulkhead, AV bulkheads, and the engine block. In addition, threaded rods were added to the AV bulkheads and L-brackets were mounted to the nose cone bulkhead.

3.3.2 Body Tube Assembly

3.3.2.1 Machine Shop

The fiberglass tubing was only available in specific lengths and our lab's tools could not cut through the 0.085-inch wall thickness, so the machine shop's assistance was required to cut the tubes to the lengths required. The tubes were measured to the correct length then brought to the machine shop's bandsaw to be cut. Once cut, the fiberglass dust and lubricant were washed off, then the cut ends were sanded to ensure they were smooth and level.

Figure 3-28 Body Tube in Bandsaw

Since the body tube supplier did not offer to cut fin slots as part of the order, the machine shop's assistance was required again. Using a mill, the machine shop supervisor was able to cut the three slots to the correct dimensions.

Figure 3-29 Fin Slots Cut by Mill

3.3.2.2 Epoxy

Once the pieces had been cut the 2-inch AV switch band was centered on the AV coupler and epoxied into place. Additionally, the payload coupler was epoxied in place with 6 inches exposed to meet requirement NASA 2.5.1. Contact info for our team lead was written on the aft AV bay coupler to meet requirement NASA 2.20.

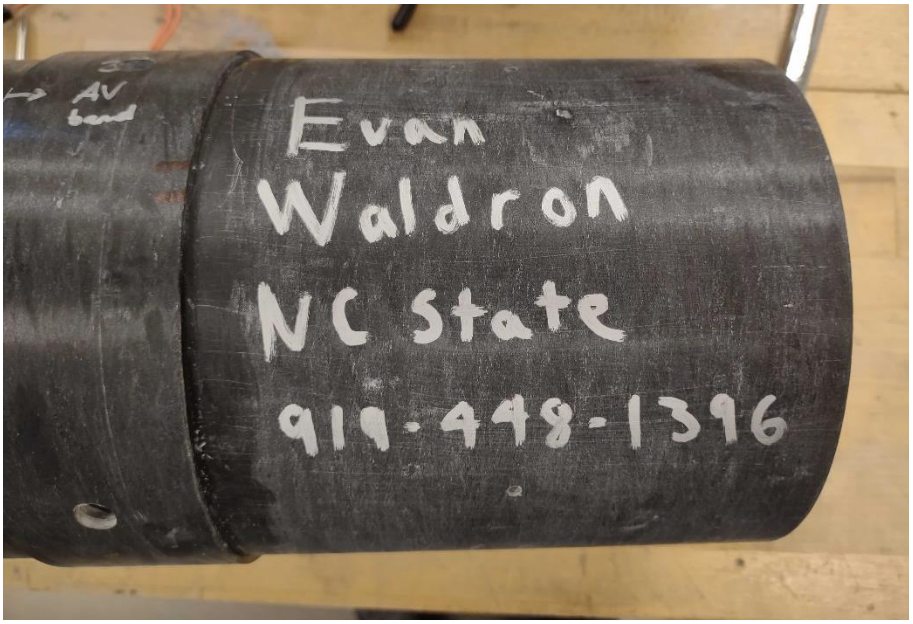


Figure 3-30 Team Lead Contact Info

3.3.2.3 Attachment Points

With the epoxy cured, the attachment points between each of the section had to be made. The separation points between the payload bay and main parachute bay as well as the AV bay and fin can were to be held together with 4-40 nylon shear pins. The tubes were slid together and four holes were marked evenly spaced around the circumference. One through hole was drilled matching the size of the shear pins. A single pin was then inserted to prevent the tubes from rotating and the remaining three holes were drilled. A similar process was followed for the bolted connections between the nose cone and payload bay and the main parachute bay and AV bay. Four equally spaced through holes matching the diameter of the bolts were drilled through the tubes. The tubes were separated, and a larger drill bit was used to create a countersink in the body tube to help the bolt sit flat relative to the surface of the launch vehicle. Because the nose cone bulkhead and the inside of the AV bay would be exceedingly difficult to reach to hold nuts in place, the nuts were epoxied to the inside surface of the AV bay and to the L-brackets on the nose cone bulkhead. This allows for the bolts to be threaded into the nuts from outside the launch vehicle without needing access to the inside.

Figure 3-31 Nuts Secured to the Inside of the AV Bay

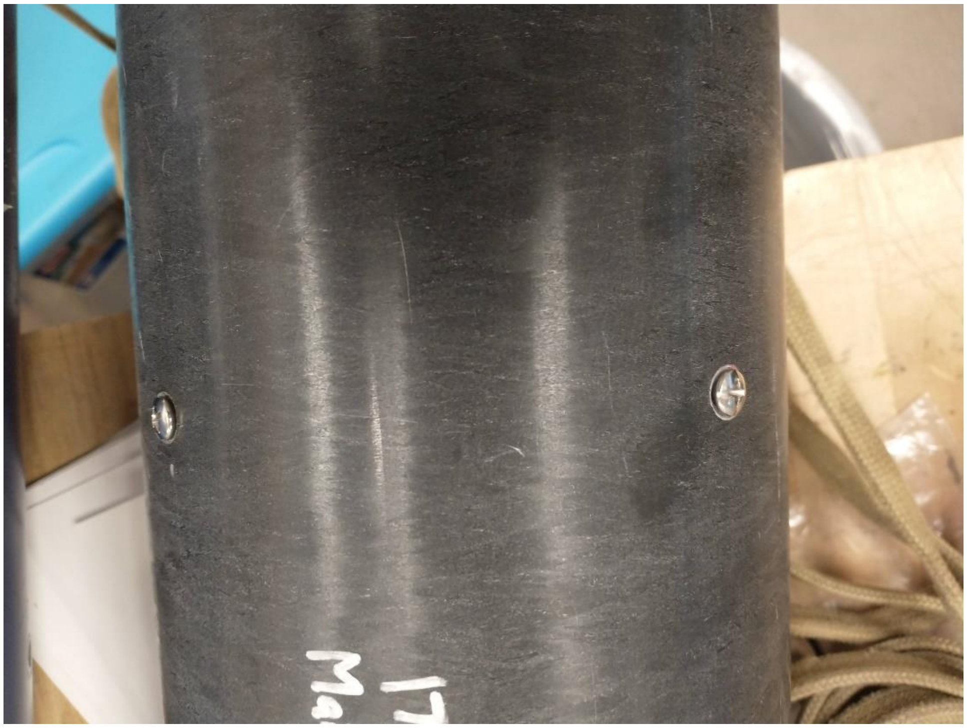


Figure 3-32 Bolted Connection between Main Parachute Bay and AV Bay

3.3.3 Fin Can Assembly

3.3.3.1 Motor Tube

The fin can assembly started with the construction of the motor tube assembly. The middle centering ring was slid onto the motor tube and epoxied at the desired location. The motor tube was then stood vertically using the fin jig to support the centering ring at the correct height. The engine block was then placed on top of the motor tube and epoxied in place. Once the epoxy had cured, fillets were added between the centering ring and engine block where they contacted the motor tube as this area would be unreachable once placed in the fin can. The entire motor tube assembly was then slid inside the fin can to the correct depth and left to cure.

Figure 3-33 Motor Tube Assembly

3.3.3.2 Fins

With the motor tube assembly in the fin can, the fins were ready to install. Some sanding and filing had to be done to ensure a smooth fit into the slots. A Dremel was then used to round the fin tabs and the edges of fins themselves to give them better aerodynamic performance. With this done, the fins were epoxied in place. The inside of the fin can was then filleted at all intersections between the fins, the body tube, the motor tube, and the middle centering ring to ensure the fins would be secure. The laser cut fin jig was used to keep the fins aligned while the epoxy and fillets cured. Fillets were also added to the outside of the fin can around the fin slots, this time using painter's tape to give smoother fillets.

Figure 3-34 Fin Can in Fin Jig

3.3.3.3 Motor Retainer and Rail Buttons

With the fins in place, the fin can could be closed off with the aft centering ring. The aft centering ring was slid overtop the motor tube and epoxied in place. Then fillets were added around the outer edge where it met the body tube. The motor retainer was then placed over the remaining motor tube and epoxied in place, with an additional fillet at its base for a stronger connection.

Figure 3-35 Motor Retainer

The locations of the two fin can centering rings had been marked on the outside of the body tube so that rail buttons could later be installed. Two vertically aligned holes were drilled through the fiberglass and bulkheads ensuring that they would not be in line with any bolt holes or shear pin holes as this would cause issues on the launch rail. A larger bit was used to drill through the fiberglass so that the wood screws would only need to thread into the wood of the bulkheads. The two 1515 rail buttons were then screwed into the launch vehicle.

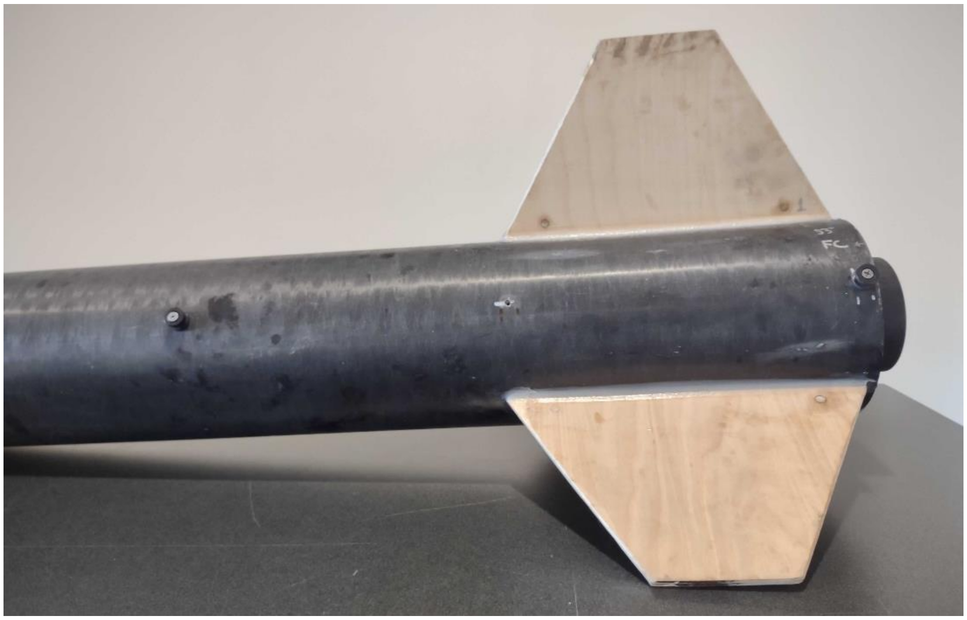


Figure 3-36 Rail Buttons

3.3.4 Nose Cone Assembly

The nose cone coupler came as a separate piece from the nose cone itself, so the coupler would need to be epoxied in later. Before inserting the coupler, four evenly spaced holes were drilled into the coupler. These would align with the bolt holes in the payload bay and would hold the nose cone bulkhead in the correct position with respect to the nose cone. The coupler was then epoxied in place with 6 inches exposed as per requirement NASA 2.5.2.

Figure 3-37 Nose Cone Coupler Attached

3.3.5 AV Sled Construction

The AV sled is made from laser cut, 1/8 inches thick aircraft grade birch plywood. Jigsaw style pieces were laser cut out, and the interlocking teeth were bonded together using wood glue. The AV sled was assembled in two halves, with the wiring mounted on the inside of the sled. The two halves of the AV sled were secured together by the same 3/8-inch threaded rods that secured the AV sled to the AV bulkheads.

3.3.6 Payload Mass Simulator

The basic structure for the DÁVÍD was laser cut and the layers were epoxied together to be 2 layers thick as opposed to the payload which is 3 layers thick. The U-bolts and ARRD were mounted in appropriate locations on the end pieces and the structure was assembled and epoxied together with one side left open so more work could be done inside. Two hinges were then attached to the door so it could be closed during flight but could be opened to access the altimeter.

Figure 3-38 The DÁVÍD Structure Being Assembled

Calculations were done to find the density of the lead pellets and epoxy mixture and the approximate volume needed to reach 9 lbf as found. Two spacers were 3D printed to hold the lead pellets in the correct location. The larger spacer was made with space for the U-bolts to stick through and had a hex-shaped hole to hold a nut that the ARRD could thread into. Both spacers were coated with a thickened epoxy mixture so epoxy would not leak out of the specified area.

Figure 3-39 3D Printed Spacers

With the volume marked, epoxy and lead pellets were added until the weight totaled 9 lbf. A portion of the door was cut off and epoxied over top of the spacers and the lead pellets to ensure it would not come loose. Once everything had cured, a ring was slid over this portion of the DÁVÍD and epoxied in place at the center of gravity. Fillets were added for additional strength and four equally spaced holes were drilled in the ring matching holes in the payload coupler where it was to be mounted.

Figure 3-40 Lead and Epoxy Mixture

3.3.7 Test Pieces

The test pieces were made at the same time as the launch vehicle, so their construction process was similar. The bulkheads were all made the same way and hardware was mounted once they were pulled out of the vacuum seal. The AV bulkhead test piece was assembled at this point as it only needed the threaded rods to hold it together. With the L-brackets mounted to the two test nose cone bulkheads, holes were marked and drilled at either end of the coupler section so the bulkheads could be mounted. The U-bolts on the nose cone bulkheads were aligned so the test piece would not rotate in the universal testing machine.

3.4 Recovery Subsystem

3.4.1 Summary

All recovery system events are controlled by four PerfectFlite StratoLogger CF Altimeters and two Jolly Logic Chute Release parachute retention devices. Of the four altimeters, one acts as the primary flight controller while a second controls a redundant system. These two altimeters control the launch vehicle recovery events. They are mounted to an avionics sled made from laser cut 1/8” aircraft grade birch plywood and mounted inside the avionics bay to two parallel threaded rods. A third altimeter, mounted to the nosecone bulkhead, controls the R4-EM rotary latch and the fourth altimeter, mounted onboard the LOPSIDED, acts to separate the LOPSIDED-POS from the main parachute shock cord. The two parachute retention devices are interlocked to form a redundant system keeping the payload parachute furled during the deployment of the main parachute and main recovery harness. All altimeters are armed using four independent screw switches, accessible from outside the airframe through holes in the nosecone, payload bay, and AV switch band. These holes are large enough to fit a screwdriver and serve as sampling ports for the altimeters.

At apogee, the primary altimeter detonates a black powder charge, separating the fin can from the midsection. One second after apogee, the secondary altimeter will detonate the redundant backup black powder charge in case of failure of the primary system. Also at apogee, the latch altimeter will unlatch the R4-EM rotary latch. The two sections descend under a Fruity Chutes 18” Classic Elliptical drogue parachute tethered to the two sections by a 40 ft length of 5/16” tubular Kevlar shock cord. The drogue parachute is protected by a 9” sheet of Nomex fabric. Loops in the end of the shock cord are formed using bowline knots and connected to U-bolts on structural bulkheads using 5/16" quick links. The aft end of the drogue shock cord is secured to a permanent bulkhead in the fin can, while the forward end is secured to the removable aft AV bulkhead. This bulkhead is held in place by two 3/8” threaded rods and lock nuts compressing the aft AV bulkhead and the companion forward AV bulkhead on the opposite side of the AV coupler. This AV can assembly contains the main and drogue ejection charges, avionics sled, and the launch vehicle altimeters.

At 700 ft, the primary altimeter will detonate the primary main parachute black powder charge, separating the nosecone and payload bay from the midsection. At 650 ft the secondary altimeter will fire the backup black powder charge. Following this event, the launch vehicle will descend under a Fruity Chutes 120” Iris UltraCompact main parachute, stored and protected up until ejection by a Nomex deployment bag. The nosecone and midsection are tethered together by an identical length of shock cord to the drogue recovery harness and make use of the same 5/16" quick links to connect to bulkheads. The aft end of the main recovery harness is tethered to the forward AV bulkhead, discussed above. The forward end of the same is tethered to a removable bulkhead in the nosecone. Also tethered to the main recovery harness is the LOPSIDED-POS by way of the ARRD, and the payload parachute which is stored in a Nomex deployment bag. The payload parachute is kept furled during flight by a pair of redundant chute releases, discussed previously. At 600 ft, these chute releases will unlatch, freeing the payload parachute.

The payload altimeter will detonate the ARRD black powder charge at 500 ft, jettisoning the LOPSIDED-POS from the main recovery harness. Two U-bolts tether the LOPSIDED-POS to one end of the payload recovery harness using ¼" quick links. The other end of the payload recovery harness is tied to the shroud lines of the payload parachute using 5/16" quick links. As the LOPSIDED-POS falls, it pulls the payload parachute clear of the deployment bag, which remains on the main recovery harness. The LOPSIDED-POS will descend under a Fruity Chutes 48” Classic Elliptical payload parachute. For the vehicle demonstration flight, the DÁVÍD payload mass simulator descended under a Fruity Chutes 60” Iris UltraCompact Parachute.

The LOPSIDED-POS is protected during main parachute deployment by means of a piston. This is a free-floating section of coupler tubing capped by a bulkhead at one end.

The piston is tied into the main recovery harness and resides in the main parachute bay during flight. During ejection, it caps the pressurized section in the forward direction and transfers ejection forces to the coupler section epoxied into the payload bay, causing failure of the shear pins leading to successful section separation.

3.4.2 Structural Components

3.4.2.1 AV Bulkheads

The AV bulkheads are made of laser cut layers of 1/8” aircraft-grade birch plywood epoxied together to a thickness of ¾". The bulkheads have been put through structural simulations in ANSYS to ensure a sufficient factor of safety and physical testing is planned to occur soon. Both the U-bolts and the threaded rods will be strong enough to resist deployment forces. More details on the bulkheads can be found in Section 3.1.5.

3.4.2.2 Avionics Sled

The AV sled is constructed out of laser cut 1/8” birch plywood and is wood glued together except for the battery compartment covers. Two threaded rods running through the AV bay hold the AV sled in place. The tilted plates hold the altimeter screw switches at a 90° angle to each other. 1” standoffs are used to mount the screw switches to ensure that they are easy to locate and activate on the launch pad. The launch vehicle altimeters are mounted to the AV sled using ½" standoffs to ensure that the pressure sensors, mounted on the bottom of the altimeter board, have sufficient space to adequately measure pressure in the AV bay. The altimeters are mounted inline such that the wires do not interfere with each other as they would if the altimeters were mounted side-by-side. The box on the top of the AV sled contains the two 9V batteries powering the launch vehicle altimeters. The box on the bottom of the AV sled contains the 7.4V LiPo battery powering the GPS transmitter. The Eggfinder TX unit is mounted using the same ½" standoffs as the altimeters. All wires are internal to the AV sled. The eight signal wires emerge from holes cut in the end of the two AV sled halves.

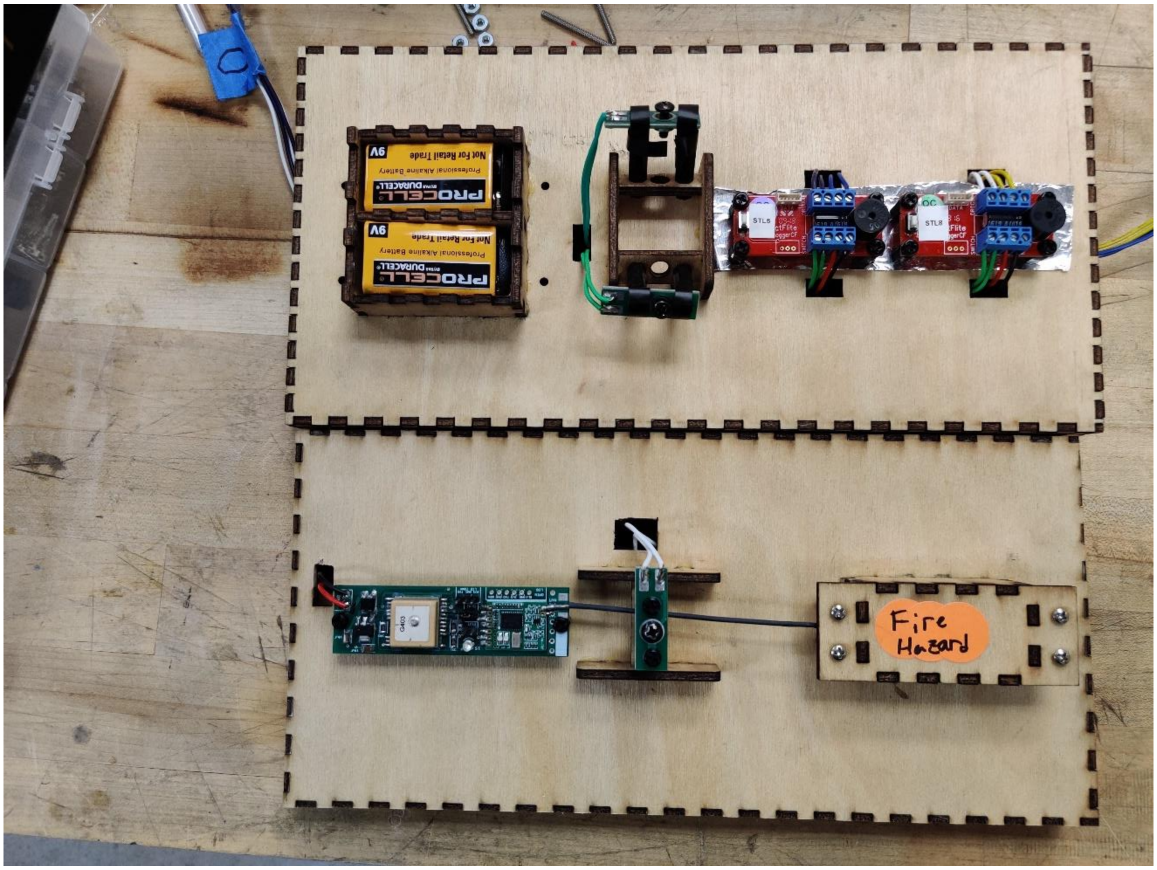


Figure 3-41 AV Sled as of VDF

Following the reduction in length of the AV bay, the AV sled was redesigned. To make full use of the reduced length available, the two 9V batteries were moved to the opposite side of the sled from the altimeters. The figure below shows CAD models of the updated AV sled.

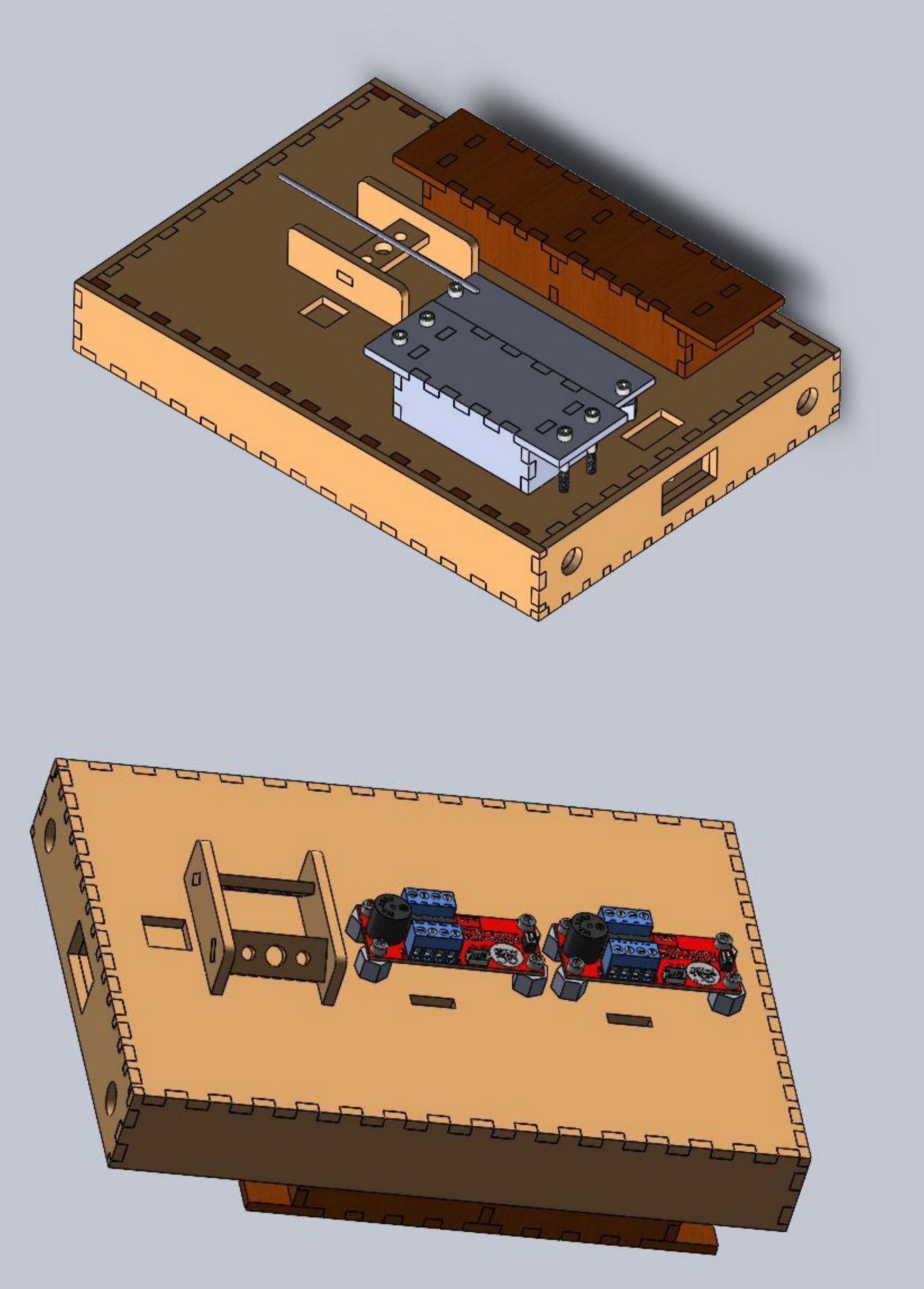


Figure 3-42 Redesigned AV Sled

3.4.2.3 Quick Links

Quick links will be used to tether all body sections, recovery hardware, and payload elements remaining attached to the recovery harness to the recovery harness discussed in Section 3.4.4.2. All quick links are either ¼" or 5/16” steel quick links rated upwards of 1200 lbs. 5/16” quick links are used to tether launch vehicle sections due to the large U-bolts utilized, and to tether the parachutes to the recovery harness. The ¼" quick links are used to tie in the ARRD, deployment bags, and Nomex sheets.

3.4.2.4 Pressure Sampling Ports

For the altimeters to detect the altitude of the launch vehicle at all points of the flight, pressure sampling ports must be drilled in the launch vehicle to sense the static pressure correctly. The sizing of these static ports was determined by recommendations set forth by PerfectFlite, the altimeter manufacturer. The user manual recommends using at least 4 holes set at 90° intervals for larger diameter rockets to avoid any fluctuations in the static pressure due to wind, angle of attack, or turbulence produced by the launch vehicle upstream of the pressure port. The following equation provided in the StratoLogger user manual is used to determine hole size.

$$d = D^2 * L * 0.0008 \tag{1}$$

Where d is the diameter of the switch hole, D is the inner diameter of the section, and L is the interior length of the section. On the AV bay and nosecone, the ports are aligned so that sampling ports can be used as access to the altimeter screw switches.

3.4.3 Parachute Selection

The launch vehicle uses a Fruity Chutes 120” Iris UltraCompact parachute for main recovery and a Fruity Chutes 18” Iris Classic Elliptical parachute for drogue recovery. The LOPSIDED-POS uses a Fruity Chutes 48” Classic Elliptical parachute for payload recovery. These parachute selections have been made based on parachute availability, descent time, wind drift, and kinetic energy at landing. Launch vehicle speed under parachute can be determined by the equation below.

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

In the equation above, m is the burnout mass of the launch vehicle, g is the acceleration due to gravity, ρ is the density of air, A is the area of the parachute, and CD is the coefficient of drag of the parachute. While the area and drag of the vehicle sections themselves do contribute to the velocity at which they fall, their contribution is negligible in comparison to the parachute. The current launch vehicle as built has a burnout mass of 2.60 slugs.

3.4.3.1 Main Parachute

The Fruity Chutes 120” Iris UltraCompact has been chosen as the main parachute for the launch vehicle. This parachute is used for its favorable kinetic energy and wind drift performance. The main parachute has a reference area of 78.53 ft^2 and a C_D of 2.11, giving a descent rate of 14.9 ft/s with the LOPSIDED-POS to the launch vehicle and a descent rate of 13.3 ft/s following detachment of the LOPSIDED-POS. In addition, the team already possesses a Fruity Chutes 120” Iris UltraCompact parachute, conserving team funds.

3.4.3.2 Drogue Parachute

The Fruity Chutes 18” Classic Elliptical parachute has been chosen as the drogue parachute for its high descent rate and team ownership. This drogue parachute has a reference area of 1.77 ft^2 and a C_D of 1.43. This gives a descent rate of 120.6 ft/s under drogue parachute, giving the high descent rate needed to remain within descent time and wind drift limits while satisfying TDR 3.3 - drogue descent velocity will be under 125 ft/s.

3.4.3.3 Payload Parachute

The Fruity Chutes 48” Classic Elliptical parachute has been chosen as the payload parachute for its kinetic energy performance. This parachute was provided the lowest descent velocity while remaining within wind drift limitations. The 48” Classic Elliptical has a reference area of 12.57 ft^2 and a C_D of 1.44. This gives the LOPSIDED-POS a descent rate of 18.04 ft/s. For the VDF flight, the DÁVÍD mass simulator was heavier than the LOPSIDED-POS, and a Fruity Chutes 60” Iris UltraCompact parachute was used. This parachute has a reference area of 19.63 ft^2 and a C_D of 2.16. This gives the DÁVÍD mass simulator a descent rate of 13.4 ft/s.

3.4.3.4 Parachute Opening Shock

Parachute opening shock was calculated to determine the loading on launch vehicle bulkheads during each deployment event. A rule of thumb for parachute inflation time is that it takes a time approximately equal to the time it takes air to travel from the edge to the center of the furled parachute. Opening time is computed using the following equation, where t_i is the inflation time of the parachute, r is the parachute radius, and V is the descent velocity prior to parachute deployment. The coefficient of 8 is taken from Ludtke for a cloth parachute.

$$t_i = 8dV \tag{3}$$

The following equation is then used to determine the opening force for a given section mass based on the deceleration of the launch vehicle taken as the difference in terminal velocities under main and drogue parachutes over the main parachute inflation time. Here, v_d is the drogue descent velocity, v_m is the main descent velocity, t_i is the parachute inflation time, and $m_{section}$ is the section mass.

$$F = \frac{v_d - v_m}{t_i} * m_{section} \tag{4}$$

At main parachute deployment, the forward assembly will experience 177 lbf at the nosecone bulkhead, the midsection will experience 327 lbf at the avionics bulkheads, and the fin can will experience 101 lbf at the engine block. At the main parachute attachment point, a loading of 393 lbf will be encountered. These loading conditions fall well within the FoS of 2 set forth in TDR 2.2 and discussed further in Section 3.2.1.3.

Table 3-2 Body Section Opening Shock

Launch Vehicle Body Section	Body Section Mass	Parachute Opening Time	Main Parachute Opening Shock
Nosecone w/ LOPSIDED-POS	.5835 slugs	.3 s	177 lbf
Full Launch Vehicle	1.2937 slugs	.3 s	393 lbf
Midsection and Fin Can	.7102 slugs	.3 s	327 lbf
Fin Can	.332 slugs	.3 s	101 lbf

3.4.4 Recovery Harness

The main and drogue recovery harnesses are 40’ x 5/8” tubular Kevlar shock cord, while the payload shock cord is 15’ x 1/4” tubular Kevlar shock cord. The 5/8” shock cord is rated for loads up to 6000 lbf, while the predicted maximum load on the shock cord is 432 lbf. This gives a FoS of 14 for the launch vehicle shock cord. The LOPSIDED-POS is expected to experience loading up to 11 lbf during payload parachute deployment and loading up to 206 lbf during the removal of the LOPSIDED-POS from the main parachute bay. The ¼" shock cord material used is rated for up to 1700 lbf, providing a FoS of 8.3 for the payload recovery harness.

3.4.4.1 Drogue Recovery Harness Description

The drogue recovery harness has a bowline knot tied on each end, and a third bowline knot tied in the middle. The drogue parachute and Nomex sheet are connected by a 5/16” quick link to the middle bowline knot. The shorter end of the drogue shock cord is connected by 5/16” quick link to the aft AV bulkhead, and the long end is connected to the engine block in the fin can. This causes the midsection to hang above the fin can during drogue descent, lessening the chance of the fin can fouling the main parachute during deployment. The figure below shows the exact position of these knots along the drogue shock cord.

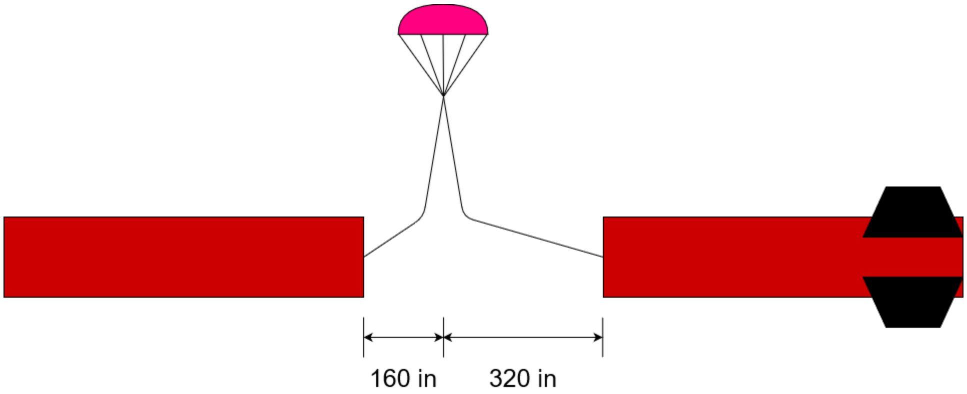


Figure 3-43 Drogue Shock Cord Dimensions

3.4.4.2 Main Recovery Harness Description

The main recovery harness has bowline knots tied in each end much as the drogue recovery harness, connecting to the nosecone bulkhead and forward AV bulkhead with 5/16” quick links. Along the length of the main recovery harness are four bowline knots and two stevedore knots. The positions of all main recovery harness attachment points are shown in the diagram below.

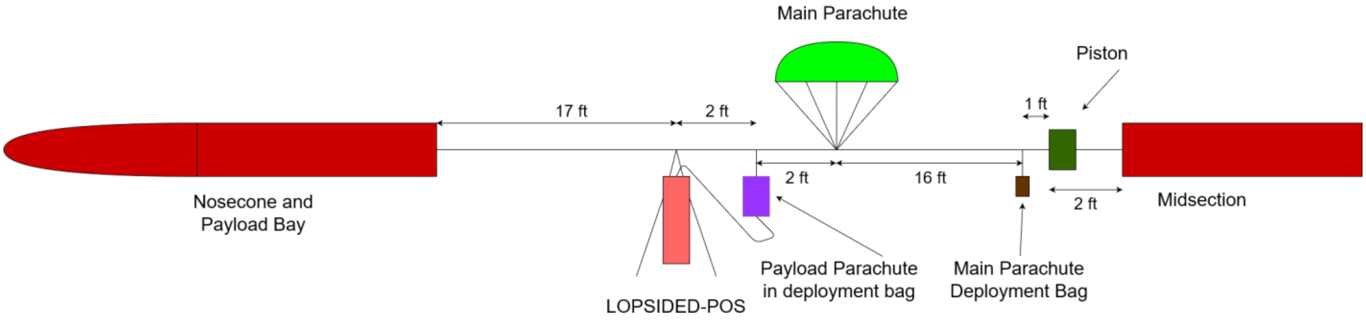


Figure 3-44 VDF Main Parachute Recovery Harness Layout

As flown, all four middle bowline knots are tied forward of the piston. Moving forward from the aft end of the shock cord are the two stevedore knots holding the piston in place along the harness, first the main parachute deployment bag is connected using a 5/16” quick link, the main parachute which is again attached with a 5/16” quick link, the LOPSIDED-POS or DÁVÍD with the ARRD connected using a 5/16” quick link, and the payload parachute deployment bag connected with another 5/16” quick link.

Following the Launch Vehicle Demonstration Flight, several issues were identified with this recovery harness layout since this layout is a suboptimal configuration resulting from insufficient space in the main parachute bay following implementation of the piston ejection system. The lengthened main parachute bay allows for the main parachute and main parachute deployment bag to be connected to the main recovery harness aft of the piston. Moving this allows the payload parachute to be moved aft of the LOPSIDED-POS, reducing the chance of the parachute fouling in the legs of the LOPSIDED-POS during deployment. The exact locations and distances of these tie-in points are shown in the figure below.

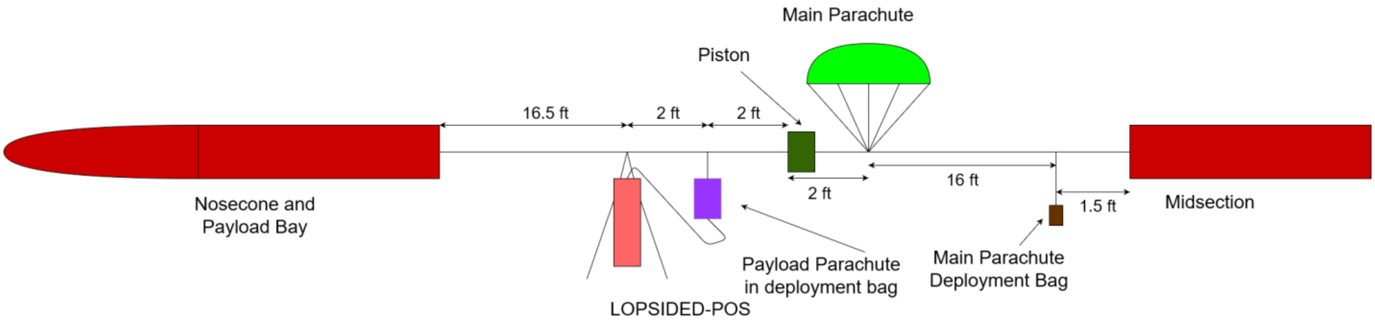


Figure 3-45 Updated Main Parachute Recovery Harness Layout

3.4.4.3 Payload Recovery Harness Description

The fifteen-foot shock cord used for the payload recovery harness has two knots tied at each end. On one end is a bowline knot, which is connected to the main recovery harness using a 5/16” quick link. The other end of the harness uses a Birmingham bowline knot, which is a bowline with multiple loops. This connects to the two tie-in points on the LOPSIDED-POS or payload mass simulator using ¼" quick links.

3.4.5 Avionics

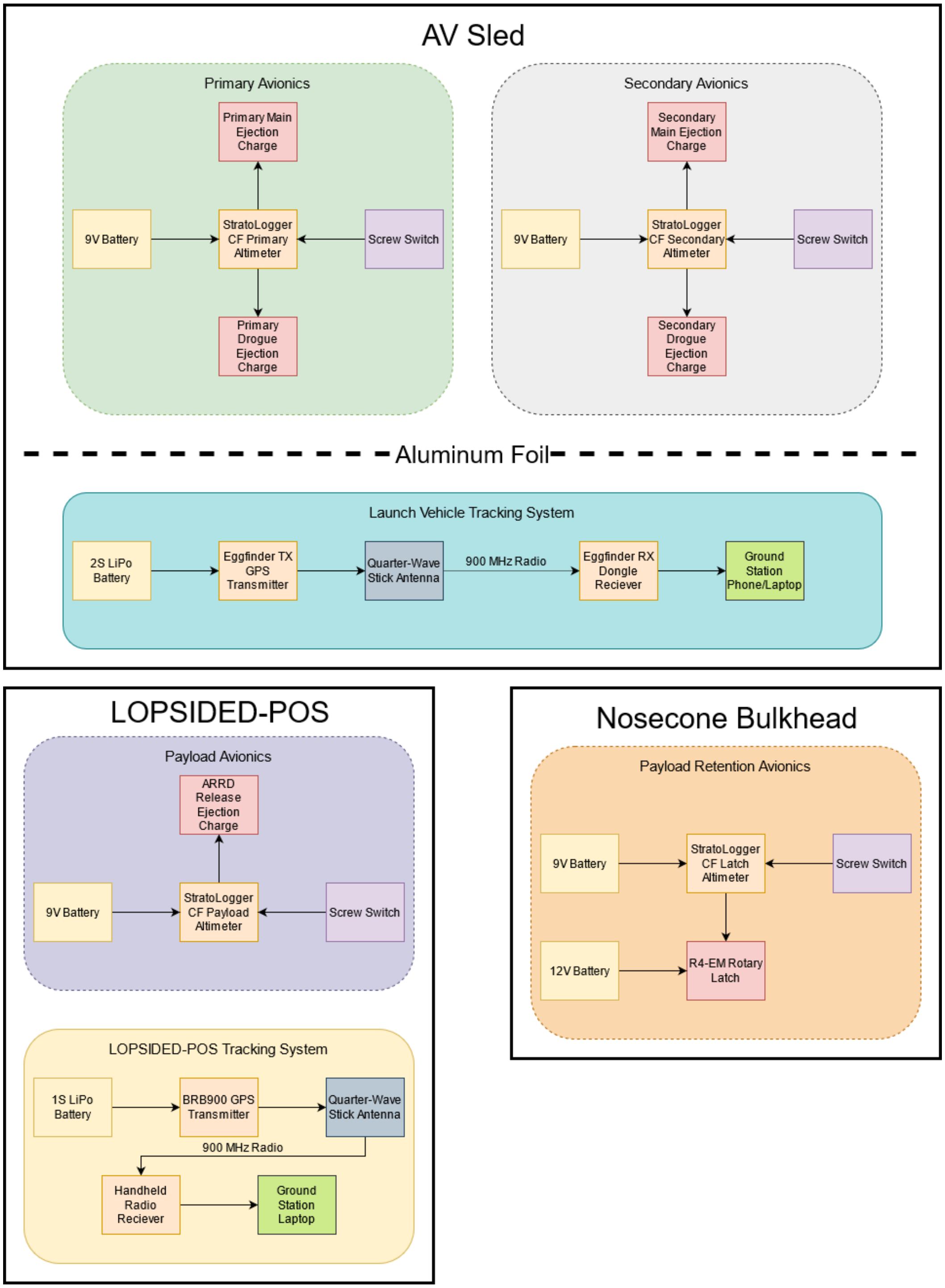


Figure 3-46 Recovery-Avionics Master Block Diagram

The above block diagram shows all components of the recovery avionics system and how each is interconnected. The dashed green box contains all components of the primary recovery system. This primary system contains the competition altimeter which will record the team's official apogee, as well as the components necessary for both main and drogue deployment events. The altimeter is connected to a 9V battery, a screw switch, and two E-matches. One E-match is housed in the drogue compartment and is fired at apogee, while the other E-match is housed in the main compartment and is fired at 700 ft. A fresh 9V battery is installed before each flight to ensure the altimeter has sufficient power to fire both E-matches, record flight data, and meet the pad stay time requirements set forth in NASA 2.7.

The dashed gray box contains all components of the secondary recovery system, providing an independent, redundant backup to the primary avionics system. The sole difference is in the mass and timing of the black powder charges, outlined further in Section 3.4.7. The drogue charge is programmed to fire one second after apogee, while the main charge is set to fire at 650 ft. Both systems are capable of independently recovering the launch vehicle, and a lack of interconnection provides system redundancy. Should any one component of either system fail, the other system will activate in its place and allow for safe recovery.

The dashed purple box contains all components of the payload recovery system. This system contains an altimeter, screw switch, 9V battery, and an E-match connected to the ARRD black powder charge. The drogue terminal blocks are left unconnected, and the main terminal blocks are wired to the ARRD E-match. At 500 ft., the ARRD E-match is programmed to fire, separating the ARRD and detaching the LOPSIDED-POS from the main recovery harness. A redundant system is unnecessary here, since a failure of the payload recovery system will result in the LOPSIDED-POS descending under the main parachute, a scenario for which the recovery system has been designed.

The dashed orange box contains all components of the payload retention avionics system. This system is comprised of the payload retention altimeter, a screw switch, a 9V battery, and the R4-EM rotary latch. The rotary latch is wired to the drogue terminal blocks on the altimeter. At apogee, the altimeter is programmed to send a signal to the drogue terminal blocks, which will unlock the latch and let the LOPSIDED-POS be retained by only the shear pins. As with the payload recovery system, a redundant system is not included since a failure of the latch to release will still result in a safe landing within mission parameters.

The solid blue box contains the launch vehicle tracker, the Eggfinder GPS, discussed further in Section 3.4.6 while the solid yellow box contains the LOPSIDED-POS tracker, a BRB900, discussed in the same section.

3.4.5.1 Altimeters

All recovery events are controlled by one of four PerfectFlite StratoLogger CF altimeters. Two of these, housed in the AV bay, are designated the primary and secondary altimeter, and control the launch vehicle recovery events. One StratoLogger is housed onboard the LOPSIDED-POS and is designated the payload altimeter, responsible for controlling the ARRD separation of the LOPSIDED-POS from the main recovery harness. The fourth altimeter is mounted on the forward face of the nosecone bulkhead and is designated the latch altimeter, responsible for releasing the rotary latch retaining the LOPSIDED-POS during ascent. The primary altimeter serves as the nominal operating point for the recovery procedure and is marked as the team's competition reporting altimeter. The primary altimeter detonates its drogue charge at apogee and its main charge at 700 ft AGL, while the secondary altimeter delays its charges by one second and 50 ft respectively. Delays are crucial to prevent simultaneous detonation of the ejection charges resulting in over pressurization of the parachute cavities. The payload altimeter is programmed to fire its main charge at 500 ft, dropping the LOPSIDED-POS free of the main recovery harness and deploying the payload parachute. The latch altimeter is programmed to send a signal to the latch at apogee, taking the weight of the LOPSIDED-POS off the retention strap and transferring it to a series of shear pins for the remainder of the descent until main parachute deployment.

The StratoLogger CF is an altimeter known for high precision, with prior team flights using a pair of StratoLogger CFs recording apogee within 10 ft of each other. The team already owns multiple StratoLoggers. The fine tunability of the StratoLogger CF is another favorable point, with apogee delay being tuned in 1 second increments and main deployment in 1 ft increments. This makes the StratoLogger CF suitable for use for all four altimeters. Each altimeter can also be set to beep out its programming at different pitches to help personnel distinguish each individual altimeter from the others.

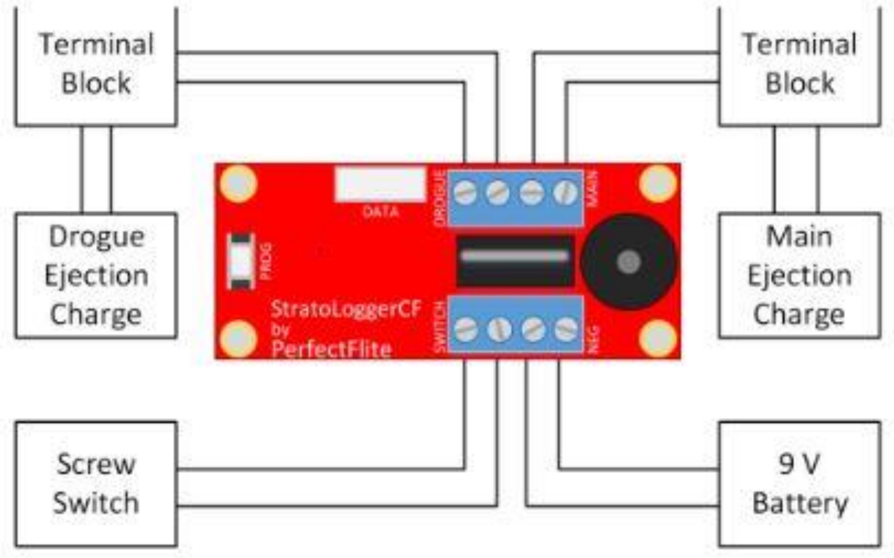


Figure 3-47 Stratologger CF Wiring Schematic

Figure 3-47 above shows the wiring of the PerfectFlite StratoLogger CF altimeter.

3.4.5.2 Parachute Retention Devices

Concerns about the payload parachute unfurling during the main parachute and recovery harness deployment sequence of events led to the implementation of a system to keep the payload parachute furled until sometime after the main parachute is deployed. Two Jolly Logic Chute Release devices are used to accomplish this task. The parachute releases have an onboard altimeter set to 600 ft. Once the correct altitude is detected, a latch is disengaged, releasing a rubber band that is wrapped around the parachute. By connecting the free end of the rubber band into the opposite parachute release as shown in the diagram below, the system is redundant. Should either of the chute releases fail to unlatch, the other will unlatch and free the parachute.

Figure 3-48 Payload Parachute in Deployment Bag with Two Jolly Logic ChuteReleases

3.4.5.3 Screw Switches

A total of five screw switches are used to arm various elements of the recovery system. Of these, four are accessed from outside the launch vehicle following being raised onto the launch pad. All five are secured to laser-cut plywood frames using 1” standoffs so they may be visible and easily accessible from outside the launch vehicle. This allows for the launch vehicle to be brought to the launch pad fully assembled without any continuous connection between an E-match and a power source. Once the launch vehicle is in the upright position, all four altimeter screw switches can be tightened by a team member using a screwdriver. This setup protects team members from premature black powder detonations and conserves the battery life of the altimeters. Screw switches also provide a strong mechanical force to maintain the connection ensuring that the altimeters remain powered on despite any flight forces or vibrations in the AV bay or the launch vehicle.

3.4.5.4 Batteries

All altimeters are powered by fresh 9V batteries for each flight. Before each flight, an unused 9V battery is tested to ensure a voltage of at least 9V, before being connected to the system and enclosed in the proper battery compartment. These compartments are designed to provide a tight fit such that there is no chance for the battery to come disconnected from its connector, ensuring uninterrupted power regardless of flight or external forces. This model of battery has been successfully tested as outlined in Section 7.1.1.7 to ensure sufficient battery life.

LiPo Batteries will be used to power the BRB900 and Eggfinder TX transmitters. The BRB900 uses a 1S, 3.7V battery that is attached to the underside of the transmitter unit. The Eggfinder uses a 2S, 7.4V battery that is housed in a battery housing on the AV sled much like the altimeter 9V batteries.

3.4.5.5 Redundancy Features

The recovery avionics system contains two fully independent systems. There are two entirely independent altimeters, screw switches, 9V batteries, e-matches, and black powder charges. If any one component of one system were to fail, the other system would activate and ensure a safe recovery of the launch vehicle. The Jolly Logic Chute Release system is also redundant with two interlinked parachute releases such that the release of one will fully free the parachute. Further redundancy is incorporated into the black powder charges, with the secondary charges being 0.5 g larger than the primary charges. This will increase the chances of section separation in case the primary recovery avionics system functions as designed but the body sections fail to separate properly after detonation of the primary charge. As such the recovery system is protected against equipment failure, miscalculations, and aberrations in the separation process. The recovery system of the LOPSIDED-POS is designed such that recovery avionics system failures will result in the LOPSIDED-POS remaining attached to the launch vehicle or main recovery harness and descending under the main parachute. Should the rotary latch fail to release, the LOPSIDED-POS will remain in the payload bay and descend under the main parachute. If the opening shock is sufficient to overcome the rotary latch or some structural component of the LOPSIDED-POS and remove it anyway, the LOPSIDED-POS will be able to be recovered in a safe manner as planned. Should the ARRD fail to release the LOPSIDED-POS from the main recovery harness, the LOPSIDED-POS will then descend under the main parachute.

3.4.6 Tracking Device

As two components of this system will be descending independently of each other, there are two tracking devices that will be used to recover the launch vehicle and LOPSIDED-POS. The launch vehicle makes use of an Eggfinder TX/RX GPS system and the LOPSIDED-POS uses a BigRedBee BRB900. Both systems are GPS trackers transmitting on the 900 MHz ISM band.

The launch vehicle transmitter is located on the AV sled in the midsection of the rocket. This location was selected due to insufficient room on the nosecone bulkhead for the tracker. The transmitter is armed during AV bay assembly by tightening a screw switch to power the transmitter. This switch is mounted in a similar fashion as the altimeter screw switches described above. The Eggfinder TX transmitter is paired with the Eggfinder RX receiver, programmed to the same frequency of 921 MHz on ID 3. The transmitter power is 100 mW, satisfying requirement NASA 2.22.8. The transmitter has a range of around 10000 ft, maintaining connection during ground testing. Even should the transmitter exit the range of the receiver during flight, since the launch vehicle will descend within 2500 ft of the launch pad signal will be able to be reacquired during descent or after landing. The receiver is mounted in a plastic case also containing a battery holder for 3 AA batteries and a Bluetooth module. This module is paired to the phone of a member of the field recovery team via Bluetooth. GPS data is then plotted on the phone using the Rocket Locator app. The app plots the vehicle's azimuth location on a satellite image as well as providing the vehicle's distance, altitude, and an azimuth line from the current location of the phone to the vehicle. Specific latitude and longitude information can be easily obtained from the logs of the app. No redundant tracking transmitter is included in the launch vehicle since the GPS tracker serves as the redundant backup to the primary method of flight tracking – visual observation of the launch vehicle.

As required by NASA 3.12.1, each section of the launch vehicle and payload descending independently requires its own tracker. To this end, the BigRedBee BRB900 was selected for tracking the payload. The BRB900 is ideal for its small form factor and light weight. The BRB900 transmits on 900 MHz and utilizes a handshake system to prevent interference. The receiver is a dedicated radio unit that displays the latitude and longitude coordinates on a readout. It can also be paired with a laptop and the data ported into Google Earth to view the 3D plot of the launch vehicle's path.

3.4.7 Ejection Charge Sizing

Black powder ejection charges were calculated by considering the gases in each launch vehicle body cavity as a mixing problem between the gaseous products of the black powder combustion and the air in the cavity at the ambient conditions. The reaction model below was used to determine the mass percentage of a given black powder charge converted into a gaseous product. 4F black powder is used for all energetic events.

$$10KNO_3 + 3S + 8C \rightarrow 2K_2CO_3(s) + 3K_2SO_4(s) + 5N_2(g) + 6CO_2(g) \qquad (5)$$

It was assumed then that a mass of gas 33.5% the mass of the black powder charge was added to the mixing chamber at the adiabatic flame temperature of black powder as obtained from the manufacturer data. A target pressure rise was specified to determine the amounts of each product gas (N2 and CO2) that would be required for the desired pressure rise by considering the partial pressure of all three gases in the chamber. Since this required mass is a known fraction of the black powder mass burned, it is trivial to back out the required powder charge mass.

Validation testing of this model has been carried out with great success, and these tests are covered further in Section 7.1.1.5. For flight, a target pressure rise of 10 psi was determined. This increase in pressure generates sufficient force to shear four shear pins with a FoS of 2.02, acceptable for this context. The exception to this is on the main parachute, where a pressure rise of 15 psi was specified over concerns about added frictional forces resulting from the piston deployment system. These concerns have been further negated by the application of silicone lubricant during assembly to the piston body. With a 15 psi pressure rise, the main primary ejection charge gives a FoS of 3.03.

If the shear pins do not break with the primary ejection charge, the secondary charge is sized up from the primary. Here a mass increase of 0.5 grams was specified. This ensures that even if the primary black powder charge does not cause section separation, the backup charge will be able to do so while remaining small enough that a sympathetic detonation will not over pressurize the body section.

As flown, the main parachute ejection charge had a primary mass of 2.9 g and a secondary mass of 3.4 g. The drogue ejection charges had a primary mass of 2.6 g and a secondary mass of 3.1 g. The ARRD ejection charge is sized according to manufacturer recommendations, and is approximately 0.1 g. Following the increase in main parachute bay length after the VDF, the main parachute ejection charge masses are increased to a 3.8 g primary and a 4.3 g secondary.

Table 3-3 Ejection Charge Masses

Ejection Event	Black Powder Mass
Main Parachute Primary - VDF	2.9 g
Main Parachute Secondary – VDF	3.4 g
Drogue Parachute Primary	2.6 g
Drogue Parachute Secondary	3.1 g
Main Parachute Primary	3.8 g
Main Parachute Secondary	4.3 g

3.5 Mission Performance Predictions

3.5.1 Launch Day Target Altitude

Based on simulations ran for PDR, the team determined the target apogee to be 4473 feet.

3.5.2 Current Flight Profile Simulations

Before the launch vehicle demonstration flight, the CG and weight of the launch vehicle were recorded, and the RockSim file was updated to reflect these recorded values. Also, as the team is now planning on launching the final performance flight from Bayboro, NC rather than in Huntington, AL, the weather data in RockSim was changed to reflect historical trends in weather for this location. Launch simulations were ran with a 5^{o} launch rail angle, a 12-foot launch rail, and in four different wind regimes ranging from 0 to 25 mph. The team found an updated apogee of 3678 feet by running twenty simulations and taking the average of their results. The velocity at launch rail departure was calculated to be 69.44 ft/s and the maximum velocity reached was 481.32 ft/s, or approximately 0.428 Mach. The flight profile of one of the simulations can be found below.

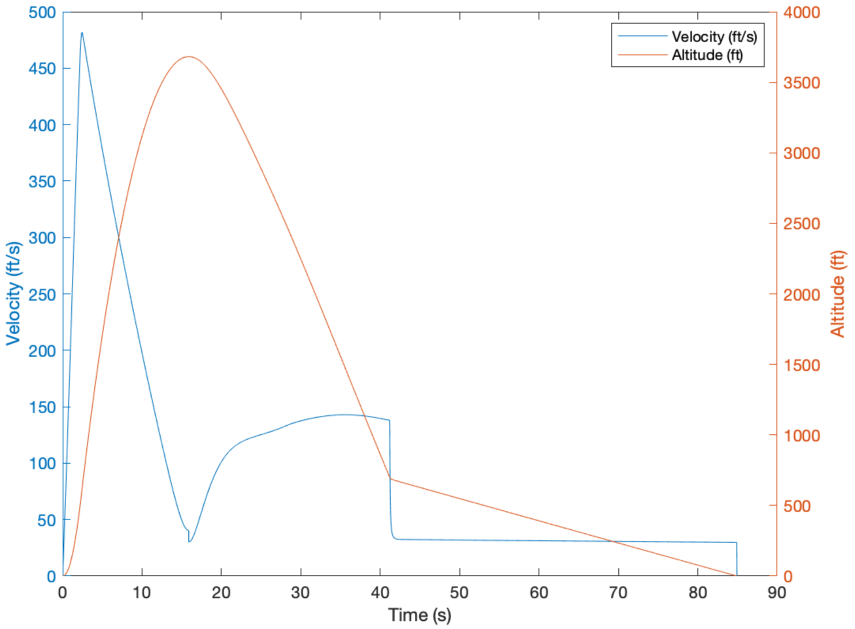


Figure 3-49 Predicted Launch Vehicle Flight Profile

As the exact weight of the payload is not yet known, the final constructed weight of the payload could affect the apogee on launch day. Windspeed is another variable that could vary widely on launch day. Due to these uncertainties, a tolerance study was conducted using RockSim, which is displayed in the figure below. All simulated launches used a 5° launch rail angle, a 12-foot launch rail, and in four different wind regimes ranging from 0 to 25 mph.

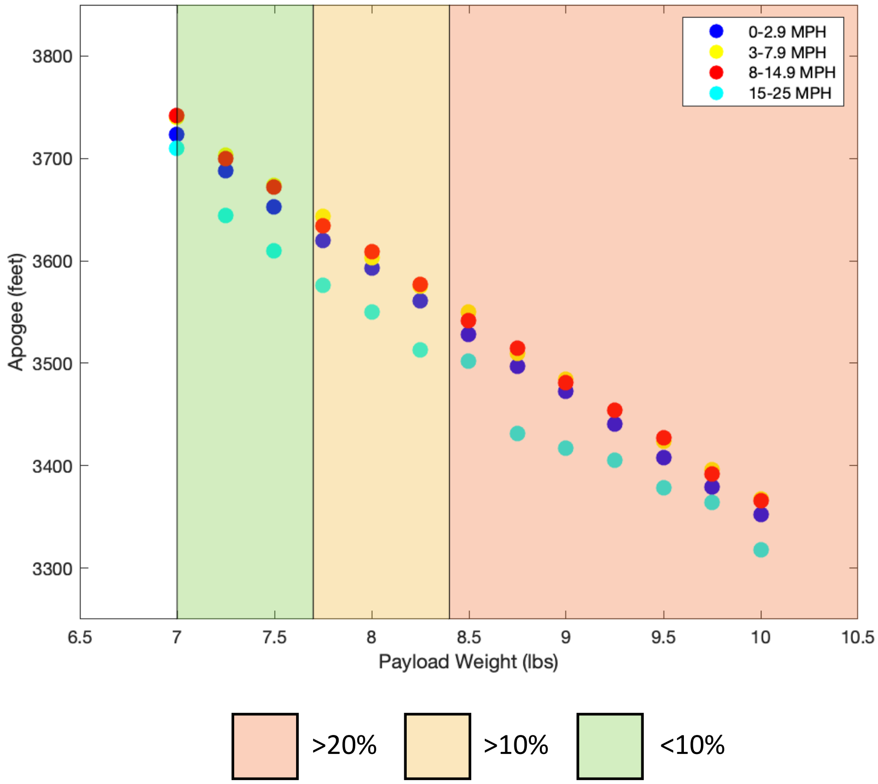


Figure 3-50 Effects of Payload and Wind Speed on Apogee

Due to some early estimates on the construction of the weight, 7 pounds was set as a lower bound for the final payload weight. As can be seen in the figure, regardless of the weight, the launch vehicle is predicted to reach over 3000 feet. However, as long as the payload is under 10% overweight, the payload will be within 900 feet of declared apogee. The tolerance study also reveals that the final weight of the payload will play the greater role in achieved apogee on launch day than wind speed will.

3.5.3 Altitude Verification

The team decided to verify the altitude prediction of RockSim using an algebraic method. All of the variables used in this method are described in the table below. The first step of this method is to calculate the wind resistance coefficient, *k*, using the density of air, ρ, the reference area of the launch vehicle, A, and the CD of the launch of vehicle. The variables *q* and *x* do not represent physical values but are merely used to simplify the final equation.

Table 3-4 Variable Definition for Altitude Verification

Quantity	Variable	Value	Units
Density	ρ	1.225	Kg/m^3
Radius	R	0.078	m
Coefficient of Drag	C_D	0.292	N/A
Average Thrust	T	1,567.8	Newtons
Mass	M	22.348	Kg
Gravity	g	9.81	m/s^2
Burn Time	t	2.4	s

$$A = \pi R^2 = 19.113 * 10^{-3}\ m^2$$

$$k = 0.5\rho C_D\ A = 3.418 * 10^{-3}\frac{kg}{m}$$

$$q = \sqrt{\frac{T - Mg}{k}} = 628.142\frac{m^2}{s^2}$$

$$x = \frac{2kq}{M} = 0.192\frac{m}{s^2}$$

With x and q calculated, the maximum velocity of the launch vehicle, v_{max}, can be calculated:

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} = 142.335\frac{m}{s}$$

Using v_{max}, the height upon motor burnout can be calculated:

$$h_{burnout} = -\frac{M}{2k}ln\left(\frac{T - Mg - kv_{max}{}^2}{T - Mg}\right) = 172.300m$$

The height gained during coast was calculated next:

$$h_{coast} = \frac{M}{2k}ln\left(\frac{Mg + kv_{max}{}^2}{Mg}\right) = 898.132\text{m}$$

The maximum height can be calculated by adding together the two previous values:

$$h_{max} = h_{burnout} + h_{coast} = 1070.4m = 3511.8\ feet$$

Table 3-5 Altitude Prediction Results

Method	Result
RockSim	3678 feet
Algebraic	3511.8

Using an algebraic method of calculating the altitude, a result was calculated that was within 5% of the RockSim calculation. Given the simplicity of the algebraic method, and the neglection of drag and atmospheric condition, the team decided this was an acceptable error margin.

3.5.4 Stability Margin Simulation

RockSim was used to calculate the CG, CP, and static stability margin of the launch vehicle throughout the flight. RockSim simulations yielded an initial stability margin of 2.17 and a stability margin of 2.23 at launch rail departure.

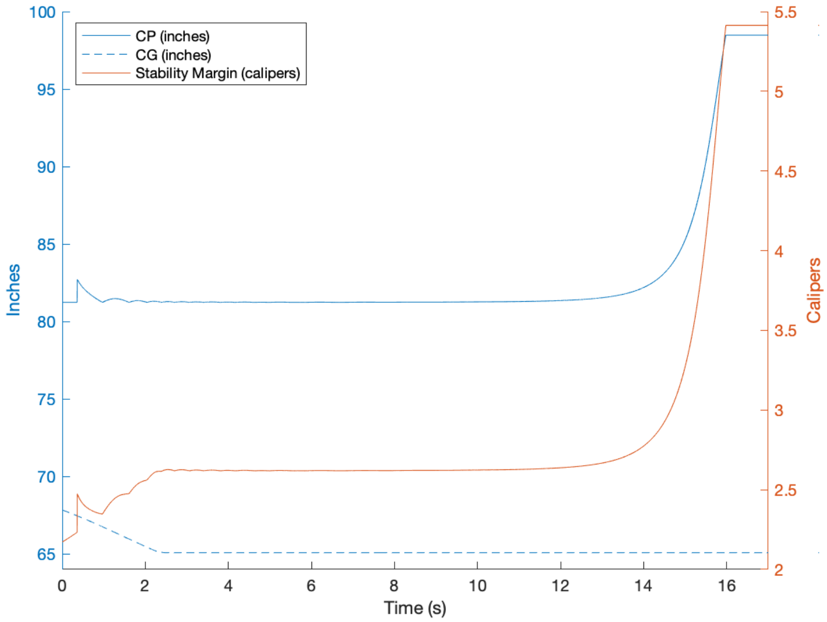


Figure 3-51 Stability Margin Simulation Results

design for the nosecone of the launch vehicle is 24 inches, which gives:

$$X_N = 0.466 \cdot L_N = 11.184 \; inches$$

The next value to be calculated is the sweep angle. The sweep angle is a simple trigonometric relationship between the fin semi-span, *S*, and the fin sweep length when measured parallel to the launch vehicle body, X_N. The leading design has S=6.00 inches and X_R=3.5 inches.

$$\theta = 90° - \tan^{-1}\frac{S}{X_R} = 30.256°$$

The sweep angle allows for the calculation of the fin mid-chord line length, L_F. Other values which are needed to calculate L_F are chord tip length, C_T, and chord root length, C_R. The leading design has C_T = 3.5 inches and C_R = 10.5 inches.

$$L_F = \sqrt{S^2 + \left(\frac{1}{2}C_T - \frac{1}{2}C_R + \frac{S}{\tan\theta}\right)} = 6.541 \; inches$$

With L_F calculated, the coefficient for the fins, C_F, can be calculated using the radius of the launch vehicle, R, and the number of fins, N. The leading design has R = 3 inches and N = 3.

$$C_F = \left(1 + \frac{R}{S+R}\right)\left(\frac{4N\left(\frac{S}{2*R}\right)^2}{1+\sqrt{1+\left(\frac{2L_F}{C_R+C_T}\right)^2}}\right) = 6.755$$

In order for the arm length of the fins to be calculated, the distance from the tip of the nose cone to the fin root chord leading edge, X_B, must be used. The leading design has an X_B = 95.25 inches.

$$X_F = X_B + \frac{X_R}{3}\frac{C_R + 2C_T}{C_R + C_T} + \frac{1}{6}\left(C_R + C_T - \frac{C_R C_T}{C_R + C_T}\right) = 102.62\ inches$$

Given that $C_N = 2$, with these values, the center of pressure is calculated:

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} = 81.72\ inches$$

Using the measured CG from the fully constructed launch vehicle, X_{CG} = 67.175 inches, the stability margin can be calculated. The stability margin from both the Barrowman method and RockSim simulations can be found in the table below. There's a 5.98% difference between the two calculation methods, but both satisfy the NASA requirement of 2.0 calipers upon launch rail departure.

Table 3-6 Stability Margin Prediction Results

Computation Method	Result (calipers)
Barrowman	$S_{M,B} = \frac{X_{CP}-X_{CG}}{R}$ =2.315
RockSim	2.17

A summary of the variables, and the values of those variables, used in the Barrowman method can also be found below.

Table 3-7 Variable Definitions for Stability Calculations

L_F – Mid-chord line length	X_F – Fin arm length	X_R – Fin sweep length measured parallel to launch vehicle body	X_B – nose cone tip to fin root chord leading edge
L_N – Length of nose cone	C_N – Nose cone coefficient	X_N – Nose cone arm length	θ – Sweep angle
R – Radius of launch vehicle	C_R – Root chord length	C_T – Tip chord length	
S – Fin semi-span	N – Number of fins	C_F – Fin coefficient	

Table 3-8 Measured Stability Variable Values

Variable	Input Value	Units
C_N	2	N/A
L_N	24	Inches
R	3	Inches
S	6	Inches
N	3	N/A
C_R	10.5	Inches
C_T	3.5	Inches
X_B	99.25	Inches
X_R	3.5	Inches
CG	67.83	Inches

Table 3-9 Calculated Stability Variable Values

Variable	Output Value	Units
X_N	11.184	Inches
θ	30.256°	Degrees
L_F	6.541	Inches
C_F	6.755	N/A
X_F	98.604	Inches
X_{CP}	78.634	Inches
$S_{M,B}$	2.369	Calipers

3.5.5 Stability Margin Tolerance Study

To account for variances in the final manufactured weight and CG of the payload, the team conducted a tolerance study to determine how this uncertainty would affect the stability of the launch vehicle.

RockSim was used to calculate the stability margin of the launch vehicle while the CG and weight of the payload were varied. The weight was varied in 0.5lb increment, starting at 7lbs, which has been determined as a lower bound for the final constructed weight of the payload. Additionally, the CG of the payload was varied in 1 inch increments up to a threshold of ±2 inches of the predicted CG. A visualization of how stability changed with these variables can be seen in the figure below.

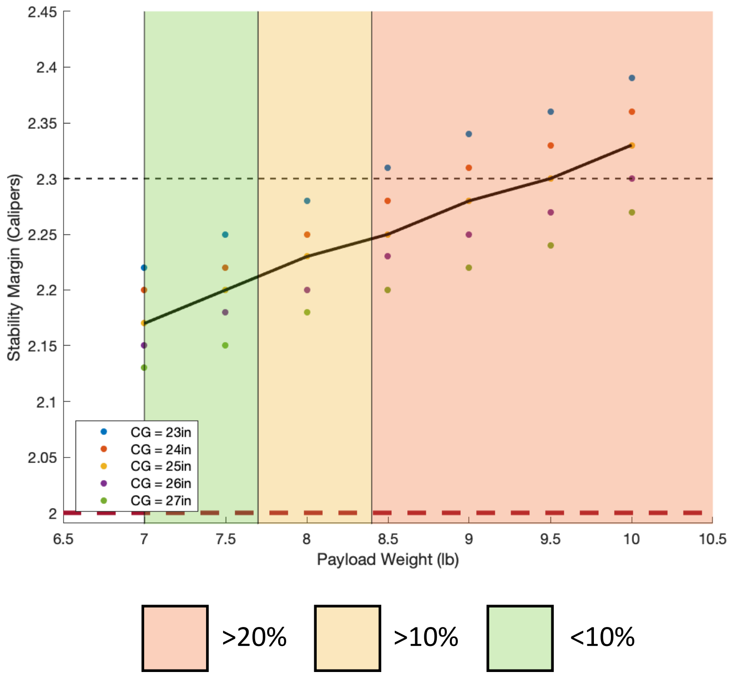


Figure 3-52 Stability Tolerance Study

A lower bound of 2.0 calipers is defined by NASA and an upper bound of stability is defined as 2.3 calipers to help reduce the effects of weathercocking. The predicted CG of the payload is denoted by a solid black trendline on the figure; each data point above or below the line represents an inch change in the CG either forward or aft. The stability tolerance study shows that the launch vehicle shows no signs of falling below 2.0 calipers when accounting for possible variations in payload weight and CG that could occur during manufacturing. Additionally, as long as the payload is under 20% overweight, the stability of the launch vehicle will stay below 2.3 calipers.

3.5.6 Kinetic Energy at Landing

Kinetic Energy can be calculated using the following equation, where KE is the kinetic energy of the object, m is its mass, and V is its velocity.

$$KE = \frac{1}{2}mv^2 \tag{6}$$

At landing, the launch vehicle will be descending under its main parachute and the LOPSIDED-POS will be descending under its payload parachute. The velocity of each component under its respective parachute will be used to calculate the kinetic energy for each section as seen below. The mass of each section was obtained by weighing the section as flown. Results are provided for nominal payload deployment, partial payload deployment, and a failure of the payload to exit the payload bay.

Table 3-10 Launch Vehicle Kinetic Energy at Landing

Section	Mass	Kinetic Energy at Landing - Payload Attached	Main Velocity - Payload Attached	Kinetic Energy at Landing - Payload Detached	Main Velocity - Payload Detached
Nosecone w/ Payload	.6457 slugs	61.8 ft-lbs	14.6 ft/s	N/A	13.3 ft/s
Nosecone	.4281 slugs	38.8 ft-lbs	14.6 ft/s	32.2 ft-lbs	13.3 ft/s
LOPSIDED-POS	.2176 slugs	23. ft-lbs	14.6 ft/s	N/A	13.3 ft/s
DÁVÍD	.2797 slugs	29.6 ft-lbs.	14.6 ft/s	N/A	12.9 ft/s
Midsection	.3781 slugs	40. ft-lbs	14.6 ft/s	33.3 ft-lbs	13.3 ft/s
Fin Can	.332 slugs	35.2 ft-lbs	14.6 ft/s	29.2 ft-lbs	13.3 ft/s

The section landing kinetic energy limit of 75 ft-lbs set forth by NASA 3.3 is sufficiently cleared by the heaviest launch vehicle section during the worst-case payload deployment scenario at 61.8 ft-lbs. However, this represents an off-design condition that would constitute at minimum a partial mission failure. For a nominal deployment of the LOPSIDED-POS, the heaviest section of the launch vehicle would have a kinetic energy of 33.3 ft-lbs which is under half of the limit set forth by NASA 3.3.

The kinetic energy for the DÁVÍD and the LOPSIDED-POS landing independently is presented in the table below. The LOPSIDED-POS is analyzed using the 48” Classic Elliptical while the DÁVÍD is analyzed as flown using the 60” Iris UltraCompact.

Table 3-11 Payload Kinetic Energy at Landing

Section	Mass	Kinetic Energy at Landing	Main Velocity
DÁVÍD	.2797slugs	25. ft-lbs	13.4 ft/s
LOPSIDED-POS	.2176 slugs	35.4 ft-lbs	18. ft/s

3.5.6.1 Alternative Calculation Method

To verify the validity of results calculated using the above method, the kinetic energy at landing was determined using RockSim. A test case was run using the worst-case scenario configuration wherein the LOPSIDED-POS fails to exit the payload bay. RockSim does not consider the configuration of the launch vehicle during descent, and as such cannot directly output section kinetic energy. The descent velocity at landing as computed in RockSim is therefore used to compute the kinetic energy at landing for each body section as below.

Table 3-12 RockSim Kinetic Energy at Landing

Section	Mass	Kinetic Energy at Landing - Payload Attached	Main Velocity - Payload Attached
Nosecone w/ Payload	.6457 slugs	67.6 ft-lbs	15.22 ft/s
Nosecone	.4281 slugs	42.4 ft-lbs	15.22 ft/s
LOPSIDED-POS	.2176 slugs	25.2 ft-lbs	15.22 ft/s
DÁVÍD	.2797 slugs	32.4 ft-lbs	15.22 ft/s
Midsection	.3781 slugs	43.8 ft-lbs	15.22 ft/s
Fin Can	.332 slugs	38.5 ft-lbs	15.22 ft/s

3.5.7 Descent Time

Descent time has been calculated as a necessary intermediate step in the wind drift calculations described in the next section and is presented as a component of those results.

3.5.8 Wind Drift

Wind drift calculations were done by assuming that the rocket traveled straight up to the projected apogee, deployed its drogue parachute, and immediately accelerated to terminal velocity under drogue, deployed the main parachute at 700 ft and immediately decelerated to terminal velocity under main parachute, then accelerates to the new terminal velocity under main parachute following the LOPSIDED-POS release at 500 ft. From apogee to landing, the launch vehicle and LOPSIDED-POS is assumed to travel in a single direction at constant speed across the ground at a constant speed equal to the steady wind condition.

Although simplifying assumptions are contained within this model, it is sufficiently accurate to reality for the purposes of this exercise. Assuming the launch vehicle immediately reaches terminal velocity at apogee will reduce total descent time by a few seconds while assuming the launch vehicle immediately reaches terminal velocity at main loses a second or two since the main parachute takes a several seconds to deploy and fully inflate. Assuming that the launch vehicle travels in a single direction at a constant wind speed also constitutes a worst-case scenario.

The distances between apogee, main deployment, and landing are known as is the descent velocity of the launch vehicle during each stage of the recovery process. The descent time can therefore be easily calculated as below where t is the total descent time, z_d is the drogue deployment altitude, z_{m-} is the main deployment altitude, z_p is the LOPSIDED-POS deployment altitude, v_d is the descent velocity under drogue, v_{m1} is the descent velocity under main with the LOPSIDED-POS attached, and v_{m2} is the descent rate under main following separation of the LOPSIDED-POS.

$$t = \frac{z_d - x_m}{v_d} + \frac{z_m - z_p}{v_{m1}} + \frac{z_p}{v_{m2}} \qquad (7)$$

Using the target apogee of 4473 ft gives a descent time of 81.0 seconds per the equation above. Multiplying this descent time by a given wind speed gives the distance traveled across the ground by the launch vehicle constantly sustaining these wind speeds, as shown in the table below for the nominal payload deployment sequence.

Table 3-13 Launch Vehicle Wind Drift

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4473 ft	81 s	0 ft
5 mph	4473 ft	81 s	596.5 ft
10 mph	4473 ft	81 s	1193. ft
15 mph	4473 ft	81 s	1789.5 ft
20 mph	4473 ft	81 s	2386. ft

The same calculations were performed for the LOPSIDED-POS following separation from the main recovery harness. The wind drift for the LOPSIDED-POS is presented in the table below.

Table 3-14 LOPSIDED-POS Wind Drift

Wind Speed	Drift Distance
0 mph	0 ft
5 mph	531.1 ft
10 mph	1062.2 ft
15 mph	1593.4 ft
20 mph	2124.5 ft

Table 3-15 DÁVÍD Wind Drift

Wind Speed	Drift Distance
0 mph	0 ft
5 mph	610.1 ft
10 mph	1220.3 ft
15 mph	1830.4 ft
20 mph	2440.6 ft

At the maximum permissible wind speed for launch of 20 mph, the launch vehicle's estimated drift distance is 2386 ft, well within the maximum allowable drift distance of

2500 ft set forth by requirement NASA 3.10. The LOPSIDED-POS under nominal deployment conditions is expected to drift 2125 ft at a wind speed of 20 mph, safely remaining within the same criteria. The DÁVÍD also remains within the 2500 ft wind drift limit, with a calculated worst case drift of 2441 ft.

3.5.8.1 Alternative Calculation Method

To confirm the validity of the above wind drift calculations, the wind drift was modeled in RockSim at the same wind speeds used for the hand calculation cases. The launch vehicle is assumed to be launched into the wind at a 5° launch rail angle. Wind drift distance is calculated by finding the difference between the range at apogee and the range at landing data points provided in the RockSim output. Descent time is calculated in a similar manner, taking the difference between the time at apogee and time at landing data points. Thus, the descent time and wind drift are determined as if the launch vehicle begins to descend directly above the launch pad. The LOPSIDED-POS separation was not considered in the alternative calculations since RockSim makes no provision for independent descent of portions of the launch vehicle.

Table 3-16 RockSim Launch Vehicle Wind Drift

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	3688 ft	70 s	0 ft
5 mph	3710 ft	59 s	431. ft
10 mph	3715 ft	60 s	879.7 ft
15 mph	3701 ft	70 s	1542.7 ft
20 mph	3665 ft	71 s	2075.2 ft

The RockSim calculations predict significantly lower descent times and wind drift distances than the hand calculations. This arises from the RockSim model not considering separation of the LOPSIDED-POS at 500 ft, which would reduce the mass of the launch vehicle assembly. As such, a higher main descent velocity is retained until touchdown.

4. Payload Criteria

4.1 Payload Mission Statement

The objective of the payload mission is to design, construct, and launch a planetary lander within a high-powered launch vehicle. This lander will achieve an upright orientation and be able to self-level within five degrees of horizontal. The initial and final angles relative to horizontal will be recorded. After leveling is complete, the payload will capture a 360-degree panoramic photo of the landing site and transmit this photograph back to the team's ground station.

4.2 Payload Success Criteria

The payload team has established the following criteria for categorizing the payload success levels based on the ability of the LOPSIDED-POS, or Lander for Observation of Planetary Surface Inclination, Details, and Environment Data, and the Planetary Observation System, to fulfill its mission as stated in Section 4.1. These success criteria have remained unchanged since the CDR document.

Table 4-1 Payload Success Criteria

Success Level	Payload Aspect	Safety Aspect
Complete Success	LOPSIDED successfully lands in its upright configuration; the self-leveling procedure is completed within 5 degrees of horizontal; the POS captures and transmits at least one 360- degree image of the landing site, which is received by the team.	No injuries are inflicted on individuals present during the execution of mission requirements.
Partial Success	LOPSIDED successfully lands in its upright configuration; the self-leveling procedure fails to level the vehicle within 5 degrees of horizontal, or the leveling system is impeded in some way; the POS captures and transmits at least one 360-degree image of the landing site, which is received by the team.	One or more close calls involving individuals present during the execution of mission requirements, but no injuries occur.
Partial Failure	LOPSIDED fails to land upright; self-leveling cannot be attempted; the POS is still able to capture and transmit photos, but the images do not properly	Minor injuries inflicted on individuals present during the execution of mission requirements.

	encapsulate the landing site; damage to LOPSIDED's landing gear/leveling system can be repaired.	
Complete Failure	LOPSIDED's deployment system fails, leading to an unrecoverable payload; no images are captured or transmitted.	Major injuries inflicted on individuals present during the execution of mission requirements.

4.3 Payload Mission Overview

The final design of the LOPSIDED-POS consists of an upright rectangular body of varying thickness, with four equally spaced legs for support. The legs are attached to the lander's two-axis, gyroscopic leveling system. The leveling system consists of two concentric rings that will allow the body of the lander to rotate about two axes. Leveling will be driven by gravitational force acting on the body of the lander. As stated in the Payload Summary in Section 1.3, the combined lander body and leveling system are designated LOPSIDED, or Lander for Observation of Planetary Surface Inclination, Details, and Environment Data. In addition to the components related to payload leveling and recovery, LOPSIDED will also house the POS, or the Planetary Observation System. The POS is responsible for capturing a series of images of LOPSIDED's landing site and transmitting these photos to the team's ground station on the launch field. Once the images are received, they will be spliced together using an automated script to form two 360-degree panoramic images.

The figure below depicts an overview of the payload mission, highlighting the major events that occur during operation and the subsystems these events pertain to. When the launch vehicle reaches apogee, a rotary latch attached to the payload bulkhead opens, which will allow the LOPSIDED-POS to be removed from the payload bay. This ejection occurs at 700 feet, when the main parachute deploys and pulls the LOPSIDED-POS from the payload bay. The LOPSIDED-POS will descend with the launch vehicle main parachute until 500 feet, when an Advanced Retention Release Device (ARRD) attached to the top surface of the LOPSIDED-POS, separates the payload from the main parachute shock cord. This event also releases the LOPSIDED-POS parachute from its parachute bag and allows the payload to descend under its own parachute. Once the LOPSIDED-POS lands, two electronic latches will open to release the parachute, and the initial surface inclination of the landing site will be recorded. Then, the solenoid latches will open to release the gravity-assisted leveling system, and the final angle post-leveling will be recorded. After this, the POS will initiate the image capture sequence, the images will be processed and compressed as necessary, and the images will be transmitted to the team's ground station for further processing.

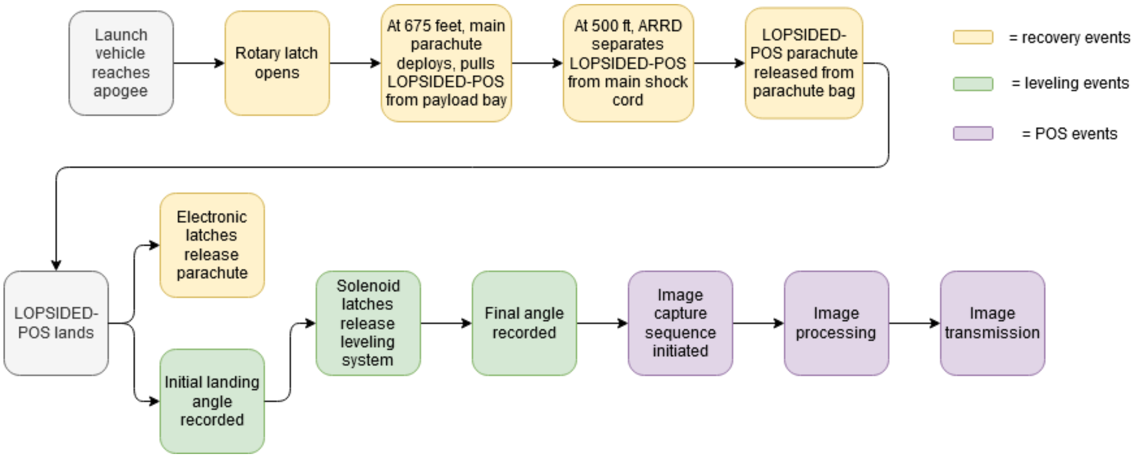


Figure 4-1 LOPSIDED-POS Mission Overview

4.4 LOPSIDED-POS Design

4.4.1 LOPSIDED Design

LOPSIDED's mission is to survive launch and landing and to level the chassis, fulfilling NASA requirements 4.3.2, and 4.3.3, and to hold the POS so that it can fulfill its requirements. LOPSIDED consists of two main assemblies, the body/chassis, and the leveling system.

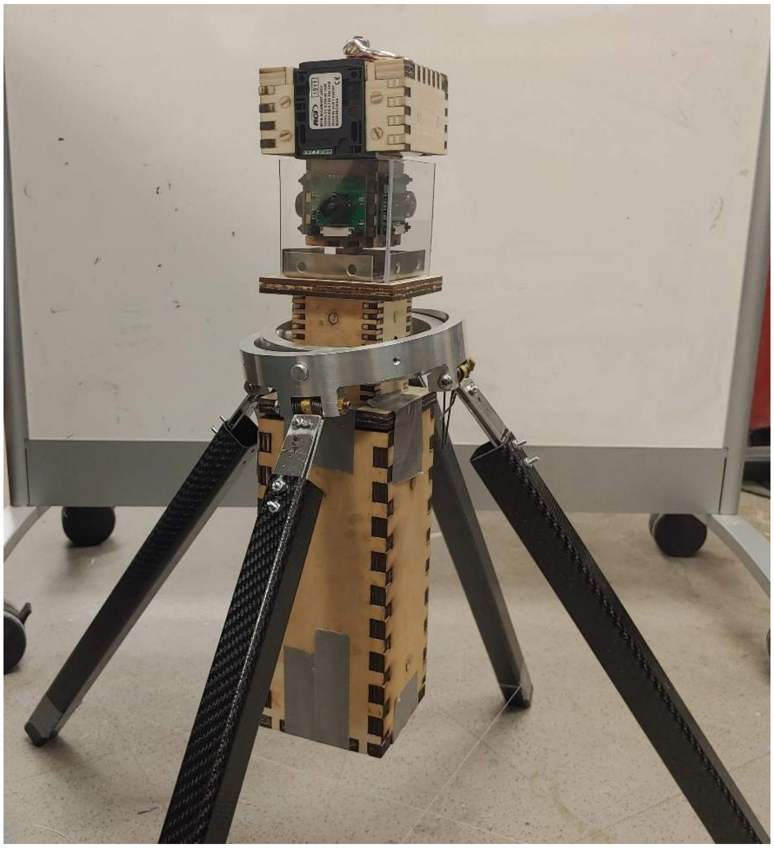


Figure 4-2 Entire LOPSIDED-POS

LOPSIDED's body consists mainly of a metal skeletal chassis to bear most of the loads. That chassis is covered in laser-cut aircraft grade plywood. This assembly houses other sub-team's systems: the POS and some integration equipment.

Figure 4-3 LOPSIDED Aluminum Chassis

The body itself can be broken into 3 sections, with different purposes: an upper, middle, and lower sections. The upper section features a skeletal bracket that mounts the integration equipment, the ARRD and the cabinet latches for the parachute. The POS is mounted beneath this bracket where clear polycarbonate walls surround it protecting it and allowing for maximum visibility.

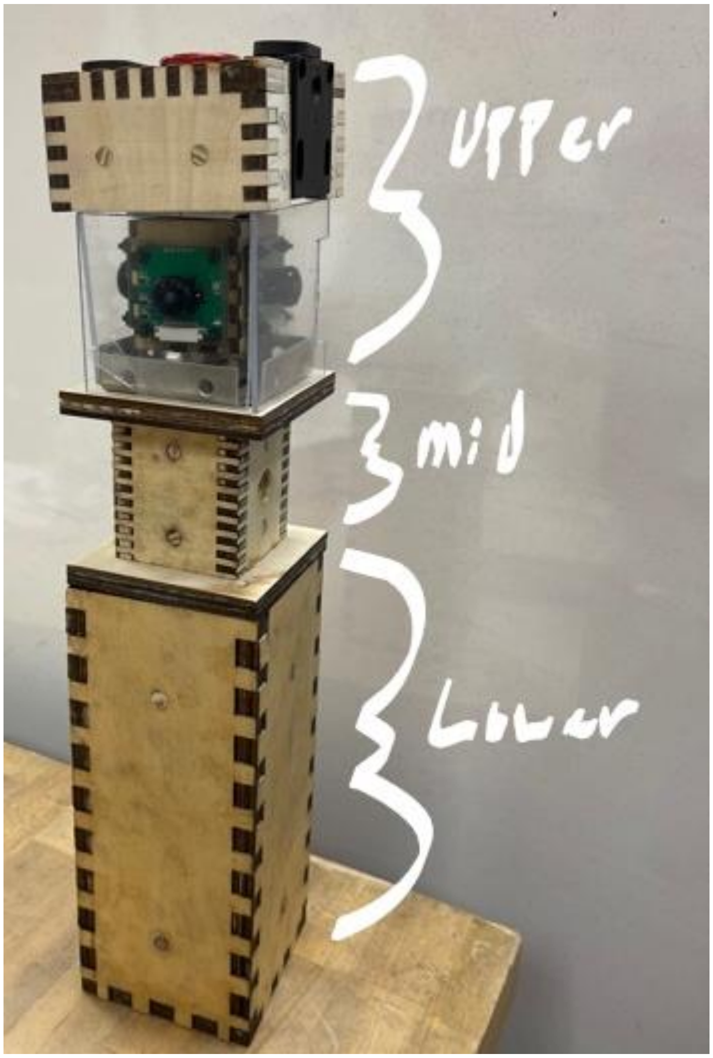


Figure 4-4 LOPSIDED Body Sections

The middle section sandwiched by the remaining two skeletal brackets serves to connect the upper and lower sections and to interface with the levelling system. It is surrounded by the skeletal brackets to both mount the other sections together and to disperse any load throughout the structure.

The lower section will feature a sled that will host all the electronic necessary for the mission. It will be mounted to the lower bracket on the underside of the middle section. It will also have a U-bolt on its bottom section for integration.

The leveling system consists of two gyroscopic rings to allow for rotation across two axes. The middle section that the inner ring interfaces with features two solenoid locks that will interface with the inner rod locking rotation across that axis. Two more solenoids are mounted on the inner ring that interface with the outer ring to lock rotation about that second axis.

Figure 4-5 Leveling System (Without Inner Ring)

The outer ring has 4 mounting blocks to which the legs will attach. The legs, torqued by torsional springs, will flay out to 60 degrees off perpendicular to the outer ring on which they are mounted. A cable set to a certain length wraps around the leg joint and attaches to the legs. Once the cable is pulled taught, the legs will rest at their desired angle.

The four total solenoids, while inactive, will be engaged with the rings preventing rotation and locking LOPSIDED in its neutral position. Once LOPSIDED has landed and recorded its initial orientation, it will retract the solenoid locks allowing the gyroscopic leveling system to reorient as best as possible.

Figure 4-6 Inner Ring Solenoid Lock Orientation

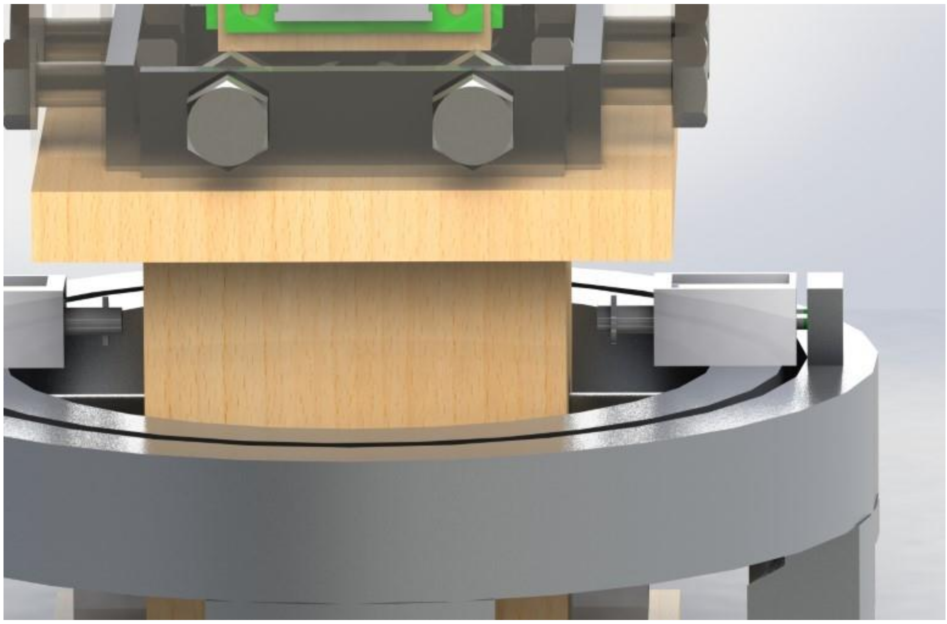


Figure 4-7 Outer Ring Solenoid Lock Orientation

The battery and other electronics in the lower section help to lower LOPSIDED’s CG to beneath the two axes so that it can self-level with the POS able to see up top. The electronics sled is offset to keep the CG centered in the middle of the rings where the two axes cross. Without disturbances and with locks releases, LOPSIDED will rest with its horizontal surfaces (including the ones to which the POS block is mounted) completely level or perpendicular to the force due to gravity.

Figure 4-8 Level LOPSIDED Demonstrating Centered CG

4.4.2 POS Design

The POS is used to capture and transmit 360-degree images of the payload landing site, to fulfill NASA requirements 4.2 and 4.3.4.1-4.3.4.4. The POS consists of on-board components including hardware for image capture, hardware for radio transmission, and an on-board computer for operating these components. The POS ground station consists of off-board components for the reception and processing of the transmitted POS images in order to generate the necessary 360-degree panoramas.

The POS utilizes four Arducam Fisheye Raspberry Pi camera modules. The camera modules are oriented 90 degrees from each other and attached to a wooden mounting block in the upper section of LOPSIDED. Each module has four mounting holes which allow the cameras to be attached with M3 screws.

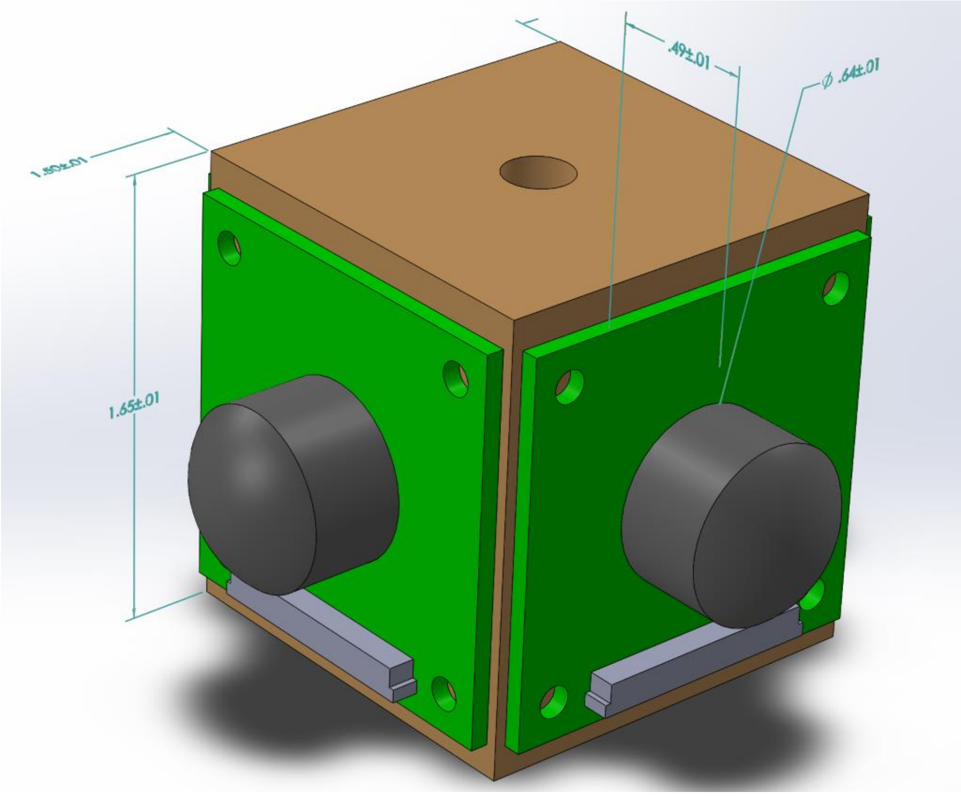


Figure 4-9 POS Camera Modules and Mounting Fixture

As per TDR 4.1, the camera modules selected have a horizontal field of view (HFOV) of 194 degrees, which allows two cameras to capture a full 360-degree image. The POS utilizes four camera modules, which allows it to capture two separate panoramic images, offset by 90 degrees. This provides redundancy in the event that one module fails, or two opposite-facing modules fail. Even if two adjacent modules were to fail, the captured field-of-view of the two operational cameras would be 284 degrees – almost 79 percent of the surveyable area. The HFOV of each camera module has been verified to exceed 180 degrees. Figure 4-10 and Figure 4-11 below show the two panoramic images produced during ground testing.

Figure 4-10 Panorama Test Image 1

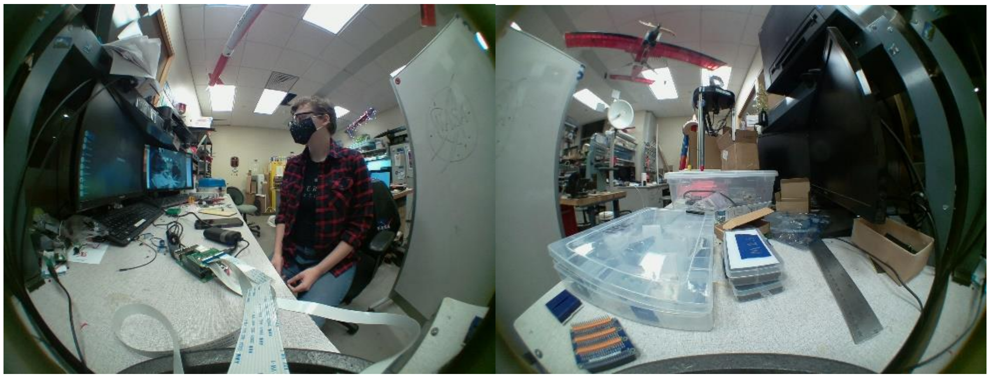


Figure 4-11 Panorama Test Image 2

These camera modules interface directly with a Raspberry Pi 3B+, which serves as the on-board computer for the LOPSIDED-POS. Standard Raspberry Pi boards are equipped with one Camera Serial Interface (CSI), which allows only one camera module to be used with the board. For this reason, an Arducam Multi-Camera Adapter Board is used. The Adapter Board allows for four individual camera modules to be attached to one Raspberry Pi. The camera modules are connected using ribbon cables. To ensure the cameras are not damaged and/or do not become disconnected during flight, 24-inch-long ribbon cables will be used This cable length provides enough slack to ensure the connections remain stable.

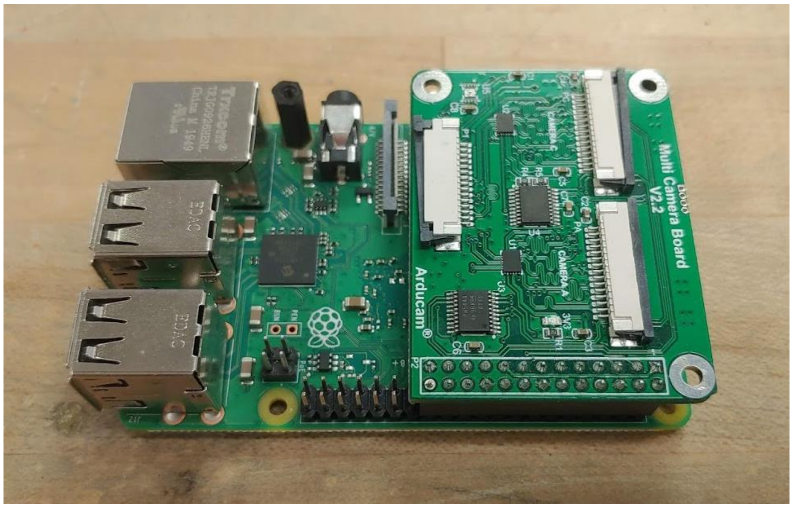


Figure 4-12 Raspberry Pi 3B+ with Camera Board

After leveling is detected by the on-board orientation sensor, a Python script will initiate image capture. These images are saved and transmitted with an Adafruit RFM69HCW 433 MHz transmitter. Slow Scan Television (SSTV) is the method of image transmission utilized by the POS. This is a communication method common in amateur HAM radio, which allows static images to be transmitted via radio waves over long distances. This is achieved by converting images into WAV audio files and transmitting this audio data over HF, VHF, or UHF radio frequencies. On the receiving end, a personal computer equipped with SSTV software can be used to demodulate the incoming signals.

Originally, the POS was going to utilize Digital Slow Scan Television (DSSTV) in order to achieve a higher quality of transmitted images. However, this was changed to traditional SSTV, since DSSTV was found to be much more difficult to implement with Python on the Raspberry Pi. DSSTV is also a less-frequently used method of communication among HAM radio operators, and thus documentation about its use and modulation techniques is limited compared to SSTV.

To receive POS transmissions, a team member's personal laptop is equipped with an Adafruit SDR Radio USB Stick. This device consists of a tunable antenna and RTL dongle connected to a USB port. This model is tunable between 24 and 1850 MHz, allowing it to receive 433 MHz transmissions easily. The SDR receiver pairs with SDRSharp, an SDR software that creates an interface for observing and analyzing incoming radio transmissions.

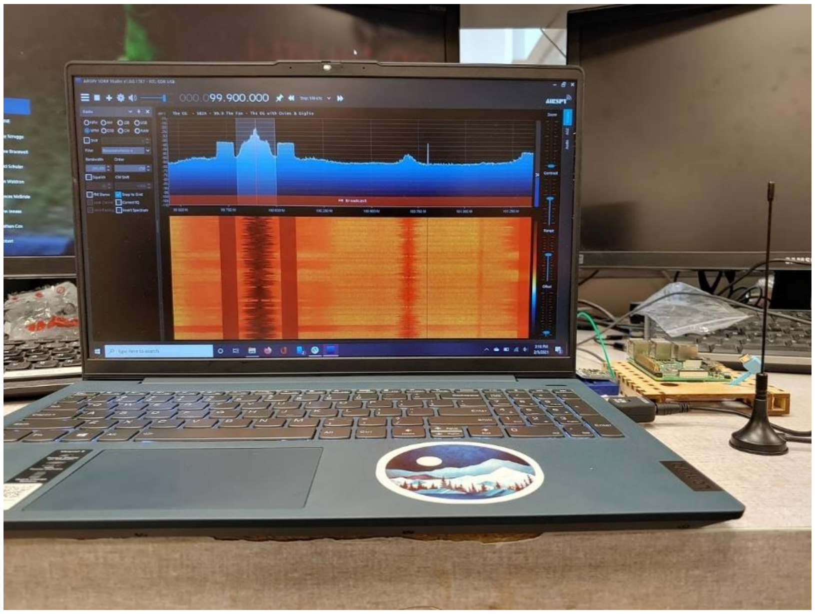


Figure 4-13 SDR Receiver with SDRSharp Software

A free SSTV software called MMSSTV will be used simultaneously to demodulate the transmissions received and save the POS images to the laptop. After the images are saved, a Python script autonomously splices the POS images together into the two distinct panoramic images mentioned previously.

The POS transmitter will be equipped with a quarter-wavelength whip, or monopole antenna. The total length of the antenna can be calculated with the formula

$$\lambda = c/f$$

$$L = \lambda/2$$

$$E = L/2$$

Where λ is the wavelength, c is the wave speed, f is the wave frequency, L is the total antenna length, and E is the dipole length. The total length of a quarter-wave antenna is equal to a quarter of the wavelength at the antenna's target frequency. At 433 MHz, the total antenna length is 0.173 meters, or 6.8 inches. Space within the LOPSIDED-POS is limited, so this length can be decreased by introducing loading coils. Coiling sections of the antenna wire allows a shorter overall length to be "electrically" equivalent to the full quarter-wavelength antenna. This will allow the antenna to fit within the limits of the lower LOPSIDED section.

A quarter wavelength antenna inductance calculator can be used to determine the matching impedance of a loaded antenna. The online calculator shown below uses a formula for calculating loading coil inductance from the paper "Off-center loaded dipole antennas," written by Jack Ponton in 1974. Inputs for this formula include frequency, antenna length, coil position, and wire diameter. A coil inductance calculator, such as Coil64, can be used to determine the physical dimensions of the coils itself, such as the number of turns, the length of winding, etc.

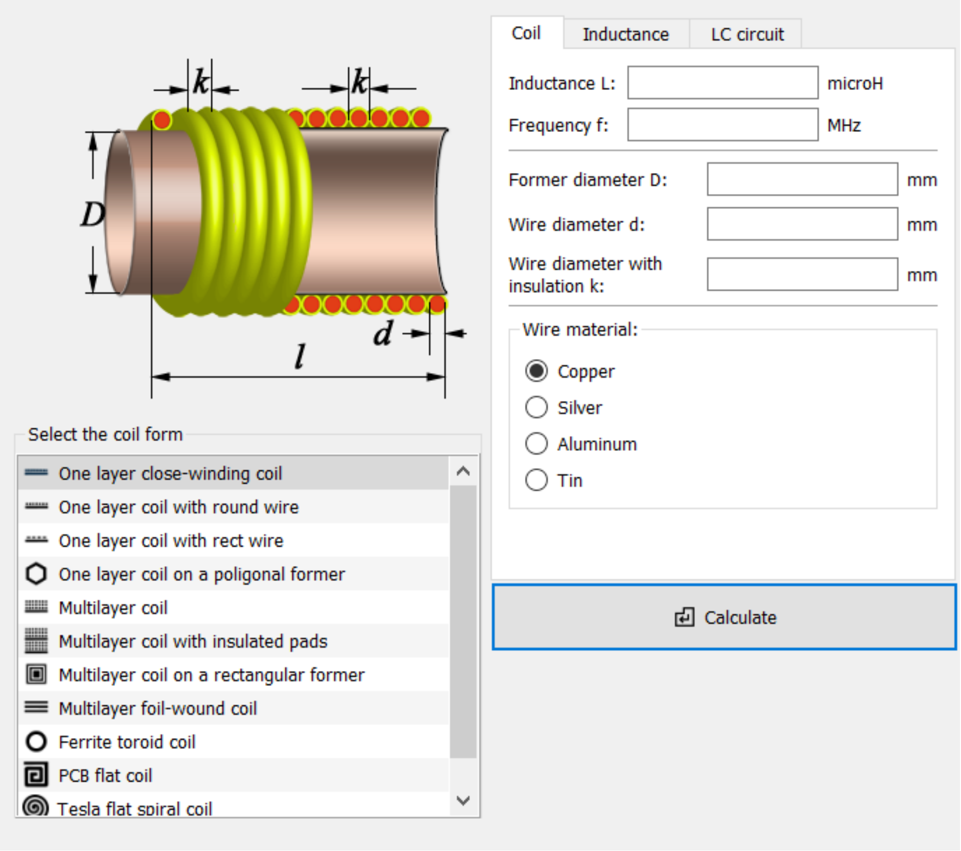


Figure 4-14 Coil64 Software for Loading Coil Determination

4.4.3 LOPSIDED-POS Electronics

The leveling, imaging and deployment systems of the LOPSIDED-POS each require multiple electronic components. These systems will be powered by the same 12V, 1600 mAh battery, and will be controlled by the same Raspberry Pi 3B+. This is to reduce weight and cost of the LOPSIDED-POS, and to ensure that the electronic components are able to fit within the 69 x 69 x 180 mm volume of the lower LOPSIDED section. Power is provided to the Raspberry Pi from the 12V battery using a Hiletgo DC-DC buck step-down USB module voltage converter. This converts 12V to 5V and allows the Pi to be powered from its micro-USB port, which is the safest and most reliable way to power a Raspberry Pi.

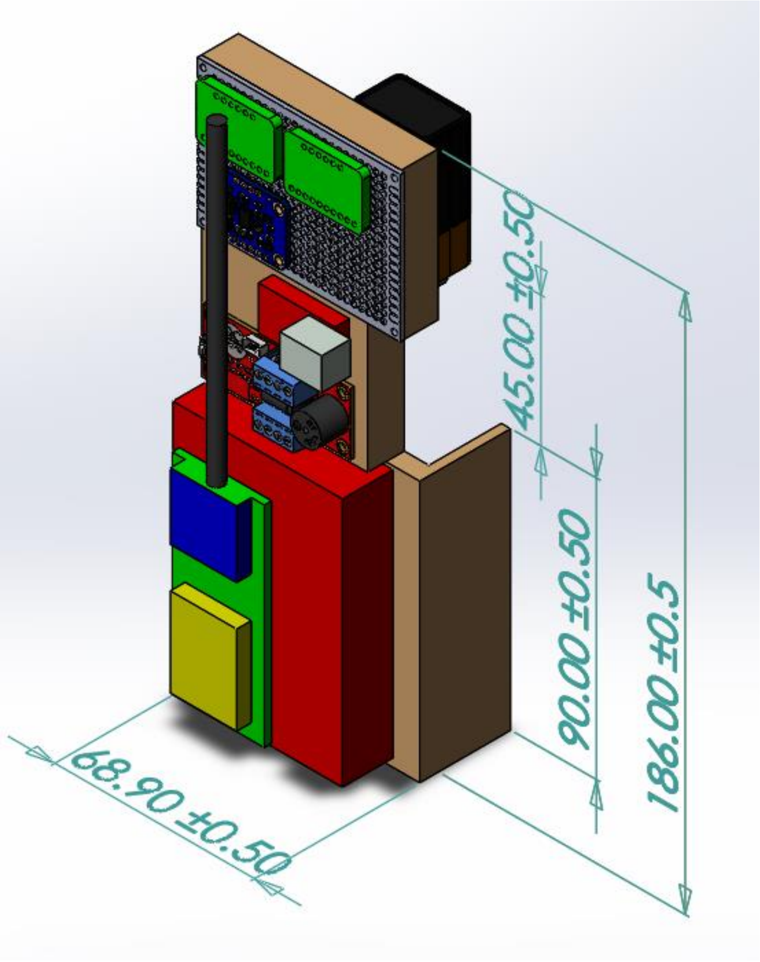


Figure 4-15 LOPSIDED-POS Electronics Sled with Dimensions

POS electronics consist of four Arducam Fisheye camera modules, the Multi-Camera Adapter Board, and an Adafruit RFM69HCW 433 MHz transmitter, which transmits to an RTL 2832 SDR receiver located at the team's ground station. The SDR receiver connects to a laptop computer to receive the transmitted POS images. Electronics for the leveling system consist of four 5V solenoid latches, two for each gimbal ring, an Adafruit TB6612 motor driver, and an Adafruit BNO055 orientation sensor. An LM2596 buck voltage converter is used to step down the battery voltage from 12V to 5V for the solenoids. Electronics for the recovery system consist of two Dormakaba 3510LM 12V electromechanical locks, an Adafruit TB6612 motor driver, a StratologgerCF altimeter, a 9V battery, and a BRB900 GPS tracker. The GPS transmitter will communicate with the BRB900 receiver, which will be located with the team at the ground station. The Stratologger altimeter and the GPS tracker module are both powered from separate batteries – a 9V Alkaline battery for the altimeter and a 3.7V LiPo battery for the GPS. The motor drivers allow the Raspberry Pi to actuate the solenoids and the electronics latches despite the difference in logic level between these devices and the Raspberry Pi. The motor drivers are rated for up to 13V and 1.1A, which fits the specifications of both the solenoids and the electromechanical locks. Each motor driver has four output channels, which allows it to control up to four solenoids on one board.

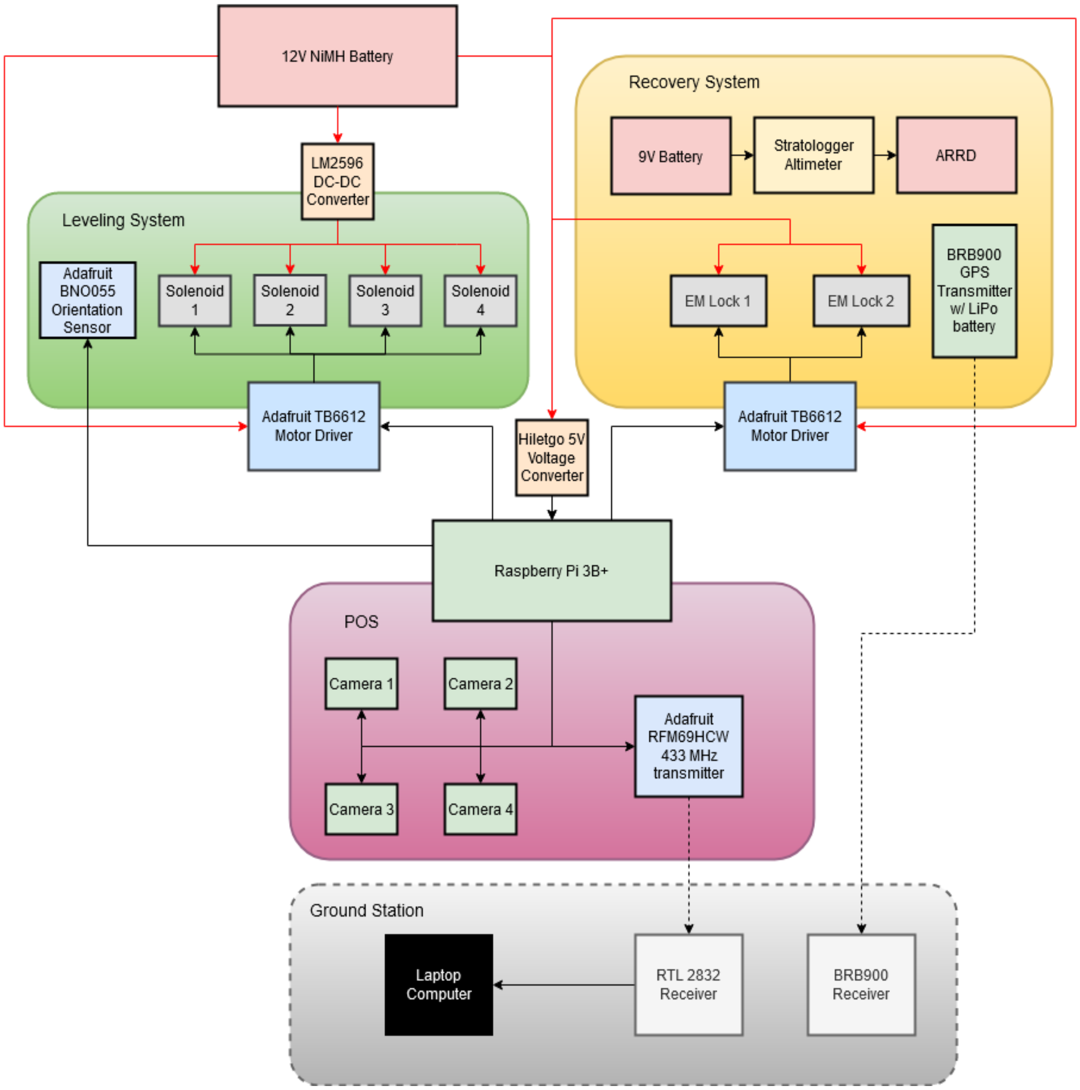


Figure 4-16 LOPSIDED-POS Electronics Flow Chart

The StratologgerCF altimeter will communicate with the ARRD, which will be activated using e-matches. The details of the ARRD will be provided in Section 4.6.1.3. It is important to clarify that the altimeters will be protected from the transmitter's frequency with the use of aluminum foil to prevent interference that can cause a failed ARRD ignition. A failed ARRD ignition means that the ARRD ignites too early or too late in which cases the payload could either not exit the launch vehicle at all as it will remain locked by the shear pins, or the payload could be falling too fast as it deploys its parachute at a lower altitude than intended. The testing setup for RF interference for the StratoLoggerCF onboard LOPSIDED-POS is shown in Figure 7-5, where the BRB 900 tracker and the altimeter are fixed to the sled as intended to place for launch and the altimeter is tested to activate at a given pressure inside a sealed bucket with a vacuum connected to it.

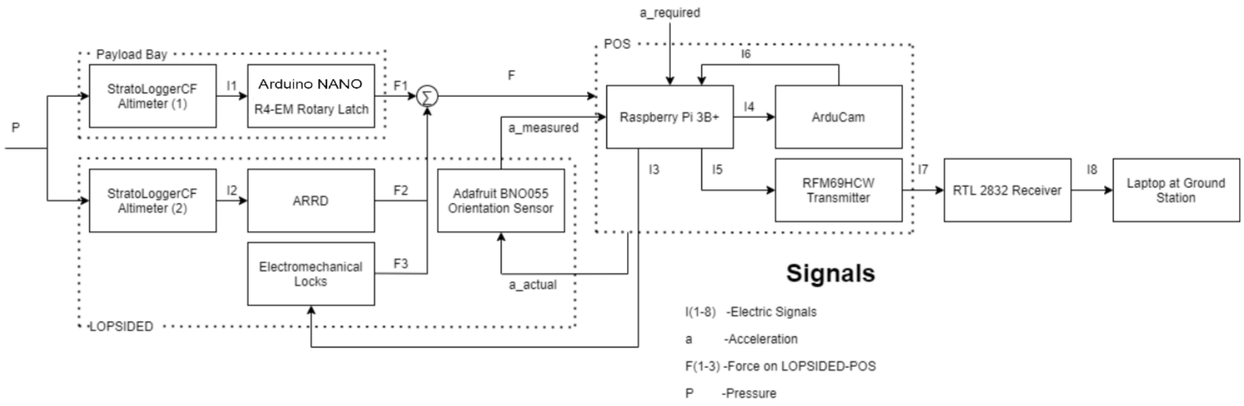


Figure 4-17 LOPSIDED-POS Signal Block Diagram

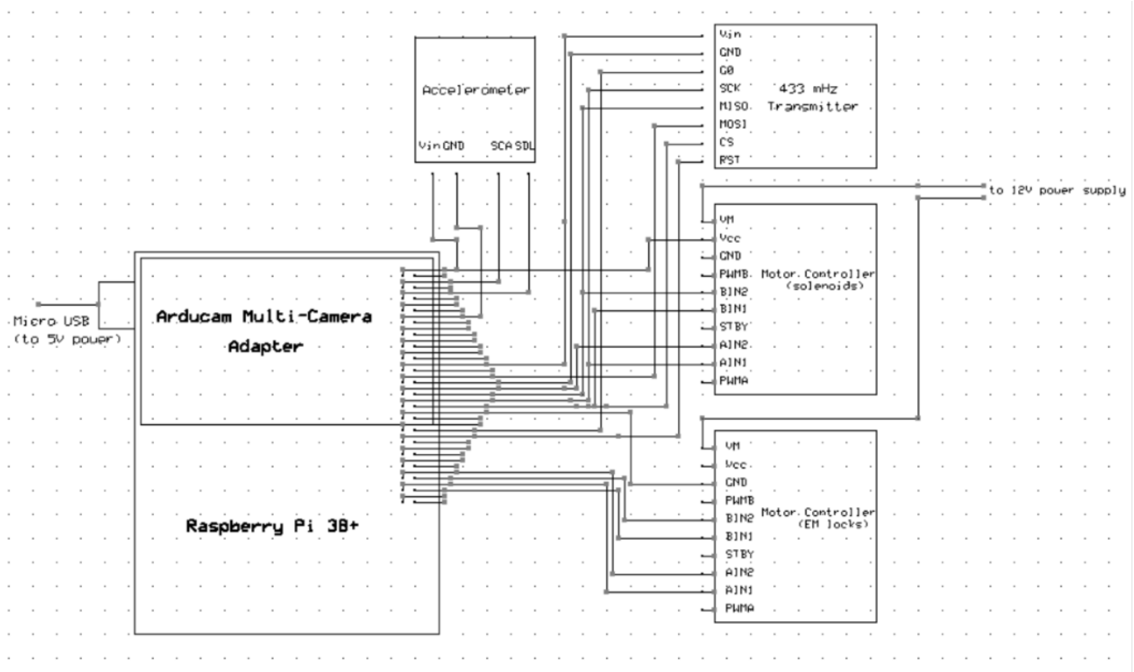


Figure 4-18 Raspberry Pi Wiring Diagram

In addition to the four camera modules, Figure 4-18 details the components which will wire directly with the Raspberry Pi. Since these devices will not all be operating synchronously, a single GPIO pin can have more than one component connected to it.

To protect from inductive flyback generated by inductive DC devices, flyback diodes will be used for each solenoid and electromechanical lock. These diodes are wired across the leads of the inductive device and prevent any voltage spikes that occur when power is disconnected. This is especially crucial in order to protect the Raspberry Pi, which could be permanently damaged as a result of flyback. Figure 4-19 below depicts a representation of the implementation of this diode. In the LOPSIDED-POS, perf board will be used to wire the diodes across the appropriate terminals.

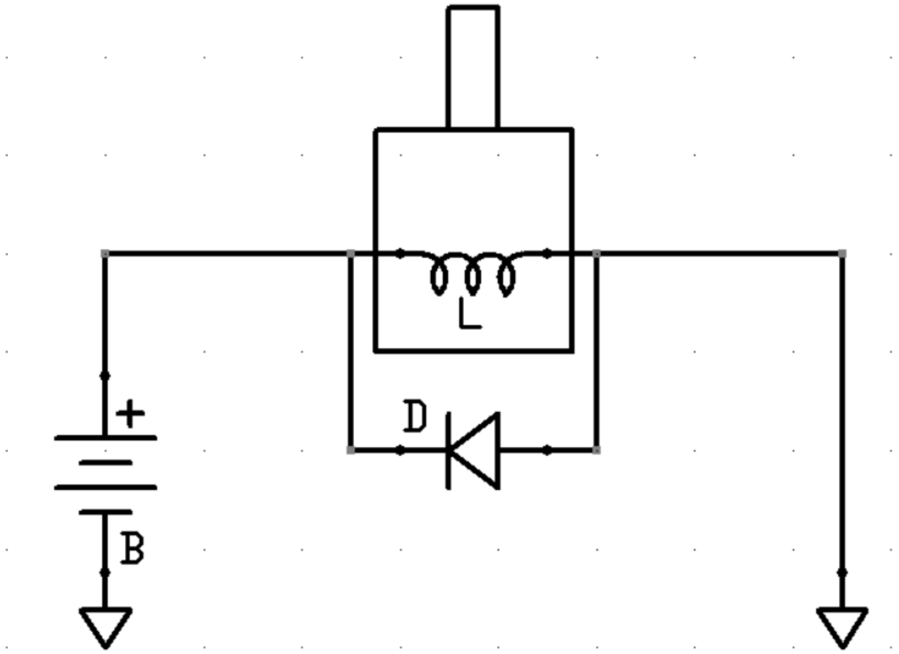


Figure 4-19 Flyback Diode Wiring Schematic

The LOPSIDED-POS has two on-board transmitters; the BRB900 is a GPS tracker, which will transmit location information for the payload at a frequency of 900 MHz. The BRB900 is equipped with its own single cell LiPo battery, and thus is separate from the rest of LOPSIDED-POS's power system. The RFM69HCW is used for POS image transmission, at a frequency of 433 MHz. This frequency was selected to avoid interference with the LOPSIDED-POS GPS tracker.

4.4.4 LOPSIDED-POS Construction

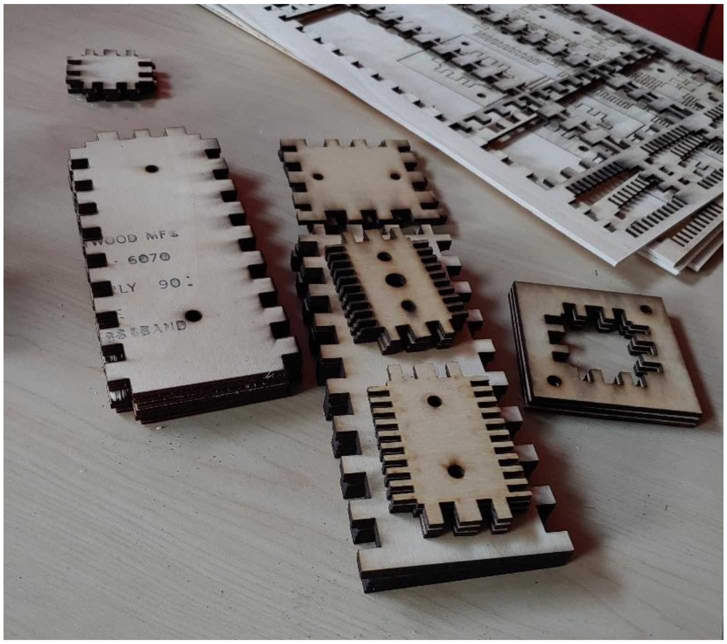


Figure 4-20 Laser Cut Lower LOPSIDED Walls

The metal frame, and other metal parts, were cut from one sheet 12” x 18” piece of 1/16” thick 6061 aluminum. As seen in Figure 4-22 these pieces could only be bent at a very small radius That was often too small for this particular sheet of metal and the pieces would break. This led to some minor design changes. As seen in Figure 4-21, the image on the right shows the ARRD latch being housed by the original 6061 alluminum and a thicker piece of aluminum replacing the faces that broke off. The pieces that survived the bending were bent in a more relaxed way with a larger angle when it could be done and not quite to 90 degrees. This allowed the material to survive but made the metal pieces slight wider than designed. One example of what was done to accommodate for this was sanding down the wooden surface that encloses the ARRD on the upper section of LOPSIDED from the inside so that its wall thickness went from 3/8” to 1/4".

Figure 4-21 Metal Frame Unassembled (Left, with Other Metal Parts), and Assembled (right)

Figure 4-22 Sheet Metal Bending

The two levelling rings, both inner and outer, were machined from one piece of 6” diameter aluminum stock that was 3” long. It made in the NC State MAE machine shop on a CNC milling machine with the proper drawings and GD&T and turned out phenomenally. The pins/rods that act as the axes are adhered to the outer ring where they should not rotate. Ball bearings are press fitted and carefully adhered to their surfaces such that they can still rotate while being secured in place.

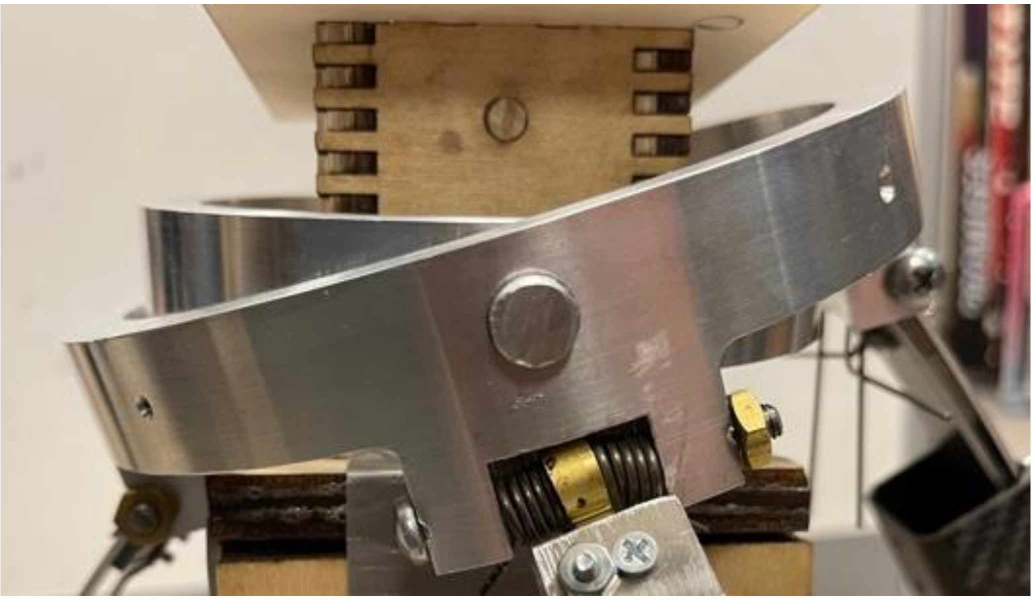


Figure 4-23 Assembled Leveling Rings

Carbon fiber legs were ordered to be 1” square cross section with rounded corners. They were measured to be 2mm larger than that which did not alter the design too much. These were cut using a bandsaw to their final size.

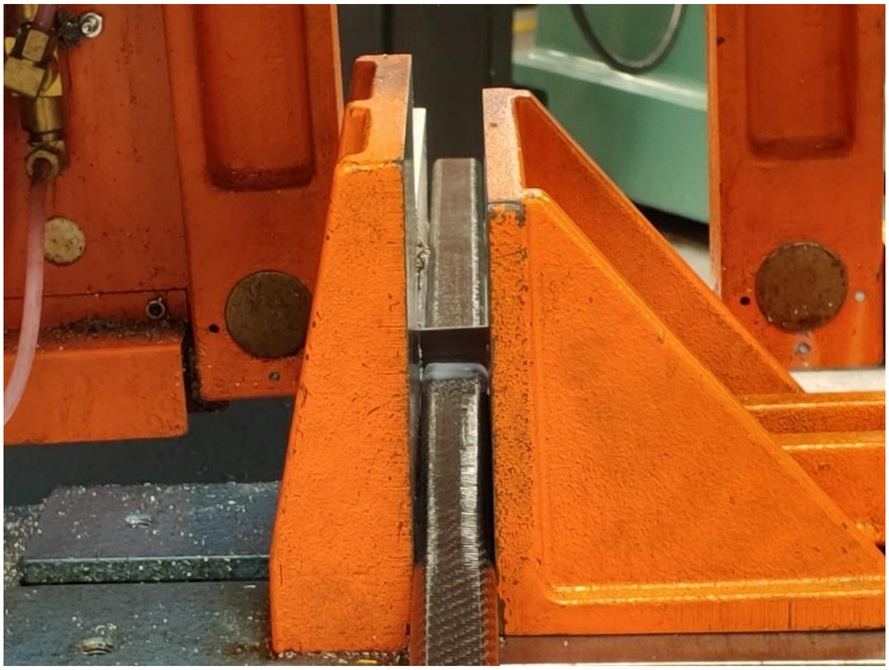


Figure 4-24 Carbon Fiber Cutting with Bandsaw

The leg hinges were custom cut from brass door hinges due to the strength of brass and the hem that they feature. The hem makes the metal curve such that the flat face's plane does not cross directly through the center point of the hem curve and therefore offsets where the legs can attach to, saving some complex bending and making them more compact.

Figure 4-25 Leg Hinges Cut from Door Hinges

Figure 4-26 Shows the assembly of the leg joint. On either side of the hinge lies a music wire torsional spring with mirrored winding patters such that the end of the spring is as close to the leg side of the hinge as possible to prevent those arms from sliding out of place.

Figure 4-26 Leg Attachment Assembly

The feet on the bottom were made from the same sheet of metal that the skeletal frame was cut from. They were pressed into a 1/2” radius curve so that they would attach to either end of the carbon fiber legs and have good contact with the ground regardless of the angle.

The walls for the upper LOPSIDED section were cut from a single sheet of polycarbonate, using a band saw. Each window has overall dimensions of 69 x 70mm, and two of the windows have a 42 x 12.7mm rectangular indent taken from their top surface. This indent is for the rectangular electromechanical locks for parachute release, since their installation point overlaps slightly with the window locations.

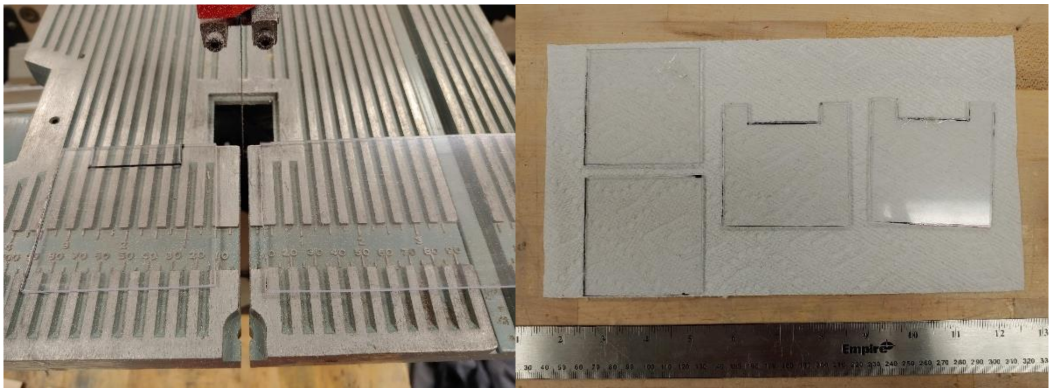


Figure 4-27 Polycarbonate Windows

To cut the indents out of the polycarbonate, a band saw was used to cut two slots perpendicular to the top surface of the window. Then, a drill press was used to perforate the distance between these slots. This weakened the polycarbonate enough to allow the intended section to be removed with a pair of plyers. The edges were sanded down using a file. Wherever possible, paper towels were used to form a barrier between the polycarbonate and work surfaces in order to reduce the chance of scratching the material and obscuring camera field of view.

Figure 4-28 Perforating Polycarbonate with Drill Press

The POS camera mounting block consists of five pieces, which are designed to fit into each other to form an open block. The pieces were cut from 1/8” thick, aircraft-grade plywood and secured together using high strength wood glue. The outer dimensions of the block are 1.8 x 1.8 x 2 inches. The outer dimensions of the mounting block had to be increased from the original dimensions to account for space between the mounting screws and the interior walls of the block. While the glue was curing, the box was clamped together and left undisturbed for 12 hours. A ¼" hole was drilled in the bottom surface of the mounting block to allow a threaded rod to pass through. The threaded rod is attached to the structural LOPSIDED frame, and the camera mounting block is secured from the bottom with a ¼" nut and washer. The nut will be tightened with a wrench to ensure the mounting block cannot rotate freely about its vertical axis.

The cameras are attached using M2.5 screws and nuts. The camera modules have two screws that protrude from the back surface of their PCBs, making flat mounting difficult. For each mounting point, one nut is placed between the wood and the camera to act as a spacer, making four spacers per camera.

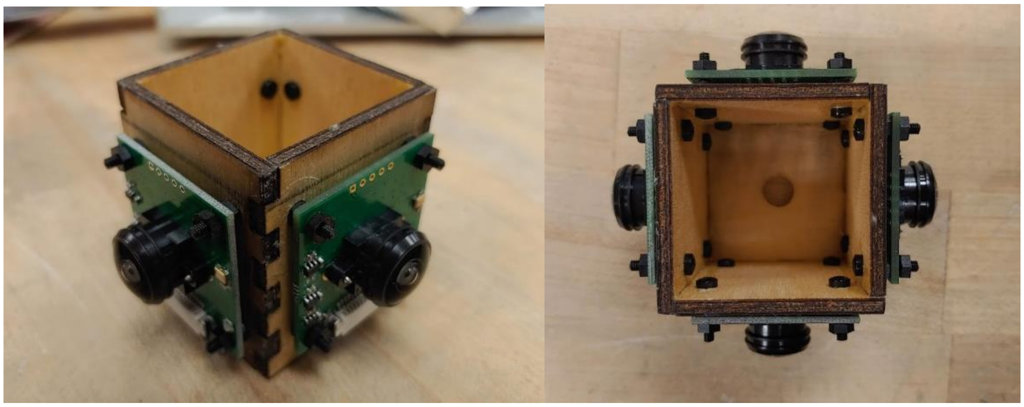


Figure 4-29 Camera Mounting Block with Cameras Attached

The electronics sled houses the majority of the payload electronics. It is a single layer of laser-cut 1/8” thick aircraft-grade plywood with dimensions of 2.95 x 7.32 inches. This is a simplification from the previous sled design, which had unnecessarily complex geometry that would be difficult to manufacture. Since the electronics sled is not a load-bearing component, its thickness was minimized. A minimized thickness is necessary to meet the clearance of the lower LOPSIDED section interior, which is 69 x 69 mm. A thicker sled would cause some electronic components to collide with the inner wall of the lower LOPSIDED section and prevent installation of the completed sled.

With the exception of the POS cameras, the parachute latches, and the leveling solenoids, all other electronic components will be mounted to the electronics sled.

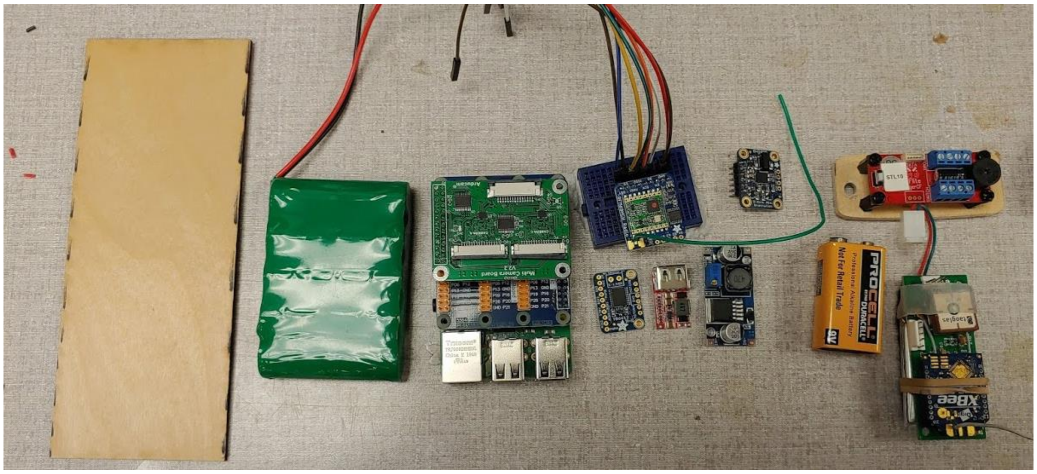


Figure 4-30 Electronics Sled with Electronic Components

To assist in the wiring of the necessary Raspberry Pi components, as shown in Figure 4-18, a pin extender board will be used with the Raspberry Pi. This is a board which simplifies the wiring of multiple components which require the use of GPIO pins. This board does not add additional GPIO pins, but simply provides multiple access points to the existing pins. This particular extender board has a row of pins running perpendicular to the board, which will allow for access to the pins located under the Multi-Camera Adapter Board.

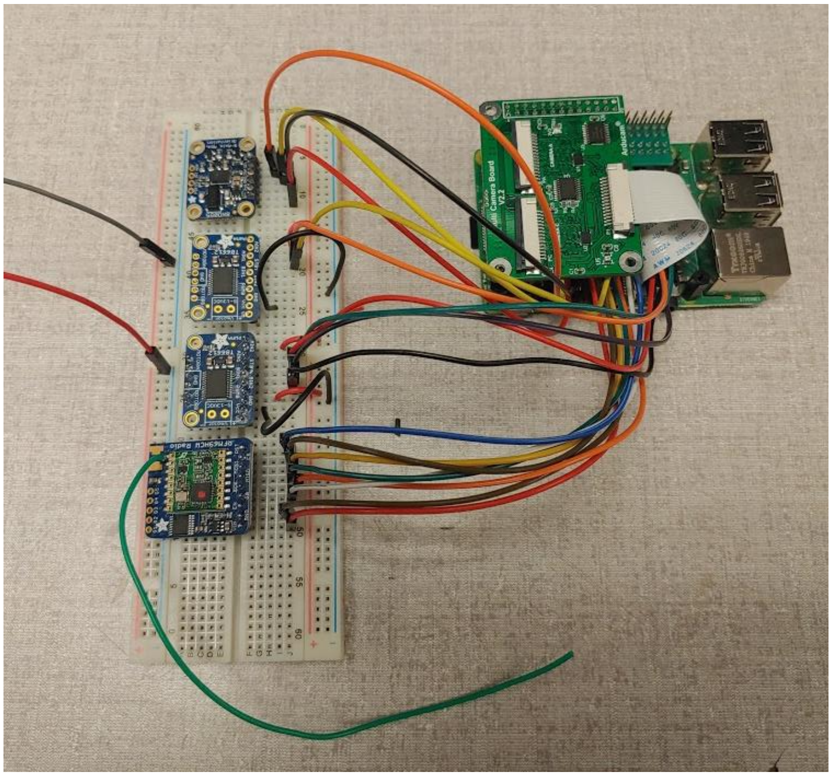


Figure 4-31 LOPSIDED-POS Wiring

Breakout boards, such as the ones for the POS transmitter, motor drivers, and orientation sensor, are soldered to perf boards which will be attached to the sled. Wiring connections made to the GPIO pins of the Raspberry Pi will not be soldered, but will be secured with an insulative adhesive such as electrical tape.

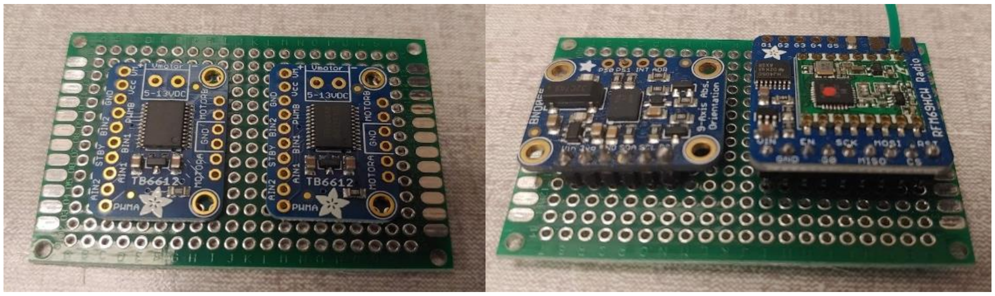


Figure 4-32 Breakout Boards for LOPSIDED-POS Wiring

As mentioned in Section 4.4.3, the solenoids and electromechanical locks require diodes connected across their leads to prevent inductive flyback. The solenoids are utilizing 1N4001 diodes, while the electromechanical locks utilize 1N4004 diodes. An example of the wiring for these diodes is shown below.

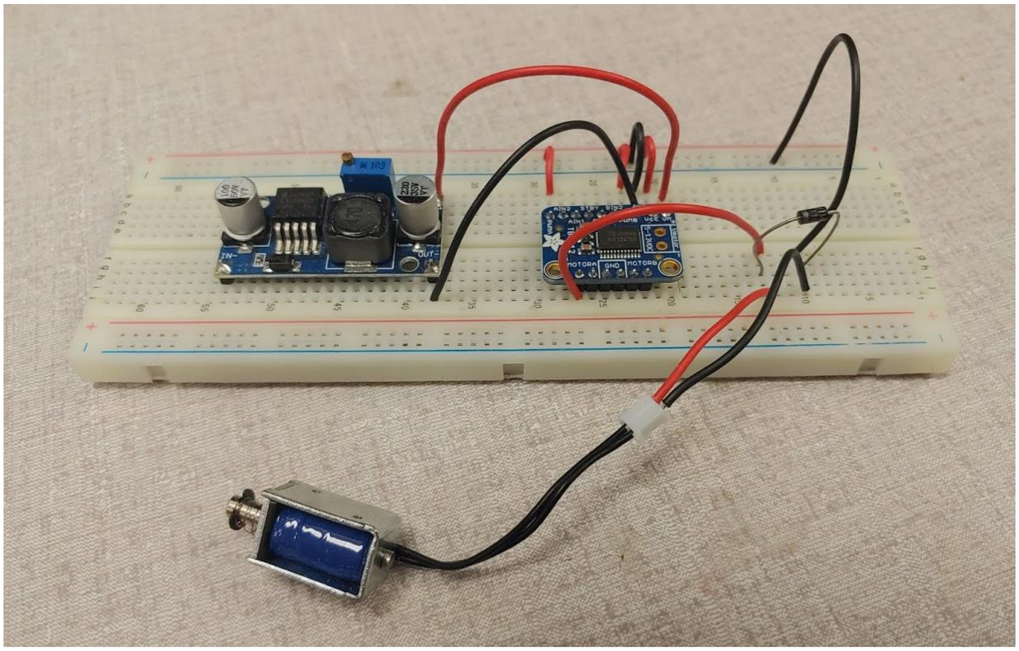


Figure 4-33 Solenoid Wiring

4.5 LOPSIDED-POS Retention and Deployment Design

4.5.1.1 Individual Component Details

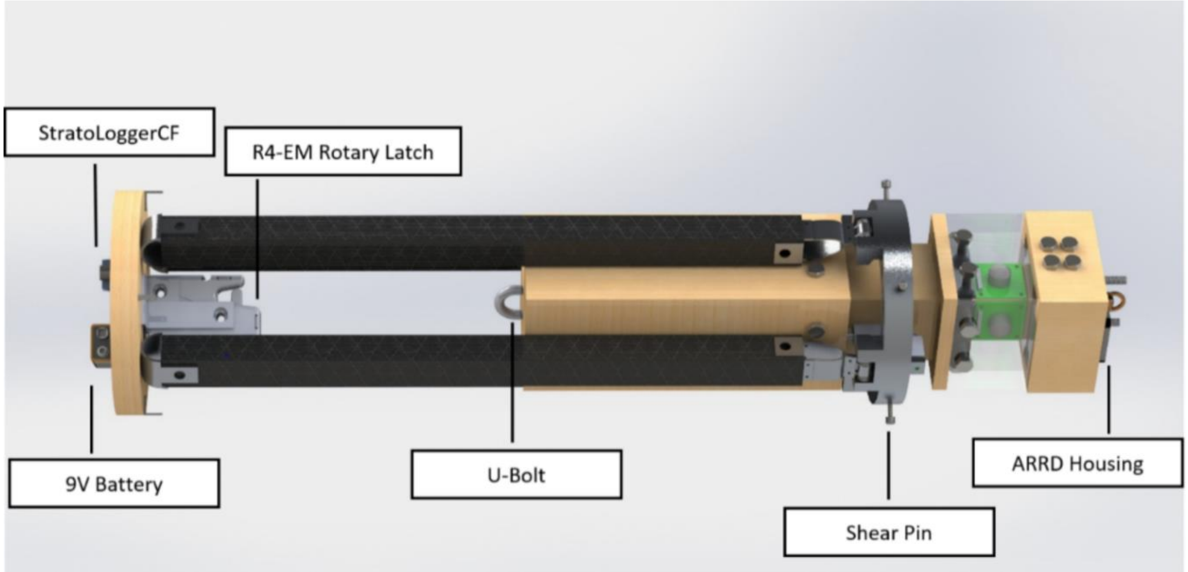


Figure 4-34 LOPSIDED-POS Retention and Deployment Components

Figure 4-34 shows the components used for the selected payload integration design. These components have not changed since CDR; however, there has been an addition of an Arduino NANO3 in order to provide a continuous electric signal to the rotary latch in order to ensure release of the payload from the retention system after the launch vehicle reaches apogee. The components presented in CDR and still in use include a StratoLoggerCF altimeter with a 9V battery, a small 12V A23 Alkaline battery for the R4-EM Rotary Latch and Arduino NANO, a U-bolt, three shear pins, and an ARRD (Advanced Retention Release Device) housing at the top. The system is set so that LOPSIDED-POS is placed pointing aft of the launch vehicle when placed on the launch rail. LOPSIDED-POS will hang from the rotary latch as it will be attached to it using a shock cord like those described in the recovery section. The rotary latch prevents LOPSIDED-POS from moving down the payload bay during ascent; in addition, the shear pins prevent LOPSIDED-POS from rotating and moving towards the payload bay walls. Moreover, the gimbal ring on LOPSIDED-POS makes a tight enough fit inside the payload bay in order to minimize unnecessary movement. Once the launch vehicle reaches apogee, the StratoLoggerCF altimeter, which has its own dedicated battery and has an accessible arming switch through a small hole on the payload bay, sends a signal to the R4-EM Rotary Latch to open and release the cord to which the payload is attached to. After that point, the payload is only supported by the shear pins that go in through the payload bay walls to screw into the LOPSIDED-POS ring. The shear pins used are 3 #4-40 nylon shear pins rated for 35 lbf breaking load as detailed in the recovery Section 3.1.2.1. The distance between the bottom of the bulkhead and the location of the shear pins is 21.5 inches. The length of the cord that attaches the rotary latch and the U-bolt is 7.60 inches.

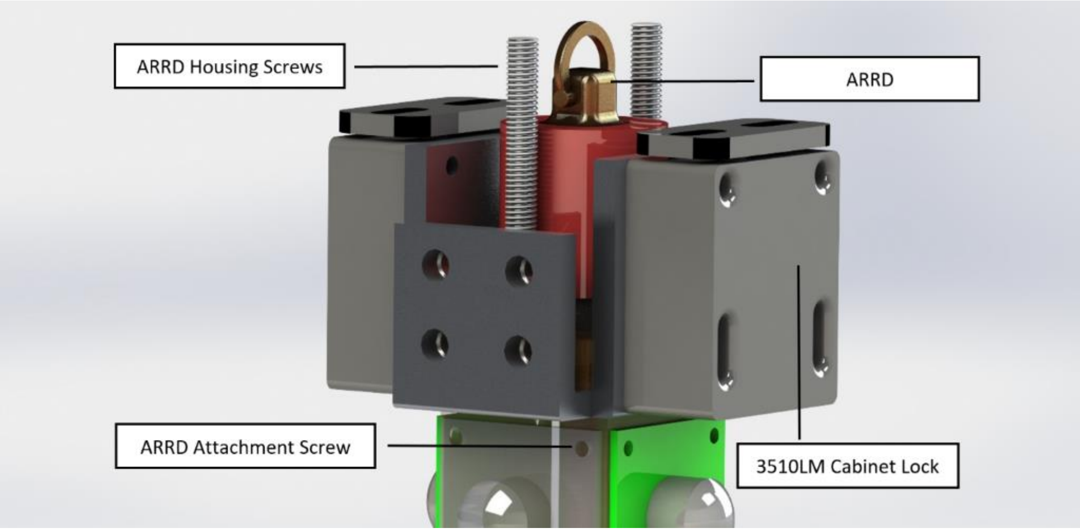


Figure 4-35 ARRD Housing and Electromechanical Locks

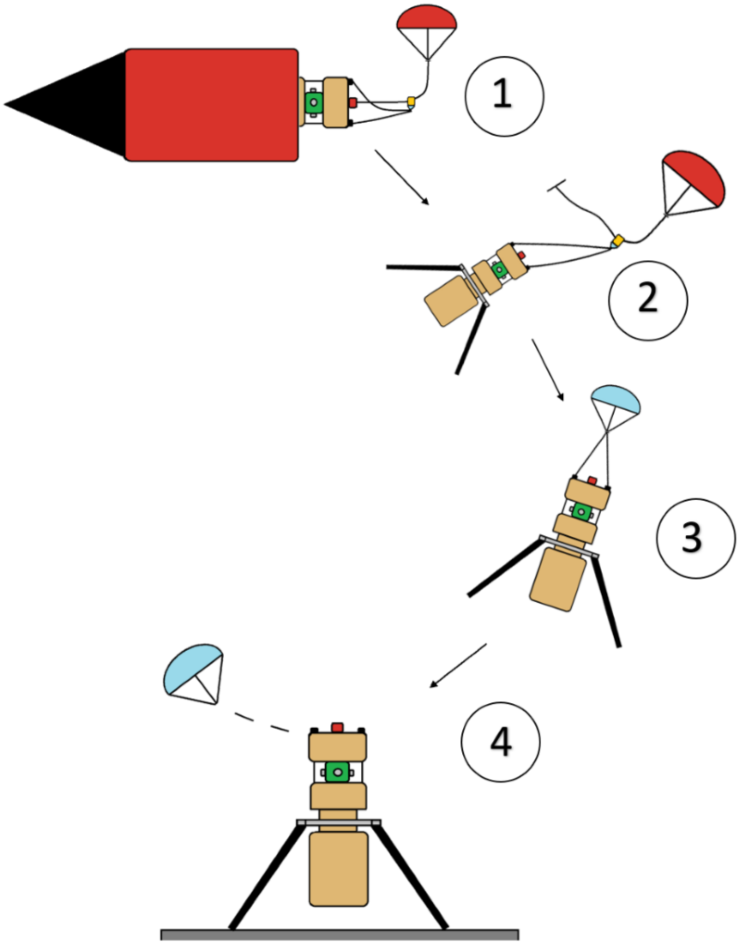


Figure 4-36 LOPSIDED-POS Deployment and Landing Sequence

The final payload deployment system is composed of mechanical as well as electronic components such as a pulling force on the ARRD by the main parachute recovery harness at main parachute deployment, and the detachment of LOPSIDED-POS's parachute at landing. It is important to mention that LOPSIDED-POS will always remain attached to a parachute being either the main parachute (attached at the ARRD) or the payload parachute (which is easily pulled out by LOPSIDED-POS's weight once the payload exits the launch vehicle). As detailed in Figure 4-36, the first step describes how LOPSIDED-POS will remain within the payload bay until the deployment of the main parachute at 700ft AGL (which is the point of main parachute deployment). On step two, LOPSIDED-POS will exit the payload bay and the ARRD device will ignite at 500ft AGL, releasing LOPSIDED-POS from the main vehicle. The main parachute (in red) will still be attached to the main vehicle while the parachute for LOPSIDED-POS (in blue) will be inside a deployment bag that is attached to the main parachute shock chord. LOPSIDED-POS will pull the parachute out of the bag and proceed to land, as depicted on step three. On step four, LOPSIDED-POS will land. The change in velocity will indicate the onboard sensors to send a signal to the post-landing parachute release devices to release the parachute. Figure 4-17 displays the block diagram for LOPSIDED-POS, and it is noticed how the rotary latch, ARRD, and the payload parachute apply a force to LOPSIDED-POS resulting in a new acceleration reading by the accelerometer (BNO055). There will be a set acceleration reading that can only be achieved after the payload is falling with the parachute and the payload suddenly decelerates due to contact with the ground. At that point, the Raspberry Pi will signal the EM locks to disengage the payload parachute.

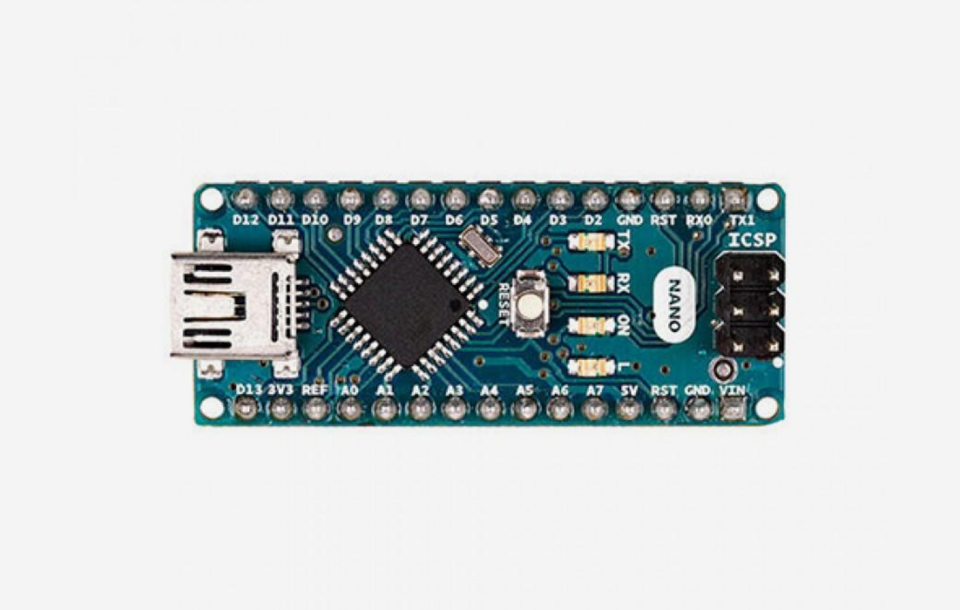


Figure 4-37 Arduino Nano

4.6 LOPSIDED-POS Retention and Deployment Construction

4.6.1.1 Construction Summary

The construction or manufacturing of LOPSIDED-POS and the payload deployment and retention systems was done using a variety of power tools at the Senior Design lab. Some of the tools used included an angle grinder, a drill press, bandsaw, sander, and a drill. The components manufactured for payload integration and deployment are as follows:

a) Retention Electronics (rotary latch) attachment to nosecone bulkhead
b) Parachute release devices and ARRD attachment plates

4.6.1.2 Retention System Construction

The nosecone bulkhead was manufactured such that the electronics that control the unlocking of the rotary latch at the correct altitude are placed forward of the bulkhead while the rotary latch and the battery are located on the aft side of the bulkhead. Figure 4-38 displays the 9V battery housing which was 3D-printed such that the cables could reach the altimeter. In addition, a screw switch was attached to the surface of the bulkhead using a wooden platform that was laser cut, lining up with the red line in order to line up with a hole in the airframe allowing a team member to turn the altimeter on at the launch pad. The altimeter was also attached to the surface of the bulkhead using a wooden platform cut using the bandsaw. The Arduino Nano board has been ordered; however, the attachment platform has been manufactured out of plywood and is seen in Figure 4-38 as the curved platform screwed on top of the switch platform, next to the battery house.

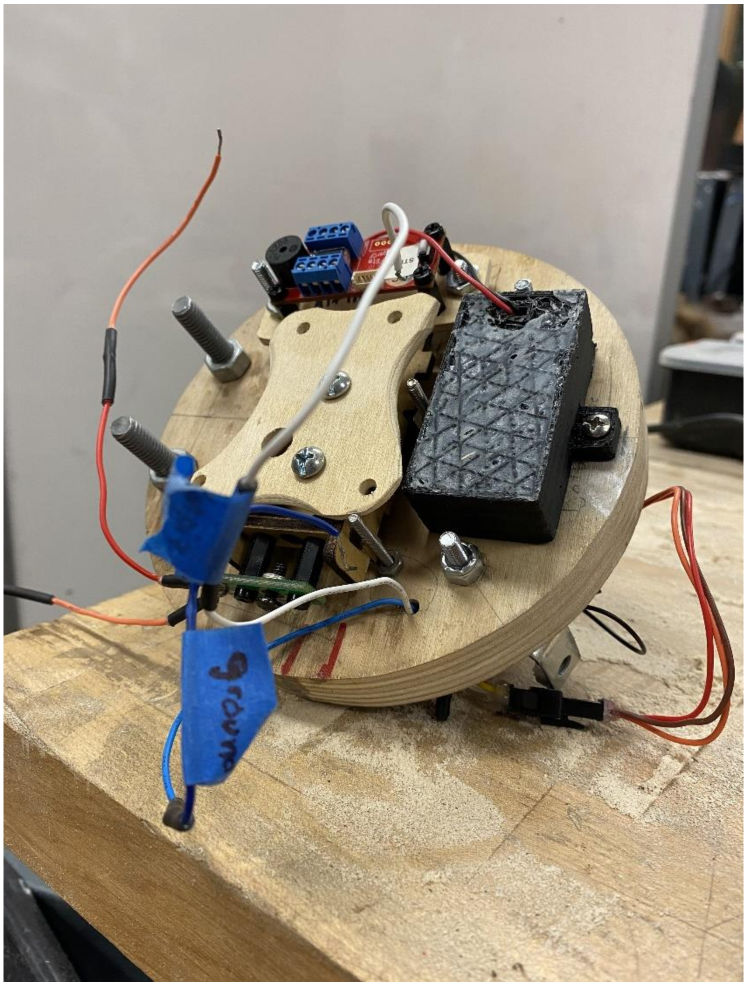


Figure 4-38 Nose Cone Bulkhead with Retention Electronics

Figure 4-39 displays the attachment of the rotary latch to the nosecone bulkhead using two L-brackets and screws. In addition, it is shown how the latch connects to the quick disconnect that shares ground, power, and the activation signal.

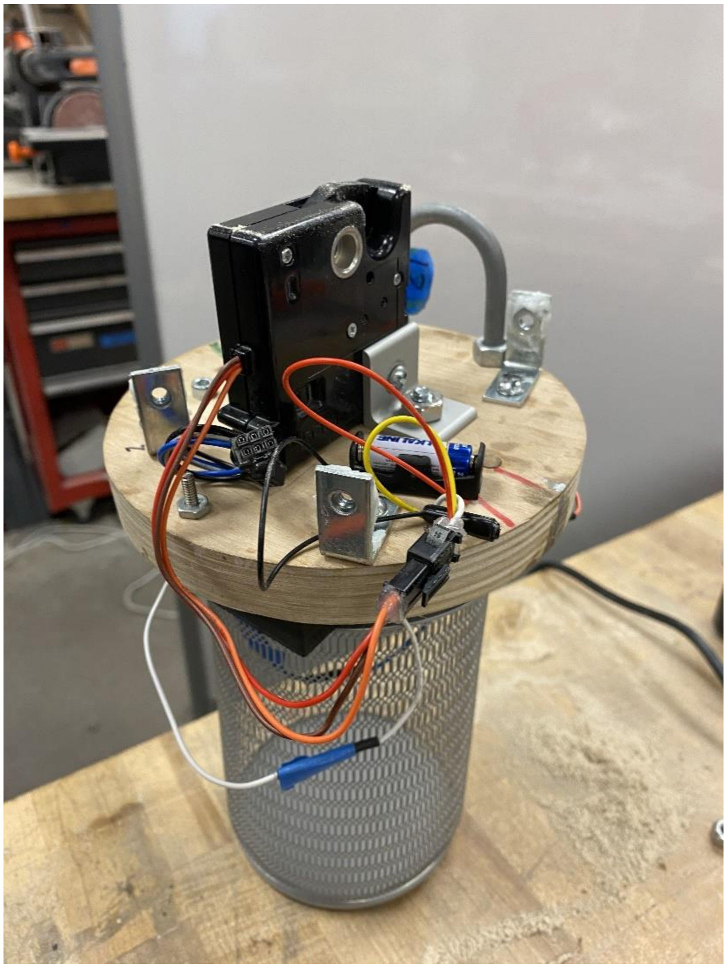


Figure 4-39 Nose Cone Bulkhead with Retention Rotary Latch and 12V Battery

4.6.1.3 Payload Deployment system: ARRD and parachute release devices

Figure 4-3 and Figure 4-40 show the ARRD housing chassis portion. The metallic chassis is the load bearing part of the ARRD housing as it is directly attached to the ARRD at the center hole as depicted. In addition, this chassis is attached to the parachute release devices which will also be applying a substantial load on the chassis. Initially, the team had bent an aluminum plate to match the attachment points for the parachute release devices; however, the two bent parts for the latches broke off and had to be replaced with a pre-bent aluminum plate. This pre-bent aluminum plate is thicker and attaches to the original aluminum plate by the four screws as depicted.

Figure 4-40 ARRD and Parachute Release Device Attachment Plate

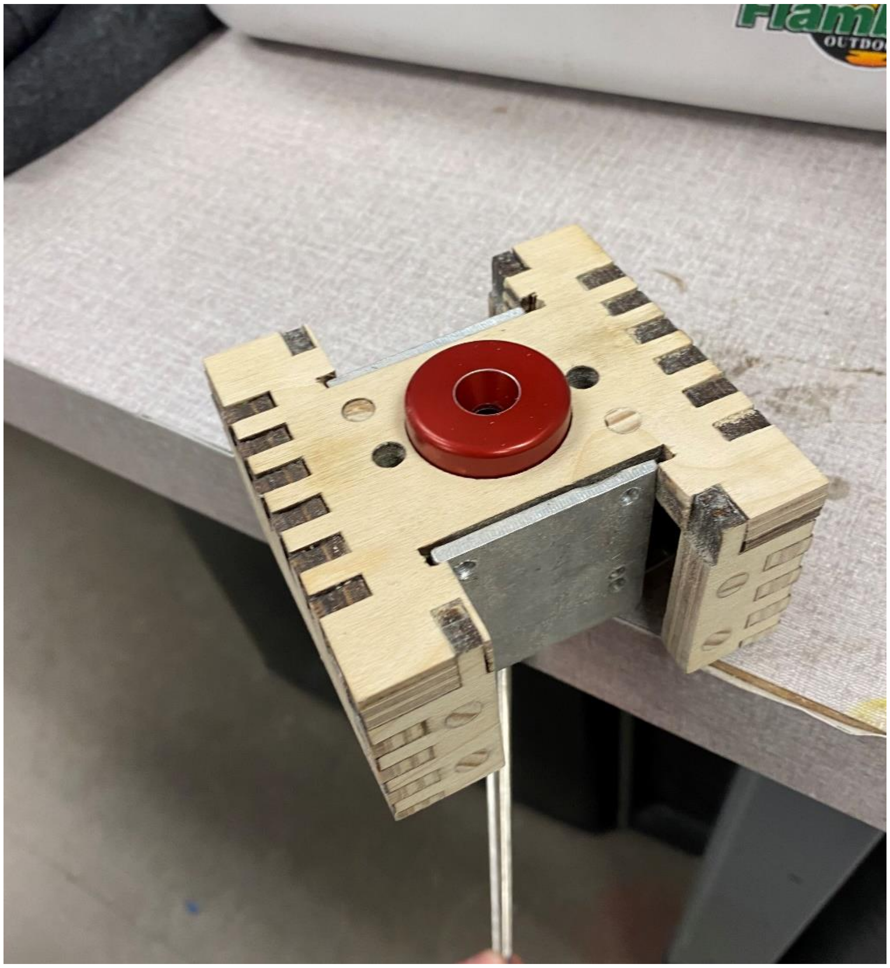


Figure 4-41 Completed ARRD Housing

Figure 4-41 shows the ARRD housing attached to the upper section of LOPSIDED-POS. It is also worth mentioning that once the placement of the electronic sled is determined, the payload body will be adapted to carry a switch on the surface of the lower section for the purpose of turning on the altimeter at launch pad. This screw switch will be accessible through the payload bay body tube with a screwdriver. Figure 4-42 also shows the attachment of the two parachute release devices at either side of the ARRD.

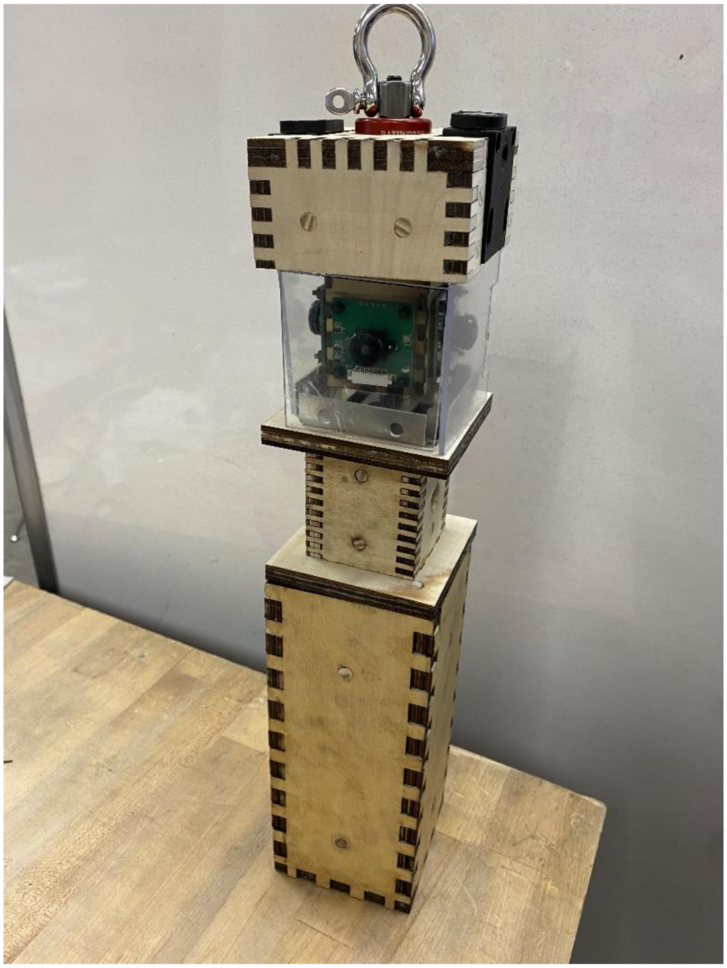


Figure 4-42 ARRD Housing Attached to LOPSIDED-POS

4.7 Payload Demonstration Flight

As of the submission of the FRR document, the team has not yet completed a payload demonstration flight. This flight is planned to be completed on March 20th at the Tripoli launch site in Bayboro, North Carolina. This flight will also serve as a requalification for the launch vehicle as discussed in Section 5.2. March 27th is a secondary launch date, if necessary. Success of the PDF will be defined as the retention of LOPSIDED within the payload bay until main parachute deployment, the complete removal of LOPSIDED from the payload bay at main parachute deployment, and the successful separation of LOPSIDED from the main parachute recovery harness using the ARRD.

5. Demonstration Flights

5.1 Vehicle Demonstration Flight

5.1.1 Launch Conditions

The launch vehicle, named *81 Point 5*, was flown on February 21st at 2:54pm EST to fulfill the requirements of the Vehicle Demonstration Flight. The table below shows the atmospheric conditions during launch as well as additional flight details.

Table 5-1 Atmospheric Conditions and Flight Details

Date	Feb 21 2021
Location	Bayboro, NC
Time	14:54 EST
Temperature	43 °F
Pressure	30.54 inHg
Humidity	34%
Wind Speed	7 mph
Motor Flown	L1520T
Payload Simulator	9 lbs
Airbrake	N/A
Final Payload Flown	No, Mass Simulator
Target Altitude	4473 feet
Predicted Altitude	3431 feet
Achieved Altitude	2995 feet

5.1.2 Payload Simulation

The construction of the DÁVÍD, the payload mass simulator, is described in detail in Section 3.3.6. In brief, a plywood box was constructed, fitted with U-bolts, an ARRD and altimeter. Epoxy and lead pellets were then used to achieve the correct weight and CG in order to properly simulate the payload.

5.1.3 Launch Analysis

The flight was an overall success. The launch field was very wet from rain earlier in the week and during ignition, the launch stand pushed into the mud slightly. Launch stand instability, coupled with effects from weather cocking, led to the vehicle pointing approximately 8.39° from vertical in the plane of viewing, seen below. However, the launch vehicle was also tilted away from the viewer, so the actual deflection from vertical is likely higher.

Figure 5-1 Launch Vehicle on the Launch Pad Immediately Prior to Launch

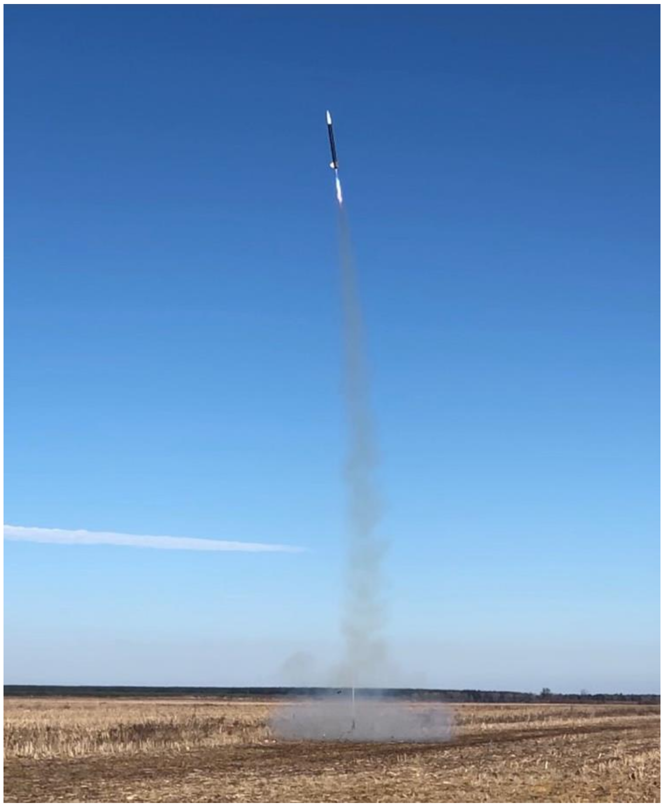


Figure 5-2 Launch Vehicle after Launch Rail Departure

Two deviations from a nominal sequence of payload deployment events occurred during the VDF. The first deviation came when an unused strap designed for attaching a pilot parachute to the payload parachute deployment bag became wrapped around the payload shock chord, which prevented the payload shock chord from extending to its full length. Secondly, the ARRD failed to release the payload from the main chute, despite the black powder charge going off, leading to the payload descending with the launch vehicle, despite the payload parachute deploying. There were no deviations from nominal main parachute deployment and operation.

The problem the ARRD experienced was found to be that the spring was too stiff, despite using the spring that came from the manufacture. Section 7.1.6 goes into depth on what caused this problem, but in order to prevent it in the future the team will be using a new spring with each subsequent launch from here on out. Additionally, the strap that attaches the deployment bag to the parachute will be taped into a compact bundle to prevent tangling. Another issue found with payload integration was that the rotary latch that retains LOPSIDED during ascent up to apogee did not release as intended due to a short time signal. After the latch unlocked at apogee, it re-locked around the payload retention harness. This issue is being addressed as described in Section 4.5.1.1 by using an Arduino Nano to provide a continuous unlock signal to the latch.

Figure 5-3 Launch Vehicle Descending under Main Parachute

Figure 5-4 Launch Vehicle after Successful Recovery

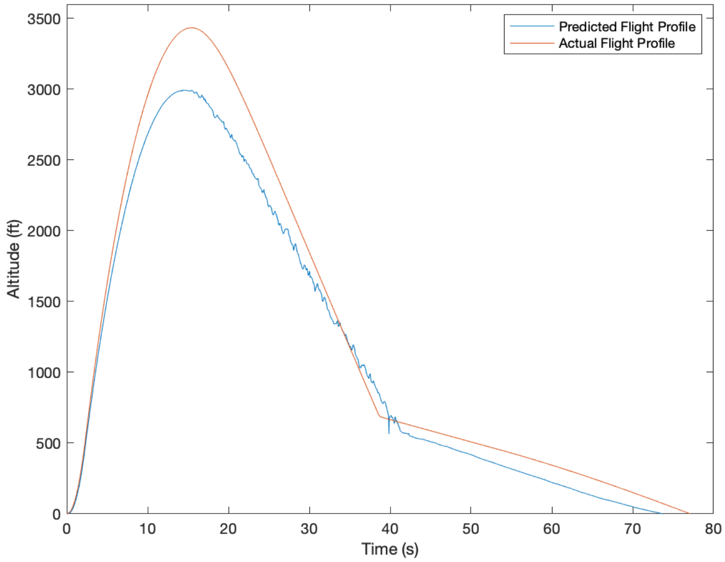


Figure 5-5 Predicted and Actual Flight Profiles for VDF

The achieved apogee was 436 feet below predicted apogee, with both simulations using the weather conditions described in the above table, a 5^{o} cant, and a 144 inch launch rail. Some of this loss in performance can be attributed to cosine losses from an angled ascent, but there are other factors in play as well. At launch, the vehicle was neither primed nor painted, leading to a rough exterior which could increase the drag coefficient of the launch vehicle.

The launch vehicle reached apogee approximately 14.2 seconds into the flight, triggering the drogue parachute deployment. This corresponds to a descent time of 59.5 seconds, in line with predicted descent times with the payload remaining attached to the main recovery harness as was the case during the VDF. The coordinates of the launch site and landing site were recorded, and the determined wind drift of 1022 ft from the launch pad. At launch, the wind was 7 mph, which is in good agreement with the calculated wind drift values provided in Section 3.5.8.

5.1.4 Estimating Launch Vehicle CD

RockSim calculates the CD of the launch vehicle iteratively and estimates that the max CD of the launch vehicle is 0.37. However, by running simulations while manually overriding the calculated CD until the simulated apogee approaches the achieved apogee, the true CD of the launch vehicle was found to be 0.634. The simulated launch profile with the adjusted CD can be seen in the figure below.

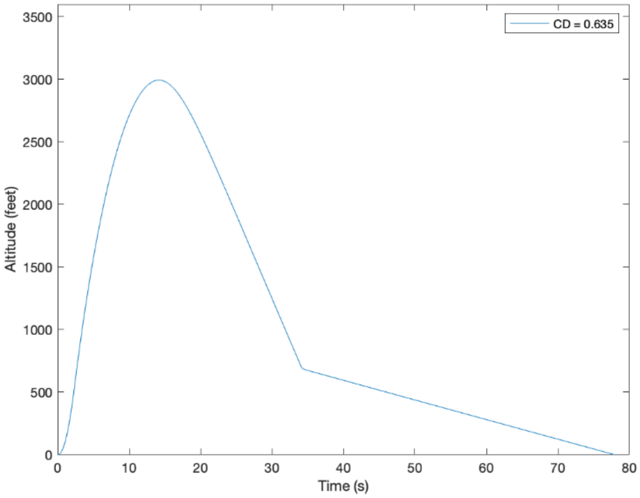


Figure 5-6 Flight Profile with Adjusted Drag Coefficient

5.1.5 Subscale Flight Comparison

The full-scale flight achieved an apogee of just slightly under double the subscale flight apogee. Despite this extreme difference in apogee, the flight events of apogee and main parachute deployment happen at very similar times. A major difference between the sub-scale and full scale flights is that while the subscale only achieved 61% of the simulated apogee, the full scale flight achieved 87.3% of the simulated apogee. This increase in simulation accuracy is largely attributed to overriding RockSim's estimations of weight parts and instead replacing them with manually recorded weights.

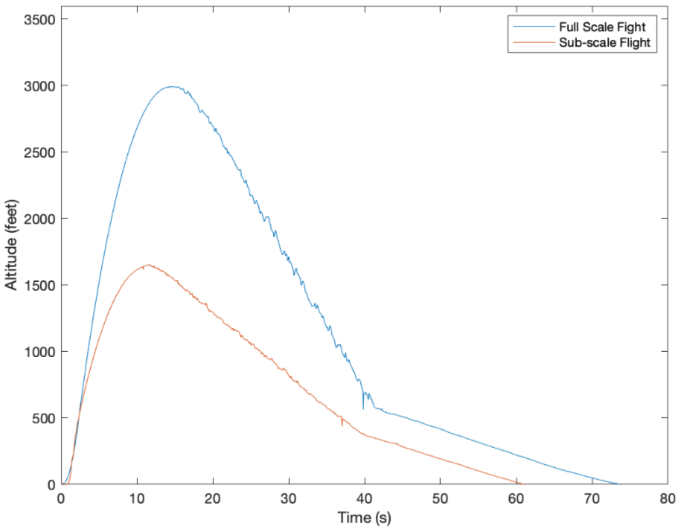


Figure 5-7 Full Scale and Subscale Flight Profiles

5.2 Payload Demonstration Flight

As of the submission of the FRR document, the team has not yet completed a payload demonstration flight. This flight is planned to be completed on March 20th at the Tripoli launch site in Bayboro, North Carolina. This flight will also serve as a Vehicle Demonstration Re-Flight to validate the extended main parachute bay and reconfiguration of the main parachute recovery harness. March 27th is a secondary launch date, if necessary. Success of the PDF will be defined as the retention of LOPSIDED within the payload bay until main parachute deployment, the complete removal of LOPSIDED from the payload bay at main parachute deployment, and the successful separation of LOPSIDED from the main parachute recovery harness using the ARRD.

The objectives of this launch are to qualify the payload retention and deployment system for the Launch Day flight, and to re-qualify the changes made to the launch vehicle since the Vehicle Demonstration Flight.

6. Safety and Procedures

6.1 Safety and Environment

6.1.1 Safety Officer

Per NASA requirements 5.1-5.3.4, the HPRC's Safety Officer, Emma McDonald, beginning January 2021 was present for the Full-Scale launch test, which was performed on February 21, 2021. Said safety officer was also present for Launch Vehicle recovery and closely monitored that all safety precautions and checklist items were followed. Safety Officer confirmations within each section of the *81 Point 5* Launch Day Checklists verify this. Any design revisions made since CDR and the sub-scale launch were dually noted, and corresponding hazards and failure modes were included in FMEAs section of the teams FRR. Payload and Launch Vehicle assembly, as well as ejection testing, was monitored by the Safety Officer.

6.1.2 Hazard Classification

In order to better classify risks and hazards associated with the project, the team has developed a likelihood-severity (LS) method of hazard classification. This classification system is detailed in Table 6-1 below.

Table 6-1 Likelihood-Severity (LS) Classifications

		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

These LS classifications are used to determine the importance of mitigations of their associated hazards. Any hazard with a severity of at least 3 or likelihood of at least C must be mitigated. The definitions of each severity level are provided in Table 6-2 below.

Table 6-2 Severity Definitions

Hazard Type	**1 (Low Risk)**	**2 (Medium Risk)**	**3 (High Risk)**	**4 (Severe Risk)**
Personnel	No personnel injury.	Any personnel injury is treatable with first aid.	Moderate personnel injuries, manageable with launch field first aid.	Severe personnel injuries requiring hospitalization.
Launch Vehicle	Any damage to launch vehicle is reversible.	Any damage to launch vehicle is repairable.	Damage to launch vehicle is repairable, but not to original condition.	Damage to launch vehicle is irreparable.
Mission	Mission success.	Partial mission failure, successful flight.	Partial mission failure, partially successful flight.	Complete mission failure, unsuccessful flight

Each hazard is also given a label for unique identification. These labels follow the format "System.Hazard Category.Number." Systems are defined by one or two-letter codes, shown in Table 6-3 below. Hazard categories are listed as horizontal bars within the FMEA table separating different sections. Their abbreviations are different for each system. The number is used to differentiate hazards with the same system and category.

Table 6-3 Hazard Label System Codes

Code	**System Represented**
A	Aerodynamics
E	Environmental
P	Payload
Pe	Personnel
R	Recovery
S	Structures

6.1.3 Personnel Hazard Analysis

Table 6-4 Personnel Hazard Analysis

Personnel Hazard Analysis							
Label	**Hazard**	**Cause**	**Effect**	**Pre-SL**	**Post-SL**	**Mitigation**	**Verification**
Hazard to Skin and Soft Tissue							
Pe.S.1	Slips, trips, and falls	Uneven launch field conditions	(1) Ligament sprain (2) Bruising (3) Skin abrasion	3C	1B	(1) Running shall be strictly forbidden on launch day (2) Those recovering launch vehicle are ONLY trained, experienced, pre-assigned personnel (3) Recovery personnel shall be instructed to wear closed toe walking shoes on launch day	(1) TDR 1.2 (2)*81 Point 5* Launch Day Checklist Section: *Field Recovery* (personnel) (3) TDR 1.2
Pe.S.2	Contact with large, airborne shrapnel	Catastrophe at takeoff	(1) Scrape (2) Deep scratch (3) Perforations to cardiovascular system	3B	1A	Aerotech motors are chosen for their low likelihood of factory defects leading to CATO	FRR 1.2.2
		On-ground explosion of motor/black power				(1) Personnel are required by the RSO to maintain a minimum distance away from the launch pad (2) Altimeters are armed and igniters are attached only when launch vehicle is on launch pad and ready for flight	(1) NAR High Power Rocket Safety Code Section 11 (2) *81 Point 5* Launch Day Checklist Section: *Launch Pad* 10.14-10.30
		Ballistic descent of payload or airframe shrapnel				See payload, recovery, and structures FMEAs for full mitigations	See payload, recovery, and structures FMEAs for full verifications

Pe.S.3	Contact with small, airborne particulates	Sanding, cutting, or drilling into brittle/granular materials				(1) Protective eye and face equipment shall be provided to personnel working with power tools (2) Dremel blades are inspected for defects prior to use	(1) Safety Handbook, TDR 1.3 (2) Safety Handbook
Pe.S.4	Exposure to uncured epoxy fluid	Working with liquid epoxy	(1) Skin irritation (2) Rash	2C	2A	Nitrile gloves shall be provided to personnel working with uncured epoxy or volatile organic compounds	TDR 1.4
Pe.S.5	Exposure to chemical fumes	Working with volatile organic compounds		3B	2A		
Pe.S.6	Contact with sharp laser cut jigsaw pieces of payload	Payload assembly prior to launch	(1) Minor cuts or skin abrasions	1C	1B	Nitrile gloves shall be provided to personnel assembling payload	TDR 1.4
	Hazard to Bones						
Pe.B. 1	Personnel contact with large airborne shrapnel	Pre-flight motor/black powder ignition Catastrophe at takeoff	Bone fracture requiring immediate medical attention	4B	4A	(1) Personnel are required by the RSO to maintain a minimum distance away from the launch pad (2) Aerotech motors are chosen for their low likelihood of factory defects leading to CATO	(1) NAR Nigh Power Rocket Safety Code Section 11 (2) FRR Section 1.2.2
Pe.B. 2	Slips, trips, and falls	Uneven ground conditions	(1) Bone bruise (2) Minor bone fracture	4C	3B	(1) Running shall be strictly forbidden on launch day (2) Those recovering launch vehicle are ONLY trained, experienced, pre-assigned personnel	(1) TDR 1.2 (2) *81 Point 5* Launch Day Checklist Section: *Field Recovery* (personnel)

			(3) Ligament sprain	🟥	🟩	(3) Recovery personnel shall be instructed to wear closed toe walking shoes on launch day	(3) TDR 1.2
Hazard to Eyes							
P.E.1	Exposure to fumes	Working with uncured epoxy	Eye irritation	2B	1A	(1) Protective eye equipment shall be provided to personnel working with uncured epoxy (2) In the event of eye irritation, eye wash stations are accessible to all personnel	(1) TDR 1.3 (2) Lab Safety Handbook
P.E.2	Eye contact with metallic, wood, or plastic shrapnel	Sanding Material failure while drilling Premature, on-ground black powder or motor ignition	(1) Eye abrasion (2) Blindness	3C	2A	(1) Protective eye equipment shall be provided to personnel working with potentially airborne material (2) Personnel shall be instructed in checklists to stand away from any potential explosives	(1) TDR 1.3 (2) *81 Point 5* Launch Day Checklist Sections: *Motor Assembly* 8.18, *Launch Pad* 10.32
Hazard to Limbs							
Pe.L.1	Contact with explosive gases Contact with large, airborne shrapnel	On ground motor/black powder ignition	(1) Limb loss (2) Severe injury warranting amputation	4B	4A	(1) Personnel shall be instructed in checklists to stand away from any potential explosives (2) Altimeters shall remain disarmed until launch vehicle is on launch rail, ready for flight	(1) *81 Point 5* Launch Day Checklist Sections: *Launch Pad* 10.32, *Mass Simulator* (DÁVÍD) *Assembly* 5.10

							(2) *81 Point 5* Launch Day Checklist Section: *Motor Assembly* 8.18
Pe.L.2	Personnel contact with ballistic launch vehicle components	Ballistic descent (R.A.2)	(1) Limb loss (2) Severe injury warranting amputation	4B	4A	(1) See recovery FMEAs for mitigations through design (2) Personnel shall be instructed to remain still until launch vehicle components are confirmed by the RSO to have landed	(1) See recovery FMEAs for verifications (2) NAR High Power Rocket Safety Code Sections 8 and 9, *81 Point 5* Launch Day Checklist Section: *Launch Pad* 10.32
Pe.L.3	Finger snag in bit of power tool	Wearing gloves while working with power tools	Finger loss	4B	2A	(1) Gloves are located at the far end of the lab from desktop power tools and in a separate cabinet from hand-held power tools (2) Safety presentations are conducted that detail proper procedure prior to use of a power tool	(1) Lab Safety Handbook (2) Unverifiable
Hazard to Respiratory System							
Pe.R.1	Exposure to fumes	Working with uncured epoxy	(1) Lung irritation (2) Difficulty breathing	2D	2A	(1) Particulate masks shall be provided to personnel working with epoxy, paint, and chemicals from the flame cabinet	(1) TDR 1.4

		Working with uncovered paint				(2) In cases where epoxy cannot be applied outside, an oxygen monitor is in use to prevent irritation/difficulty breathing (3) Painting shall occur outdoors	(2) Lab Safety Handbook (3) Lab Safety Handbook
		Off-gassed chemicals stored in flame cabinet					
Pe.R. 2	Exposure to particulates	Sanding, drilling, and/or cutting brittle or granular materials		3D	2A	Particulate masks shall be provided to personnel working with power tools	TDR 1.3
Hazard to Head							
Pe.H. 1	Impact with ballistic launch vehicle sections	Shock cord breakage or disconnection	(1) Concussion (2) Memory loss (3) Brain injury (4) Skull fracture	4B	3A	(1) Kevlar shock cord shall be used to withstand, at least, twice the maximum expected load (786 lbf) (2) Any bulkhead-shock cord systems shall have a factor of safety of at least 2	(1) FRR Section 3.4.4.2 (2) TDR 2.2
		No/late parachute deployment				(1) Adequately sized pressure ports are drilled during construction (2) 4-40 shear pins shall be used	(1) FRR Section 3.4.2.4 (2) NASA 3.9
	Impact with ballistic payload	Premature payload		4B	3A	(1) Payload and recovery altimeters shall be tested before flight	

		parachute ejection		🟨	🟩	(2) Personnel shall maintain a minimum distance away from the launch site as maintained by the RSO	(1) *81 Point 5* Launch Day Checklist section *Avionics Bay Assembly* 4.1-4.3 (2) NAR High Power Rocket Safety Code Section 11
		Premature payload ejection from launch vehicle					
	Impact with large, airborne shrapnel (payload or launch vehicle components)	Catastrophe at takeoff		4B	3A	Aerotech APCP motors are chosen for their low likelihood of factory defects leading to CATO	FRR Section 1.2.2
		Premature on-ground motor/black powder ignition				(1) Personnel shall be instructed in checklists to stand away from any potential explosives (2) Altimeters shall remain disarmed until launch vehicle is on launch rail, ready for flight	See PE.L.1 verifications
		Shock cord shear; shock cord disconnection from bulkhead				(1) Kevlar shock cord shall be used to withstand, at least, the maximum expected load (3660 lbf) (2) Any bulkhead-shock cord systems shall have a factor of safety of at least 2	(1) See R.P.1 verification (2) TDR 2.2

6.1.4 Failure Modes and Effects Analysis

Table 6-5 Failure Modes and Effects Analysis

Structures FMEAs							
Label	**Hazard**	**Cause**	**Effect**	**Pre-SL**	**Post-SL**	**Mitigation**	**Verification**
Fin Hazard							
S.F.1	Fin structural damage (cracks/shears)	Freestream velocity approaching transonic values; fin flutter	(1) Flight path diverted (2) Failure to reach target apogee (3) Launch vehicle enters nose-over-tail spin	4B	4A	Flight velocity simulations have been performed in RockSim – no part of the launch vehicle nears transonic speeds	(1) TDR 2.4 (2) FRR Section 3.5.2 (See Figure 3-49)
S.F.2	Fin delamination from airframe	Insufficient time for a complete fillet cure Gaps in fillet epoxy	(1) Flight path diverted (2) Failure to reach target apogee (3) Launch vehicle enters nose-over-tail spin	4C	2A	Epoxy fillets are given at least 24 hours to fully cure before flight	TDR 1.1 FRR Section 3.3.1.2, Figure 3-27
Airframe Hazard							
		Fin loss; launch vehicle enters into nose-over-tail spin		4C	2A	See S.F.1 and S.F.2	See S.F.1 verification

S.A.1	Airframe cracking/rupture	Loose inner payload components during flight	(1) Premature black powder detonation due to rapid pressure change (2) Loss of inner components	2D	2A	An Arduino is used to control the payload retention latch	FRR Section 4.5.1.1
		Excessive internal stresses		2C	1B	(1) G12 Fiberglass, a strong and durable material, is chosen for the full scale airframe (2) Prior to launch, ejection tests shall be performed to confirm that the minimum necessary black powder amount is used	Ejection test performed on 02/19/21
S.A.2	Shear Pin Failure	Insufficient black powder discharge	(1) Ballistic launch vehicle descent; LV lands in surrounding woods or irrigation ditches	4B	4A	(1) Black powder mass is calculated using the ideal gas law (2) Ejection tests shall be performed prior to launch to confirm appropriate black powder mass	(1) TDR 3.4, FRR Section 3.4.7 (2) TDR 3.1, Ejection test performed on 02/19/21

		Excessive shear pin diameter		🟧	🟩	(1) 4-40 shear pins are used (2) Shear pin stress tests shall be performed prior to launching the launch vehicle	(1) NASA 3.9, FRR Section 3.4.1 (2) Shear pin stress test scheduled to be performed on 03/10/21
S.A.3	Premature shear pin shear	Premature black powder detonation	(1) Potential airframe exposure to burning motor (2) Ballistic payload descent (3) Failure to reach target apogee	3B	3A	Pressure ports are drilled into airframe	FRR Section 3.4.2.4
		Insufficient shear pin diameter				(1) 4-40 shear pins are used (2) Shear pin stress tests shall be performed prior to launching the launch vehicle	See S.A.2 verification
S.A.4	Airframe exposure to burning motor	Premature section separation	Inability of airframe to withstand flight forces; complete disintegration	4A	3A	See S.A.3 Mitigations	See S.A.3 verification
S.A.5	LV section collision	Excessive OR insufficient shock cord length	Airframe cracking/rupture	4C	2A	Shock cord length for full scale is 40 ft x 5/8 in	FRR Section 3.4.4.2

S.A.6	Elevated pressure inside LV	Insufficient pressure ports	(1) Airframe rupture (2) Inability of black powder to detonate	4B	4A	Pressure ports are drilled into airframe	See S.A.3 verification
Hazard to Bulkheads							
S.B.1	Bulkhead delamination	Gaps in epoxy layers Excessive forces from bolts causing stresses in LV	(1) Inner LV component structural damage (2) Airframe cracking/shear (3) Motor separation from airframe	3B	2A	(1) Bulkheads shall be designed with a factor of safety of at least 2 (2) Bulkhead stress/delamination tests shall be performed	TDR 2.2 (1) Bulkhead stress test scheduled to be performed on 03/10/21 (2) FRR Section 7.1.1.1
S.B.2	Bulkhead cracking/ripping	Excessive force from bolts causing stresses in LV Insufficient bulkhead thickness	(1) Airframe cracking/shear (2) Parachute separation from LV	2A	1A	U-bolts shall be chosen over eyebolts for their superior load distribution (1) Bulkheads and their U-bolts shall have a FOS greater than or equal to 2	TDR 3.5, FRR Section 3.4.2.1 (1) FRR Section 3.2.1.3 TDR 2.2

						(2) Nose cone bulkheads shall have a thickness of 0.75 in	(2) FRR Section 3.1.2.1
Aerodynamics/Propulsion FMEAs							
A.S.1	Launch vehicle weather cocks into wind gust	Overstability (Stability margin ≥ 2.5)	Diverted flight path; failure to reach target apogee	3C	1B	(1) CP, CG, and stability margin calculated through RockSim prior to flight (2) CG, weight, and stability margin observed manually directly prior to flight	(1) FRR Section 3.5.4 (2) NASA 2.14
A.S.2	Launch vehicle diversion away from wind gust	Understability (Stability margin ≤ 2.0)		3C	2B		(1) FRR Section 3.5.4 (2) *81 Point 5* Launch Day Checklist Section *Final Measurements* 9.4-9.10, NASA 2.14
A.S.3	Fin flutter	Transonic freestream velocity around fins	(1) Fin structural damage (2) Loss of fins (3) Launch vehicle enters nose-over-tail spin	4B	4A	Flight velocity simulations have been performed in RockSim – no part of the launch vehicle nears transonic speeds	See S.F.1 verification

Motor Hazard							
A.M.1	Motor retention ring ejection	Structural failure of retention ring	Catastrophe at Takeoff (CATO)	4B	4A	Aerotech motor casings and retention rings are chosen for their strength and durability	FRR Section 3.3.3.3
A.M.2	Pressure buildup inside of motor	Gap/bubble in motor propellant grain		4B	4A	Aerotech motors are chosen for their low likelihood of factory defects leading to CATO and motor failures	FRR Section 1.2.2
		Clogged nozzle					
		Holes/cracking in motor casing					
A.M.3	Rapid change in stability margin	Difference between inflight and theoretical thrust curve of L1520T	Diverted flight path; failure to reach target apogee	2B	1A		See A.M.2 verification
A.M.4		High humidity		4C	4A	The team shall not launch in high humidity	NAR High-Power Safety Code

	Absence of igniter ignition		Absence of motor ignition; inability to fly	🟥	🟩		*81 Point 5 Night Before* Checklist
		Faulty igniters				Extra igniters are supplied by the team on launch day	
Recovery FMEAs							
Hazard to/from Avionics							
R.A.1	Avionics exposure to ejection gases	Gap between AV bulkheads and body tube	(1) Electronics damage/ destruction (2) Failure of altimeter to detonate second charge; LV lands with excessive kinetic energy	3B	3A	Bulkhead airframe contacts filleted on both sides; bulkheads confirmed to be flush with airframe	FRR Section 3.1.5
R.A.2	Dual deploy with main at apogee	Crossed main and drogue signal wires	Large wind drift resulting in inability to recover rocket	4C	4A	AV Bay wiring will be confirmed by at least four team members prior to final assembly	*81 Point* 5 Launch Day Checklist Section: *Avionics Bay Assembly* 4.22
R.A.3	No parachute deployment		(1) Ballistic descent (2) Personnel injury from LV	4C	4A		
Hazard to Parachutes/Shock Cords							

R.P.1	Shock cord disconnection	U-bolt shear or disconnection	(1) Ballistic descent of at least one launch vehicle section (2) Excessive kinetic energy upon landing (3) Personnel injury from LV	4B	3A	Bulkheads and their connecting pieces shall be designed with a factor of safety of 2 or greater	FRR Section 3.2.1.3 See verification for S.A.2
		Bulkhead wood cracking or shearing					
		Bulkhead delamination					
		Shock cord tear/rip		4A	2A	Kevlar shock cord is chosen to withstand twice the maximum expected force on shock cord, 786 lbf	FRR Section 3.4.4.2
R.P.2	Parachute rip/hole/tear	Contact with explosive black powder	Partial or no parachute deployment	3D	2B	Fireproof Nomex cloth is wrapped around parachute to insulate it from ejection gases	*81 Point 5* Launch Day Checklist Section: *Drogue Recovery Assembly* 6.19
R.P.3	Partial or no parachute deployment	Parachute rip/hole/tear	(1) Ballistic descent of at least one launch vehicle section (2) Excessive kinetic energy upon landing (3) Personnel injury from LV	4B	4A		
		Recovery harness + parachute entanglement					
		Impact of body section with parachute				Shock cord length for drogue is 15 ft; shock cord length for main is 40 ft	FRR Section 3.4.4
R.P.4		Delayed e-match burning		3B	3A	Fingertip sized pieces of paper towel will fill the remaining space	*81 Point 5* Launch Day Checklist

	Delayed parachute deployment	Delayed black powder detonation	Structural damage due to excessive force on shock cords			in the blast cap to aid in combustion.	Section: *Drogue Black Powder* 3.11
R.P.5	Premature parachute deployment	Incorrect altimeter pressure readings	(1) Parachute deployment during ascent (2) Recovery harness/airframe structural damage	4B	3A	Pressure ports are drilled in airframe to allow for ambient pressure changes to be detected	See S.A.3 verifications
		Excessive flight forces				(1) 4-40 Shear pins are used to secure body sections (2) Shear pin stress tests shall be performed prior to launch	See S.A.2 verifications
Hazard to/from Black Powder							
		Shear pins of excessive diameter/strength	(1) Ballistic descent; excessive kinetic energy upon landing	4C	4A	(1) 4-40 Shear pins are used to secure body sections (2) Shear pin stress tests shall be performed prior to launch	See S.A.2 verifications

R.BP.1	Lack of shear pin breakage		(2) Personnel injury from LV	🟥	🟩		
		Insufficient black powder charges				(1) Black powder mass is calculated using the ideal gas law (2) Ejection tests shall be performed prior to launch to confirm appropriate black powder mass	(1) FRR Section 3.4.7, TDR 3.1 (2) Ejection test performed on 02/19/21
R.BP.2	Premature section separation	Premature shear pin breakage during ascent	(1) Body tube zippering from shock cord (2) Diverted flight path resulting in low final apogee (3) Premature payload ejection	3B	3A	(1) 4-40 Shear pins are used to secure body sections (2) Shear pin stress tests shall be performed prior to launch	See S.A.2 verifications
		Shear pins of insufficient		🟨	🟩		

R.BP.3	Premature shear pin breakage during ascent	diameter/strength	Premature section separation	3B	3A	(1) 4-40 Shear pins are used to secure body sections (2) Shear pin stress tests shall be performed prior to launch	See S.A.2 verifications
		Shear pin ejection					
R.BP.4	High wind drift	Premature section separation during descent	Inability to communicate with payload or launch vehicle GPS	4B	3A	Pressure ports are dilled into airframe	See S.A.3 verifications
R.BP.5	Excessive pressure in AV bay	Sympathetic detonation of primary and secondary black powder charges	(1) Hoop stress on body tube (2) Structural damage (See S.A.1)	4B	4A	Bulkheads separate primary and secondary black powder charges such that they fire away from one another	FRR Section 3.4.2.1
Payload FMEAs							
Payload Structure Hazard							
P.S.1	Pre-separatio	Premature payload	(1) LOPSIDED essential power/ communication cord disconnection	2B	2A	Payload retention latch test is	Payload retention latch test scheduled

	n retention latch disengagement	altimeter signal	(2) LOPSIDED/POS cracks, chips, and breaks			scheduled to be completed prior to flight	to be completed on 03/10/21 *81 Point 5* Launch Day Checklist Section: *Main Recovery Assembly* 7.12-7.18
P.S.2	LV ground touchdown while retaining payload in payload bay	Failure of retention latch to open	(1) Cracks, chips, and breaks in payload structure from loads imparted to system by payload latch and rail (2) Destruction of LOPSIDED's supportive rollers and rails	2B	2A	Payload retention latch test is scheduled to be completed prior to flight	See P.S.1 verifications
P.S.3	Payload-parachute connection shear/break	Excessive load from payload parachute	(1) Ballistic descent of payload (2) Irreparable payload structural damage (3) Personnel hazard from LV	4C	2B	LOPSIDED POS has an internal aluminum frame such that it can withstand the approximately 112 lbf of maximum load	FRR Section 4.4.1
Payload Retention Hazard							

P.R.1	Failure of retention latch to open	Retention latch power cord disconnection	Payload retention structural failure	2B	2A	An Arduino will be used for control of the payload retention latch.	FRR Section 4.5.1.1
P.R.2	Excess in-flight load imparted to payload parachute connection	Parachute movement during flight	Structural failure (cracks, breaks) in payload parachute connection	3C	3A	LOPSIDED POS is made out of carbon fiber such that it can withstand the 112 lbf of maximum load	See P.S.3 verification
P.R.3	Payload parachute attachment at landing	Electronic latch failure	(1) Payload abrasion against ground from parachute drag (2) Inability of leveling system to right POS; no clear picture	2B	2A	The electronic latches shall be tested for their ability to disconnect the payload parachute prior to flight	Electronic latch test performed scheduled to be completed on 03/18/21
Imaging System Hazards							
P.I.1	In-flight camera dislodgement	LV structural failure	(1) Obstructed field of view (2) No clear picture obtained	4B	4A	(1) POS cameras are isolated within LOPSIDED to mitigate risk of damage during flight.	(1) FRR Section 4.4.2, TDR 4.2, NASA 4.3.3
		Inability of camera to		3B	3A		

		withstand flight forces				(2) POS electronics, excluding the camera modules, SHALL be contained below the pivoting axis of LOPSIDED's leveling system.	(2) TDR 4.4
P.I.2	Abrasion to camera surface	LV Structural Failure Parachute movement during flight	No clear picture obtained	3B	2A	(1) Payload bay is confirmed to be clean prior to launch (2) LOPSIDED will right the payload such that no contact is made between the lenses and the ground	(1) *81 Point 5* Launch Day Checklist Section: *Mass Simulator* (DÁVÍD) *Assembly* 5.33 (2) TDR 4.4
P.I.3	Disconnection of camera cable Disconnection of	Pre-separation retention	Inability for POS to capture/transmit image	3C	3A	Wire lengths shall be chosen such that slack is present in each wire	FRR Section 4.4.3

	Raspberry Pi USB cable	latch disengagement		🟧	🟩		
	Disconnection of transmitter wire						
	Disconnection of accelerometer wire						
P.I.4	Payload landing outside of transmitter range	Wind drift	Poor signal quality of photo transmission	3B	3A	See R.A.2 Mitigation	See R.A.2 verifications
	RF interference between POS transmitter and GPS transmitter	Recovery Failure (See R.A.2 and R.BP.1)					
		POS and GPS transmitters sharing a frequency				POS and GPS transmitters shall operate on different frequencies	FRR Flysheet. The POS transmitter operates on 433 MHz, while the GPS transmitter operates on 900 MHz.

P.I.5	Battery disconnection	Excessive loads from main parachute (see F.P.R.3)	Loss of power to POS	2B	2A	(1) A piece of electrical tape secures the lead to the battery (2) Wire lengths shall be chosen such that slack is present in each wire	(1) FRR Section 4.4.3 (2) FRR Section 4.4.3
	Insufficient battery capacity	Unanticipated in-flight current draw		2A	1A	All batteries used for launch shall be tested with a multimeter prior to launch	*81 Point 5* Launch Day Checklist Section: *Avionics Bay Assembly* 4.1-4.3

6.1.5 Environmental Hazard Analysis

Table 6-6 Hazards to the Environment from the Project

Hazard to Environment							
Label	**Hazard**	**Cause**	**Effect**	**Pre-SL**	**Post-SL**	**Mitigation**	**Verification**
Hazard to Land							
E.L.1	Catastrophe at takeoff	Cracks in motor casing	(1) Fire around launch field	4B	4A	(1) Aerotech APCP motors shall be chosen for their low	(1) FRR Section 1.2.2, NAR High Power Safety Code Section 3, NASA 2.10

		Holes/bubbles in propellant grain	(2) Wildfire risk			likelihood of defects contributing to CATO (2) A fire extinguisher is made available to personnel by the RSO	(2) *81 Point 5* Launch Day Checklists Section: Launch Pad (Required Items)
E.L.2	Explosion on touchdown	Late black powder charge detonation	(1) Fire at recovery site (2) Wildfire risk	3A	1A	A fire extinguisher, provided by the team, shall be brought to the recovery site	*81 Point 5* Launch Day Checklist Section: Field Recovery (Required Items)
E.L.3	Creation of launch field craters and ruts	Launch vehicle ballistic landing (see recovery FMEA table)	Disruption of launch field for primary purpose: farming	3D	2A	The launch vehicle shall descend with a kinetic energy no greater than 75 ft-lbs	NASA 3.3
E.L.4	Wildfire on field	Catastrophe at takeoff	Significant damage to leftover crops that fertilize the next round of corn	4B	4A	Aerotech APCP motors shall be chosen for their low likelihood of defects contributing to CATO	(1) FRR Section 1.2.2, NAR High Power Safety Code Section 3, NASA 2.10 (2) *81 Point 5* Launch Day Checklists Section: Launch Pad (Required Items)
		Explosion on touchdown		3A	1A	A fire extinguisher is made available to personnel by the RSO	
Hazard to Air and Water							
E.AW.1	Chemical off-gassing	Avionics/payload battery leak	Air pollution	1C	1A	Batteries are shielded from environmental hazards through protective casing	FRR Section 3.4.2.2

		Uncured epoxy remaining on launch vehicle		1D	1A	Epoxy shall be given at least 24 hours to fully cure before assembly, launch prep, or launch	FRR Section 3.3.1.2, Figure 3-27, TDR 1.1
		Production of combustion by-products		2D	1C	Aerotech APCP motors shall be used for their known reliability and relatively low environmental impact	FRR Section 1.2.2, NAR High Power Safety Code Section 3, NASA 2.10
						The full-scale launch vehicle shall use an L1520T motor, well within the acceptable limit for creation of by-product gases	FRR Section 1.2.2, NAR High Power Rocket Safety Code Section 8, NASA 2.12
E.AW. 2	Creation of wildfire smoke	Catastrophic explosion at takeoff		4B	4A	Aerotech APCP motors shall be chosen for their low likelihood of defects contributing to CATO	FRR Section 1.2.2, NAR High Power Safety Code Section 3, NASA 2.10
		Black powder explosion on landing		3A	1A	A fire extinguisher, provided by the team, is brought to the recovery site	*81 Point 5* Launch Day Checklist Section: *Recovery* (Materials)
		Contact between exhaust flame and dry corn stalks		4C	2B	A blast plate, provided by the RSO protects the dry ground from launch flames	FRR Figure 5-2

E.AW. 3	Creation of hydrochloric acid from combustion by-product reaction with water	Excessive amount of by-product from APCP combustion	Pollution of surrounding irrigation ditches	3B	2A	The full-scale launch vehicle shall use an L1520T motor, well within the acceptable limit for creation of by-product gases	FRR Section 1.2.2, NAR High Power Rocket Safety Code Section 8, NASA 2.12
Hazard to Wildlife							
E.W.1	Payload/avionics battery leakage	Puncture during flight	Consumption of volatile chemicals by wildlife	4B	2A	Batteries are shielded from environmental hazards through protective casing	FRR Section 4.4.3
E.W.2	Noise pollution	Launch in proximity to wildlife	Wildlife disruption and anxiety	2D	1A	Launches conducted in Bayboro, NC are at least one mile from the surrounding tree line	FRR Section 5.1.1, NAR High Power Rocket Safety Code Section 10
						One high-power launch is performed at a single time, reducing contributions to volume amplitude	FRR Section 5.1.1
E.W.3	Wildfire	Black powder explosion on touchdown	Loss of wildlife Significant tree damage Inability to use field for farming	3A	1A	(1) A fire extinguisher, provided by the team, shall be brought to the recovery site (2) See recovery FMEA for black powder mitigations	(1) *81 Point 5* Launch Day Checklist Section: *Recovery* (Materials) (2) See recovery FMEA for black powder verification

E.W.4	Abandonment of irretrievable launch vehicle shrapnel	Catastrophe at takeoff	Consumption of hazardous material by wildlife	4B	2A	As much shrapnel is collected as possible by members of the recovery team	*81 Point 5* Launch Day Checklist Section: *Recovery*
		Catastrophic payload failure					
E.W.5	LV touchdown in surrounding trees	Large wind gusts contributing to wind drift	Damage to trees and local wildlife	3B	3A	(1) The team shall exclusively launch in wind conditions below 20 mph (2) The team shall abandon launch vehicle components that are irretrievable without tree damage	(1) NAR High Power Rocket Safety Code Section 9 (2) NAR High Power Rocket Safety Code Section 13
E.W.6	High-velocity contact between launch vehicle and avian wildlife	Launch into uncleared skies	Significant wildlife injury/loss of life	4B	3A	Working with the RSO, the team will wait to launch until skies are clear and will avoid all	NAR High Power Rocket Safety Code Section 9

Table 6-7 Hazards to the Project from the Environment

Hazard from Environment							
Label	**Hazard**	**Cause**	**Effect**	**Pre-SL**	**Post-SL**	**Mitigation**	**Verification**
Hazard to Launch Vehicle Structure							
E.S.1	LV touchdown in surrounding trees	Large wind gusts contributing to wind drift	Launch vehicle structural damage	4C	3A	The team shall exclusively launch in wind conditions below 20 mph	NAR High Power Rocket Safety Code Section 9
			Inability to recover launch vehicle				
E.S.2	Body tube water saturation	Launch vehicle touchdown in irrigation ditch	Inability to repair damaged components without significant effort	4C	1C	The launch vehicle shall be water resistant; G12 Fiberglass is used to construct the full scale	TDR 2.1, FRR Section 3.2.1.1
E.S.3	High-velocity contact between launch vehicle and avian wildlife	Launch into uncleared skies	Body tube crack, rupture, and irreparable damage	2B	1A	Working with the RSO, the team will wait to launch until skies are clear and will avoid all	NAR High Power Rocket Safety Code Section 9
			Diverted flight path leading to lower apogee	2B	1A		
			Launch vehicle enters nose-over-tail spin	4B	4A		

Hazard to Payload

E.PA. 1	Waterlogged payload bay	Launch vehicle touchdown in irrigation ditch	Waterlogged payload electronics; insufficient power to complete mission	3C	3B	The launch vehicle shall be water resistant; G12 Fiberglass is used to construct the full scale	TDR 2.1 FRR Section 3.2.1.1
E.PA. 2		Launch during rain and high humidity					
	Electronics rust		Loss of payload-controlling electronics			The team shall exclusively launch in dry conditions	NAR High Power Rocket Safety Code Section 9
	In-flight electronics short		No payload ignition or deployment				
E.PA. 2	LOPSIDED lopsided touchdown	Launch field ruts, ditches, and dips	Inability of LOPSIDED to right the system; no clear picture obtained	3D	3A	LOPSIDED successfully rights the system at touchdown angles less than or equal to 15°	FRR Section LOPSIDED Tilt Range Test, Payload Ground Test performed on 3/6/2021
E.PA. 3	POS camera abrasion	Lens contact with launch field dust and debris	Clouded lens; inability to take a clear picture	3D	1A	Four cameras make up POS; if one or more cameras fails, at least one camera can take a partial picture	FRR Section 4.4.2
						The cameras of POS are housed in a protective casing in LOPSIDED	FRR Section 4.4.2

Hazard to Flight Success

E.F.1	Wind drift	High wind conditions	Launch vehicle touchdown outside of GPS tracking range; inability to recover launch vehicle	4C	4A	The team shall exclusively launch in wind conditions below 20 mph	NAR High Power Rocket Safety Code Section 9
			Launch vehicle touchdown in trees; inability to recover launch vehicle				
E.F.2	Damp propellant grains	High humidity	Inability to ignite motor; failure to launch	4B	4A	The team shall exclusively launch in dry conditions	
E.F.3	High-velocity contact between launch vehicle and avian wildlife	Launch into uncleared skies	Diverted flight path	2B	1A	Working with the RSO, the team will wait to launch until skies are clear and will avoid all obstructions in the sky	NAR High Power Rocket Safety Code Section 9
			Launch vehicle nose-over-tail spin	4B	4A		
E.F.4	Live black powder charges on touchdown	High humidity	BP explosion prompted by personnel-generated pressure changes	4B	4A	(1) The team shall exclusively launch in dry conditions (2) Altimeters are disarmed in the event of un-detonated black	(1) NAR High Power Rocket Safety Code Section 9 (2) *81 Point 5* Launch Day Checklist Section: *Recovery* (11.12.1-11.12.2)

						powder charges remaining	
Hazard to Personnel							
E.PE.1	Ballistic descent of launch vehicle	Waterlogged black powder from rain/high humidity	Head injury, broken bones, damage to soft tissue, and/or loss of life	4C	2A	Launch rails are directed by the RSO away from assembling and onlooking personnel	NAR High Power Rocket Safety Code Section 9
						The team shall exclusively launch in wind conditions below 20 mph	
						Team members are instructed by the RSO to maintain a minimum distance away from the launch pad	NAR High Power Rocket Safety Code Section 11
E.PE.2	Heat exhaustion and/or heat stroke	Exposure to temperature extremes	Organ failure, permanent or semipermanent brain damage	4B	2A	A tent is set up to provide shade	*81 Point 5* Night Before Checklist, Packing List
	Hypothermia			4A	2A	Cars used to transport team members and launch materials can be used to quickly balance bodily temperature	

E.PE.3	Slips, trips, and falls	Uneven launch field conditions	Sprains, broken bones, bruising, and/or head injury	3B	2A	Recovery team members are instructed to wear closed-toed shoes at all times	TDR 1.2
						Team members shall maintain a walking pace, especially during recovery events	TDR 1.2

6.2 Launch Operations Procedures

The following pages contain the packing, assembly, and abnormal checklists used for the Vehicle Demonstration Flight on February 21, 2021. The annotated changes will be made prior to the Payload Demonstration Flight, along with the rewriting of Checklist 5 to reflect payload assembly and installation instead of the mass simulator.

81 Point 5

Night Before Checklist

This checklist completed by: ____________________________

On: __ / __ / __

LAUNCH VEHICLE TASKS:

- ☐ Fold drogue parachute for launch
- ☐ Pack main deployment bag for launch
- ☐ Fold drogue shock cord for launch
- ☐ Fold main shock cord for launch
- ☐ Pour black powder charges

PACKING LIST:

- ☐ Nose cone
  - ☐ (4) bolts
- ☐ Payload bay
- ☐ AV bay airframe
  - ☐ (4) bolts
- ☐ Main Parachute Bay
- ☐ Fin can
  - ☐ Motor retainer screw
- ☐ Mass simulator with ARRD attached
- ☐ HPRC Laptop and Charger
- ☐ Recovery lead Laptop and Charger
- ☐ DeWalt Drill
  - ☐ (2) charged batteries
- ☐ Drill bit set
- ☐ (2) Folding tables
- ☐ Pop-up tent
- ☐ (2) clipboards with pens
  - ☐ (2) launch day checklists
  - ☐ (1) abnormal checklist
- ☐ First aid kit
- ☐ Launch Day Toolbox
  - ☐ Top Compartment
    - ☐ Baby wipes
    - ☐ Plumber's putty
    - ☐ Stamps
    - ☐ Multimeter
    - ☐ Circle stickers
    - ☐ Vaseline
    - ☐ Rubber mallet
    - ☐ Tape measure
    - ☐ Assorted zip tie tube

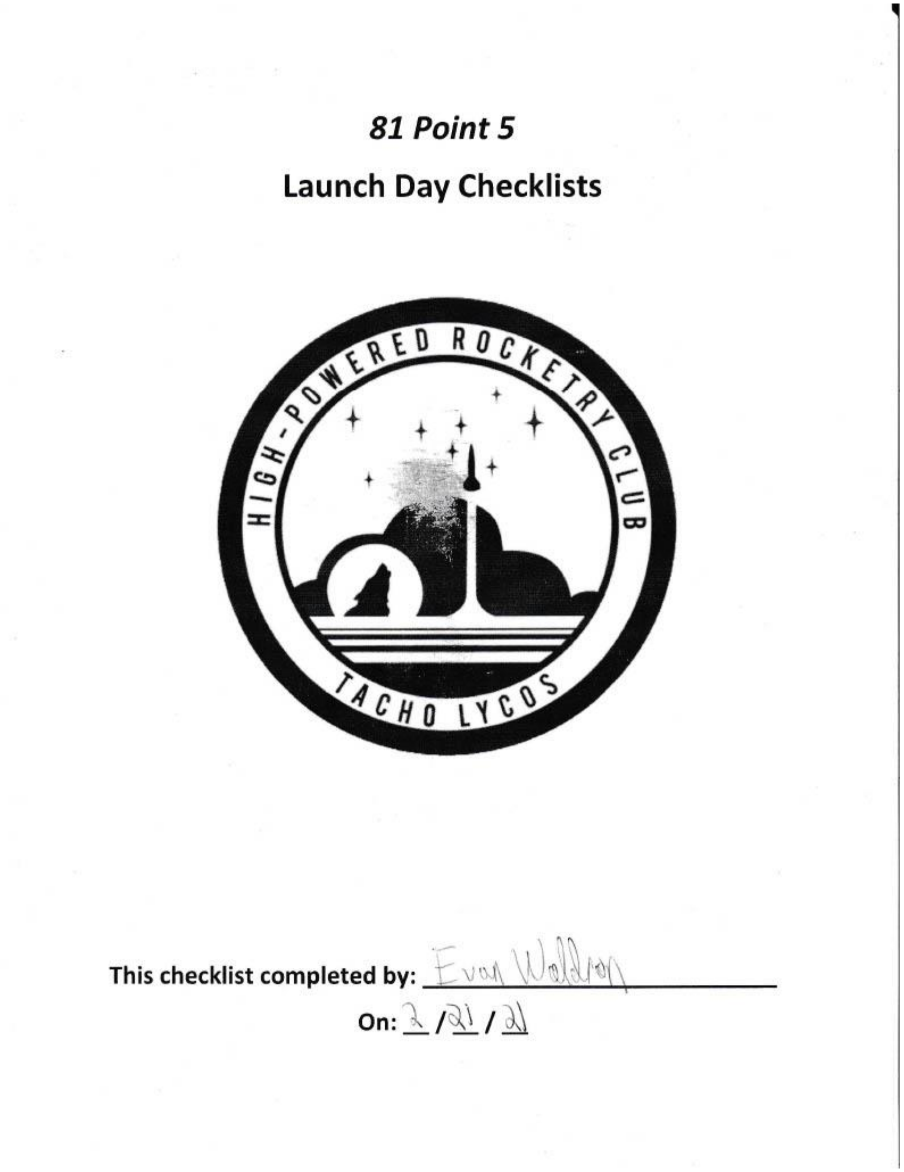
- ☐ (3) sharpie markers
- ☐ (3) pens
- ☐ (2) sheets of copy paper
- ☐ Vise grips
- ☐ Drug scale
- ☐ (2) large trash bags

- ☐ Top Drawer
  - ☐ Blue tape
  - ☐ Duct tape
  - ☐ Electrical tape
  - ☐ Tent tape
  - ☐ Allen wrench set
  - ☐ Spare 1515 rail buttons
  - ☐ WD-40
  - ☐ Scissors
  - ☐ Ruler
  - ☐ Leatherman multitool
  - ☐ Lincoln labs screwdriver set
  - ☐ Forceps
  - ☐ (5) E-matches
  - ☐ (2) Motor ignitors
  - ☐ Double-Sided Gorilla Tape
- ☐ Middle Drawer
  - ☐ Needle nose pliers
  - ☐ Wire strippers
  - ☐ Wire cutters
  - ☐ Thicc black and red screwdriver
  - ☐ 9/16 Wrench
  - ☐ 9/16 Sockets
  - ☐ ½ inch wrench
  - ☐ Adjustable wrench
  - ☐ Midget wrench set
  - ☐ Husky file set
  - ☐ Husky screwdriver set
  - ☐ Kobalt screwdriver set
  - ☐ X-acto knife
- ☐ Bottom Drawer
  - ☐ Sandpaper (various grits)
  - ☐ Baby powder
  - ☐ Thicc Boi
  - ☐ Fish scale

- ☐ Rope for scale
- ☐ JB-weld
- ☐ Super glue
- ☐ Liquid nails
- ☐ Velcro

- ☐ AV Bulkhead Box
  - ☐ FWD AV Bulkhead
  - ☐ AFT AV Bulkhead attached to AV sled and threaded rods
- ☐ Avionics HDX Box
  - ☐ (4) black powder charges
  - ☐ (2) empty black powder containers
  - ☐ Extra 9V connectors
  - ☐ (2) backup Stratologger CF altimeters
  - ☐ Stratologger data cable
  - ☐ 4-40 bolts, nuts, washers
  - ☐ (4) 9V batteries
  - ☐ Spare LiPo battery
  - ☐ (2) spare screw switches
- ☐ Recovery Tupperware
  - ☐ Drogue shock cord
  - ☐ Payload shock cord
  - ☐ Main parachute in deployment bag
  - ☐ Drogue parachute (wrapped in nomex)
  - ☐ Payload parachute in deployment bag (with 2 jolly logics)
  - ☐ (4) remove before flight tags
- ☐ Recovery Tupperware 2
  - ☐ Main shock cord
  - ☐ Piston
  - ☐ Roll of paper towels
  - ☐ Jolly logic accessories
  - ☐ GPS receiver
- ☐ Recovery Hardware Box
  - ☐ Quick links 1-11
  - ☐ 4-40 nylon shear pins (at least 15)
  - ☐ Rubber bands
  - ☐ 3/8-inch nuts, lock nuts, and washers
- ☐ Motor Box
  - ☐ Black 75mm motor casing
  - ☐ (2) Aerotech L1520T fuel grain boxes (3 grains total)
  - ☐ L1520T Phenolic liner
  - ☐ Aerotech RMS 75mm reload kit

  - ☐ GOEX black powder container
- ☐ PPE Box
  - ☐ Full box of nitrile gloves
  - ☐ (2) pairs of heavy-duty gloves
  - ☐ Lots of safety glasses
- ☐ Field Recovery Box
  - ☐ Fire Extinguisher
  - ☐ Silicon lubricant

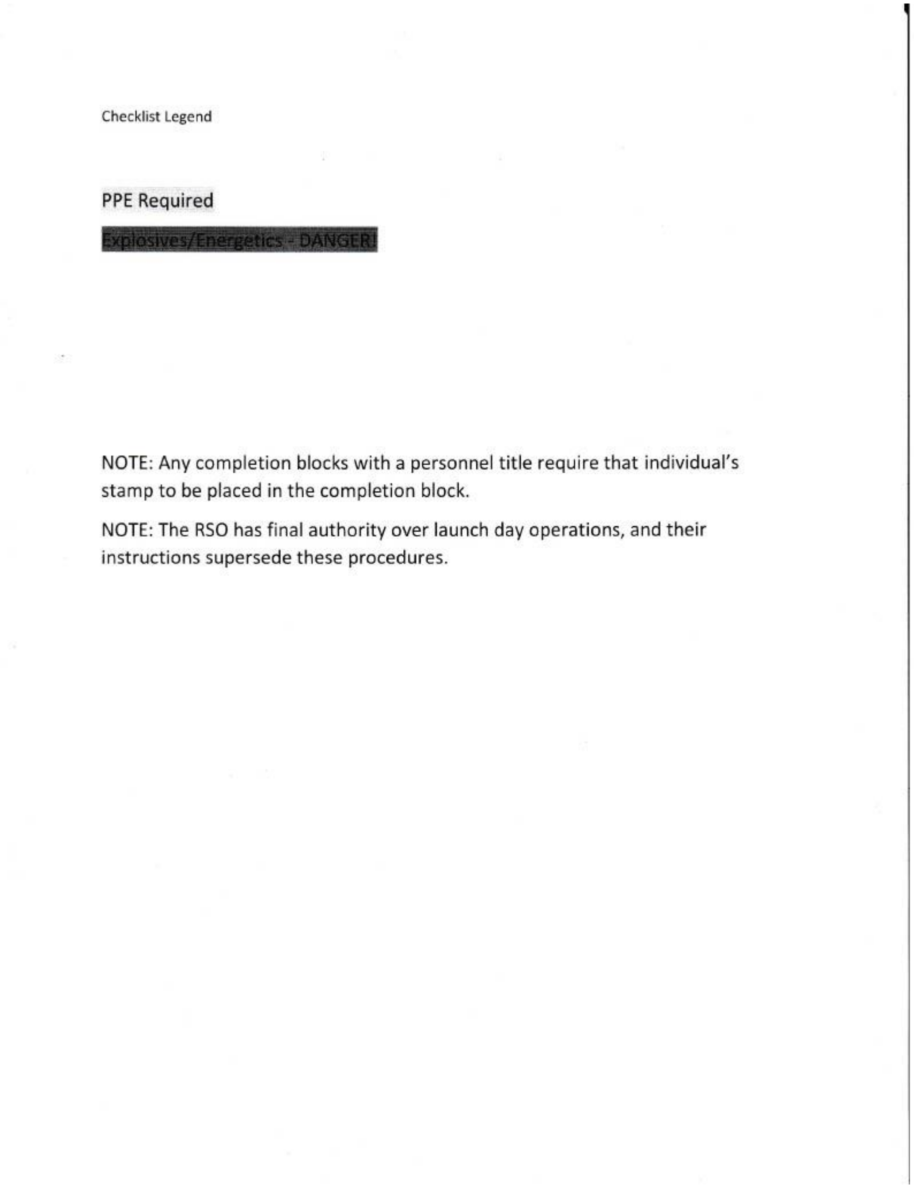


81 Point 5

Launch Day Checklists

This checklist completed by: Evan Waldron

On: 2 / 21 / 21



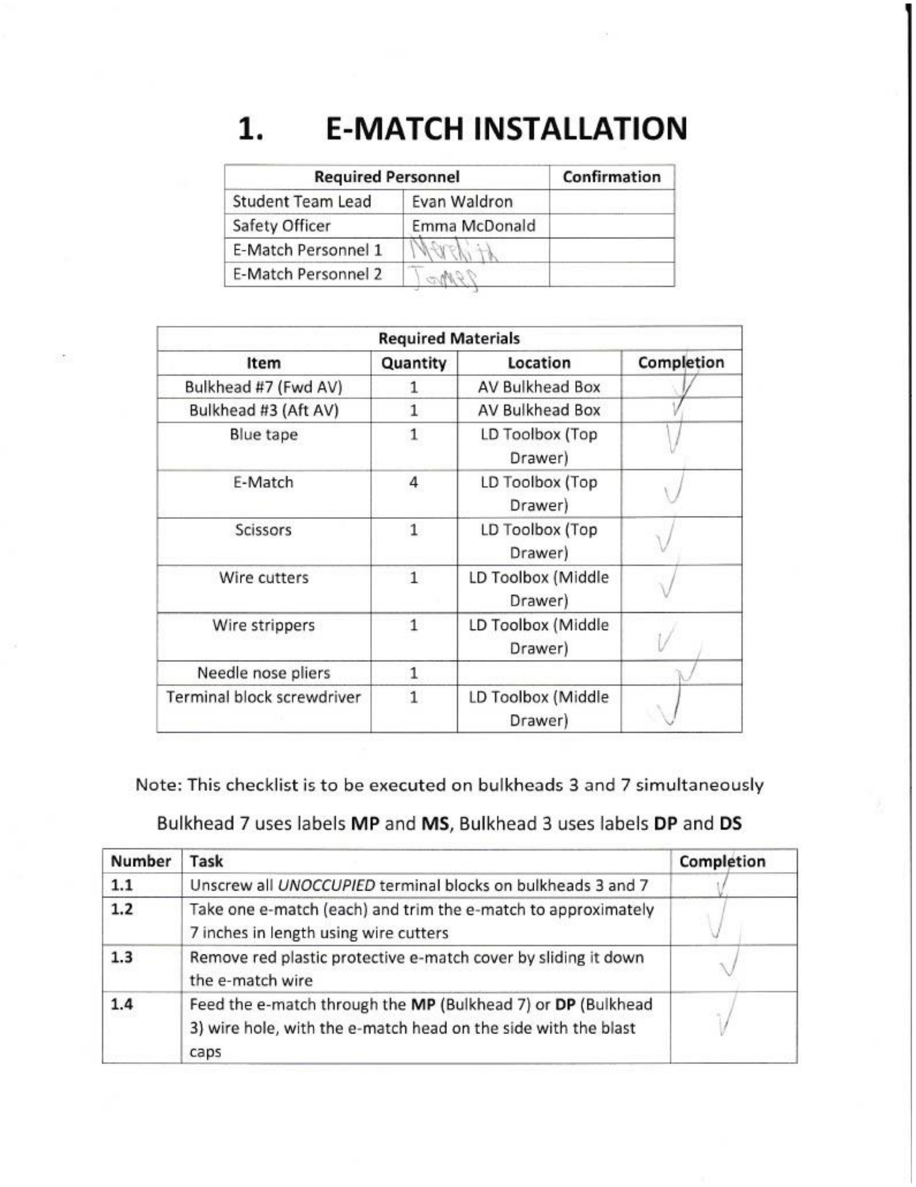
Checklist Legend

PPE Required

Explosives/Energetics - DANGER!

NOTE: Any completion blocks with a personnel title require that individual's stamp to be placed in the completion block.

NOTE: The RSO has final authority over launch day operations, and their instructions supersede these procedures.



1. E-MATCH INSTALLATION

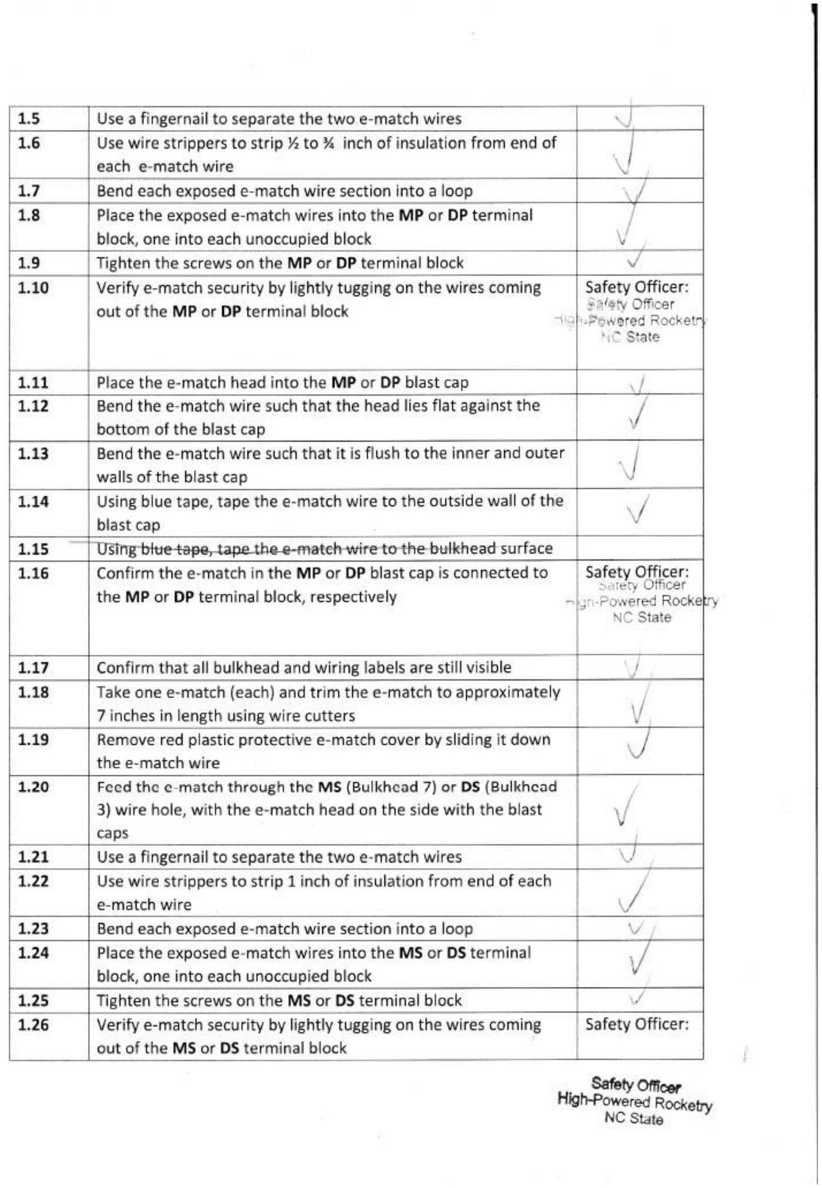
Required Personnel		Confirmation
Student Team Lead	Evan Waldron	
Safety Officer	Emma McDonald	
E-Match Personnel 1	Meredith	
E-Match Personnel 2	James	

Required Materials			
Item	Quantity	Location	Completion
Bulkhead #7 (Fwd AV)	1	AV Bulkhead Box	✓
Bulkhead #3 (Aft AV)	1	AV Bulkhead Box	✓
Blue tape	1	LD Toolbox (Top Drawer)	✓
E-Match	4	LD Toolbox (Top Drawer)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Wire cutters	1	LD Toolbox (Middle Drawer)	✓
Wire strippers	1	LD Toolbox (Middle Drawer)	✓
Needle nose pliers	1		✓
Terminal block screwdriver	1	LD Toolbox (Middle Drawer)	✓

Note: This checklist is to be executed on bulkheads 3 and 7 simultaneously

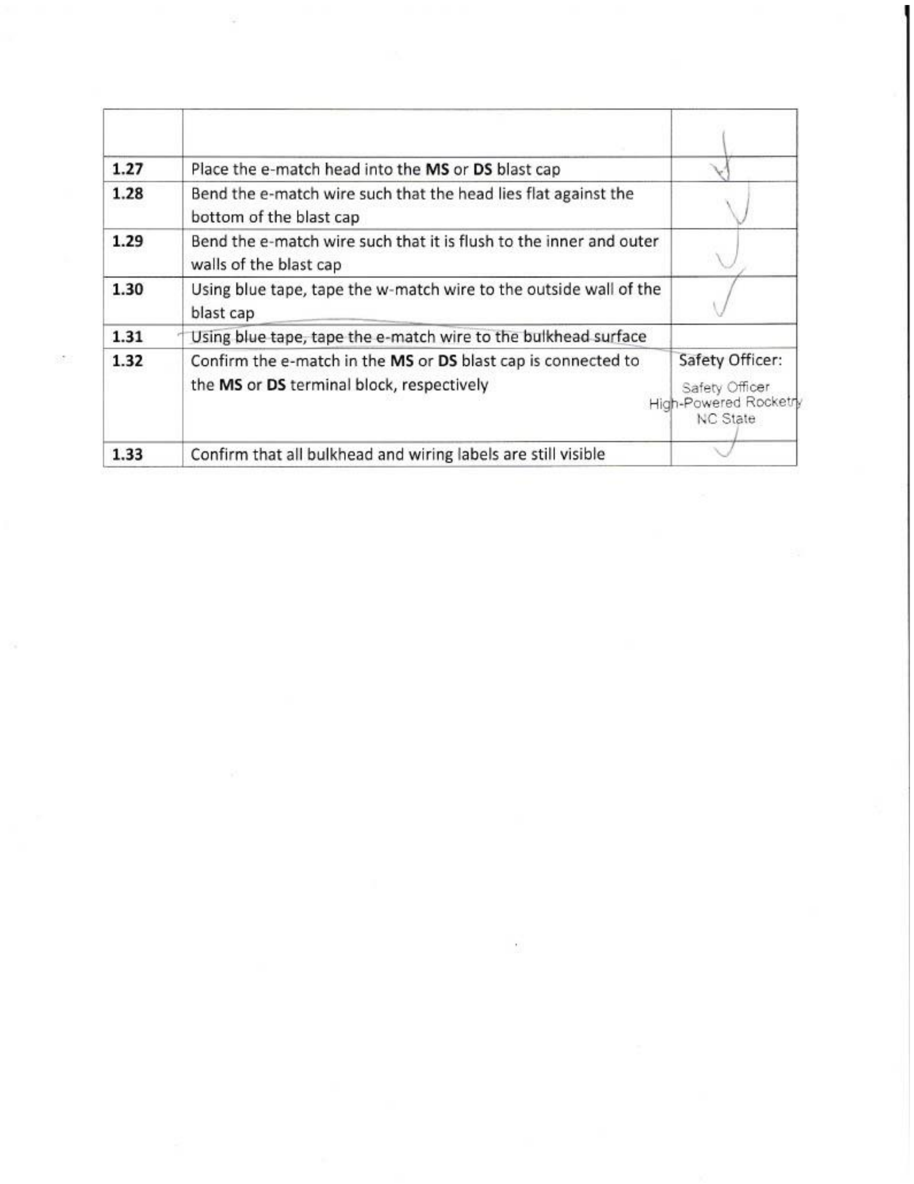
Bulkhead 7 uses labels **MP** and **MS**, Bulkhead 3 uses labels **DP** and **DS**

Number	Task	Completion
1.1	Unscrew all *UNOCCUPIED* terminal blocks on bulkheads 3 and 7	✓
1.2	Take one e-match (each) and trim the e-match to approximately 7 inches in length 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 7) or **DP** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps	✓

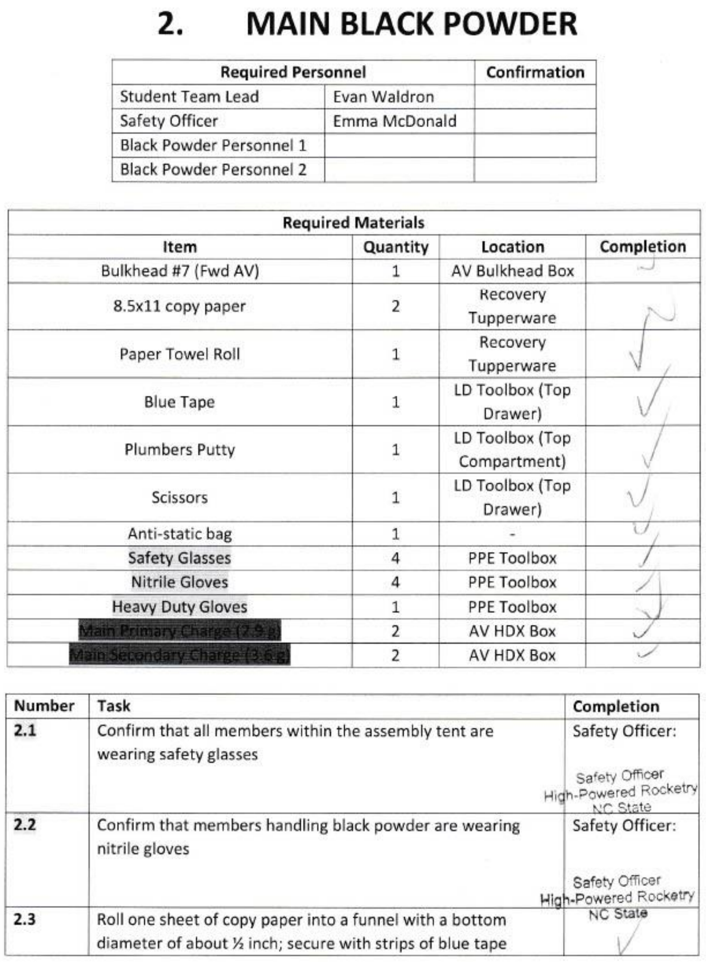


1.5	Use a fingernail to separate the two e-match wires	✓
1.6	Use wire strippers to strip ½ to ¾ inch of insulation from end of each e-match wire	✓
1.7	Bend each exposed e-match wire section into a loop	✓
1.8	Place the exposed e-match wires into the **MP** or **DP** terminal block, one into each unoccupied block	✓
1.9	Tighten the screws on the **MP** or **DP** terminal block	✓
1.10	Verify e-match security by lightly tugging on the wires coming out of the **MP** or **DP** terminal block	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.11	Place the e-match head into the **MP** or **DP** blast cap	✓
1.12	Bend the e-match wire such that the head lies flat against the bottom of the blast cap	✓
1.13	Bend the e-match wire such that it is flush to the inner and outer walls of the blast cap	✓
1.14	Using blue tape, tape the e-match wire to the outside wall of the blast cap	✓
1.15	~~Using blue tape, tape the e-match wire to the bulkhead surface~~	
1.16	Confirm the e-match in the **MP** or **DP** blast cap is connected to the **MP** or **DP** terminal block, respectively	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.17	Confirm that all bulkhead and wiring labels are still visible	✓
1.18	Take one e-match (each) and trim the e-match to approximately 7 inches in length using wire cutters	✓
1.19	Remove red plastic protective e-match cover by sliding it down the e-match wire	✓
1.20	Feed the e-match through the **MS** (Bulkhead 7) or **DS** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps	✓
1.21	Use a fingernail to separate the two e-match wires	✓
1.22	Use wire strippers to strip 1 inch of insulation from end of each e-match wire	✓
1.23	Bend each exposed e-match wire section into a loop	✓
1.24	Place the exposed e-match wires into the **MS** or **DS** terminal block, one into each unoccupied block	✓
1.25	Tighten the screws on the **MS** or **DS** terminal block	✓
1.26	Verify e-match security by lightly tugging on the wires coming out of the **MS** or **DS** terminal block	Safety Officer:

Safety Officer
High-Powered Rocketry
NC State



1.27	Place the e-match head into the **MS** or **DS** blast cap	✓
1.28	Bend the e-match wire such that the head lies flat against the bottom of the blast cap	✓
1.29	Bend the e-match wire such that it is flush to the inner and outer walls of the blast cap	✓
1.30	Using blue tape, tape the w-match wire to the outside wall of the blast cap	✓
1.31	~~Using blue tape, tape the e-match wire to the bulkhead surface~~	
1.32	Confirm the e-match in the **MS** or **DS** blast cap is connected to the **MS** or **DS** terminal block, respectively	Safety Officer: Safety Officer High-Powered Rocketry NC State
1.33	Confirm that all bulkhead and wiring labels are still visible	✓

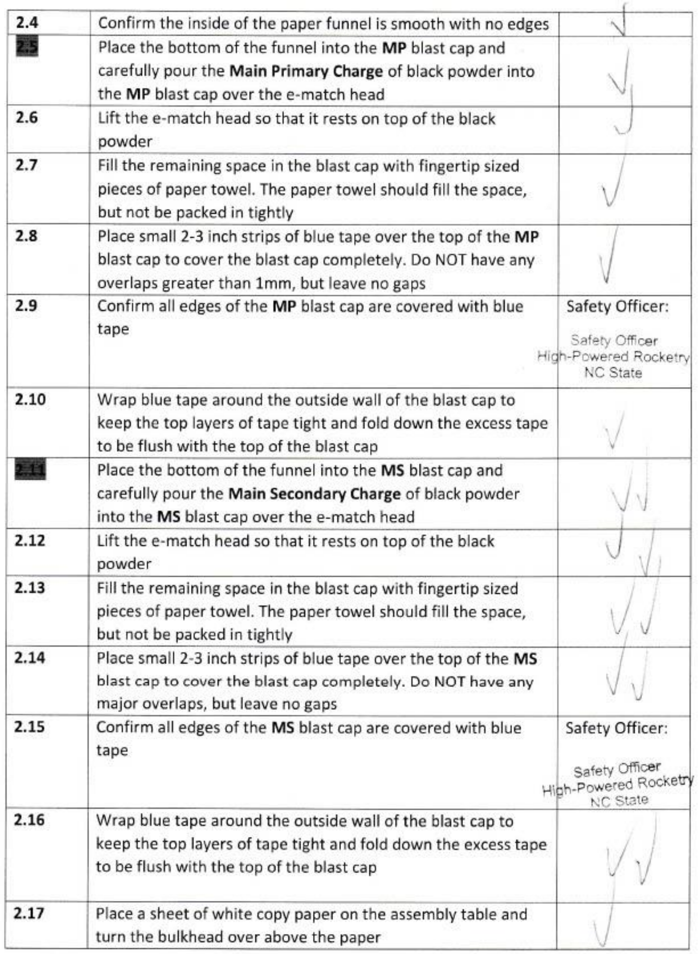


2. MAIN BLACK POWDER

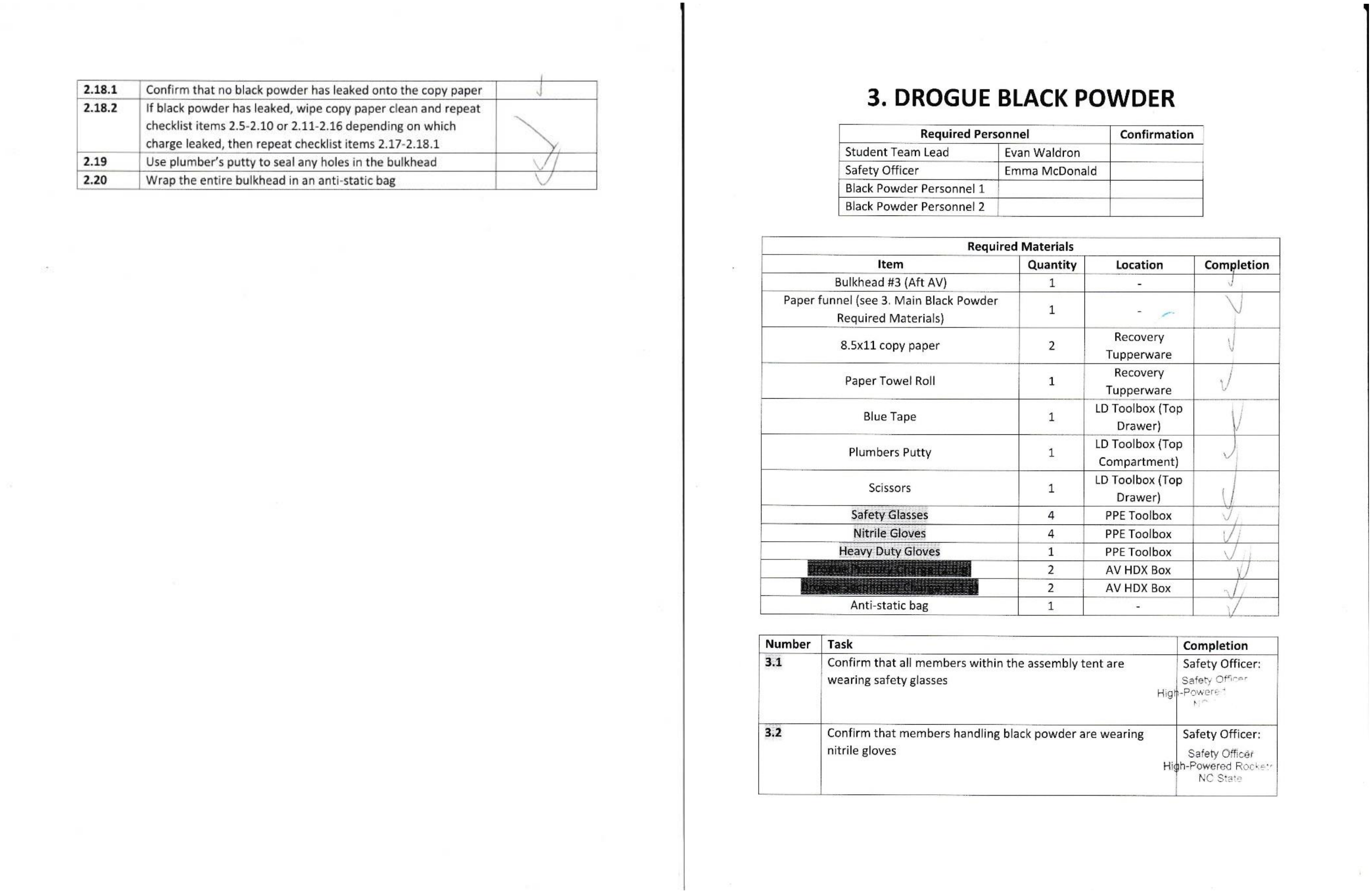
Required Personnel		Confirmation
Student Team Lead	Evan Waldron	
Safety Officer	Emma McDonald	
Black Powder Personnel 1		
Black Powder Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Bulkhead #7 (Fwd AV)	1	AV Bulkhead Box	✓
8.5x11 copy paper	2	Recovery Tupperware	✓
Paper Towel Roll	1	Recovery Tupperware	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Anti-static bag	1	-	✓
Safety Glasses	4	PPE Toolbox	✓
Nitrile Gloves	4	PPE Toolbox	✓
Heavy Duty Gloves	1	PPE Toolbox	✓
[redacted]	2	AV HDX Box	✓
[redacted]	2	AV HDX Box	✓

Number	Task	Completion
2.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.3	Roll one sheet of copy paper into a funnel with a bottom diameter of about ½ inch; secure with strips of blue tape	✓



2.4	Confirm the inside of the paper funnel is smooth with no edges	✓
[redacted]	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	✓
2.6	Lift the e-match head so that it rests on top of the black powder	✓
2.7	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	✓
2.8	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	✓
2.9	Confirm all edges of the **MP** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.10	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	✓
[redacted]	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	✓ ✓
2.12	Lift the e-match head so that it rests on top of the black powder	✓ ✓
2.13	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	✓ ✓
2.14	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	✓ ✓
2.15	Confirm all edges of the **MS** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered Rocketry NC State
2.16	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	✓ ✓
2.17	Place a sheet of white copy paper on the assembly table and turn the bulkhead over above the paper	✓



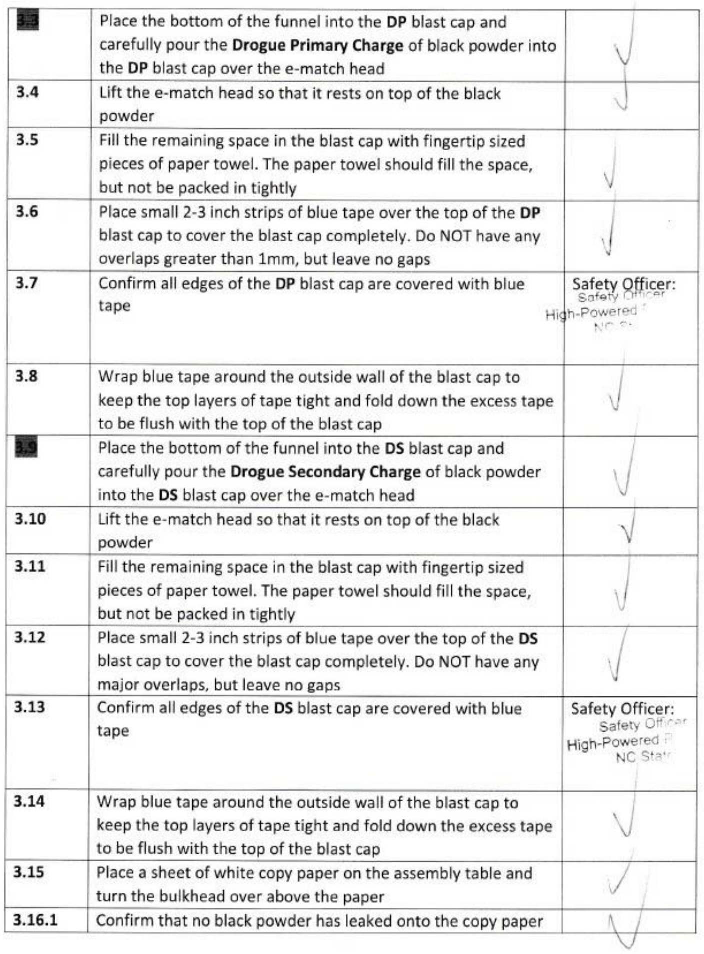
2.18.1	Confirm that no black powder has leaked onto the copy paper	✓
2.18.2	If black powder has leaked, wipe copy paper clean and repeat checklist items 2.5-2.10 or 2.11-2.16 depending on which charge leaked, then repeat checklist items 2.17-2.18.1	✓
2.19	Use plumber's putty to seal any holes in the bulkhead	✓
2.20	Wrap the entire bulkhead in an anti-static bag	✓

3. DROGUE BLACK POWDER

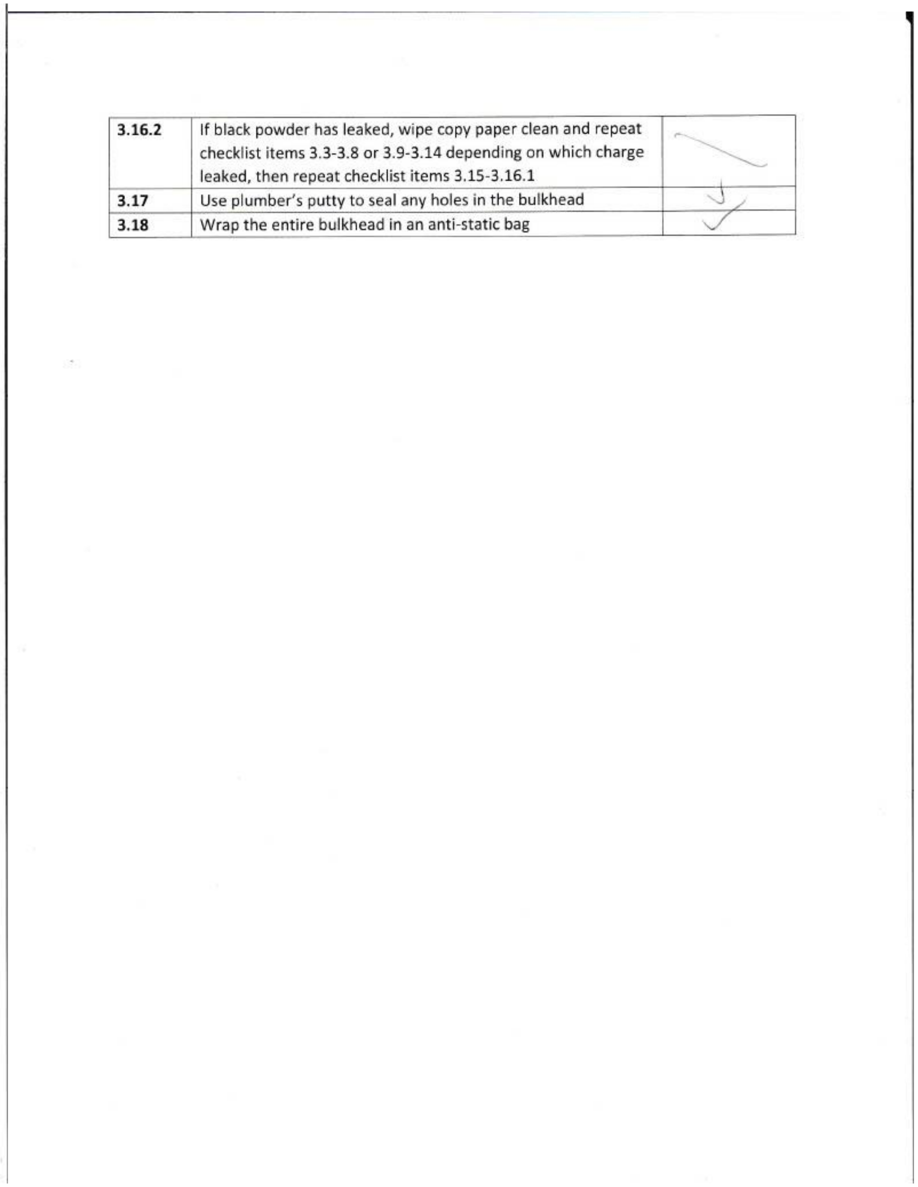
Required Personnel		**Confirmation**
Student Team Lead	Evan Waldron	
Safety Officer	Emma McDonald	
Black Powder Personnel 1		
Black Powder Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	**Completion**
Bulkhead #3 (Aft AV)	1	-	✓
Paper funnel (see 3. Main Black Powder Required Materials)	1	-	✓
8.5x11 copy paper	2	Recovery Tupperware	✓
Paper Towel Roll	1	Recovery Tupperware	✓
Blue Tape	1	LD Toolbox (Top Drawer)	✓
Plumbers Putty	1	LD Toolbox (Top Compartment)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Safety Glasses	4	PPE Toolbox	✓
Nitrile Gloves	4	PPE Toolbox	✓
Heavy Duty Gloves	1	PPE Toolbox	✓
[redacted]	2	AV HDX Box	✓
[redacted]	2	AV HDX Box	✓
Anti-static bag	1	-	✓

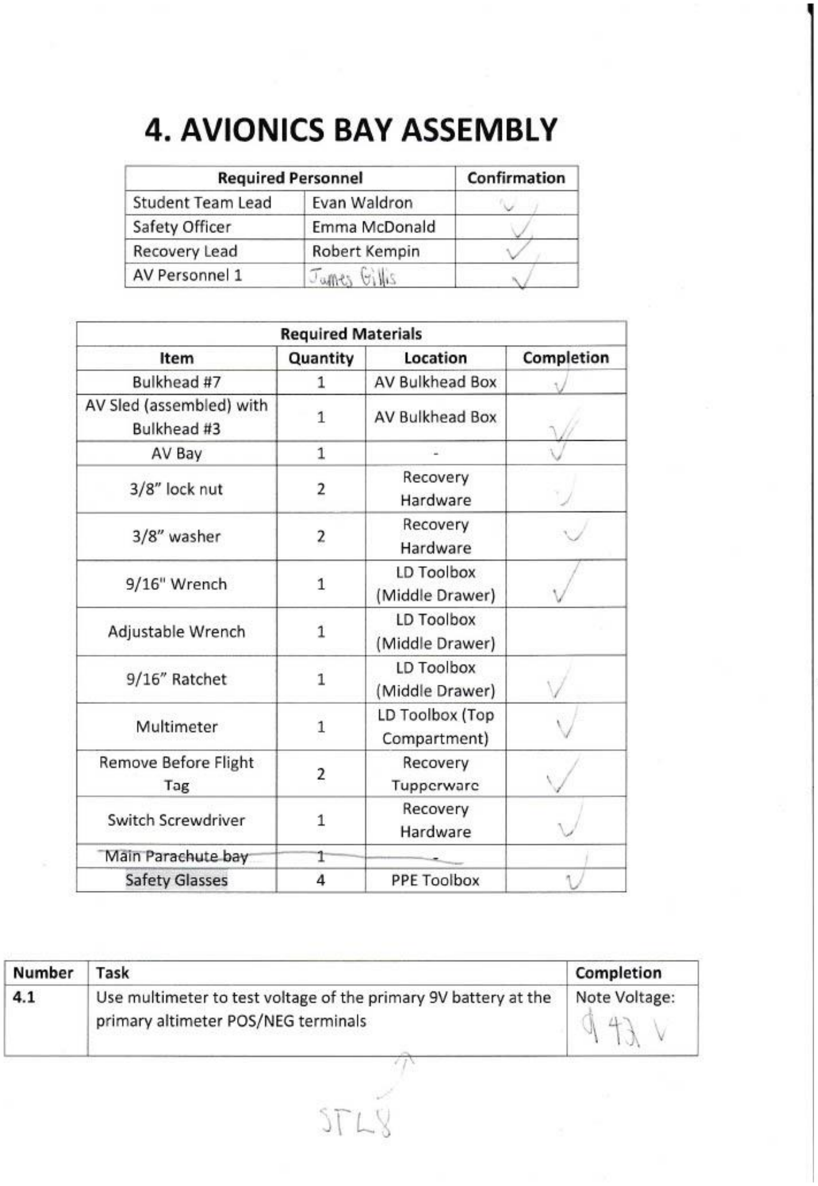
Number	**Task**	**Completion**
3.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powere
3.2	Confirm that members handling black powder are wearing nitrile gloves	Safety Officer: Safety Officer High-Powered Rocketr NC State



3.3	Place the bottom of the funnel into the **DP** blast cap and carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head	✓
3.4	Lift the e-match head so that it rests on top of the black powder	✓
3.5	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓
3.6	Place small 2-3 inch strips of blue tape over the top of the **DP** blast cap to cover the blast cap completely. Do NOT have any overlaps greater than 1mm, but leave no gaps	✓
3.7	Confirm all edges of the **DP** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered NC St
3.8	Wrap blue tape around the outside wall of the blast cap to keep the top layers of tape tight and fold down the excess tape to be flush with the top of the blast cap	✓
3.9	Place the bottom of the funnel into the **DS** blast cap and carefully pour the **Drogue Secondary Charge** of black powder into the **DS** blast cap over the e-match head	✓
3.10	Lift the e-match head so that it rests on top of the black powder	✓
3.11	Fill the remaining space in the blast cap with fingertip sized pieces of paper towel. The paper towel should fill the space, but not be packed in tightly	✓
3.12	Place small 2-3 inch strips of blue tape over the top of the **DS** blast cap to cover the blast cap completely. Do NOT have any major overlaps, but leave no gaps	✓
3.13	Confirm all edges of the **DS** blast cap are covered with blue tape	Safety Officer: Safety Officer High-Powered NC Stat
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 3.15-3.16.1	—
3.17	Use plumber's putty to seal any holes in the bulkhead	✓
3.18	Wrap the entire bulkhead in an anti-static bag	✓



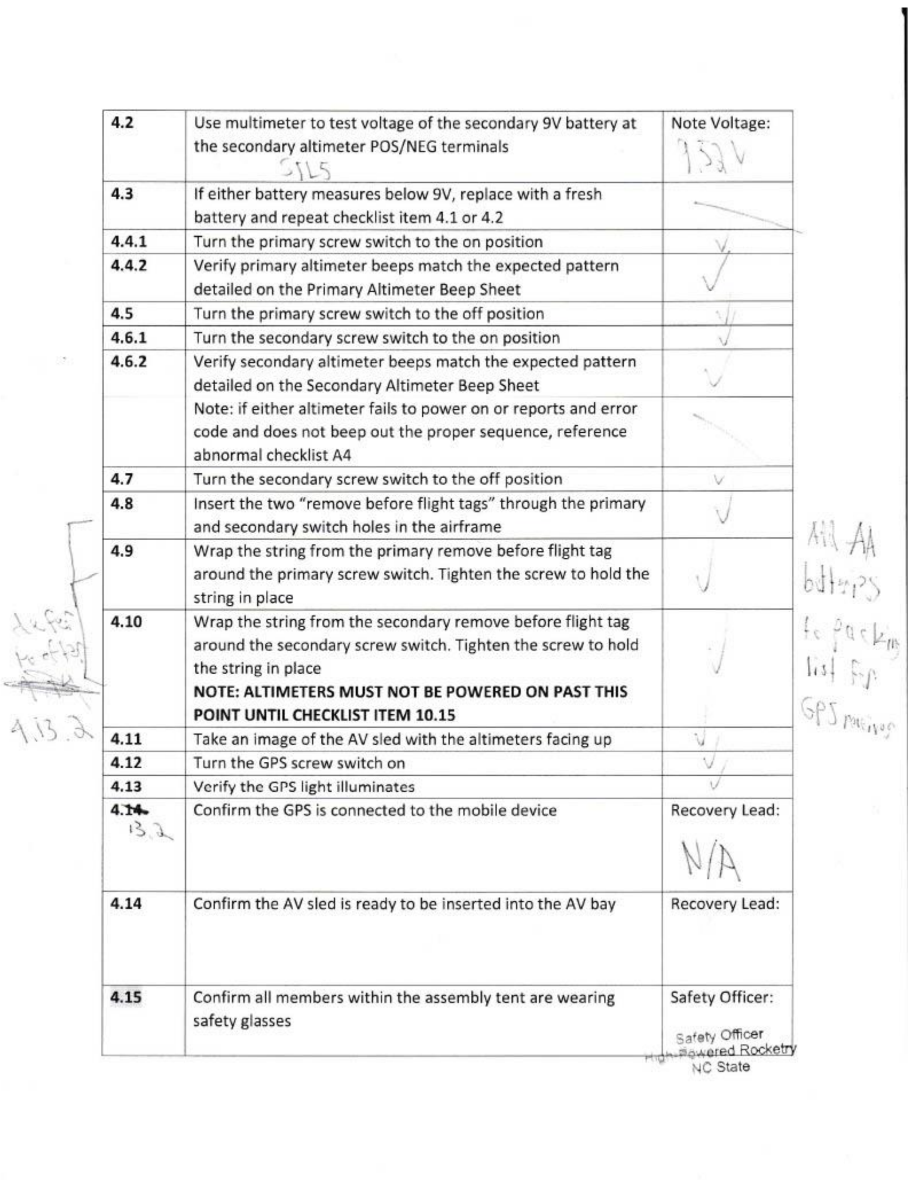
4. AVIONICS BAY ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Evan Waldron	✓
Safety Officer	Emma McDonald	✓
Recovery Lead	Robert Kempin	✓
AV Personnel 1	James Gillis	✓

Required Materials			
Item	Quantity	Location	Completion
Bulkhead #7	1	AV Bulkhead Box	✓
AV Sled (assembled) with Bulkhead #3	1	AV Bulkhead Box	✓
AV Bay	1	-	✓
3/8" lock nut	2	Recovery Hardware	✓
3/8" washer	2	Recovery Hardware	✓
9/16" Wrench	1	LD Toolbox (Middle Drawer)	✓
Adjustable Wrench	1	LD Toolbox (Middle Drawer)	
9/16" Ratchet	1	LD Toolbox (Middle Drawer)	✓
Multimeter	1	LD Toolbox (Top Compartment)	✓
Remove Before Flight Tag	2	Recovery Tupperware	✓
Switch Screwdriver	1	Recovery Hardware	✓
~~Main Parachute bay~~	~~1~~	~~-~~	✓
Safety Glasses	4	PPE Toolbox	✓

Number	Task	Completion
4.1	Use multimeter to test voltage of the primary 9V battery at the primary altimeter POS/NEG terminals	Note Voltage: 9.43 V

STL8

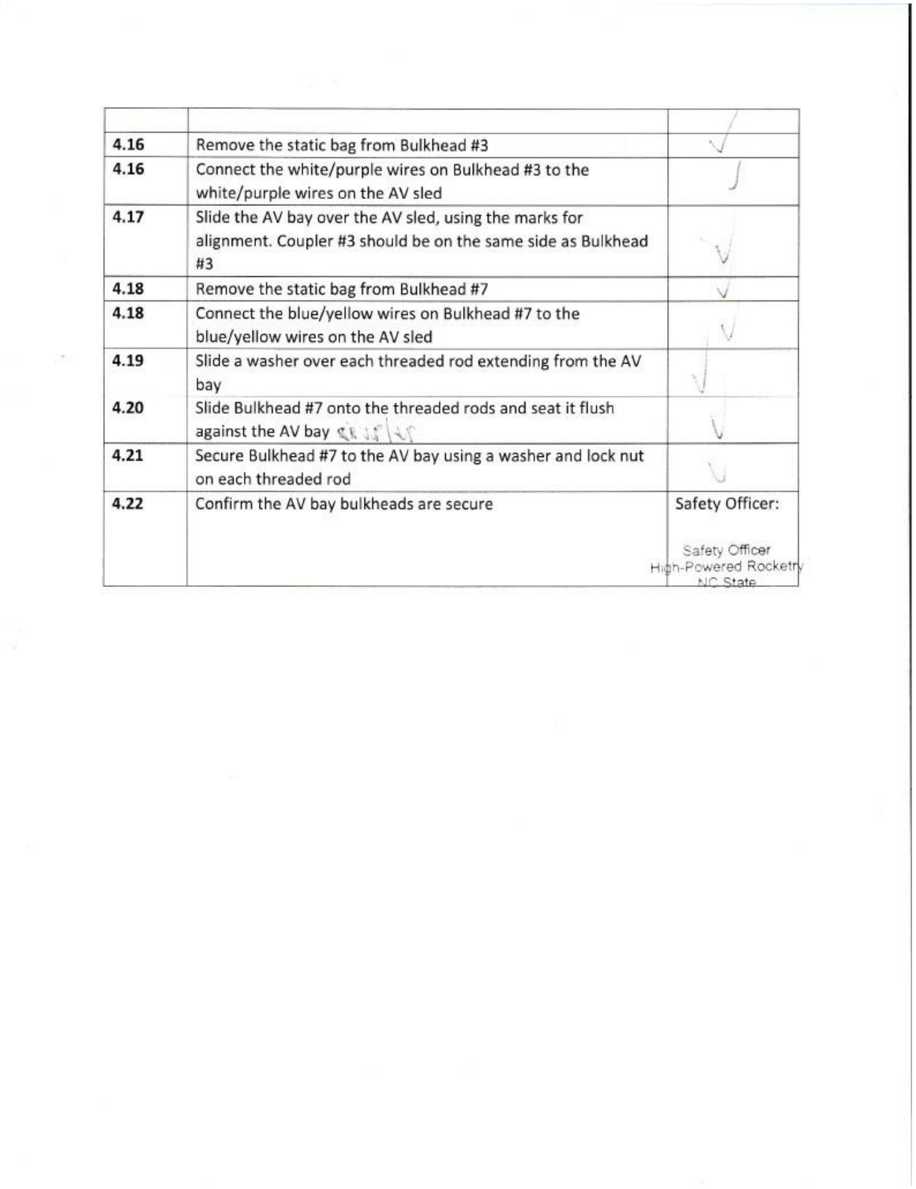


4.2	Use multimeter to test voltage of the secondary 9V battery at the secondary altimeter POS/NEG terminals STL5	Note Voltage: 9.52 V
4.3	If either battery measures below 9V, replace with a fresh battery and repeat checklist item 4.1 or 4.2	—
4.4.1	Turn the primary screw switch to the on position	✓
4.4.2	Verify primary altimeter beeps match the expected pattern detailed on the Primary Altimeter Beep Sheet	✓
4.5	Turn the primary screw switch to the off position	✓
4.6.1	Turn the secondary screw switch to the on position	✓
4.6.2	Verify secondary altimeter beeps match the expected pattern detailed on the Secondary Altimeter Beep Sheet	✓
	Note: if either altimeter fails to power on or reports and error code and does not beep out the proper sequence, reference abnormal checklist A4	—
4.7	Turn the secondary screw switch to the off position	✓
4.8	Insert the two "remove before flight tags" through the primary and secondary switch holes in the airframe	✓
4.9	Wrap the string from the primary remove before flight tag around the primary screw switch. Tighten the screw to hold the string in place	✓
4.10	Wrap the string from the secondary remove before flight tag around the secondary screw switch. Tighten the screw to hold the string in place **NOTE: ALTIMETERS MUST NOT BE POWERED ON PAST THIS POINT UNTIL CHECKLIST ITEM 10.15**	✓
4.11	Take an image of the AV sled with the altimeters facing up	✓
4.12	Turn the GPS screw switch on	✓
4.13	Verify the GPS light illuminates	✓
4.~~14~~ 13.2	Confirm the GPS is connected to the mobile device	Recovery Lead: N/A
4.14	Confirm the AV sled is ready to be inserted into the AV bay	Recovery Lead:
4.15	Confirm all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State

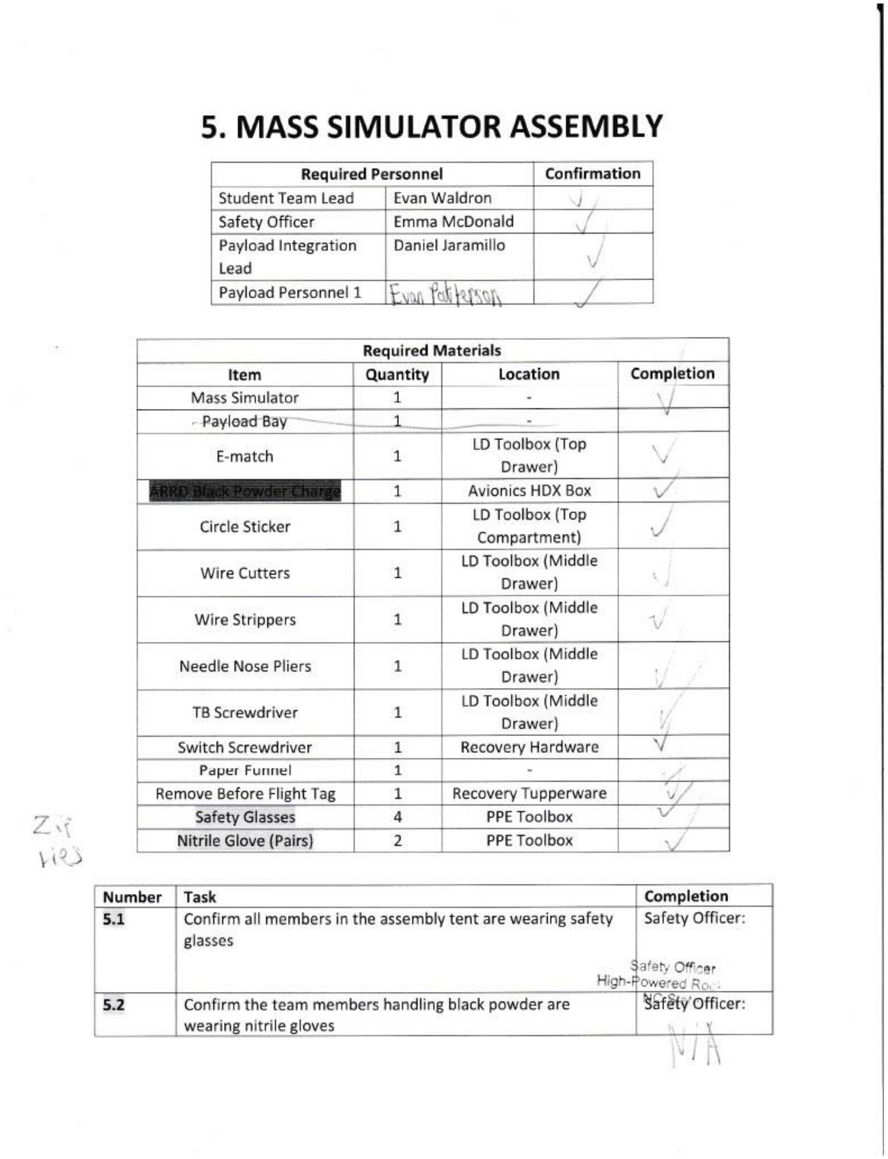
Refer to after ~~[illegible]~~

4.13.2

Add AA batteries to packing list for GPS receiver



4.16	Remove the static bag from Bulkhead #3	✓
4.16	Connect the white/purple wires on Bulkhead #3 to the white/purple wires on the AV sled	✓
4.17	Slide the AV bay over the AV sled, using the marks for alignment. Coupler #3 should be on the same side as Bulkhead #3	✓
4.18	Remove the static bag from Bulkhead #7	✓
4.18	Connect the blue/yellow wires on Bulkhead #7 to the blue/yellow wires on the AV sled	✓
4.19	Slide a washer over each threaded rod extending from the AV bay	✓
4.20	Slide Bulkhead #7 onto the threaded rods and seat it flush against the AV bay	✓
4.21	Secure Bulkhead #7 to the AV bay using a washer and lock nut on each threaded rod	✓
4.22	Confirm the AV bay bulkheads are secure	Safety Officer: Safety Officer High-Powered Rocketry NC State



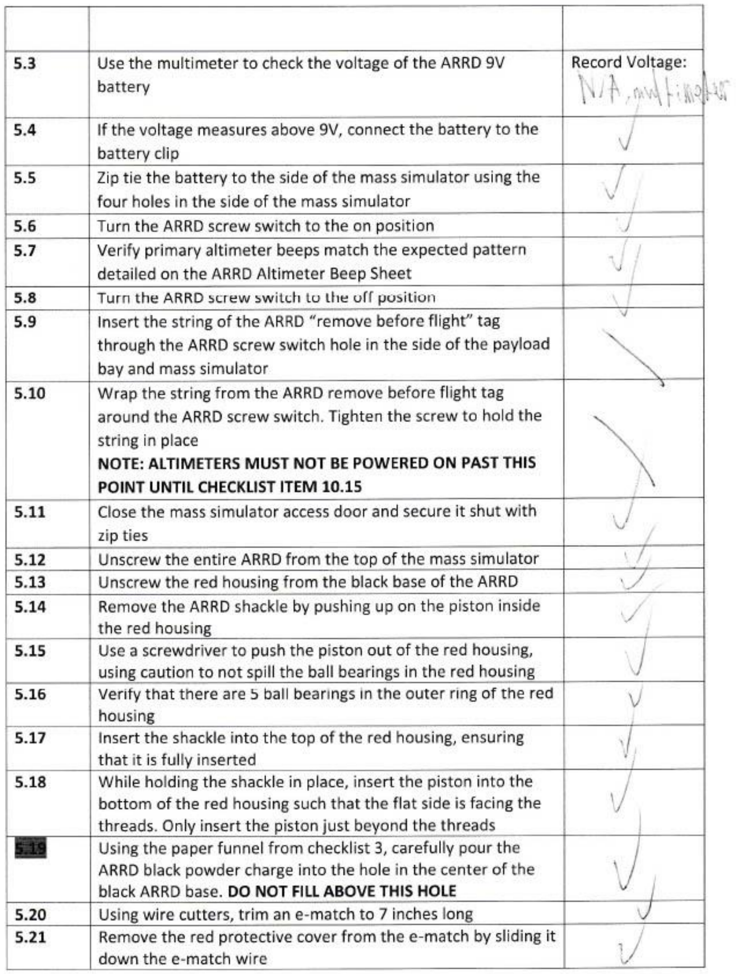
5. MASS SIMULATOR ASSEMBLY

Required Personnel		Confirmation
Student Team Lead	Evan Waldron	✓
Safety Officer	Emma McDonald	✓
Payload Integration Lead	Daniel Jaramillo	✓
Payload Personnel 1	Evan Patterson	✓

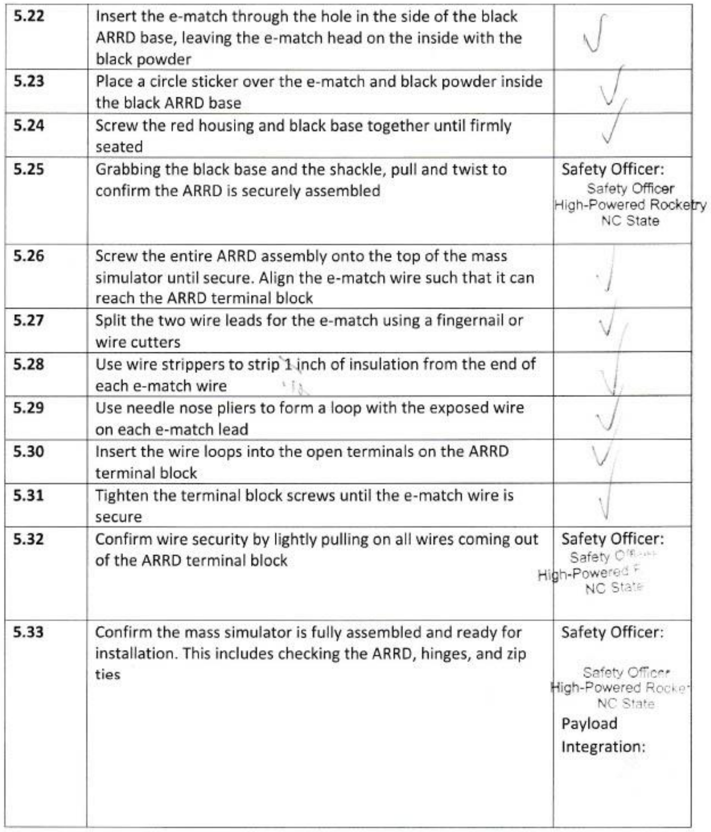
Required Materials			
Item	**Quantity**	**Location**	**Completion**
Mass Simulator	1	-	✓
~~Payload Bay~~	~~1~~	~~-~~	
E-match	1	LD Toolbox (Top Drawer)	✓
[redacted]	1	Avionics HDX Box	✓
Circle Sticker	1	LD Toolbox (Top Compartment)	✓
Wire Cutters	1	LD Toolbox (Middle Drawer)	✓
Wire Strippers	1	LD Toolbox (Middle Drawer)	✓
Needle Nose Pliers	1	LD Toolbox (Middle Drawer)	✓
TB Screwdriver	1	LD Toolbox (Middle Drawer)	✓
Switch Screwdriver	1	Recovery Hardware	✓
Paper Funnel	1	-	
Remove Before Flight Tag	1	Recovery Tupperware	✓
Safety Glasses	4	PPE Toolbox	✓
Nitrile Glove (Pairs)	2	PPE Toolbox	✓

Zip ties

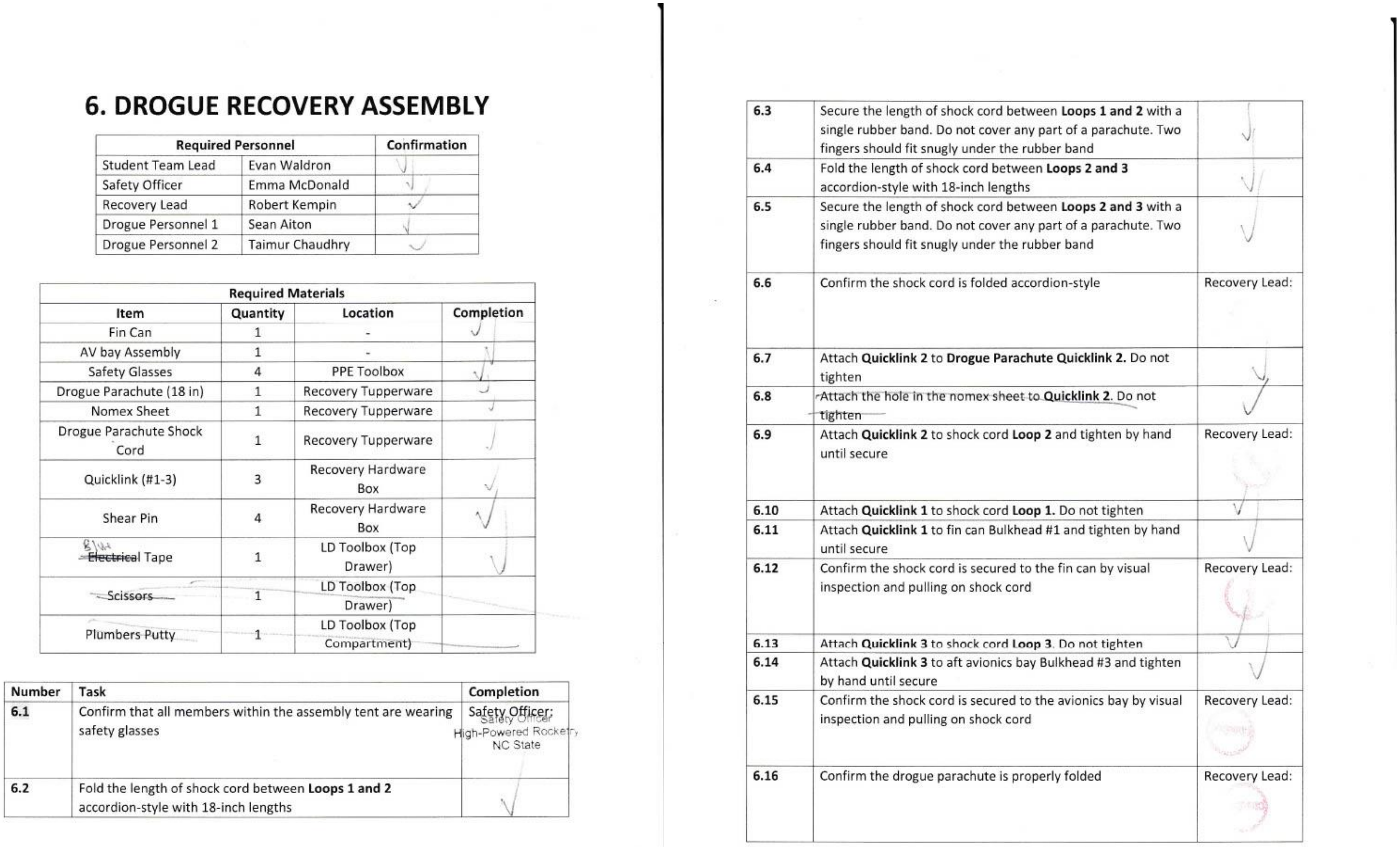
Number	Task	Completion
5.1	Confirm all members in the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Ro… NC State
5.2	Confirm the team members handling black powder are wearing nitrile gloves	Safety Officer: N/A



5.3	Use the multimeter to check the voltage of the ARRD 9V battery	Record Voltage: N/A, [illegible]
5.4	If the voltage measures above 9V, connect the battery to the battery clip	✓
5.5	Zip tie the battery to the side of the mass simulator using the four holes in the side of the mass simulator	✓
5.6	Turn the ARRD screw switch to the on position	✓
5.7	Verify primary altimeter beeps match the expected pattern detailed on the ARRD Altimeter Beep Sheet	✓
5.8	Turn the ARRD screw switch to the off position	✓
5.9	Insert the string of the ARRD "remove before flight" tag through the ARRD screw switch hole in the side of the payload bay and mass simulator	✓
5.10	Wrap the string from the ARRD remove before flight tag around the ARRD screw switch. Tighten the screw to hold the string in place **NOTE: ALTIMETERS MUST NOT BE POWERED ON PAST THIS POINT UNTIL CHECKLIST ITEM 10.15**	✓
5.11	Close the mass simulator access door and secure it shut with zip ties	✓
5.12	Unscrew the entire ARRD from the top of the mass simulator	✓
5.13	Unscrew the red housing from the black base of the ARRD	✓
5.14	Remove the ARRD shackle by pushing up on the piston inside the red housing	✓
5.15	Use a screwdriver to push the piston out of the red housing, using caution to not spill the ball bearings in the red housing	✓
5.16	Verify that there are 5 ball bearings in the outer ring of the red housing	✓
5.17	Insert the shackle into the top of the red housing, ensuring that it is fully inserted	✓
5.18	While holding the shackle in place, insert the piston into the bottom of the red housing such that the flat side is facing the threads. Only insert the piston just beyond the threads	✓
5.19	Using the paper funnel from checklist 3, carefully pour the ARRD black powder charge into the hole in the center of the black ARRD base. **DO NOT FILL ABOVE THIS HOLE**	✓
5.20	Using wire cutters, trim an e-match to 7 inches long	✓
5.21	Remove the red protective cover from the e-match by sliding it down the e-match wire	✓



5.22	Insert the e-match through the hole in the side of the black ARRD base, leaving the e-match head on the inside with the black powder	✓
5.23	Place a circle sticker over the e-match and black powder inside the black ARRD base	✓
5.24	Screw the red housing and black base together until firmly seated	✓
5.25	Grabbing the black base and the shackle, pull and twist to confirm the ARRD is securely assembled	Safety Officer: Safety Officer High-Powered Rocketry NC State
5.26	Screw the entire ARRD assembly onto the top of the mass simulator until secure. Align the e-match wire such that it can reach the ARRD terminal block	✓
5.27	Split the two wire leads for the e-match using a fingernail or wire cutters	✓
5.28	Use wire strippers to strip 1 inch of insulation from the end of each e-match wire	✓
5.29	Use needle nose pliers to form a loop with the exposed wire on each e-match lead	✓
5.30	Insert the wire loops into the open terminals on the ARRD terminal block	✓
5.31	Tighten the terminal block screws until the e-match wire is secure	✓
5.32	Confirm wire security by lightly pulling on all wires coming out of the ARRD terminal block	Safety Officer: Safety Officer High-Powered R NC State
5.33	Confirm the mass simulator is fully assembled and ready for installation. This includes checking the ARRD, hinges, and zip ties	Safety Officer: Safety Officer High-Powered Rocket NC State Payload Integration:

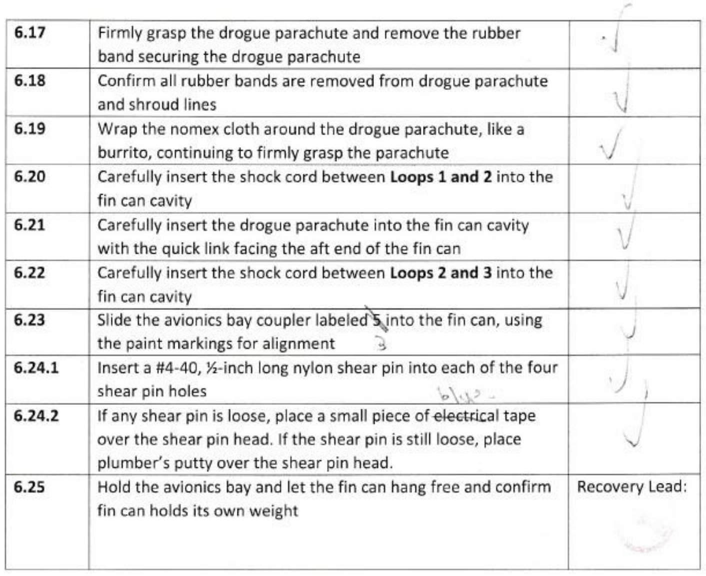


6. DROGUE RECOVERY ASSEMBLY

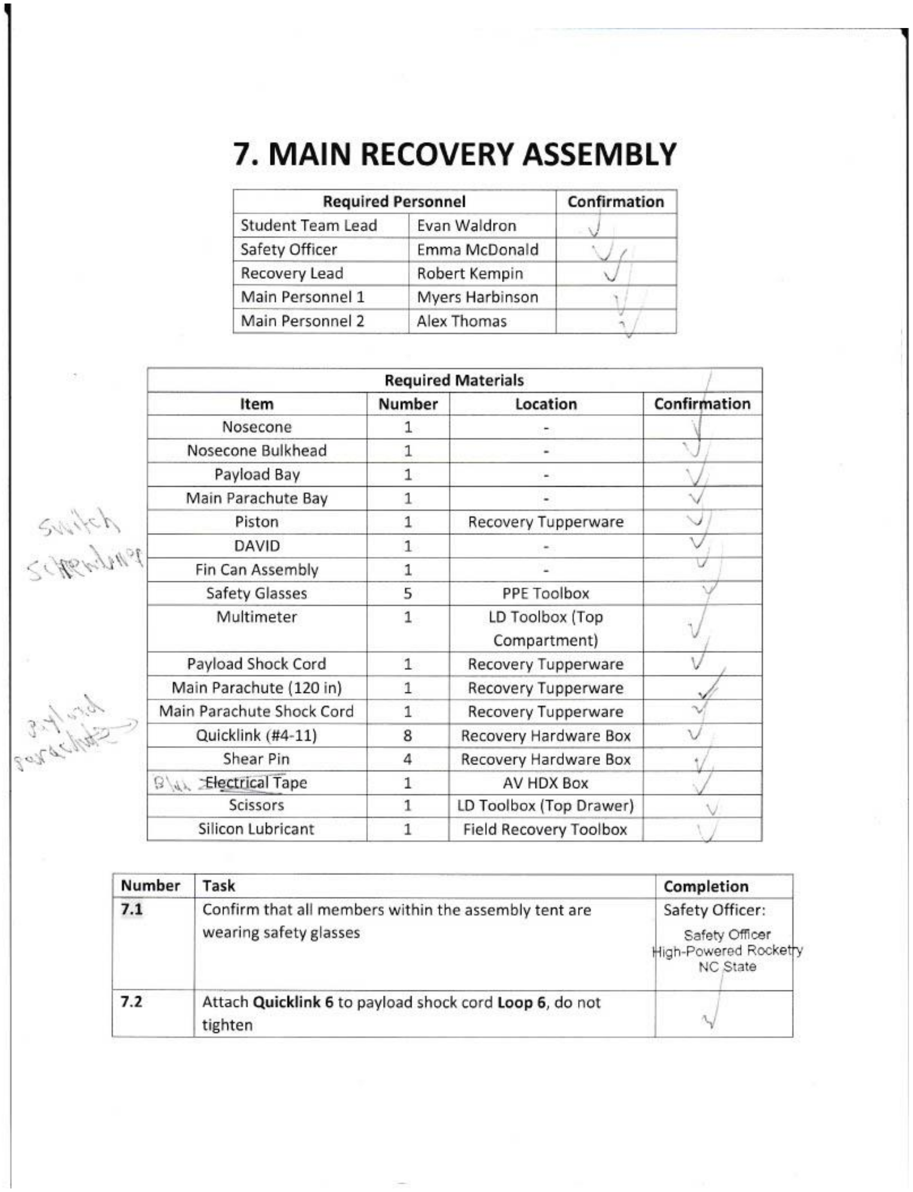
Required Personnel		Confirmation
Student Team Lead	Evan Waldron	✓
Safety Officer	Emma McDonald	✓
Recovery Lead	Robert Kempin	✓
Drogue Personnel 1	Sean Aiton	✓
Drogue Personnel 2	Taimur Chaudhry	✓

Required Materials			
Item	Quantity	Location	Completion
Fin Can	1	-	✓
AV bay Assembly	1	-	✓
Safety Glasses	4	PPE Toolbox	✓
Drogue Parachute (18 in)	1	Recovery Tupperware	✓
Nomex Sheet	1	Recovery Tupperware	✓
Drogue Parachute Shock Cord	1	Recovery Tupperware	✓
Quicklink (#1-3)	3	Recovery Hardware Box	✓
Shear Pin	4	Recovery Hardware Box	✓
Blue ~~Electrical~~ Tape	1	LD Toolbox (Top Drawer)	✓
~~Scissors~~	~~1~~	~~LD Toolbox (Top Drawer)~~	
~~Plumbers Putty~~	~~1~~	~~LD Toolbox (Top Compartment)~~	

Number	Task	Completion
6.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
6.2	Fold the length of shock cord between **Loops 1 and 2** accordion-style with 18-inch lengths	✓
6.3	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	✓
6.4	Fold the length of shock cord between **Loops 2 and 3** accordion-style with 18-inch lengths	✓
6.5	Secure the length of shock cord between **Loops 2 and 3** with a single rubber band. Do not cover any part of a parachute. Two fingers should fit snugly under the rubber band	✓
6.6	Confirm the shock cord is folded accordion-style	Recovery Lead:
6.7	Attach **Quicklink 2** to **Drogue Parachute Quicklink 2.** Do not tighten	✓
6.8	~~Attach the hole in the nomex sheet to **Quicklink 2**. Do not tighten~~	✓
6.9	Attach **Quicklink 2** to shock cord **Loop 2** and tighten by hand until secure	Recovery Lead:
6.10	Attach **Quicklink 1** to shock cord **Loop 1.** Do not tighten	✓
6.11	Attach **Quicklink 1** to fin can Bulkhead #1 and tighten by hand until secure	✓
6.12	Confirm the shock cord is secured to the fin can by visual inspection and pulling on shock cord	Recovery Lead:
6.13	Attach **Quicklink 3** to shock cord **Loop 3**. Do not tighten	✓
6.14	Attach **Quicklink 3** to aft avionics bay Bulkhead #3 and tighten by hand until secure	✓
6.15	Confirm the shock cord is secured to the avionics bay by visual inspection and pulling on shock cord	Recovery Lead:
6.16	Confirm the drogue parachute is properly folded	Recovery Lead:



6.17	Firmly grasp the drogue parachute and remove the rubber band securing the drogue parachute	✓
6.18	Confirm all rubber bands are removed from drogue parachute and shroud lines	✓
6.19	Wrap the nomex cloth around the drogue parachute, like a burrito, continuing to firmly grasp the parachute	✓
6.20	Carefully insert the shock cord between **Loops 1 and 2** into the fin can cavity	✓
6.21	Carefully insert the drogue parachute into the fin can cavity with the quick link facing the aft end of the fin can	✓
6.22	Carefully insert the shock cord between **Loops 2 and 3** into the fin can cavity	✓
6.23	Slide the avionics bay coupler labeled ~~5~~ 3 into the fin can, using the paint markings for alignment	✓
6.24.1	Insert a #4-40, ½-inch long nylon shear pin into each of the four shear pin holes blue	✓
6.24.2	If any shear pin is loose, place a small piece of ~~electrical~~ tape over the shear pin head. If the shear pin is still loose, place plumber's putty over the shear pin head.	✓
6.25	Hold the avionics bay and let the fin can hang free and confirm fin can holds its own weight	Recovery Lead:



7. MAIN RECOVERY ASSEMBLY

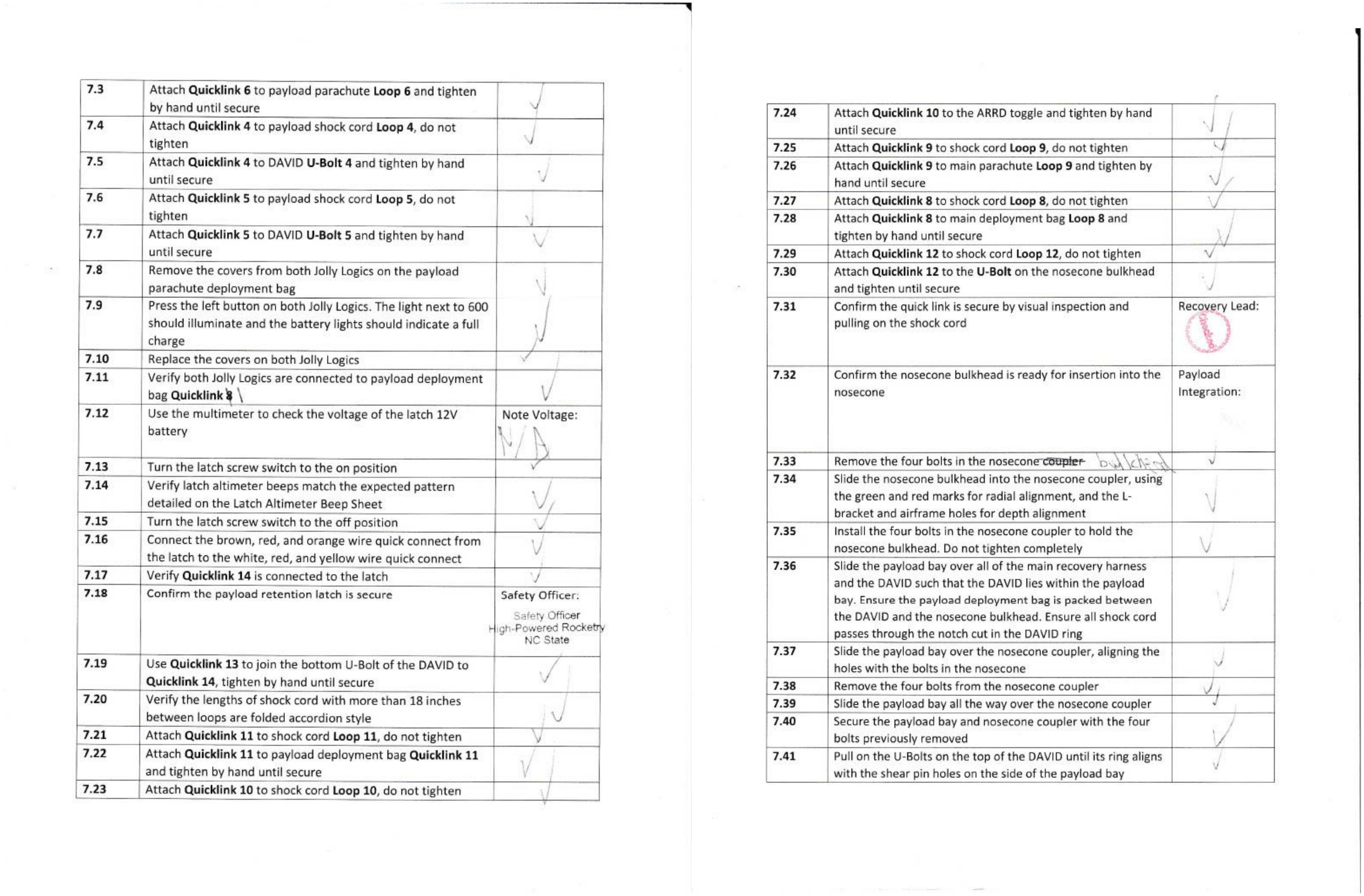
Required Personnel		Confirmation
Student Team Lead	Evan Waldron	✓
Safety Officer	Emma McDonald	✓
Recovery Lead	Robert Kempin	✓
Main Personnel 1	Myers Harbinson	✓
Main Personnel 2	Alex Thomas	✓

Switch Schedule?

Payload parachute

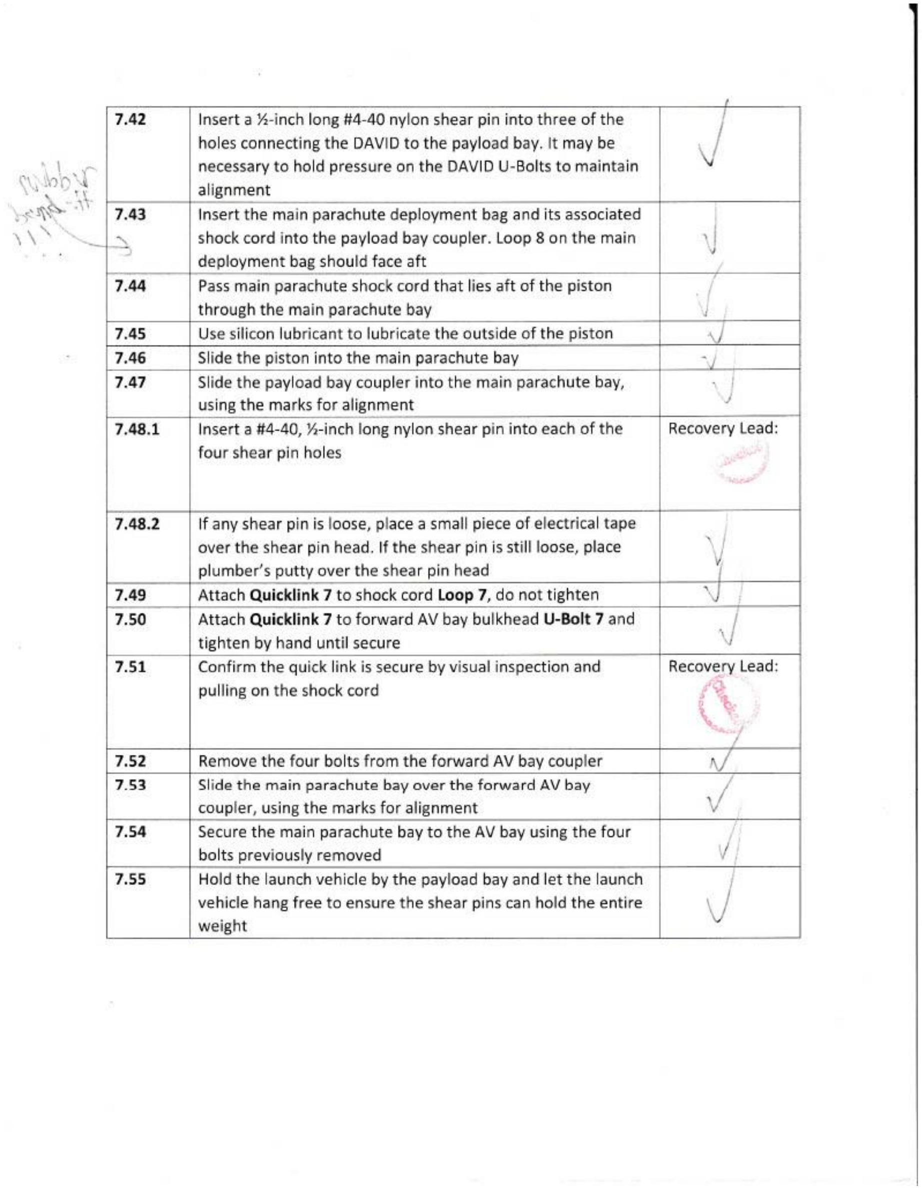
Required Materials			
Item	**Number**	**Location**	**Confirmation**
Nosecone	1	-	✓
Nosecone Bulkhead	1	-	✓
Payload Bay	1	-	✓
Main Parachute Bay	1	-	✓
Piston	1	Recovery Tupperware	✓
DAVID	1	-	✓
Fin Can Assembly	1	-	✓
Safety Glasses	5	PPE Toolbox	✓
Multimeter	1	LD Toolbox (Top Compartment)	✓
Payload Shock Cord	1	Recovery Tupperware	✓
Main Parachute (120 in)	1	Recovery Tupperware	✓
Main Parachute Shock Cord	1	Recovery Tupperware	✓
Quicklink (#4-11)	8	Recovery Hardware Box	✓
Shear Pin	4	Recovery Hardware Box	✓
Blue ~~Electrical~~ Tape	1	AV HDX Box	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Silicon Lubricant	1	Field Recovery Toolbox	✓

Number	Task	Completion
7.1	Confirm that all members within the assembly tent are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
7.2	Attach **Quicklink 6** to payload shock cord **Loop 6**, do not tighten	✓



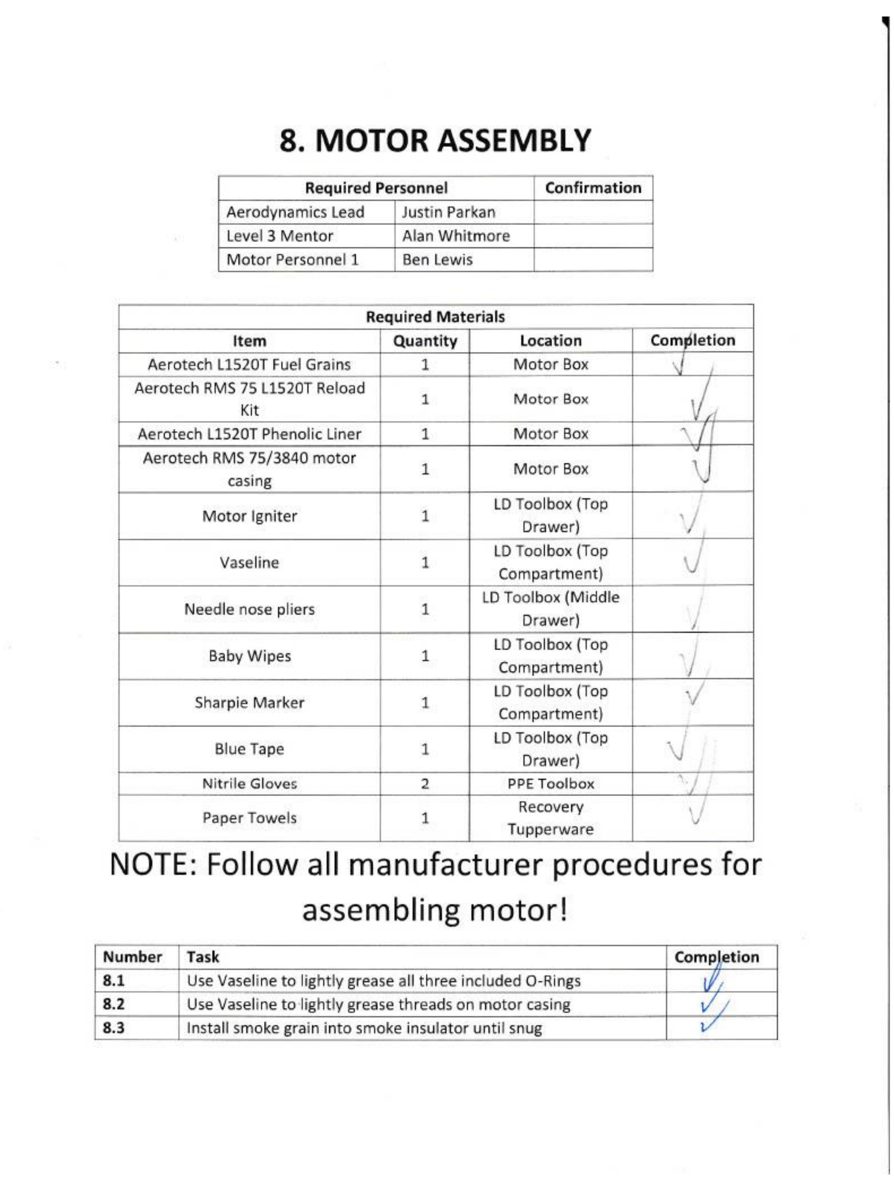
7.3	Attach **Quicklink 6** to payload parachute **Loop 6** and tighten by hand until secure	✓
7.4	Attach **Quicklink 4** to payload shock cord **Loop 4**, do not tighten	✓
7.5	Attach **Quicklink 4** to DAVID **U-Bolt 4** and tighten by hand until secure	✓
7.6	Attach **Quicklink 5** to payload shock cord **Loop 5**, do not tighten	✓
7.7	Attach **Quicklink 5** to DAVID **U-Bolt 5** and tighten by hand until secure	✓
7.8	Remove the covers from both Jolly Logics on the payload parachute deployment bag	✓
7.9	Press the left button on both Jolly Logics. The light next to 600 should illuminate and the battery lights should indicate a full charge	✓
7.10	Replace the covers on both Jolly Logics	✓
7.11	Verify both Jolly Logics are connected to payload deployment bag **Quicklink 8**	✓
7.12	Use the multimeter to check the voltage of the latch 12V battery	Note Voltage: N/A
7.13	Turn the latch screw switch to the on position	✓
7.14	Verify latch altimeter beeps match the expected pattern detailed on the Latch Altimeter Beep Sheet	✓
7.15	Turn the latch screw switch to the off position	✓
7.16	Connect the brown, red, and orange wire quick connect from the latch to the white, red, and yellow wire quick connect	✓
7.17	Verify **Quicklink 14** is connected to the latch	✓
7.18	Confirm the payload retention latch is secure	Safety Officer: Safety Officer High-Powered Rocketry NC State
7.19	Use **Quicklink 13** to join the bottom U-Bolt of the DAVID to **Quicklink 14**, tighten by hand until secure	✓
7.20	Verify the lengths of shock cord with more than 18 inches between loops are folded accordion style	✓
7.21	Attach **Quicklink 11** to shock cord **Loop 11**, do not tighten	✓
7.22	Attach **Quicklink 11** to payload deployment bag **Quicklink 11** and tighten by hand until secure	✓
7.23	Attach **Quicklink 10** to shock cord **Loop 10**, do not tighten	✓

7.24	Attach **Quicklink 10** to the ARRD toggle and tighten by hand until secure	✓
7.25	Attach **Quicklink 9** to shock cord **Loop 9**, do not tighten	✓
7.26	Attach **Quicklink 9** to main parachute **Loop 9** and tighten by hand until secure	✓
7.27	Attach **Quicklink 8** to shock cord **Loop 8**, do not tighten	✓
7.28	Attach **Quicklink 8** to main deployment bag **Loop 8** and tighten by hand until secure	✓
7.29	Attach **Quicklink 12** to shock cord **Loop 12**, do not tighten	✓
7.30	Attach **Quicklink 12** to the **U-Bolt** on the nosecone bulkhead and tighten until secure	✓
7.31	Confirm the quick link is secure by visual inspection and pulling on the shock cord	Recovery Lead:
7.32	Confirm the nosecone bulkhead is ready for insertion into the nosecone	Payload Integration:
7.33	Remove the four bolts in the nosecone ~~coupler~~ bulkhead	✓
7.34	Slide the nosecone bulkhead into the nosecone coupler, using the green and red marks for radial alignment, and the L-bracket and airframe holes for depth alignment	✓
7.35	Install the four bolts in the nosecone coupler to hold the nosecone bulkhead. Do not tighten completely	✓
7.36	Slide the payload bay over all of the main recovery harness and the DAVID such that the DAVID lies within the payload bay. Ensure the payload deployment bag is packed between the DAVID and the nosecone bulkhead. Ensure all shock cord passes through the notch cut in the DAVID ring	✓
7.37	Slide the payload bay over the nosecone coupler, aligning the holes with the bolts in the nosecone	✓
7.38	Remove the four bolts from the nosecone coupler	✓
7.39	Slide the payload bay all the way over the nosecone coupler	✓
7.40	Secure the payload bay and nosecone coupler with the four bolts previously removed	✓
7.41	Pull on the U-Bolts on the top of the DAVID until its ring aligns with the shear pin holes on the side of the payload bay	✓



rubber band it !!!

7.42	Insert a ½-inch long #4-40 nylon shear pin into three of the holes connecting the DAVID to the payload bay. It may be necessary to hold pressure on the DAVID U-Bolts to maintain alignment	✓
7.43	Insert the main parachute deployment bag and its associated shock cord into the payload bay coupler. Loop 8 on the main deployment bag should face aft	✓
7.44	Pass main parachute shock cord that lies aft of the piston through the main parachute bay	✓
7.45	Use silicon lubricant to lubricate the outside of the piston	✓
7.46	Slide the piston into the main parachute bay	✓
7.47	Slide the payload bay coupler into the main parachute bay, using the marks for alignment	✓
7.48.1	Insert a #4-40, ½-inch long nylon shear pin into each of the four shear pin holes	Recovery Lead:
7.48.2	If any shear pin is loose, place a small piece of electrical tape over the shear pin head. If the shear pin is still loose, place plumber's putty over the shear pin head	✓
7.49	Attach **Quicklink 7** to shock cord **Loop 7**, do not tighten	✓
7.50	Attach **Quicklink 7** to forward AV bay bulkhead **U-Bolt 7** and tighten by hand until secure	✓
7.51	Confirm the quick link is secure by visual inspection and pulling on the shock cord	Recovery Lead:
7.52	Remove the four bolts from the forward AV bay coupler	✓
7.53	Slide the main parachute bay over the forward AV bay coupler, using the marks for alignment	✓
7.54	Secure the main parachute bay to the AV bay using the four bolts previously removed	✓
7.55	Hold the launch vehicle by the payload bay and let the launch vehicle hang free to ensure the shear pins can hold the entire weight	✓



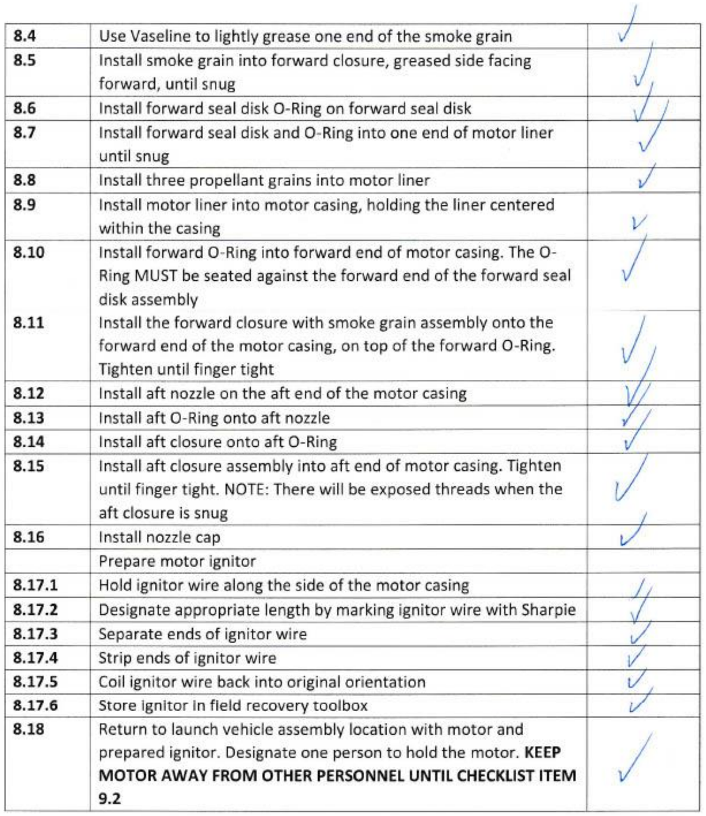
8. MOTOR ASSEMBLY

Required Personnel		Confirmation
Aerodynamics Lead	Justin Parkan	
Level 3 Mentor	Alan Whitmore	
Motor Personnel 1	Ben Lewis	

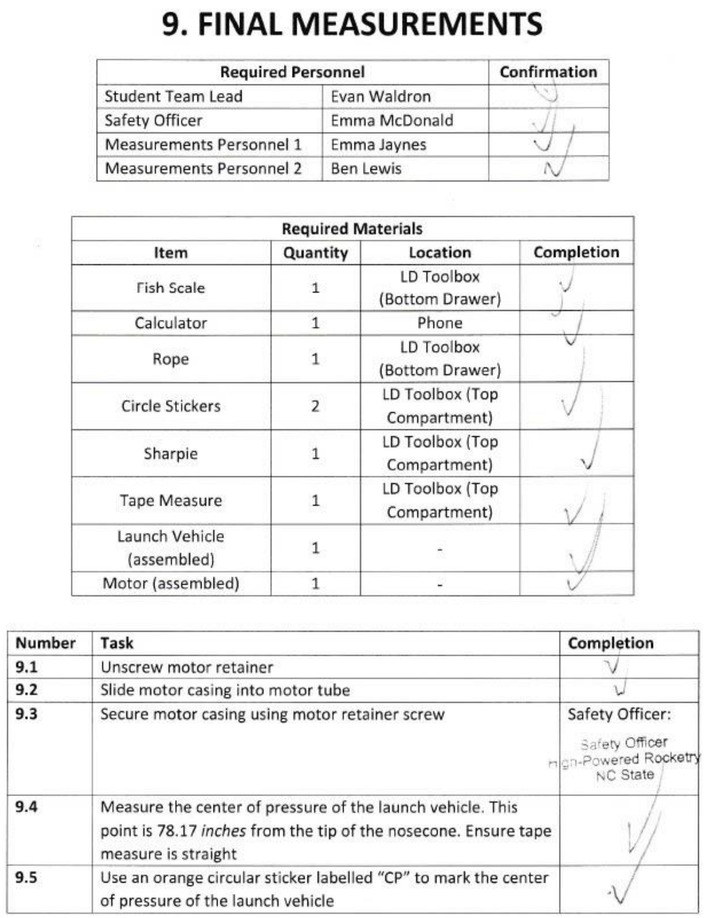
Required Materials			
Item	**Quantity**	**Location**	**Completion**
Aerotech L1520T Fuel Grains	1	Motor Box	✓
Aerotech RMS 75 L1520T Reload Kit	1	Motor Box	✓
Aerotech L1520T Phenolic Liner	1	Motor Box	✓
Aerotech RMS 75/3840 motor casing	1	Motor Box	✓
Motor Igniter	1	LD Toolbox (Top Drawer)	✓
Vaseline	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 Tupperware	✓

NOTE: Follow all manufacturer procedures for assembling motor!

Number	Task	Completion
8.1	Use Vaseline to lightly grease all three included O-Rings	✓
8.2	Use Vaseline to lightly grease threads on motor casing	✓
8.3	Install smoke grain into smoke insulator until snug	✓



8.4	Use Vaseline to lightly grease one end of the smoke grain	✓
8.5	Install smoke grain into forward closure, greased side facing forward, until snug	✓
8.6	Install forward seal disk O-Ring on forward seal disk	✓
8.7	Install forward seal disk and O-Ring into one end of motor liner until snug	✓
8.8	Install three propellant grains into motor liner	✓
8.9	Install motor liner into motor casing, holding the liner centered within the casing	✓
8.10	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	✓
8.11	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	✓
8.12	Install aft nozzle on the aft end of the motor casing	✓
8.13	Install aft O-Ring onto aft nozzle	✓
8.14	Install aft closure onto aft O-Ring	✓
8.15	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	✓
8.16	Install nozzle cap	✓
	Prepare motor ignitor	
8.17.1	Hold ignitor wire along the side of the motor casing	✓
8.17.2	Designate appropriate length by marking ignitor wire with Sharpie	✓
8.17.3	Separate ends of ignitor wire	✓
8.17.4	Strip ends of ignitor wire	✓
8.17.5	Coil ignitor wire back into original orientation	✓
8.17.6	Store ignitor in field recovery toolbox	✓
8.18	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**	✓

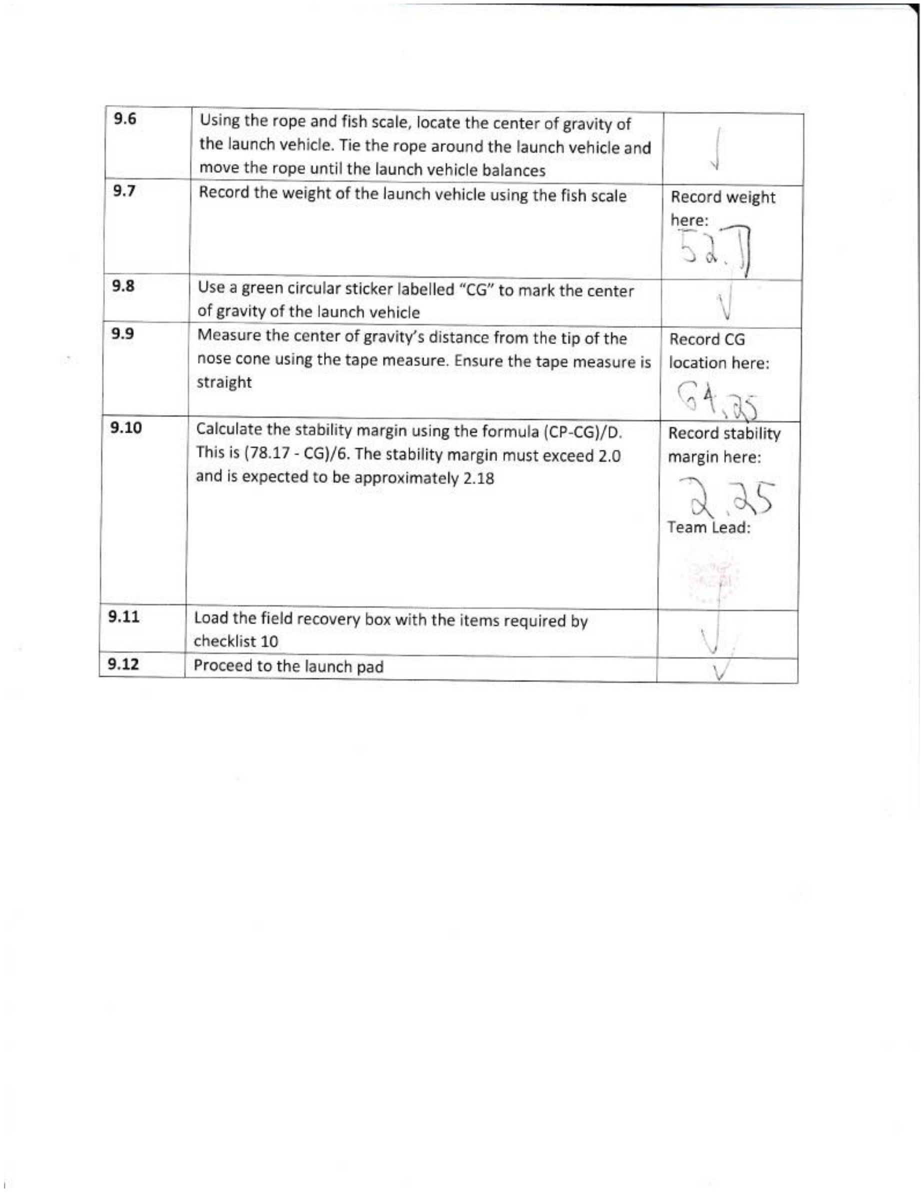


9. FINAL MEASUREMENTS

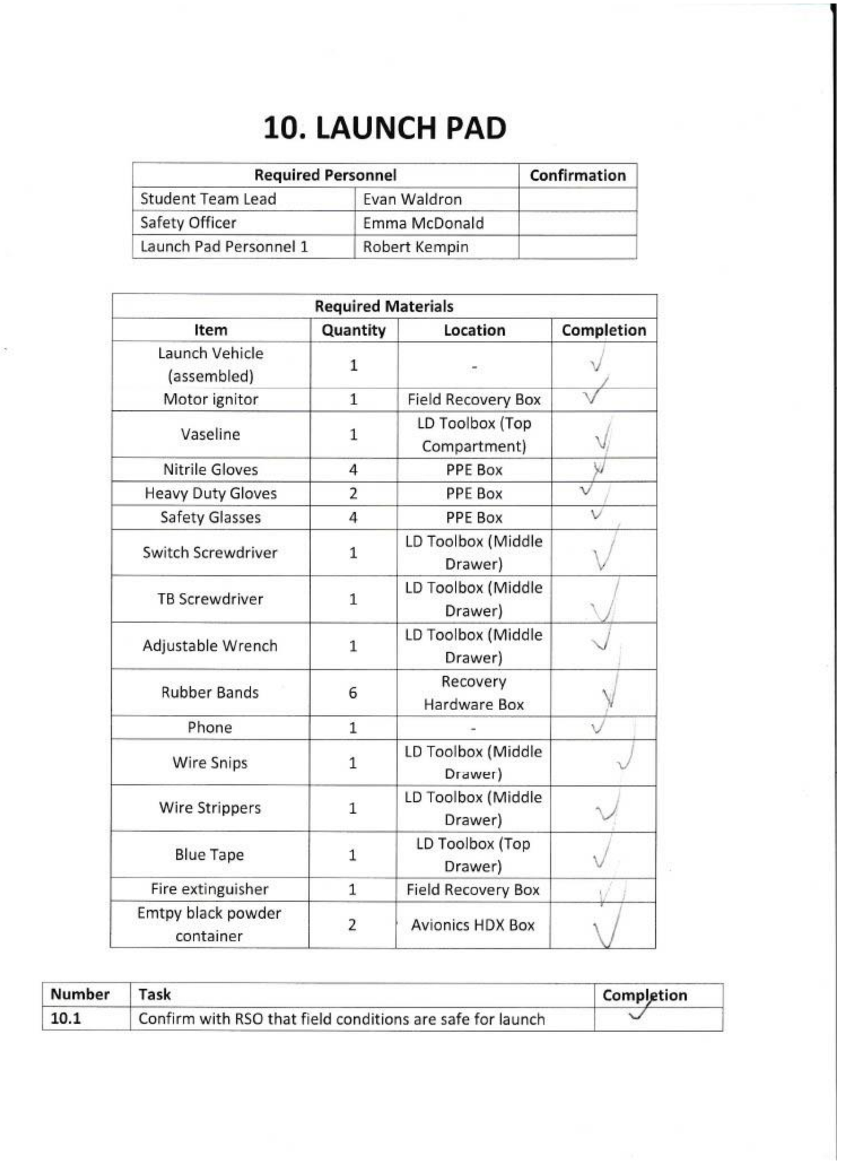
Required Personnel		**Confirmation**
Student Team Lead	Evan Waldron	✓
Safety Officer	Emma McDonald	✓
Measurements Personnel 1	Emma Jaynes	✓
Measurements Personnel 2	Ben Lewis	✓

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)	✓
Tape Measure	1	LD Toolbox (Top Compartment)	✓
Launch Vehicle (assembled)	1	-	✓
Motor (assembled)	1	-	✓

Number	**Task**	**Completion**
9.1	Unscrew motor retainer	✓
9.2	Slide motor casing into motor tube	✓
9.3	Secure motor casing using motor retainer screw	Safety Officer: Safety Officer High-Powered Rocketry NC State
9.4	Measure the center of pressure of the launch vehicle. This point is 78.17 *inches* from the tip of the nosecone. Ensure tape measure is straight	✓
9.5	Use an orange circular sticker labelled "CP" to mark the center of pressure of the launch vehicle	✓



9.6	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	✓
9.7	Record the weight of the launch vehicle using the fish scale	Record weight here: 52.7
9.8	Use a green circular sticker labelled "CG" to mark the center of gravity of the launch vehicle	✓
9.9	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: 64.25
9.10	Calculate the stability margin using the formula (CP-CG)/D. This is (78.17 - CG)/6. The stability margin must exceed 2.0 and is expected to be approximately 2.18	Record stability margin here: 2.25 Team Lead:
9.11	Load the field recovery box with the items required by checklist 10	✓
9.12	Proceed to the launch pad	✓

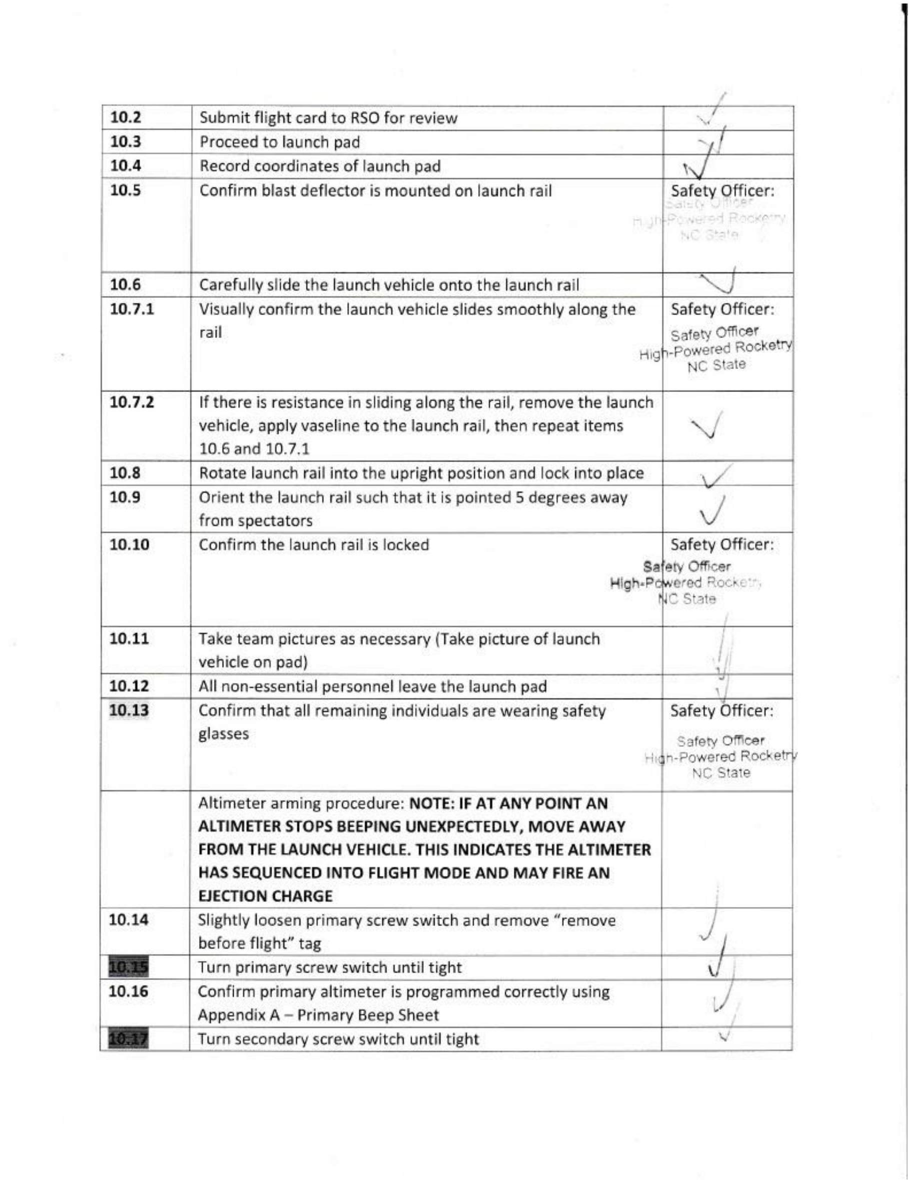


10. LAUNCH PAD

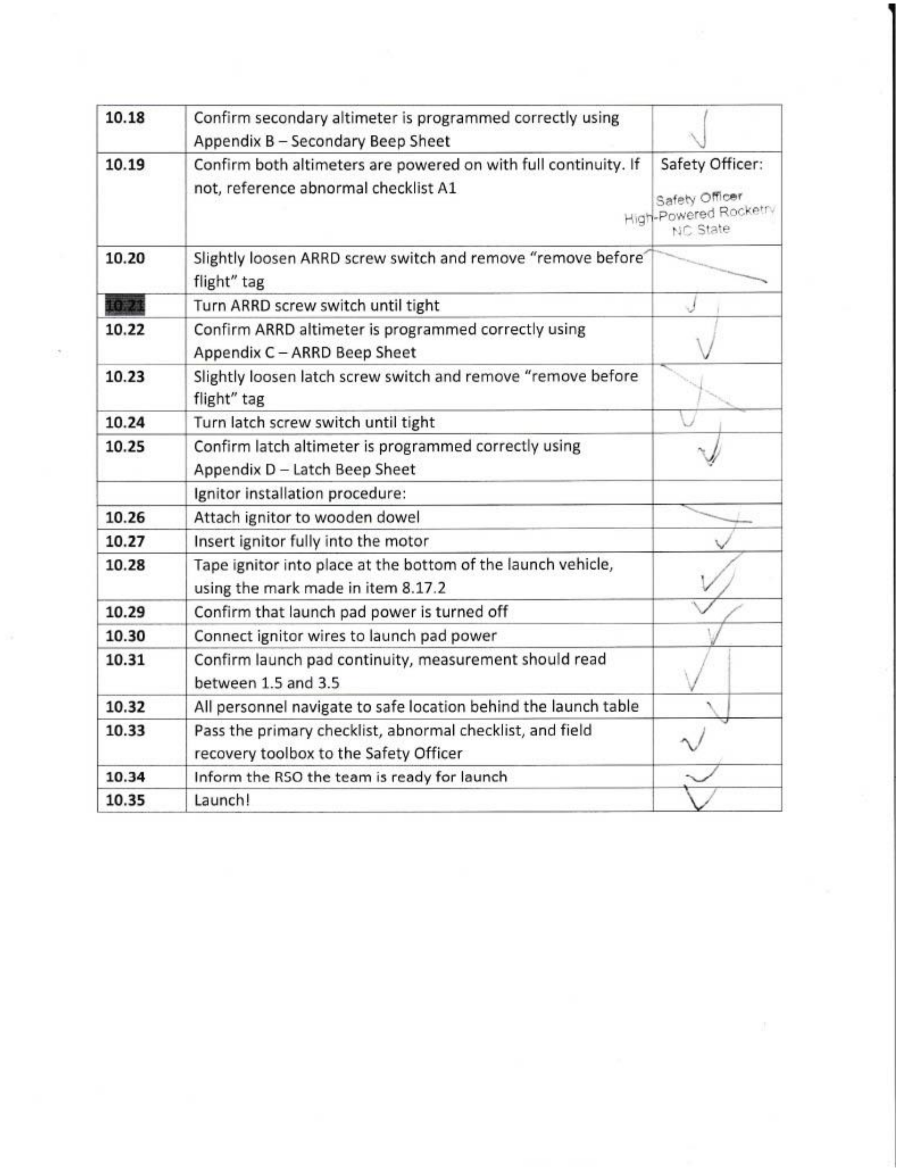
Required Personnel		Confirmation
Student Team Lead	Evan Waldron	
Safety Officer	Emma McDonald	
Launch Pad Personnel 1	Robert Kempin	

Required Materials			
Item	Quantity	Location	Completion
Launch Vehicle (assembled)	1	-	✓
Motor ignitor	1	Field Recovery Box	✓
Vaseline	1	LD Toolbox (Top Compartment)	✓
Nitrile Gloves	4	PPE Box	✓
Heavy Duty Gloves	2	PPE Box	✓
Safety Glasses	4	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	-	✓
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	✓
Emtpy black powder container	2	Avionics HDX Box	✓

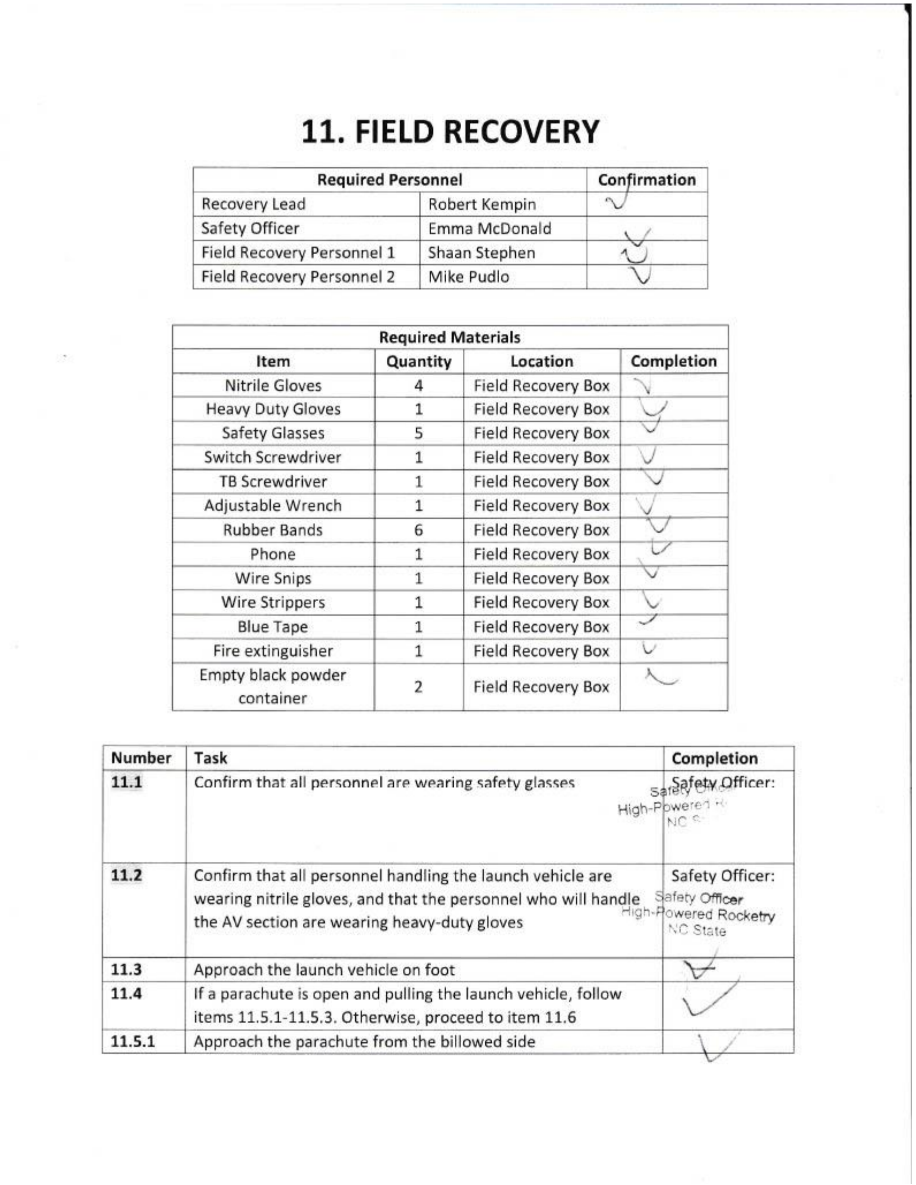
Number	Task	Completion
10.1	Confirm with RSO that field conditions are safe for launch	✓



10.2	Submit flight card to RSO for review	✓
10.3	Proceed to launch pad	✓
10.4	Record coordinates of launch pad	✓
10.5	Confirm blast deflector is mounted on launch rail	Safety Officer: Safety Officer High-Powered Rocketry NC State
10.6	Carefully slide the launch vehicle onto the launch rail	✓
10.7.1	Visually confirm the launch vehicle slides smoothly along the rail	Safety Officer: Safety Officer High-Powered Rocketry NC State
10.7.2	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	✓
10.8	Rotate launch rail into the upright position and lock into place	✓
10.9	Orient the launch rail such that it is pointed 5 degrees away from spectators	✓
10.10	Confirm the launch rail is locked	Safety Officer: Safety Officer High-Powered Rocketry NC State
10.11	Take team pictures as necessary (Take picture of launch vehicle on pad)	✓
10.12	All non-essential personnel leave the launch pad	✓
10.13	Confirm that all remaining individuals are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
	Altimeter arming procedure: **NOTE: IF AT ANY POINT AN ALTIMETER STOPS BEEPING UNEXPECTEDLY, MOVE AWAY FROM THE LAUNCH VEHICLE. THIS INDICATES THE ALTIMETER HAS SEQUENCED INTO FLIGHT MODE AND MAY FIRE AN EJECTION CHARGE**	
10.14	Slightly loosen primary screw switch and remove "remove before flight" tag	✓
10.15	Turn primary screw switch until tight	✓
10.16	Confirm primary altimeter is programmed correctly using Appendix A – Primary Beep Sheet	✓
10.17	Turn secondary screw switch until tight	✓



10.18	Confirm secondary altimeter is programmed correctly using Appendix B – Secondary Beep Sheet	✓
10.19	Confirm both altimeters are powered on with full continuity. If not, reference abnormal checklist A1	Safety Officer: Safety Officer High-Powered Rocketry NC State
10.20	Slightly loosen ARRD screw switch and remove "remove before flight" tag	—
10.21	Turn ARRD screw switch until tight	✓
10.22	Confirm ARRD altimeter is programmed correctly using Appendix C – ARRD Beep Sheet	✓
10.23	Slightly loosen latch screw switch and remove "remove before flight" tag	✓
10.24	Turn latch screw switch until tight	✓
10.25	Confirm latch altimeter is programmed correctly using Appendix D – Latch Beep Sheet	✓
	Ignitor installation procedure:	
10.26	Attach ignitor to wooden dowel	—
10.27	Insert ignitor fully into the motor	✓
10.28	Tape ignitor into place at the bottom of the launch vehicle, using the mark made in item 8.17.2	✓
10.29	Confirm that launch pad power is turned off	✓
10.30	Connect ignitor wires to launch pad power	✓
10.31	Confirm launch pad continuity, measurement should read between 1.5 and 3.5	✓
10.32	All personnel navigate to safe location behind the launch table	✓
10.33	Pass the primary checklist, abnormal checklist, and field recovery toolbox to the Safety Officer	✓
10.34	Inform the RSO the team is ready for launch	✓
10.35	Launch!	✓

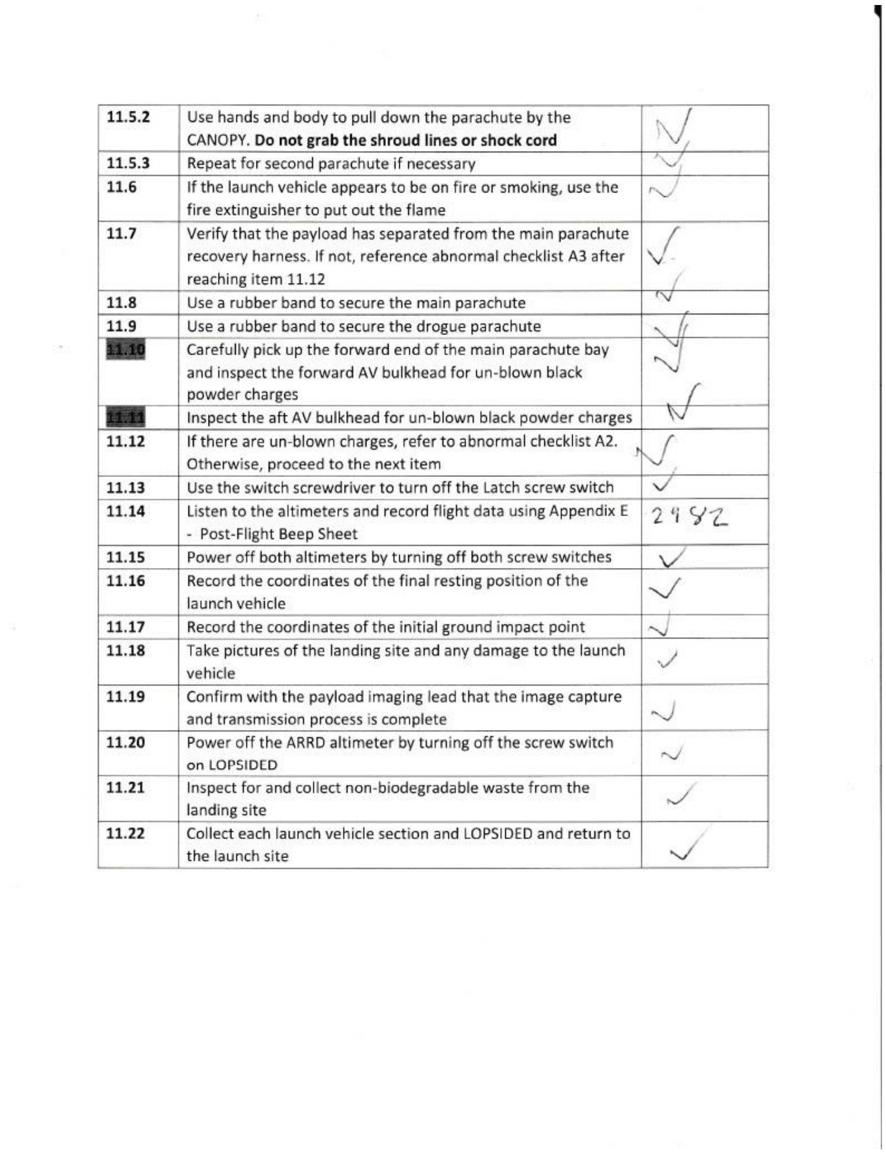


11. FIELD RECOVERY

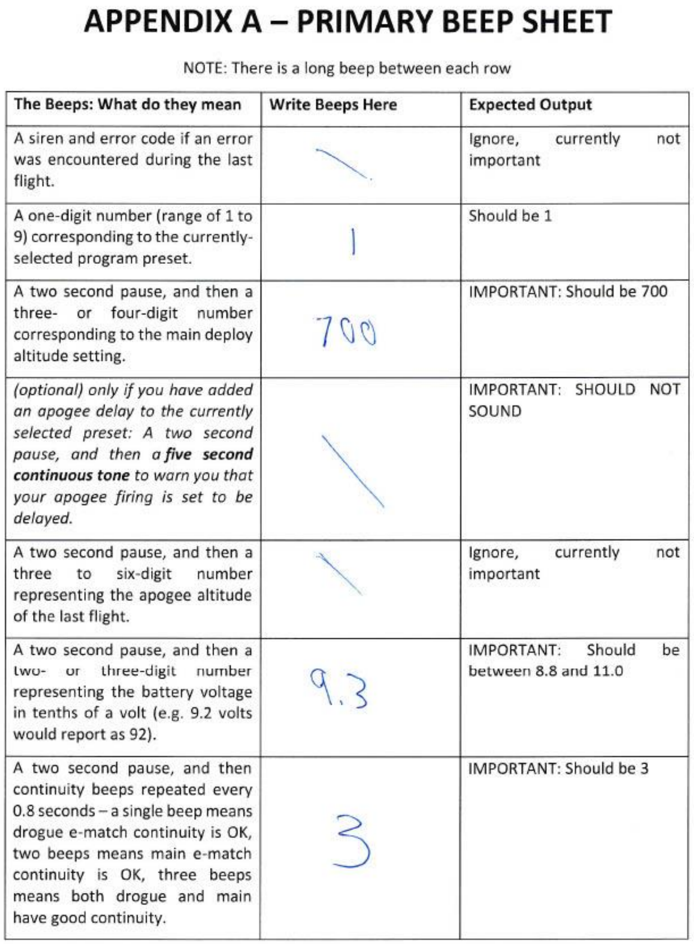
Required Personnel		Confirmation
Recovery Lead	Robert Kempin	✓
Safety Officer	Emma McDonald	✓
Field Recovery Personnel 1	Shaan Stephen	✓
Field Recovery Personnel 2	Mike Pudlo	✓

Required Materials			
Item	Quantity	Location	Completion
Nitrile Gloves	4	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	✓
Empty black powder container	2	Field Recovery Box	✓

Number	Task	Completion
11.1	Confirm that all personnel are wearing safety glasses	Safety Officer: Safety Officer High-Powered Rocketry NC State
11.2	Confirm that all personnel handling the launch vehicle are wearing nitrile gloves, and that the personnel who will handle the AV section are wearing heavy-duty gloves	Safety Officer: Safety Officer High-Powered Rocketry NC State
11.3	Approach the launch vehicle on foot	✓
11.4	If a parachute is open and pulling the launch vehicle, follow items 11.5.1-11.5.3. Otherwise, proceed to item 11.6	✓
11.5.1	Approach the parachute from the billowed side	✓



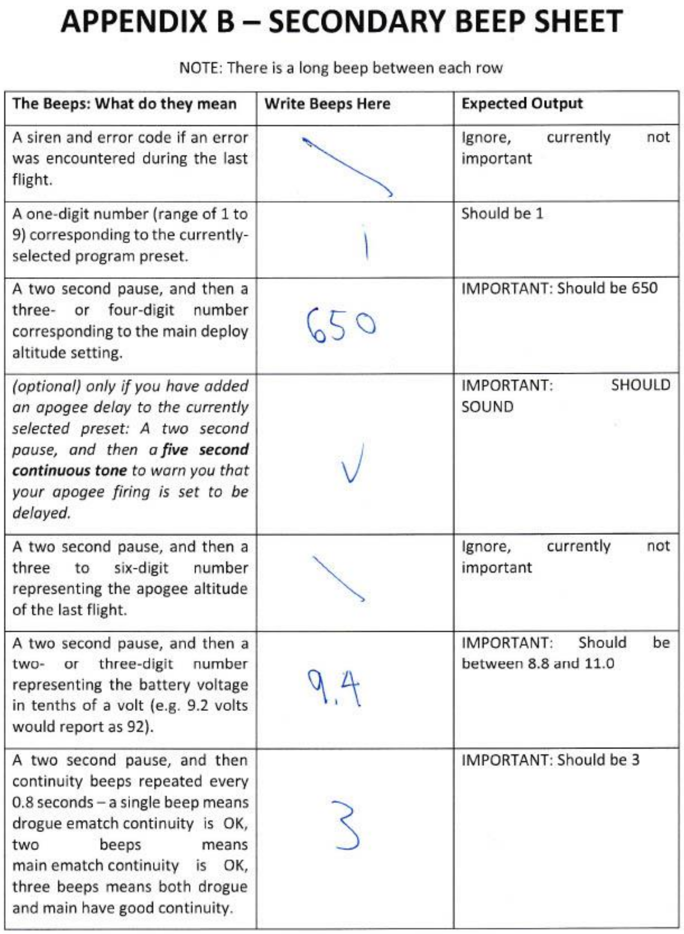
11.5.2	Use hands and body to pull down the parachute by the CANOPY. **Do not grab the shroud lines or shock cord**	✓
11.5.3	Repeat for second parachute if necessary	✓
11.6	If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the flame	✓
11.7	Verify that the payload has separated from the main parachute recovery harness. If not, reference abnormal checklist A3 after reaching item 11.12	✓
11.8	Use a rubber band to secure the main parachute	✓
11.9	Use a rubber band to secure the drogue parachute	✓
11.10	Carefully pick up the forward end of the main parachute bay and inspect the forward AV bulkhead for un-blown black powder charges	✓
11.11	Inspect the aft AV bulkhead for un-blown black powder charges	✓
11.12	If there are un-blown charges, refer to abnormal checklist A2. Otherwise, proceed to the next item	✓
11.13	Use the switch screwdriver to turn off the Latch screw switch	✓
11.14	Listen to the altimeters and record flight data using Appendix E - Post-Flight Beep Sheet	2982
11.15	Power off both altimeters by turning off both screw switches	✓
11.16	Record the coordinates of the final resting position of the launch vehicle	✓
11.17	Record the coordinates of the initial ground impact point	✓
11.18	Take pictures of the landing site and any damage to the launch vehicle	✓
11.19	Confirm with the payload imaging lead that the image capture and transmission process is complete	✓
11.20	Power off the ARRD altimeter by turning off the screw switch on LOPSIDED	✓
11.21	Inspect for and collect non-biodegradable waste from the landing site	✓
11.22	Collect each launch vehicle section and LOPSIDED and return to the launch site	✓



APPENDIX A – PRIMARY BEEP SHEET

NOTE: There is a long beep between each row

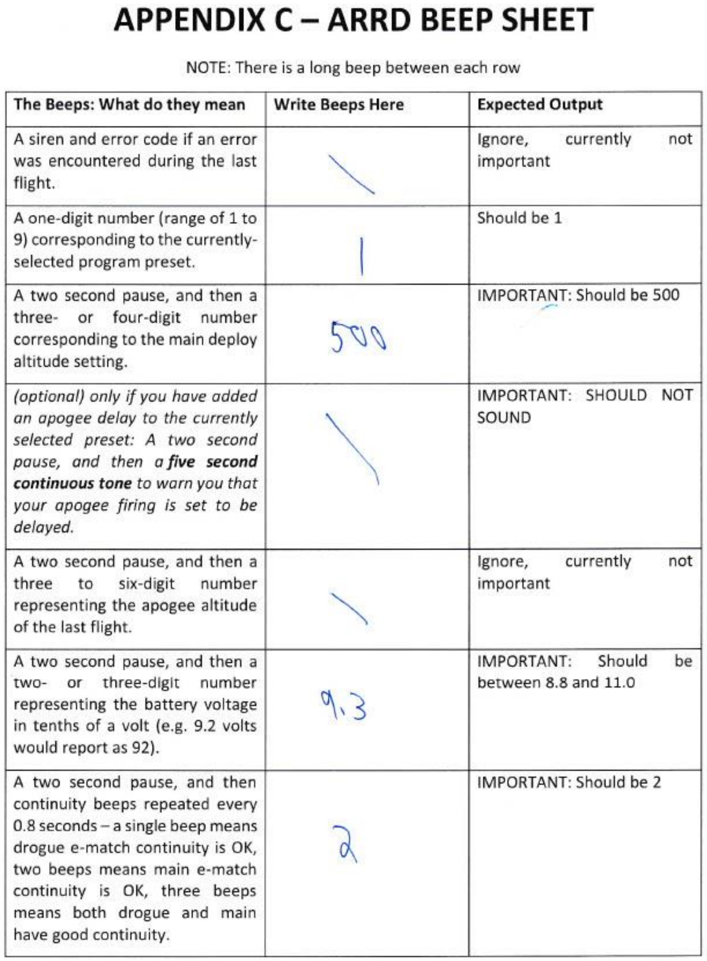
The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.	\	Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	700	IMPORTANT: Should be 700
*(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.*	\	IMPORTANT: SHOULD NOT SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.	\	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).	9.3	IMPORTANT: Should be between 8.8 and 11.0
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

NOTE: There is a long beep between each row

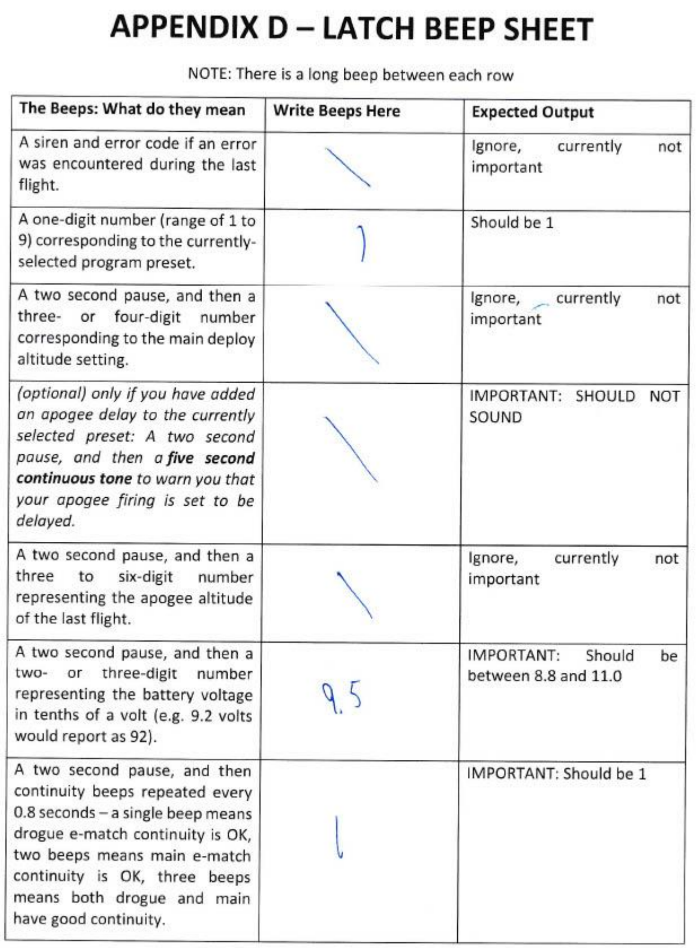
The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.	\	Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	650	IMPORTANT: Should be 650
*(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.*	✓	IMPORTANT: SHOULD SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.	\	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).	9.4	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue ematch continuity is OK, two beeps means main ematch continuity is OK, three beeps means both drogue and main have good continuity.	3	IMPORTANT: Should be 3



APPENDIX C – ARRD BEEP SHEET

NOTE: There is a long beep between each row

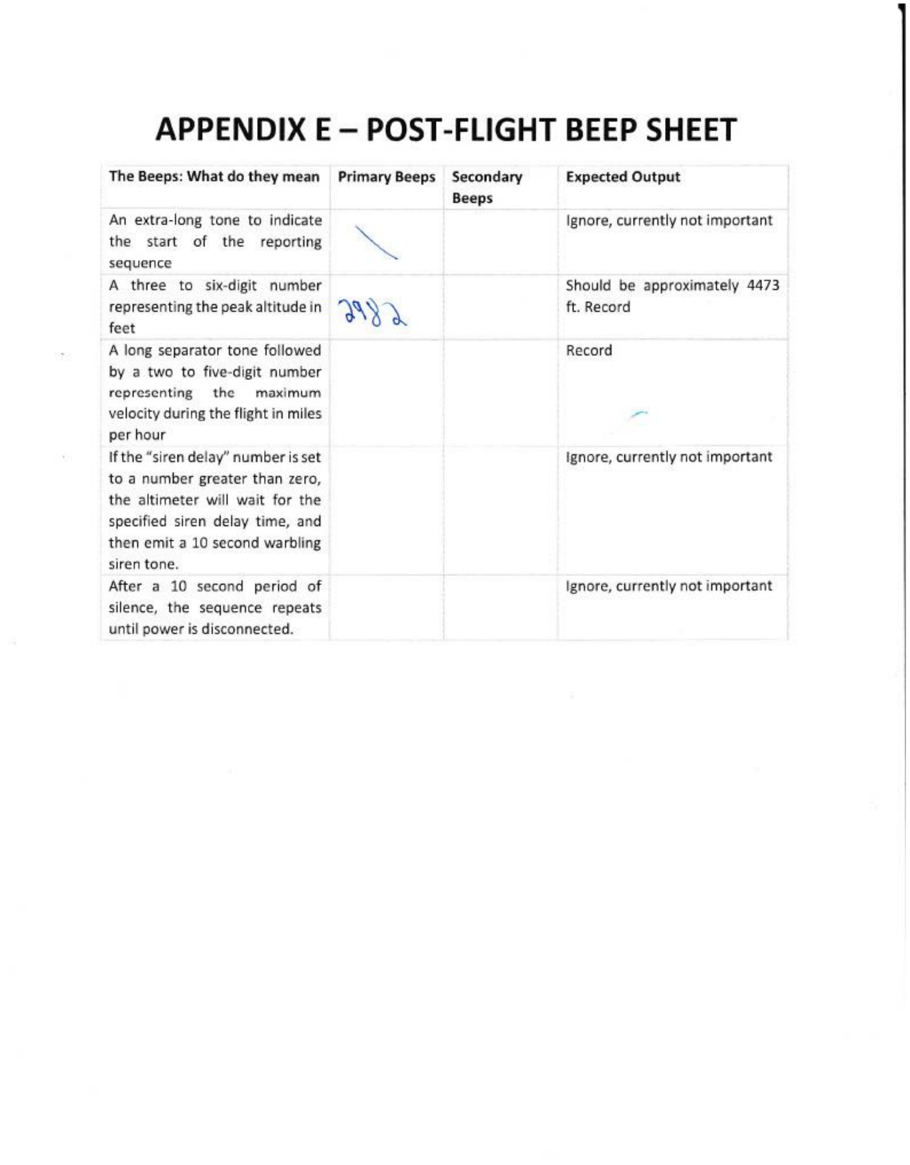
The Beeps: What do they mean	**Write Beeps Here**	**Expected Output**
A siren and error code if an error was encountered during the last flight.	\	Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	500	IMPORTANT: Should be 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.*	\	IMPORTANT: SHOULD NOT SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.	\	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).	9.3	IMPORTANT: Should be between 8.8 and 11.0
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.	2	IMPORTANT: Should be 2



APPENDIX D – LATCH BEEP SHEET

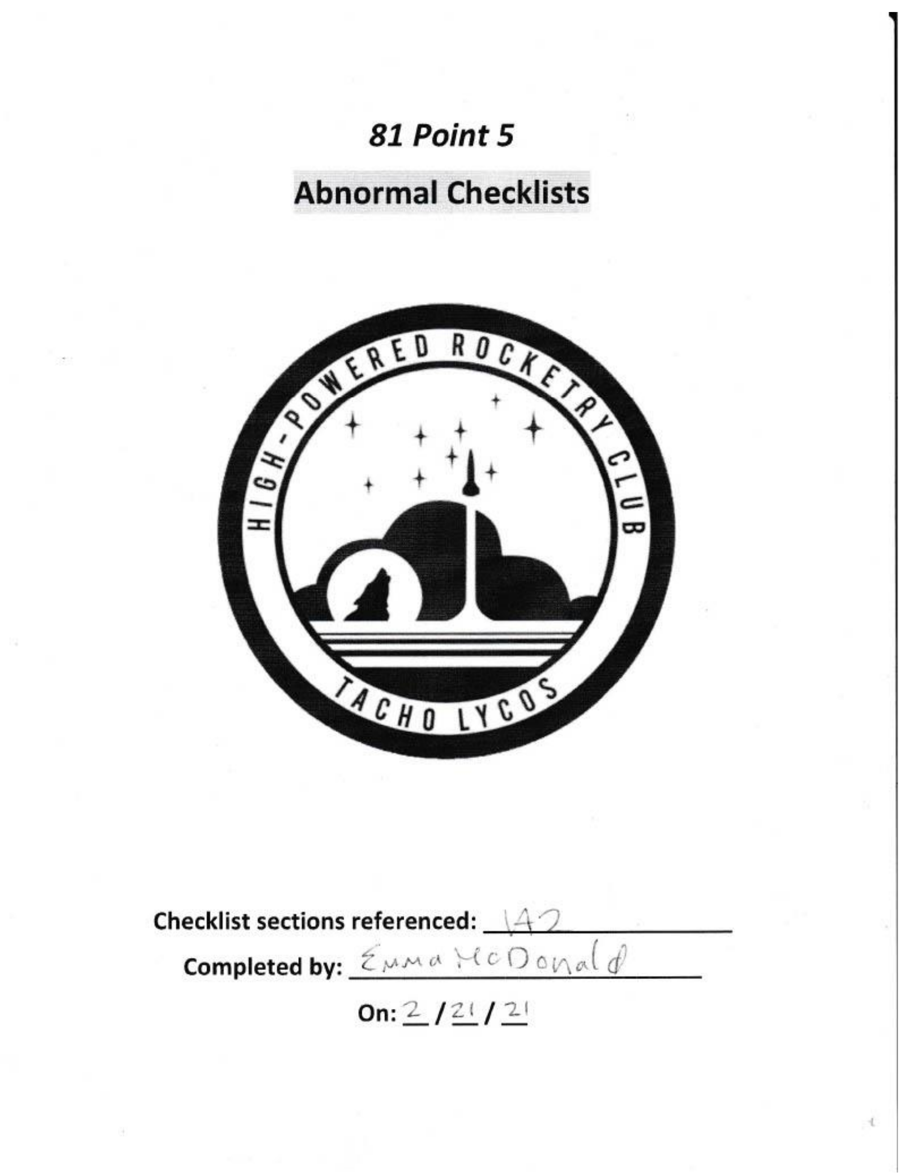
NOTE: There is a long beep between each row

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.	\	Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	\	Ignore, currently not important
(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.*	\	IMPORTANT: SHOULD NOT SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.	\	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 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.	1	IMPORTANT: Should be 1



APPENDIX E – 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	2982		Should be approximately 4473 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



81 Point 5

Abnormal Checklists

Checklist sections referenced: 142

Completed by: Emma McDonald

On: 2 / 21 / 21

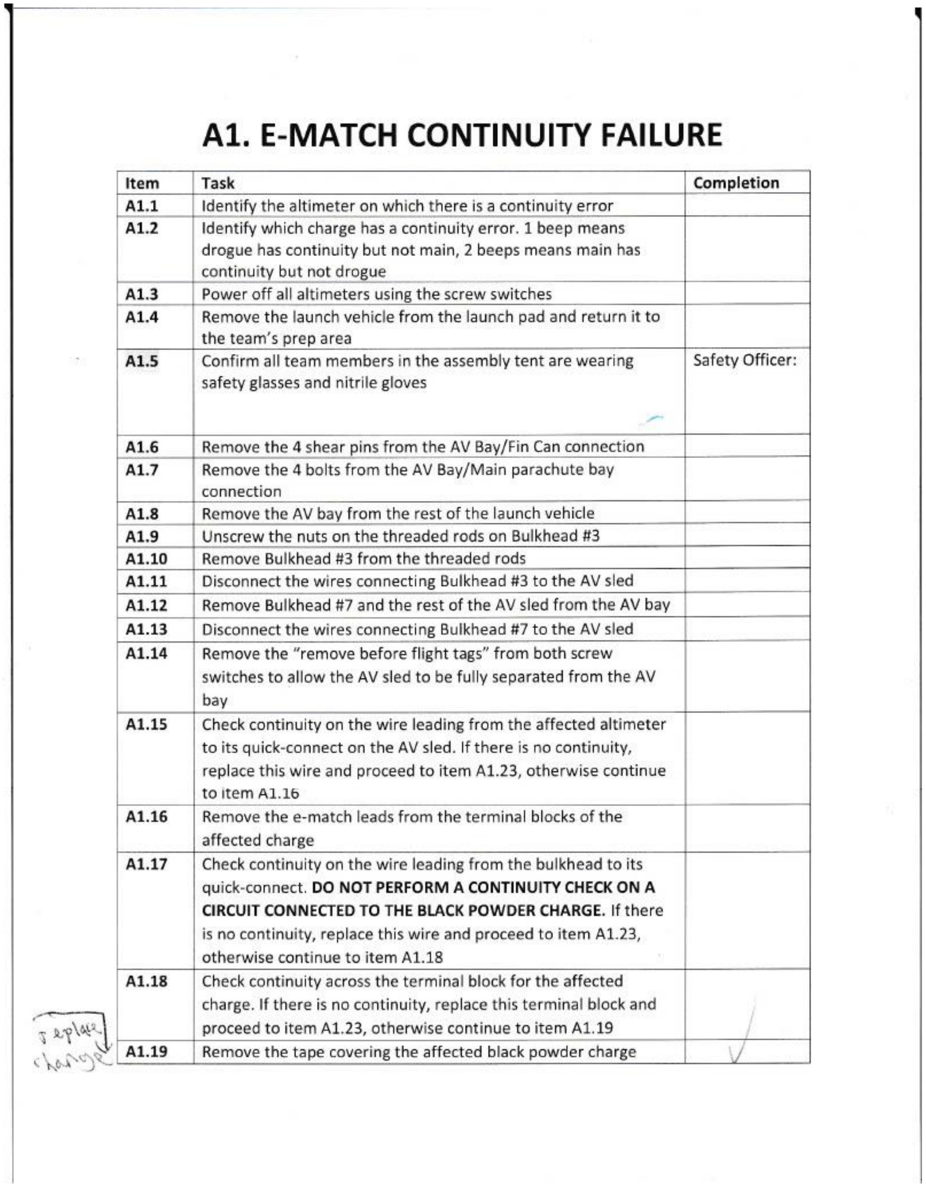
This packet contains procedures for addressing the following abnormal situations:

- **A1 – E-Match Continuity Failure**
- **A2 – Un-blown Black Powder Charge**
- **A3 – Payload Jettison Failure**
- **A4 – Altimeter Failure**
- **A5 – GPS Failure**
- **A6 – Motor Ignition Failure**

These checklists are not intended to be sequential. Only the checklist for the abnormal situation experienced should be completed. Numbering is provided for reference only. Items within each checklist, however, should be completed in numerical order unless otherwise specified by the checklist.

Deviations from these procedures are approved and encouraged if an extenuating unsafe situation exists. When in doubt, the RSO has final authority over launch day operations, and their instructions supersede these procedures.

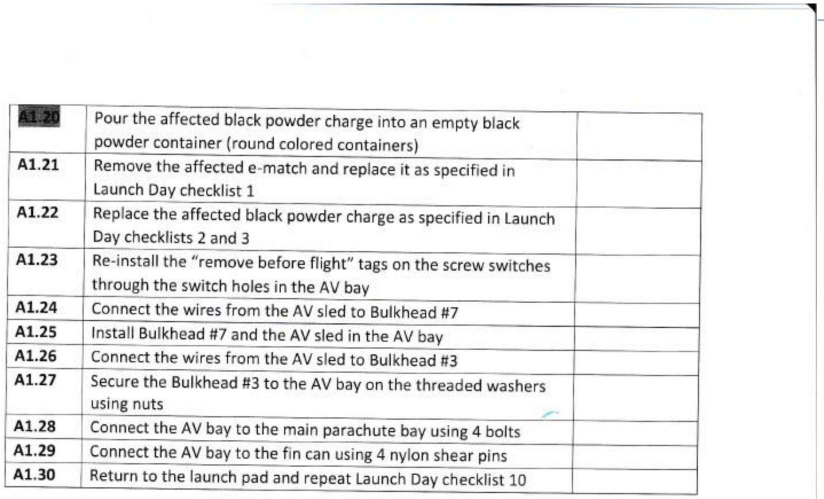
Abnormal situations not covered by these procedures shall be addressed at the RSO's discretion.



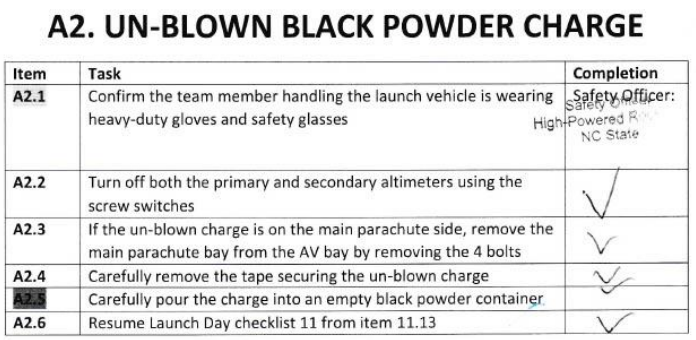
A1. E-MATCH CONTINUITY FAILURE

Item	Task	Completion
A1.1	Identify the altimeter on which there is a continuity error	
A1.2	Identify which charge has a continuity error. 1 beep means drogue has continuity but not main, 2 beeps means main has continuity but not drogue	
A1.3	Power off all altimeters using the screw switches	
A1.4	Remove the launch vehicle from the launch pad and return it to the team's prep area	
A1.5	Confirm all team members in the assembly tent are wearing safety glasses and nitrile gloves	Safety Officer:
A1.6	Remove the 4 shear pins from the AV Bay/Fin Can connection	
A1.7	Remove the 4 bolts from the AV Bay/Main parachute bay connection	
A1.8	Remove the AV bay from the rest of the launch vehicle	
A1.9	Unscrew the nuts on the threaded rods on Bulkhead #3	
A1.10	Remove Bulkhead #3 from the threaded rods	
A1.11	Disconnect the wires connecting Bulkhead #3 to the AV sled	
A1.12	Remove Bulkhead #7 and the rest of the AV sled from the AV bay	
A1.13	Disconnect the wires connecting Bulkhead #7 to the AV sled	
A1.14	Remove the "remove before flight tags" from both screw switches to allow the AV sled to be fully separated from the AV bay	
A1.15	Check continuity on the wire leading from the affected altimeter to its quick-connect on the AV sled. If there is no continuity, replace this wire and proceed to item A1.23, otherwise continue to item A1.16	
A1.16	Remove the e-match leads from the terminal blocks of the affected charge	
A1.17	Check continuity on the wire leading from the bulkhead to its quick-connect. **DO NOT PERFORM A CONTINUITY CHECK ON A CIRCUIT CONNECTED TO THE BLACK POWDER CHARGE.** If there is no continuity, replace this wire and proceed to item A1.23, otherwise continue to item A1.18	
A1.18	Check continuity across the terminal block for the affected charge. If there is no continuity, replace this terminal block and proceed to item A1.23, otherwise continue to item A1.19	
A1.19	Remove the tape covering the affected black powder charge	✓

replace charge

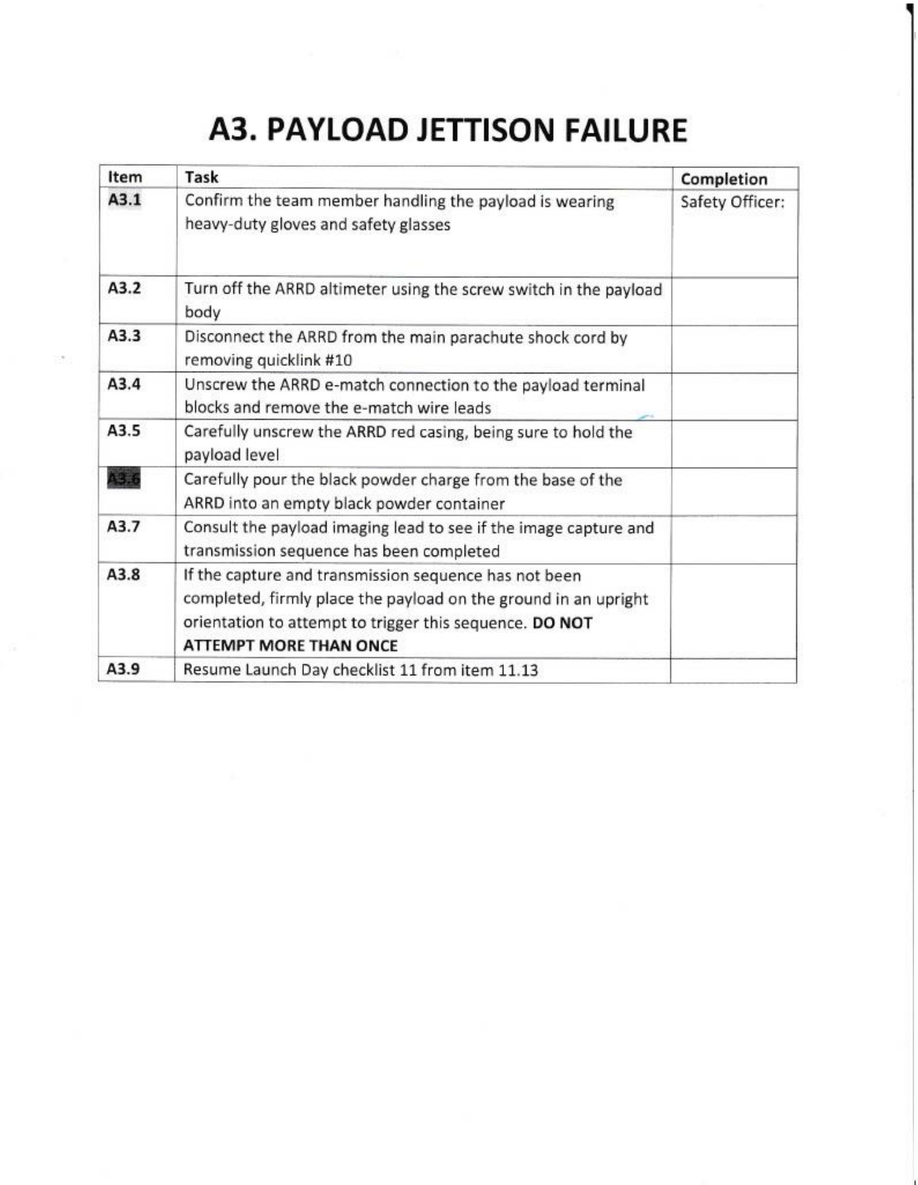


A1.20	Pour the affected black powder charge into an empty black powder container (round colored containers)	
A1.21	Remove the affected e-match and replace it as specified in Launch Day checklist 1	
A1.22	Replace the affected black powder charge as specified in Launch Day checklists 2 and 3	
A1.23	Re-install the "remove before flight" tags on the screw switches through the switch holes in the AV bay	
A1.24	Connect the wires from the AV sled to Bulkhead #7	
A1.25	Install Bulkhead #7 and the AV sled in the AV bay	
A1.26	Connect the wires from the AV sled to Bulkhead #3	
A1.27	Secure the Bulkhead #3 to the AV bay on the threaded washers using nuts	
A1.28	Connect the AV bay to the main parachute bay using 4 bolts	
A1.29	Connect the AV bay to the fin can using 4 nylon shear pins	
A1.30	Return to the launch pad and repeat Launch Day checklist 10	



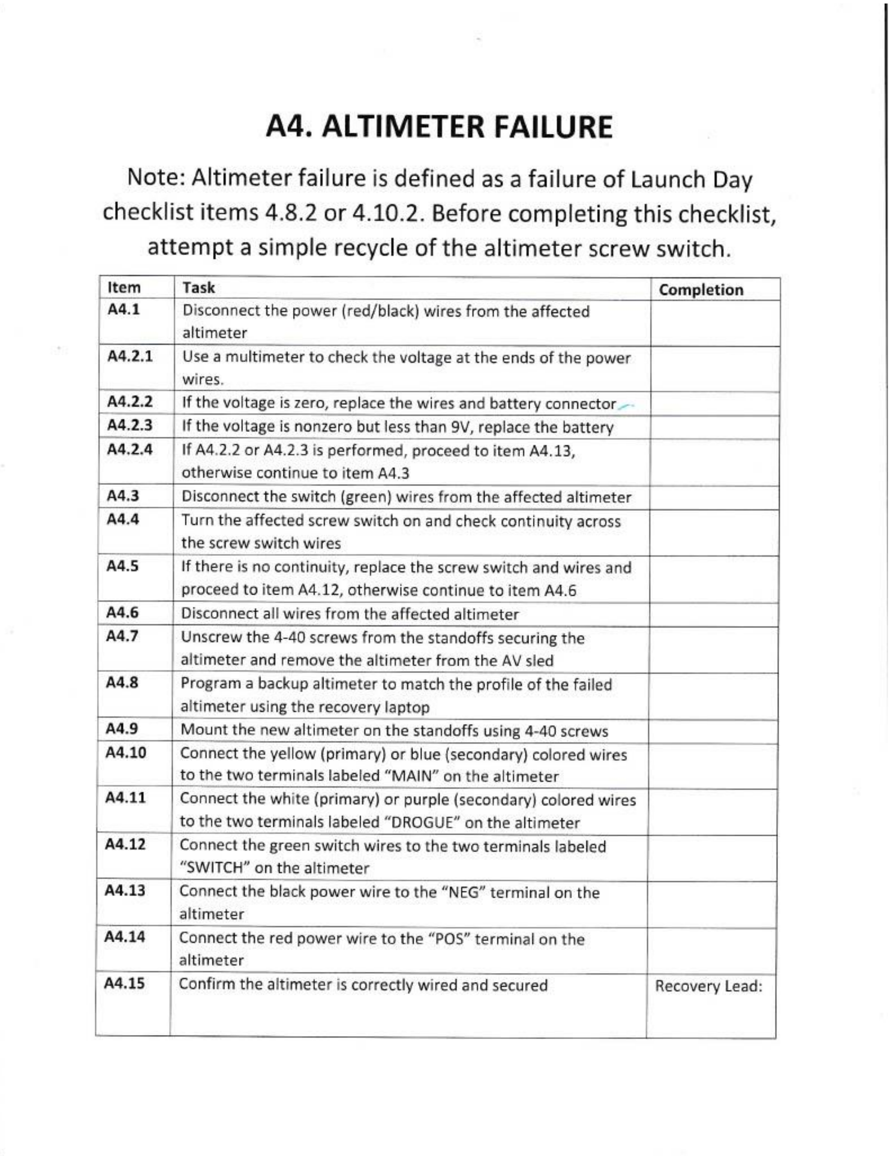
A2. UN-BLOWN BLACK POWDER CHARGE

Item	Task	Completion
A2.1	Confirm the team member handling the launch vehicle is wearing heavy-duty gloves and safety glasses	Safety Officer: Safety Officer High-Powered R NC State
A2.2	Turn off both the primary and secondary altimeters using the screw switches	✓
A2.3	If the un-blown charge is on the main parachute side, remove the main parachute bay from the AV bay by removing the 4 bolts	✓
A2.4	Carefully remove the tape securing the un-blown charge	✓
A2.5	Carefully pour the charge into an empty black powder container	✓
A2.6	Resume Launch Day checklist 11 from item 11.13	✓



A3. PAYLOAD JETTISON FAILURE

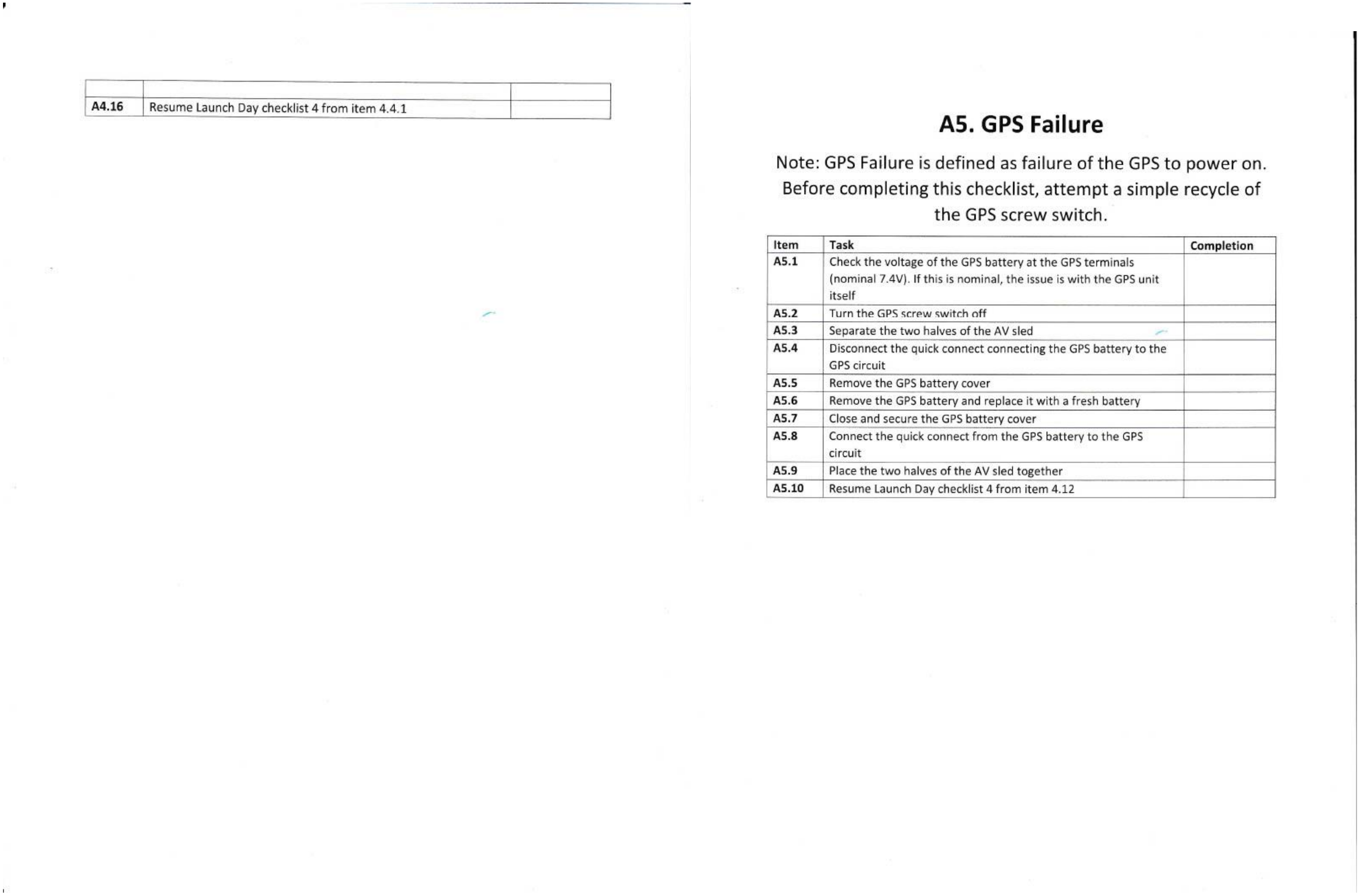
Item	Task	Completion
A3.1	Confirm the team member handling the payload is wearing heavy-duty gloves and safety glasses	Safety Officer:
A3.2	Turn off the ARRD altimeter using the screw switch in the payload body	
A3.3	Disconnect the ARRD from the main parachute shock cord by removing quicklink #10	
A3.4	Unscrew the ARRD e-match connection to the payload terminal blocks and remove the e-match wire leads	
A3.5	Carefully unscrew the ARRD red casing, being sure to hold the payload level	
A3.6	Carefully pour the black powder charge from the base of the ARRD into an empty black powder container	
A3.7	Consult the payload imaging lead to see if the image capture and transmission sequence has been completed	
A3.8	If the capture and transmission sequence has not been completed, firmly place the payload on the ground in an upright orientation to attempt to trigger this sequence. **DO NOT ATTEMPT MORE THAN ONCE**	
A3.9	Resume Launch Day checklist 11 from item 11.13	



A4. ALTIMETER FAILURE

Note: Altimeter failure is defined as a failure of Launch Day checklist items 4.8.2 or 4.10.2. Before completing this checklist, attempt a simple recycle of the altimeter screw switch.

Item	Task	Completion
A4.1	Disconnect the power (red/black) wires from the affected altimeter	
A4.2.1	Use a multimeter to check the voltage at the ends of the power wires.	
A4.2.2	If the voltage is zero, replace the wires and battery connector	
A4.2.3	If the voltage is nonzero but less than 9V, replace the battery	
A4.2.4	If A4.2.2 or A4.2.3 is performed, proceed to item A4.13, otherwise continue to item A4.3	
A4.3	Disconnect the switch (green) wires from the affected altimeter	
A4.4	Turn the affected screw switch on and check continuity across the screw switch wires	
A4.5	If there is no continuity, replace the screw switch and wires and proceed to item A4.12, otherwise continue to item A4.6	
A4.6	Disconnect all wires from the affected altimeter	
A4.7	Unscrew the 4-40 screws from the standoffs securing the altimeter and remove the altimeter from the AV sled	
A4.8	Program a backup altimeter to match the profile of the failed altimeter using the recovery laptop	
A4.9	Mount the new altimeter on the standoffs using 4-40 screws	
A4.10	Connect the yellow (primary) or blue (secondary) colored wires to the two terminals labeled "MAIN" on the altimeter	
A4.11	Connect the white (primary) or purple (secondary) colored wires to the two terminals labeled "DROGUE" on the altimeter	
A4.12	Connect the green switch wires to the two terminals labeled "SWITCH" on the altimeter	
A4.13	Connect the black power wire to the "NEG" terminal on the altimeter	
A4.14	Connect the red power wire to the "POS" terminal on the altimeter	
A4.15	Confirm the altimeter is correctly wired and secured	Recovery Lead:

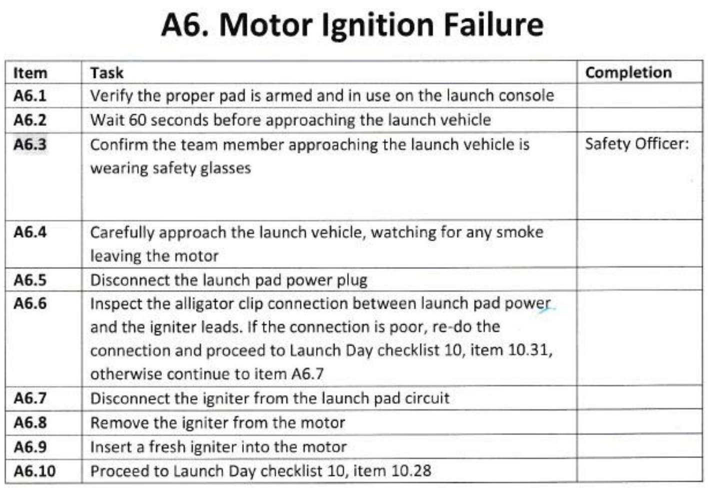


A4.16	Resume Launch Day checklist 4 from item 4.4.1	

A5. GPS Failure

Note: GPS Failure is defined as failure of the GPS to power on. Before completing this checklist, attempt a simple recycle of the GPS screw switch.

Item	**Task**	**Completion**
A5.1	Check the voltage of the GPS battery at the GPS terminals (nominal 7.4V). If this is nominal, the issue is with the GPS unit itself	
A5.2	Turn the GPS screw switch off	
A5.3	Separate the two halves of the AV sled	
A5.4	Disconnect the quick connect connecting the GPS battery to the GPS circuit	
A5.5	Remove the GPS battery cover	
A5.6	Remove the GPS battery and replace it with a fresh battery	
A5.7	Close and secure the GPS battery cover	
A5.8	Connect the quick connect from the GPS battery to the GPS circuit	
A5.9	Place the two halves of the AV sled together	
A5.10	Resume Launch Day checklist 4 from item 4.12	



A6. Motor Ignition Failure

Item	Task	Completion
A6.1	Verify the proper pad is armed and in use on the launch console	
A6.2	Wait 60 seconds before approaching the launch vehicle	
A6.3	Confirm the team member approaching the launch vehicle is wearing safety glasses	Safety Officer:
A6.4	Carefully approach the launch vehicle, watching for any smoke leaving the motor	
A6.5	Disconnect the launch pad power plug	
A6.6	Inspect the alligator clip connection between launch pad power and the igniter leads. If the connection is poor, re-do the connection and proceed to Launch Day checklist 10, item 10.31, otherwise continue to item A6.7	
A6.7	Disconnect the igniter from the launch pad circuit	
A6.8	Remove the igniter from the motor	
A6.9	Insert a fresh igniter into the motor	
A6.10	Proceed to Launch Day checklist 10, item 10.28	

7. Project Plan

7.1 Testing

Due to a possible COVID-19 exposure, access was temporarily lost to the lab with the universal testing machine. Because of this, structural testing was not able to be completed before the FRR document was due. However, the lab supervisor has been contacted and testing has been scheduled for the near future. Additionally, payload testing has been delayed due to COVID-19 related shipping delays.

7.1.1.1 Nose Cone Bulkhead Tensile Loading Test

Per TDR 2.2, all critical components of the launch vehicle shall be designed with a minimum factor of safety of 2. This test aims to validate the strength of the nose cone bulkhead and the bolted connection. Sufficient bulkhead strength is critical to the success of the launch vehicle. Should parachute deployment cause a bulkhead to fail, sections of the rocket may descend untethered to a parachute, causing a safety hazard. Success criteria are shown in Table 7-1 below. Should any of the criteria not be met, the bulkheads will need to be redesigned.

Two 3/4-inch bulkheads have been manufactured in the nose cone configuration and inserted into a coupler section as detailed in Section 3.3.7. The piece will be tested to a tensile loading of 412 lbf using a universal testing machine, this value gives a factor of safety of 2 with the expected deployment force of 206 lbf.

Table 7-1 Nose Cone Bulkhead Tensile Loading Success Criteria

Success Criteria	Met? (Y/N)
The test sample withstands a load of over 412 lbf	
The test sample shows no visible damage under 412 lbf loading	

7.1.1.1(a) Controllable Variables

- Bulkhead material: aircraft-grade birch plywood
- Bulkhead thickness: 3/4 inches
- Applied loading: 412 lbf

7.1.1.1(b) Procedure

- Ensure everyone in attendance is wearing safety glasses
- Attach a quick link to each bulkhead U-bolt
- Insert the quick links into each end of the universal testing machine
- Begin increasing the force on the test piece in increments of 50 lbf
- Once the force passes 200 lbf, decrease the increment to 25 lbf
- Allow the test piece to settle for ~5 seconds between each increment
- Continue increasing the loading until one of the test pieces fails
- Record the failure point

7.1.1.1(c) Results

See information provided in section 7.1.

7.1.1.2 AV Bay Bulkhead Tensile Loading Test

Per TDR 2.2, all critical components of the launch vehicle shall be designed with a minimum factor of safety of 2. This test aims to validate the strength of the AV Bay bulkheads and the bolted connection. Sufficient bulkhead strength is critical to the success of the launch vehicle. Should parachute deployment cause a bulkhead to fail, sections of the rocket may descend untethered to a parachute causing a safety hazard. Success criteria are shown in Table 7-2 below. Should any of the criteria not be met, the bulkheads will need to be redesigned.

A test AV Bay has been made using two 3/4-inch AV Bay bulkheads inserted into a coupler section as detailed in section 3.3.7. The piece will be tested to a tensile loading of 686 lbf using a universal testing machine, this value gives a factor of safety of 2 with the highest expected deployment force of 343 lbf.

Table 7-2 AV Bay Bulkhead Tensile Loading Success Criteria

Success Criteria	Met? (Y/N)
The test sample withstands a load of over 686 lbf	
The test sample shows no visible damage under 686 lbf loading	

7.1.1.2(a) Controllable Variables

- Bulkhead material: aircraft-grade birch plywood
- Bulkhead thickness: 3/4 inches
- Applied loading: 686 lbf

7.1.1.2(b) Procedure

- Ensure everyone in attendance is wearing safety glasses
- Attach a quick link to each bulkhead U-bolt
- Insert the quick links into each end of the universal testing machine
- Begin increasing the force on the test piece in increments of 50 lbf
- Once the force passes 300 lbf, decrease the increment to 25 lbf
- Allow the test piece to settle for ~5 seconds between each increment
- Continue increasing the loading until one of the test pieces fails
- Record the failure point

7.1.1.2(c) Results

See information provided in section 7.1.

7.1.1.3 Shear Pin Shear Loading Test

This test is used to ensure the accuracy of the shear strength specified by the shear pin manufacturers. Should the tested shear strength differ from manufacturer specifications, the test strength will be used for recovery calculations. Should the shear pin strength differ from expected values on launch day, the vehicle may fail to separate leading to a ballistic descent, proving the necessity of the test. Success criteria are detailed in Table 7-3 below. Should the criteria not be met the new tested shear strength will be used in calculations.

Two steel plates will be used in conjunction with a universal testing machine for shear testing. Each plate will have a hole drilled at the end to allow for a quick link connection to the testing machine. Another hole matching the diameter of the shear pins will be drilled at the opposite end.

Table 7-3 Shear Pin Loading Success Criteria

Success Criteria	Met? (Y/N)
The shear pins fail within 1 lbf of manufacturer specifications	

7.1.1.3(a) Controllable Variables

- Chosen shear pin: 4-40 nylon
- Applied loading: 35 lbf (manufacturer specified)

7.1.1.3(b) Procedure

- Attach a quick link through the large holes on each plate
- Align the two remaining holes and insert a shear pin
- Insert the quick links into each end of the universal testing machine
- Begin increasing the applied loading in increments of 5 lbf
- Once within 10 lbf of the expected failure, decrease the increment to 1 lbf
- Continue increasing the loading until the shear pin fails
- Record the failure point

7.1.1.3(c) Results

See information provided in section 7.1.

7.1.1.4 Fastener Shear Loading Test

Per TDR 2.2, all critical components of the launch vehicle shall be designed with a minimum factor of safety of 2. This test aims to validate the strength of the chosen bolts for the nose cone bulkhead and the bolted connections between sections. Should parachute deployment cause the bolts to fail, sections of the rocket may descend untethered to a parachute causing a safety hazard. Success criteria are shown in Table 7-4 below. Should any of the criteria not be met, new bolts will need to be chosen.

Two steel plates will be used in conjunction with a universal testing machine for shear testing. Each plate will have a hole drilled at the end to allow for a quick link connection to the testing machine. Another hole matching the diameter of the bolt will be drilled at the opposite end. Due to the off-center location of the U-bolt on the nose cone bulkhead, the bolts closest to the U-bolt will experience a higher loading of 100 lbf based on FEA analysis. Accounting for a factor of safety of 2, the bolt will be tested to a loading of 200 lbf.

Table 7-4 Fastener Shear Loading Success Criteria

Success Criteria	Met? (Y/N)
The fastener withstands a loading of 200 lbf	

7.1.1.4(a) Controllable Variables

- Chosen fastener size: 10-24 machine screws
- Applied loading: 200 lbf

7.1.1.4(b) Procedure

- Attach a quick link through the 1/4-inch holes on each plate
- Align the two remaining holes and insert a bolt
- Insert the quick links into each end of the universal testing machine
- Begin increasing the applied loading in increments of 20 lbf
- Once the force passes 150 lbf, decrease the increment to 5 lbf
- Continue increasing the loading until the bolt fails
- Record the failure point

7.1.1.4(c) Results

See information provided in section 7.1.

7.1.1.5 Ejection Testing

Ejection testing is performed to verify the calculation of black powder charges for the launch vehicle recovery subsystem. Sufficient black powder charges are a critical factor for successful recovery operation. Insufficient black powder charges can lead to a lack of separation leading to ballistic descent of the launch vehicle. Excessive kinetic energy of launch vehicle sections on landing due to ballistic descent can damage the launch vehicle and pose a serious risk to personnel safety. Alternatively, excessive black powder charges can cause critical damage to the launch vehicle bulkheads and parachutes. This damage may also cause ballistic descent, which is why testing the recovery system prior to flight is imperative. Here a series of ejection tests have been recorded to verify experimentally the black powder calculations outlined in Section 3.4.7.

Table 7-5 Ejection Success Criteria

Success Criteria	Met? (Y/N)
Launch vehicle shows vigorous and complete separation	Y
No damage is done to launch vehicle components	Y

7.1.1.5(a) Controllable Variables

- Black powder charge mass

7.1.1.5(b) Procedure

- The AV sled and electronics mounted thereon are not placed in the AV bay

- 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
- The motor is backed against a wall with another piece of foam between the wall and the launch vehicle
- All team members retreat to a safe distance and out of the path of the launch vehicle
- One designated team member approaches the launch vehicle to attach the ejection switch to the drogue e-match wires using alligator clips
- The designated tram member retreats to a safe distance
- The battery is attached to the switch, and the switch is thrown to detonate the drogue ejection charge
- The fin can is placed out of the way and the remaining midsection is placed back against the wall and a piece of foam is again used for padding.
- All team members retreat to a safe distance and out of the path of the launch vehicle
- One designated team member approaches the launch vehicle to attach the ejection switch to the main e-match wires using alligator clips
- The designated tram member retreats to a safe distance
- The battery is attached to the switch, and the switch is thrown to detonate the main ejection charge
- The launch vehicle body sections are placed out of the way
- Once it is safe to approach, team members may approach the launch vehicle and clean up the test site

7.1.1.5(c) Results

A total of eight firings utilizing the calculation method described in Section 3.4.7 were attempted using four launch vehicles. Two of these launch vehicles were subscale-class launch vehicles and two were full scale launch vehicles. All four ejection tests performed with subscale launch vehicles were successful, and three of the four performed with full scale launch vehicles were successful as well. The fourth detonation failed to detonate due to a broken wire running between the bulkhead terminal block and the test leads. Out of test runs that detonated, a 100% success rate was achieved on the first attempted ejection.

7.1.1.6 Altimeter Operational Test

This test confirms the satisfactory operation of the altimeters used in the launch vehicle flight. Altimeters ensure the ability to recover the launch vehicle and prevent excessive kinetic energy on landing through their role in the recovery system.

This test is created by simulating conditions during flight. In order to test altimeter functionality, the pressure decrease as a function of altitude will be duplicated using a vacuum chamber. The altimeters to be tested will be connected to a test circuit and powered. The pressure will then be decreased, and slowly increased to simulate first launch then recovery. Visual indicators of the firing signal will be observed through the viewing port of the pressure vessel.

Table 7-6 Altimeter Operation Success Criteria

Success Criteria	Met? (Y/N)
LED #1 lights when the altimeter senses apogee	Y
LED #2 lights when the altimeter senses the main deployment altitude	Y
Pre- and post-flight beeps match what is recorded in the beep sheet. See Section 6.2, Appendices A-E for beep sheets.	Y

7.1.1.6(a) Controllable Variables

- Pressure surrounding altimeters
- Rate of change of pressure
- Altimeter type

7.1.1.6(b) Procedure

- Primary and secondary altimeters are wired to the test assembly
- Each altimeter is powered on with one 9 V battery
- The test assembly is placed in the vacuum chamber
- The vacuum chamber is sealed, making sure the lights are visible through the view port
- The vacuum pump is connected to the vacuum chamber fitting
- A vacuum is drawn down to simulate ascent
- The vacuum pressure is slowly decreased while the test assembly is observed
- Once the vacuum begins to be rolled off, the first light should turn on
- Shortly afterwards, as the vacuum is rolled off, the second light should turn on
- Open the vacuum chamber and record the post-flight beep sheet
- Confirm the recorded altitudes are the same
- Download the post-flight data and confirm that the recorded altitude and event timings are as expected

7.1.1.6(c) Results

The test was conducted for all four flight altimeters. During each test, the LED #1 lit at simulated apogee, LED #2 lit at approximately the simulated main altitude pressure, and the beep sheets were as expected. The post-flight data was as expected for the pressure changes encountered during the test.

7.1.1.7 Recovery Avionics Battery Life Test

Per requirement NASA 2.7, a demonstration of the launch vehicle's capacity to remain in a launch-ready state for extended duration is required. The Recovery Avionics Battery Life Demonstration will prove that the batteries powering the recovery avionics can last more than 2 hours once connected to the altimeters and powered on. The success criteria for this test are defined in Table 7-7 below. A failure to meet these success criteria will result in a change to the type of battery or altimeter until the success criteria are met.

For this test, all Recovery Avionics Systems will be assembled in a flight-ready configuration and powered on. Here, a timer will be started, and the system monitored at a regular interval to confirm continued functionality. Once sufficient time has passed to demonstrate suitable battery life, the test will be concluded.

Table 7-7 Recovery-Avionics Battery Life Success Criteria

Success Criteria	Met? (Y/N)
Primary altimeter's battery life lasts longer than two hours	Y
Secondary altimeter's battery life lasts longer than two hours	Y
Eggfinder GPS tracking system's battery life lasts longer than two hours	Y
BRB900 tracking system's battery life lasts longer than two hours	Y

7.1.1.7(a) Controllable Variables

- Altimeter type
- 9V Battery type
- LiPo Battery type
- Choice of Tracking Device

7.1.1.7(b) Procedure

- Assemble the AV sled with altimeters, tracking device, and batteries
- Connect a 9V battery to each altimeter
- Connect a 2S LiPo to the tracking device
- Start the stopwatch
- Check every 15 minutes to confirm the altimeters and tracking device remain functional
- At 3 hours, conclude the test

7.1.1.7(c) Results

All four devices were powered, active, and reporting battery life remaining when the test concluded at the 3-hour mark.

7.1.1.8 Tracking Device Operational Test

Per requirement NASA 3.12.1, a tracking system is required for all independent sections of the launch vehicle and LOPSIDED-POS. The tracking device operational test serves to confirm that the GPS locator devices being placed in the launch vehicle and the LOPSIDED-POS function and are accurate in relaying the GPS location data. The success criteria for this test are defined in Table 7-8 below. If the GPS fails this test, the cause will be determined and repaired if possible or the tracker replaced.

To test the ability of the tracking device to accurately record location data, the device will be placed in the private vehicle of a team member and driven on a course of at least five miles, the route of which will be determined by the driver of the vehicle. The tracker will be set to record and store this data, and the resulting course will be compared to the actual course for accuracy.

Table 7-8 Tracking Device Operation Success Criteria

Success Criteria	Met (Y/N)
The recorded GPS tracker paths match that taken by the driving team member	Y

7.1.1.8(a) Controllable Variables

The controllable variables in this test are as follows:

- Selected route
- Selected GPS tracker

7.1.1.8(b) Procedure

The procedure for carrying out this test is as follows:

- Power on the Eggfinder ground receiver dongle and transmitter
- Pair the Eggfinder ground receiver dongle to a club member's Android phone with Rocket Locator installed
- Power on the BRB900 handheld receiver
- Power on the BRB900 transmitter
- Establish connection between ground receivers and transmitters
- Make sure the location is properly displaying on Rocket Locator
- Have one team member carry the transmitters into their car
- Have another team member hold the receiver dongles and the Rocket Locator phone, while displaying Google Maps on the laptop
- While the team member with the transmitters is driving, the receiver member is comparing the track plotted on Rocket Locator to the course of the road
- After the transmitter member returns, compare the recorded tracks to the actual route taken by the transmitter team member

7.1.1.8(c) Results

The BRB900 and Eggfinder systems were tested separately as the BRB900 had a depleted battery on the day of testing. Both devices performed sufficiently, matching the route taken by the driving team member with a reasonable degree of accuracy.

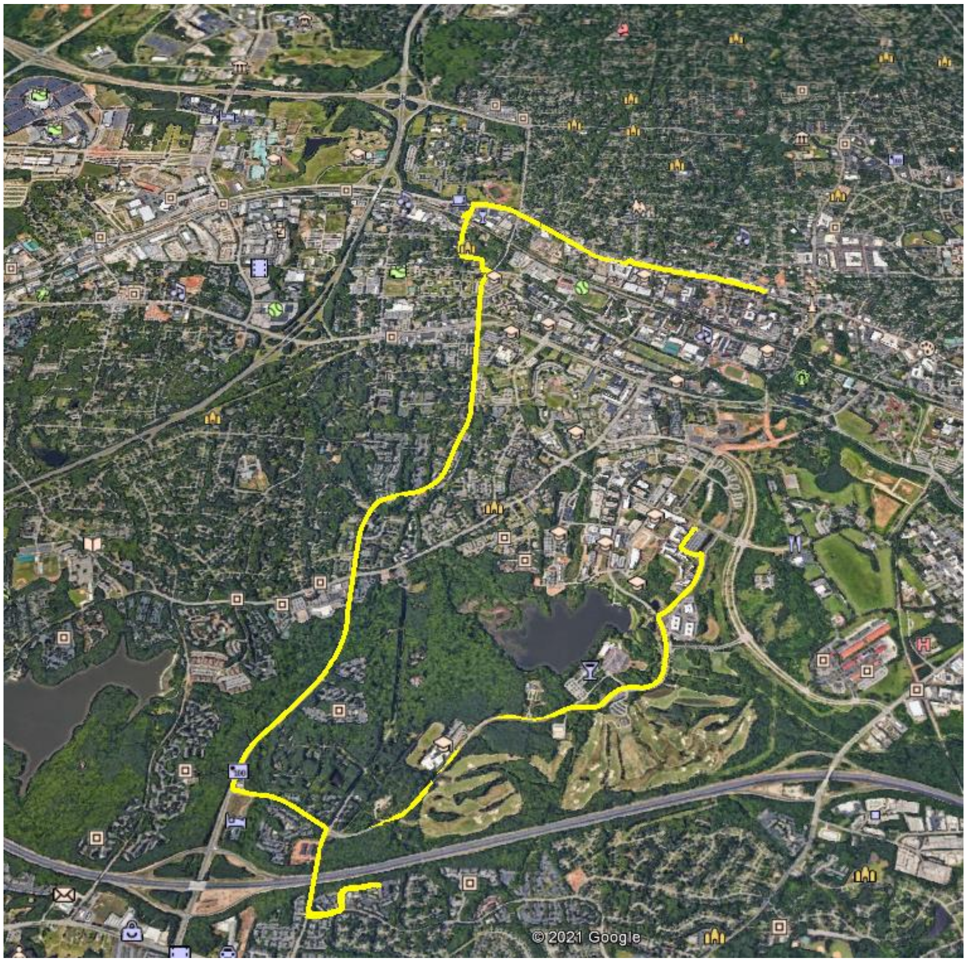
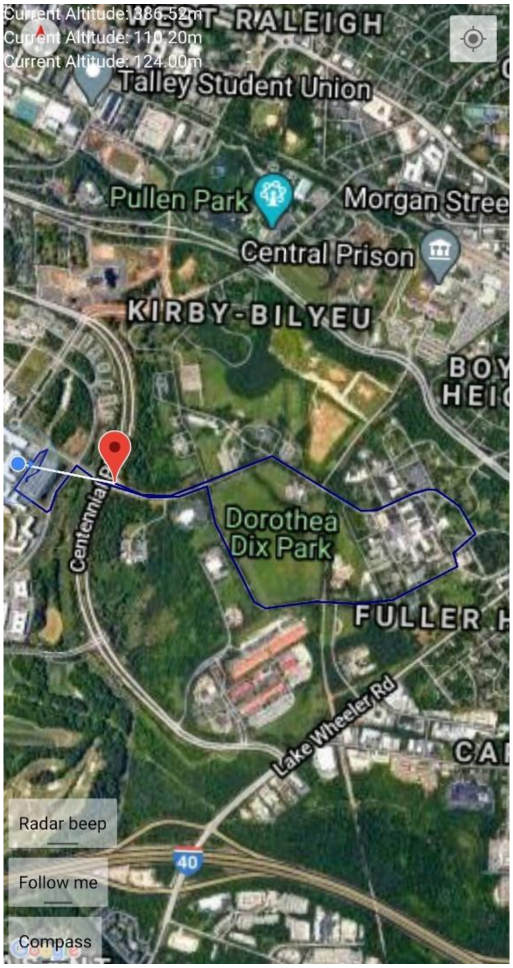


Figure 7-1 BigRedBee BRB900 Test Track



Current Altitude: 386.52m
Current Altitude: 110.20m
Current Altitude: 124.00m

Figure 7-2 EggFinder GPS Test Track

7.1.2 POS Transmission Range Test

This experimental test is designed to determine the practical range of the POS image transmission components. Per Requirement TDR 4.14, the POS should be able to transmit images from up to 2500 from the ground station, and the ground station should be able to receive these images within a reasonable time, and the quality of the received images should high enough such that the content of the photograph can be discerned. Transmission for a single image should not exceed 5 minutes. Failure to meet the success criteria for this test will result in further analysis of the POS transmission system. A transmitter capable of higher transmission power, or a modified transmission antenna may be necessary. As mentioned in Section 2.3, the POS transmission range requirement in TDR 4.14 was updated from 4500 feet to 2500 feet to reflect the set-up of the team's home launch field, since the competition flight will not be taking place in Huntsville.

7.1.2.1 Modified POS Transmission Range Test

The procedure for this test was initially outlined in the team's Critical Design Review. However, due to delays in the successful implementation of the SSTV transmission method, the test procedure was modified. Instead of transmitting test images, the POS transmitter was programmed to send three test packets of byte data in intervals of five seconds. The original test procedure is planned to be completed once the SSTV transmission method is fully functioning.

7.1.2.2 Control Variables

The control variables for this test include; transmitter make and model, SDR receiver make and model, transmitter power, transmission frequency, receiver frequency

7.1.2.3 Modified Test Procedure

1. Save Radio Test Python script into proper directory on the Raspberry Pi prior to testing.
2. In a flat, open area, connect the Raspberry Pi, POS transmitter, and charged battery pack.
3. Enable Wi-Fi hotspot on cellular phone and connect laptop and Raspberry Pi
4. Establish SSH connection with Raspberry Pi.
5. Connect SDR Receiver hardware to laptop and set receiver to 433 MHz.
6. Begin test transmission by using nohup command in Raspberry Pi in SSH terminal.
7. With POS set-up, move in a straight line away from the SDR receiver in increments of 150 feet.
8. With a cell phone, maintain contact with personnel at the ground station to confirm test packets are still being received.
9. Repeat steps 4-7 eight times. The ninth transmission should take place at 2500 feet.

7.1.2.4 Modified Success Criteria

Table 7-9 POS Transmission Range Success Criteria

Success Criteria	Met (Y/N)?
The POS is able to transmit and receive test packets from up to 2500 feet	N
Receiving time does not exceed 5 minutes for a single image	N/A

7.1.2.5 Test Results

Due to the topography of the field selected for this test, team personnel transporting the POS transmitter could not travel the full 2500 feet away from the POS ground station. The furthest point of packet reception was 1091 feet, which was out of the line of sight of the ground station receiver. It should be noted that signal strength remained well above the noise level for the entirety of the test – at the furthest transmitter location, despite having lost line of sight, the signal to noise ratio (SNR) of the incoming signal was 15 dB. Before line of sight was lost was much higher, between 30 and 45 dB, which in signal processing applications is considered an extremely strong signal. As stated previously, the original version of this test will be conducted at a later date, and an alternate test location will be used in order to allow for the full range of the test.

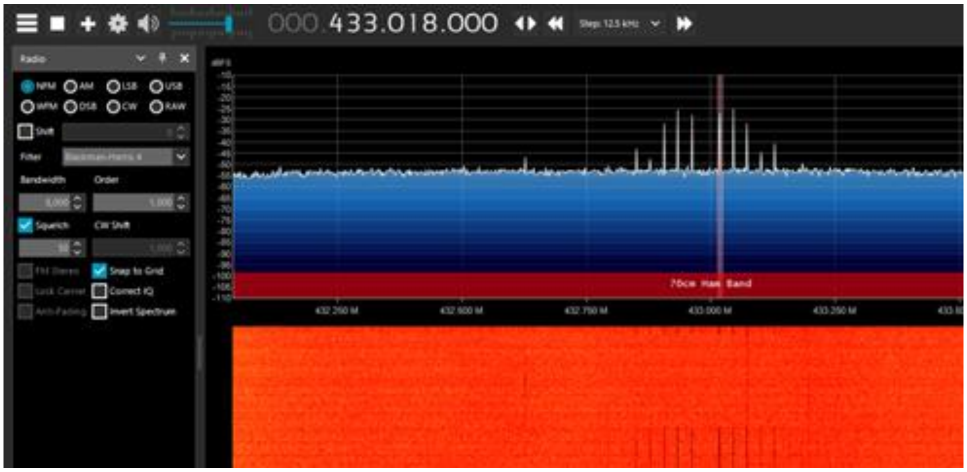


Figure 7-3 Transmission Sample from SDRSharp Software

7.1.3 LOPSIDED-POS Battery Capacity Test

This demonstration test is designed to ensure the LOPSIDED-POS battery can provide sufficient power for all payload components and operations. This includes operating time after the payload lands, as well as the “stand-by” launch pad configuration. This test will verify Requirement NASA 2.7, which states that the payload must be able to maintain launch pad configuration for at least two hours. It will also verify TDR 4.15, which states that the LOPSIDED-POS must be powered from a single battery pack, with the exception of the payload altimeter, which will be powered with its own 9V battery. Failure to meet the success criteria for this test will require further analysis of the LOPSIDED-POS power system, including the current draw of individual components, the time they spend active, and the specifications of the selected battery pack. If the selected battery pack does not have the capacity required to cover the full operating range of the LOPSIDED-POS, a new battery will need to be used, which could lead to structural changes within LOPSIDED to accommodate the new battery.

7.1.3.1 Control Variables

Control variables for this test include; battery make and model, LOPSIDED-POS electronic components, and the power on/off states of these components during payload operation.

7.1.3.2 Procedure

1. Ensure LOPSIDED-POS battery is fully charged prior to testing.
2. Check the battery voltage with a multimeter and ensure it matches battery specifications.
3. Wire all LOPSIDED-POS electronics, according to procedures documented in LOPSIDED-POS assembly checklists.
4. Supply power by connecting the payload battery.
5. Run Battery Capacity Test Python script on Raspberry Pi.

6. Leave set-up in launch pad configuration for two hours, using a timer. Check the functionality of components in 20-minute intervals
7. After the two-hour stand-by window has passed, the Battery Capacity Test script will initiate all payload events which draw power from the payload battery, including:
    a. Release of parachute latches
    b. Release of leveling system solenoid latches
    c. Image capture
    d. Image transmission
8. Verify that all payload events occur without loss of power.

7.1.3.3 Success Criteria

Table 7-10 LOPSIDED-POS Battery Capacity Success Criteria

Success Criteria	Met?
The LOPSIDED-POS remains in stand-by mode for two hours without loss of power	TBD – Test not completed
The LOPSIDED-POS completes mission procedures after two hours on stand-by, without loss of power	TBD – Test not completed

7.1.3.4 Test Results

Due in part to delays mentioned in Section 7.1, this test has not been completed in time for the submission of this document. The results of this test will be included in the team's FRR Addendum submitted after the Payload Demonstration Flight.

7.1.4 LOPSIDED Tilt Range Test

The LOPSIDED Tilt Range Test will demonstrate the range in which LOPSIDED can orient itself. The test will show the maximum grade that the payload can level on to be within 5 degrees of vertical as described in NASA 4.3.3. The test will also look at LOPSIDED's maximum tilt range at different orientations around the body to verify TDR 4.8.

7.1.4.1 Control Variables

Control variables for this test include the leg splay angle and an accelerometer to measure the orientation.

7.1.4.2 Procedure

1. Place LOPSIDED on a level surface and verify using the accelerometer
2. Secure the feet to the surface
3. Splay the legs out to the desired angle
4. Tie a string to the U-bolt on the bottom of LOPSIDED
5. Use a protractor to mark 15-degree sections around the center of LOPSIDED on the surface
6. Pull the string out from the center along the 0-degree mark until LOPSIDED collides with itself and cannot be tilted any farther
7. Record the tilt angle as measured by the accelerometer

8. Repeat steps 6 and 7 for all 15-degree increments.

7.1.4.3 Success Criteria

Table 7-11 LOPSIDED Tilt Range Success Criteria

Success Criteria	Met?
LOPSIDED can tilt up to 15 degrees regardless of its orientation	Y

7.1.4.4 Test Results

The test was deemed successful as the smallest maximum tilt that LOPSIDED can achieve is when tilting directly against one of its legs. This angle was recorded to be 23 degrees. The largest maximum tilt can be achieved at 45 degrees off any one of its legs and was recorded to be 26 degrees. With the 5 degree tolerance, depending on the landing orientation, LOPSIDED can handle grades equal to or lower than 28-31 degrees.

Figure 7-4 LOPSIDED Maximum Tilt Range

7.1.5 LOPSIDED-POS Tracker-Altimeter Interference Test

The altimeter and the tracker are planned to be tested to ensure that the tracker does not interfere the altimeter as this can result in an unsuccessful payload jettison, where the payload will either remain attached to the main-parachute shock chord or the payload may remain within the payload bay. This happens as the altimeter can either ignite the ARRD prematurely or not ignite it at all. Either way, the payload is set to remain attached to the main vehicle during recovery. This test shall verify NASA requirements 3.13 and 3.13.2.

7.1.5.1 Control Variables

Control variables for this test include the BRB 900, the StratoLoggerCF, and the pressure of activation.

7.1.5.2 Procedure

- Attach the tracker and altimeter to a test sled with an aluminum foil sheet in between, simulating placement for launch
- Place the assembled test sled inside a sealed space
- Vary the pressure inside the sealed space to increase altitude read by altimeter
- Observe LED lights to check if altimeter activates at desired pressure/altitude

7.1.5.3 Success Criteria

Table 7-12 LOPSIDED-POS Transmitter-Altimeter Interference Success Criteria

Success Criteria	Met (Y/N)
The altimeter activates noise signal at desired pressure	Y
The tracker is still active	Y
The altimeter activates visual signal at desired pressure	Y
The tracker functions correctly throughout test	Y

7.1.5.4 Test Results

The test was successful as the altimeter maintained fully operational during the test and afterwards while activating at the desired pressure while the BRB900 was operating on the other side of the aluminum foil.

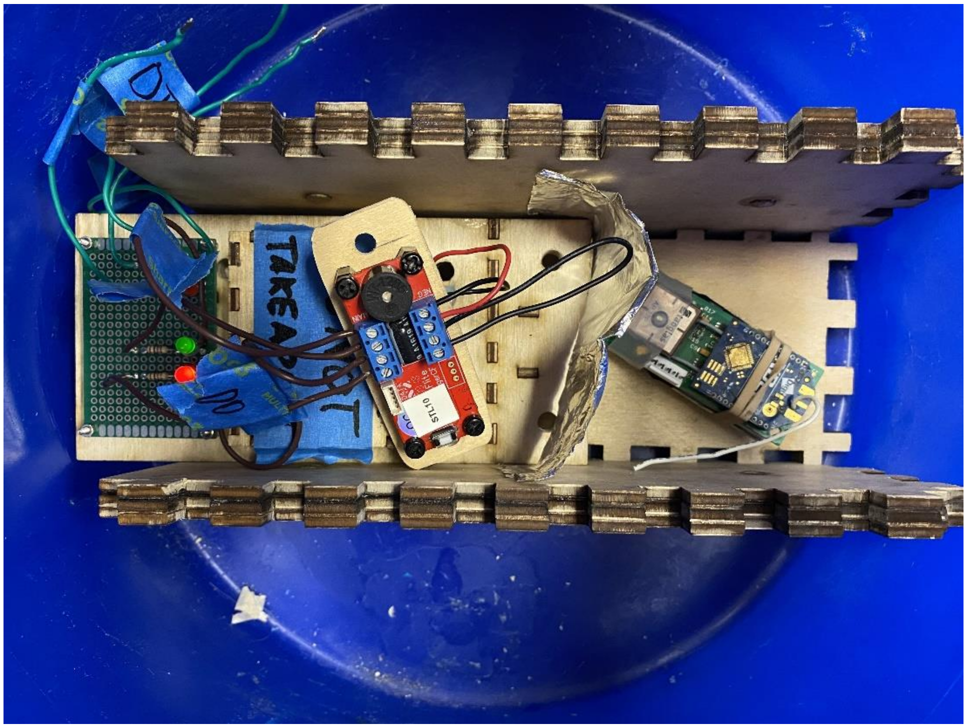


Figure 7-5 Altimeter and BRB900 in Test Stand with Aluminum Foil

Figure 7-6 Sealed Bucket to Conduct Altimeter Pressure Testing

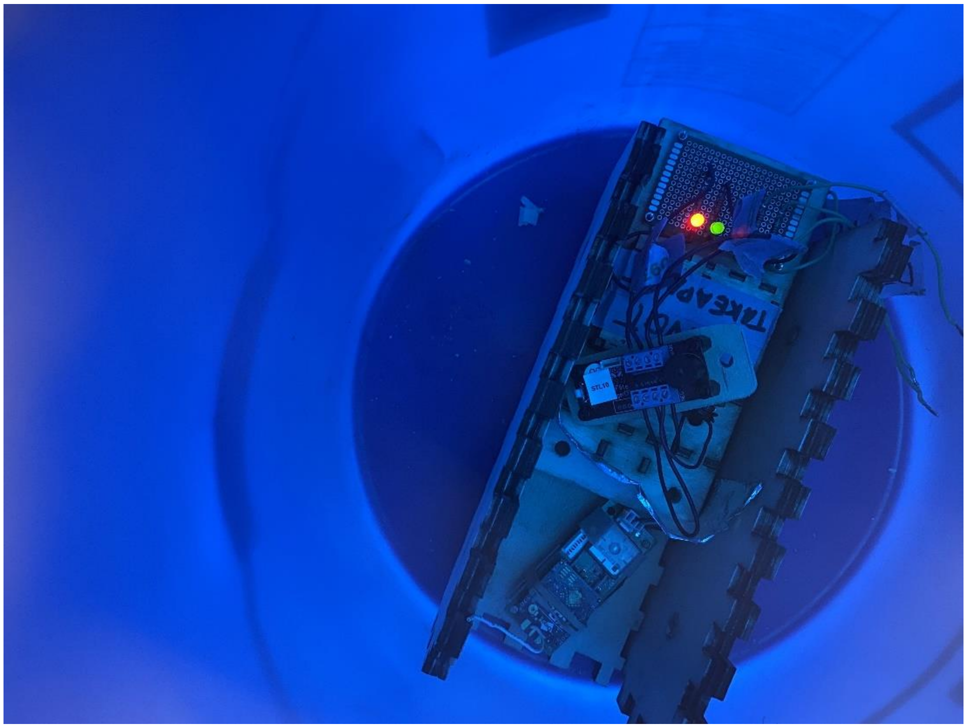


Figure 7-7 LED Lights Indicating Altimeter Functionality

7.1.6 ARRD Ejection Test

The payload ARRD release test will demonstrate the operation of LOPSIDED-POS deployment as it hangs from the main parachute chord. The test will show how the system works and its reliance. is in preventing the parachute from interfering in the leveling process after landing.

7.1.6.1 Control Variables

Control variables for this test include altitude for drop, ARRD assembled, 0.1 grams of black powder, e-match, and a switch.

7.1.6.2 Procedure

- Follow the LOPSIDED-POS checklist for ARRD assembly
- Before the test, identify an outdoor location with a minimum of 5 feet of radius
- Set the stand and attach payload at ARRD using toggle and a quicklink
- Turn switch on as it is connected to e-match
- Observe if LOPSIDED-POS touches the ground after ejection

7.1.6.3 Success Criteria

Table 7-13 ARRD Ejection Success Criteria

Success Criteria	Met (Y/N)
LOPSIDED weight is held by the ARRD	Y
ARRD black powder ignites	Y
LOPSIDED is detached from ARRD toggle	Y

Figure 7-8 Mass Simulator Held on Test Rig by ARRD

Figure 7-9 Toggle Attached to Quick Link after ARRD Separation

7.1.7 LOPSIDED-POS Payload Parachute Release Test

The payload parachute release test will demonstrate the operation of the LOPSIDED-POS parachute release system upon landing. The test will show how robust the system is in preventing the parachute from interfering in the leveling process after landing. This test will verify requirements NASA 4.2 and TDR 4.16. A code is required for this test due to the reliance on an accelerometer to detect the moment of landing; therefore, a modified Python script will be written for this test.

7.1.7.1 Control Variables

Control variables for this test include altitude for drop, the type of parachute, the EM locks used, and the accelerometer in use.

7.1.7.2 Procedure

- Before the test, identify an outdoor location with a minimum of 10 feet of altitude with a landing site on grass
- Follow the LOPSIDED-POS checklist for assembly
- Set the parachute attached to LOPSIDED-POS so that it inflates as soon as it is dropped

- Observe for any early parachute detachments while LOPSIDED-POS falls
- Observe parachute as LOPSIDED-POS touches the ground

7.1.7.3 Success Criteria

Table 7-14 LOPSIDED-POS Payload Parachute Release Success Criteria

Success Criteria	Met (Y/N)
LOPSIDED is detached from the parachute	TBD- Test not completed
LOPSIDED successfully lands on all four of its legs	TBD - Test not completed
The parachute does not cover LOPSIDED-POS	TBD - Test not completed
The accelerometer collected correct acceleration data	TBD - Test not completed

7.1.7.4 Test Results

Due to delays mentioned in Section 7.1, this test has not been completed in time for the submission of this document. The results of this test will be included in the team's FRR Addendum submitted after the Payload Demonstration Flight.

7.2 Requirements Compliance

7.2.1 NASA Handbook Requirements

Table 7-15 below is the requirements verification matrix for NASA handbook requirements. All requirements have been verified except those relating to the PDF, and the apogee requirement due to a low apogee on the VDF.

Table 7-15 NASA Handbook Requirements Verification Matrix

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 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 will 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 new and original work.	Inspection	Project Management	Verified	All design, construction, reports, presentations, and flight preparation have been done by students and is new work specifically for this year's challenge.
NASA 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, including 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 7.3 for the final project plan. See Section 2.3 for updates to project plan since CDR.

NASA 1.3	Foreign National (FN) team members SHALL be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Foreign National (FN) team members are identified and reported in the PDR milestone document.	Inspection	Project Management	Verified	There are no Foreign National team members.
NASA 1.4	The team SHALL identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR).	All team members attending launch week activities are identified and reported in the CDR milestone document.	Inspection	Project Management	Verified	The team is not travelling to Launch Week.
NASA 1.4.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team identifies and selects members actively engaged in the project throughout the year to attend competition.	Inspection	Project Management	Verified	The team is not travelling to Launch Week.
NASA 1.4.2	Team members attending competition SHALL include one mentor (see requirement 1.13).	The project management team invites the mentors listed in section 1.1.2 to attend competition.	Inspection	Project Management	Verified	The team is not travelling to Launch Week.
NASA 1.4.3	Team members attending competition SHALL include no more than two adult educators.	The project management team invites the adult educator listed in section 1.1.2 to attend competition.	Inspection	Project Management	Verified	The team is not travelling to Launch Week.

NASA 1.5	The team SHALL engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. The STEM Engagement Activity Report SHALL be submitted via email within two weeks of the completion of each event.	The outreach lead implements STEM engagement plans with K-12 student groups throughout the project lifecycle. The outreach lead submits a STEM Engagement Activity Report via email within two weeks of the completion of each event.	Inspection	Project Management	Verified	The team has reached a total of 308 students between project acceptance and the FRR due date.
NASA 1.6	The team SHALL establish a social media presence to inform the public about team activities.	The webmaster and social media lead coordinate to develop an educational and engaging social media presence on platforms including, but not limited to: the club website, Facebook, Instagram, and Twitter	Inspection	Project Management	Verified	Team social media information has been sent to the NASA project management team. This presence is continuously maintained throughout the year.

NASA 1.7	The team 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 will be sufficient.	The team lead sends all deliverables to the NASA project management team prior to each specified deadline. In the event that the deliverable is too large, the webmaster posts the document on the team's website, and the team lead sends the NASA project management team a link to the file.	Inspection	Project Management	Verified	All deliverables, including this report, have been emailed to the NASA project management team by the specified deadline. The FRR and PLAR will also be emailed to the NASA project management team by their respective deadlines.
NASA 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.
NASA 1.9	In every report, the team SHALL provide a table of contents including major sections and their respective sub-sections.	The team lead creates and manages a Table of Contents in each milestone report.	Inspection	Project Management	Verified	A Table of Contents is included on page ii of this document.
NASA 1.10	In every report, the team SHALL include the page number at the bottom of the page.	For each milestone report, the team uses a document template which includes page numbers at the bottom of each page.	Inspection	Project Management	Verified	Page numbers are listed at the bottom of each page of this document.

NASA 1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel.	Each team member participating in the video teleconference acquires the necessary equipment for them to perform a video teleconference with the review panel.	Inspection	Project Management	Verified	The team has provided all necessary computer equipment for the PDR and CDR teleconferences, and will be providing necessary computer equipment for the FRR teleconference.
NASA 1.12	The team SHALL be required to use the launch pads provided by Student Launch's launch services provider.	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 this design.	Inspection	Aerodynamics; Structures	Verified	The launch vehicle is designed to be launched from a 12-foot 1515 rail. See section 3.3.3.3 for final launch rail interface design. See Figure 5-2 for VDF launch rail interface.
NASA 1.13	Each team SHALL identify a "mentor."	The team lead identifies qualified community members to mentor team members.	Inspection	Project Management	Verified	See section 1.1.2 for mentor listing and contact information.
NASA 1.14	Each team 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 for time spent on this milestone.

NASA 2.1	The vehicle SHALL deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL).	The aerodynamics lead designs a launch vehicle to reach an apogee between 3,500 and 5,500 feet AGL. The team then constructs the vehicle as designed and the launch vehicle flies between 3,500 at 5,500 feet AGL.	Analysis; Demonstration	Aerodynamics	Not verified	The launch vehicle is predicted to deliver the payload to an apogee of 3678 feet AGL. See section 3.5.3 for apogee predictions. The launch vehicle reached an apogee of 2,982 ft on its VDF with a mass simulator. Due to mass discrepancies, it is expected that the actual payload will be lighter than the mass simulator. This requirement will be verified following the PDF.
NASA 2.2	The team SHALL identify their target altitude goal at the PDR milestone.	The aerodynamics lead declares the team's target altitude goal in the PDR milestone report.	Inspection	Aerodynamics	Verified	The target altitude of 4,473 feet was identified in the PDR document. See section 3.5.1 for target altitude identification.

NASA 2.3	The vehicle SHALL carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner.	The recovery lead designates one onboard altimeter to record the official altitude used in determining the Altitude Award winner.	Inspection	Recovery	Verified	One of the recovery system's Stratologger CF altimeters, designated by the team as STL8, will be designated as the official altimeter for competition purposes. See Figure 3-41 for verification of altimeter STL8 on the AV sled for the VDF.
NASA 2.4	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 structures and recovery leads design the launch vehicle such that it is capable of being recovered with minimal damage and launched again on the same day without repairs or modifications.	Demonstration	Recovery; Structures	Verified	The launch vehicle was recovered and is in a reusable state following the VDF. See Figure 5-4 for post-flight images of the launch vehicle.
NASA 2.5	The launch vehicle SHALL have a maximum of four (4) independent sections.	The aerodynamics and recovery subsystem leads design a launch vehicle that has fewer than four (4) independent sections.	Inspection	Aerodynamics; Recovery	Verified	The launch vehicle has a total of three independent sections, excluding the payload lander. See section 3.4.4.2 for the final recovery separation design.

NASA 2.5.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 1 body diameter in length.	The aerodynamics lead designs the airframe such that couplers/shoulders at in-flight separation points are at least 1 body diameter in length	Inspection	Aerodynamics	Verified	Coupler shoulders at in-flight separation points are 6 inches long. See section 3.3.2.2 for the final launch vehicle design.
NASA 2.5.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least 1/2 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	The nosecone shoulder is not located at an in-flight separation point. See section 3.3.4 for the final launch vehicle design.
NASA 2.6	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 less than two (2) hours.	Demonstration	Project Management; Safety	Verified	Total launch vehicle assembly time at the VDF was 1 hour, 48 minutes.
NASA 2.7	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.	The project management and safety teams monitor the power consumption of each electrical launch vehicle and payload component and verify functionality of each component after two (2) hours.	Demonstration	Project Management; Safety	Verified	The launch vehicle and payload are designed to remain fully function in a launch-ready configuration for at least 2 hours. See section 7.1.1.7 for pad stay time test information.

NASA 2.8	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system.	The project management and safety teams select a motor ignitor capable of being ignited from a 12-volt direct current firing system.	Demonstration	Project Management; Safety	Verified	The launch vehicle was launched on a standard 12V DC firing system for the VDF.
NASA 2.9	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 limit the launch vehicle such that no external circuitry or ground support equipment is required for launch.	Demonstration	Project Management; Safety	Verified	The launch vehicle did not require external circuitry for launch at the VDF. See Figure 5-1 for images of the vehicle on the launch pad in flight-ready configuration.
NASA 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	The team has selected the Aerotech L1520T as its final motor. See section 1.2.2 for final motor selection.
NASA 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.	Inspection	Aerodynamics	Verified	The team has selected the Aerotech L1520T as its final motor. See section 1.2.2 for final motor selection.

NASA 2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO).	The project management team requests approval from the NASA RSO for motor changes following submission of the CDR milestone report.	Inspection	Project Management	Verified	The team has selected the Aerotech L1520T as its final motor, which was the motor declared at the CDR milestone. See section 1.2.2 for final motor selection.
NASA 2.11	The launch vehicle SHALL be limited to a single stage.	The aerodynamics lead designs the launch vehicle such that it only utilizes a single stage.	Inspection	Aerodynamics	Verified	The launch vehicle is a single stage. See section 3.1.1 for the final launch vehicle design.
NASA 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 selects a motor that does not exceed 5,120 Newton-seconds of total impulse.	Inspection	Aerodynamics	Verified	The team has selected the Aerotech L1520T as its final motor. See section 1.2.2 for final motor selection.
NASA 2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary data on any onboard pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Verified	No pressure vessels are included in the final design.

NASA 2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) for pressure vessels on the vehicle SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The structures lead includes design documentation supporting a factor of safety of 4:1 for any pressure vessel on the launch vehicle in each milestone report.	Analysis; Inspection	Structures	Verified	No pressure vessels are included in the final design.
NASA 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 any onboard pressure vessels such that they include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Analysis; Inspection	Structures	Verified	No pressure vessels are included in the final design.
NASA 2.13.3	The full pedigree of any pressure vessel on the launch vehicle SHALL be described, including the application for which the tank was designed and the history of the tank. This SHALL include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The structures lead records the full history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and the name of each person or entity administering the pressure events.	Inspection	Structures	Verified	No pressure vessels are included in the final design.

NASA 2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit.	The aerodynamics lead designs the launch vehicle such that it has a static stability margin of at least 2.0 at the point of rail exit.	Analysis	Aerodynamics	Verified	The launch vehicle will have a static stability margin of 2.23 at rail exit. See section 3.5.4 for stability calculations for the final launch vehicle design.
NASA 2.15	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability	The aerodynamics lead designs the launch vehicle such that there are no structural protuberances forward 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	The final launch vehicle design does not include structural protuberances forward of the burnout center of gravity. See section 3.1.1 for the final launch vehicle design.
NASA 2.16	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 minimum velocity of 52 fps is achieved by rail exit.	Analysis	Aerodynamics	Verified	See section 3.5.2 for performance calculations for the final launch vehicle design.

NASA 2.17	The team SHALL successfully launch and recover a subscale model of their rocket prior to CDR. Subscale flight data SHALL be reported at the CDR milestone.	The team launches and recovers a subscale model of the launch vehicle. The team reports subscale flight data in the CDR milestone report.	Demonstration	Project Management	Verified	The team completed a successful launch of the subscale model on November 21, 2020. Subscale flight results were discussed in the CDR.
NASA 2.17.1	The subscale model SHALL 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	The subscale model was designed to resemble the full scale launch vehicle. Subscale design details were discussed in the CDR. The subscale is a different launch vehicle than the full scale launch vehicle.
NASA 2.17.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery lead installs an altimeter capable of recording the subscale launch vehicle's apogee altitude in the subscale launch vehicle.	Inspection	Recovery	Verified	Two Stratologger CF altimeters were carried by the subscale model. Subscale avionics were discussed in the CDR.
NASA 2.17.3	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 and built specifically for this year's project.	Inspection	Project Management	Verified	The team has constructed a new subscale rocket specifically built for this year's project.

NASA 2.17.4	Proof of a successful flight SHALL be supplied in the CDR report.	The team supplies proof of a successful subscale flight in the CDR milestone report.	Inspection	Project Management	Verified	Subscale flight results were discussed in the CDR.
NASA 2.18.1	Vehicle Demonstration Flight - All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	The team launches and recovers the full-scale launch vehicle in its final flight configuration prior to the FRR milestone.	Demonstration	Project Management	Verified	The VDF was completed in which the launch vehicle was successfully launched and recovered on February 21, 2021. See section 5.1 for VDF results.
NASA 2.18.1.1	The vehicle and recovery system SHALL function as designed during the VDF.	No anomalies are detected in the performance of the launch vehicle and its recovery system during the VDF.	Demonstration	Project Management	Verified	The launch vehicle and recovery system functioned as designed during the VDF. See section 5.1 for VDF results.
NASA 2.18.1.2	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, designed and build specifically for this year's project.	Inspection	Project Management	Verified	The full scale rocket was newly constructed, designed, and built specifically for this year's project. See section 3.3 for construction details.
NASA 2.18.1.3.1	If the payload is not flown on the VDF, mass simulators SHALL be used to simulate the payload mass.	If the payload is not flown on the VDF, the structures lead installs mass simulators to simulate the payload mass.	Inspection	Structures	Verified	The team flew a mass simulator on the VDF. See section 3.1.7 for mass simulator details.

NASA 2.18.1.3.2	Payload mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	If the payload is not flown on the VDF, the structures lead install mass simulators in the same approximate location of the missing payload mass.	Inspection	Structures	Verified	The mass simulator was made the same general shape, size, mass, and had approximately the same CG of the payload, and was located in the same section of the launch vehicle and in the same orientation as the payload. See section 3.3.6 for mass simulator details.
NASA 2.18.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	If the payload changes the external surfaces or manages the total energy of the launch vehicle, the project management team activates those systems during the VDF.	Inspection	Project Management	Verified	The payload does not change any external surfaces or manage the total energy of the vehicle. See section 4.4 for final payload design.
NASA 2.18.1.5	Teams SHALL fly the Launch Day motor for the Vehicle Demonstration Flight.	The aerodynamics lead installs the Launch Day motor for the VDF.	Inspection	Aerodynamics	Verified	The team flew an Aerotech L1520T motor for the VDF. See section 5.1 for VDF results and details.

NASA 2.18.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight.	The structures lead installs all required ballast for the VDF.	Inspection	Structures	Verified	The launch vehicle was flown in its fully ballasted configuration during the VDF. No ballast was installed in the launch vehicle aside from the mass simulator. See section 5.1 for VDF details.
NASA 2.18.1.7	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).	Following a successful VDF, the project management team does not allow modification of the launch vehicle or any of its components without approval from the NASA RSO.	Inspection	Project Management	Verified	The team will not modify components of the launch vehicle without approval from the NASA RSO. The proposed main parachute bay and AV coupler change has been approved by the Student Launch team.
NASA 2.18.1.8	Proof of a successful flight SHALL be supplied in the FRR report. Altimeter data output is required to meet this requirement.	The recovery lead includes altimeter data from the VDF in the FRR milestone report.	Inspection	Recovery	Verified	Proof of a successful VDF has been included in this report in section 5.1. Altimeter data from the VDF is supplied in section 5.1.3

NASA 2.18.1.9	Vehicle Demonstration flights SHALL be completed by the FRR submission deadline. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team completes the VDF by the FRR milestone report submission deadline. If a re-flight is required, the team submits an FRR addendum by the FRR addendum deadline.	Inspection	Project Management	Verified	The team completed the VDF on February 21, 2021. VDF Re-Flight information will be included in the FRR Addendum.
NASA 2.18.2	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 on Launch Day.	The team completes the PDF prior to the PDF deadline using the same rocket to be flown on Launch Day.	Inspection	Project Management	Not verified	The team plans on completing the PDF on March 20, 2021. See section 5.2 for the current PDF plan. This requirement will be verified following successful completion of the PDF.
NASA 2.18.2.1	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 remains fully retained until the point of intended deployment with each retention mechanism functioning as designed and not sustaining damage requiring repair during the PDF.	Demonstration	Payload Integration	Not verified	During the PDF, the payload will be inspected to verify proper retention until the desired deployment point at 700 ft. AGL. The payload retention system will be inspected for damage. This requirement will be verified following demonstration of retention during the

						PDF. See section 5.1.3 for payload retention systems active during the VDF.
NASA 2.18.2.2	The payload flown SHALL be the final, active version.	The payload flown on the PDF is the final, active version of the payload.	Inspection	Project Management	Not verified	The payload flown on the PDF will be the final, active version. This requirement will be verified by inspection of the payload installed during the PDF.
NASA 2.18.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline.	The PDF is completed by the FRR Addendum deadline.	Inspection	Project Management	Not verified	The team plans on completing the PDF on March 20, 2021. See section 5.2 for the current PDF plan. This requirement will be verified following successful completion of the PDF.

NASA 2.19	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	The FRR Addendum will be completed by March 29, 2021. This requirement will be verified at the FRR Addendum.
NASA 2.19.1	If a re-flight is necessary, the team SHALL submit the FRR Addendum by the FRR Addendum deadline.	The team lead submits the FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Not verified	The FRR Addendum will be completed by March 29, 2021. This requirement will be verified at the FRR Addendum.
NASA 2.19.2	The team SHALL successfully execute a PDF to fly a final competition launch.	The project management team manages the schedule such that a PDF is successfully completed by the FRR Addendum deadline.	Demonstration	Project Management	Not verified	The team plans on completing the PDF on March 20, 2021. See section 5.2 for the current PDF plan. This requirement will be verified following successful completion of the PDF.

NASA 2.20	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 team lead places their contact information on the rocket airframe and any section of the vehicle that is not tethered to the main airframe in a manner that allows this information to be retrieved without opening or separating the vehicle.	Inspection	Project Management	Verified	The team lead has written their Launch Day contact information on the aft AV bay coupler. See Figure 3-30 for an image of this information.
NASA 2.21	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 safety team ensures all Lithium Polymer batteries are sufficiently protected from ground impact and are marked appropriately.	Analysis; Inspection	Safety	Verified	The only Lithium Polymer battery is on the AV sled to power the GPS. It is shielded from impact and is indicated on the AV sled as seen in Figure 3-41.
NASA 2.22.1	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics lead designs the launch vehicle such that it does not utilize forward firing motors.	Inspection	Aerodynamics	Verified	The final launch vehicle design does not include forward firing motors.
NASA 2.22.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, Metal-Storm, etc.)	The aerodynamics lead selects a motor that does not expel titanium sponges.	Analysis; Inspection	Aerodynamics	Verified	See section 1.2.2 for the final motor selection.
NASA 2.22.3	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics lead selects a motor which uses exclusively APCP.	Analysis; Inspection	Aerodynamics	Verified	See section 1.2.2 for the final motor selection.

NASA 2.22.4	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics lead selects a single motor only for use in the launch vehicle.	Analysis; Inspection	Aerodynamics	Verified	See section 1.2.2 for the final motor selection.
NASA 2.22.5	The launch vehicle SHALL not utilize friction fitting for motors.	The structures lead installs a motor retention system that does not use friction fitting.	Inspection	Structures	Verified	See section 3.3.3.3 for the final launch vehicle motor retention design.
NASA 2.22.6	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 flight.	Analysis	Aerodynamics	Verified	See section 3.5.2 for the final launch vehicle performance predictions.
NASA 2.22.7	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad	The aerodynamics lead designs the launch vehicle such that it does not require ballast exceeding 10% of the total unballasted weight of the launch vehicle.	Analysis; Inspection	Aerodynamics	Verified	No ballast was included on the launch vehicle for VDF. See section 5.1 for VDF details.
NASA 2.22.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The safety team verifies all transmitters activated prior to landing are not capable of transmissions exceeding 250 mW of power per transmitter.	Analysis	Safety	Verified	The Eggfinder TX transmitter and POS image transmitter both use 100 mW of power. See section 3.4.6 for tracker details, see section 4.4.3 for image transmitter details. The BRB 900 GPS uses 250 mW of power. See section

						4.4.3 for payload tracker details.
NASA 2.22.9	Transmitters SHALL not create excessive interference. Teams SHALL utilize unique frequencies, hand-shake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The safety team verifies no transmitter creates excessive interference. The safety team enforces the usage of unique frequencies to mitigate interference with other teams.	Analysis; Demonstration	Safety	Verified	See the FRR Flysheet for transmitter handshake and interference mitigation information.
NASA 2.22.10	Excessive and/or dense metal SHALL not be utilized in the construction of the vehicle.	The structures lead minimizes the amount of metal onboard the launch vehicle.	Inspection	Structures	Verified	The final design includes metal only for threaded rods for the AV bay, the payload internal chassis, and on the payload levelling system. See section 3.1.5 for AV bay discussion, and section 4.4.1 for leveling system and chassis discussion.

NASA 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.	The recovery lead designs a dual-deployment recovery system.	Demonstration	Recovery	Verified	The dual-deployment recovery system functioned successfully during the VDF. See section 3.4.1 for recovery system details.
NASA 3.1.1	The main parachute SHALL be deployed no lower than 500 feet.	The recovery lead designs the recovery system such that the main parachute deploys no lower than 500 feet.	Demonstration	Recovery	Verified	The main parachute was deployed at 700 feet on the VDF. See section 3.4.3.1 for recovery system details.
NASA 3.1.2	The apogee event SHALL contain a delay of no more than 2 seconds.	The recovery lead designs the recovery system such that the apogee event has a delay of no more than 2 seconds.	Demonstration	Recovery	Verified	No apogee delay is programmed for the primary altimeter. A one second apogee delay is programmed for the secondary altimeter. See section 3.4.5.1 for final recovery system design. This configuration was flown on the VDF.
NASA 3.1.3	Motor ejection SHALL not be used for primary or secondary deployment.	The recovery lead designs a recovery system that does not utilize motor ejection.	Inspection	Recovery	Verified	Motor ejection is not used for any recovery events. See section 3.4.1 for final recovery system design.

NASA 3.2	The 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 performs a ground ejection test for each electronically initiated recovery event prior to the initial flights of the subscale and full scale launch vehicles.	Demonstration	Recovery	Verified	The team plans on completing ground ejection testing prior to the full scale launches. Ejection testing was completed on November 13, 2020 for the subscale launch vehicle and on February 19, 2020 for the full scale launch vehicle.
NASA 3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing.	The recovery lead designs a recovery system that results in no launch vehicle section having a kinetic energy greater than 75 ft-lbf at landing.	Analysis	Recovery	Verified	The maximum section kinetic energy at landing is 61.8 ft-lbf in the worst-case scenario where the payload fails to leave the payload bay. See section 3.5.6 for final recovery system calculations.
NASA 3.4	The recovery system SHALL contain redundant, commercially available altimeters.	The recovery lead includes at least two independent commercially available altimeters in the recovery system.	Inspection	Recovery	Verified	The recovery system contains two redundant Stratologger CF altimeters. See section 3.4.5.1 for final altimeter selection.

NASA 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 the recovery system such that each altimeter has a dedicated power supply of commercially available batteries.	Inspection	Recovery	Verified	Each altimeter is powered by a dedicated off-the-shelf 9V battery. See section 3.4.5.4 for final avionics system design.
NASA 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 installs dedicated mechanical arming switches accessible from the exterior of the launch vehicle airframe for each altimeter.	Inspection	Recovery	Verified	Each altimeter is capable of being armed by a screw switch accessible through a hole in the avionics bay airframe. See section 3.4.5.3 for final avionics system design.
NASA 3.7	Each arming switch SHALL be capable of being locked in the ON position for launch.	The recovery lead selects mechanical arming switches capable of being locked in the ON position.	Inspection	Recovery	Verified	Each altimeter is armed by a screw switch, which once tightened, is locked in the on position. See section 3.4.5.3 for final avionics system design.
NASA 3.8	The recovery system electrical circuits SHALL be completely independent of any payload electrical circuits.	The recovery lead designs the recovery system so that its electrical circuits are completely independent of any payload electrical circuits.	Inspection	Recovery	Verified	The recovery system electrical circuits are completely independent and located separately from all payload electrical circuits. See section 3.4.5 for final

						avionics system design.
NASA 3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The recovery lead designs the recovery system to use removable shear pins for the main parachute compartment and drogue parachute compartment.	Inspection	Recovery	Verified	#4-40 Nylon shear pins are used on the main and drogue parachute compartments. See section 3.4.1 for final recovery system design.
NASA 3.10	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The recovery lead selects parachutes that prevent the launch vehicle from drifting more than 2,500 ft. from the launch pads.	Analysis; Demonstration	Recovery	Verified	The maximum predicted wind drift is 2386 feet. See section 3.5.8 for final recovery system performance calculations. The wind drift on the VDF was 1022 feet. See section 5.1.3 for VDF results.
NASA 3.11	Descent time of the launch vehicle SHALL be limited to 90 seconds (apogee to touch down).	The recovery lead selects parachutes that allow the launch vehicle to touch down within 90 seconds of reaching apogee.	Analysis; Demonstration	Recovery	Verified	The maximum predicted descent time is 81 seconds. See section 3.5.7 for final recovery system performance calculations. Descent

						time on the VDF was 59.5 seconds. See section 5.1.3 for VDF results.
NASA 3.12	An electronic 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 selects and installs an electronic tracking device capable of transmitting the position of the launch vehicle or any independent section to a ground receiver.	Inspection; Demonstration	Recovery	Verified	An EggFinder TX/RX system is used for launch vehicle tracking. A BigRedBee BRB 900 is used for payload tracking. Both of these systems transmit to ground receivers. See section 3.4.6 for final tracking device selection. See section 3.3.5 for EggFinder installation on the AV sled. See section 7.1.1.8 for GPS transmitter test results.
NASA 3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic tracking device.	The recovery lead installs an electronic tracking device in any launch vehicle section or payload component which lands untethered to the launch vehicle.	Inspection	Recovery	Verified	The payload is the only untethered component of the launch vehicle. It contains its own tracking device. See section 4.4.3 for final

						tracking device selection.
NASA 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 the recovery system such that it is not affected by other on-board electronic devices.	Demonstration	Recovery	Verified	Recovery system electronics were not adversely affected on the VDF. See section 3.4.5 for avionics system details.
NASA 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 which houses the recovery system altimeters in a physically separate compartment within the launch vehicle.	Inspection	Recovery	Verified	All recovery system altimeters are located in the avionics bay, which is physically separate from the rest of the launch vehicle. See section 3.4.5 for final avionics system design.
NASA 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 and installs shielding for the recovery system electronics from all onboard transmitting devices.	Inspection	Recovery	Verified	The recovery electronics are shielded from onboard transmitters with aluminum foil. See section 3.4.5 for shielding details.

NASA 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 and installs shielding for the recovery system electronics from all devices which may generate magnetic waves.	Inspection	Recovery	Verified	The recovery electronics are shielded from the payload solenoid latches with aluminum foil. See section 3.4.5 for shielding details.
NASA 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 and installs shielding for the recovery system electronics from all devices which may adversely affect the proper operation of the recovery system electronics.	Inspection	Recovery	Verified	The recovery electronics are shielded with aluminum foil. See section 3.4.5 for shielding details.

NASA 4.2	The team SHALL design a planetary landing system to be launched in a high-power rocket. The lander system SHALL be capable of being jettisoned from the rocket during descent, landing in an upright configuration or autonomously uprighting after landing. The system SHALL self-level within a five-degree tolerance from vertical. After autonomously uprighting and self-leveling, it SHALL take a 360-degree panoramic photo of the landing site and transmit the photo to the team.	The payload team designs a planetary landing system to be launched in a high-powered rocket. The payload is capable of being jettisoned from the launch vehicle during descent, landing in an upright configuration or autonomously uprighting after landing, self-levelling within a five-degree tolerance from vertical, and taking a 360-degree panoramic photo of the landing site and transmitting the photo to the team.	Demonstration	Payload vehicle; Payload integration; Payload imaging	Not verified	See section 4.4 for final payload design. This requirement will be verified by successful demonstration of payload capabilities during the PDF.
NASA 4.3.1	The landing system SHALL be completely jettisoned from the rocket at an altitude between 500 and 1,000 ft. AGL. The landing system SHALL land within the external borders of the launch field. The landing system SHALL not be tethered to the launch vehicle upon landing.	The payload integration lead designs the payload such that it jettisons from the launch vehicle between 500 and 1,000 AGL, lands within the external border of the launch field, and is not tethered to the launch vehicle.	Demonstration	Payload integration	Not verified	The payload will be removed from the payload bay at 700 ft. AGL. The payload will release itself from the launch vehicle at 500 ft. AGL. See section 4.5 for final payload jettison design. This requirement will be verified by demonstration of payload deployment

						during the PDF. See section 5.1.3 for payload jettison systems operated during the VDF.
NASA 4.3.2	The landing system SHALL land in an upright orientation or SHALL be capable of reorienting itself to an upright configuration after landing. Any system designed to reorient the lander SHALL be completely autonomous.	The payload vehicle lead designs the payload such that it lands in an upright position or reorients itself to an upright configuration after landing using a completely autonomous system.	Demonstration	Payload vehicle	Not verified	The lander is designed to land in an upright orientation. See section 4.4.1 for final payload lander design. This requirement will be verified by successful levelling system performance during ground demonstrations or during the PDF.
NASA 4.3.3	The landing system SHALL self-level to within a five-degree tolerance from vertical.	The payload vehicle lead designs the payload such that it is capable of self-leveling within a five-degree tolerance from vertical.	Demonstration	Payload vehicle	Verified	The leveling system is designed to self-level to within 5 degrees of vertical and can accommodate up to a 23-degree slope. See section 7.1.4 for

						LOPSIDED tilt range test results.
NASA 4.3.3.1	Any system designed to level the lander SHALL be completely autonomous.	The payload vehicle lead designs a payload leveling system that is completely autonomous.	Demonstration	Payload vehicle	Not verified	The leveling system is completely autonomous. See section 4.4.1 for final payload leveling system design. This requirement will be verified by autonomous levelling system operation during the PDF.
NASA 4.3.3.2	The landing system SHALL record the initial angle after landing, relative to vertical, as well as the final angle, after reorientation and self-levelling. This data SHALL be reported in the Post Launch Assessment Report (PLAR).	The payload vehicle lead designs a payload leveling system which records the initial angle after landing as well as the final angle relative to vertical. The payload vehicle lead reports this data in the PLAR.	Demonstration	Payload vehicle	Not verified	The lander will record the initial and final angles relative to vertical. See section 4.4.1 for final payload leveling system design. This requirement will be verified by demonstrating the recorded angles during the PDF.

NASA 4.3.4	Upon completion of reorientation and self-levelling, the lander SHALL produce a 360-degree panoramic image of the landing site and transmit it to the team.	The payload imaging lead designs an imaging system capable of producing a 360-degree panoramic image and transmitting it to the team following self-levelling of the payload vehicle.	Demonstration	Payload imaging	Not verified	Four cameras allow the lander to capture a 360-degree panoramic image. Slow-scan television will be used to transmit the image to the team. See section 4.4.2 for final imaging system design. This requirement will be verified by demonstrating imaging system performance during the PDF.
NASA 4.3.4.1	The hardware receiving the image SHALL be located within the team's assigned prep area or the designated viewing area.	The payload imaging lead selects a ground station capable of receiving the image and being located within the team's prep area or designated viewing area.	Inspection	Payload imaging	Not verified	The laptop used to receive the lander's image will be located within either the team's assigned prep area or the designated viewing area. See section 4.4.2 for final imaging system design. This requirement will be verified by inspecting the location of the team's laptop during the PDF.

NASA 4.3.4.2	Only transmitters that were onboard the vehicle during launch SHALL be permitted to operate outside of the viewing or prep areas.	The team does not operate transmitters outside the viewing or prep areas that were not onboard the vehicle during launch.	Demonstration	Payload imaging	Verified	No transmitters will be used that were not onboard the launch vehicle at launch. See the FRR Flysheet for transmitter information.
NASA 4.3.4.3	Onboard payload transmitters SHALL be limited to 250 mW of RF power while onboard the launch vehicle but may operate at a higher RF power after landing on the planetary surface. Transmitters operating at higher power SHALL be approved by NASA during the design process.	The payload imaging lead selects onboard transmitters limited to 250 mW of RF power while onboard the launch vehicle. The payload imaging lead receives approval from NASA for operating transmitters outside of the launch vehicle at higher power.	Inspection	Payload imaging	Verified	No transmitter will be operated at power levels exceeding 250 mW. See section 4.4.3 for final image transmitter system design. See the FRR Flysheet for transmitter information.
NASA 4.3.4.4	The image SHALL be included in the team's PLAR.	The payload imaging lead includes the captured image in the PLAR.	Inspection	Payload imaging	Not verified	The team will include the lander's image in the PLAR. This requirement will be verified at the PLAR milestone.

NASA 4.4.1	Black powder and/or similar energetics SHALL only be used for deployment of in-flight recovery systems.	The payload integration lead designs the payload recovery system such that any energetics are only utilized in-flight.	Inspection	Payload integration	Verified	Black powder is only used in-flight with the ARRD to separate the payload vehicle from the main parachute recovery harness and deploy the payload parachute. See section 4.5 for final payload deployment design.
NASA 4.4.2	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	The final payload design complies with all FAA and NAR rules and regulations. All FRR and NAR rules and regulations were followed at the VDF. This requirement will be verified following demonstration of adherence to FAA and NAR rules and regulations at the PDF.
NASA 4.4.3	Any experiment element that is jettisoned, except for planetary lander experiments, during the recovery phase SHALL receive real-time RSO permission prior to initiating the jettison event.	The payload integration lead receives real-time RSO permission prior to initiating the jettison of any experiment element except for the planetary lander.	Demonstration	Payload integration	Verified	The team is not including a secondary payload experiment.

NASA 4.4.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, SHALL be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	The payload integration lead designs any UAS payload to be tethered to the launch vehicle with a remotely controlled release mechanism until the RSO gives permission to release the UAS.	Demonstration	Payload integration	Verified	The final payload design is not a UAS.
NASA 4.4.5	Teams flying UASs SHALL abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336).	The safety team verifies any UAS payload's compliance with all applicable FAA regulations.	Demonstration	Safety	Verified	The final payload design is not a UAS.
NASA 4.4.6	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	The payload vehicle lead registers any UAS weighing more than .55 lbs with the FAA and marks the registration number of the vehicle.	Demonstration	Payload vehicle	Verified	The final payload design is not a UAS.
NASA 5.1	The team SHALL use a launch and safety checklist. The final checklists SHALL be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	The safety team creates a launch and safety checklist. The safety team includes these checklists in the FRR milestone report and verifies their use during LRR and Launch Day operations.	Inspection; Demonstration	Safety	Verified	Launch and safety checklists are presented in section 6.2 of this document.

NASA 5.2	Each team SHALL identify a student safety officer who will be responsible for all items in requirements section 5.3.	A safety officer is identified in each milestone report.	Inspection	Project management	Verified	See section 6.1.1 for safety officer identification.
NASA 5.3.1.1	The safety officer SHALL monitor team activities with an emphasis on safety during the design of the launch vehicle and payload.	The safety officer is present for and engages in at least half of all launch vehicle and payload design meetings.	Inspection	Safety	Verified	The safety officer has been present for more than half of all design meetings. See section 6.1.1.
NASA 5.3.1.2	The safety officer SHALL monitor team activities with an emphasis on safety during the construction of the launch vehicle and payload components.	The safety officer is present and engaged for all launch vehicle and payload construction meetings.	Inspection	Safety	Verified	The safety officer has been present for all construction activities. See section 6.1.1
NASA 5.3.1.3	The safety officer SHALL monitor team activities with an emphasis on safety during the assembly of the launch vehicle and payload.	The safety officer is present and engaged during the assembly of the launch vehicle and payload.	Inspection	Safety	Verified	The safety officer was present and monitored monitoring assembly of the subscale and full scale launch vehicle and payload. See section 6.2 for launch day checklists with safety officer verification.
NASA 5.3.1.4	The safety officer SHALL monitor team activities with an emphasis on safety during the ground testing of the launch vehicle and payload.	The safety officer is present and engaged for all ground tests of the launch vehicle and payload.	Inspection	Safety	Verified	The safety officer has been present all ground testing. See section 6.1.1

NASA 5.3.1.5	The safety officer SHALL monitor team activities with an emphasis on safety during the subscale launch test(s).	The safety officer is present and engaged at any subscale launch test.	Inspection	Safety	Verified	The safety officer attended the subscale launch test and supervised all steps of the assembly, launch, and recovery procedure. Safety officer sign-offs on subscale launch checklists were presented in the CDR document.
NASA 5.3.1.6	The safety officer SHALL monitor team activities with an emphasis on safety during the full-scale launch test(s).	The safety officer is present and engaged at any full-scale launch test.	Inspection	Safety	Verified	The safety officer attended and supervised the full scale launch test. See section 6.2 for launch day checklists with safety officer verification.
NASA 5.3.1.7	The safety officer SHALL monitor team activities with an emphasis on safety during Launch Day.	The safety officer is present and engaged at Launch Day.	Inspection	Safety	Verified	The safety officer will attend launch day. See section 6.1.1.
NASA 5.3.1.8	The safety officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The safety officer is present and engaged for all recovery activities.	Inspection	Safety	Verified	The safety officer is assigned to the field recovery team. See section 6.2, checklist 11 for field recovery personnel assignments.

NASA 5.3.1.9	The safety officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The safety officer is present and engaged for at least half of all STEM engagement activities.	Inspection	Safety	Verified	The safety officer has attended over half of the team's STEM engagement activities. See section 6.1.1.
NASA 5.3.2	The safety officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer develops a safety plan for construction, assembly, launch, and recovery activities, and verifies team adherence to this plan.	Demonstration	Safety	Verified	The safety officer has implemented procedures for construction, assembly, launch, and recovery activities. See section 6.2 for launch and safety checklists.
NASA 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 safety officer manages and maintains current revisions of all hazard analyses, procedures, and MSDS/chemical inventory data.	Demonstration	Safety	Verified	The safety officer is responsible for maintaining hazard analyses, procedures, and MSDS/chemical inventory data. See section 6.1.2.
NASA 5.3.4	The safety officer SHALL assist in the writing and development of the team’s hazard analyses, failure modes analyses, and procedures.	The safety officer leads in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	Safety	Verified	The safety officer has written the team's hazard analysis and failure mode analysis in Section 6.1.3. See section 6.1.1 for details.

NASA 5.4	During test flights, the team SHALL abide by the rules and guidance of the local rocketry club's RSO. Teams SHALL communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The safety officer communicates the team's intentions to the local club's President or Prefect and RSO prior to attending any NAR or TRA launch. The safety officer verifies team adherence to the rules and guidance of the local club's RSO.	Demonstration	Safety	Not verified	The team abided by the rules and guidance of the local club's RSO at the VDF. The team has communicated our intentions to the local club's Prefect. This requirement will be verified by demonstration of adherence to local RSO guidance at the PDF.
NASA 5.5	Teams SHALL abide by all rules set forth by the FAA.	The safety officer verifies the team adheres to all rules set forth by the FAA.	Demonstration	Safety	Not verified	The team currently complies with all FAA regulations. This requirement will be verified at the FRR milestone by demonstration of adherence to FAA rules at the PDF.

7.2.2 Team-Derived Requirements

Table 7-16 below shows the Team-Derived Requirements verification matrix. All requirements have been verified except those remaining to be verified at the PDF.

Table 7-16 Team-Derived Requirements Verification Matrix

Req No.	Shall Statement	Justification	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
TDR 1.1	Epoxy SHALL be left to cure for at least 24 hours prior to use	Uncured epoxy weakens the overall system, making components vulnerable to structural failure	Epoxied components are unmoved from their position until the date and time indicated on their respective label.	Inspection	Safety	Verified	All construction was completed using a 24-hour epoxy cure time. See section 3.3.1.2 and Figure 3-27 for construction details.
TDR 1.2	Launch day attendees SHALL be instructed to wear closed-toed shoes and maintain a walking pace at all times, including during assembly, launch, and recovery	Maintaining a walking pace at all times will decrease the likelihood of slips, trips, and falls contributing to personnel injury	Team members have one foot on the ground at all times.	Inspection	Safety	Verified	All launch day procedures explicitly prohibit running. Launch day safety briefings include instructions to walk at all times. See section 6.2 for launch and safety checklists
TDR 1.3	Safety glasses SHALL be provided to personnel working with power tools	The use of personal protective equipment will reduce the likelihood of skin and eye injury from large and small debris due to working with power tools	The number of safety glasses in the PPE cabinet matches or exceeds the number of personnel working with power tools.	Inspection	Safety	Verified	Safety glasses are provided in the lab space and all team members are instructed to use safety glasses when operating power tools. See section 6.1.3 for safety procedure details.

TDR 1.4	Nitrile gloves, safety glasses, and particulate masks SHALL be provided to personnel working with volatile liquid and powder chemicals	The use of PPE will reduce the likelihood of skin, eye, and lung irritation due to working with volatile liquids or powders	The number of glove pairs, safety glasses, and particulate masks in the PPE cabinet matches or exceeds the number of personnel working with volatile liquids and/or powders (max 3).	Inspection	Safety	Verified	Nitrile gloves, safety glasses, and particulate masks are provided in the lab space and all team members are instructed to use appropriate PPE when working with volatile liquid and powder chemicals. See section 6.1.3 for safety procedure details.
TDR 2.1	The launch vehicle airframe SHALL be water resistant.	The team's home launch field in Bayboro, NC has several large irrigation ditches that are typically filled with water. Should the launch vehicle land in the water, a water-resistant airframe will help reduce potential damage.	The airframe is not damaged or deformed upon exposure to water.	Inspection, Analysis	Structures	Verified	G12 Fiberglass has been selected as a water-resistant material for the launch vehicle airframe. See section 3.2.1.1 for details on material selection.

TDR 2.2	All critical components of the launch vehicle SHALL be designed with a minimum factor of safety of 2.	This will ensure that assumptions made in analysis or higher than expected loading will not cause unpredicted failure during flight. A factor of safety of 2 has been deemed sufficient to account for unexpected loading, while allowing components to remain lightweight.	The factor of safety of each critical component is reported in documentation and proven by structural testing.	Analysis, Test	Structures	Verified	Factor of safety is at least 2 for all structural components. See section 3.2.1.3 for details on simulations. See section 7.1.1.1 for testing details.
TDR 2.3	The launch vehicle SHALL be no larger than 6 inches in diameter.	Limiting the size of the launch vehicle makes it safer and easier to manipulate on the field.	The diameter of the airframe is not larger than 6 inches.	Inspection	Aerodynamics, Structures	Verified	The final launch vehicle airframe selection is 6 inches in diameter. See section 3.1.1 for launch vehicle design.
TDR 2.4	The launch vehicle SHALL maintain speeds below transonic (M<=0.7)	Transonic speeds leave the launch vehicle vulnerable to fin flutter and delamination that can cause irreparable structural failure and total flight failure	Simulations in RockSim are performed to confirm the launch vehicle's maximum velocity.	Analysis	Safety	Verified	The maximum flight velocity of the launch vehicle is 481.32 ft/s. See section 3.5.2 for mission performance predictions.

TDR 3.1	The secondary black powder charges SHALL be of greater mass than the primary black powder charges.	In the event the primary black powder charge fails to cause section separation, a larger charge will have a better chance of successful separation.	The secondary black powder charges when weighed are of greater mass than the primary black powder charges.	Inspection	Recovery	Verified	The secondary black powder charges are 0.5g larger than the primary black powder charges. See section 3.4.7 for black powder charge sizing calculations. These charges were flown during the VDF.
TDR 3.2	The launch vehicles blast caps SHALL be exposed and accessible.	Accessible energetic materials containers allow for safer loading of energetic materials.	The designed Avionics Bay has easily accessible blast caps.	Inspection	Structures; Recovery	Verified	The avionics bay is designed to leave all blast caps exposed and accessible. See section 3.4.2.1 for the as-built AV bay design.
TDR 3.3	Drogue descent velocity SHALL be less than 125 fps.	This speed will minimize main parachute opening shock.	Calculations for launch vehicle velocity under drogue parachute are less than 125 fps.	Analysis	Recovery	Verified	Drogue descent velocity is 120.6 fps. See section 3.5.7 for descent velocity calculations.
TDR 3.4	The black powder ejection charges SHALL produce at least 10 psi.	This 10 psi target will produce sufficient force in most cases to shear a reasonable number of shear pins.	Black powder ejection charge calculations indicate a pressure of 10 psi will be reached.	Analysis	Recovery	Verified	The black powder charges will produce 10 psi for drogue and 15 psi for main. See section 3.4.7 for black powder charge sizing calculations.

TDR 3.5	The launch vehicle SHALL use U-bolts for all recovery harness attachment points.	U-bolts reduce the chance of a single point of failure and distribute the opening shock across the bulkhead.	The load bearing bulkheads have recovery attachment points that use U-bolts.	Inspection	Recovery	Verified	U-Bolts are used for all recovery harness attachment points. See section 3.2.1.3(d) for bulkhead design.
TDR 3.6	The launch vehicle SHALL use threaded quick-links for all recovery harness attachment points.	Thread quick-links reduce the likelihood of recovery harness detachment due to flight forces.	The recovery harness will be attached at all points by threaded quick-links.	Inspection	Recovery	Verified	Threaded quick-links are used for all recovery harness attachment points. See section 3.4.2.3 for recovery component selection.
TDR 3.7	A deployment bag SHALL be utilized for packing of the main parachute.	Deployment bags reduce the likelihood of parachute damage from hot ejection charge gasses and reduce reliance on folding technique for proper parachute deployment.	A deployment bag will be utilized to pack the main parachute.	Inspection	Recovery	Verified	A deployment bag is used to pack the main parachute. See section 3.4.4.2 for recovery component selection.
TDR 3.8	The onboard altimeters SHALL use one 9V battery for each flight.	StratoLogger CF Altimeters use one 9V battery each.	The avionics sled is designed to hold two 9V batteries, one for each altimeter.	Inspection	Recovery	Verified	Each altimeter is connected to a single 9V battery. See section 3.4.5.4 for avionics sled design.

TDR 3.9	A fresh 9V battery SHALL be selected for both onboard altimeters before each flight.	The system must be capable of remaining powered on for prolonged periods of time.	Each 9V battery placed on the avionics sled before flight must measure greater than 9 V before flight.	Inspection	Recovery	Verified	See checklist item 4.1 in section 6.2 for verification of battery voltage. Fresh 9V batteries were selected for all onboard altimeters on the VDF.
TDR 3.10	The recovery system SHALL be capable of recovering the launch vehicle within NASA Handbook requirements should the LOPSIDED-POS fail to separate from the launch vehicle.	The system must be robust enough to accommodate potential mission failures.	Descent calculations are within limits even should the payload fail to separate.	Analysis	Recovery	Verified	The recovery system meets all NASA handbook requirements with the LOPSIDED-POS still onboard. See section 3.5.6 for descent calculations.

TDR 4.1	The POS SHALL capture two separate 360-degree images, offset by 90 degrees.	Capturing two images provides redundancy in a variety of camera-failure events.	Each POS camera is capable of capturing at least a 180-degree field of view.	Demonstration	Payload Imaging	Verified	The POS includes four cameras mounted at 90-degree angles from each other. Each camera has a 194-degree field of view. This allows for the capture of two separate 360-degree images. See section 4.4.2 for POS camera design. See Figure 4-10 for test panoramic image captured by the POS.
TDR 4.2	POS cameras SHALL be protected from physical damage associated with launch, deployment, and landing while having a proper field of view for image capture.	If the camera modules are damaged, the ability of the payload to capture 360-degree images will be compromised.	The top section of LOPSIDED allows cameras to be housed with significant protection and field of view.	Analysis	Payload Imaging	Verified	The POS cameras are isolated within LOPSIDED to mitigate the risk of damage during flight. The polycarbonate section provides the POS cameras with an adequate field of view. See section 4.4.2 for description of current payload design.
TDR 4.3	POS electronics SHALL fit in a 69 x 69 x 190 mm volume.	The payload vehicle size is constrained by the 6-inch launch vehicle diameter, as well as hardware for the self-leveling system.	The POS electronics, not including the camera modules, successfully fit within LOPSIDED.	Inspection	Payload Imaging	Verified	The POS electronics fit within a 69 x 69 x 190 mm volume. See section 4.4.4 for description of assembled POS.

TDR 4.4	POS electronics, excluding the camera modules, SHALL be contained below the pivoting axis of LOPSIDED's leveling system.	For the proposed leveling system to work, LOPSIDED must have an overall CG below the pivoting axis.	LOPSIDED is able to self-level after all POS components have been installed.	Inspection	Payload Imaging	Verified	The POS electronics are installed below the pivoting axis of LOPSIDED. See section 4.4.3 for description of payload electronics design.
TDR 4.5	LOPSIDED SHALL fit within a 6-inch diameter constraint.	This allows the LOPSIDED to fit within the Launch Vehicle's payload bay.	LOPSIDED is able to fit within the launch vehicle's payload bay.	Inspection	Payload Vehicle	Verified	The maximum diameter of LOPSIDED is 6 inches. See section 4.4.4 for description of as-built payload design.
TDR 4.6	LOPSIDED SHALL remain locked in its neutral position until after landing and taking its initial orientation measurement.	The payload orientation system must remain locked in order to not damage the launch vehicle, interfere with any deployment mechanisms, and allow for an initial orientation measurement to be recorded.	The gimbal-based leveling system is not allowed to rotate until the initial orientation measurement is recorded.	Demonstration	Payload Vehicle	Not verified	Four solenoid latches will hold LOPSIDED in its neutral position until its initial orientation has been recorded. See section 4.4.1 for description of current payload design. This requirement will be verified at the FRR Addendum following the demonstration of solenoid latch operation.

TDR 4.7	LOPSIDED's legs SHALL deploy immediately after exiting the payload bay.	This will expand the payload's footprint from its stowed configuration, increasing its stability. By having this event happen immediately, this decreases the risk of the legs not deploying in time for landing.	LOPSIDED's legs deploy as soon as they are no longer constrained by the payload bay.	Test	Payload Vehicle	Verified	LOPSIDED's legs are spring-loaded to deploy as soon as they are no longer constrained. See section 4.4.4 for description of LOPSIDED leg design.
TDR 4.8	LOPSIDED's gravity-assisted self-levelling system SHALL allow the body to reorient within ~15 degrees of its neutral orientation.	Given the requirement of being withing 5 degrees of vertical, the design allows for the body to move 15 degrees, allowing LOPSIDED to land on grades of up to 20 degrees in any direction and still complete the mission.	LOPSIDED has at least a 15-degree range of motion about either axis.	Test	Payload Vehicle	Verified	The leveling system is capable of rotating up to 23 degrees. See section 4.4.1 for description of leveling system design. See section 7.1.4 for leveling system test results.
TDR 4.9	LOPSIDED SHALL have an allotted volume of 69x69x69 cubic mm for the POS camera frame to fit within.	This will allow the POS to operate fully without any obstruction and will interface with the rest of LOPSIDED.	LOPSIDED has a 69x69x69 mm internal volume of air.	Analysis	Payload Vehicle	Verified	LOPSIDED has an allotted volume of 69x69x69 cubic mm for the POS camera frame. See section 4.4.1 for description of current payload design.

TDR 4.10	LOPSIDED SHALL have designated mounting point at the top.	This will interface with integration subsystem so that any forces it may receive from that system will not destroy the payload and will allow for the parachutes to detach.	LOPSIDED has four screw rods at its top for the AARD to be mounted to.	Analysis	Payload Vehicle	Verified	LOPSIDED has four screw rods at its top for mounting of the ARRD. See section 4.6.1.3 for description of current payload design.
TDR 4.11	LOPSIDED SHALL have a center of gravity beneath its pivoting axes.	This will allow the levelling system to utilize the force due to gravity and not require any motors to operate.	The LOPSIDED CG is below its pivoting axes.	Analysis	Payload Vehicle	Verified	LOPSIDED's center of gravity lies below its pivoting axes. See section 4.4.1 for description of LOPSIDED design.
TDR 4.12	LOPSIDED-POS SHALL weigh no more than 10.5 lbs.	Maintaining a standard payload weight serves for a stable location of center of gravity for launch vehicle stability purposes.	LOPSIDED-POS has a total weight of 10.5 lbs or less.	Inspection	Payload Vehicle, Payload Integration, Payload Imaging	Verified	LOPSIDED-POS currently weighs 8.5 lbs. See section 4.4.1 for payload design.

TDR 4.13	LOPSIDED SHALL exit within 3 seconds of deployment during jettison	Successful deployment of the payload vehicle depends on the payload being able to slide out of the payload bay	LOPSIDED is completely removed from the payload bay within 3 seconds of deployment.	Test	Payload Integration	Verified	LOPSIDED is designed to be removed from the payload bay within 3 seconds of main deployment. See section 4.5 for payload design. The payload mass simulator was removed from the payload bay approximately 1 second after main parachute deployment during the VDF.
TDR 4.14	The POS SHALL transmit and receive images from up to 2500 feet from the team's ground station.	In the event of excessive wind drift after parachute deployment, image transmissions from the POS will still need to be received.	Images sent by the POS transmitter are successfully received by the ground station from up to 2500 feet away.	Test	Payload Imaging	Not verified	The current POS design is capable of transmitting 1091 ft. See section 4.4.3 for payload design. See section 7.1.2 for image transmission range test results.
TDR 4.15	All on-board LOPSIDED-POS electronics, with the exception of the payload altimeter, SHALL be powered with one battery pack.	Having one battery saves weight and volume on board the LOPSIDED-POS.	One 12V battery will be used to power all electronics housed within the LOPSIDED-POS, excluding the payload altimeter.	Inspection	Payload Vehicle, Payload Integration, Payload Imaging	Verified	LOPSIDED-POS design is powered by a single battery pack. See section 4.4.3 for payload electronics design.

TDR 4.16	LOPSIDED SHALL release the payload parachute upon landing.	Releasing the parachute once LOPSIDED has landed prevents the parachute from interfering with the leveling system if it were to inflate and apply a load.	The parachute detaches completely from LOPSIDED while also not covering POS.	Demonstration	Payload Vehicle, Payload Integration, Payload Imaging	Not verified	The current LOPSIDED-POS design includes a parachute release system. See section 4.6.1.3 for payload deployment and electronics. This requirement will be verified at the FRR addendum following the parachute release test.

7.3 Budgeting and Funding Summary

Table 7-17 below details the year-long budget for the 2020-2021 NASA Student Launch competition.

Table 7-17 2020-2021 NASA Student Launch Competition Budget

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A motor	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	(Already own) $0.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$14.82	$88.92
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$541.42**
Full-Scale Structure	6" G12 Airframe, Full Length (60"), 3 Slots	1	$300.00	$300.00
	6" G12 Airframe, Half Length (30")	1	$114.00	$114.00
	3"/75mm G12 Motor Tube, 22" length	1	$37.00	$37.00
	6” G12 Coupler 14” Length	2	$70.00	$140.00
	6" G12 Coupler 12" Length	2	$66.00	$132.00
	6" Fiberglass 4:1 Ogive Fiberglass Nosecone	1	$149.95	$149.95
	Domestic Birch Plywood 1/8"x2x2	8	$14.82	(Already own) $0.00
	Aerotech 75/3840 Motor Case	1	$360.00	(Already own) $0.00
	75 mm Motor Retainer	1	$72.00	$72.00
	Rail Buttons	4	$2.50	(Already own) $0.00
	U-Bolts	4	$1.00	(Already own) $0.00
	Aerotech L1520T motor	2	$224.00	$448.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	(Already own) $0.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$10.00
	Key Switches	2	$12.00	$24.00

	Subtotal:			**$1,485.45**
Payload	Arducam Camera w/fisheye lens	4	$29.00	$116.00
	Rasberrry Pi multi-camera adapter board	1	$50.00	$50.00
	Rasberrry Pi model 3	1	$35.00	$35.00
	5V battery supply	1	$40.00	$40.00
	Accelerometer	1	$8.00	$8.00
	433 MHz Transmitter	1	$9.95	$9.95
	FFP FPC ribbon cable extension	2	$4.75	$9.50
	SDR Receiver USB stick	1	$22.50	$22.50
	Voltage Converter with USB	1	$7.59	$7.59
	200 mm T8 Lead Screw	4	$10.99	$43.96
	1" OD carbon fiber tube 24" long	4	$39.99	$159.96
	Stepper motor	4	$19.95	$79.80
	Aluminum sheet metal	1	$21.48	$21.48
	1/4" thick acrylic Sheet 24x48	1	$55.37	$55.37
	Arduino uno	1	$17.60	$17.60
	Accelerometer	1	$15.95	$15.95
	Stratologger CF Altimeter	2	$69.95	(Already Own) $0.00
	AARD	1	$119.00	$119.00
	Threaded Rods	3	$6.88	$20.64
	U-bolt	1	$2.66	$2.66
	T-track	2	$33.50	$67.00
	Southco Latch	2	$62.50	$125.00
	Wheels	1	$10.59	$10.59
	Ball bearing	4	$12.96	$51.84
	Subtotal:			**$1,089.39**
Recovery and Avionics	Standoffs	1	$10.99	(Already own) $0.00
	Iris Ultra 120" Parachute	1	$541.97	(Already own) $0.00
	Iris Ultra Compact 60” Parachute	1	$241.88	$241.88
	Stainless Steel Quick Links	14	$1.97	(Already own) $0.00
	5/8 inch Kevlar Shock Cord (yards)	26.7	$6.35	(Already own) $0.00
	Black powder	1	$17.95	$17.95
	E-matches	1	$80.25	$80.25
	Shear Pins Pack of 40	1	$1.00	$1.00
	StratoLogger CF	2	$49.46	(Already Own) $0.00
	Classic Elliptical 18" Parachute	1	$57.17	(Already Own) $0.00
	6" Deployment Bag	1	$46.23	$46.23

	21" Nomex Cloth	1	$27.00	$27.00
	Eggfinder TX Transmitter	1	$70.00	(Already own) $0.00
	Eggfinder TX Receiver	1	$55.00	(Already own) $0.00
	Lipo battery for Eggfinder	1	$17.69	$17.69
	4" Deployment Bag	1	$43.00	(Already Own) $0.00
	13" Nomex Cloth	1	$16.00	$16.00
	3/8 inch threaded rod 2’ length	3	$2.58	$7.74
	3/8 inch spacer	12	$1.30	$15.60
	3/8 inch locknuts	8	$0.19	$1.52
	3/8 inch washers	16	$0.16	$2.56
	Subtotal:			**$475.42**
Miscell.	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	1	$5.50	$5.50
	Screws (box)	1	$5.00	$5.00
	Washers	1	$5.00	$5.00
	Wire	1	$13.00	$13.00
	Zip Ties	1	$11.00	$11.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	1	$25.00	$25.00
	Battery Connectors	3	$5.00	$15.00
	Shipping			$1,000.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,500.00
	Subtotal:			**$2,915.74**
Promotion	T-Shirts	40	$14.00	$560.00
	Polos	30	$25.00	$750.00
	Stickers/Pens	500	$0.37	$185.00
	Outreach Supplies	1	$250.00	$250.00
	Subtotal:			**$1,745.00**
Total Expenses:				**$8,252.42**

Figure 7-10 below shows a budget breakdown for the 2020-2021 competition cycle.

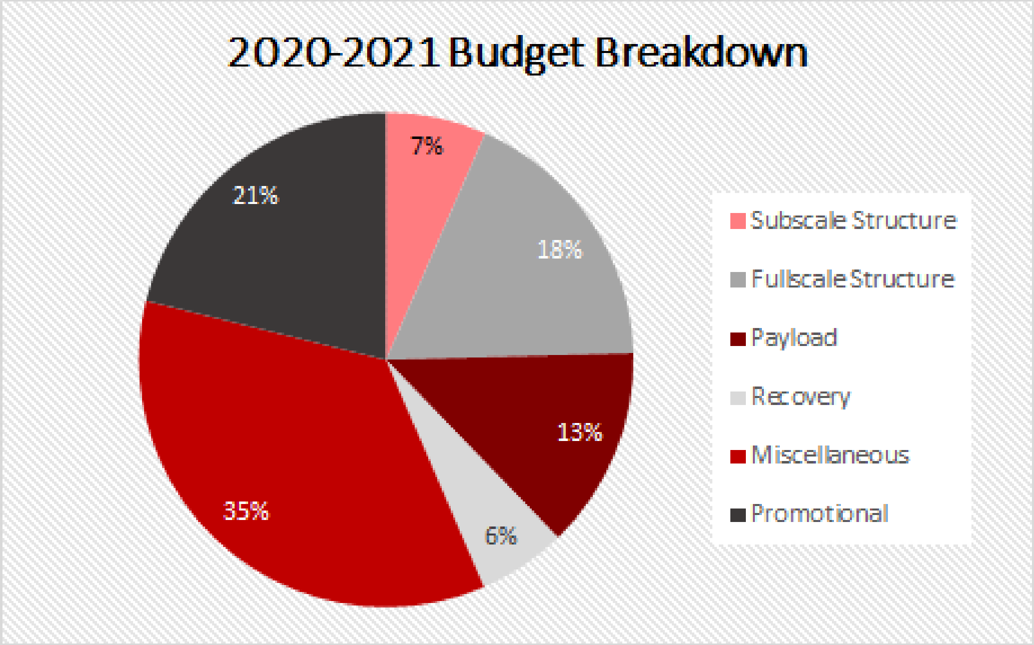


Figure 7-10 2020-2021 Budget Breakdown Chart

HPRC receives all funds from multiple NC State University organization and North Carolina Space Grant (NCSG). Below is a breakdown of the team's current funding sources.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. Each semester the application process consists of a proposal, presentation, and an in-person interview. HPRC received $750 for 2020 fall semester and $1,200 for the 2021 spring semester.

Some project costs will be covered by NC State's College of Engineering Technology Funds. These funds come from a pool of money dedicated to supporting engineering extracurriculars and Senior Design teams at NC State. The total funds dedicated to the High-Powered Rocketry Club from this source comes to an estimated $1,300.

In addition to funding through NC State organizations, North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG has awarded the team the full amount requested. These funds have been made available for use as of November 2020.

In the past, HPRC has held sponsorships with Collins Aerospace, Jolly Logic, and more. The team is currently seeking out new sponsorships and reaching out to past sponsors. The team hopes to gain more in funders within the next few years.

Lastly, our team has previously held funding sources for club travel to the student launch competition at Marshall Space Flight Center. These funding sources are not being used this year due to the cancellation of the in-person competition launch due to the ongoing COVID-19 pandemic.

These totals are listed in Table 7-18 below, which compares the projected costs and incoming grants for the 2020-2021 school year.

Table 7-18 Projected Funding for 2020-2021 Competition

Organization	Fall Semester Amount	Spring Amount	School Year Total
Engineering Technology Fund	-	-	$1,300.00
SGA Appropriations	$750.00	$1,200.00	$1,950.00
NC Space Grant	-	-	$5,000.00
Total Funding:			**$8,250.00**
Total Expenses:			**$8,252.42**
Difference:			**-$2.42**