Tacho Lycos

2024 NASA Student Launch

Flight Readiness Review

High-Powered Rocketry Club at NC State University
1840 Entrepreneur Drive
Raleigh, NC 27606

March 4, 2024

Common Abbreviations and Nomenclature

AGL = Above Ground Level
AIAA = American Institute of Aeronautics and Astronautics
APCP = Ammonium Perchlorate Composite Propellant
ASME = American Society of Mechanical Engineers
AV = Avionics
BEMT = Blade Element Momentum Theory
BP = Black Powder
CDR = Critical Design Review
CG = Center of Gravity
CP = Center of Pressure
ECD = Electronics, Communication, & Data
EIT = Electronics and Information Technology
FAA = Federal Aviation Administration
FEA = Finite Element Analysis
FMEA = Failure Modes and Effects Analysis
FN = Foreign National
FRR = Flight Readiness Review
HEO = Human Exploration and Operations
HPR = High-Power Rocketry
HPRC = High-Powered Rocketry Club
L3CC = Level 3 Certification Committee (NAR)
LCO = Launch Control Officer
LRR = Launch Readiness Review
MAE = Mechanical & Aerospace Engineering
MSDS = Material Safety Data Sheets
MSFC = Marshall Space Flight Center
NAR = National Association of Rocketry
NCSU = North Carolina State University
NFPA = National Fire Protection Association
PDR = Preliminary Design Review
PLAR = Post-Launch Assessment Review
PPE = Personal Protective Equipment
RF = Radio Frequency
RFP = Request for Proposal
RSO = Range Safety Officer
SAIL = STEMnauts Atmosphere Independent Lander
SL = Student Launch
SLS = Space Launch System
SME = Subject Matter Expert
SOW = Statement of Work
STEM = Science, Technology, Engineering, and Mathematics
TAP = Technical Advisory Panel (TRA)
TRA = Tripoli Rocketry Association
VARTM = Vacuum-Assisted Resin Transfer Molding

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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: 1840 Entrepreneur Drive, Raleigh, NC 27606

Primary Contact: Hanna McDaniel, hgmcdani@ncsu.edu, (336)553-7882

1.1.2 Final Launch Location

The team will conduct their final competition launch at Bragg Farms in Huntsville, AL.

1.1.3 Team Mentor Information

Name	Email	Phone	TRA Certification	Flyer #
Alan Whitmore	acwhit@nc.rr.com	(919)929-5552	Level 3	05945
Jim Livingston	livingston@ec.rr.com	(910)612-5858	Level 3	02204

1.1.4 Hours Spent on FRR Milestone

The team spent approximately 455 hours on the FRR milestone.

1.2 Launch Vehicle Summary

1.2.1 Vehicle Size and Mass

The launch vehicle's as-built dimensions include a maximum airframe diameter of 6.17 in., a total length of 107.43 in., and an estimated wet mass of 51.6 lb. Additionally, the dry mass of the launch vehicle without the maximum ballast is 44.98 lb. With this maximum ballast of 2.58 lb., the launch vehicle has a total dry mass (or burnout mass) of 47.58 lb. The launch vehicle includes a nose cone, a main parachute/payload bay, an avionics bay, and a drogue parachute bay/fin can. The as-built effective lengths of each are 27.06 in., 38.94 in., 2 in., and 37 in., respectively. The swept fins also contribute roughly 2.5 in. of additional length to the launch vehicle. Fully loaded, the sections weigh approximately 6.67 lb., 18.70 lb., 5.59 lb., and 20.64 lb., respectively. Finally, the landing masses are 9.46 lb. and 26.11 lb for the nose cone/deployment bay and the remainder of the launch vehicle, respectively.

1.2.2 Competition Launch Motor

The launch vehicle will utilize an AeroTech L1940X-PS motor for propulsion to the target apogee.

1.2.3 Target Altitude

The official target altitude is 4050 ft. above ground level.

1.2.4 Recovery System

The final recovery system design utilizes a MissileWorks RRC3 for the primary altimeter, an Eggtimer Quasar for the secondary altimeter and launch vehicle tracker in the avionics bay, and a Big Red Bee 900 tracker in the nose cone. The drogue parachute is a Fruity Chutes 15" Classic Elliptical, the main parachute is a Fruity Chutes 96" Iris Ultra Compact, and the nose cone parachute is a Fruity Chutes 48" Classic Elliptical. At 800 ft., the main parachute will be deployed, allowing the nose cone and payload to completely separate from the rest of the launch vehicle and to stabilize before payload deployment.

1.2.5 Rail Size

The launch vehicle will require a standard 1515 launch rail that is at least 12 ft. in length.

1.3 Payload Summary

The purpose of this year's payload is to safely recover four STEMnauts in a lander without the use of parachutes or streamers. The STEMnaut Atmosphere Independent Lander, or SAIL, will consist of a contra-rotating propeller system to decrease descent velocity after releasing from the rest of the launch vehicle.

2 Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

Table 2.1: Changes Made to Vehicle Criteria

Change Description	Justification	Affected Subsystem(s)
Number of shear pins connecting AV bay to drogue bay/fin can and main parachute/payload bay to nose cone changed from four to two pins (see Section 3.2.1).	Two shear pins are able to hold the load of the launch vehicle and require less black powder to break during recovery.	Structures, Recovery
Friction-fit battery compartment added to nose cone sled.	Battery retention that takes up less space and materials	Recovery
Deployment bay orientation within LV flipped. Bulkhead now faces down with shock cord running alongside deployment bay, and main parachute deployment bag shock cord attached directly to deployment bay bulkhead.	Prevents main parachute from getting stuck in bottom of deployment bay and allows for more space for packing between nose cone and deployment bay.	Recovery
Nose cone parachute shock cord and deployment bay shock cord changed from 1/4" to 5/8" thick.	Shock cord thickness reduced to save space between nose cone and deployment bay.	Recovery
Drogue shock cord changed from 227" to 288". Main shock cord changed from 100" to 122". The nose cone shock cord changed from 60" to 108".	Shock cord lengths increased due to the lengths shock cord available to team. Wanted the assurance of cords being longer instead of shorter than needed.	Recovery
Deployment bay shock cord changed from 24" to 83". Deployment bag shock cord changed from 25" to 18".	Deployment bay shock cord had to be increased so that the length of cord could run past the bay to where the bulkhead was situated below. Likewise, the deployment bag shock cord could be shortened and connected to the deployment bay bulkhead directly above it.	Recovery
Quasar operating frequency changed to 420.2	Per NASA SL admin request.	Recovery

2.2 Changes Made to Payload Criteria

Table 2.2: Changes Made to Payload Criteria

Change Description	Justification	Affected Subsystem(s)
STEMnaut housing compartment increased.	Allow for easier ingress/egress of STEMnauts.	Payload Structures, Payload Electronics
Deployment bay electronics sled redesigned to decrease wall thickness.	Save on weight and space inside deployment bay. Some walls removed/reduced.	Payload Systems

3D printed hex nut attachments added.	Allows for securing electronics housing from outside of blue tube without welding/epoxying nuts to corner brackets.	Payload Systems
Rotor blade sections all have voids and separate rectangular prisms are epoxied in those voids.	Improves rotor blade section alignment and eases fabrication. Could not retrieve PET-Gloop.	Payload Structures
Snap rings replaced with clamp collars.	Improves gear alignment and strength of side bevel gear attachment.	Payload Structures
Mounting point of rotor blades changed to a lofted design.	Allows for a smoother adhesion of the carbon fiber layup to the rotor blade mounting section.	Payload Structures
Leg mechanism replaced with bolt and nut system versus a pin and retaining ring system.	Stainless steel pins could not be properly lathed with in-house tools.	Payload Structures
Orientation of the leg spring hinges altered.	The spring hinge was not strong enough to extend the leg from a starting angle of 45 degrees.	Payload Structures
Landing leg length shortened, deployed angle decreased.	Provide more space for recovery system in main/payload bay.	Payload Structures, Payload Systems
Deployment bay blue tube shortened.	Provide more space for recovery system in main/payload bay.	Payload Systems
Logic level shifter added to SAIL electronics.	ESC motor controller requires 5V to operate. Adafruit Feather can only give 3.3V.	Payload Electronics

2.3 Changes Made to Project Plan

Table 2.3: Changes Made to Project Plan

Change Description	Justification	Affected Subsystem(s)
Payload completion and fully-configured payload validation tests pushed back to March.	Part shipping delays and challenges with payload construction.	Payload Electronics, Payload Structures, Payload Systems

3 Vehicle Criteria

3.1 Vehicle Mission Statement and Success Criteria

The mission of the launch vehicle is to safely house all payload structures, electronics, and occupants as it ascends to a declared apogee of 4050 ft. Once achieved, the launch vehicle must then follow a pre-defined recovery timeline in which each section descends under a parachute that provides an appropriate kinetic energy for the vehicle at touchdown. During this recovery timeline, the launch vehicle must also successfully release the payload after approval is given by the range safety officer.

The launch vehicle will be designed to be reusable, reliable, and safe while aligning with all NASA and team-derived vehicle requirements viewed in Section 7.3.1. If the launch vehicle accomplishes the above mission statement, it will be declared successful. Some further guidelines for vehicle success criteria are included in Table 3.1 below.

Table 3.1: Success Criteria for Launch Vehicle

Success Level	Vehicle Criteria
Success	Nominal takeoff and ascent; Reaches within $\pm$ 250 ft. of declared apogee; Follows recovery timeline; Payload ejected without damage; Recovered without any damage; Can be relaunched the same day
Partial Success	Nominal takeoff and ascent; Reaches within $\pm$ 500 ft. of declared apogee; Some minor damage upon landing that can be repaired at the field; Payload tangled during ejection but retains all functions
Partial Failure	Nominal takeoff and ascent; Reaches within $\pm$ 750 ft. of declared apogee; Damage upon landing that would prevent another launch within the same day; Payload damaged upon ejection
Failure	Catastrophe at takeoff; Nominal takeoff and ascent, but fails to get over 3000 ft. or manages to exceed 6000 ft.; Irreparable damage upon landing; Payload destroyed upon ejection

3.2 Launch Vehicle Design Overview

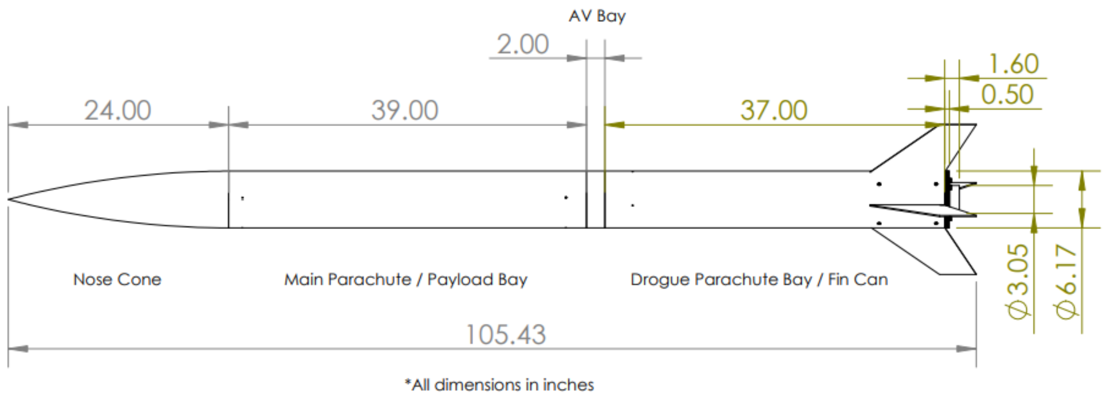

Figure 3.1: Final dimensions of the launch vehicle.

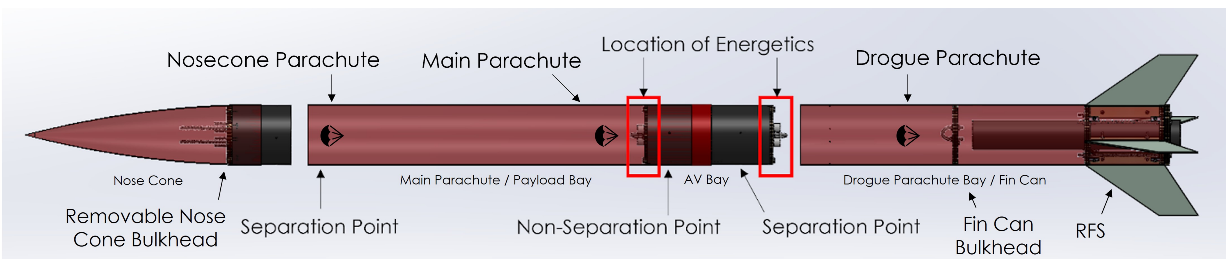

Figure 3.2: Annotated diagram of the launch vehicle.

Figure 3.3: Launch vehicle fully assembled and painted.

A dimensioned CAD drawing, an annotated CAD model, and a photo of the fully assembled and painted launch vehicle are shown above in Figures 3.1, 3.2, and 3.3, respectively. The designed launch vehicle has a maximum length of approximately 105.43 in and a maximum diameter of 6.17 in. The as-built launch vehicle has a maximum length of 107.43 in. and a maximum diameter of 6.17 in. It currently weighs 51.6 lb fully loaded and 47.58 lb after motor burnout. There are two separation points and one non-separation point. Sections that contain a separation point are held together with two 4-40 Nylon shear pins and non-separating sections are held together with four 1/4 in. Nylon push-clip rivets. The first separation point is located between the nose cone and the main parachute/payload bay while the second separation point is between the drogue parachute bay/fin can and the AV bay. Hence, the one non-separation point is located between the main parachute/payload bay and the AV bay. The location of each separation point is labeled in Figure 3.2. Using this configuration, the launch vehicle will separate into three sections during descent, satisfying NASA Requirement 2.4. Additionally, 1515 Delrin rail buttons will be fixed to the drogue parachute bay/fin can and the AV bay switchband to allow the launch vehicle to be launched from a standard 1515 launch rail.

3.2.1 Launch Vehicle Design Changes

The only launch vehicle design changes to report are the number of shear pins connecting the nose cone to the main parachute/payload bay and connecting the AV bay to the drogue parachute bay/fin can. It was found that two of the 4-40 Nylon shear pins (rather than four) were more than capable of keeping the launch vehicle sections together, which allows for smaller black powder charges needed for separation of the sections. More details on the shear pin testing that confirmed this are found in Section 7.1.7.

3.2.2 Nose Cone

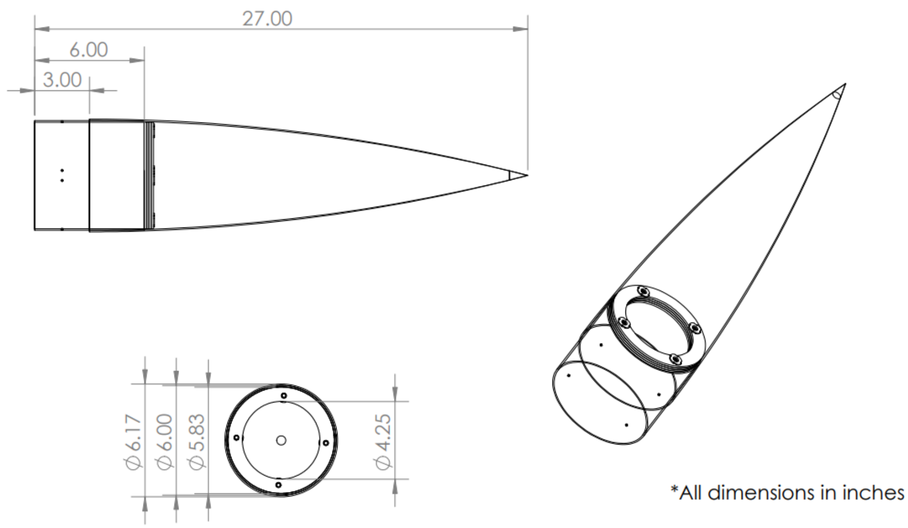

Figure 3.4: Nose cone dimensions from CDR.

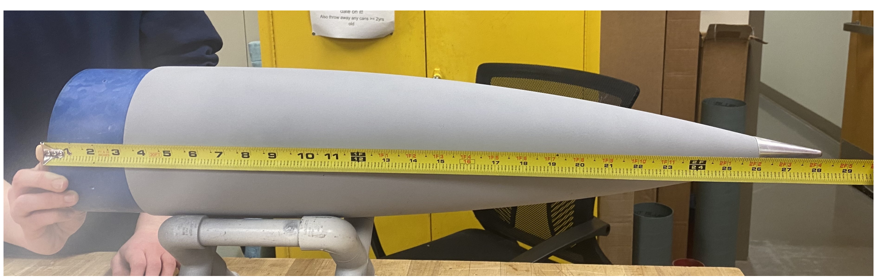

Figure 3.5: Full scale nose cone.

Figure 3.6: Close up of full scale nose cone dimension.

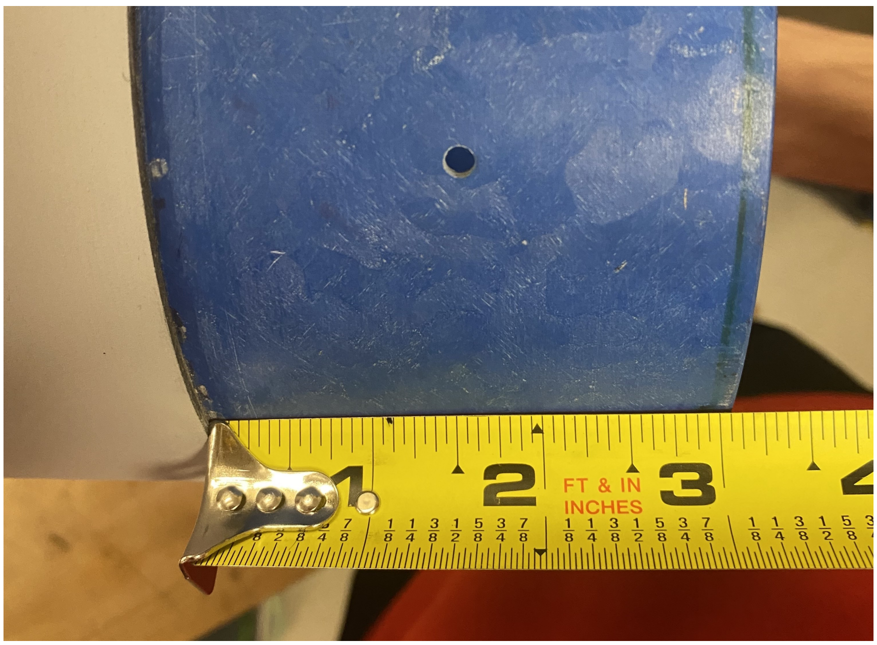

Figure 3.7: Close up of full scale nose cone shoulder.

Figure 3.8: Close up of full scale nose cone coupler length.

The nose cone chosen for the launch vehicle was a 6 in. diameter 4:1 tangent o-give. Thus, the length of the nose cone alone should be 24 in. A 6 in. coupler section was to be epoxied into the nose cone such that 3 in. of the coupler will remain exposed acting as a nose cone shoulder satisfying NASA Vehicle Requirement 2.4.3. The dimensions of the nose cone from the CDR milestone are shown in Figure 3.4. There is also a permanent centering ring that is epoxied at the forward end of the nose cone coupler to mount a removable bulkhead inside the nose cone.

The completed nose cone airframe assembly is shown in Figures 3.5 and 3.6. In Figure 3.6, it is evident that the total length of the nose cone airframe assembly is slightly longer than what was predicted in the drawing in Figure 3.4. This is likely because the anodized aluminum tip that this particular manufacturer adds to their nose cones provides some additional length (in this case about 2 in.) to the nose cone geometry. Such a small addition in length causes no concern for the aerodynamics or stability of the launch vehicle.

In Figures 3.7 and 3.8, the lengths of the nose cone shoulder and coupler are verified, respectively. Figure 3.7 shows that the nose cone shoulder is about 3.0625 in. long, which is acceptable with respect to the design criteria. Likewise, the full length of the nose cone coupler is about 6.125 in., meaning that about 3.0625 in. of the coupler is bonded to the nose cone. Again, these tolerances are expected and perfectly acceptable.

3.2.3 Main and Payload Bay

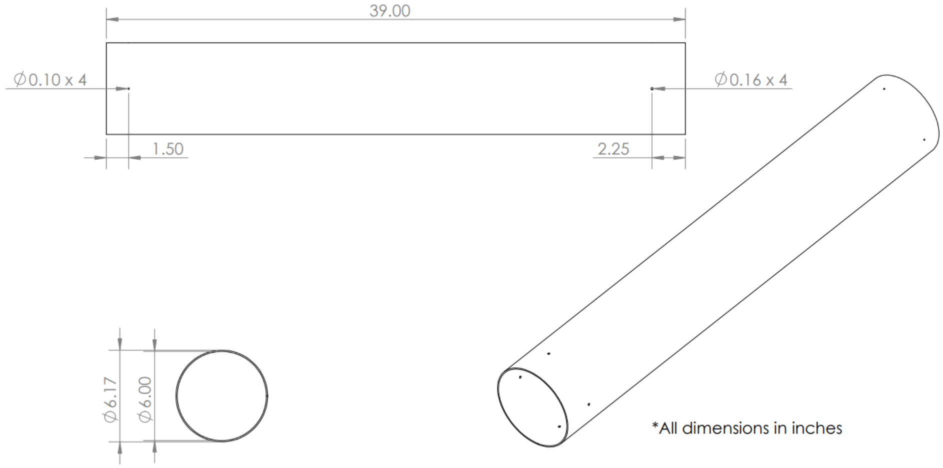

Figure 3.9: Main parachute/payload bay dimensions from CDR.

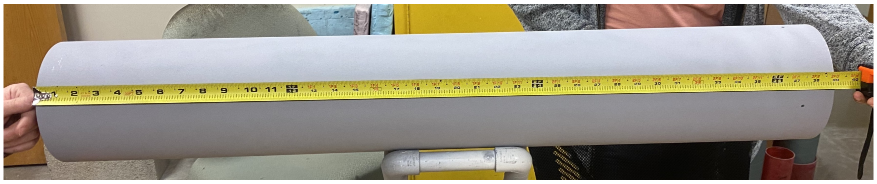

Figure 3.10: Full scale main parachute/payload bay.

Figure 3.11: Close up of full scale main parachute/payload bay dimensions.

The main parachute/payload bay is located between the nose cone and the AV bay. It is connected to the former with two #4-40 Nylon shear pins and to the latter with four 1/4 in. Nylon push-clip rivets. This section will house the payload deployment bay (and thus the payload), the main parachute, a deployment bag for this parachute, the nose cone parachute in its own Nomex cloth, and Kevlar shock cord. The design length of the main parachute/payload bay is 39 in. It was predicted that the unloaded section would weigh about 4.94 lb. from the manufacturer data available.

Figures 3.10 and 3.11 show the completed main parachute/payload bay. It is slightly shorter than the design length at approximately 38.938 in., which is both expected and acceptable. The weight of the section alone is roughly 5 percent lighter at 4.7 lb.

3.2.4 Avionics Bay

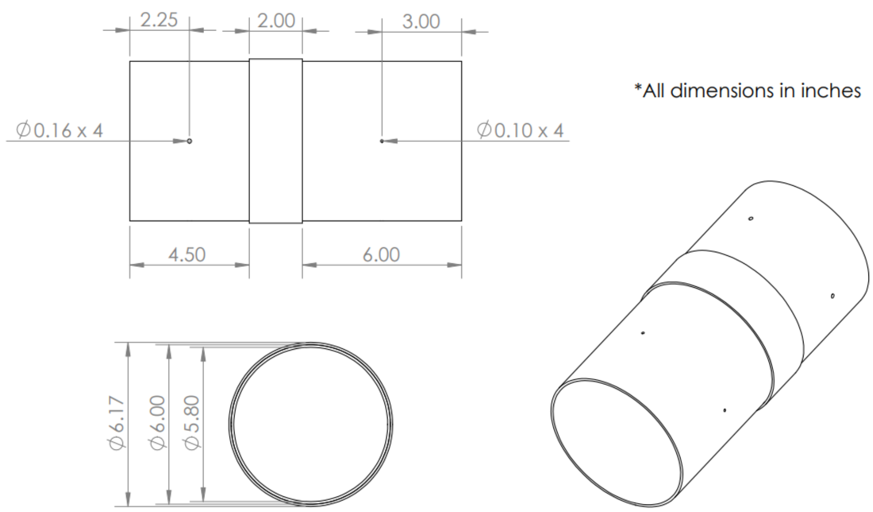

Figure 3.12: AV bay dimensions from CDR.

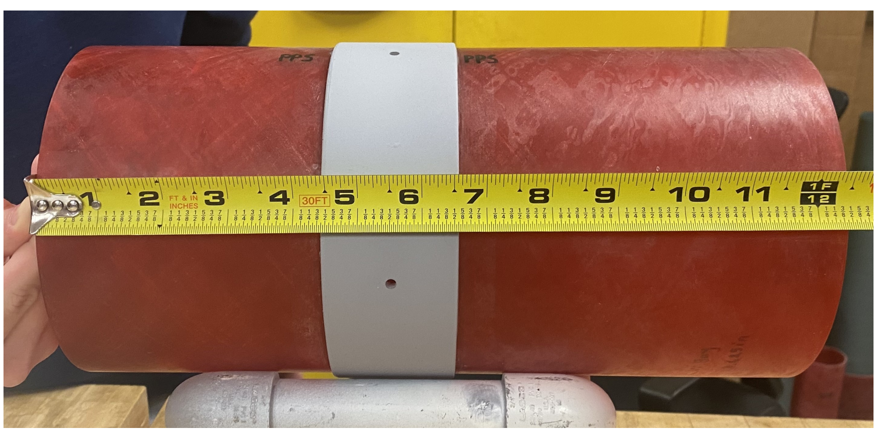

Figure 3.13: Full scale AV bay.

Figure 3.14: Close up of full scale AV bay dimensions.

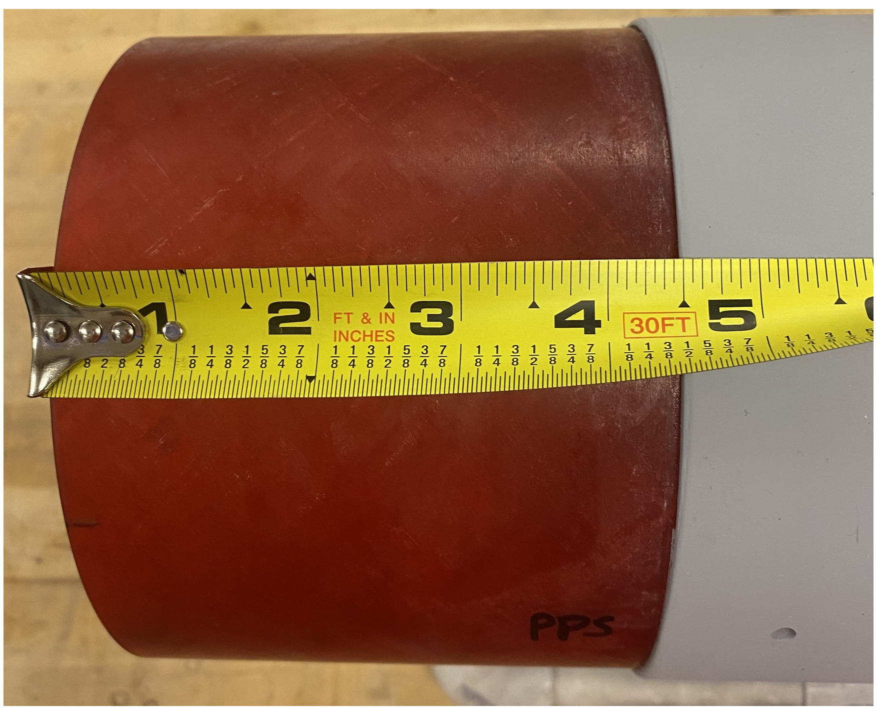

Figure 3.15: Close up of full scale non-separating coupler section dimensions.

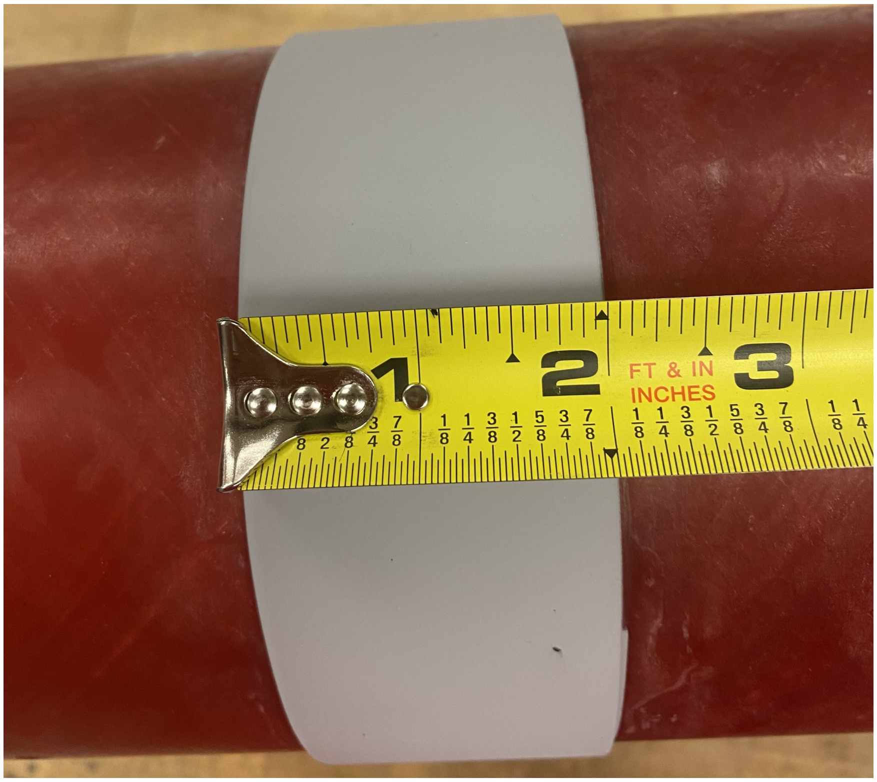

Figure 3.16: Close up of full scale AV bay switch band dimensions.

Figure 3.17: Close up of full scale separating coupler section dimensions.

The AV bay is located between the main parachute/payload bay and the drogue parachute bay/fin can. It is connected to the former with four 1/4 in. Nylon push-clip rivets and to the latter with two #4-40 Nylon shear pins. The AV bay houses an electronics sled which is mounted onto two 1/4 in.-20 zinc-plated steel threaded rods that extend through the entire assembly. The AV bay is made from a 12.5 in. coupler section and a 2 in. airframe section. The 2 in. airframe section is permanently epoxied to the coupler section such that 4.5 in. of exposed coupler is left on the non-separating side and 6 in. of exposed coupler is left on the separating side. These coupler lengths satisfy NASA Vehicle Requirements 2.4.2 and 2.4.1, respectively. From available manufacturer data, it was estimated that the AV bay airframe assembly would be roughly 1.48 lb. The dimensions of the AV bay from the CDR milestone are shown in Figure 3.12.

The AV bay airframe assembly is shown in Figures 3.13 and 3.14. Figure 3.14 shows that the coupler length is almost exactly its design length of 12.5 in. The as-built AV bay airframe assembly weighs 1.8 lb., which is about 17.9 % heavier than expected. The additional weight most likely comes from the epoxy mixture used to assemble the airframe and coupler sections, as well as the installation of the wooden rail button mount. More details regarding AV bay fabrication can be found in Section 3.4.5.

Figures 3.15, 3.16, and 3.17 show the as-built lengths of the AV bay non-separating coupler section, switch band, and separating coupler section. All of them are almost exactly their design lengths of 4.5 in., 2 in., and 6 in., respectively.

3.2.5 Drogue Bay and Fin Can

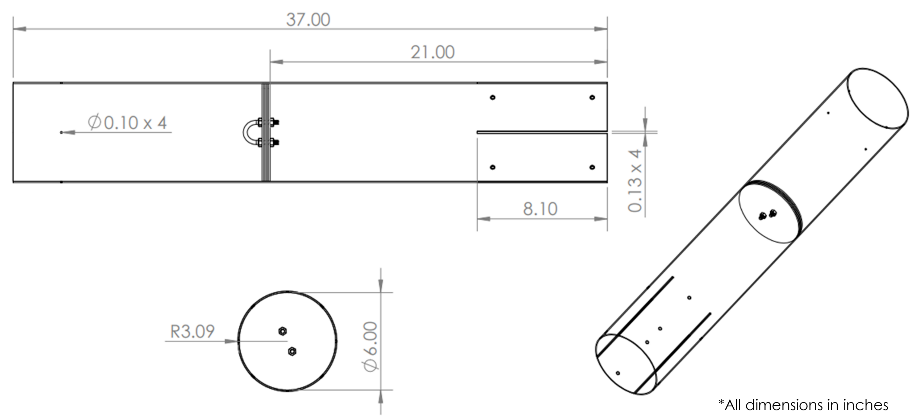

Figure 3.18: Drogue parachute bay/fin can dimensions from CDR.

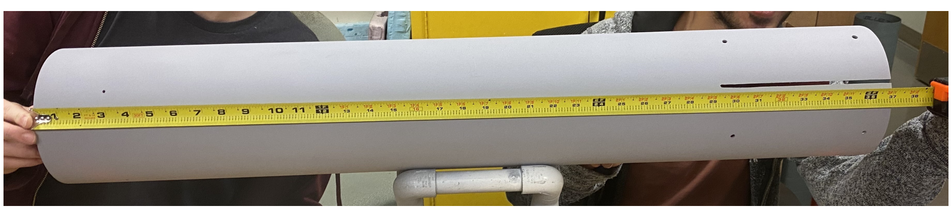

Figure 3.19: Full scale drogue parachute bay/fin can.

Figure 3.20: Close up full scale drogue parachute bay/fin can dimensions.

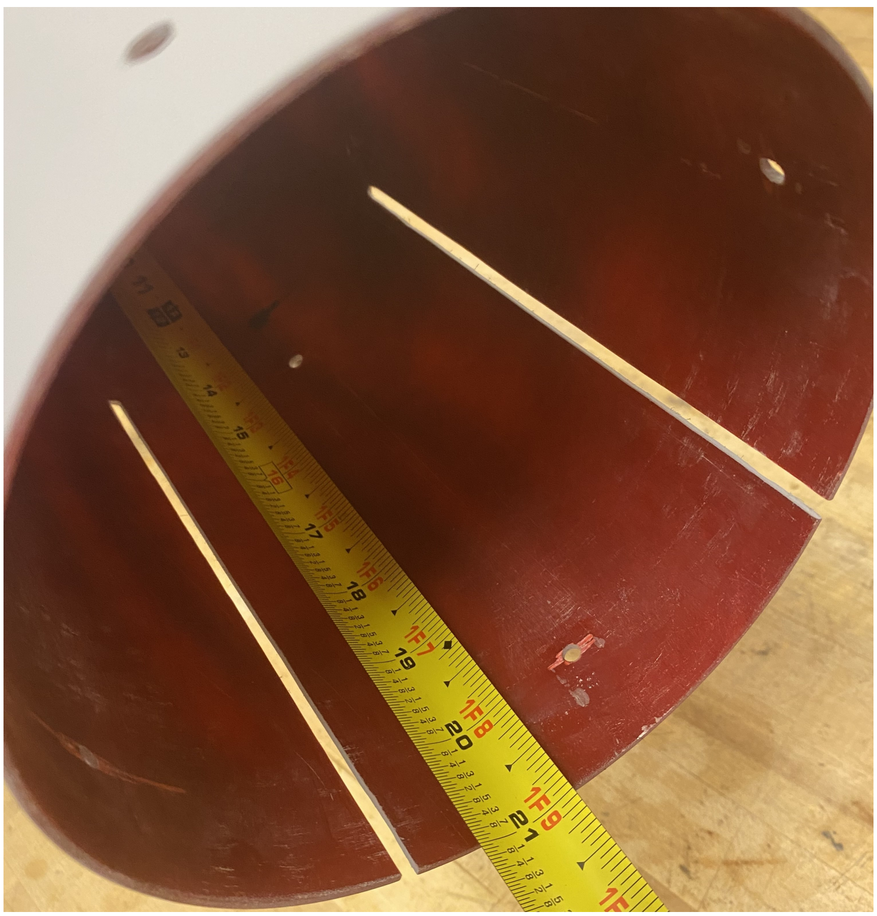

Figure 3.21: Fin can bulkhead distance.

Figure 3.22: Fin can bulkhead installed in the drogue parachute bay/fin can.

The drogue parachute bay/fin can is located aft of the AV bay and is connected to it with two #4-40 Nylon shear pins. This section contains a drogue parachute wrapped in a Nomex cloth, Kevlar shock cord, a fin can bulkhead, and the removable fin system. The design length of this section is 37 in. The estimated unloaded weight of this section using available manufacturer data was about 4.68 lb. The dimensions of the drogue parachute bay/fin can from the CDR milestone are shown in the drawing in Figure above.

The drogue parachute bay/fin can airframe assembly is shown above in Figures 3.19 and 3.20. Figure 3.20 shows that the as-built section is almost exactly its design length of 37 in. The unloaded section weighs approximately 4.9 lb., which is 4.43% heavier than expected. The source of the excess weight likely emerges from the epoxy mixture used to secure the fin can bulkhead in place.

The fin can bulkhead was permanently installed into the drogue parachute bay/fin can such that its bottom face was 21 in. from the aft end of the airframe per the dimensions shown in Figure 3.18. This dimension is shown in the as-built configuration in Figure 3.21 and is precisely 21 in. Figure 3.22 shows this bulkhead installed from the forward end of the section.

3.2.6 Removable Fin System

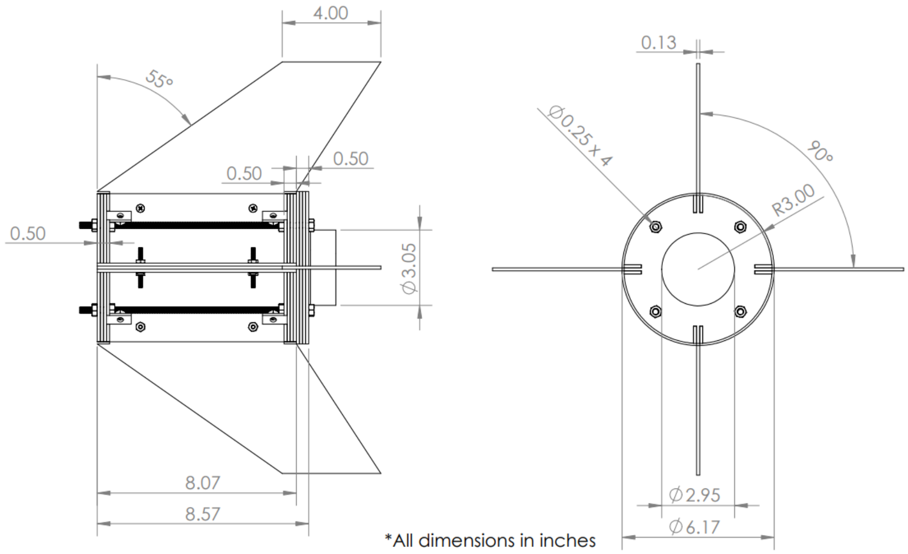

Figure 3.23: RFS assembly dimensions from CDR.

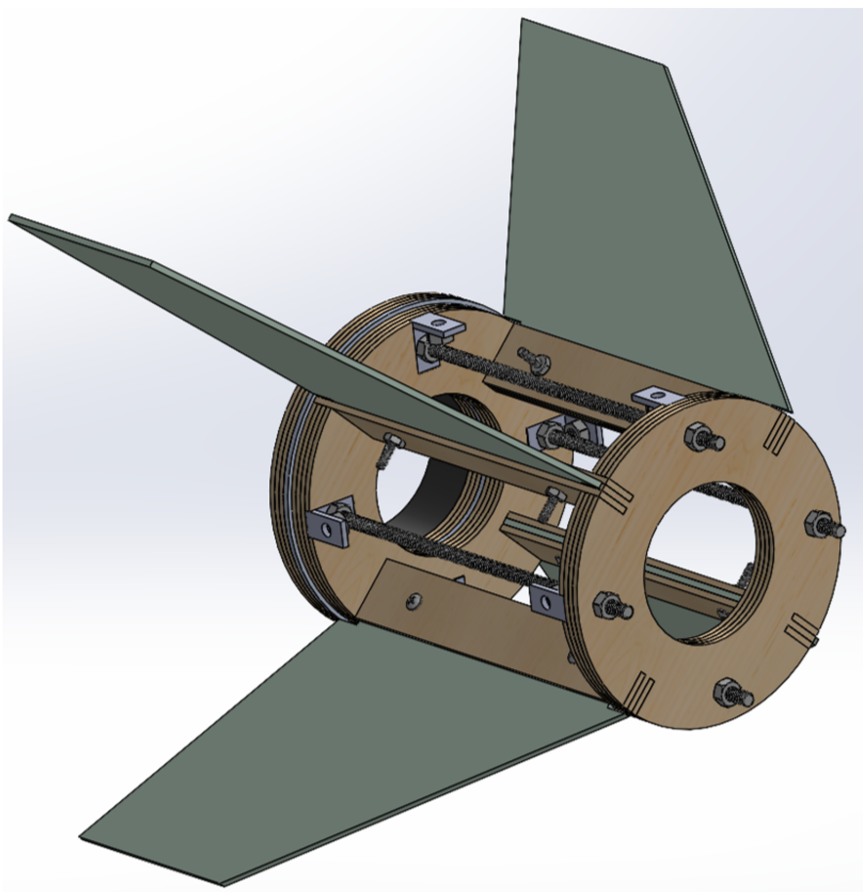

Figure 3.24: RFS CAD model from CDR.

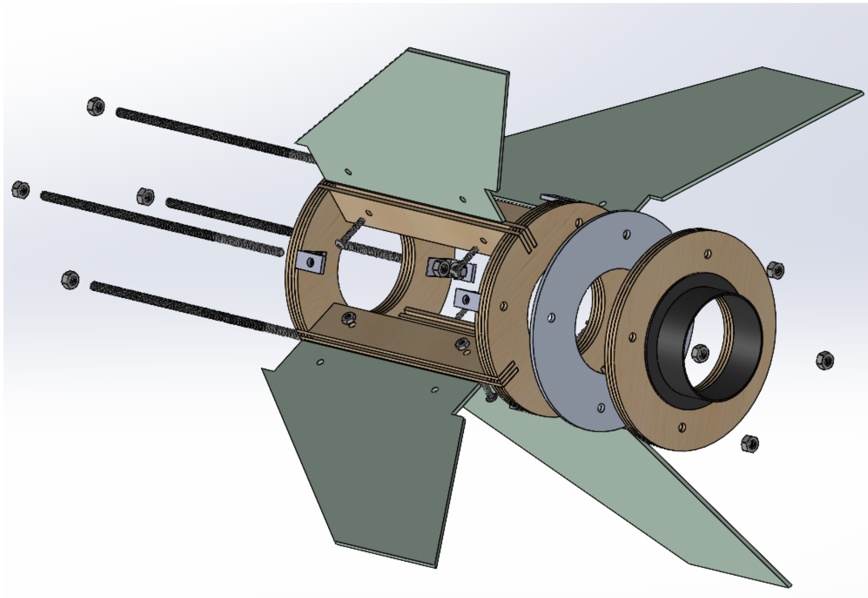

Figure 3.25: Exploded RFS CAD model from CDR.

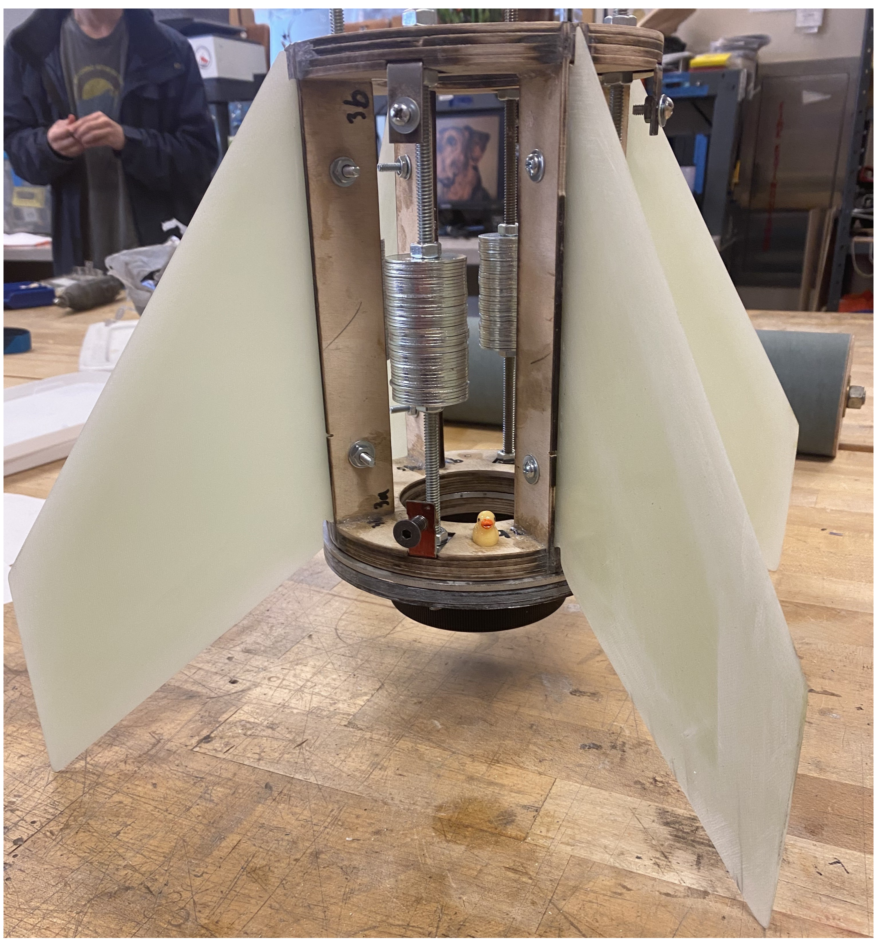

Figure 3.26: Complete RFS assembly with ballast installed.

The removable fin system (RFS) is located inside the aft end of the drogue parachute bay/fin can and is attached to it with seven #8-32 zinc-plated steel machine screws and one 1/4 in. steel screw which holds a standard 1515 rail button in place. The RFS holds the four G10 fiberglass fins in place by sandwiching the fin tabs between a pair of runners made from aircraft-grade birch plywood. Each fin is secured to its pair of runners using two #8-32 zinc-plated steel machine screws. The runners are permanently epoxied to a bulkhead on each end. On the aft end of the assembly is a 1/8 in. thick ply of 6061 aluminum with the same outer diameter as the airframe which serves as a thrust plate. Finally, a 1/2 in. thick thrust bulkhead made from aircraft-grade birch plywood is placed aft of the thrust plate. This thrust bulkhead also contains a 75 mm (2.95 in) diameter motor retaining ring. Four 1/4 in. zinc-plated steel threaded rods extend through the entire assembly holding the RFS, thrust plate, and thrust bulkhead together. Finally, eight custom L-brackets are mounted on the RFS bulkheads such that the RFS can be secured from the outside of the airframe. The weight of the RFS without ballast was estimated to be about 3.55 lb. using available manufacturer data and experimental measurements. The relevant dimensions of the RFS from the CDR milestone are shown in Figure 3.23. CAD models of the assembled and exploded views of the RFS are also shown in Figures 3.24 and 3.25 for better visualization.

The as-built RFS assembly is shown in Figure 3.26. Each threaded rod contains a certain number of stainless steel washers which have been locked in place with a nut on either end that has been torqued down as much as possible with two ratcheting wrenches. As such, this amount of ballast is in no way permanent and can be adjusted based on flight conditions. Without the ballast installed, the as-built RFS weighs approximately 3.68 lb.

3.2.7 Fins

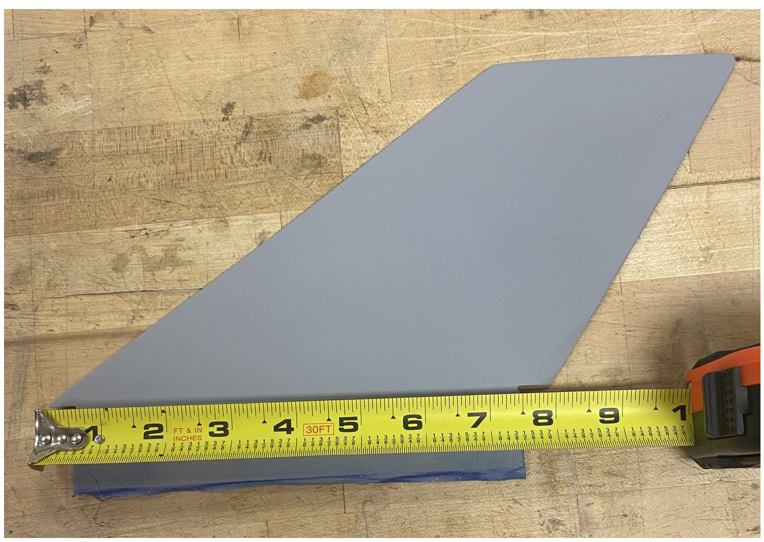

Figure 3.27: Root dimension of the as-built fins.

Figure 3.28: Tip dimension of the as-built fins.

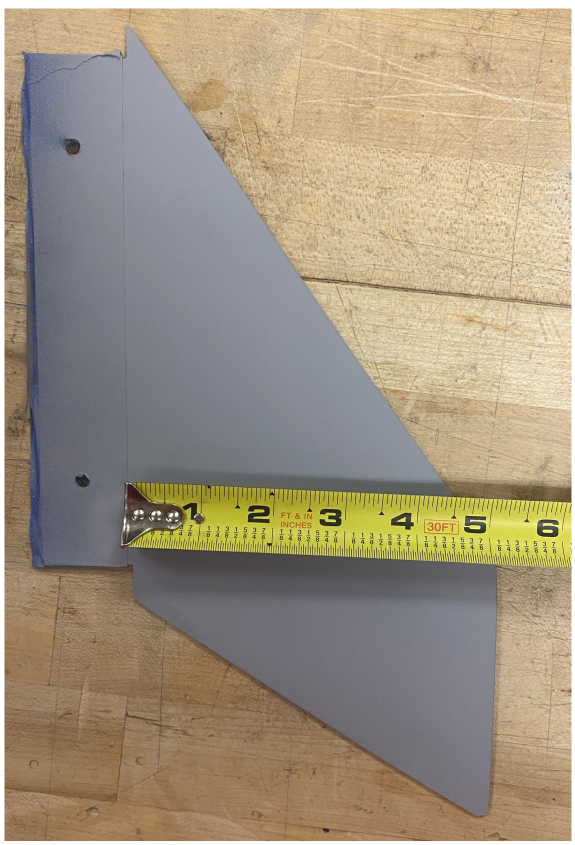

Figure 3.29: Span dimension of the as-built fins.

Figure 3.30: Sweep angle of the as-built fins.

The fins were constructed using 0.125 in. thick G10 fiberglass as designed. The fins were modeled with a tab so that the fins could be mounted to the RFS internal slats. The shape of the fin was cut using a Dremel to ensure dimensional accuracy. Post-processing of the fins involved measuring the driving dimensions using calipers and sanding of the fins as necessary to mirror the design geometry as closely as possible. The fin leading edge was beveled to decrease the surface area normal to the oncoming flow in order to reduce drag. A layer of primer and paint was added to the fins which smooths out any imperfections in the fiberglass. Additional information regarding fin construction can be found in Section 3.4.6. To verify the structural integrity of the fins during landing, Section 7.1.5 outlines the specific methodology and success criteria for fin verification. As-built dimensions of the fins have been supplied for reference in Figures 3.27, 3.28, 3.29, and 3.30.

3.2.8 Motor Selection

The launch vehicle motor selected for competition has not changed since CDR. A successful VDF was performed on the selected motor and the as-built mass of the launch vehicle was within acceptable margins of error for the motor performance. The AeroTech L1940X-PS is the highest performing motor for the casing size available to the team, thus mass growth does not allow for an increase in motor performance. The motor properties used in launch vehicle simulations is provided in Table 3.2 along with the thrust profile (Figure 3.31) and the geometry definition used in RocketPy simulations (Figure 3.32).

Table 3.2: AeroTech L1940X-PS Performance Properties.

Motor	Propellant Mass (slug)	Total Mass (slug)	Total Impulse (lb•sec)	Average Thrust (lb)	Maximum Thrust (lb)	Burn Time (sec)	Casing	Length (in)
L1940X	0.1250	0.2642	973.24	435.97	521.21	2.2	RMS-75/3840	22.04

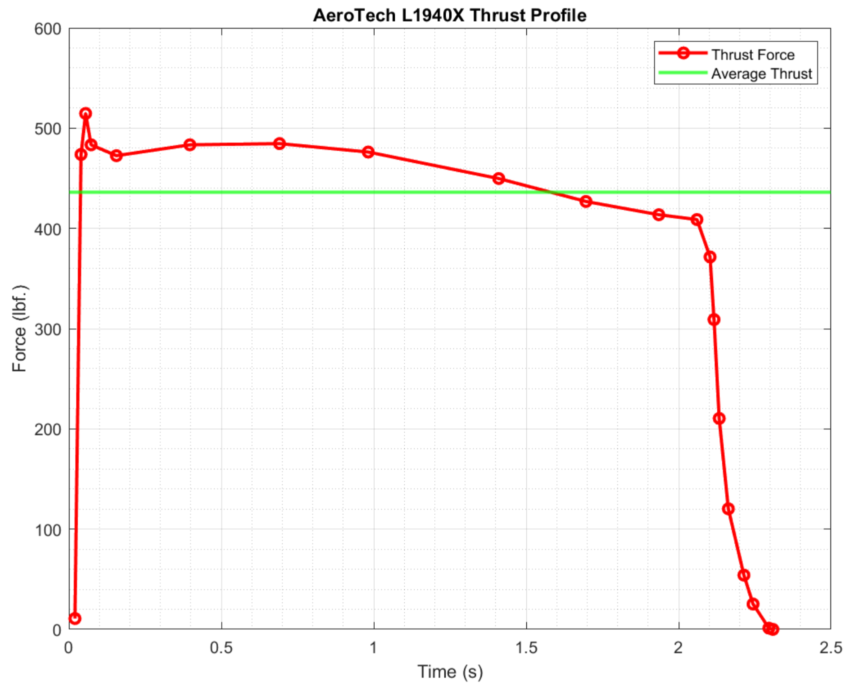

Figure 3.31: AeroTech L1940X Thrust Profile.

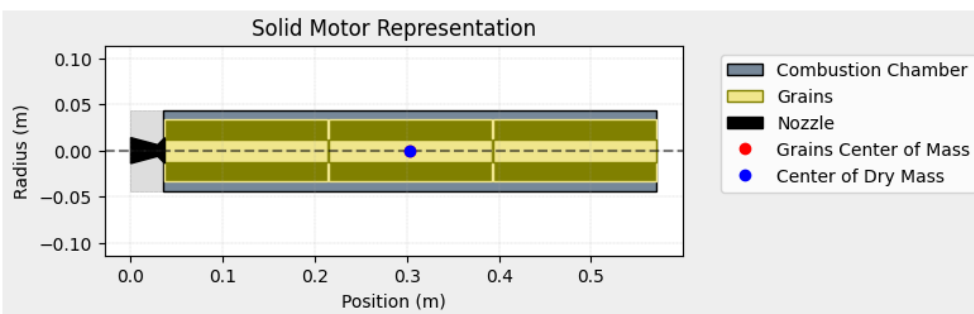

Figure 3.32: AeroTech L1940X geometry definition in RocketPy.

3.2.9 Motor Retention

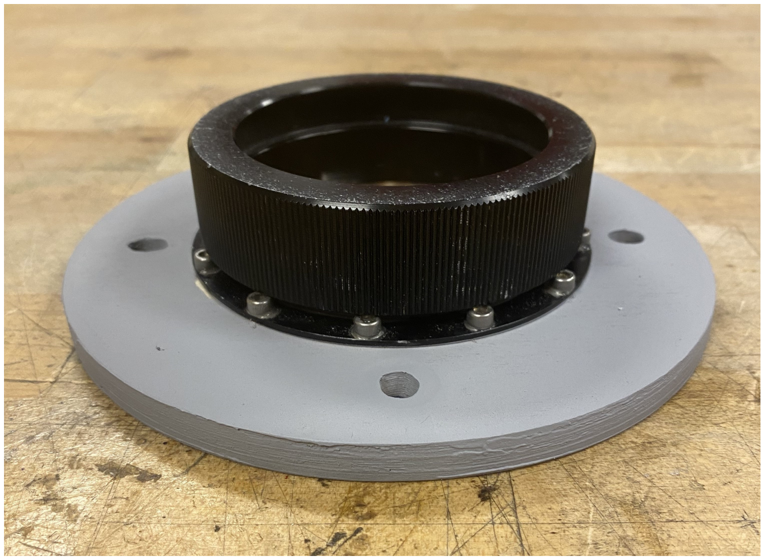

Figure 3.33: Full scale thrust bulkhead.

Figure 3.34: Full scale Aeropack motor retainer.

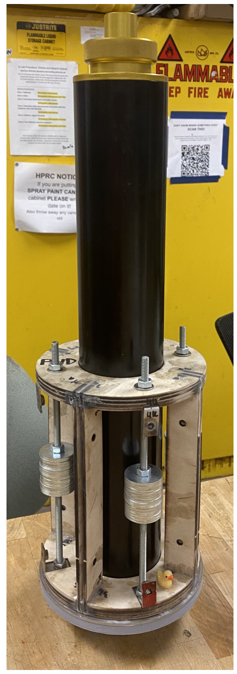

Figure 3.35: Motor retention demonstration.

The Aerotech 75/3840 motor casing is retained using a 75 mm (2.95 in.) Aeropack flanged motor retainer which was installed using its included hardware into the thrust bulkhead. In addition to tightening this hardware sufficiently, epoxy was added to the threads and to the retainer itself to ensure that it would not come loose from the thrust bulkhead. Figures 3.33 and 3.34 show the completed thrust bulkhead and the installed Aeropack motor retainer.

Once the thrust bulkhead is installed on the RFS and the RFS is installed into the drogue parachute bay/fin can, the motor casing can be inserted. This is done by unscrewing the retaining ring on the Aeropack motor retainer, then inserting the casing through the retainer, thrust bulkhead, thrust plate, and both RFS bulkheads until the aft closure on the casing rests inside the groves on the motor retainer. Then the retaining ring can be screwed back on to hold the casing in place. Figure 3.35 shows how the motor casing is retained within the RFS.

3.2.10 Mass Growth Analysis

Certainly, it is expected that there will be differences in the predicted weights of the launch vehicle's components versus the as-built weights. Such differences could be the result of manufacturer inconsistencies, rough estimation calculations, the unexpected addition of components, etc. Table 3.3 below shows the predicted weight, as-built weight, and the percent error between the two for each section of the launch vehicle.

Table 3.3: Launch Vehicle Weight Comparison

Section	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Nose Cone	5.65	6.67	15.32
Main Parachute/Payload Bay	18.57	18.70	0.73
AV Bay	4.57	5.59	18.36
Drogue Parachute Bay/Fin Can	19.59	20.64	5.08
Total	48.38	51.61	6.27

Table 3.4 below shows a more in-depth analysis of which components of the launch vehicle sections contributed to either a mass growth or a mass regression. For instance, the nose cone weight experienced a mass growth due

to the manufacturer data not being available for the nose cone and coupler section chosen. A similar 4:1 tangent o-give nose cone owned by the club was used to obtain this predicted mass, so, understandably, the error is large here. Similarly, extra quick links were added to the main parachute/payload bay for the deployment bay, so the predicted weight was 0 lb., thus yielding a percent error of 100%. Despite this, the main parachute/payload bay had the lowest percent error between predicted and as-built masses, being only 0.13 lb. heavier. The remaining three sections were each roughly 1 lb. heavier than predicted. As such, the launch vehicle is about 3 lb. heavier than predicted.

Table 3.4: Launch Vehicle Section Weight Comparison

Nose Cone			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	3.976	5	20.46
Sled and Electronics	0.178	0.156	13.96
Removable Bulkhead	0.972	0.906	7.25
Recovery Components	0.523	0.609	14.15
Total	5.65	6.67	15.32
Main Parachute/Payload Bay			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	4.94	4.70	5.02
Payload Mass Simulator	7.88	8	1.5
Deployment Bay	2.82	3.44	17.06
Main Recovery Components	2.11	1.40	50.71
Nose Cone Parachute Quick Links	0.328	0.344	4.56
Main Parachute Quick Links	0.492	0.516	4.56
Deployment Bay Quicklinks	0	0.344	100
Total	18.57	18.70	0.733
AV Bay			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	1.48	1.8	17.94
Sled and Electronics	0.945	0.734	28.69
Ballast	0.66	0.66	0
Bulkheads and Hardware	1.49	2.4	38.2
Total	4.57	5.59	18.36
Drogue Parachute Bay / Fin Can			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	4.68	4.90	4.43
Removable Fin System	5.47	5.60	2.31
Drogue Parachute Recovery Components	0.751	0.80	6.16
Drogue Parachute Quick Links	0.492	0.563	12.52
Loaded Motor	8.20	8.78	6.64
Total	19.59	20.64	5.08

3.3 Launch Vehicle Flight Reliability

3.3.1 Structural Elements

Airframe

The airframe and coupler sections of the launch vehicle are made from G12 fiberglass tubes. These filament wound tubes are made from fiberglass roving and epoxy with multiple layers and wind angles. G12 fiberglass is widely used in high-powered rocketry due to its high resistance to abrasion, cracking, shattering, delamination, etc. It is also water-resistant, which is important because the club's home launch field contains multiple irrigation ditches that the launch vehicle could land in. This material has been used by the club in the past and has survived multiple launches, irrigation ditch landings, failed recovery landings, and even motor catastrophes. As such, there is complete confidence in the integrity of this material for the launch vehicle.

Bulkheads

All the bulkheads in the launch vehicle are made from four 1/8 in. plies of aircraft-birch plywood that have been epoxied together to make a 1/2 in. thick specimen. More details of bulkhead construction are found in Section 3.4.2. This bulkhead thickness and material has been used for multiple launch vehicles in the club's past and has been completely reliable for flight conditions. The maximum shock forces that the recovery components exert on the bulkheads are always well below the bulkheads' yielding loads. Sections 7.1.9 and 7.1.8 show, for instance, that the factor of safety for the AV bay bulkheads and nose cone bulkhead are about 7.6 and 4.3, respectively.

Fins

The fins are cut out of a 1/8 in. thick sheet of G10 fiberglass. Section 3.4.6 gives more detail about the construction process for the fins. G10 fiberglass is a similar material to G12 fiberglass in terms of strength but is readily produced in sheets instead of tubes. This material is commonly used for fins in high-powered rocketry in both supersonic and altitude endurance flights. Furthermore, cutting the fins out of a ready-made composite allows for the benefit of composite strength without the complexity, time, expense, and human errors involved in producing composites in-house. A drop test was also conducted on these fins to assess their durability. After multiple high-impact drop tests, there was no visible damage detected. More details of this test are found in Section 7.1.5.

Epoxy Connections

Multiple fiberglass-to-fiberglass and wood-to-fiberglass connections are made on the launch vehicle using epoxy. The epoxy used is a one-to-one mixture of West System's 105 Resin, 206 Slow Hardener, and often 406 Colloidal Silica Adhesive Filler. Without the Colloidal Silica, the mixture has a tensile strength of about 7,320 psi, which is more than enough to ensure reliable bonds. This epoxy mixture has, again, been used historically by the club on multiple launch vehicles and has been proven to withstand the forces associated with high-powered launch vehicle flights. For more details about how this epoxy mixture is used throughout the launch vehicle, see Section 3.4.1.

Bolted Connections

The removable nose cone bulkhead is secured to the permanent nose cone centering ring with four 1/4 in.-20 x 1 in. zinc-plated steel bolts. Such bolts are screwed into four zinc-plated steel T-nuts that are permanently installed in the permanent centering ring. After testing the nose cone bulkhead test article, the removable bulkhead showed no signs of damage around any of the screw holes. None of the bolts or the threads holding the removable bulkhead in place were damaged either. The nose cone bulkhead failed at the epoxy joint where the permanent centering ring is epoxied to the coupler section first, which took place at about 1,248 lb. This gave the nose cone bulkhead a factor of safety of about 4.3. More details of the nose cone bulkhead test can be found in Section 7.1.8. Given that these are the only bolted connections on the launch vehicle that will be load-bearing, there is no concern for failure of any of the remaining bolted connections on the launch vehicle.

Threaded Rods

Zinc-plated steel 1/4 in.-20 threaded rods are used on the launch vehicle in the nose cone, in the AV bay, and the RFS. The threaded rods in the nose cone are not load-bearing and only serve to hold the nose cone electronics sled in place. The threaded rods on the RFS are slightly load-bearing but mostly serve to add structural rigidity to the system and to have a place to add ballast to the aft end of the launch vehicle. The most load-bearing threaded rods on the launch vehicle are in the AV bay. While providing a structure for the AV electronics sled to be mounted onto, these threaded rods also penetrate through the forward and aft AV bay bulkheads to sandwich them around the AV bay airframe assembly. When the main and drogue parachutes deploy, they will exert a shock force on the forward and aft AV bay bulkheads which will pull on the threaded rods. In the test verifying the strength of the AV bay bulkheads in Section 7.1.9 it was found the bulkheads yielded at about 950 lb., giving them a factor of safety of about 7.6. The threaded rods and nuts on them took no damage at all even after the bulkheads yielded. Therefore, there is no concern for failure of the threaded rods on the launch vehicle.

Recovery Attachment Hardware

Stainless steel 1/4 in.-20. x 1-1/2 in. U-bolts and 1/4 in.-20 stainless steel quick links are used for all recovery attachments on the bulkheads in the launch vehicle. These U-bolts were tested along with the nose cone bulkhead and AV bay bulkheads in Sections 7.1.8 and 7.1.9. After the bulkheads yielded in both tests, there was no visible damage or deformation done to the U-bolts, the quick links, or the threads on both. Furthermore, none of the recovery hardware was damaged after the vehicle demonstration flight. The selected recovery hardware is thus deemed suitable for flight.

3.3.2 Electrical Elements

Wiring

16-gauge copper wiring is used for all onboard wiring. Quick disconnects are used in the AV bay connecting the altimeters to the terminal blocks on the AV Bay bulkheads. DuPont connectors are used for these quick disconnects, and each connection in the header is hot-glued to ensure the wire does not come out during flight. See Section 3.5.3 for more information.

Switches

The primary altimeter, and the secondary altimeter and tracker are both armed using pull-pin switches. Steel M2 screws are bolted to secure the switches to the AV sled. All wired connections to the switch are soldered, and the pins have a ”Remove Before Flight” tag attached to them to ensure the system works properly. See more information in section 3.5.3.

The AV Bay has compartments on the 3D printed sled to friction fit all batteries in the recovery system, where they are then secured using zip ties and electrical tape. The Nose Cone sled also has the same feature, and uses the same retention system. See Sections 3.5.2 and 3.5.3 for more.

Avionics Retention

All recovery electronics onboard are mounted using M3 heated inserts, and M3 plastic mounting hardware. There are two 1/4” threaded rods that run through the AV Bay, where the sled is mounted onto these threaded rods, and secured into place using 1/4” nuts and washers. The nose cone sled is also mounted onto two 1/4” threaded rods that run through the nose cone, and is secured with nuts. See Sections 3.5.3 and 3.5.2 for more information.

3.4 Launch Vehicle Manufacturing

3.4.1 Airframe Cutting and Bonding

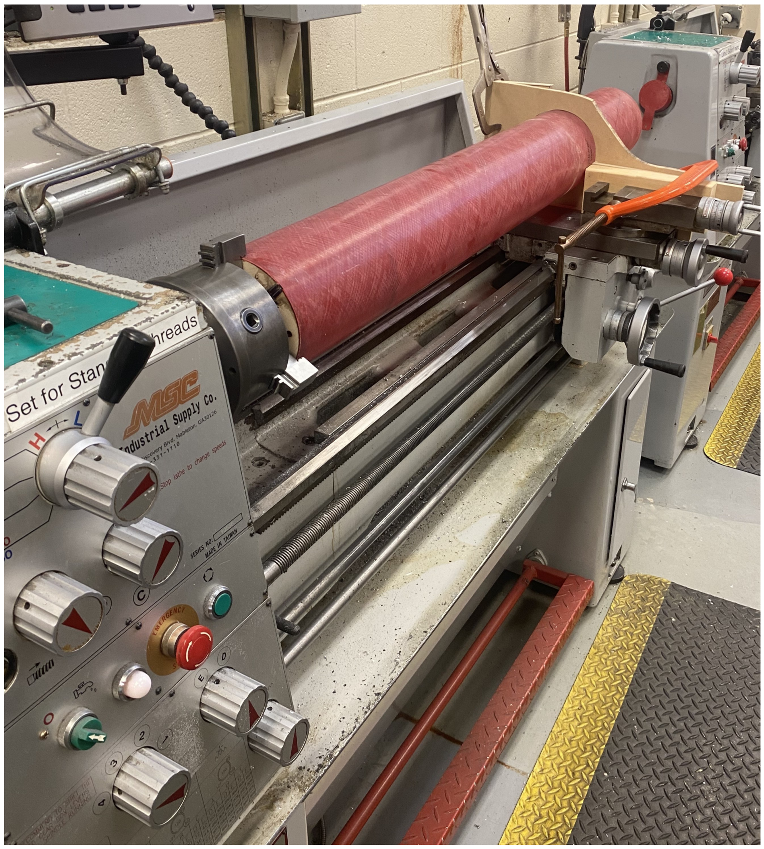

Figure 3.36: Lathe setup for airframe and coupler cutting.

Before making any cuts on the airframe and coupler sections, all sections were measured and marked at their design lengths. Everything was measured at least three times to ensure accurate dimensions. Airframe and coupler sections were cut to their design lengths in NC State’s MAE Senior Design Lab by the Lab Manager, Amos Tucker. The G12 fiberglass tubes were placed on a lathe and then secured with a custom wooden mount at the other end. This mount ensured that any precessing motion of the tube from uneven ends would be inhibited. The lathe setup is shown in Figure 3.36.

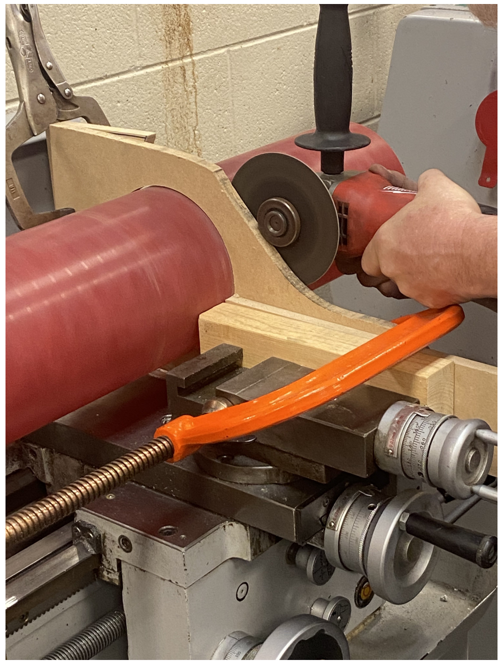

Figure 3.37: Cutting G12 fiberglass on the lathe.

Once the G12 fiberglass tubes were in place, the lathe was turned on at a low speed, and a cut-off wheel with a diamond-tipped blade was used to slowly cut along the marked lines. Each cut was made slightly outside of the marks in the hopes of preserving some extra material. Figure 3.37 shows how the sections were cut using this setup.

Figure 3.38: Sanding the edges and the bonding surfaces of the fiberglass tubes.

After all the necessary cuts were made to the G12 fiberglass airframe and coupler sections, the freshly cut edges were sanded smooth with 100-grit sandpaper to avoid the possibility of fiberglass splinters or delamination. Any surfaces that would eventually be bonded to one another were also sanded thoroughly with 100-grit sandpaper to promote a mechanical bond. Figure 3.38 shows the newly cut fiberglass tubes being sanded by club members.

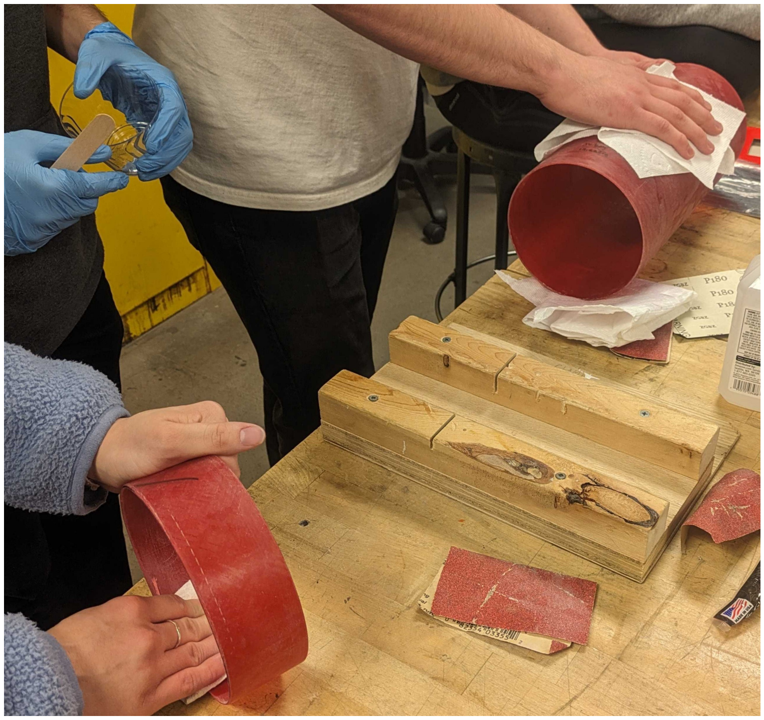

Figure 3.39: Cleaning the fiberglass tubes with acetone.

To promote a chemical bond, all the bonding surfaces were wiped down thoroughly with acetone after sanding. This cleaning also helps contain any fiberglass dust or splinters that might have remained on the tubes. Such cleaning is shown in Figure 3.39.

Figure 3.40: Applying epoxy to the bonding surfaces of the fiberglass tubes.

Figure 3.41: Resting the bonded fiberglass in its curing position.

After the bonding surfaces were thoroughly cleaned with acetone, the sections could be epoxied together. A well-mixed one-to-one ratio of West System's 105 Resin and 206 Slow Hardener was applied in a thin coat to both bonding surfaces (on, for instance, the switchband and the AV bay coupler section) and then set in place to cure. The sections were left to cure for 24 hours before touching them again. In Figures 3.40 and 3.41, the epoxying process and curing position are shown, respectively. Any wooden pieces bonded to the fiberglass (such as the fin can bulkhead, permanent nose cone centering ring, and the rail button mount) were bonded using these same procedures.

3.4.2 Bulkhead Construction

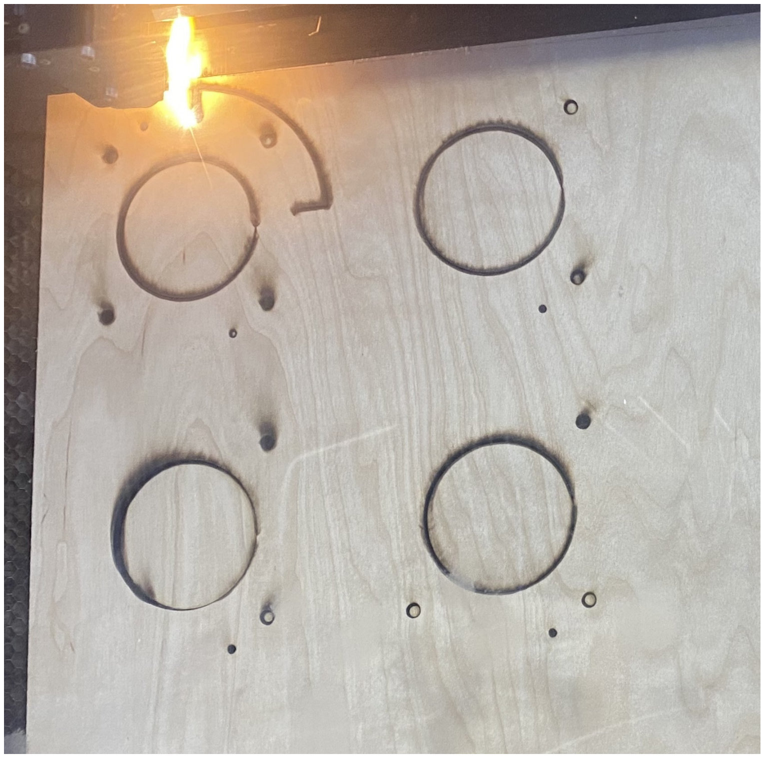

Figure 3.42: Laser cutting bulkhead plies from 1/8 in. aircraft-grade birch plywood.

All bulkheads were constructed by epoxying four plies of 1/8 in. aircraft-grade birch plywood together and letting them cure for 24 hours under a vacuum. Such plies were cut out of a single sheet of 1/8 in. aircraft-grade birch plywood using a Universal Laser Systems 75 W laser cutter available at NC State's Entrepreneurship Garage. Figure 3.42 shows the plies of a single RFS bulkhead being cut out of a sheet of aircraft-grade birch plywood using this laser cutter. Note that additional holes were added to each of the plies to accept 1/8 in. diameter wooden dowels to align the plies when epoxying them together.

Figure 3.43: Sanding the faces of the bulkhead plies.

After the plies were cut out of the sheet of aircraft-grade birch plywood, the faces of each of the plies were sanded with 100 grit sandpaper to promote a mechanical bond between the plies. The 1/8 in. wooden dowels were also cut to length (1/2 in. for all bulkheads since each bulkhead is 1/2 in. thick) to prepare for the next step. Figure 3.43 shows the bulkhead plies being sanded.

Figure 3.44: Epoxying the faces of the bulkhead plies.

Once the faces of all the bulkhead plies were sanded, each of them was placed in a stack next to each other on a sheet of peel ply. This sheet was cut large enough such that half of the sheet could be folded over the top of the bulkheads once they were completely epoxied. A well-mixed one-to-one ratio of West System's 105 Resin and 206 Slow Hardener was applied in a thin layer on each of the bulkhead faces before stacking the plies on top of one another and inserting the alignment dowels. Figure 3.44 shows the bulkhead plies being epoxied before being stacked on top of one another.

Figure 3.45: Vacuum setup for bulkheads.

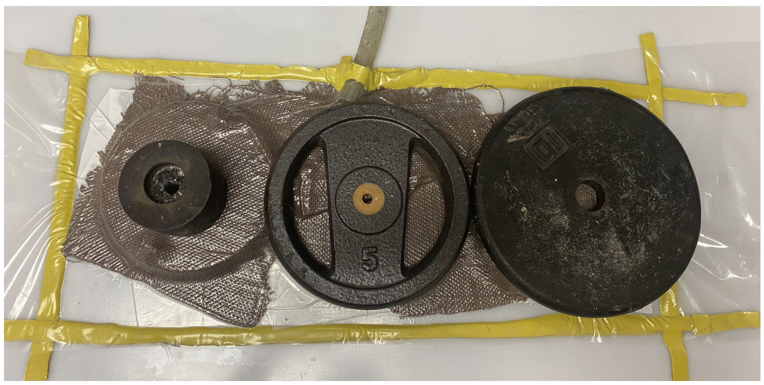

Figure 3.46: Curing setup for bulkheads.

After the bulkhead plies were stacked and aligned, the sheet of peel ply was folded over the bulkheads to stop excess epoxy that leaks out from permanently bonding the bulkheads to the vacuum table. A border of yellow sealant tape was added around the peel ply for the polyethylene vacuum bag to stick to and create an air-tight seal. Before this vacuum bag was added, burlap was added over the peel ply serving as a breather material. The vacuum tube was placed within the yellow sealant tape border and a bit of extra sealant tape was added over the top of it to help prevent air leaks. Finally, the vacuum bag is added over the top of the breather material and pressed firmly on the yellow sealant tape border. The vacuum is then turned on and left on for 24 hours. Figure 3.45 shows how the vacuum setup looks once all the steps are complete. Weights were also added over the top of the bulkheads to ensure that the plies were being compressed together as much as possible. The addition of these weights is shown in Figure 3.46.

3.4.3 Nose Cone Construction

Figure 3.47: Marking the nose cone coupler for epoxy.

The nose cone was purchased from Performance Hobbies and came with a 9 in. coupler section. This 9 in. coupler section was cut down to 6 in. using the procedures outlined in Section 3.4.1. Likewise, the coupler section was carefully measured and marked before cutting, which can be seen in Figure 3.47.

Figure 3.48: Adding the T-nuts to the nose cone's permanent centering ring.

After the coupler section was cut, thorough sanding and cleaning of the section followed as in Section 3.4.1. It was then time to prepare the nose cone's permanent centering ring. The centering ring was made using the same procedures outlined in Section 3.4.2 before hammering four 1/4 in. T-nuts into the pre-cut holes. Installation of these T-nuts is shown in Figure 3.48.

Figure 3.49: Weight added to the nose cone coupler and centering ring assembly for curing.

The permanent centering ring was then added to the forward end of the nose cone coupler section using the procedures outlined in 3.4.1. A well-mixed one-to-one mixture of West System's 105 Resin, 206 Hardener, and 406 Colloidal Silica Adhesive Filler was used to bond the centering ring to the coupler section. The interior joint where the coupler meets the centering ring was reinforced with a fillet made from the same epoxy/filler mixture. Finally. various weights were added on top of the centering ring to keep it level on the coupler section as the epoxy cured over the next 24 hours. The assembly is shown in its curing position in Figure 3.49.

Figure 3.50: Sanding bonding surface for the nose cone.

To permanently fix the nose cone coupler to the nose cone, the bonding surfaces of both were sanded thoroughly with 100 grit sandpaper and then cleaned with acetone as in Section 3.4.1. Figure 3.50 shows the interior of the nose cone being prepped for epoxy.

Figure 3.51: Nose cone coupler epoxied to the nose cone.

A one-to-one mixture of West System's 105 Resin and 206 Slow Hardener was applied in a thin layer on both the outside of the nose cone coupler and its permanent centering ring and on the inside of the nose cone. The nose cone assembly was placed on a PVC stand and carefully leveled before leaving the sections to cure for 24 hours. Figure 3.51 shows the nose cone assembly in its curing position.

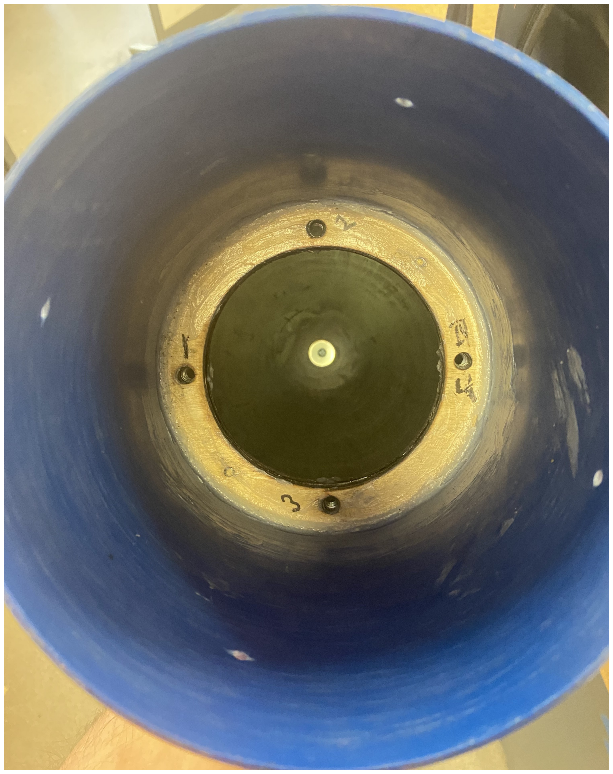

Figure 3.52: Permanent centering ring installed in the nose cone.

In Figure 3.52, the permanent centering ring can be seen inside the nose cone assembly.

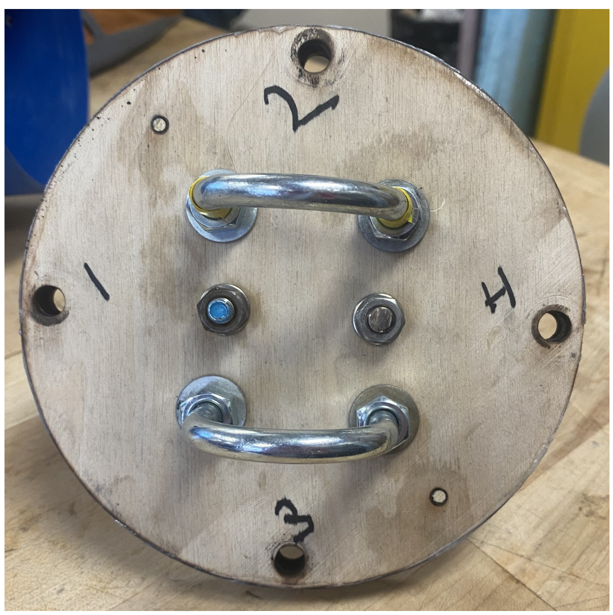

Figure 3.53: Hardware added to the removable nose cone bulkhead (front).

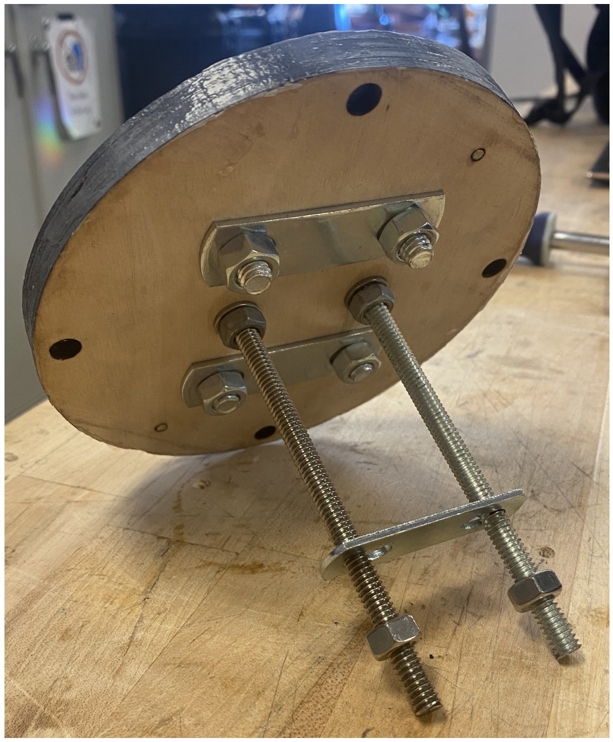

Figure 3.54: Hardware added to the removable nose cone bulkhead (back).

The removable nose cone bulkhead was manufactured the same way as the rest of the bulkheads shown in Section 3.4.2. Two U-bolts were added to their pre-cut holes in the bulkhead. Washers were added on both faces of the bulkhead and a drop of Removable Loctite Thread Locker was added to the threads before tightening the nuts down. Similarly, two 1/4 in.-20 x 5 in. threaded rods were added between the two U-bolts in their pre-cut holes to mount the nose cone electronics sled. Washers were again added to the front and back faces of the bulkhead on the threaded rods. A drop of Removable Loctite Thread Locker was added to the threads before tightening down the nuts on both sides of the bulkhead. A stainless steel bracket was added to the threaded rods and secured with two more nuts to prevent the electronics sled from translating in flight. The front and back faces of the removable nose cone bulkhead are shown in Figures 3.53 and 3.54, respectively.

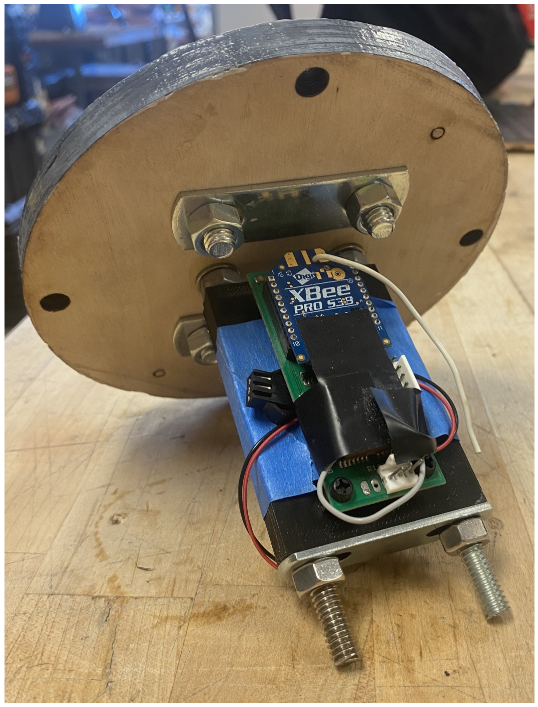

Figure 3.55: Removable nose cone bulkhead with electronics sled installed.

Figure 3.55 shows the nose cone electronics sled mounted on the threaded rods and secured with the stainless steel bracket and nuts.

Figure 3.56: Removable nose cone bulkhead installed in the nose cone.

The removable nose cone bulkhead is then secured to the permanent nose cone centering ring with four 1/4 in.-20 x 1 in. steel round head bolts each with a 1/4 in. washer. Figure 3.56 shows the removable nose cone bulkhead installed in the nose cone assembly.

3.4.4 Main and Payload Bay Construction

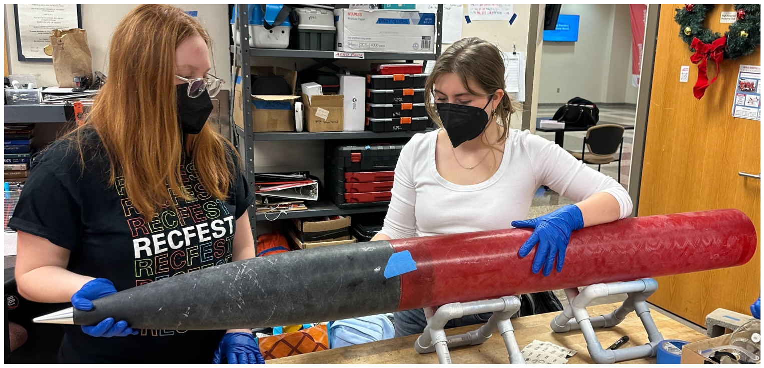

Figure 3.57: Preparing to drill shear pin holes in the main parachute/payload bay and the nose cone shoulder.

The main parachute/payload bay construction consisted of cutting the fiberglass tube to length and sanding the edges smooth with 100-grit sandpaper as described in Section 3.4.1. Holes were also drilled in this section to accept four 1/4 in. Nylon push-clip rivets and four #4-40 Nylon shear pins. Such holes were drilled with the non-separating AV bay coupler section and nose cone shoulder installed in the main parachute/payload bay, respectively. This method ensured that the holes would remain aligned in each section. Figure 3.57 above shows the main parachute/payload bay being prepared for drilling these holes.

3.4.5 Avionics Bay Construction

The AV bay was made from a 12.5 in. coupler section with a 2 in. section of airframe permanently epoxied to it such that 4.5 in. of exposed coupler remains for the non-separating section and 6 in. of exposed coupler remains for the separating section. This coupler lengths satisfy NASA Vehicle Requirements 2.4.1 and 2.4.2, respectively. Section 3.2.4 shows the CAD drawing as well as the as-built dimensions of the AV bay airframe assembly. The airframe and coupler sections were joined together using methods described in Section 3.4.1. Specifically, Figures 3.38, 3.39, 3.40, and 3.41 show the steps carried out to bond the coupler section and switchband of the AV bay.

The bulkheads for the AV bay were fabricated using the same procedures outlined in Section 3.4.2. Once the bulkheads were fabricated, U-bolts were installed in their pre-cut holes. Like the other bulkheads, washers were added to the U-bolts on both faces of the bulkheads and then a drop of Removable Loctite Thread Locker was added to the threads before tightening the nuts down to keep the U-bolts in place.

Figure 3.58: Drilling holes in the AV bay bulkheads to add hardware.

Figure 3.59: Adding hardware to AV bay bulkheads.

To add PVC blast caps and terminal blocks to the AV bay bulkheads, holes were drilled using an electric hand drill as shown in Figure 3.58. Figure 3.59 shows these blast caps and terminal blocks attached to the drogue AV bay bulkhead. Blue electrical tape was also added to the blast caps and U-bolt to distinguish the drogue AV bay bulkhead from the main AV bay bulkhead (which has red electrical tape).

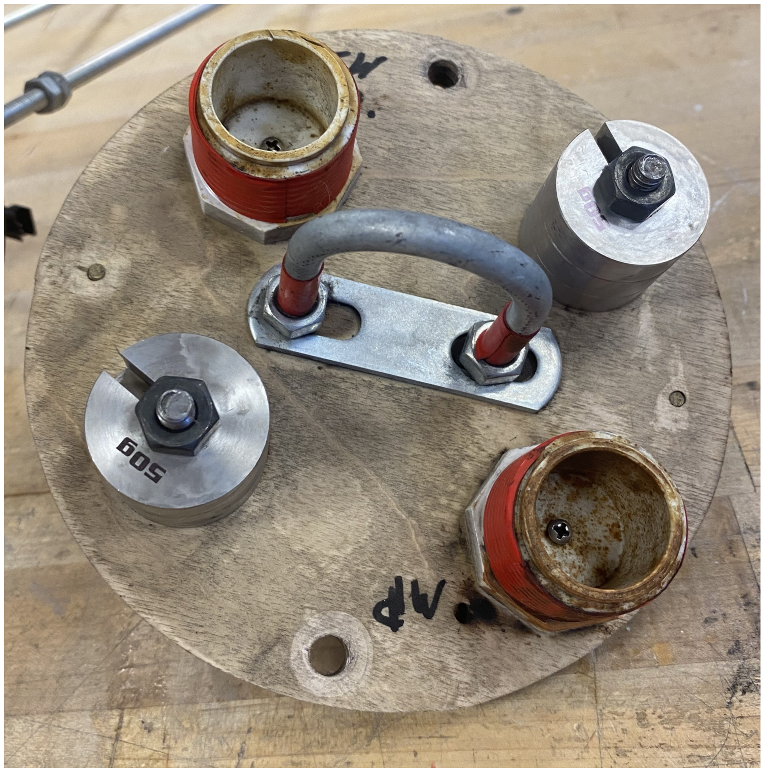

Figure 3.60: Completed main AV bay bulkhead.

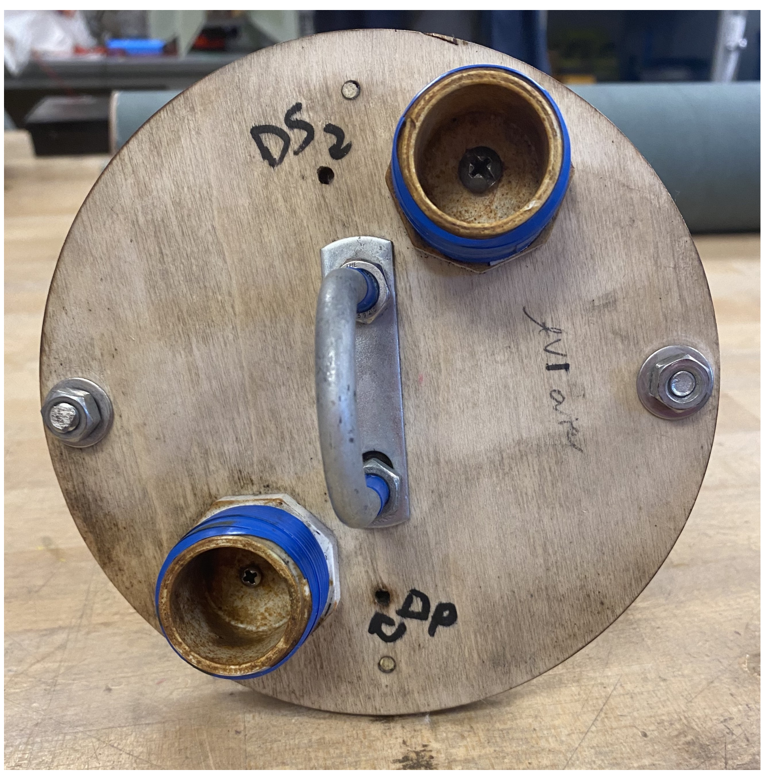

Figure 3.61: Completed drogue AV bay bulkhead.

Figure 3.60 shows the completed main AV bay bulkhead. It was constructed similarly to the drogue AV bulkhead except for the addition of weights that are mounted onto the bulkhead with 1/4 in.-20 threaded rods and secured in place with nuts. Notice in Figure 3.60 that there are small holes near the blast caps marked ”MP” and ”MS” for ”Main Primary” and ”Main Secondary,” respectively. These holes were made large enough to fit an E-match wire through so that it could be fed from the electronics sled inside the AV bay to the appropriate blast cap. The completed drogue AV bay bulkhead shown in Figure 3.61 contains these E-match holes as well. Instead, they are labeled ”DP” and ”DS” for ”Drogue Primary” and ”Drogue Secondary,” respectively. Finally, both bulkheads contain pre-cut holes for the 1/4 in.-20 x 14 in. threaded rods which extend through the AV bay and hold the AV bay bulkheads and electronics sled in place.

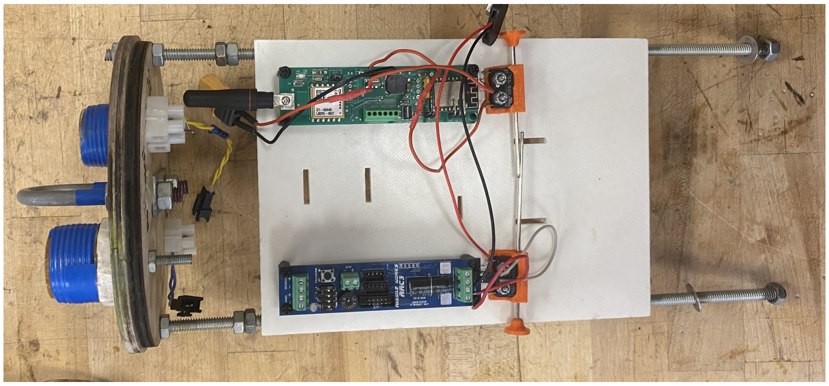

Figure 3.62: Electronics sled on AV bay threaded rods.

In Figure 3.62, the drogue AV bay bulkhead is pictured with the electronics sled mounted on the threaded rods. These threaded rods are secured to the drogue and main AV bay bulkheads with both a washer and a nut on each face. Given that the sled needs to be in a certain position on the threaded rods for the pull-pin switches to align with the switchband, two nuts were locked against each other to stop the sled at the correct location. Removable Loctite Thread Locker was added to the threads between these two nuts to ensure that they will not come loose.

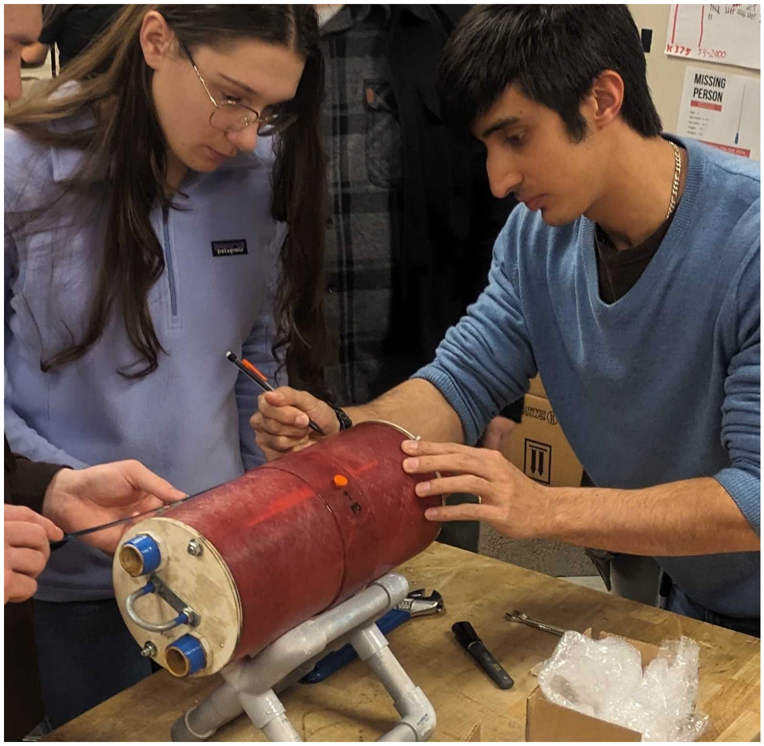

Figure 3.63: Marking shear pin and rivet holes on the AV bay.

After the holes were marked and drilled for the pull-pin switches on the switchband, holes for #4-40 Nylon shear pins and 1/4 in. Nylon push-clip rivets were marked on the AV bay coupler sections. Such marking is shown in Figure 3.63. The non-separating section of the AV bay was then inserted into the main parachute/payload bay so the hole marks could be traced onto the main parachute/payload bay. The sections were kept together when drilling these holes to make sure that they were aligned on each section. The same method was used to drill the shear pin holes through the drogue parachute bay/fin can and the AV bay at the same time. Finally, two 1/4 in. pressure port holes were drilled on the switchband so that the altimeters would have adequate exposure to the air.

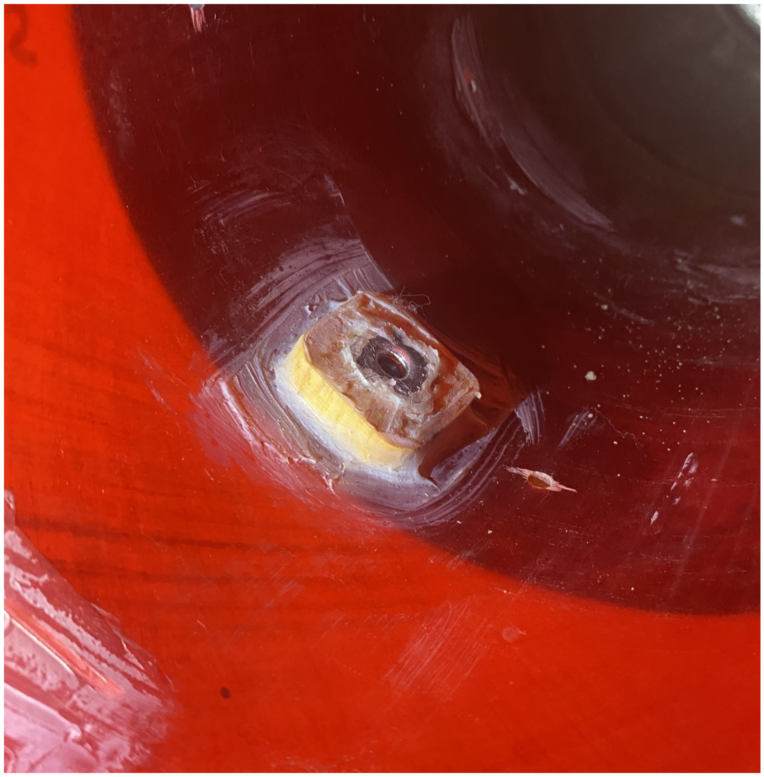

Figure 3.64: Switchband rail button mount on the inside of the AV bay.

Finally, the forward rail button was added to the AV bay switchband. The AV bay and drogue parachute bay/fin can with the RFS installed (and thus the aft rail button installed) were aligned using previous alignment marks to determine where to drill the hole on the switchband. Once the hole was marked and drilled, a small wooden attachment was made to screw the rail button into. A 1/4 in.-20 x 5/16 in. T-nut was hammered into a piece of wood that was then cut and sanded until it matched the contour of the inside of the coupler section. The rail button screw was screwed into this wooden attachment to hold it in place inside the AV bay. Using a one-to-one mixture of West System's 105 Resin, 206 Slow Hardener, and 406 Colloidal Silica Adhesive Filler, the wooden attachment was epoxied in place and left to cure for 24 hours. The completed rail button attachment can be seen epoxied inside the AV bay in above in Figure 3.64.

Figure 3.65: Complete AV bay assembly.

The complete AV bay assembly is shown in Figure 3.65.

3.4.6 Drogue Bay and Fin Can Construction

Figure 3.66: Cutting the fin slots with a diamond blade.

The drogue parachute bay/fin can was cut to its design length using the same procedures in Section 3.4.1. After the section was cut, sanded, and cleaned, the RFS was inserted into one end and a light was shown from the outside of the section to see the fin slots. Once the fin slots were visible from the outside, a black marker was used to trace over the area to mark where the cuts needed to be made. The fin slots were cut with a diamond-tipped blade on a Dremel tool in NC State's Aerospace Senior Design Lab which has a designated ventilated room for cutting and sanding composites. This process can be seen in Figure 3.66. After the fin slots were cut, the area was again thoroughly sanded with 100-grit sandpaper and cleaned with acetone.

Figure 3.67: Drilling screw holes for the RFS.

After the fin slots were created, the RFS was placed back into the drogue parachute bay/fin can such that the runners aligned with the fin slots. A bright light was once again shown on the outside of the airframe to reveal the shadows of the L-brackets from the RFS. Using these shadows, it was possible to mark exactly where the screw holes for the RFS needed to be drilled on the airframe. Using these marks, all eight holes were drilled as seen in Figure 3.67. The shear pin holes for the drogue parachute bay/fin can were drilled during AV bay construction, which is covered in further detail in Section 3.4.5.

The fin can bulkhead was created using the same procedures outlined in Section 3.4.2. A single U-bolt was added to the pre-cut holes in the bulkhead and secured with two washers and two nuts on each face along with a drop of Removable Loctite Thread Locker on the threads. The inside of the drogue parachute bay/fin can was prepped for epoxy just as in Section 3.4.1. After this preparation was complete, a one-to-one mixture of West System's 105 Resin, 206 Slow Hardener, and 406 Colloidal Silica Adhesive Filler was added to the fiberglass and the outer edge of the bulkhead before positioning the bulkhead inside the airframe. Using this same epoxy mixture, fillets were added on both sides of the bulkhead where it meets the airframe. The airframe was then left in a horizontal position and left to cure for 24 hours. Figures 3.22 and 3.21 in Section 3.2.5 show the bulkhead installed and its position inside the section, respectively.

Removable Fin System

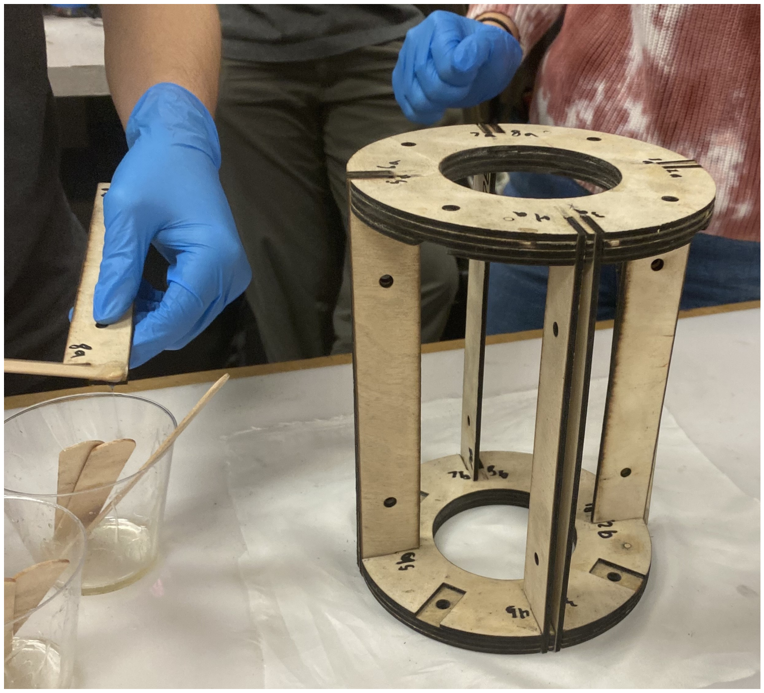

Figure 3.68: Epoxying the runners to the RFS bulkheads.

The RFS bulkheads and the thrust bulkhead were constructed using the procedures outlined in Section 3.4.2. The runners, however, are constructed from single plies of 1/8 in. aircraft-grade birch plywood and thus do not need to undergo a layup process. The first step for constructing the RFS was to epoxy the runners to both of the RFS bulkheads. The slots on the bulkheads and the tabs on the runners were sanded with 100-grit sandpaper before preparing a one-to-one mixture of West System's 105 Resin and 206 Slow Hardener. Thin coats of this mixture were applied to both the runner tabs and bulkhead slots before the runners were set in place and left to cure for 24 hours. This process is shown in Figure 3.68.

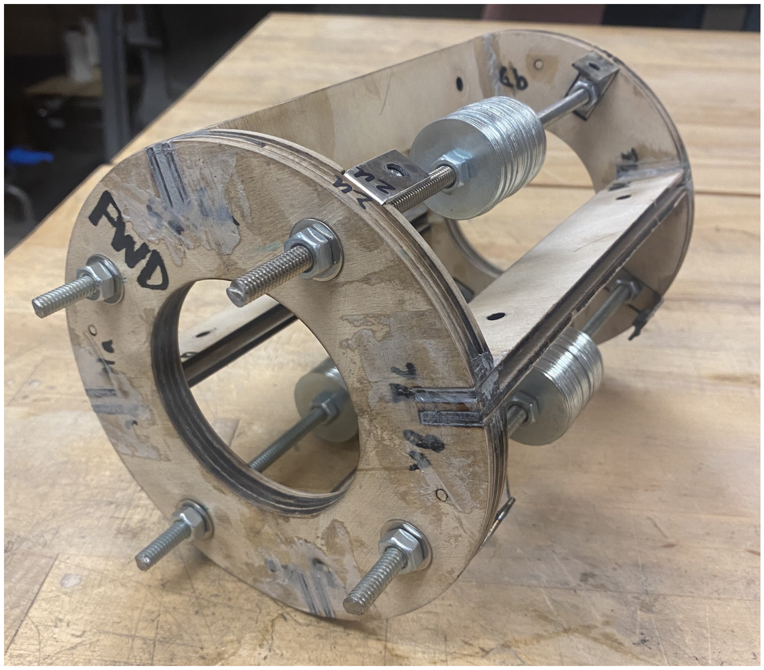

Figure 3.69: RFS with threaded rods, custom L-brackets, and ballast.

After the runners were attached to the bulkheads, four 1/4 in.-20 x 10 in. steel threaded rods were cut to length using a metal cutting bit on a Dremel tool. These threaded rods will hold eight custom L-brackets and any necessary ballast in place. Each custom L-bracket consists of a stainless steel L-bracket with a #8-32 stainless steel nut welded over one of its screw holes (except for the one L-bracket that holds the aft rail button which has a 1/4 in. stainless steel nut welded on it instead). Such welding was done by one of the teaching assistants in NC State's MAE Senior Design Lab. First, the necessary ballast (in the form of stainless steel washers) was added to the threaded rods. Nuts were added on either side of the washers to keep the washers in place. Next, a nut and a custom L-bracket were inserted on each end of the threaded rods. The threaded rods could then be fed through the pre-cut holes in the forward and aft RFS bulkheads. Each custom L-bracket was slid down into its grooves on the RFS bulkhead and then secured in place by tightening the nuts that were added to the threaded rods earlier. Washers and nuts were added to the ends of the threaded rods which terminate after the top face of the forward bulkhead. Figure 3.69 shows what the RFS looks like after the addition of the threaded rods, custom L-brackets, and ballast.

Thrust Plate and Thrust Bulkhead

Figure 3.70: Thrust plate made from 6061 aluminum.

The thrust plate for the RFS was waterjet from a piece of 6061 aluminum in NC State's MAE Senior Design Lab. The holes for the threaded rods were slightly off, so they were made larger with a routing bit on a Dremel tool. The final part is shown in Figure 3.70

Figure 3.71: Motor retainer hardware being added to the thrust bulkhead.

The thrust bulkhead was constructed using the same procedures outlined in Section 3.4.2. After this bulkhead was constructed, an Aeropack motor retainer was added to it using the threaded inserts and screws that it came with. A drop of West System's 105 Resin and 206 Slow Hardener was added in and around the threaded inserts and in the threads of the screws to ensure there is no chance of the motor retainer coming loose. Figure 3.71 shows the screws being added to the threaded inserts on the thrust bulkhead to make sure they would work properly.

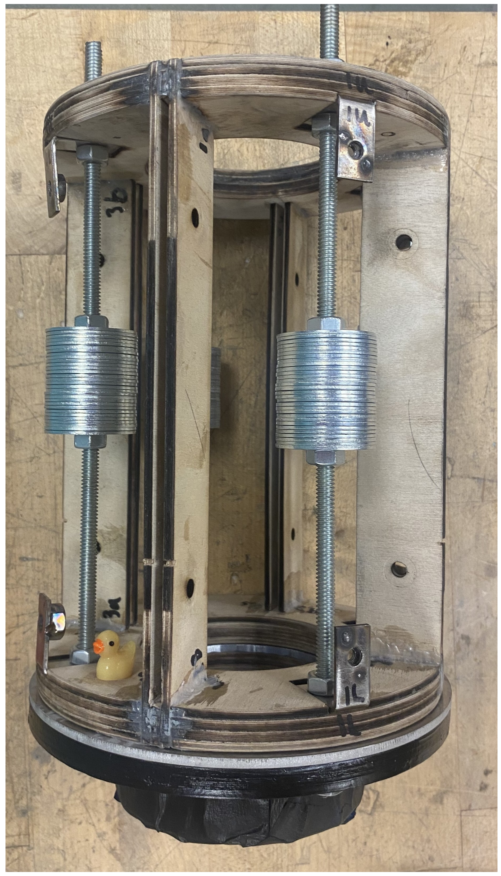

Figure 3.72: RFS with thrust plate and thrust bulkhead installed.

After the thrust plate and thrust bulkhead were made, both were slid onto the ends of the threaded rods on the aft RFS bulkhead. and secured in place with a washer and a nut on the end of each threaded rod. Figure 3.72 shows what the RFS looked like at this point.

G10 Fiberglass Fins

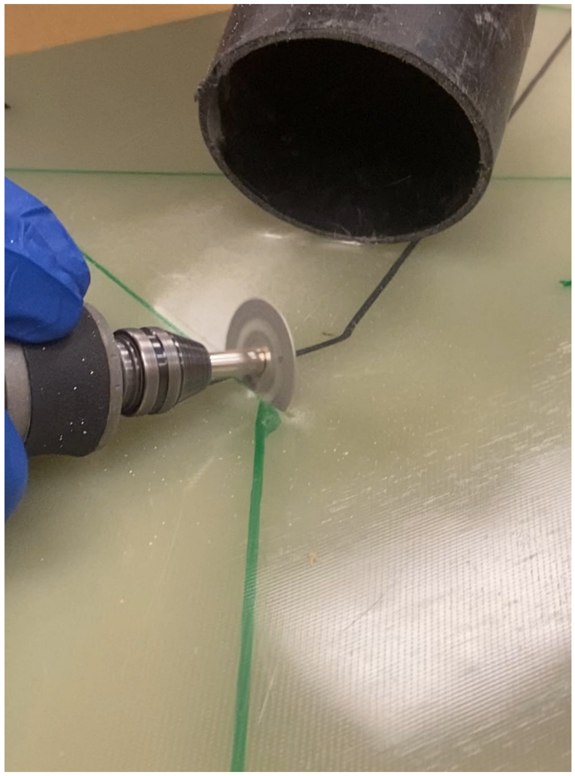

Figure 3.73: Cutting out the G10 fiberglass fins.

The fins were made by first laser cutting a template out of aircraft-grade birch plywood. This template was used to trace the shape of the fins onto a 1 x 2 ft. x 1/8 in. sheet of G10 fiberglass. After the fin shapes were traced, a diamond-tipped cutting blade was used on a Dremel tool to cut them out. The cuts were made on the outside of the traced lines to leave room for sanding and beveling later on. This process took place in NC State's Aerospace Senior Design Lab which has a dedicated ventilated room for cutting and sanding composite materials. Figure 3.73 shows the cutting process taking place.

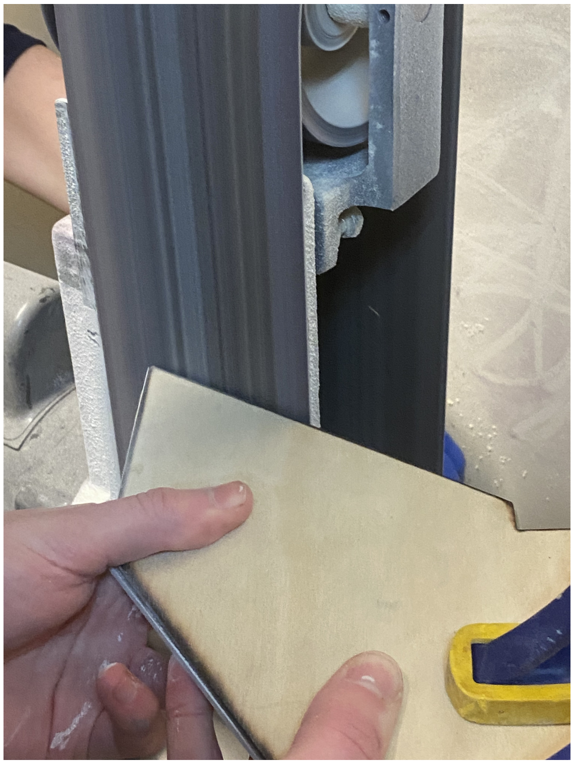

Figure 3.74: Leveling and beveling the G10 fiberglass fins.

Figure 3.75: Complete G10 fiberglass fin.

To make the fins identical in shape, the fin template was clamped to each newly cut fin to expose the excess material. With the template still clamped to the fin, a belt sander in the same ventilated lab space was used to remove this excess material. After all the fins were the same shape, this same belt sander was used to bevel the edges so that the cross-section was no longer rectangular. Finally, the template was used to mark and drill holes in the fin tabs so they could be attached to the RFS later. Figures 3.74 and 3.75 show the fins being sanded with the template and an example of a completed fin, respectively.

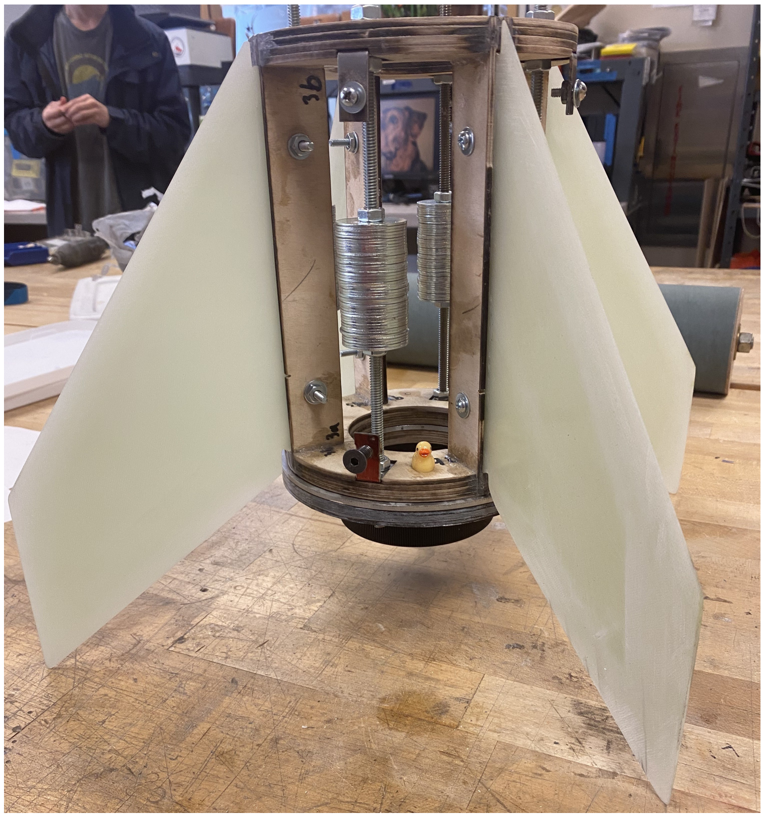

Figure 3.76: Complete RFS assembly.

Finally, the four G10 fiberglass fins were screwed into the runners on the RFS using #8-32 x 1 in. zinc-plated steel screws and nuts. Washers were added on the outside faces of the runners at each of these connections to reduce the risk of cracking around the screw holes. The complete RFS assembly is shown in Figure 3.76.

Figure 3.77: RFS screwed into drogue parachute bay/fin can.

Figure 3.78: Complete drogue parachute bay/fin can assembly.

After the RFS assembly was complete, it could be screwed into the drogue parachute bay/fin can with seven #8-32 x 1/2 in. zinc-plated steel screws and one 1/4 in.-20 x 1 in. rail button screw. Figures 3.77 and 3.78 show the RFS assembly screwed into the drogue parachute bay/fin can and the complete drogue parachute bay/fin can, respectively.

3.4.7 Test Piece Fabrication

AV Bay Bulkhead Test Article

Figure 3.79: AV bay bulkhead test article.

The AV bay bulkhead test article was constructed by first making two AV bay bulkheads using the procedures outlined in Section 3.4.2 and attaching U-bolts to both of them with washers, nuts, and a drop of Removable Loctite Thread Locker on the threads. For testing purposes, no blast caps, terminal blocks, or ballast were added to these bulkheads. The two AV bay bulkheads were connected by two 1/4 in.-20 threaded rods just as they are in the launch vehicle. These threaded rods, however, had to be much shorter than they are on the launch vehicle for the test article to be able to fit into the testing machine in NC State's Structural Mechanics Lab. The complete test article assembly is shown in Figure 3.79.

Nose Cone Bulkhead Test Article

Figure 3.80: Nose cone bulkhead test article.

The nose cone bulkhead test article was constructed out of an AV bay bulkhead, a permanent centering ring, a removable nose cone bulkhead, and a scrap section of G12 fiberglass coupler. The AV bay bulkhead, permanent centering ring, and removable nose cone bulkhead were fabricated using the same procedures described in Section 3.4.2. A U-bolt was attached to the AV bay bulkhead with washers and nuts on both faces and a drop of Removable Loctite Thread Locker in the threads. Using the methods described in Section 3.4.1, the AV bay bulkhead was permanently epoxied to the G12 fiberglass coupler section with a one-to-one mixture of West System's 105 Resin, 206 Slow Hardener, and 406 Colloidal Silica Adhesive Filler. The permanent centering ring (with its four 1/4 in.-20 x 5/16 in. steel T-nuts already installed) was likewise permanently epoxied to the other side of the coupler section with this same epoxy mixture. The removable nose cone bulkhead was then screwed into the permanent centering ring with four 1/4 in.-20 x 1 in. steel round head bolts and four washers. Note that the test version of the removable nose cone bulkhead only has one U-bolt attached to it. One U-bolt was chosen over two for this test because the test article could not fit properly into the grippers on the testing machine with both U-bolts in place. The complete nose cone bulkhead test article assembly is shown in Figure 3.80.

G10 Fiberglass Fin Test Article

Figure 3.81: G10 fiberglass fin test article with weights attached.

The G10 fiberglass fin test article was made with the same batch of fins produced for the launch vehicle. Section 3.4.6 describes in detail how the fins were produced. The only difference for the test fin is the fasteners in the screw holes. To attach rail buttons and ballast to the fins, 1/4 in.-20 steel threaded rods were added to the holes so everything could be secured with 1/4 in. nuts. For ballast, round 50g weights and a five-pound bumper plate were added to the threaded rods and secured with nuts. The complete G10 fiberglass fin test article is shown in Figure 3.81

3.5 Recovery Subsystem

3.5.1 Recovery Design Overview

The recovery subsystem ensures that the launch vehicle will have a controlled descent and will land safely in a reusable condition. This includes the use of a recovery harness and parachute system, an avionics system, and a tracking system. The majority of the electronics used for the recovery of the launch vehicle are mounted on an AV sled that is located in the AV bay of the launch vehicle, with the exception of a tracker in the separating nose cone. Section 3.5.2 contains a more detailed description of this AV sled.

As a quick overview, the primary altimeter shall be an RRC3 sport altimeter, and the secondary altimeter shall be an Eggtimer Quasar. The RRC3 will be powered by a standard 9V battery, while the Quasar will be powered by a 2S/ 7.4 LiPo battery. These altimeters are responsible for launch vehicle separation through the use of a black powder ejection system. On the forward and aft bulkheads of the AV bay rests two PVC blast cast caps used to store black powder. Each altimeter will be connected to two terminal blocks on the inside of the bulkheads. E-matches will also be connected to the terminal block and will then be feed through the bulkhead and placed in the blast caps. There is a U-bolt on each bulkhead that is used to link the Kevlar shock cord via a stainless steel quick-link that will keep the separated sections together and hold the parachutes.

There will be two GPS tracking devices onboard the launch vehicle, one for the launch vehicle itself, and one for the nose cone since it is separating independently. The launch vehicle tracker shall be an Eggtimer Quasar, which also functions as the secondary altimeter, and the nose cone tracker will be a Big Red Bee 900. The launch vehicle tracker will be powered on during AV bay assembly and connected to the Eggfinder handheld LCD receiver. The nose cone tracker will be powered on during nose cone assembly and will connect to its handheld receiver. Both of the receivers for each tracker will be in the possession of the Recovery Lead during launch operations.

To ensure the safety of launch personnel, the altimeters will not be powered on when there is black powder inside the blast caps. To comply with this safety step, a continuity check will be be performed on the E-match before the E-matches are connected to the terminal block. These steps prevent the risk of accidental detonation of the black powder while still ensuring that the recovery system is functional. The one exception to this policy is when the AV bay is being assembled on the field. The altimeters must be armed momentarily while connected to charges to allow the AV bay sled and bulkheads to be put into place. This is only done after ensuring that all members are wearing safety glasses and the blast caps are pointed away from personnel. Upon completion, the pull-pin switch is re-inserted through the exterior of the rocket, disarming the altimeters. These altimeters will then remain disarmed until the launch vehicle is on the launch pad where pre-flight inspections will occur, verifying that the recovery system is still operational.

Upon successful launch of the vehicle, once the primary altimeter detects apogee, a signal will be sent to the primary drogue ejection charge. One second after apogee, the secondary altimeter will send a signal to the secondary drogue ejection charge, separating the rocket if the first charge did not. With successful drogue separation, the 15 in. drogue parachute will deploy, and the launch vehicle will descend under the drogue to 800 ft (Figure 3.82).

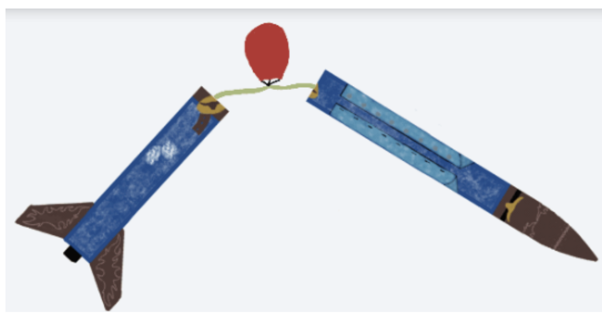

Figure 3.82: Drogue Recovery Event.

Once the primary altimeter senses the launch vehicle is at 800 ft, a signal is sent to the primary main ejection charge, separating the nose cone from the launch vehicle. Additionally, once the secondary altimeter detects a height of 700 ft, a signal is sent to the main secondary ejection charge, separating the nose cone if the first charge failed to do so (Figure 3.83).

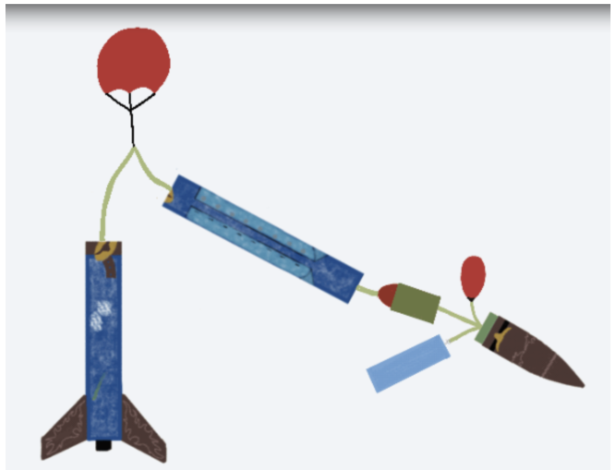

Figure 3.83: Main Recovery Event.

Connected to the nose cone is its parachute, the deployment bay for the payload, and the deployment bag that covers the main parachute used for the rest of the launch vehicle. The deployment bag is now connected to the U-bolt on the deployment bay bulkhead instead of the nose cone bulkhead, a change since CDR. After successful nose cone separation, the 96 in. main parachute for the launch vehicle will deploy (Figure 3.84).

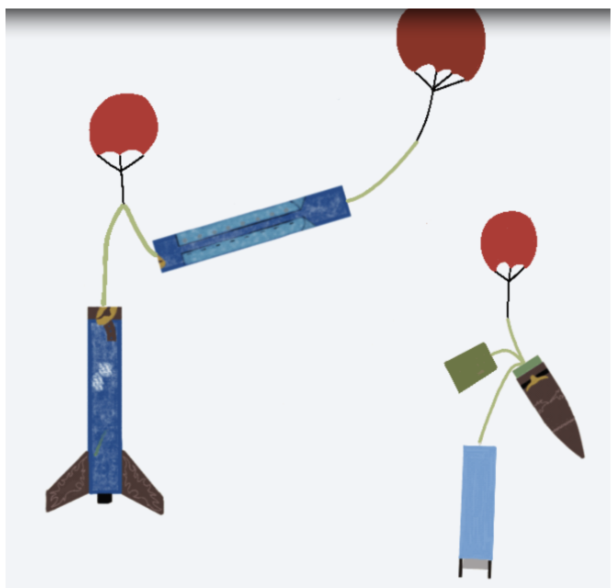

Figure 3.84: Main and Nose Cone Descent.

The nose cone will then descend with a 48 in. parachute with the payload attached until approximately 450 ft, where the payload is dropped via a latch (Figure 3.85), discussed in Section 4.4.3.

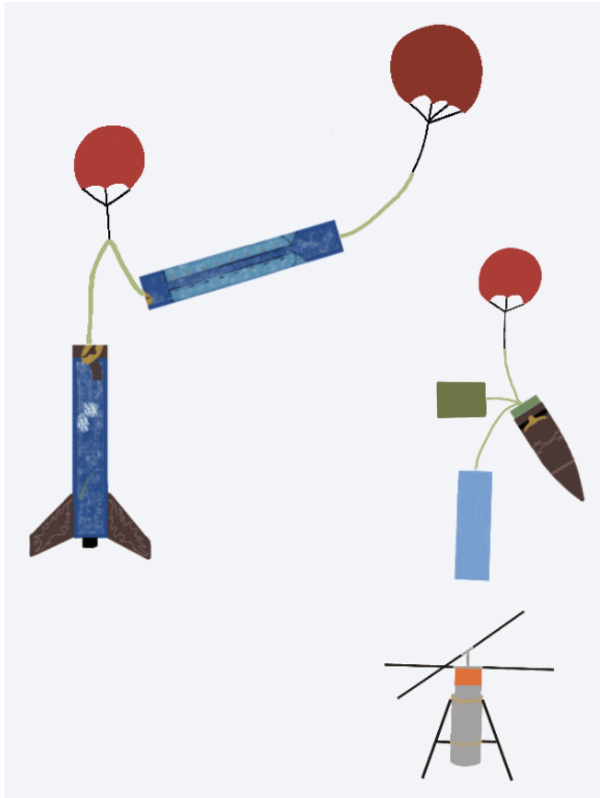

Figure 3.85: Payload Deployment.

The drogue and nosecone parachutes will be protected from ejection charges with a Nomex cloth, and the main parachute will be protected by the deployment bag. An illustration that conveys the deployment timeline of the recovery system is shown in Figure 3.86.

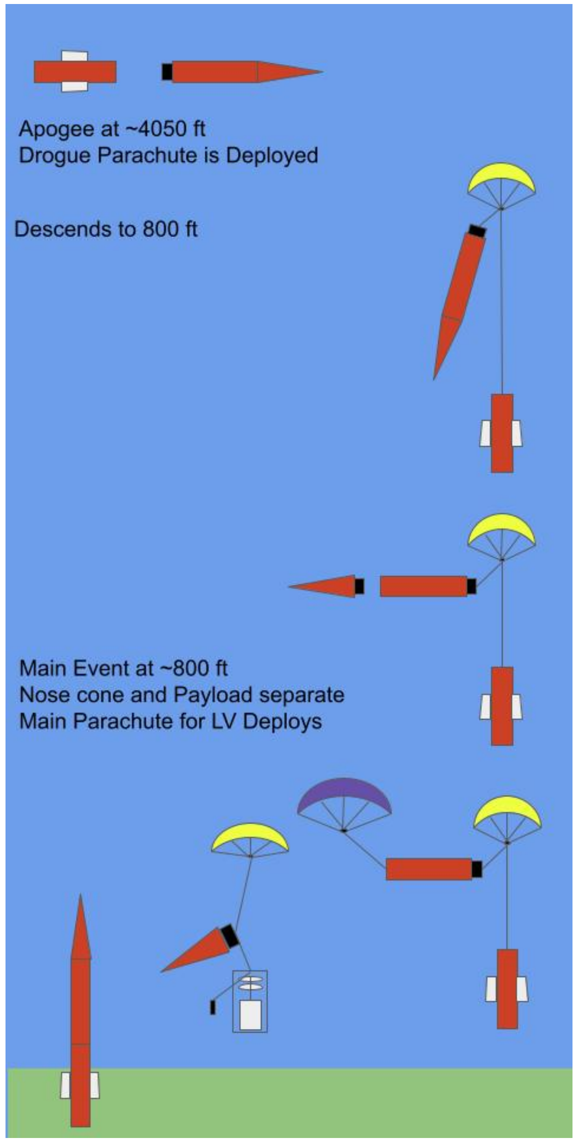

Figure 3.86: Deployment timeline of the launch vehicle.

The drogue event separation point is aft of the AV bay and forward of the drogue parachute bay/fin can. These sections of the rocket are held together by 4-40 nylon shear pins. Detonation of the drogue ejection charges during flight will break these pins, allowing the sections to separate. Additionally, the main event separation point is aft of the nose cone and forward of the main parachute bay/ payload bay. These sections are also held together by 4-40 nylon shear pins that are built to break upon detonation of the main charges. Furthermore, the nose cone will separate and descend untethered to the rest of the launch vehicle independently with a 48 in. parachute, the main parachute's deployment bag, the SAIL deployment bay, and the SAIL. The mass of the ejection charges is calculated, shown in Section 3.5.7, to ensure the pressure created from the detonation is large enough to shear the pins, and therefore separate the rocket. Lastly, before each launch, an ejection test will be conducted to ensure that the masses of these charges will separate the launch vehicle.

Upon successful launch vehicle recovery, the handheld receivers will be used to locate the nose cone and the launch vehicle. The apogee detected by both altimeters will be recorded and then disarmed by inserting the pull-pin switch.

3.5.2 Structural Components

AV Bay Bulkheads

The AV Bay Bulkheads are fabricated by epoxying four 1/8” laser cut birch plywood sections. Two 1/4 in. holes are on the edges for threaded rods to run through the AV Bay. The bulkheads are secured in place by 1/4 in. nuts installed on the threaded rods. The inside of each bulkhead features two terminal blocks that will connect the altimeters to the e-matches that will feed through 1/8” holes in the bulkhead. These holes will be sealed with plumbers putty during ejection testing and during launches to protect the avionics in the AV Bay. The outside of each bulkhead features two PVC blast caps that hold the primary and secondary black powder ejection charges. Additionally, there is a centered U-bolt that is secured with 1/4” nuts, used for recovery harness attachment points. For more detail, see 3.59. Shown below is an image of the AV Bay bulkheads.

Figure 3.87: AV Bay Bulkheads.

Avionics Sled

The AV sled will hold the launch vehicle avionics, their batteries, and the pull-pin switches. It was designed in SolidWorks and will be fabricated with a 3D printer using PETG filament. The rectangular mounting surface will have an area of 48.8 square inches. The avionics will be mounted on M3 4-40 nylon standoff screws attached to the sled. These screws will be attached to M3 threaded heat inserts placed into the top surface with a soldering iron tip. The battery compartments for both altimeters are located on the bottom surface, the smaller one for the 9V primary altimeter battery, and the bigger one for the 2S/ 7.4 V LiPo secondary altimeter/tracker battery. The batteries will be secured in their compartments using zip ties and electrical tape. For mounting, the hollow tubes serve as rails for the threaded rods that run through the AV bay, securing the sled on the rods using 1/4 in. nuts. Lastly, the small holes in the design are for the pull-pin mechanical arming switches that will be bolted onto the sled 3.25 inches from the forward edge of the sled. The first two figures below show the modeled AV Sled with its dimensions, and the following two show the top and bottom views of the fully assembled and built AV Sled.

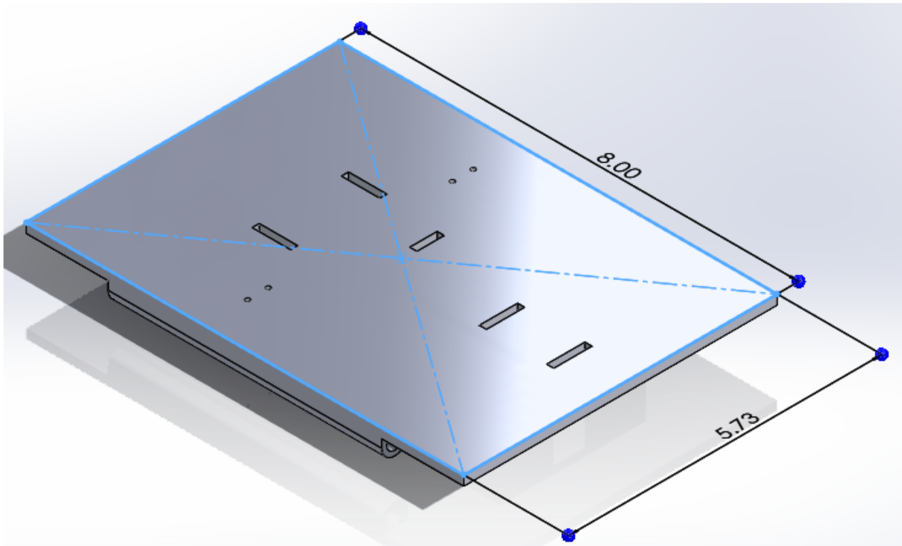

Figure 3.88: Top surface of modeled Full-Ccale avionics sled.

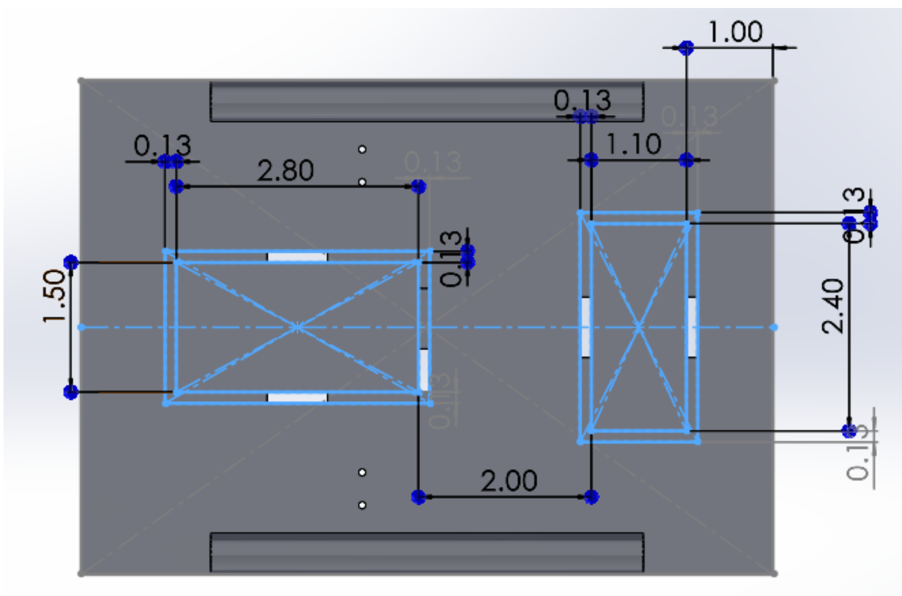

Figure 3.89: Bottom surface of modeled Full-Scale avionics sled.

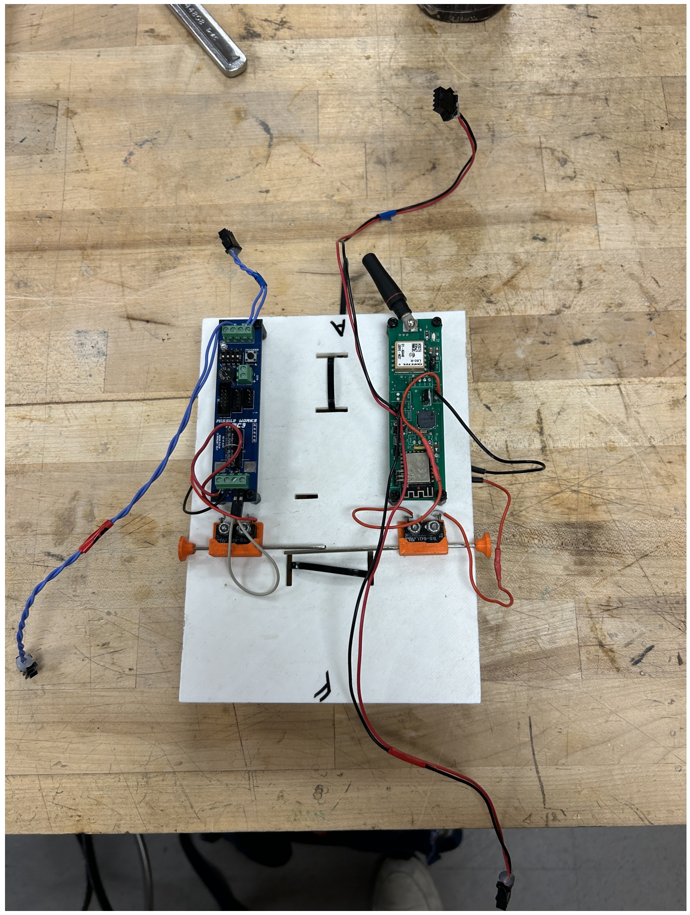

Figure 3.90: Top surface of built Full-Scale avionics sled.

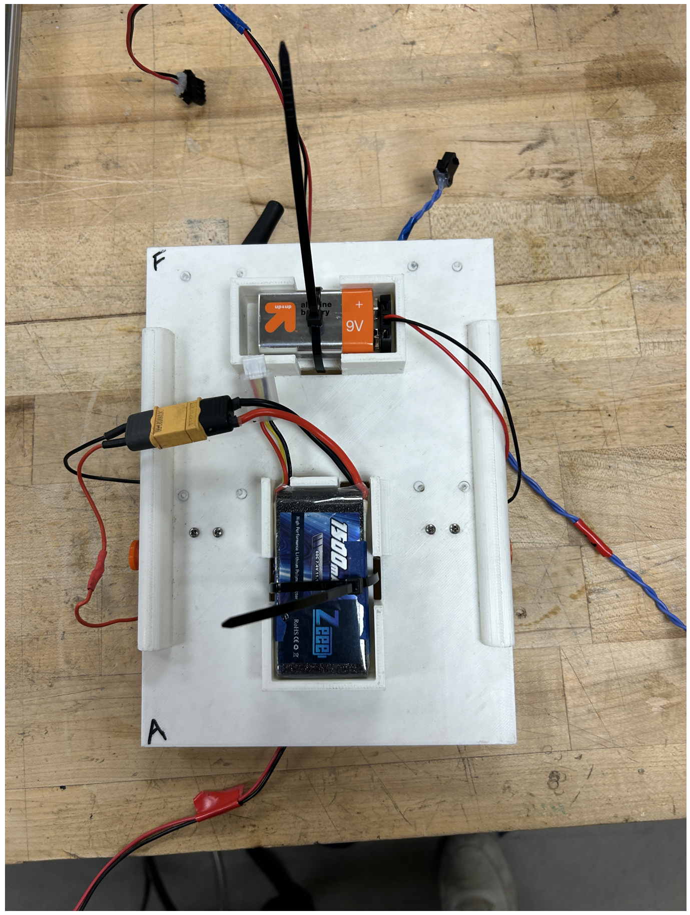

Figure 3.91: Bottom surface of built Full-Scale avionics sled.

Nose Cone Sled

Due to the nose cone separating as an independent section upon the main deployment ejection charge, there needs to be a GPS tracking device in it to comply with NASA Requirement 3.13. This will be done by using a nose cone sled that will hold the nose cone tracker and its battery. This sled is similar to the AV sled in that it will sit on 1/4 in. threaded rods that run through the middle of the nose cone bulkhead seen in Section 3.2.2. Furthermore, like the AV sled, this sled was modeled in SolidWorks and will be 3D printed using PETG filament. The tracker will be mounted through 4-40 nylon standoff screws, and threaded heat inserts for 3D printed material. The 1s 3.7V LiPo will be attached through a zip tie around the sled and electrical tape. Lastly, the nose cone sled shall be secured firmly in place on the threaded rod using 1/4 in. nuts. Shown in Figures 3.92 and 3.93 is the design of the nose cone sled, and in Figures 3.94 and 3.94 below are images of the fully assembled/ built nose cone sled.

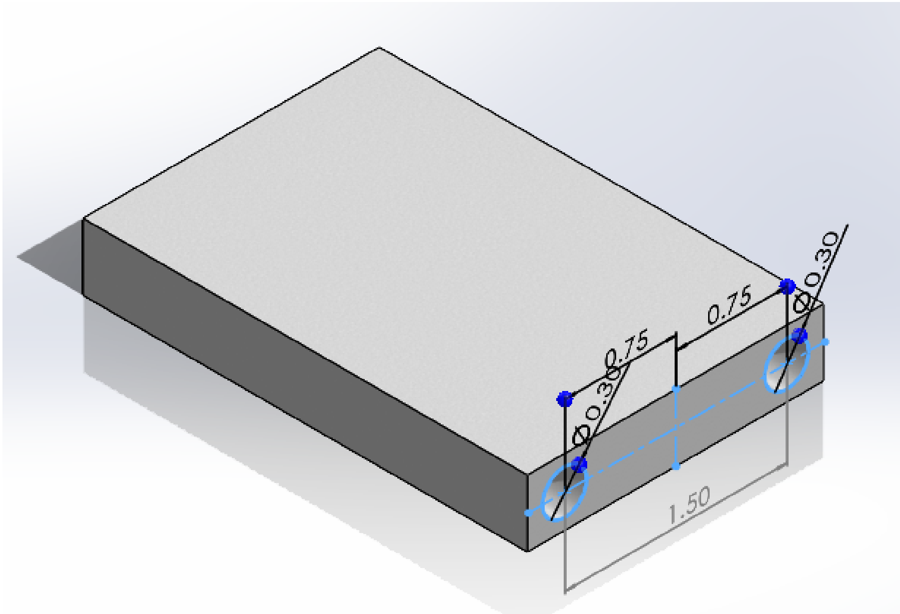

Figure 3.92: Top surface of Full-Scale nose cone sled model.

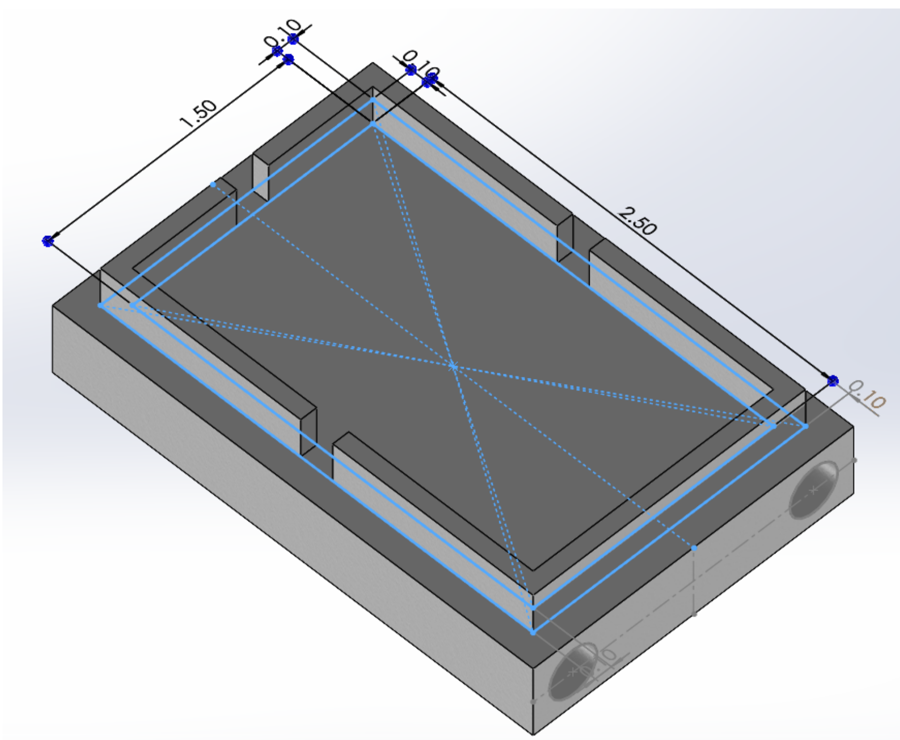

Figure 3.93: Bottom surface of Full-Scale nose cone sled.

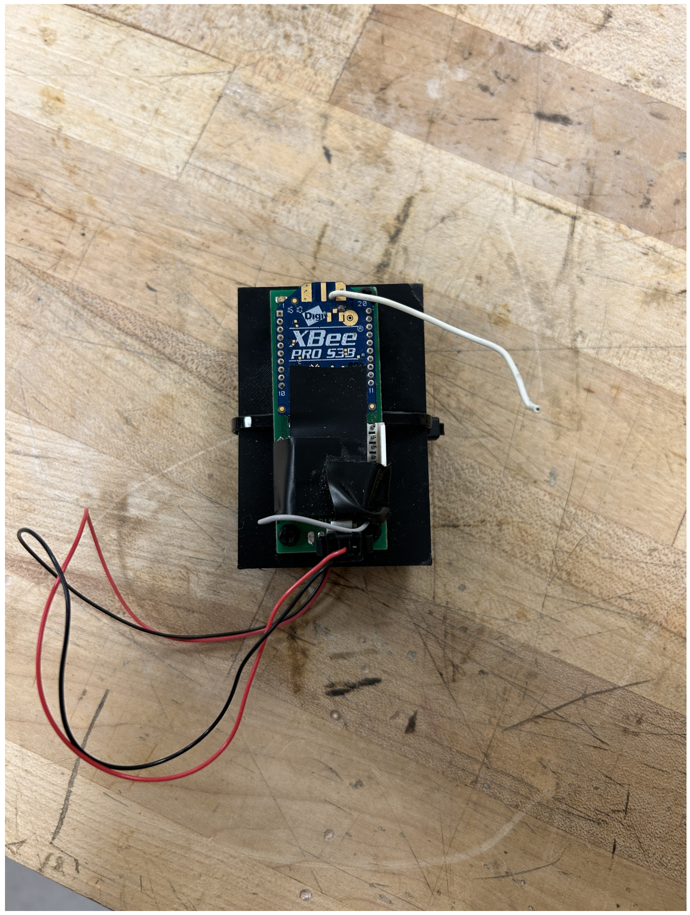

Figure 3.94: Top surface of built Full-Scale nose cone sled.

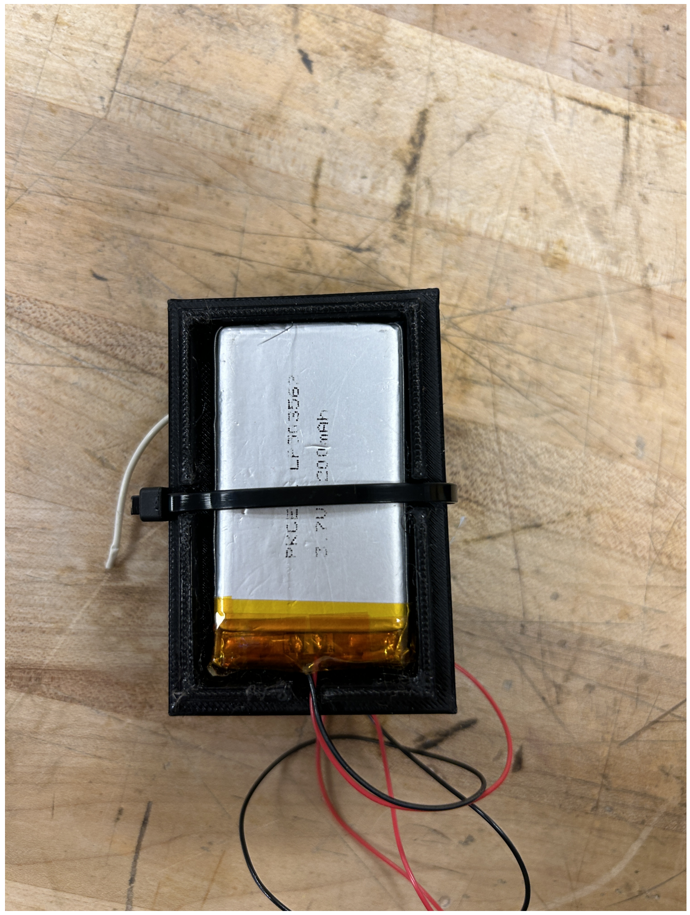

Figure 3.95: Bottom surface of built Full-Scale nose cone sled.

Quick Links

All recovery harness connection points on the launch vehicle are connected via 5/16" steel quick-links. This includes bulkhead connection points on the U-bolts, and parachute connection points on loops in the shock cord. These are also attached to the deployment bag used for main parachute separation, and are rated for 1200 lbs of force.

Pressure Sampling Ports

Pressure port holes are drilled into the band of the AV bay so the onboard altimeters can detect the altitude during launch by measuring the static pressure. The size of these holes are calculated using MissileWork's guidelines, the manufacturer of the RRC3 primary altimeter. The formula for the diameter of this hole given my MissileWork's is shown below, where D is the minimum diameter of the pressure port when only one hole is being used.

$$D = 2 * \sqrt{\frac{V}{6397.71}} \quad (1)$$

Using this equation, the minimum diameter for one pressure port shall be .42 in. From there, one can calculate the size of the pressure ports if there are multiple in use. Let A be the area of the port when only one port is being used (using the D calculated above), B shall be the minimum port diameter when there are multiple ports, and N is the number of ports.

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

Assuming 4 holes, the minimum port diameter shall be .21 in. For the launch vehicle, four 1/4" holes will be drilled into the AV band symmetrically around the circumference. Two holes will be for the pull-pin switch mechanical arming device pins, and the other two holes will be strictly for pressure ports. The pull-pins will not obstruct the altimeter's ability to sense static pressure, as the pin will be removed on the launch pad before flight. This will allow for complete functionality of the onboard altimeters.

3.5.3 Avionics

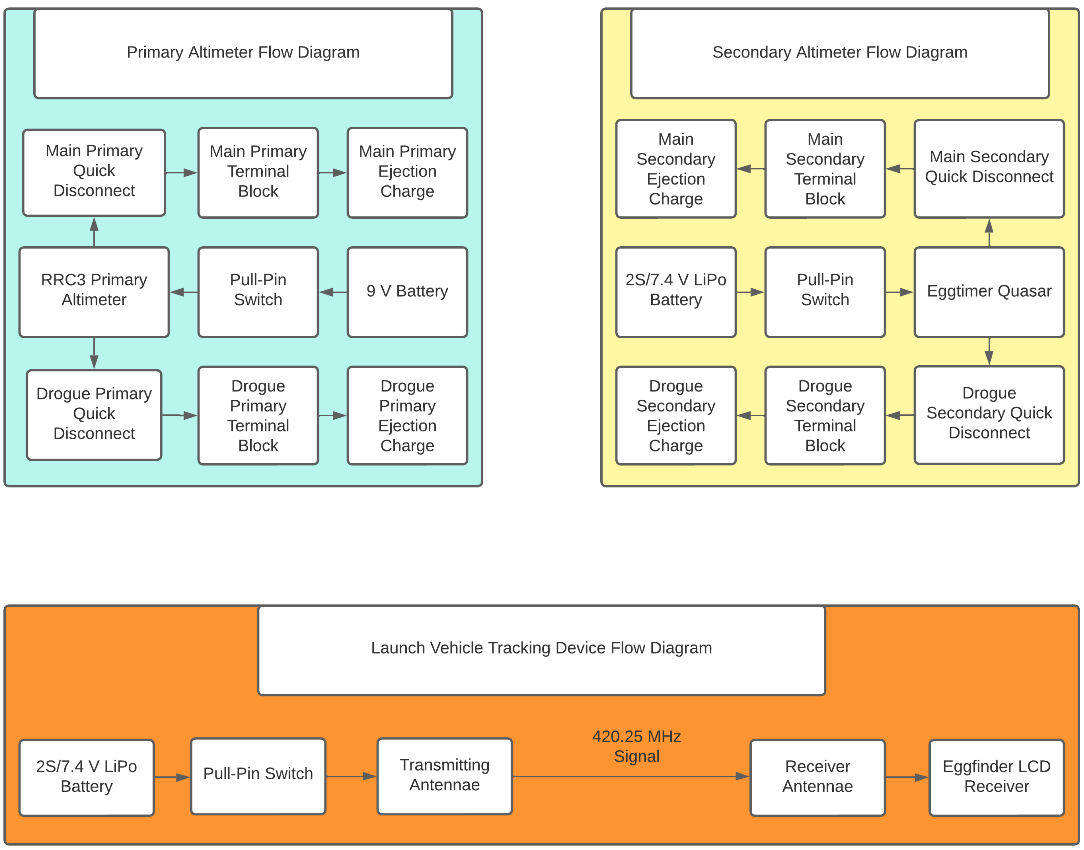

Figure 3.96: AV Bay Recovery-Avionics Master Block Diagram

Shown above is the master block diagram of all the avionics in the AV Bay: the RRC3 primary Altimeter, and the Quasar secondary altimeter and launch vehicle tracker. The blue diagram represents the wiring diagram for the RRC3 primary altimeter which will report the competition altitude, while the yellow diagram represents the wiring diagram for the Quasar secondary altimeter. A 9V battery will power the primary altimeter, which is jumped to the pull-pin switch and the altimeter. Wires will connect the altimeters to the ejection charges by connecting one end to the altimeter drogue/main pins, and the other end to the terminal blocks on the AV Bay bulkhead via quick disconnects. From there, an e-match is connected to the other side of the terminal block and feeds through the bulkhead where the e-match head lays in the blast cap holding an ejection charge on the outside of the bulkhead. Each altimeter has a drogue and main version of this setup. The primary altimeter will detonate the primary drogue charge once the altimeter sense apogee and will detonate the primary main charge once the altimeter senses the altitude for main deployment of 800 ft. The secondary altimeter operates the same way, except it uses a 2S/7.4V LiPo battery, has different deployment conditions, and the secondary ejection charges contain an additional 0.5 grams more than the primary charges. To be more specific, the Quasar will detonate the drogue ejection charge 1 second after apogee and will detonate the main ejection charge at 700 ft. This delay in deployment is done to ensure redundancy in the system by having a backup system to recover the launch vehicle.

At no point during launch vehicle assembly will the altimeters be armed and connected to ejection charges at the same time. This is done by following a launch day checklist, which can be seen in section 5.3.2.

The orange diagram represents the flow diagram for the launch vehicle tracker located in the AV Bay, the Eggtimer Quasar. This is powered by a 2S/7.4 LiPo battery and is jumped to a pull-pin switch, as this device is the launch vehicle's secondary altimeter as well. The pull-pin switch is necessary as we do not want the altimeter on this device to be armed while connected to ejection charges prior to launch. Once the pin is removed, the Quasar will connect to the satellite and then transmit GPS coordinates to the Eggfinder LCD receiver using the 70 cm bandwidth with a frequency of 420.2 MHz. This process is very similar to the Nose Cone Receiver shown in the diagram below.

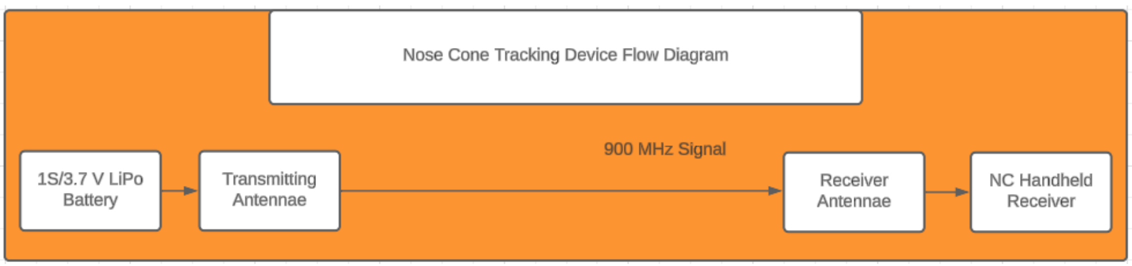

Figure 3.97: Nose Cone Recovery-Avionics Master Block Diagram

Shown above is the master block diagram for the avionics in the Nose Cone, the Big Red Bee 900 GPS tracker. A 1S/3.7V LiPo will be used to power this tracker, and it is directly connected to the BRB 900. No pull-pin switch is needed for this because it is not an altimeter, and pull-pins should not go into the nose cone. Once the tracker is connected to the satellite, it will transmit its coordinates to the NC handheld receiver with a frequency of 900 MHz.

Altimeters

There will be two altimeters onboard the launch vehicle for the competition launch. The primary altimeter will be the RRC3 "sport" altimeter, and the secondary will be an Eggtimer Quasar that also functions as a tracker. These altimeters control the recovery events at apogee and main deployment altitude of 800 ft. The secondary altimeter operates on a one-second delay after apogee for the secondary drogue charge and sends the secondary main charge at 700 ft. (a 100 ft. delay). This is because the Quasar does not have a time delay feature for the main deployment, only an altitude specification in increments of 100 ft. Additionally, the primary altimeter will be connected to one primary drogue ejection charge and one primary main ejection charge, with the secondary altimeter being connected to one secondary drogue ejection charge and one secondary main ejection charge. The RRC3 primary altimeter will report the competition altitude.

Due to its high precision, ease of programming, historic reliability in the High Powered Rocketry Club, and the possession of one already, the RRC3 was chosen to be the primary altimeter. This device boasts a 1 ft. altitude logging resolution, a 20/s sampling rate, and can be programmed from the MissleDacs software on a computer [6]. An image of this altimeter is shown below in Figure 3.98.

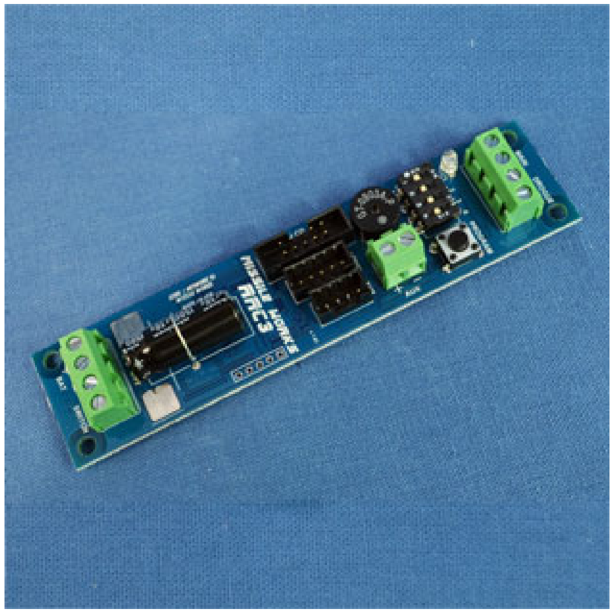

Figure 3.98: RRC3 Sport altimeter by Missile Works [6].

Though the Eggtimer Quasar has not been used as an altimeter in the club's history, its precision and ease of use are great characteristics to use it as a secondary altimeter. It can be programmed and armed from a smartphone, and flight data can be pulled from the phone as well. The main appeal to this device is its dual functionality as a tracker [3]. Additionally, this was used as the NCSU 2022-2023 NASA SLI competition launch vehicle tracker and has been proven to be reliable. Therefore, due to its GPS tracking capabilities, and altimeter functionality, the Eggtimer Quasar was chosen to be the secondary altimeter. Shown below in Figure 3.99 is an image of the Eggtimer Quasar.

Figure 3.99: Quasar altimeter/tracker by Eggfinder.

The primary altimeter will be powered by a standard 9V battery, and the Quasar will be powered by a 2S/ 7.4V LiPo battery. Additionally, both altimeters will be tested several times before every launch in a pressure chamber to ensure it is operating correctly.

Tracking Devices

As mentioned in the altimeter section, the launch vehicle tracker will be the Eggtimer Quasar, which also functions as the secondary altimeter. This transmits a signal on the 70 cm band, has a 250 mW transmitter power, and has a transmitter frequency of 420.2 MHz, thus the receiver must be operated by someone with a HAM radio license to comply with FCC regulations [3]. Additionally, Eggtimer states the range for a line of sight signal is approximately 40,000 ft. While the threaded rods and other electronics in the bay could reduce the range, Eggtimer states there will only be a small reduction in range. Due to the launch vehicle having a drift distance of less than 2,500 ft for recovery points, this will not be an issue at all. This device transmits to the Eggfinder LCD handheld receiver, which will display the GPS coordinates of the tracker after it detects 5 seconds of no movement. While the LCD receiver does not have a GPS module itself, it has a GPS location sensor that points in the direction the signal is emitting from. Once the rocket has landed, the GPS coordinates can be placed into Goodle Maps to locate the rocket. This receiver will be held by the recovery lead on the ground during launch, and is shown below in Figure 3.100. Upon successful recovery, the Quasar will transmit its location after five seconds of no movement from the launch vehicle. An image of this launch vehicle tracker is shown in Figure 3.99.

The Quasar emits a WiFi signal, allowing a smartphone to connect to it with a password provided by the manufacturer Eggtimer. Once connected to the Quasar's WiFi, the IP address of the device is inserted into the browser on the phone, allowing access to the Quasar's menu. This menu entails the drogue and main continuity status, GPS status, and the settings the drogue and main signals are set for. There is also an additional setting page where the drogue and main charges can be programmed, a setting page for frequency, and a flight data page entailing previous flight data. Once the Quasar has made a connection to the satellite, it will transmit real-time GPS data to the handheld LCD receiver. The Quasar can then be armed from the phone menu once the pull-pin switch is removed so the device has power, and it senses continuity in the drogue and main charges.

Figure 3.100: Eggfinder LCD Receiver for Launch Vehicle Tracker

Due to the nose cone separating as an individual section, not tethered to the launch vehicle, it will need a separate tracker. The nose cone tracker shall be the Big Red Bee 900. It has a transmitter power of 250 mW and a transmitter frequency of 900 MHz, meaning no HAM license is required to operate this tracker [2]. This was chosen due to its ease of use, simplicity, and small form factor since it will be in the nose cone. Additionally, it is paired with a handheld receiver that will display the GPS coordinates of the tracker. This receiver will be held by the recovery lead on the ground during launch. Figure 3.101 below shows an image of the nose cone tracker, and Figure 3.102 shows an image of the nose cone receiver.

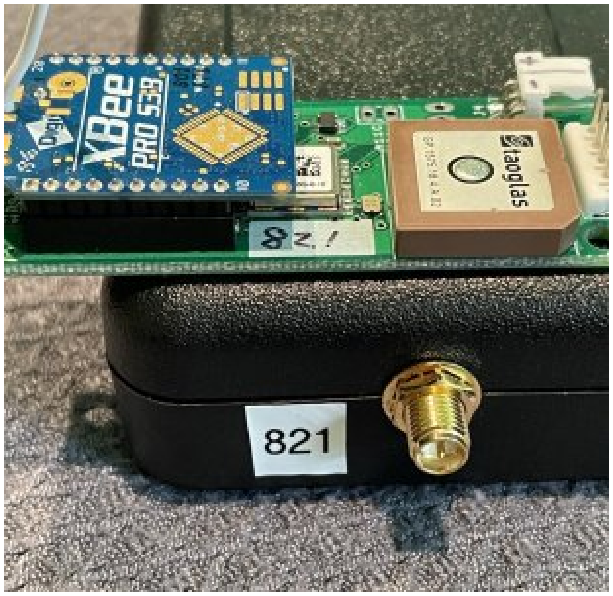

Figure 3.101: Big Red Bee 900 tracker by BigRedBee.

Figure 3.102: Big Red Bee 900 Receiver for Nose Cone Tracker.

These tracking devices satisfy NASA Requirement 3.13, both having a range exceeding 6 miles and a transmitter power of less than 250 mW. Each tracker will be tested several times before each launch to ensure they are operating correctly.

Pull-Pin Switches

All avionics in the AV bay shall be armed and disarmed by a pull-pin switch. These were chosen due to previous success within the club, its ease of use, and its effectiveness for the subscale launch vehicle. There are two pull-pin switches bolted to the sled with steel M2 screws, one for the primary altimeter, and one for the secondary altimeter and tracker. When the pin is inserted in the switches, the circuit from the batteries to the altimeters is open, preventing them from being armed. Upon removal of the pin, the devices will be powered and armed. During the AV bay assembly on launch day, the pull-pin must be removed when inserting the sled into the bay, thus the altimeters will be on momentarily. To prevent accidental activation of the charges, there will be no connection to the black powder charges until the pin is re-inserted through the exterior of the rocket. The pins will then remain inserted until the launch vehicle is in the correct orientation on the launch pad. Presented in Figure 3.103 is an image of the pull-pin switch kit that will be used on the launch vehicle [5].

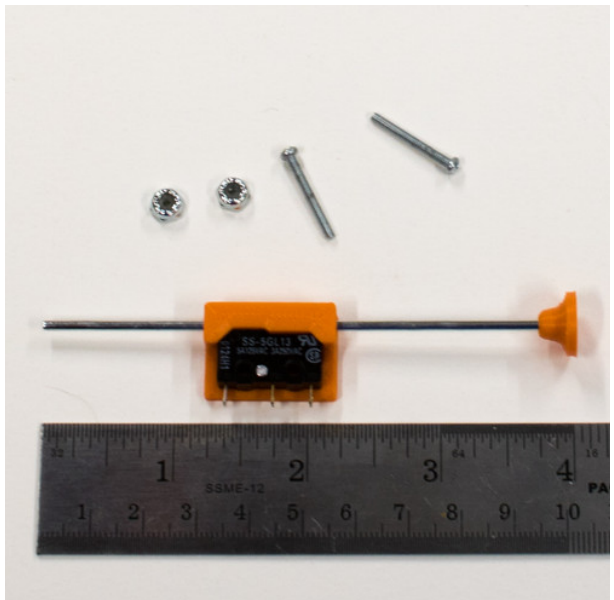

Figure 3.103: Pull-pin switch by Lab Rat Rocketry [5].

Quick Disconnects

Due to its reliability, safety, and ease of use and manufacturing, quick disconnects are used on the drogue and main wires. These are added to the end of the wires, where one connector goes into the drogue/main ports on both altimeters, and the other connector goes into the corresponding terminal block on the inside of the AV bay bulkhead. All together, there are 4 sets, 2 for drogue primary and secondary, 2 for main primary and secondary. DuPont connectors are used for these quick disconnects, and each connection in the header is hot-glued to ensure the wire does not come out during flight. Shown below is an example of one, where one free end goes into the altimeter, and the other goes into the corresponding terminal block.

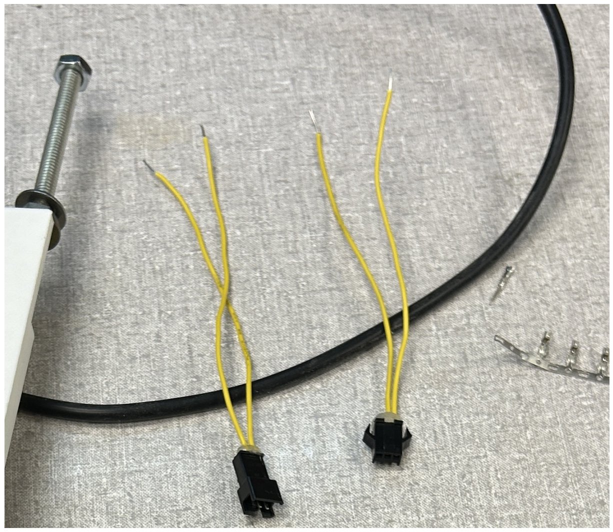

Figure 3.104: Image of Quick Disconnect used on all drogue and main wires.

Batteries

The RRC3 primary altimeter uses a standard 9V battery for its power source. For each launch, a new 9V battery is used and its charge will be checked with a multimeter. If it does not have a charge above 9 volts, that battery will be replaced with another 9V battery until it has the correct charge. Once this is done, the battery is attached to the battery connector that is jumped to the primary altimeter and pull-pin switch. It is then placed into its friction-fit battery compartment on the sled, where a zip tie and electrical tape are used to secure it safely in place.

The Eggtimer Quasar functions as the launch vehicle's secondary altimeter and tracker. Eggtimer recommends a 2S/7.4 LiPo battery with a capacity of at least 800 mAh so it is powered for a few hours. As such, the battery for this device will be a 2S/7.4 V with a capacity of 1500 mAh, ensuring the team will have no power issues on launch day. This battery is jumped to the pull-pin switch and the battery pins on the Quasar. On launch day, the fully charged battery will be placed into its friction-fit compartment on the sled, where a zip tie and electrical tape are used to secure it safely in place. Shown below is an image of the LiPo battery used for the Quasar.

A 1S/3.7V LiPo battery with a capacity of 200 mAh will be used for the Big Red Bee 900 nose cone tracker. While it has a small capacity, the BRB 900 does not draw a lot of power so there is no concern for power on launch day. The battery's small form factor is an additional plus as it can easily fit on the nose cone sled. This battery is directly connected to the BRB 900, as no pull-pin switch is needed since it is only a tracker. On launch day, the fully charged battery will be placed into its friction-fit compartment on the sled, where a zip tie and electrical tape are used to secure it safely in place.

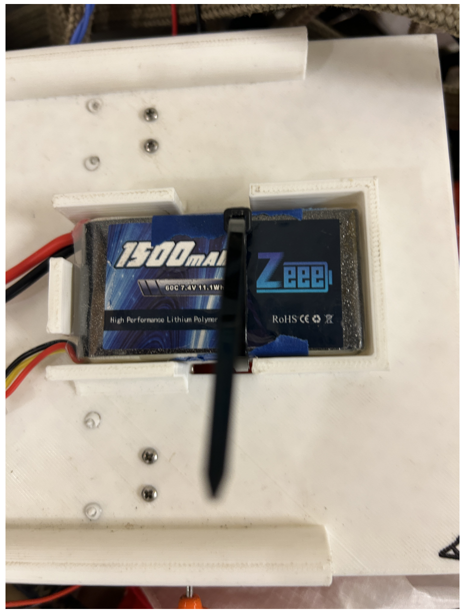

Figure 3.105: Image of LiPo battery used for Eggtimer Quasar.

Redundancy Features

The primary and secondary altimeters have their own independent system, where if any of the components for one system were to fail during launch, the other system will not be affected and would function independently in parallel with the other system. Each system has its own set of drogue/-main wires, altimeter, altimeter retention, terminal blocks, e-matches, ejection charges, batteries, and battery retention. In addition, there is redundancy in the ejection charges, as there is a primary and secondary charge for drogue and main each. The secondary charge is .5 grams larger than the primary charge in case the launch vehicle fails to separate on primary ejection, ensuring separation without damaging any components of the launch vehicle.

3.5.4 Parachute Selection

The launch vehicle uses a 15” Classic Elliptical parachute by Fruity Chutes for drogue recovery, a 96” Iris UltraCompact parachute for main recovery, and a 48” Classic Elliptical parachute by Fruity Chutes for nose cone recovery. These parachutes have been selected due to their ability to meet the descent time, kinetic energy, and drift distance recovery requirements. It is worth noting this parachute configuration worked nominally for the vehicle demonstration flight.

Drogue Parachute

Deployed at apogee via an ejection charge, the drogue parachute for the launch vehicle shall be a Fruity Chutes 15 in. classic elliptical parachute. This parachute has a drag coefficient of 1.5. With a burnout mass of 1.479 slugs, the launch vehicle will descend under this drogue parachute at a rate of 112.82 ft/s until an altitude of 800 ft. The drogue descent velocity, along with main and nose cone descent velocities were calculated using the descent velocity under a parachute equation in Section 3.6.6.

Main Parachute

Once the launch vehicle reaches 800 ft, the nose cone separates, pulling the payload out of the launch vehicle and the deployment bag off of the main parachute for the launch vehicle. The main parachute for the launch vehicle shall be a Fruity Chutes 96 in. Iris Ultra Compact. This parachute has a drag coefficient of 2.09. Once the main parachute is deployed, the launch vehicle, with a new mass of .917 slugs, will fall at a rate of 15.38 ft/s until it lands. At this point, the launch vehicle will no longer contain the nose cone or payload deployment bay, hence the smaller mass. Under this main parachute, the maximum drift distance is 2370.5 ft, the maximum kinetic energy is 61.114 ft-lbs, and the descent time of the launch vehicle is calculated to be 80.81 seconds. These parameters are calculated using the equations in Sections 3.6.6, 3.6.7, and 3.6.8.

Nose Cone Parachute

The nose cone parachute shall be a Fruity Chutes 48 in. classic elliptical parachute. This parachute has a drag coefficient of 1.44. With a mass of .562 slugs, the nosecone will descend at a rate of 28.99 ft/s while the payload is attached. Once the payload is released at approximately 450 ft., the nose cone, with a mass of .207 slugs will descend at a rate of 17.615 ft/s. Under this parachute, the landing kinetic energy for the nose cone is 48.77 ft-lbs, the maximum drift distance from the launch pad is 1809.12 ft, and the descent time after main separation is 32.86 seconds. The descent time of the launch vehicle from apogee to main deployment altitude is 28.81 seconds, thus the total descent time of the nose cone from apogee to landing will be 61.67 seconds. Once again, these parameters are calculated using the equations in Sections 3.6.6, 3.6.7, and 3.6.8. Therefore, this parachute meets the wind drift distance, kinetic energy, and descent time requirements for the nose cone, and these specifics are shown in detail in Section 3.6.

3.5.5 Filler

During launch vehicle assembly on launch day, a biodegradable flame retardant recovery wadding insulation is used inside the separating sections to protect the parachutes from ejection charges. In addition, it reduces the amount of free volume in the separating section, allowing the ejection charge to build up higher pressure and separate the sections more effectively. It is also necessary due to the larger size of the main ejection charge, as it can heat the recovery hardware to flammable temperatures. Due to how packed the main parachute bay is, only a few handfuls are used to fill the main bay with insulation. This proved effective for the VDF launch.

3.5.6 Recovery Harness

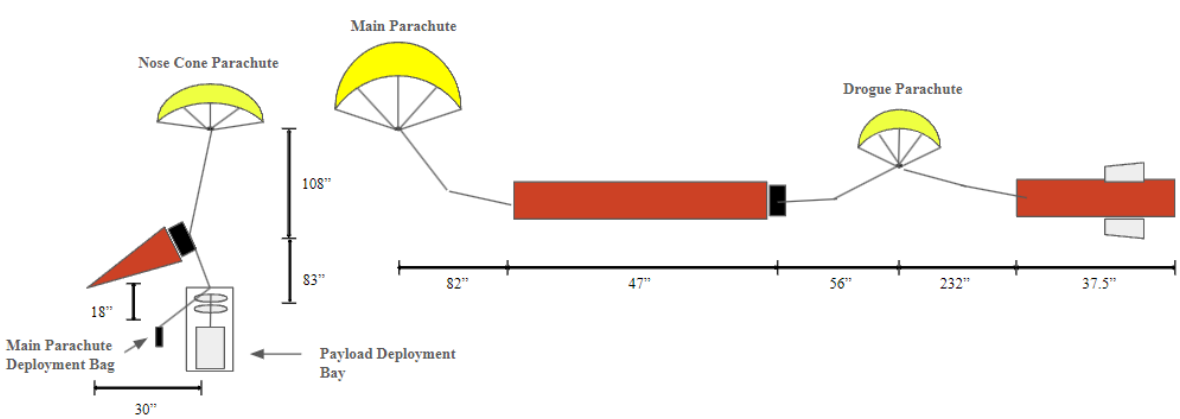

Figure 3.106: As-Built Recovery Harness.

The shock cords used for the launch vehicle will be 5/8 in. thick Kevlar webbed shock cords. This includes the shock cord for the main parachute and the shock cord for the drogue parachute. The nose cone parachute and deployment bay will be tethered to the nose cone with 1/4 in. Kevlar shock cord instead of 5/8 in. shock cord due to space issues in the main parachute bay. While it is a small thickness, the quarter-inch Kevlar cord is rated for 2200 lb, which is more than enough to withstand the loads that the nose cone independent section will undergo. Furthermore, the orientation of the deployment bay flipped 180 degrees to fit the nose cone parachute between the legs of the SAIL in order to save space. As a result, the length of the shock cord connecting the deployment bay to the nose cone bulkhead increased. Additionally, the deployment bag for the main parachute is now connected to the bulkhead of the deployment bay instead of the nose cone bulkhead, allowing for a smaller shock cord length to save space. Note that the deployment bag will still separate with the nose cone at main ejection. This configuration was used for VDF and worked nominally. Shown in Figure 3.106 is a diagram of the as-built final shock cord configuration and lengths used for the recovery system. Additionally, Figure 3.107 shows a detailed packing diagram of the main parachute bay.

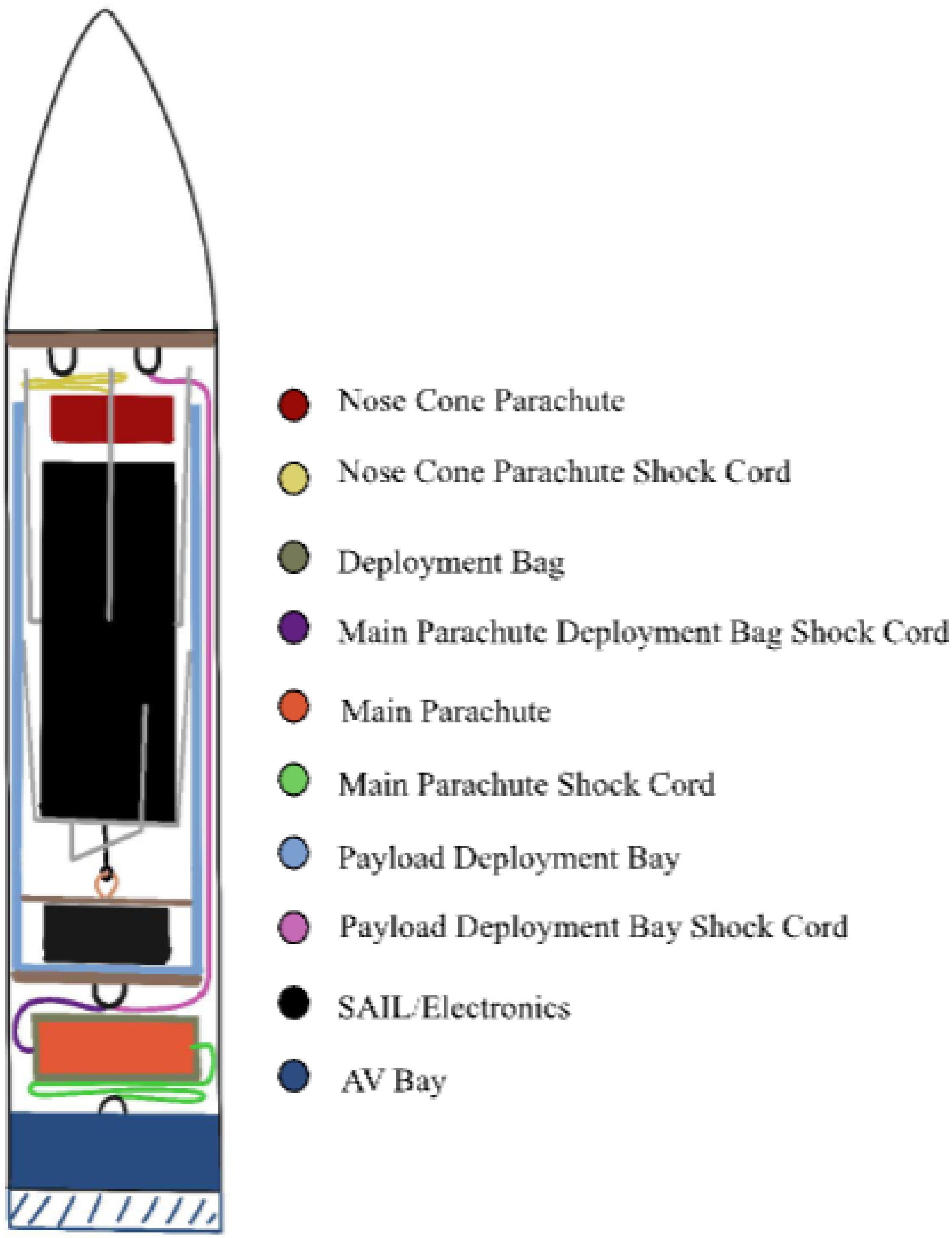

Figure 3.107: Main Parachute Bay Packing Diagram.

Drogue Recovery Harness

The drogue recovery harness will be a 288” long Kevlar shock cord of 5/8 in. thickness. There will be three bowline knots tied on it, due to it’s self-tightening capability allowing it to not come loose during forces during launch. Two loops are on the end of the shock cord, one end is attached to the aft AV bay bulkhead U-bolt with a 5/16” steel quicklink, and the other end is attached to the fin-can bulkhead U-bolt with a 5/16” steel quicklink. The last loop will be 56” from the AV Bay bulkhead, where it is connected to the 15” drogue parachute and nomex via a 5/16” steel quicklink. This arrangement allows for at least a 5 ft difference between the bottom of the fin-can and top of the nose cone during descent, preventing the separated sections from hitting each other and obstructing nose cone separation at main. While the image below does not exactly show what the LV will look like during drogue descent since the nose cone is not attached in the image, it proves that the fin can will not hit the main parachute bay during drogue descent.

Figure 3.108: Drogue Descent Recovery Configuration.

Main Recovery Harness

The main parachute recovery harness will be a 122” long Kevlar shock cord of 5/8 in. thickness. There will be two bowline knots for the loops, with one on each end. One loop will connect to the forward AV bulkhead U-bolt through a 5/16” steel quicklink, and the other will connect to the main parachute via a steel quicklink as well. There as at least 5 ft between the top edge of the main parachute bay and the main parachute, ensuring the main parachute will not touch the bay during descent. Shown below is an image of what the main parachute bay will look like during descent after the nose cone has separated and the main parachute deployed.

Figure 3.109: Main Descent Recovery Configuration.

Nose Cone Recovery Harness

The nose cone has two bulkheads, one for connecting the nose cone parachute via 1/4” thick Kevlar shock cord, and one for connecting the deployment bay for the SAIL with 1/4” thick shock cord as well. These have a smaller thickness to reduce the space taken up above the deployment bay, as the team was having fitting issues when trying to fully assemble the launch vehicle. This shock cord is still strong enough to ensure the loads during launch, and worked nominally for VDF. The nose cone parachute shock cord will be 108” long and will have two bowline knots for loops on the ends. One end will connect to the nose cone bulkhead U-bolt, and the other end will connect to the 48” nose cone parachute and nomex, both via a 5/16” steel quicklink. The deployment bay shock cord will be 83” long and will have two bowline knots for loops on the ends as well. One end will connect to the other U-bolt on the nose cone bulkhead, and the other end will connect to the U-bolt on the deployment bay bulkhead. Lastly, a 18” 1/4” shock cord will connect the main parachute deployment bag to the U-bolt on the deployment bay. Once the main ejection charge occurs, the nose cone will separate pulling the deployment bay out, which in turn will pull the main parachute deployment bag with it, allowing the main parachute to deploy for the launch vehicle. Shown below is an image of the nose cone recovery harness during descent, where one can see the deployment bag connected to the U-bolt of the deployment bay.

Figure 3.110: Nose Cone Descent Recovery Configuration.

3.5.7 Ejection Charge Sizing

When determining the mass of the black powder charge, the varying factor is the empty volume in the section that is separating. This empty volume is found by taking the volume of the compartment and subtracting the volume of the shock cord, parachute, and any other recovery/payload components in the section. The other factor to be found is the pressure that will separate the section by breaking the shear pins. Once the empty volume and the pressure are calculated, the ideal gas law equation can be used to determine the mass needed for black powder. The ideal gas law is shown in Equation 3 below.

$$PV = mRT \tag{3}$$

Let P represent the pressure needed to separate the section, V represents the empty volume of the section, m is the mass of the black powder, R is the gas constant of black powder combustion products, and T is the temperature of black powder during combustion. This temperature is known to be 3,307 degrees Rankine, the gas constant is 22.16 ft-lb, and the calculated pressure needed to shear the pins is 20 psi. Note that each 4-40 nylon shear pin is rated for 2.5 psi, thus a pressure of 10 psi is necessary to shear 4 pins holding the separating sections together. However, a factor of safety of 2 is used on the necessary pressure to shear the pins to account for any incomplete combustion of black powder during the ejection charge, and the skin friction between the separating section and coupler tubes.

The recovery system includes a secondary black powder charge to ensure redundancy for launch vehicle separation. Each secondary charge will be 0.5 grams more than the primary charge for that section, ensuring separation in case of primary charge failure while not being large enough to cause damage. Shown below in Table 3.5 are the calculated ejection charge sizes.

Table 3.5: Ejection Charge Sizing for Each Separating Section

Point of Separation	Primary Charge Mass	Secondary Charge Mass
Nose Cone and Main Parachute/ Payload Bay	5.0 grams	5.5 grams
Avionics Bay and Drogue Bay/ Fin Can	2.0 grams	2.5 grams

The ejection charge itself shall be 777-grade FFF black powder, its very fine grains allowing for faster combustion. Faster combustion is preferred since it allows for clean separation and leaves less unburnt black powder scattered in the separated section.

To comply with NASA Requirement 3.2, a ground ejection test will be performed for both primary charges before launch. A successful ejection test demonstrates that the launch vehicle will be able to separate and the ejection charges are sized appropriately. If the launch vehicle fails to separate during the ejection test, an additional 0.2 grams will be added to the primary charge, and the test will be repeated. This process, outlined in Section 7, will continue until safe, successful separation is ensured. These black powder masses were tested in several successful ejection tests, and worked nominally for VDF as well. Therefore, they will be used for the competition launch as well.

3.6 Missions Performance Predictions

3.6.1 Launch Day Target Apogee

The official competition target apogee for the full-scale launch vehicle is 4050 ft. AGL. Using RocketPy backed with hand calculations, the team predicts that the launch vehicle will come close to achieving this target apogee within a high degree of accuracy.

3.6.2 Flight Profile Simulations

The environment profile of Huntsville, AL, along with a sample wind forecast utilizing the National Oceanic and Atmospheric Administration Global Forecasting System sample data was used in the flight profile simulations. Using the as-built mass distribution of the launch vehicle imported from OpenRocket, simulations showed that the apogee will increase from the apogee predictions indicated in CDR. NASA Requirement 1.12 outlines the specific launch requirements used in this simulation which are a 12 ft. launch rail and a 5° rail cant. From the current model, the predicted apogee of the launch vehicle was found to be 4056.32 ft, occurring at 16.11 seconds into the flight.

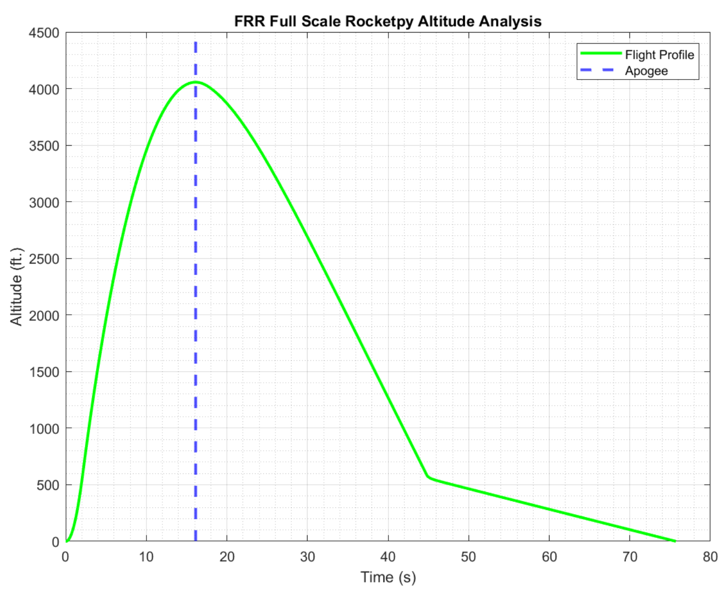

Figure 3.111: Calculated launch vehicle flight profile.

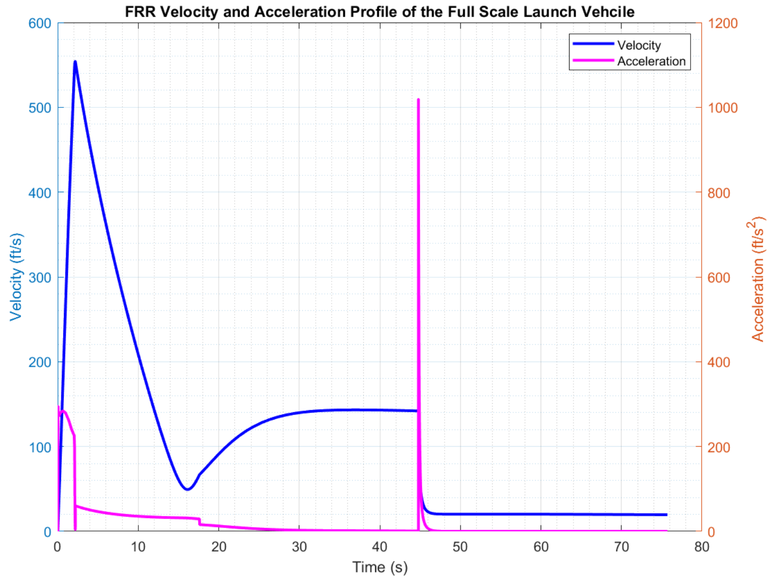

Figure 3.112: Calculated launch vehicle velocity and acceleration profile.

From Figure 3.112, the maximum velocity of the launch vehicle occurs at 2.2 seconds into the flight directly following motor burnout with a value of 558.84 feet per second or mach 0.496. This satisfies NASA Vehicle Requirement 2.22.6. The maximum acceleration is 294.99 ft/s^2, occurring during peak motor performance, and shown in Figure3.31 satisfies LVD 8. As discussed in the CDR, the large spike in acceleration at 45 seconds into flight is due to the shock force experienced during the main parachute opening. A sample flight profile as KML data has been provided in Figure 3.113 using Google Earth mapping.

Figure 3.113: Rocketpy flight profile KML plotted in Google Earth.

Launch field atmospheric conditions are hard to predict. In reality, wind speeds will vary throughout the course of a launch, but a constant wind environment can be used to study the affect of ballast weight on launch vehicle apogee. The tabulated results of the simulations ran in this fashion have been provided in Table 3.6.

Table 3.6: Required ballast to reach the intended apogee.

Wind Speed	Ballast Required	Apogee
5 mph.	2.6 lb.	4049.42 ft.
10 mph.	2.3 lb.	4055.51 ft.
15 mph.	1.9 lb.	4054.56 ft.
20 mph.	1.3 lb.	4056.57 ft.

3.6.3 Altitude Verification Calculations

Verification of the predicted apogee from RocketPy can be calculated using Equations 4 - 10. The background regarding these equations was discussed in detail in the PDR document.

The drag force unit velocity squared can be expressed by the constant k:

$$k = \frac{1}{2}\rho C_d A \tag{4}$$

The empirical factor q, which is a relationship between the thrust, drag, and gravity, can be expressed as:

$$q = \sqrt{\frac{T - Mg}{k}} \tag{5}$$

The empirical factor x, which relates the drag and q per unit mass, can be expressed as:

$$x = \frac{2kq}{M} \tag{6}$$

The maximum velocity of the launch vehicle can then be derived by using Equations 5 and 6:

$$v_{max} = q\frac{1 - e^{-xt}}{1 + e^{-xt}} \tag{7}$$

The altitude of motor burnout, where the force of drag and gravity become the primary forces acting on the launch vehicle, can be determined by:

$$Z_{burnout} = -\frac{M}{2k}\ln\left(\frac{T - Mg - kv_{max}^2}{T - Mg}\right) \tag{8}$$

The total coast distance of the launch vehicle after burnout can be determined by:

$$Z_{coast} = \frac{m\ln\left(\frac{mg+kv^2}{mg}\right)}{2k} \tag{9}$$

Finally, to determine the apogee of the launch vehicle, the coast distance and height of burnout can be summed:

$$Z_{apogee} = Z_{burnout} + Z_{coast} \tag{10}$$

With these equations, the constants and resulting values can viewed in Table 3.7.

Table 3.7: Apogee Calculation Constants and Results

Constant	Variable Name	Value	Units
M	Power On Average Mass	1.4976	$slug$
m	Power Off Average Mass	1.431	$slug$
g	Gravitational Acceleration	32.174	ft/s^2
t	Motor Burn Time	2.2	s
T	Average Thrust	435.97	lbf
ρ	Air Density	0.002377	$slug/ft^3$
A	Launch Vehicle Frontal Area	0.2076	ft^2
C_d	Drag Coefficent	0.54	N/A
Equation	**Result**		**Units**
k	0.00013323		$slug/ft$
q	1706.0275		ft^2/s^2
x	0.30355		ft/s^2
v_{max}	549.395		ft/s
$Z_{burnout}$	615.321		ft
Z_{coast}	3371.353		ft
Z_{apogee}	3986.674		ft

From the analytical calculation, the apogee of the launch vehicle is within 70 ft. of the numerical simulation-derived value, a 1.74% difference. This value has increased since the PDR and CDR maturity of the launch vehicle, but the overall difference can be attributed to environmental and mass distribution factors of the as-built launch vehicle.

3.6.4 Stability Margin

From the design stability margin presented in the CDR, the expected center of gravity location has shifted further aft due to the payload requiring more volume within the payload bay than initial aerodynamic assumptions. This has resulted in a stability margin reduction from CDR presented values. However, all stability margin calculations conducted in OpenRocket meet NASA and team derived requirements. The updated OpenRocket launch vehicle with the larger payload section has been included in Figure 3.114.

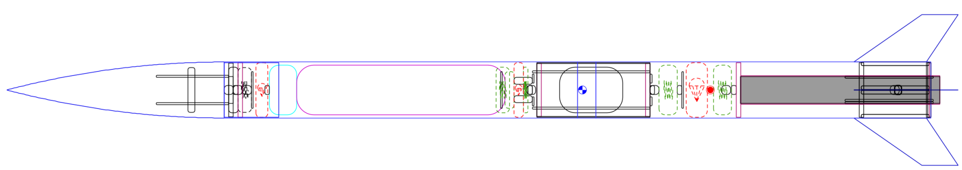

Figure 3.114: Full scale launch vehicle diagram in OpenRocket.

The transient stability margin exported using OpenRocket has been supplied in Figure 3.115 for verification of NASA Requirement 2.14.

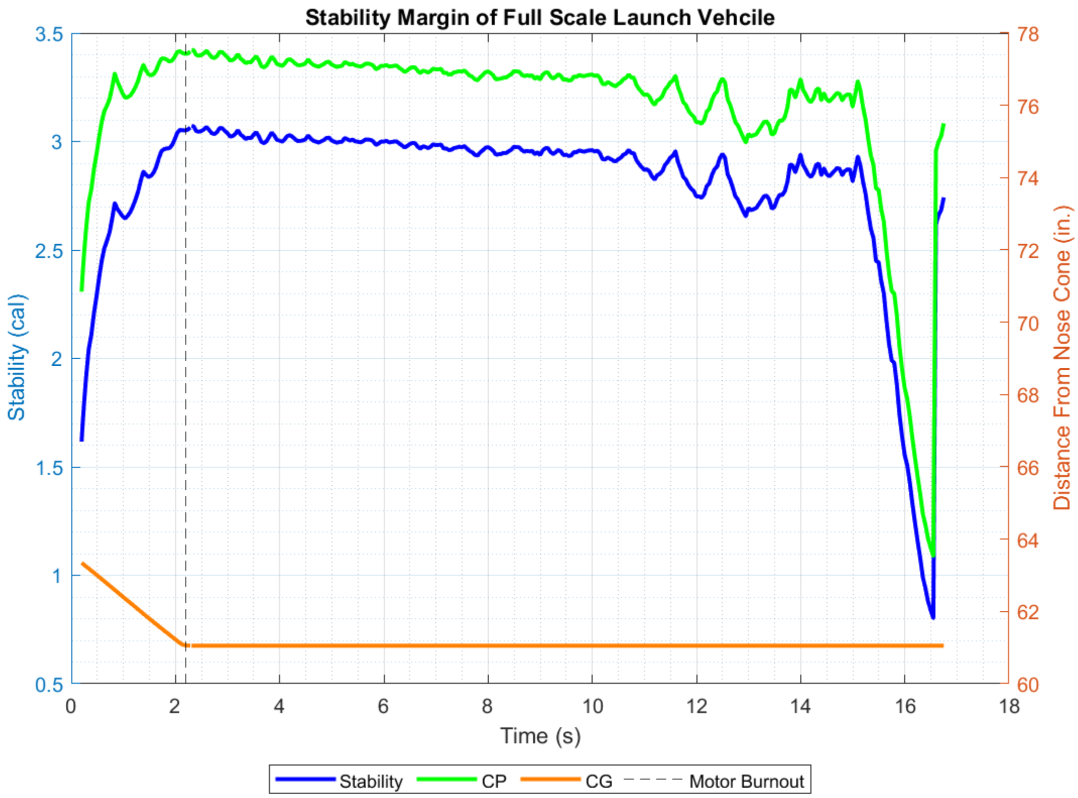

Figure 3.115: Transient stability margin of the launch vehicle during ascent.

From Figure 3.115, the launch vehicle stability at the rail exit is 2.38, which satisfies the NASA stability requirement. To verify the stability margin, Barrowman's equations can be used. Barrowman's equations are listed below.

$$X_N = 0.466 L_N \tag{11}$$

$$(C_{N_f}) = 1 + \frac{R}{S+R}\left[\frac{4N(\frac{S}{d})^2}{1+\sqrt{1+(\frac{2L_F}{C_R+C_T})^2}}\right] \tag{12}$$

$$X_f = X_B + \frac{X_R(C_R+2C_T)}{3(C_R+C_T)} + \frac{1}{6}\left[(C_R+C_T-\frac{C_RC_T}{C_R+C_T}\right] \tag{13}$$

$$X_{CP} = \frac{C_N X_N + C_F X_F}{C_N + C_F} \tag{14}$$

$$SM = \frac{X_{CP} - X_{CG}}{2R} \tag{15}$$

The constants used in these equations, along with the results of each equation, are provided in Table 3.8.

Table 3.8: Stability Margin Constants and Results

Constant	Variable Name	Value	Units
$(C_N)_N$	Nose Cone Coefficient	2	N/A
X_N	Nose Cone Length Factor	11.184	in.
R	Body Radius	3.085	in.
S	Fin Span	5.25	in.
N	Number of Fins	4	N/A
d	Base of Nose Diameter	6.17	in.
L_F	Fin Midchord Line Length	7.60	in.
C_R	Fin Root Chord Length	8	in.
C_T	Fin Tip Chord Length	4	in.
X_B	Nose to Root Chord LE length	93.5	in.
X_R	Tail to Root Chord LE length	7.5	in.
Equation	Result		Units
$(C_N)_f$	6.83		N/A
X_f	98.388		in.
X_{CP}	78.62		in.
SM	2.45		Calibers

From the hand calculations, the stability margin calculated is within 6.75% of the OpenRocket predicted value. This value falls within the bounds of LVD 8 and LVD 9, ensuring that our stability will meet NASA and team derived requirements.

3.6.5 Ballast Placement

Due to additional mass forward on the launch vehicle, the ballast location was chosen further aft to offset the forward mass and maintain a viable stability margin. Within the RFS, aluminum rods that provide structural support for the thrust plate can be fitted with removable ballast for center of gravity tuning. The maximum ballast mass that can be added to the RFS is 1.9 lb. A depiction of this ballast is shown in Figure 3.72. Another location to add ballast is on the AV bay bulkhead. Addition of ballast on the AV bay bulkhead allows for day-of-launch weight and apogee adjustments. The AV bay is located near the center of gravity of the entire launch vehicle, therefore adding ballast to the AV bulkhead location will not change the location of the center of gravity. The maximum ballast weight that can be added to the AV bay bulkhead is 0.66 lb. Table 3.9 shows example ballast location parameters and their contribution to the overall launch vehicle stability margin.

Table 3.9: Stability Margin Fluctuation with ballast modification.

AV Bay Ballast	RFS Ballast	Stability Margin
0 lb.	1.9 lb.	2.27 Calipers.
0 lb.	1 lb.	2.37 Calipers.
0.33 lb.	1.9 lb.	2.28 Calipers.
0.33 lb.	1 lb.	2.38 Calipers.
0.66 lb.	1.9 lb.	2.29 Calipers.
0.66 lb.	1 lb.	2.38 Calipers.

3.6.6 Kinetic Energy at Landing

Through the use of Newtonian Mechanics, the kinetic energy for the launch vehicle upon landing can be calculated using Equation 16. Let KE represent the kinetic energy, m represent the mass of the launch vehicle or independent section, and V represent its velocity.

$$KE = \frac{1}{2}mV^2 \tag{16}$$

Per NASA Requirement 3.3, the maximum impact energy allowed for each body section is 75 ft-lbf. Additional points can be attained for being below 65 ft-lbf. Using the equation listed above, the impact velocity necessary to meet the kinetic energy requirement for each section of the launch vehicle under main parachute descent is shown in Table 3.10.

Table 3.10: Required Velocity for Kinetic Energy Requirement

Section	Section of Mass	Descent Velocity Necessary to be Awarded Points	Descent Velocity Necessary to be Awarded Bonus Points
Nose Cone	.207 slugs	26.919 ft/s	25.063 ft/s
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	19.36 ft/s	18.03 ft/s
Drogue Bay/ Fin Can	.516 slugs	17.05 ft/s	15.87 ft/s

Mentioned in Section 3.5.4, the main parachute selected is the 96 in. Iris Ultra Compact by Fruity Chutes. The descent velocity for the launch vehicle and nose cone without the payload attached can be found using Equation 17 below. Let m be the burnout mass of the launch vehicle, g be Earth's gravitational acceleration constant, S be the parachute's area, C_D the drag coefficient of the parachute, ρ the density of the air, and V_D the descent velocity of the launch vehicle.

$$v_d = \sqrt{\frac{2gm}{SC_D\rho}} \tag{17}$$

Using the equation above, the descent velocity of each section can be used to calculate their kinetic energy upon landing. These values are presented in Table 3.11 below.

Table 3.11: Landing Kinetic Energy for Each Section

Section	Section of Mass	Velocity Under Main Parachute	Impact Energy
Nose Cone	.207 slugs	21.64 ft/s	48.77 ft-lb
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	15.38 ft/s	47.31 ft-lb
Drogue Bay/ Fin Can	.516 slugs	15.38 ft/s	61.11 ft-lb

Mentioned in Section 3.5.4, and seen in the table above, the descent velocity calculated for the launch vehicle with the 94 in. Iris Ultra Compact parachute is 15.38 ft/s. Additionally, the descent velocity of the nose cone without the payload will be 15.83 ft/s. It can be seen from Table 3.11 that the kinetic energy requirement for each section hitting the ground is satisfied. The velocities provided were calculated using Equation 17, where the AV bay, main parachute/payload bay, and fin can have the same descent rate since they are tethered together under the main parachute.

3.6.7 Expected Descent Time

The total descent time for the launch vehicle is broken up into two sections, the descent time under drogue, and the descent time under main parachute. Calculated using 17, the descent velocity of the launch vehicle under drogue and main parachutes is used to find the descent time. Additionally, the descent time is a factor of the apogee height and the main deployment altitude. Total descent time is found using Equation 18 below.

$$t = \frac{h_a - h_m}{v_d} + \frac{h_m}{v_m} \tag{18}$$

Let t represent the total descent time for the launch vehicle, h_a is the apogee altitude, h_m is the main deployment altitude, v_d is the descent velocity of the vehicle under drogue parachute, and v_m is the descent velocity of the launch vehicle under main parachute. The total descent time for the launch vehicle was calculated to be 80.81 seconds, which meets NASA Requirement 3.12.

Additionally, the nose cone descent time can be found using Equation 19 and both the descent velocity of the nose cone with the payload attached to the payload deployment bay at an altitude of 450 ft., and the descent velocity of the nose cone when the payload is not attached to the deployment bay at landing. These parameters are referenced in Section 3.5.4.

$$t_n = t_d + \frac{h_m - h_p}{v_p} + \frac{h_p}{v_n} \tag{19}$$

Where t_n is the total descent time of the nose cone, t_d is the descent time of the launch vehicle under drogue, h_m is the height the main parachute is deployed (800 ft.), h_p is the height the payload is deployed (450 ft.), v_p is the descent velocity of the nose cone and payload under the nose cone parachute, and v_n is the descent velocity of the nose cone without the payload attached. The total descent time of the nose cone from apogee to landing is 61.67 seconds, which meets NASA Requirement 3.12.

3.6.8 Expected Wind Drift Distance

When determining the expected drift distance, a large overestimation is used to ensure the launch vehicle will not drift more than 2,500 ft. from the launch pad. This consists of assuming that the drift velocity of the launch vehicle is equal to the wind speed, where this drift velocity is completely horizontal. Another assumption is that the launch vehicle will only travel vertically to apogee, the launch vehicle immediately descends under the drogue parachute's terminal velocity upon drogue separation, and the launch vehicle immediately falls under the main parachute's terminal velocity upon main separation. Therefore, it is assumed that from apogee to landing, the launch vehicle and separated nose cone will descend in one direction at a constant horizontal drift speed equivalent to the wind speed. It is important to state that the actual drift speed is a function of the drag from the parachute, the descent velocity, and other factors meaning it is not equivalent to the wind speed in reality. It is desirable to overshoot this estimation to eliminate the risk of even getting close to the maximum 2,500 ft. drift distance. Using the following equation, the drift distance of the launch vehicle can be calculated for different wind speed conditions. Let v_w be the wind speed, t be the estimated descent time, and D is the expected drift. As mentioned in Section 3.6.7, the total descent time for the launch vehicle is approximately 81.54 seconds, and the descent time for the nose cone from the main deployment altitude is 41.32 seconds.

$$D = v_w t \tag{20}$$

Using this equation, the total wind drift for the launch vehicle can be calculated using the wind drift under the drogue parachute and adding the wind drift from the main parachute. For the nose cone, the total wind drift is found using the wind drift for the launch vehicle under drogue, and adding the wind drift of the nose cone under its parachute. Presented below in Table 3.12 are the wind drift distances calculated for various wind speeds.

Table 3.12: Wind Drift Distances for Varying Wind Speeds

Wind Velocity	Launch Vehicle Drift Distance	Nose Cone Drift Distance
0 mph	0 ft	0 ft
5 mph	592.62 ft	452.27 ft
10 mph	1,185.25 ft	904.56 ft
15 mph	1,777.87 ft	1,356.84 ft
20 mph	2,370.5 ft	1809.12 ft

From looking at the table, the overestimated maximum drift distance under a 20 mph wind will be 2,309.63 ft., which is under the 2,500 ft. requirement set by NASA.

3.6.9 Parachute Opening Shock Calculations

One of the largest loads the launch vehicle experiences is the shock force experienced when the main parachute deploys. The shock force is a function of the time it takes the parachute to open, the change in velocity of the launch vehicle from drogue descent to main descent, and the mass of the launch vehicle. To calculate the shock force, the time it takes the parachute to open needs to be calculated first. This is found using the equation below, where r is the radius of the parachute opening, v is the drogue descent velocity, and t is the time it takes the parachute to open.

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

Found in a study by W. Ludtke on how to calculate opening shock forces for a parachute, a coefficient of 8 is necessary to find the time it takes the parachute to open [1]. For the Fruity Chutes 96 in. parachute with a drogue descent rate of 112.82 ft/s, the time it takes to open is approximately 0.2905 seconds. From there the shock force can be found using the equation below where F is the shock force, m is the mass of the launch vehicle, Δv is the change is descent velocity from drogue to main, and t is the time it takes the main parachute to open.

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

Shown below, Table 3.13 contains the maximum shock force the launch vehicle and some of its core components will experience. Note that the 5/8 in. Kevlar webbed shock cord is rated up to 6000 lbf, thus there are large factors of safety for these shock force loads experienced upon main deployment.

Table 3.13: Maximum Shock Forces

Section	Mass of Section	Parachute Opening Time	Parachute Opening Shock
Nose Cone with Payload	.562 slugs	.142 s	385.64 lbf
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	.284 s	137.24 lbf
Drogue Bay/ Fin Can	.516 slugs	.284 s	177.04 lbf
Separated Launch Vehicle	.917 slugs	.284 s	314.62 lbf

4 Payload Criteria

4.1 Payload Mission Statement and Success Criteria

The payload mission is to successfully land four STEMnauts that have human survivability characteristics. The payload must deploy between 400-800 ft. AGL and can not use parachutes or streamers for the recovery method. Additionally, the payload must land in a pre-define orientation, in this case vertically.

Table 4.1: Payload Success Criteria

Success Level	Payload Aspect	Safety Aspect
Complete Success	The SAIL lands in the pre-defined orientation and with a landing velocity of under 5 mph. Additionally, the SAIL does not experience any sustained forces greater than 3 G's.	No personnel are harmed or at risk during payload recovery
Partial Success	The SAIL lands in the pre-defined orientation but with a velocity between 5 mph and 15 mph OR the SAIL lands with a velocity under 5 mph but does not come to rest in the pre-defined orientation.	No personnel are harmed during payload recovery but there is at least one close call.
Partial Failure	The SAIL impacts the ground with a velocity greater than 15 mph but receives no major damage.	Personnel receive minor injuries during payload recovery.
Total Failure	The SAIL impacts the ground with a velocity greater than 15 mph AND sustains catastrophic damage.	Personnel receive major injuries during payload recovery.

4.2 FAA Classification

The following quotation was taken from FAA Advisory Circular No. 91-57A:

> Section 336 of P.L. 112-95 defines a model aircraft as an unmanned aircraft that is capable of sustained flight in the atmosphere, flown within visual line of sight of the person operating the aircraft, and flown only for hobby or recreational purposes. [4]

The SAIL has been designed in a way that it is not capable of sustained flight. It does not have any form of cyclic controls to allow for translational movements. Additionally, the thrust is limited by the flight computer to never produce enough thrust to lift the vehicle off of the ground. The function of the rotor blade system is to only slow the vehicle down prior to landing, not to fly. After communicating with the FAA, we received confirmation that our design would be viewed similarly to a helicopter duration model rocket and would NOT be considered an UAS because it cannot fly.

4.3 STEMnaut Survivability

To verify that the flight is survivable for the STEMnauts, the following criteria was established:

- Impact velocity is less than 15 mph to ensure that the landing legs do not fail.
- The STEMnauts do not experience more than 6 G of force for more than 1 second.
- The STEMnauts do not experience more than 3 G of sustained force.
- The STEMnauts are restrained in their chairs for the entire flight and are recovered in their seated positions.
- The pressure inside the SAIL body remains approximately 1 atm after the SAIL is released.

Additionally, the altimeter will be measuring the descent velocity and the camera will show that the STEMnauts did not move during the flight. Lastly, the IMU will measure the force of impact as well as any rapid deceleration that the crew may experience.

4.4 Payload Design Overview

Figure 4.1: SAIL in the deployed state

4.4.1 Payload Design Changes

SAIL Electronics Sled

The STEMnaut crew area height was increased by .15 inches to allow for easier ingress/egress of the STEMnauts. Additionally, some material has been removed from the battery compartment to reduce the weight of the sled.

Deployment Bay Electronics Sled

In order to save on weight and space, the deployment bay electronics sled was redesigned. The same overall shape was kept to support the functionality of the servo. Section sizes were decreased to give more space to access the latch, as well as creating more space for the attached electronics to more easily fit inside of the deployment bay Blue Tube. The updated sled is shown in Figure 4.2.

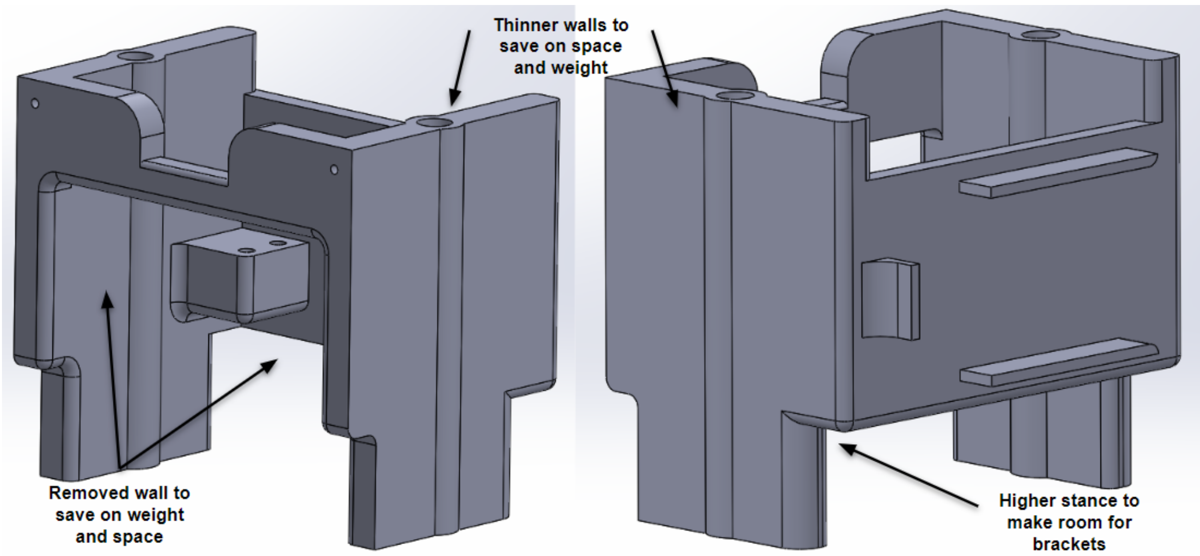

Figure 4.2: Updated Sled for Deployment Bay Electronics

Deployment Bay Blue Tube Retention

The electronics housing for the deployment bay is designed to be attached from the outside by attaching screws to a set of nuts and corner brackets. A 3D printed attachment for the hex nuts was added to the corner brackets in order to keep the nuts in place when securing the deployment bay from the outside. The 3D printed attachment on the corner brackets is shown below in Figure 4.3.

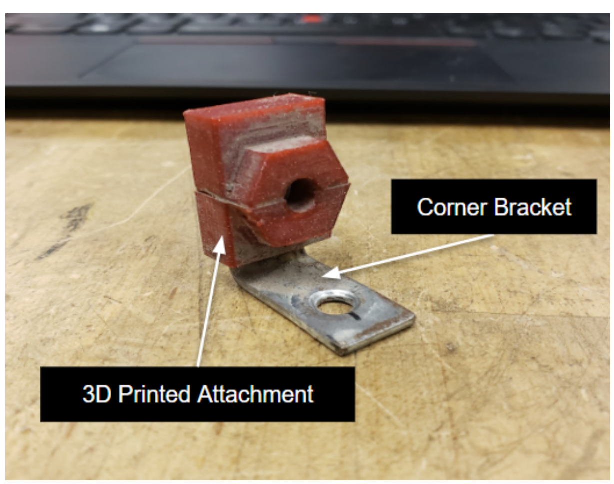

Figure 4.3: 3D Printed Connector for Corner Brackets and Hex Nuts

Gearbox

During testing of the gearbox, the snap rings holding the side bevel gear axles in place would slip out of the groove, flying free of the assembly. In order to prevent this from occuring during flight, the snap rings have been replaced with 8mm locking collars.

Rotor Blades

The mounting point of the rotor blades was changed from a flat rectangular section to a lofted section to ease the fabrication process. The initial design made it difficult to obtain a clean finish during the carbon fiber layup process. The new loft allows the carbon fiber to adhere to the rotor blades more efficiently, resulting in a stronger joint. Additionally, West Systems epoxy will be used to join the rotor blades together due to PET Gloop being out of stock.

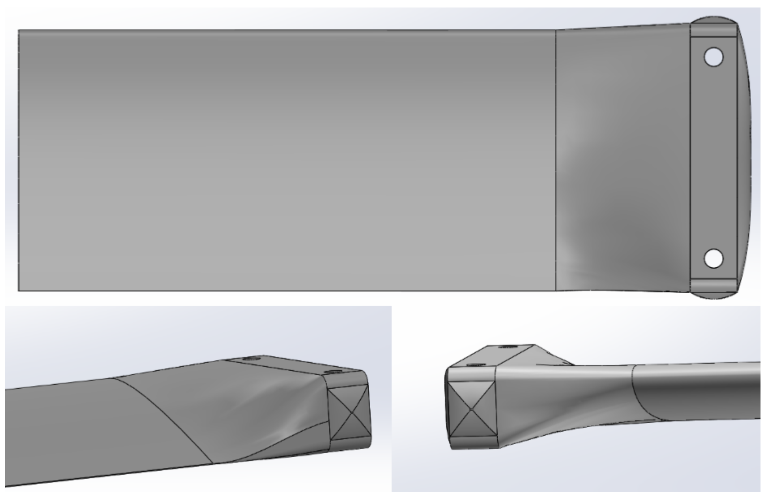

Figure 4.4: Rotor Blade Lofted Section

Another change for ease of manufacturing was printing the connection pieces separately from the blade sections. This improved how the sections epoxied together and how they mesh due to 3D-printing inconsistencies. This layout can be seen in Figure 4.5.

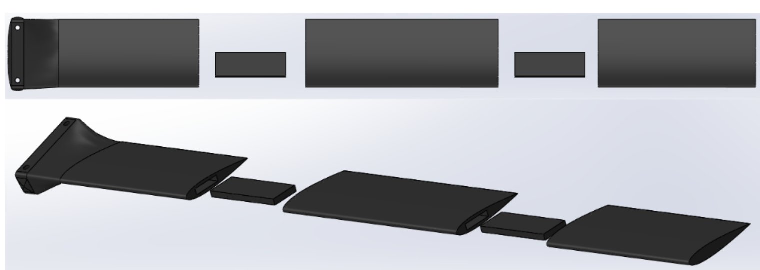

Figure 4.5: Rotor Blade Sections Laid Out

Flight Computer Logic Level Shifter

The ESC requires a 5V PWM signal to control the brushless motor. However, the Adafruit Feather operates at 3.3V. In order to allow the flight computer to control the propulsion system, a 3.3V to

5V logic level shifter was added to the SAIL electronics. Additionally, the Adafruit Feather will be powered from the 3.3V Buck Converter rather than directly from the BEC.

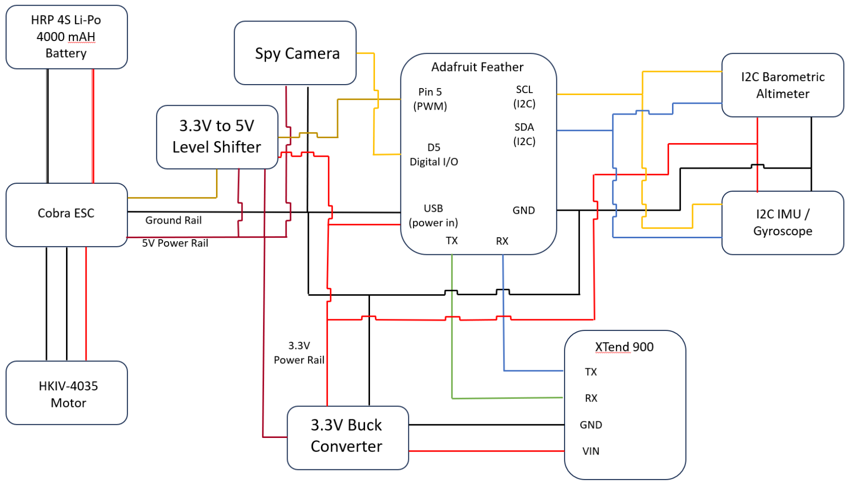

Figure 4.6: Updated SAIL Electronics Diagram

Landing Legs

The landing legs were shortened to a length of 13 in. in order to provide more room inside of the payload bay for the recovery systems. As a result, the angle of the deployed legs was decreased to 23.75 degrees to ensure that the bottom of the SAIL is not resting on the ground after landing. This also reduces the diameter that the legs span to 15.05 in. The holes in the SAIL body will be moved up higher due to these geometric changes, which can be seen below in Figure 4.7.

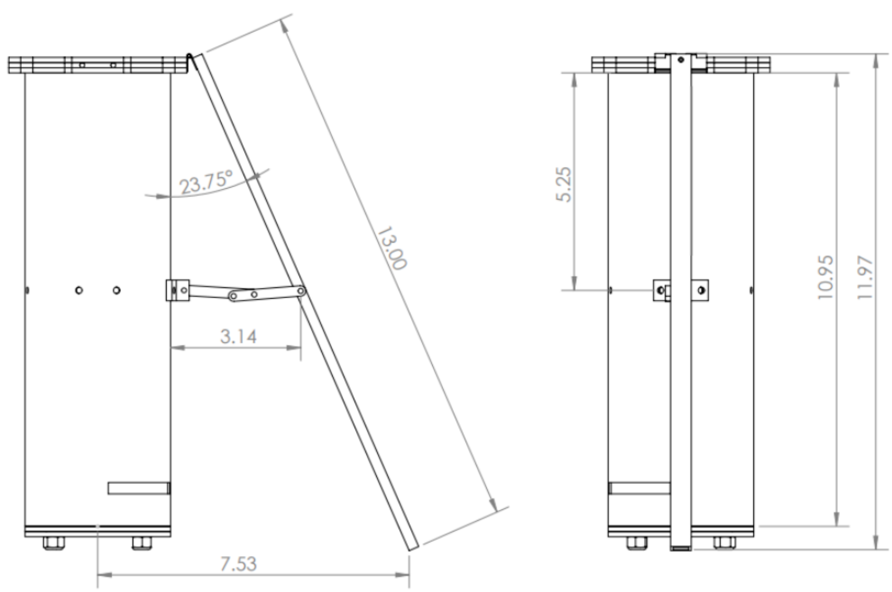

Figure 4.7: Leg Mechanism Drawing (in.)

The leg mechanism was also changed from a pin and retaining ring system to a bolt and nut system. Since the 3 mm pins are case hardened steel, there were no proper tools in the lab that could be used to cut out slots for the retaining rings. Thus, the pins will be replaced with M3 bolts and the retaining rings with thin M3 hex nuts. On the end of each bolt will be an M3 lock nut to ensure the mechanism is held together. This setup can be seen in Figure 4.8. Also seen is the change to the spring hinge placement. Since the spring hinge ordered is too weak to fully extend the locking mechanism from a 90 degree starting point, it will be wound up to 180 degrees instead.

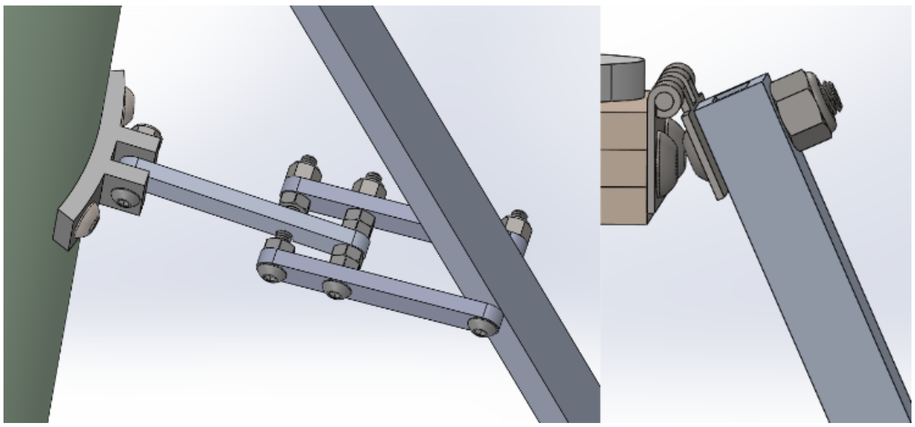

Figure 4.8: Changes to the Leg Mechanism and Spring Hinge Placement

To accommodate these changes, the linkage and leg geometries have to change. Figures 4.9, 4.10, and 4.11 show the new dimensions of each changed component.

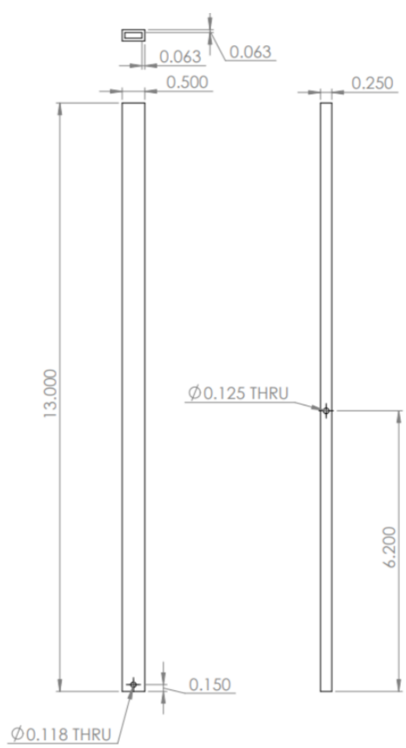

Figure 4.9: Landing Leg Drawing (in.)

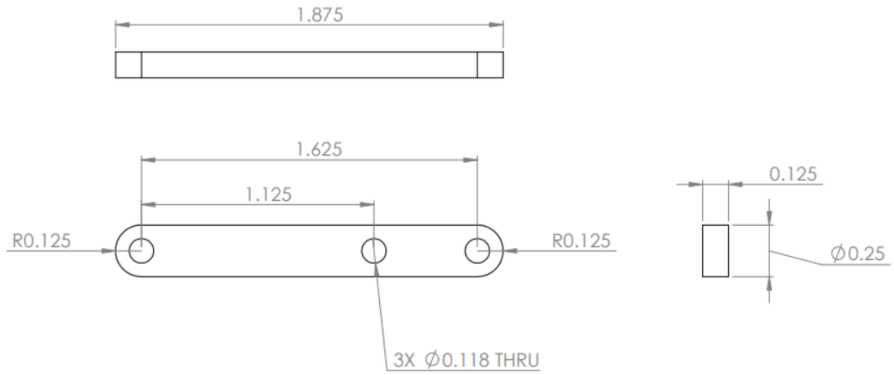

Figure 4.10: Leg Linkage Drawing (in.)

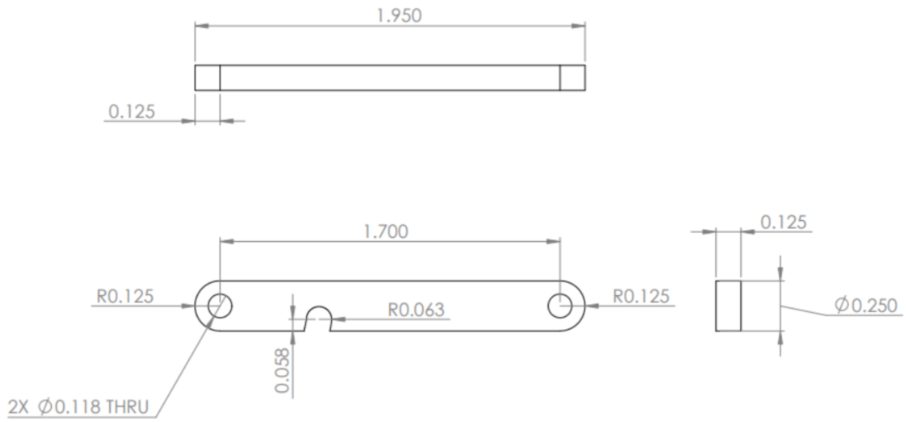

Figure 4.11: Body Linkage Drawing (in.)

Deployment Bay Blue Tube

The deployment bay was shortened to a length of 29.3 inches in order to make more space inside the payload bay for the recovery systems (parachutes/shock cord). This was done in conjunction with decreasing the length and deployment angle of the SAIL landing legs.

4.4.2 SAIL Design Overview

Propulsion

The SAIL will be powered by a Scorpion HKIV-4035-330KV shown below in figure 4.12. This motor has a max continous power output of 2664 watts with a maximum continuous current draw of 60 amps. The motor will be controlled by a Cobra 150A electronic speed controller and powered by a 4S 4000 mAH LiPo battery.

Figure 4.12: Scorpion HKIV-4035-330KV Brushless Motor [7]

The motor will be connected to a custom built gearbox that will reverse the direction of rotation for one of the rotor blades. The gearbox is fabricated from 6061 aluminum sheet metal along with commercial bearings/gears. A breakdown of the gearbox assembly is shown below in Figure 4.13.

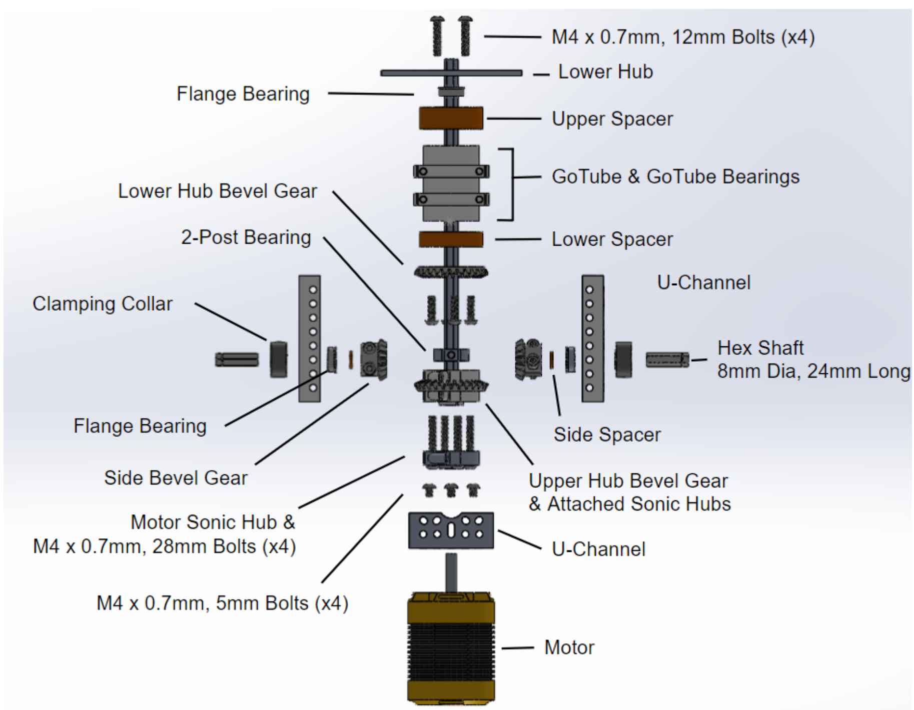

Figure 4.13: Gearbox Exploded View

Rotor Blades

The rotor blades are 3D printed using CF-PC filament. Due to size limitations with the available 3D printers, the blades are printed in three separate sections. They are then epoxied together using rectangular pieces which fill in the voids in the blade sections, securing them to each other. After the epoxy has cured, a carbon fiber wrap will be applied to the blade using the VARTM process. The blades will be connected to the rotor hubs using springed hinges, allowing the rotor blades to fold so that the SAIL will fit within the deployment bay.

Electronics

The SAIL will be controlled using an Adafruit Feather. Additional electronics include an altimeter, IMU, spy camera, 5V to 3.3V buck converter and a XBee transceiver. The flight computer will use data from the altimeter to control the descent velocity of the SAIL by increasing the power output from the brushless motor until a steady velocity has been reached. All of the electronics will be mounted to a 3D printed sled that will also house the STEMnauts.

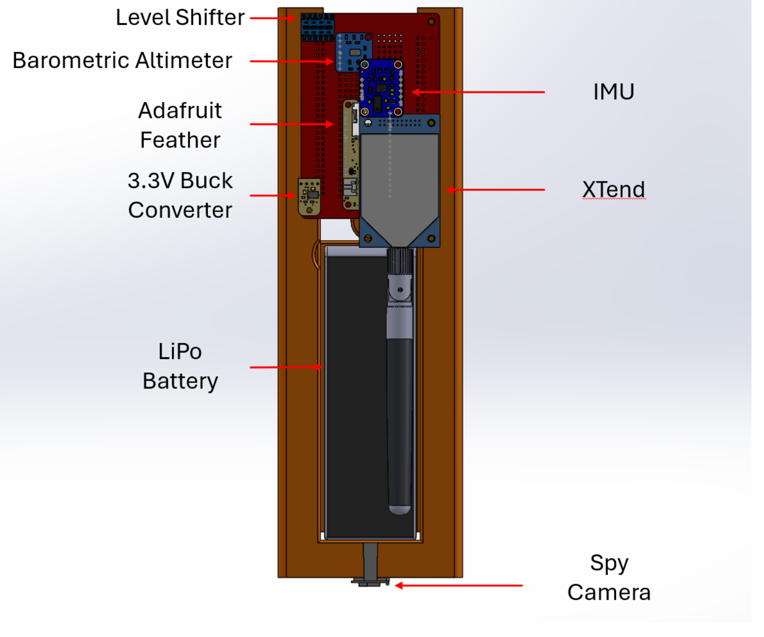

Figure 4.14: SAIL Electronics Sled

4.4.3 SAIL Deployment Overview

Sequence of Events for Release

The sequence of events for release of the SAIL from the deployment bay has not changed since CDR. However, the orientation of the SAIL in the main/payload has been adjusted by rotating it by 180 degrees. This was done to create more space in the main/payload bay, allowing for the nose cone parachute to be held within the bottom of the deployment bay.

To reiterate the deployment events of the SAIL, a U bolt on the top side of the deployment bay will be attached to a shock cord, which in turn will be attached to the nose cone. The main parachute deployment bag will also be attached to the top of the deployment bay. The main recovery event will separate the SAIL deployment bay from the payload section of the launch vehicle. Afterwards, the deployment bay will be descending under the nose cone parachute. Once RSO permission is given, an RF command will be sent to the deployment bay, unlatching the SAIL. Next, the SAIL will fall out of the deployment bay which in turn will unfold the spring loaded rotor blades and landing legs. and start the descent process. A diagram of this sequence of events is shown in Figure 4.15.

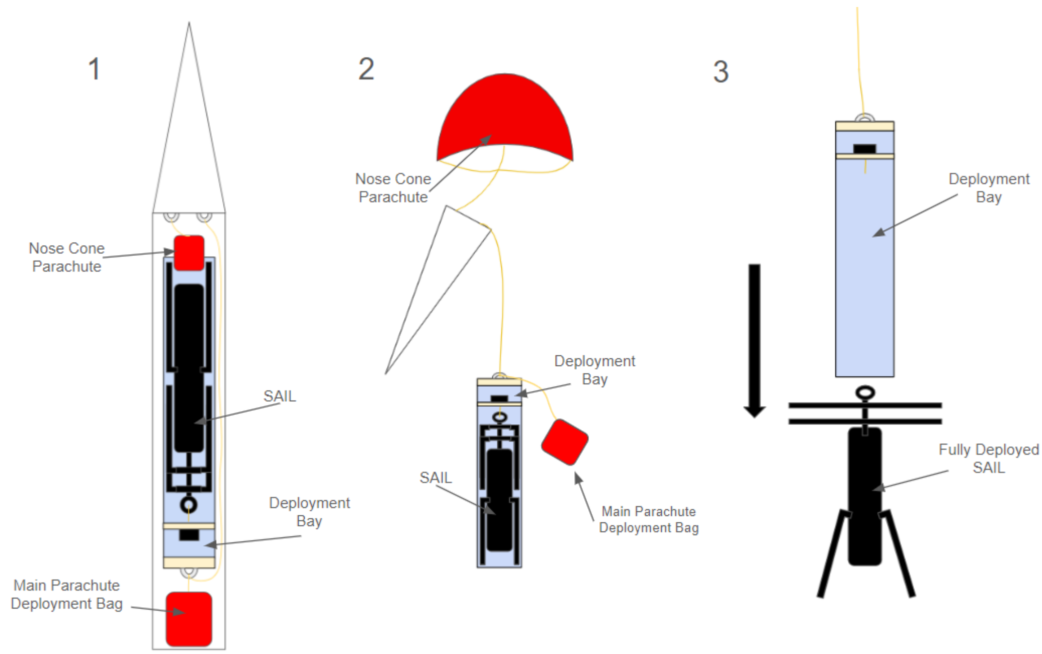

Figure 4.15: Sequence of Events for SAIL Deployment

Deployment Bay

The SAIL will be retained and released from a deployment bay, constructed out of a 5.5” diameter BlueTube. The purpose of this deployment bay is to provide a housing for the SAIL during launch and recovery events, as well as allowing for manual release of the SAIL upon receiving RSO permission. The electronics and latch housing mock up is shown in Figures 4.16 and 4.17. The fully assembled deployment bay mock up is shown in Figure 4.18.

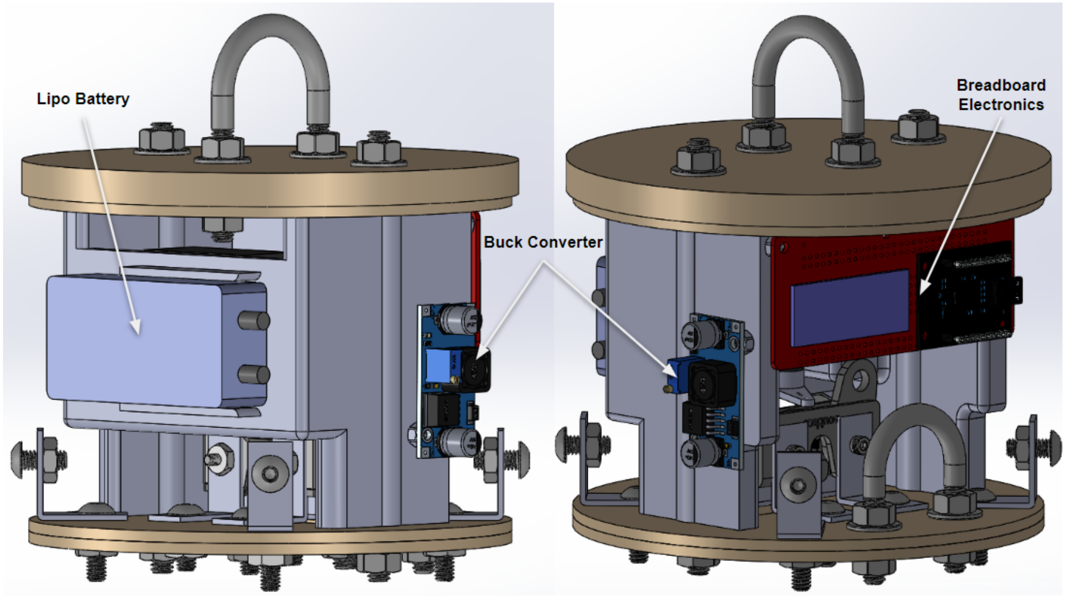

Figure 4.16: CAD of Deployment Bay Electronics Housing

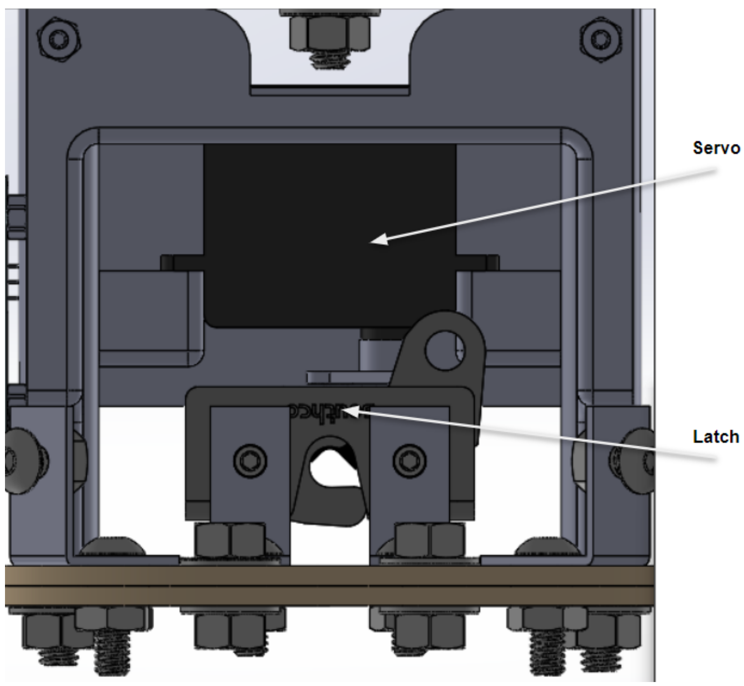

Figure 4.17: CAD of Latch Setup in Electronics Housing

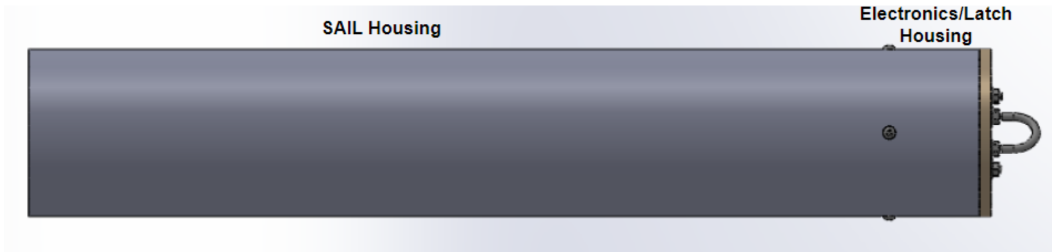

Figure 4.18: CAD of Fully Assembled Deployment Bay

The deployment bay needed to be cut shorter in order to accommodate space inside of the main/-payload bay. The updated drawing for the Blue Tube is shown in Figure 4.19.

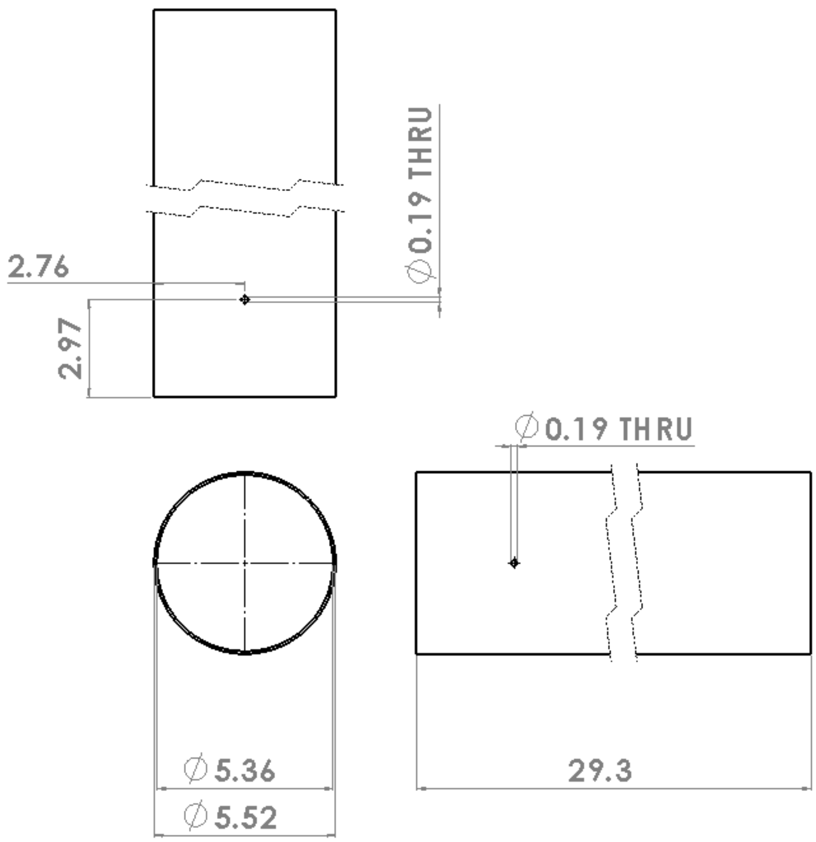

Figure 4.19: Part Drawing of Deployment Bay Blue Tube (inches)

In order to save weight and space in the electronics housing of the deployment bay, the electronics sled/housing needed to be redesigned. This was done by removing most of the front wall where the breadboard is mounted. The walls were also made thinner, as well as lifted up slightly to make room for the 3D printed attachments on the Blue Tube retention corner brackets. The updated drawing can be seen in Figure 4.20.

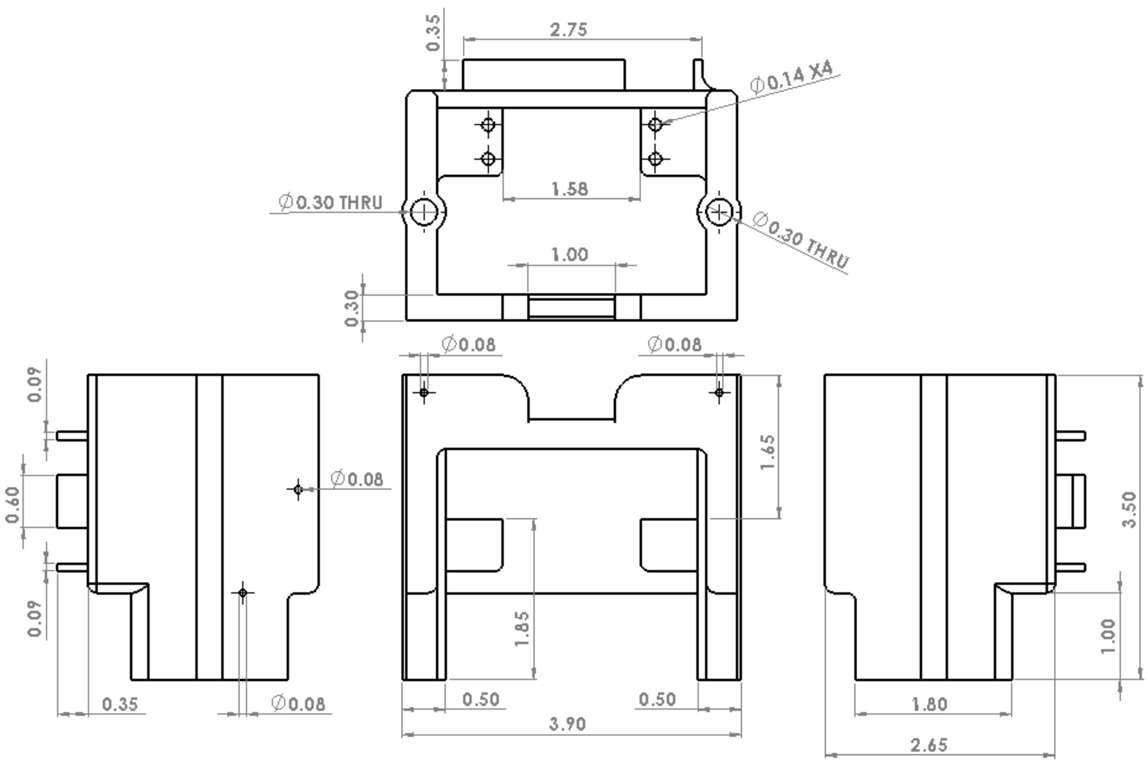

Figure 4.20: Part Drawing of Deployment Bay Electronic Sled (inches)

Deployment Bay Weight Breakdown

Below is the weight breakdown of the as-built deployment bay. Additionally, the predicted weight is compared to the actual weight.

Table 4.2: Deployment Bay Weight Breakdown

Component	Unit Weight (lb)	Quantity	Predicted Weight (lb)	Actual Weight (lb)
Blue Tube Body	1.656	1	1.538	1.656
Forward Bulkhead	0.3047	1	0.2229	0.3047
Aft Bulkhead	0.1328	1	0.0024	0.1328
U-Bolt: 1/4”-20, 1.5” Ctr.-to-Ctr.	0.0703	1	0.0081	0.0703
U-Bolt: 1/4”-20, 1.25” Ctr.-to-Ctr.	0.0547	1	0.0071	0.0547
Electronics Sled	0.1719	1	0.1229	0.1719
Southco Latch	0.1094	1	0.0938	0.1094
HS-7950TH Servo	0.1484	1	0.1484	0.1484
Breadboard Electronics	0.1094	1	0.1016	0.1094
7.4V Li-Po Battery	0.1963	1	0.1953	0.1963
Threaded Rods: 1/4”-20, 5” long	0.0513	2	0.0136	0.1092
Hex Nuts: 1/4”-20	0.0069	14	0.0928	0.0963
Washers: 1/4”	0.0031	8	0.0410	0.0250
L-Bracket: 1”x1”x0.5”	0.0175	4	0.0625	0.0700
L-Bracket: 11/16”x1”x0.5”, 3D Print	0.0281	4	0	0.1125
L-Bracket: 11/16”x1”x0.5”	0	0	0.0119	0
Hex Nuts: 12-24	0.0025	6	0.0091	0.0150
Nylon Screws: 5-40, 3/4” long	0.0006	8	0.0012	0.0050
Button Screw: 12-24, 0.75” long	0.0081	4	0.0090	0.0325
Button Screw: 12-24, 0.5” long	0.0031	4	0.0034	0.0125
Socket Head Screw: 5-40, 3/4” long	0.0056	2	0.0008	0.0113
Hex Nut: 5-40	0	0	0.0006	0
		Total Weight (lb):	2.82	3.44

As Table 4.2 shows, the predicted weight for the deployment bay was underestimated. This mainly shows in the bulkhead weights, and individual fasteners. The method for estimating weight for the bulkheads and fasteners was using volume calculations obtained from SolidWorks and then using density values for a given material. The change in weight for the deployment bay has been accounted for in launch vehicle performance calculations.

4.5 Payload Flight Reliability

4.5.1 SAIL Flight Reliability

The SAIL will be put through extensive ground testing prior to PDF. The most critical test will be the thrust measurement test. The gearbox and rotor blades will be attached to a thrust stand and the motor will be commanded to rotate. The RPM will be increased until the SAIL is producing 8 lbf of thrust, enough to slow the descent velocity down to 5 mph. The data from this test will also be used to create a thrust curve profile that will be used in the final programming of the SAIL.

Additional ground tests include measuring the time it takes the rotor blades to deploy after release and the strength of the landing legs. These tests are currently planned for the week of March 4th. After all ground tests are successful, the entire system will be tested during PDF on March 23rd.

4.5.2 Deployment Bay Reliability

The retention and deployment of the SAIL is important for the safety of the payload operation. The deployment bay keeps the SAIL in a secure position during launch events, and will only release the SAIL when the RSO has determined that it is safe.

The latch setup has been verified to withstand shock forces during separation. The latch was put under a 100 lb sustained load, with minimal deflection. There was no visible damage to the latch housing, and the latch still operated normally after the test. This test reinforces the confidence of the latch not fracturing during launch events. See Section 7.2.6 for more information.

Additionally, the range of the XBee transceivers for releasing the latch has been proven to operate to at least 2500 ft. This will allow the SAIL to be released at the maximum calculated drift distance for the launch vehicle during recovery, if necessary. For more information on the RF signal range, see Section 7.2.5.

For Vehicle Demonstration Flight, a SAIL mass simulator was flown and released under a parachute. The latch held the mass simulator and did not release until it was manually commanded to do so. This proves that the retention and release system is safe for flight, as the SAIL will not be released until it is appropriate.

4.6 Payload Manufacturing

4.6.1 SAIL Manufacturing

Rotor Blades

Since there are three rotor blade sections, they have to be epoxied together first before applying a carbon fiber wrap. As seen in Figure 4.21, there are two sections on the right side that are already epoxied. Meanwhile, the leftmost section contains a rectangular piece that has not been epoxied and inserted into the middle blade section. Once it is epoxied together but uncured, the full rotor blade will be clamped and weighed down to keep them straight as seen in 4.23. This is done in two sessions where two sections are put together at a time. The halfway point of this process is seen in Figure 4.21. For a comprehensive view of the blade layout, refer to Figure 4.5.

Figure 4.21: Rotor Blade Sections

To get a better view of the new mounting sections with an improved loft, Figure 4.22 below shows how the carbon fiber can be smoothly vacuumed to the 3D-print, reducing any cracking. Note that any fraying or inconsistencies in the print is easily sanded down.

Figure 4.22: Lofted Blade Section

Figure 4.23: Clamping and Weighing Down the Curing Rotor Blade Sections

Once the epoxy fully cures after 24 hours, it is ready to be handled. The next steps lay out how the carbon fiber is wrapped around the 3D-printed rotor blade. This employs the vacuum-assisted resin transfer molding (VARTM) method, otherwise known as infusion molding. Epoxy transfers through the carbon fiber plies using a vacuum to pull it along. The layout can be seen in Figure 4.24 while the physical layer-by-layer process is shown in Figure 4.25.

First, there is a glass plate that is wiped down with acetone to ensure a clean surface where the sealant tape can stick to. Bagging material is placed on the glass and held down by a layer of sealant tape on the outer edges. Then, a layer of matrix is placed on top of the bagging material. This allows the epoxy to flow easily, preventing the vacuum from prohibiting it. Peel ply is then placed on top of the matrix so that it does not stick to the carbon fiber and the rotor blade can be peeled off with ease. Two uni-directional, 4 oz carbon fiber plies are placed on bottom and top of the rotor blade, and placed down on top of the peel ply. The carbon fiber is laid along the span-wise direction. Another layer of peel ply and matrix is then placed on top of the carbon fiber. On the sides of the rotor blades, spiral tubing is stretched along the span-wise direction. A quarter-inch tube is inserted into both of the tubes.Both tubes are parsed through a wrap of sealant tape and exit the bagging area. One tube is placed inside a cup for epoxy while the other tube is attached to the vacuum. Another layer of bagging material is then stuck to the outer sealant tape. Once epoxy is placed in the cup, the vacuum can be run, suctioning the carbon fiber to the rotor blade. Epoxy will flow through the carbon fiber plies and exit out the other tube. Figure 4.25 shows the carbon fiber partially soaked in the last step.

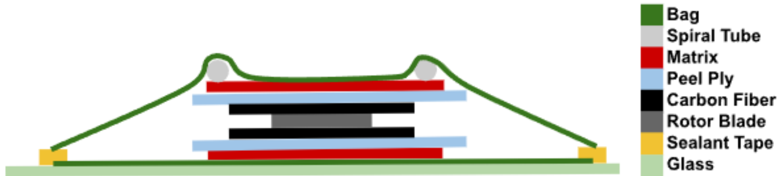

Figure 4.24: VARTM Layout

Figure 4.25: VARTM Process

Once the blade is left in the vacuum to cure for 24 hours, it can be peeled out. The excess carbon fiber is trimmed and sanded down to smoothen out the blades. The result can be seen below in Figure 4.26. To ensure the blades are even smoother to reduce turbulence, a thin layer of epoxy will be brushed on and sanded down. This avoids digging into the carbon fiber, which can reduce strength. Holes are then drilled out to secure them to the spring hinges.

Figure 4.26: Assembled Rotor Blades

Rotor Blade Test Article

In order to test the rotor blade connection point strength, a test article was made. It is important to note that the rotor blade design has been improved upon since this was manufactured. The test article had some slight carbon fiber cracking near the mounting holes where it fractured.

The test article underwent the same process as the full rotor blades as can be seen in Figure 4.27. The only difference is that the carbon fiber was wrapped around rather than having two plies on bottom and top of the rotor blade. The geometry is also noticeably different as it does not have a continuous loft. Both of these factors were detrimental to how the carbon fiber suctioned to the

3D-print, meaning the new rotor blades should be able to withstand larger axial loads. The carbon fiber maintained its shape for the most part, however.

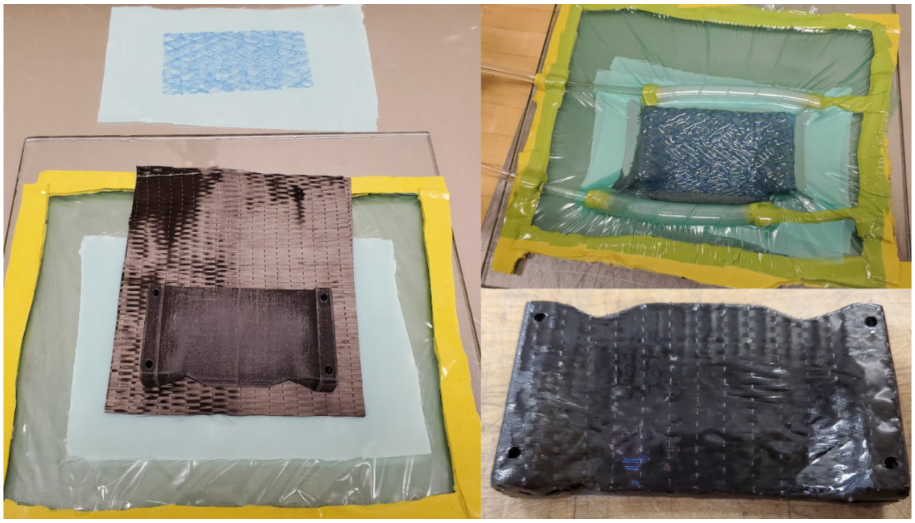

Figure 4.27: Rotor Blade Test Article

Once the test article was manufactured, aluminum plates were bolted through the mounting holes using 4-40 bolts and nuts as will be the case for the full assembly. They are then threaded with another bolt to hold a quick link. This quick link will be compressed by a tensile testing machine and stretched until failure. This setup can be seen below in Figure 4.28.

Figure 4.28: Rotor Blade Test Article Setup

Hub Assembly

The main hub components were made out of 1/8" aluminum sheet metal using a water jet. All of the big components that were cut using the water jet can be seen in Figure 4.29. The hardstop spacers, which are made out of 1/4" aluminum sheet metal, were also cut using a water jet. This can be seen in Figure 4.30.

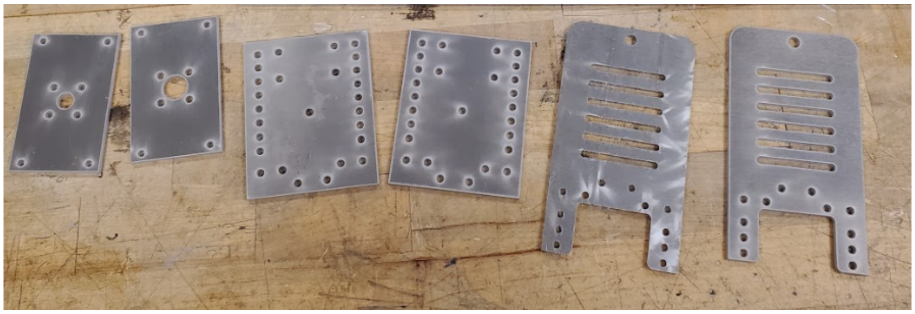

Figure 4.29: 1/8” Thick Aluminum Water Jet Parts

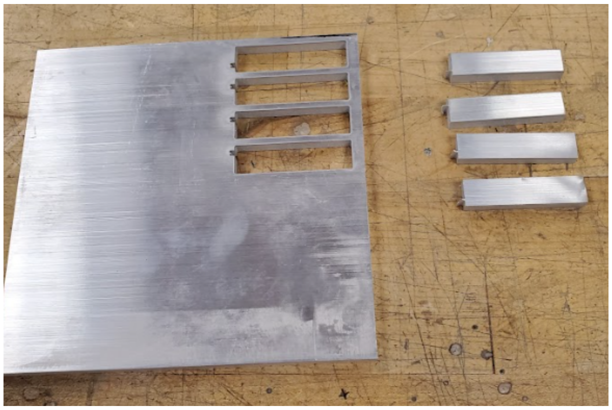

Figure 4.30: 1/4” Thick Aluminum Water Jet Parts

With these aluminum parts, the hubs were assembled as seen in Figure 4.31. The current assembly showcases the hard stops which will prevent the rotor blades from moving beyond a horizontal position. There will be spring hinges bolted at the bottom of the hubs, which will also attach to the rotor blades.

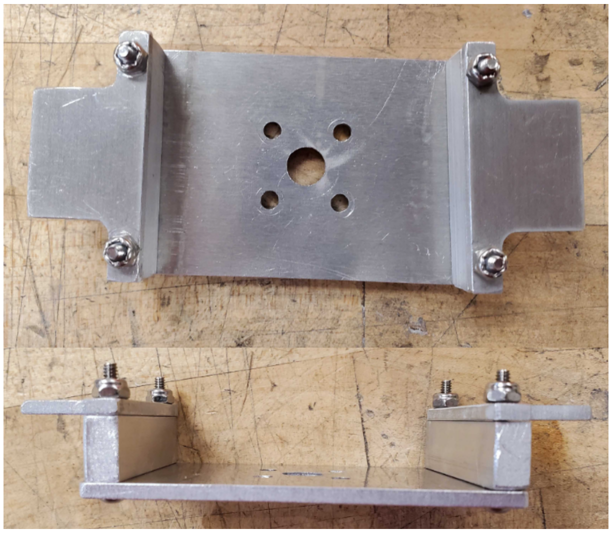

Figure 4.31: Hub Assembly

Gearbox

The aluminum side components were cut out of 1/8” aluminum sheet metal using a water jet (Figure 4.29). These parts were then joined together using a combination of bolts and locking nuts. The brushless motor shaft was cut to length using an angle grinder to allow the gears to align properly within the gearbox. The completed assembly is shown below in Figure 4.32. Also seen in this figure are the components on each side of the gearbox that have a 90 degree bend and will be bolted down to the SAIL body. These L-brackets were bent using heat and a sheet metal bending brake.

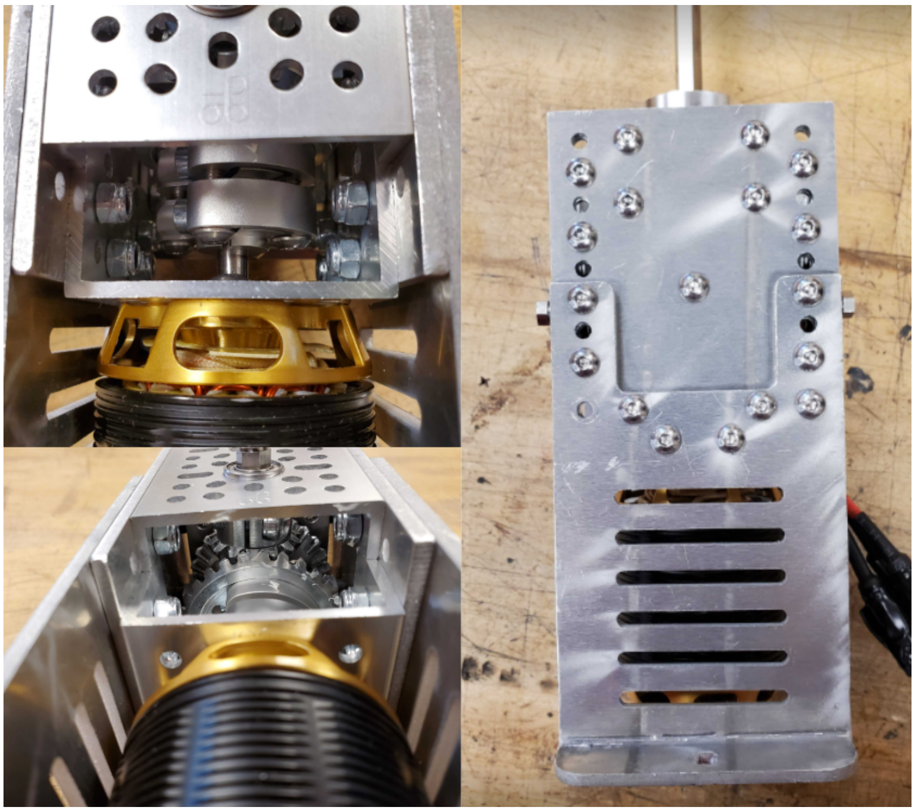

Figure 4.32: Gearbox Outer Structure and Motor-to-Shaft Assembly

Some of the gearing and the bearings along with their respective spacers are shown below in Figure 4.33. Here, the GoTube bearing spacers fill in the space between the walls and the bearings to prevent any warping. The side bevel gear spacers can also be seen, which allow the gears to mesh properly, maximizing efficiency and reducing wear.

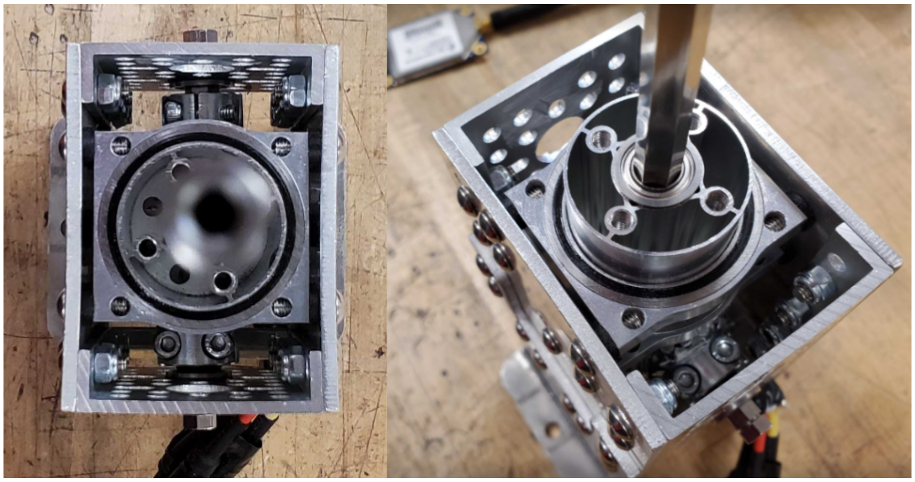

Figure 4.33: Gearbox Gearing and Bearings

All of the spacers were 3D-printed using CF-PC filament for extra strength. These can be seen below in Figure 4.34.

Figure 4.34: Spacers 3D-Printed

Electronics Sled

The electronics sled was 3D printed in 2 parts using PLA filament. The sled will fit between the 2 bulkheads on either end of the SAIL body. The sled, LiPo battery and bulkheads are shown below in Figure 4.35.

Figure 4.35: SAIL Electronics Sled and Bulkheads

The STEMnauts are located at the bottom of the electronics sled. The crew is shown below in Figure 4.36. During flight, the crew will be retained by a velcro strap running over their backs, securing them in their seats.

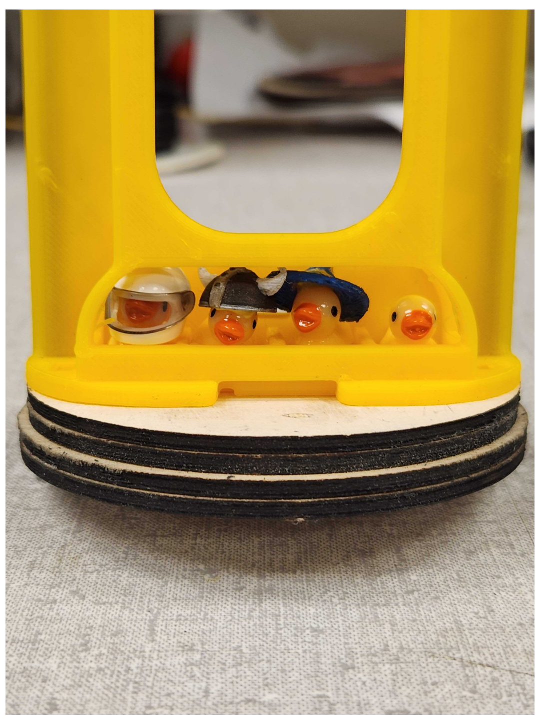

Figure 4.36: STEMnauts in SAIL seats

The SAIL electronics are shown below in Figure 4.37. The power rail on the left hand side is powered by the 3.3V buck converter. Because some components also require a 5V power source, the 1st row on the right side of the breadboard was turned into a 5.5V power supply, powered directly from the BEC. This 5.5V rail powers the buck converter and the logic level shifter. All of the electrical components were soldered directly to the breadboard to provide a high strength bond and eliminate the chance of wires coming loose during flight. Additionally, JST-SM locking connectors were installed on the wires leading to the BEC and the XTend, simplifying the process of assembling the payload and conducting ground testing.

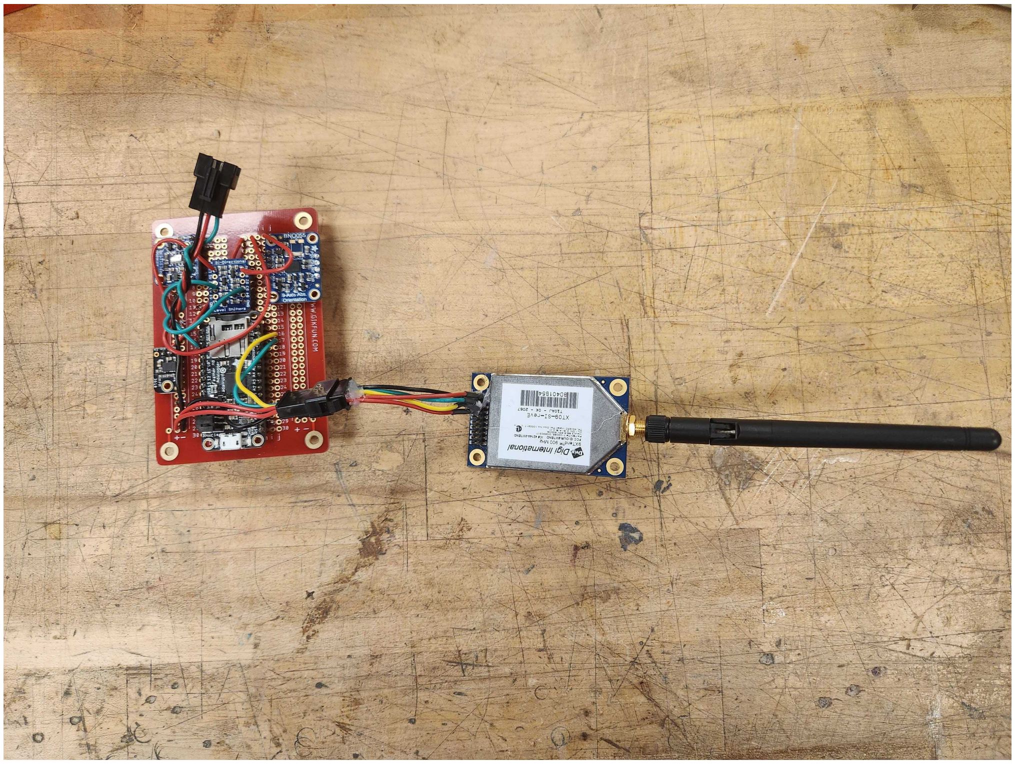

Figure 4.37: SAIL Electronics

Landing Legs

The landing leg linkages, shown below in Figure 4.38, were cut from a 1/8 in sheet of 6061 aluminum using a water jet.

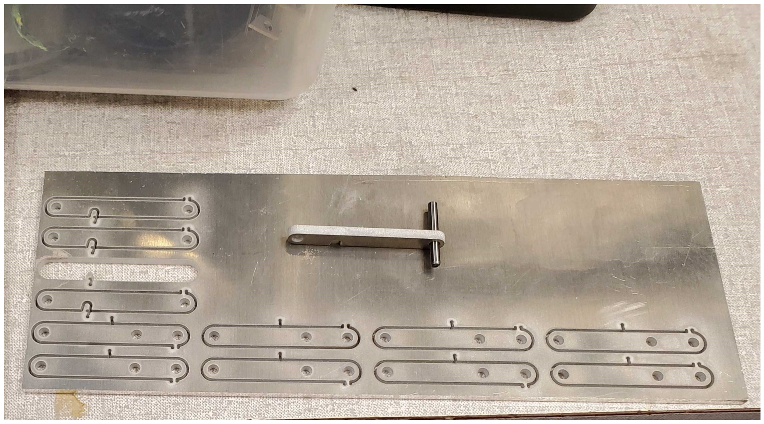

Figure 4.38: Landing Leg Linkages

The landing leg mechanism, shown below in Figure 4.39, locks in place when fully extended. The legs were cut to 13 in. in length. This was done using a horizontal bandsaw. Holes were then drilled out to secure the linkages and spring hinge to the leg. It is important to note that the fiberglass tube for the SAIL body has not arrived due to delivery difficulties. Thus, the figure shows the leg mechanism as stand-alone. As can be seen from the bottom view, the pin and retaining ring system was replaced with a bolt and nut system where the linkages rotate around bolts and are secured in place by thin hex nuts. The leg will begin in its folded configuration until it is released out of the deployment bay to extend and lock in place as seen on the right side of the figure. This gives a 23.75 degree angle from the vertical and a 15 in. spanning diameter around the center of the SAIL.

Figure 4.39: Landing Leg Mechanism

Weight

There is no weight table since a few parts have yet to arrive and it is difficult to get an accurate estimate since the SAIL has not been fully assembled. Note that the simulated SAIL weight for Vehicle Demonstration Flight was 8 lbs., which is the maximum SAIL weight. This ensured that the vehicle flight could be completed under this extremity. This remains the case for all calculations involving the SAIL weight.

4.6.2 Deployment Bay Manufacturing

Electronics Sled

The electronics sled for the deployment bay was modeled in SolidWorks as a 3D model. The sled was then printed out of PLA, and cleaned up using files and a heat gun. For attaching the electronics to the sled, heat inserts were used. On each of the heat inserts, nylon standoffs and screws were used to secure electronics.

Bulkheads

The deployment bay consists of two bulkheads. The top bulkhead is four plies of 1/8 inch plywood, and the bottom bulkhead is two plies of 1/8 inch plywood. Each ply of the bulkheads was laser cut, and then epoxied together under a vacuum. For more information, see Section 3.4.2. The curing process for the bulkheads is shown in Figure 4.40.

Figure 4.40: Deployment Bay Bulkheads Being Manufactured with Vehicle Bulkheads

Blue Tube

The main body of the deployment bay is a 5.5 inch diameter section of Blue Tube. For manufacturing, the Blue Tube was cut into a 29.3 inch section using a miter saw. For the retention holes, four holes were drilled out in a circular pattern 90 degrees apart from one another. The ridges inside of the Blue Tube was smoothed out by applying a layer of silicon caulk which was then sanded down suing sandpaper. The final deployment bay body tube is shown in Figure 4.41.

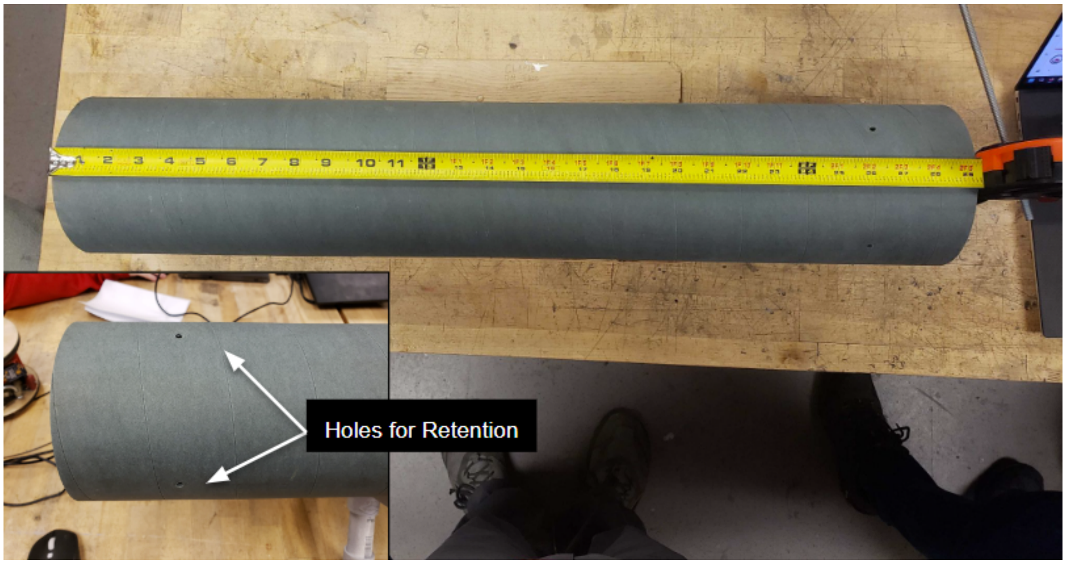

Figure 4.41: Cut Blue Tube with Holes Drilled for Retention

Full Deployment Bay Assembly

Once the two bulkheads were created and the sled was printed, the full assembly of the deployment bay could begin. M3 heat inserts were applied to the electronics sled, where nylon standoffs and nylon screws were used to screw on the breadboard, buck converter, and servo.

On the bottom bulkhead, the four corner brackets with 3D printed attachments, 1.25 inch U-bolt, and four corner brackets to hold the latch were secured using hex screws and hex nuts. To secure the latch to the corner brackets, two screws with hex nuts were put through the attachment slots of the latch, and were secured using a wrench.

For the top bulkhead, the 1.5 inch U-bolt was secured using hex nuts and washers. In order to secured the two bulkheads and sled together, two 5 inch threaded rods were cut using a dremel. These two threaded rods were placed through the top bulkhead, the sled, and then the bottom bulkhead. The two threaded rods were secured in place using four hex nuts and four washers, and tightened with a wrench. The entire electronics bay assembly is shown in Figure 4.42. A better view of the servo setup is shown in Figure 4.43.

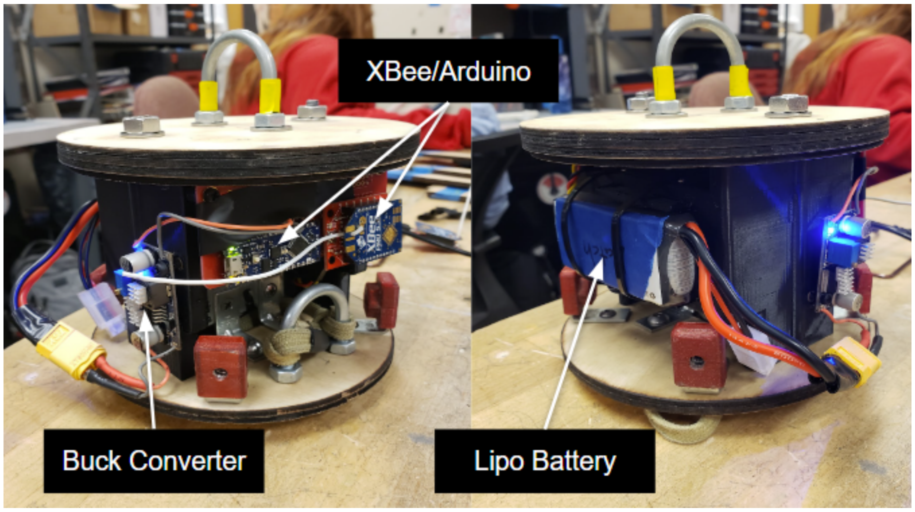

Figure 4.42: Deployment Bay Electronics

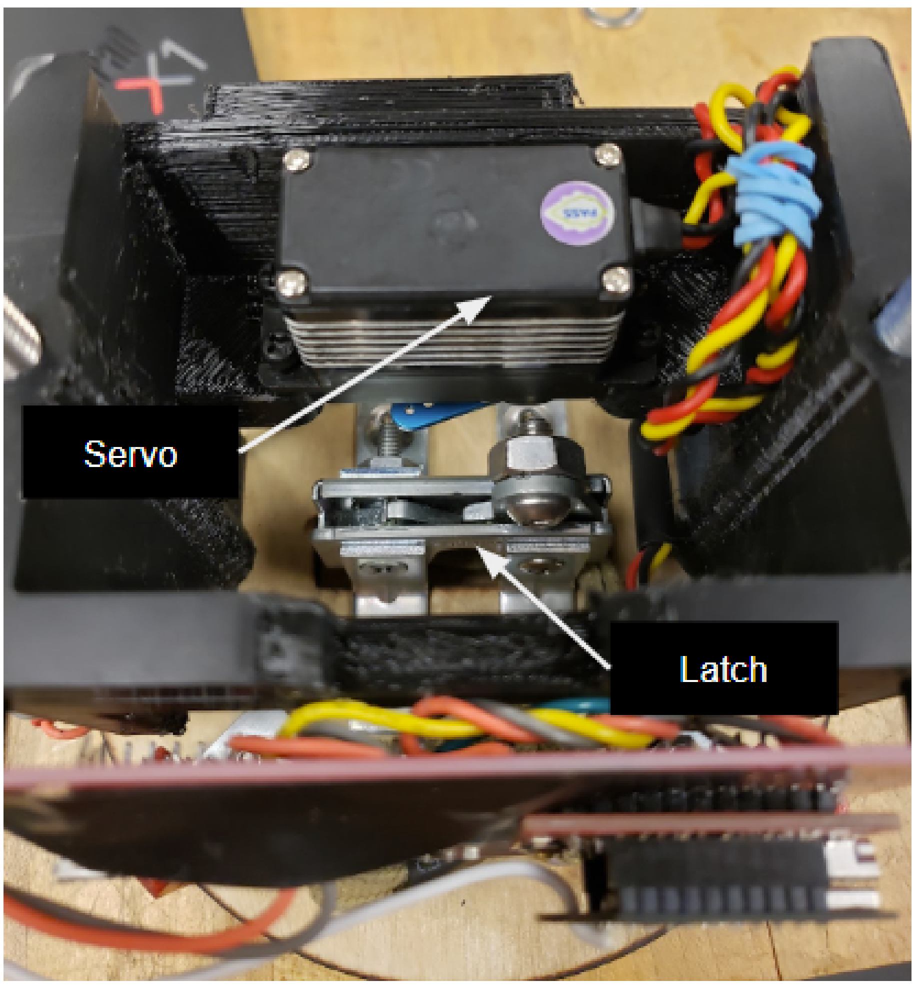

Figure 4.43: Deployment Bay Latch and Servo Setup

Once the electronics bay is assembled, the SAIL is secured to the latch. This is done by looping a bight of shock cord that is secured to the U-bolt on the inside of the electronics bay through the eye bolt on the SAIL and securing the tip of the bight to the latch. This way the SAIL is secured and the shock cord does not impede the SAIL as it falls out of the deployment bay. This shock cord configuration is shown in Figure 4.44.

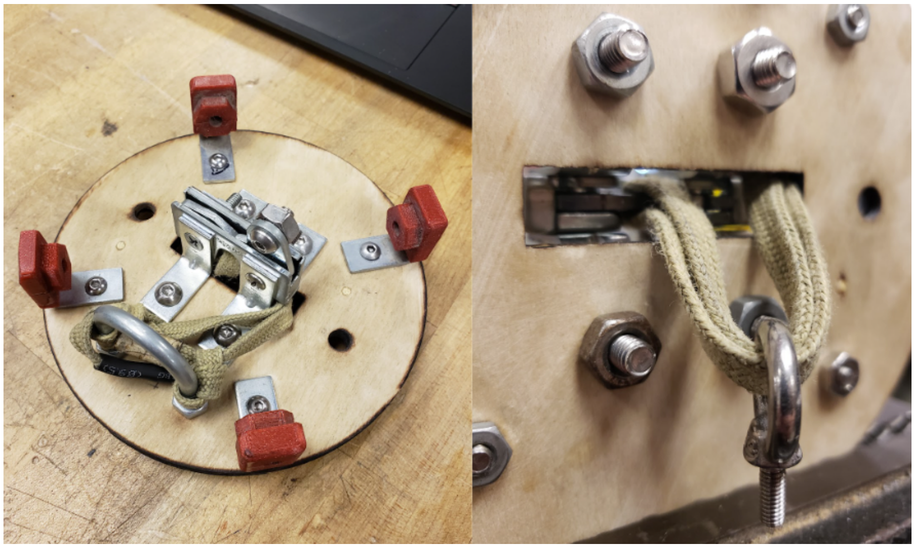

Figure 4.44: Shock Cord Configuration for Securing SAIL in Deployment Bay

The electronics bay with the SAIL attached is then lowered into the deployment bay. The electronics bay is secured to the Blue Tube using four screws and a 3/16 inch Allen key. The screws are placed in the holes of the Blue Tube and are screwed into the corner brackets lining the perimeter of the lower bulkhead. Once the bay is secured, it is ready to be integrated into the launch vehicle. The fully assembled deployment bay is shown in Figure 4.45.

Figure 4.45: Full Deployment Bay with Electronics Housing Secured

5 Safety and Procedures

5.1 Safety Officer

Megan Rink is the 2023-2024 Safety Officer. Megan is responsible for ensuring the safe operation of lab tools and materials, including, but not limited to, drill presses, hand tools, band saws, power tools, flammable items, and hazardous materials. She is required to attend all launches and must be present during the construction of the launch vehicle, payload, and associated components. She is responsible for maintaining all lab equipment and the lab space to NASA, MAE, and Environmental Health and Safety standards. This includes, but is not limited to, displaying proper safety information and documentation, maintaining the safe operation of a flame and hazardous materials cabinet, keeping lab inventory, and stocking an appropriate first aid kit. She can be reached via email at mdrink@ncsu.edu.

5.2 Safety and Environment

5.2.1 Hazard Analysis Methods

Safety documentation is performed through FMEA analysis, Likelihood-Severity (LS) matrices, and Fault Tree Analysis (FTA). LS matrices detail each hazard and the corresponding causes, effects, and LS as determined by the matrix. Mitigation methods for each hazard have been analyzed and the LS after mitigation has been determined. Additionally, Fault Tree Analysis has been performed for the payload and recovery subsystems.

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

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

Table 5.1: LS Matrix Key

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

5.2.2 Failure Modes and Effects Analysis (FMEA)

Out of 94 hazards analyzed, none result in failure modes after mitigarion.

Risk Assessment Before Mitigation					
44.681% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	2.123%	2.123%	5.319%	7.447%
	B Unlikely	3.194%	10.638%	10.638%	5.319%
	C Likely	3.194%	5.319%	5.319%	6.383%
	D Very Likely	5.319%	14.894%	11.702%	1.064%

Risk Assessment After Mitigation					
0.00% result in failure modes		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	12.766%	14.894%	9.574%	10.638%
	B Unlikely	5.319%	12.766%	14.894%	0%
	C Likely	7.497%	9.574%	0%	0%
	D Very Likely	2.123%	0%	0%	0%

Figure 5.1: Overall LS Figures

Table 5.2: Launch Vehicle Hazards

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to and from Bulkheads							
S.B.1	U-bolt failure	Excessive deployment force	Ballistic reentry	4A	Distribution of load during construction	4A	Inspection: CDR 3.1.2
S.B.2	Nosecone bulkhead bolt failure			4A	Load management during construction	4A	Inspection: CDR 3.1.2
S.B.3	Cracked bulkhead	Excessive stress on stress points	Bulkhead separates from airframe	3D		3B	Tests and Verification Pending
S.B.4	Bulkhead delamination	Excessive axial stress caused by shock cord connection points		3D		3B	Tests and Verification Pending
S.B.5	Separation of bulkhead from airframe	Epoxy is softened Latch connections cause excessive force	LV stabilization is changed	3D		3B	Tests and Verification Pending
S.B.6	Bulkhead exposure to hot ejection gases	Motor or ejection charges cause excessive heat		3B	Ensure LV is kept in optimal environmental conditions	3A	Tests and Verification Pending
Hazards to and from Removable Fin System							
S.F.1	Bolt failure	Excessive force caused by motor or landing	CATO, loss of stability, potentially repairable damage to LV components	3B	Bolts and rods selected have a high safety factor	3A	Tests and Verification Pending
S.F.2	Fin runners, threaded rods, or fin can buckle		CATO, loss of stability	3B		3A	Tests and Verification Pending
S.F.3	Thrust plate failure		CATO, airframe damage	3A	Material selected during design phase has a high safety factor	2A	Tests and Verification Pending
S.F.4	Fin breakage	Excessive force upon landing or fin flutter	Loss of stability in flight	3B	Reinforcement during construction	1C	Tests and Verification Pending
S.F.5	Delamination of or cracks to centering ring	Excessive force caused by motor	CATO, loss of stability, motor not securely held	3A	Proper construction techniques	1A	Tests and Verification Pending
S.F.6	Motor retainer-airframe connection failure	Epoxy weakened by heat or other factors	Motor descends prematurely and separate from LV	2B	Epoxy selected during design phase is rated for expected temperatures	1A	Tests and Verification Pending

Table 5.2 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to and from Airframe							
S.A.1	Cracks in fin can body tube	Hoop stress caused by internal pressure	CATO, inability to relaunch LV	4A	Propellant grains are properly fastened in the appropriate motor tube, motor construction is overseen by mentors defined in Section 1.1.2	2A	Tests and Verification Pending
S.A.2	Cracks in AV bay body tube	Hoop stress caused by internal pressure	Inadequate force to separate LV sections	3B	Calculations performed to determine necessary amount of black powder, ejection tests performed prior to each flight	3A	Tests and Verification Pending
S.A.3	Zippering of body tube	Shock cord causes excessive forces; Excessively low altitude parachute ejection	Airframe rupture	2B	Fiberglass body tube and appropriately-sized couplers are used per SL Requirements 2.4.1 and 2.4.2	2A	Tests and Verification Pending
S.A.4	High-energy impact with ground	No or late parachute deployment	Airframe rupture	3B	Appropriate recovery system is used to decrease LV descent velocity	3A	Tests and Verification Pending
S.A.5	LV sections collide	Insufficient length of shock cord	Airframe rupture	3B	Appropriate recovery system is used to decrease LV descent velocity	3A	Tests and Verification Pending
S.A.6	Airframe exposed to water	Sudden inclement weather	Airframe disintegration/ rupture	2C	Full scale LV airframe is constructed with fiberglass, subscale LV not constructed in inclement conditions	2B	Tests and Verification Pending
S.A.6	Airframe exposed to water	LV lands in wet area of launch field	CATO	2C	Full scale LV airframe is constructed with fiberglass, subscale LV not constructed in inclement conditions	2B	Tests and Verification Pending
S.A.7	Airframe exposed to black powder	Uncontrolled ejection charges	Airframe disintegration/ rupture	1D	Airframes are constructed with heat-resistent materials	1C	Tests and Verification Pending
S.A.8	Body tube abrasion	High-energy impact with the ground	Changes in LV center of pressure/stability, damage to LV	1C	Appropriate recovery system is used to decrease LV descent velocity	1B	Tests and Verification Pending
S.A.8	Body tube abrasion	Body tube is dragged due to parachute re-inflation	Changes in LV center of pressure/stability, damage to LV	1C	Launches will not occur in high winds	1B	Tests and Verification Pending

Table 5.3: Payload Hazards

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to/from Payload Structure							
PA.S.1	Cracking/breaking of payload	Impact between components of the payload and the inside of LV during launch/separation	Loss of power to payload electronics, loss of communication with payload, payload damage	1D	Payload is secured within the LV to prevent launch/separation forces from causing damage	1C	Verification Pending
PA.S.2	Payload rotor failure	Rotor system does not function properly, payload high-energy impact with ground	Payload is destroyed beyond repair	4C	Payload system is tested before it is dropped from the full required height	4A	Verification Pending
Hazards to/from Payload Electronics							
PA.E.1	Damage to LiPo battery connection/low power	LiPo battery is not fully charged, friction due to contact between cable and housing	Loss of power to payload electronics, loss of communication with payload	3D	Voltage of battery measured prior to flight, all wired connections secured	1A	Verification Pending
PA.E.2	Over-voltaging of electronic components	Voltage from LiPo battery is higher than components can withstand	Electronics are fried and no longer usable	2D	Use of buck converters to regulate voltage into components	1D	Verification Pending
PA.E.3	Wire shortage	Wires are loosely connected and contact each other	Incorrect voltages are passed through the circuit, excessive current flow, possible fire hazard	2D	Wires are properly soldered, all exposed wire is covered in shrink wrap and secured with electrical tape	1D	Verification Pending

Table 5.4: Hazards from Environmental Factors

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to LV Structure							
E.S.1	LV contact with water	LV lands in irrigation ditch, body of water	Structural damage to airframe	4C	LV is made of water-resistant materials	4A	Inspection: CDR 3.1.3
E.S.2	LV collides with birds	Birds fly in close proximity to LV flight path		2B	Flight path confirmed to be clear by RSO ahead of launch	2A	Inspection: Checklist Section Launch Pad, NAR Safety Code #9
E.S.3	LV lands in tree	Large gusts of wind, wind drift	Inability to recover LV	3D	Launches will not occur if wind speed at launch field exceed 20 mph	2C	
Hazards to Personnel							
E.PE.1	Personnel have excessive contact with sunlight and heat	Lack of appropriate PPE, hot launch conditions	Heatstroke, dehydration, sunburn	4B	Personnel are provided with sunscreen and are highly encouraged to bring sunglasses, a tent is set up at the launch field for personnel to take shelter	2B	Inspection: Checklist Section Launch Pad/Recovery
E.PE.2	Personnel slip, trip, or fall	Uneven ground, debris on the ground, working near/next to irrigation ditches	Bruising, broken bones, concussion	4C	Personnel are required to wear closed-toed shoes to all launch day activities, only specific personnel are allowed on the launch field itself	2B	Inspection: Checklist Section Launch Pad/Recovery
E.PE.3	Rain or hail	Inclement weather conditions	Damage to airframe	3C	No launches occur during periods of inclement weather, weather is monitored and launches may be postponed, personnel take shelter as appropriate	3A	Inspection: NAR Safety Code #9
E.PE.4	Lightning strike			1D		1A	Inspection: NAR Safety Code #9
E.PE.5	Wet and/or icy terrain		Personnel slip, trip, or fall	2C		1C	Inspection: Checklist Section Launch Pad/Recovery
E.PE.6	Pollen or other allergens present at launch site	Seasonal allergens, personnel allergic to crops grown at launch field	Potentially severe allergic reactions	3B	Personnel are asked to make the Safety Officer aware of any environmental allergies, antihistamines and other OTC allergy medications are kept in the Launch Day Safety Box	2B	Inspection: Checklist Section Launch Pad/Recovery

Table 5.4 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Payload System							
E.PA.1	Payload contact with water	LV lands in irrigation ditch, body of water	Damage to payload electronics	1C	Mitigation pending	1C	Inspection: CDR 3.1.3
E.PA.2	Lightning strike	Inclement weather conditions	Damage to payload electronics	3C	Launches will not occur in inclement weather, local Tripoli Prefect dictates if launch weekends are postponed	2A	Inspection: NAR Safety Code #9
Hazards to Mission Success							
E.M.1	Damp propellant grains	High humidity	No motor ignition, LV does not fly	1D	Launches will not occur in inclement weather	1B	Inspection: NAR Safety Code #9
E.M.2	Damp black powder grains	High humidity	No motor ignition, LV does not fly	2D	Launches will not occur in inclement weather	1B	Inspection: NAR Safety Code #9
E.M.3	LV flight path blocked by birds	Flight path not clear at launch	LV does not reach intended apogee	2B	RSO confirms LV flight path is clear before launch	2A	Inspection: NAR Safety Code #9
E.M.4	Unauthorized aircraft in designated airspace	Aircraft knowingly ignores restricted airspace designations	Any and all launches suspended until further notice	4A	RSO has contact with local air traffic controllers	1A	RSO is contacted directly by air traffic control

Table 5.5: Hazards to Environmental Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Wildlife							
E.W.1	Launch field catches fire	Motor ignition	Crop damage, harm to wildlife, personnel burns	3D	Areas surrounding launch pad are clear of flammable materials, blast plates are properly fitted to launch rails	3B	Inspection: NAR Safety Code #7
E.W.2		Black powder ignition		2C	Personnel are equipped with a functional fire extinguisher	1C	
E.W.3		Battery explosion		2D	Batteries are isolated from moisture, abrasion, and heat	2B	
E.W.4	Payload battery explosion	Battery is punctured, leading to contact with moisture Excessive heat surrounding battery	Hazmat leakage onto launch field, water contamination, fire on launch field	3D		3B	Inspection: NASA 2.22
E.W.5	LV comes into contact with flying birds	Birds fly in close proximity to LV	Wildlife injury or death, bird migration patterns are obstructed	1C	RSO confirms airways are clear ahead of launch	1A	Inspection: Checklist Section Launch Pad
E.W.6	Nomex permanently jettisons	Rips or tears in Nomex	Contamination of wildlife habitats, food supply, or water supply	2A	Nomex is rated to withstand flight forces, sheets are inspected before launch to ensure no rips or tears are present	1A	Inspection: Checklist Section Main/Drogue Recovery
E.W.7		Breakage in Nomex connection		1A	Nomex sheets are properly connected to shock cord with quick links, Safety Officer verifies proper connections	1A	
E.W.8	Parachute permanently jettisons	Quick link is not properly tightened and secured before parachute is inserted into LV	LV descends at an unsafe speed	1A	Parachutes are properly connected to shock cord with quick links, Safety Officer verifies proper connections	1A	
E.W.9	Hazmat deposit in irrigation ditch	Battery explosion Explosion byproducts	Toxins remain in food crops and could be consumed by humans/wildlife	2B	Any additional protective insulation is biodegradable	2A	Verification Pending
E.W.10	Wildlife consumes hazmats or other toxins	Littering of hazmats	Wildlife develop digestive issues or incur injury or death	3D		3B	

Table 5.5 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
E.W.11	CATO	Motor defects	Water supply is contaminated, wildlife incur injury or death	2D	AeroTech motors are selected for their low likelihood of catastrophic failure and personnel experience with the brand	2C	Verification Pending
E.W.12	LV lands in tree	Premature parachute deployment, wind drift	Destruction of wildlife habitats	4C	Recovery systems are tested and LV is flown away from trees	3B	Verification Pending
E.W.13	Emission of microplastics	Exceptionally high usage of single-use plastics	Wildlife infertility, bodily inflammation, choking/strangling/digestive hazard	4B	Personnel are encouraged to use reusable containers	3B	Inspection: Team Safety Briefing
Hazards to Land							
E.L.1	LV impacts with ground	Late or no deployment of parachute	Permanent ruts left in launch field, inability for soil to be used in future farming endeavors	3A	Recovery system utilizes altimeters to ensure accuracy in parachute deployment	2A	Verification Pending
E.L.2	Non-recoverable landing in tree	Premature parachute deployment, wind drift	Permanent tree damage	4C	Launch pads are placed far from trees or other hazards	4A	Verification Pending
E.L.3	Launch field catches fire	CATO, motor ignition, black powder detonation, battery explosion	Trees and crops destroyed, inability for land to be used in future farming endeavors	2D	Areas surrounding launch pad is clear of flammable materials, blast plates are properly fitted to launch rails	2B	Inspection: NAR Safety Code #3
Hazards to Air/Water							
E.A.1	Emission of greenhouse gases	Transportation to/from launch field, byproducts from motor and black powder ignition, use of power-drawing electronics	Air pollution, further contribution to climate change	4A	Personnel are encouraged to carpool, take public transportation, or walk to any club activities	4A	Inspection: Safety Briefing Slides
E.A.2	Emission of microplastics	Exceptionally high usage of single-use plastics	Pollution of air and water	4A	Use of single use plastics is limited in LV design	4A	Verification Pending

Table 5.5 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
E.A.3	Chemical off-gassing	Working with hazmats	Air pollution	1B	Hazmats that off-gas are used in well-ventilated areas with proper PPE	1A	Inspection: HPRC Safety Handbook
E.A.4	Emission of smoke	CATO	Air pollution	2B	AeroTech motors are selected for their low likelihood of catastrophic failure and personnel experience with the brand	2A	Inspection: PDR 3.2.9
E.A.5	Emission of smoke	Motor ignition	Air pollution	2B	LV operation produces few combustion byproducts in nominal conditions	2A	Verification Pending
E.A.6	Emission of smoke	Black powder detonation	Air pollution	2B	LV operation produces few combustion byproducts in nominal conditions	1A	Inspection: NAR Safety Code #3
E.A.7	Emission of smoke	Man-made wildfire	Air pollution	2D	Heat sources are not allowed within 25 feet of LV motors	2B	Inspection: Aerotech Motors Safety Data Sheet

Table 5.6: Hazards to Personnel Safety

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Skin and Soft Tissue							
PE.S.1	Slips, trips, falls	Material spills	Skin abrasion or bruising	3B	Lab floors are inspected for spills after handling assembly materials	1B	Inspection: HPRC Safety Handbook, Checklist Section Field Recovery
		Wet or uneven launch field conditions			Only authorized personnel recover LV, recovery personnel are required to wear treaded closed-toe shoes		
PE.S.2	Appendage caught in bandsaw	Improper operation of bandsaw	Skin or muscle tear/abrasion	2D	Personnel are trained how to properly handle manufacturing tools, appropriate PPE is always used	2C	Inspection: HPRC Safety Handbook
		Jewelry or clothing caught in bandsaw blade					
PE.S.3	Skin comes into contact with hot soldering iron	Personnel negligence	Mild to severe burns	3C		3B	Inspection: Checklist Section Launch Pad
PE.S.4	LV collides with personnel	Launch rail tips with assembled LV	Skin or muscle tear/abrasion	2C	Launch rails are provided by TRA/NAR, launch rails have a locking mechanism that is engaged when LV is righted	2B	Inspection: Checklist Section Night Before Checklist
PE.S.5		Severe instability causes sideways propulsion		2B	The stability of LV is no less than 2.0	1B	Inspection: NASA 2.14
PE.S.6		LV lands within close proximity to personnel		1B	The LV is angled away from any personnel or spectators	1A	Inspection: NAR Safety Code
PE.S.7	Personnel muscles placed under high load	Heavy LV components	Muscle strain or tear	4C	At least two personnel carry the assembled LV, proper lifting techniques are always used	4A	Inspection: Checklist Section Launch Pad
PE.S.8	Insect sting/bite	Prolonged exposure to wildlife during launch day activities	Itchiness, rash, and/or anaphylaxis	4A	Bug spray is provided to personnel, personnel have knowledge on appropriate use of EpiPens	3A	Inspection: Checklist Section Launch Pad
PE.S.9	Personnel come into contact with black powder charges	Contact with unblown charges during recovery	Mild to severe burns or abrasions	3C	Personnel recovering the LV are provided with heavy duty gloves, LV sections are inspected for unblown charges before handling	3B	Inspection: Checklist Section Final Measurements

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
PE.S.10	Contact with large, airborne shrapnel	CATO	Severe skin abrasion or laceration	2D	Personnel are separated from the launch pad according to the minimum distance table, AeroTech motors are selected for their low likelihood of failure	2B	Inspection: NAR Safety Code
PE.S.11	Contact with small, airborne shrapnel	Sanding, cutting, drilling brittle or granular materials	Cuts or bruises	3C	Appropriate PPE is provided for personnel working with power tools	2C	Inspection: HPRC PPE Cabinet
PE.S.12	Exposure to uncured epoxy	Working with epoxy	Skin rash/irritation	3A	Appropriate PPE is provided for personnel working with hazardous materials	2A	
PE.S.13	Exposure to vaporous chemicals	Hazmat off-gassing		2A		2A	
PE.S.14	Excessive amount of walking	LV lands far from recovery personnel	Muscle strain, shin splints	3A	LV is equipped with a GPS, personnel wear shoes appropriate for walking large distances	2A	Inspection: Checklist Section Field Recovery
Hazards to Bones and Joints							
PE.B.1	Slips, trips, falls	Material spills, wet or uneven field conditions	Bone fracture/bruise, joint dislocation	1D	Lab floors are inspected for spills after handling assembly materials, only authorized personnel recover LV, recovery personnel are required to wear treaded closed-toe shoes	1C	Inspection: Checklist Section Field Recovery
PE.B.2	Excessive amount of walking	LV lands far from recovery personnel	Stress fracture	2D	LV is equipped with a GPS, personnel wear shoes appropriate for walking large distances	2C	Inspection: Checklist Section Field Recovery
PE.B.3	Appendage caught in bandsaw blade	Improper operation of bandsaw	Broken bone	2D	Personnel are trained how to properly handle manufacturing tools, appropriate PPE is always used	2C	Inspection: HPRC Safety Handbook
		Jewelry or clothing caught in bandsaw blade				2C	
PE.B.4	Contact with large, airborne shrapnel	CATO	Bone fracture/break/loss requiring immediate medical attention	2D	Personnel are separated from the launch pad according to the minimum distance table, AeroTech motors are selected for their low likelihood of failure	2C	Inspection: NAR Safety Code, RSO instruction

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards to Respiratory System							
PE.R.1	Inhalation of carcinogenic particles	Working with filet epoxy	Respiratory infection and/or irritation, cancer	4D	Personnel working with fillet epoxy are provided with appropriate PPE	3B	Inspection: HPRC PPE Cabinet
PE.R.2	Inhalation of epoxy fumes	Working with epoxy	Respiratory irritation, difficulty breathing	2C	Personnel working with epoxy are provided with appropriate PPE, an oxygen sensor is triggered if there is insufficient oxygen in the lab	2B	Inspection: HPRC PPE Cabinet
PE.R.3	Inhalation of aerosolized particles	Sanding, cutting, drilling brittle or granular materials	Respiratory irritation, difficulty breathing	4B	Personnel are provided with appropriate PPE, including particle masks	4A	Inspection: HPRC PPE Cabinet
PE.R.4	Inhalation of paint fumes	Use of spray paint for LV aesthetics	Respiratory irritation, difficulty breathing	4B	Personnel are provided with appropriate PPE, including particle masks	4A	Inspection: HPRC PPE Cabinet
PE.R.5	Inhalation of combustion reactants	Personnel are in close proximity to ejection charges	Respiratory irritation, difficulty breathing	3B	Personnel are provided with appropriate PPE, including particle masks	3A	Inspection: NAR Safety Code, RSO instruction
Hazards to Head							
PE.H.1	High energy LV components come into contact with personnel	High energy LV components are in proximity to personnel during descent	Concussion, brain damage, memory loss, skull fracture	2D	Personnel are separated from the launch pad according to the minimum distance table, the LV recovery system is dual-redundant	2C	Inspection: NAR Safety Code
PE.H.2	LV tips during assembly	Launch rail is improperly assembled	Concussion, brain damage, memory loss, skull fracture	3D	Launch rails are provided by TRA/NAR, launch rails have a locking mechanism that is engaged when LV is righted	3B	Inspection: Checklist Section Launch Pad
PE.H.3	Slips, trips, falls	Attempting to jump over irrigation ditches at launch field	Concussion, brain damage, memory loss, skull fracture	3D	Personnel are made aware that jumping over ditches is forbidden	3B	Inspection: Checklist Section Field Recovery
PE.H.4	Contact with large, airborne shrapnel	CATO	Concussion, brain damage, memory loss, skull fracture	2D	Personnel are separated from the launch pad according to the minimum distance table	2B	Inspection: NAR Safety Code
Hazards to Eyes							
PE.E.1	Exposure to epoxy fumes	Working with epoxy	Eye irritation, temporary blindness, permanent or semi-permanent blindness	3D	Personnel are provided with appropriate PPE	3B	Inspection: HPRC PPE Cabinet
PE.E.2	Exposure to aerosolized particles	Working with spray paint, sanding, cutting, drilling	Eye irritation, temporary blindness, permanent or semi-permanent blindness	2D	Personnel are provided with appropriate PPE	2B	Inspection: HPRC PPE Cabinet
PE.E.3	Extended exposure to the sun	Maintained eye contact with descending LVs	Temporary or permanent blindness	1B	Personnel maintaining eyes with descending launch vehicles are encouraged to wear sunglasses or other forms of eye protection	1A	Inspection: Checklist Section Field Recovery

Table 5.6 continued from previous page

Label	Hazard	Cause	Effect	LS Before	Mitigation	LS After	Verification
Hazards from Payload							
PE.P.1	Personnel contact spinning rotor blades while payload is powered on	LV is released above personnel, recovery personnel approaches payload	Personnel injury to head, skin, bones, or soft tissue	4B	Payload is not released above or near crowds, payload is confirmed to be powered down before recovery personnel approach	2A	RSO permission to deploy payload required on launch day

5.2.3 Environmental Safety

Located in a humid subtropical climate, the Bayboro, NC launch site includes farmland, pine flat, and wetland habitats. Biological resources include terrestrial vegetation and wildlife. Major threats to native vegetative communities include invasive non-native species, wildfire, and human development. The variety of habitats provides for a wide diversity of terrestrial species. The team, in tandem with the local TRA Prefecture, works to ensure there is minimal impact to the natural environment at our launch site. All persons launching in Bayboro, NC are asked to keep the site clean from trash and debris, to avoid the use of motor vehicles to aid in recovery, and to avoid the use of sparky motors, all to keep the farmland viable for future growing seasons.

A safe environment is one in which there is no, or optimally reduced, potential for death, serious bodily injury, illness, or property damage. Various stressors in the environment can adversely affect human health and safety. Identification and control or elimination of these stressors can reduce risks to health and safety to acceptable levels or eliminate risk entirely. Emergency services are organizations that ensure public safety and health by addressing different emergencies. The three main emergency service functions include police, fire and rescue service, and emergency medical service.

5.2.4 Fault Tree Analysis

Fault Tree Analysis has been performed for the payload and recovery subsystems as these are the systems that change the most from year to year and contain the most potential risk. Analyzing these systems through the lens of an undesired state allows the team leads to identify and further mitigate any failure modes within these systems.

5.3 Launch Procedures

5.3.1 Changes to Launch Procedure

Due to a CATO caused by a manufacturing defect in the motor grain during the 2022-23 competition year, there have been several changes to the team's launch and safety procedures for this competition year.

Prior to the CATO in March 2023, the team leads consulted with the RSO and received approval to fly despite a crack in the motor grain caused by a manufacturing defect. In subsequent launches, the team has diligently inspected the motor grains and other motor hardware ahead of installation and launch. The standard for the size of acceptable motor grain cracks has changed to reflect this incident and to prevent any similar occurrences from happening in the future.

Changes have also been made to our procedures for handling and disposing of separation charges. Following the CATO, there were several un-detonated separation charges that posed a significant safety risk to personnel and bystanders as the altimeter electronics could not be switched off. Subsequently, there is now a section in every pre-launch safety brief informing all personnel about these risks and the proper course of action in the event there are un-detonated charges either before or after launch.

5.3.2 Checklist and Launch Procedure

During all demonstration launches, an assembly checklist will be utilized to ensure the proper, timely, and safe assembly of the launch vehicle. The full checklist used for the assembly, launch, and recovery of the full-scale launch vehicle on February 24th, 2024 can be viewed in Appendix A. The checklist includes items that require completion the night before launch (e.g. E-match installation, loading charges) and the launch day assembly items to be completed on the field prior to launch (e.g. AV bay assembly, recovery system assembly, payload assembly). Each step was appropriately checked off upon completion and important assembly items were verified with the designated safety officer and/or the team lead. This checklist will be modified to include steps for payload assembly for the PDF.

6 Demonstration Flights

6.1 Vehicle Demonstration Flight

The vehicle demonstration flight was conducted on February 24th, 2024 in Bayboro, NC. This flight was the first launch of the fully-configured full-scale launch vehicle. The payload demonstration flight was not completed during this launch due to delays with payload construction, but the launch vehicle did fly with all payload deployment electronics and a payload mass simulator. The payload mass simulator was released via command during descent between 700 and 400 feet under its own parachute to simulate the deployment of the fully-configured payload. Table 6.1.1 provides a summary of the launch day conditions and the launch vehicle information.

Figure 6.1: Full-scale launch vehicle on the launch pad and ready for takeoff.

6.1.1 Launch Day Details

Launch Day Data	
Attribute	**Details**
Date	2/24/24
Time	1:43 pm EST
Location	Paul Farm, Bayboro, NC
Temperature (F)	60
Pressure (in Hg)	29.96
Humidity (%)	39
Wind (mph)	10
Motor	AeroTech L1940X-PS
Ballast (lb)	2.6
Payload	Deployment electronics, mass simulator
Airbrakes	No
Target Altitude (ft)	4050
Predicted Altitude (ft)	3968
Measured Altitude (ft)	4204

The team launched at Paul Farm in Bayboro, NC. This launch field is a corn field used by the Eastern NC TRA chapter in the off season (October-April) and comprises roughly 6.5 miles of crop field divided by irrigation ditches. The irrigation ditches as well as the tilled ground littered with dead cornstalks creates a challenging field to traverse during the recovery segment of the team's launch days. Safety measures have been put into place to prevent injury for the recovery team (See Secton 5.2). The irrigation ditches also pose a danger to the launch vehicle itself. Incidents in the team's past have included losing blue tube rocket sections to irrigation ditches after a day's rain as well as payload electronics. Therefore, the team tends to construct full-scale vehicles out of fiberglass to prevent airframe water damage.

On February 24th, 2024, the launch field was slightly muddy due to rain the day before. The skies were partly cloudy and winds varied from 8 to 10 mph with gusts up to 20 mph throughout the day.

6.1.2 Predicted Altitude

To predict the altitude of the launch vehicle, the NOAA Global Forecast System (GFS) weather forecast data was imported into RocketPy. The expected atmospheric conditions have been provided in Figure 6.2

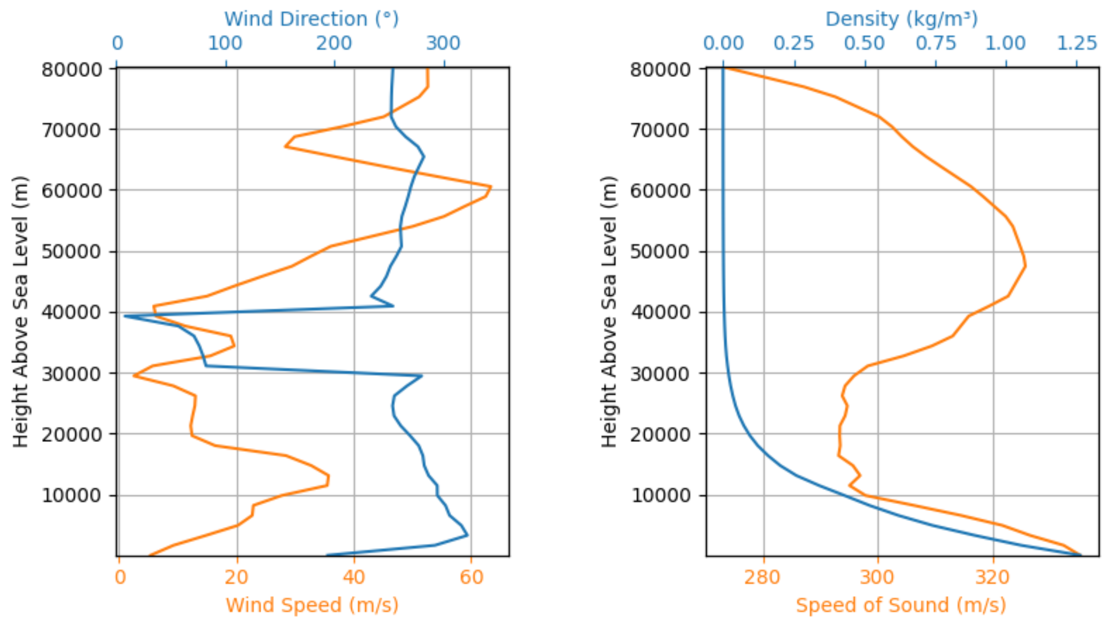

Figure 6.2: Forcasted atmospheric Profile for VDF.

Using these atmospheric conditions, a simulation was run within RocketPy for this launch using the launch vehicle's most up-to-date center of gravity location. From this simulation, the predicted apogee in the fully ballasted configuration was 3968 ft. AGL. Figure 6.3 shows the predicted ascent profile generated with RocketPy for the VDF flight and Figure 6.4 shows the predicted velocity and acceleration profiles.

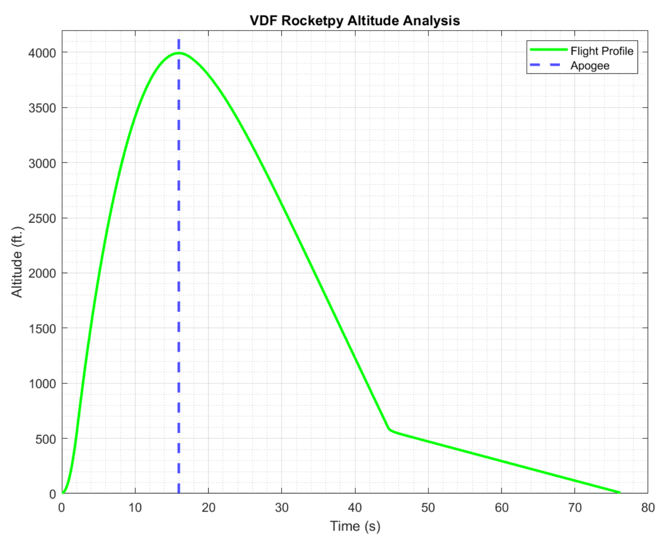

Figure 6.3: Predicted ascent profile of the VDF flight.

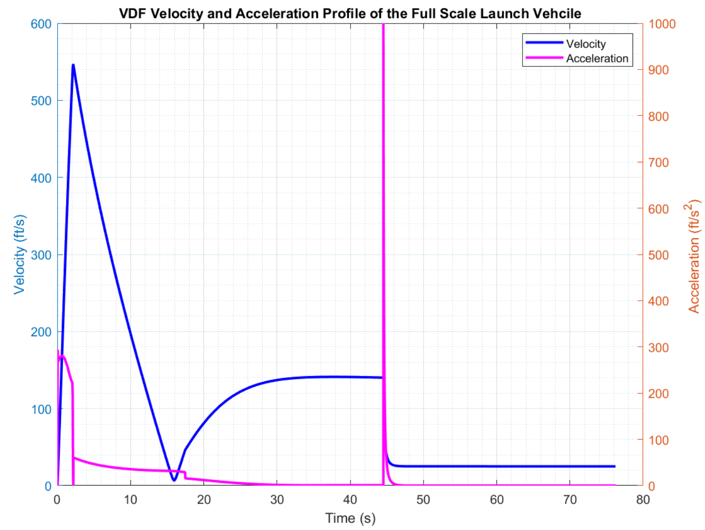

Figure 6.4: Predcted velocity and acceleration profile of the VDF Flight.

A Monte Carlo analysis was also conducted to simulate the apogee and landing locations in space. The results of this simulation have been provided.

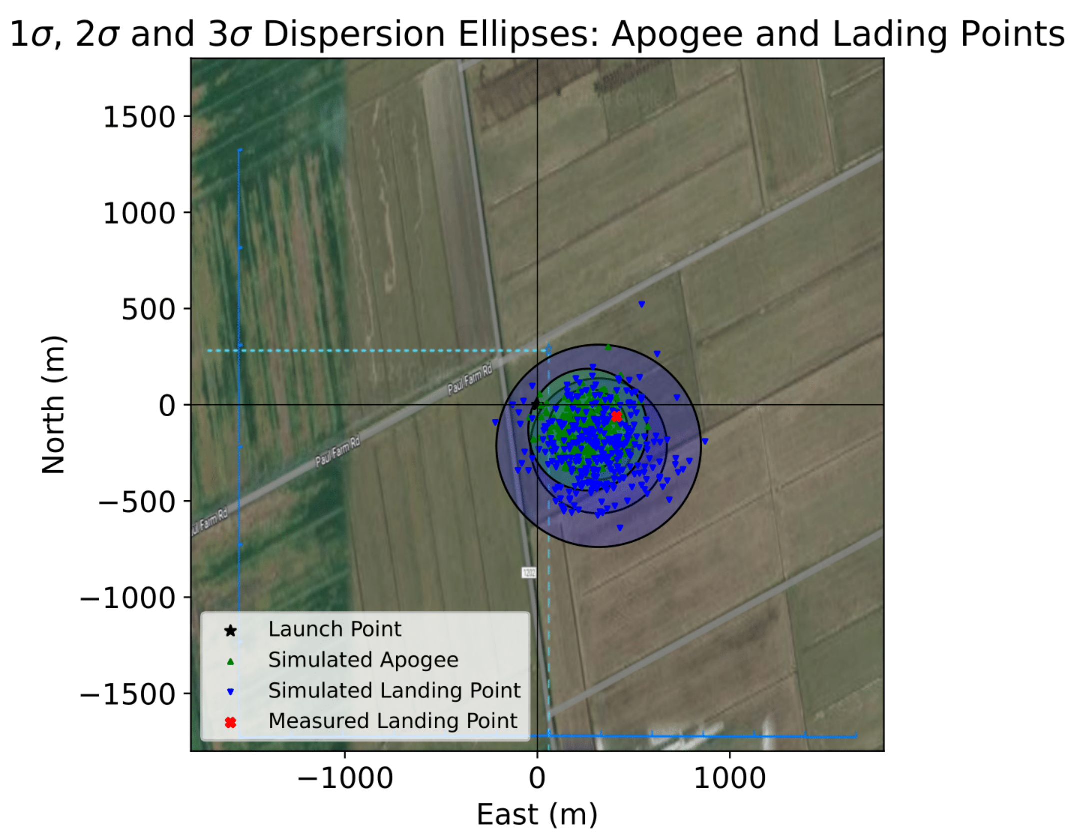

Figure 6.5: Monte Carlo dispersion Analysis of the launch vehicles apogee and landing points.

6.1.3 Flight Results

The first flight of the full-scale launch vehicle went perfectly. Despite the higher winds of the day, there was no visible weather cocking. The primary altimeter, responsible for reporting competition altitude, measured an apogee of 4204 ft.

Recovery

Drogue separation occurred at apogee nominally, allowing the launch vehicle to descend under drogue parachute. At 800 ft, the main primary ejection charge occurred, separating the nose cone as intended. The nose cone pulled out the sail deployment bay, and the nose cone parachute popped. Once the nose cone completely separated, the deployment bag was pulled off of the main parachute, and the main parachute deployed for the launch vehicle. The launch vehicle descended under its main parachute until landing. The nose cone descended under its parachute, where the payload mass simulator was dropped from the deployment bay at approximately 400 ft via the latch (see Section 4.4.3. Note that instead of dropping the SAIL as it was still being manufactured, the team used a mass simulator of similar size via blue tube and weights. Two bulkheads were sandwiching the payload mass simulator, and a 42” parachute was attached to the U-bolt on the top bulkhead of the mass simulator. Once the mass simulator was dropped at 400 ft, the parachute popped, allowing the mass simulator to descend safely. The nose cone continued to descend under its parachute with the payload deployment bay until touch down. Shown below is an image of all the separated sections after main deployment, and the payload mass simulator has been ejected at 400 ft.

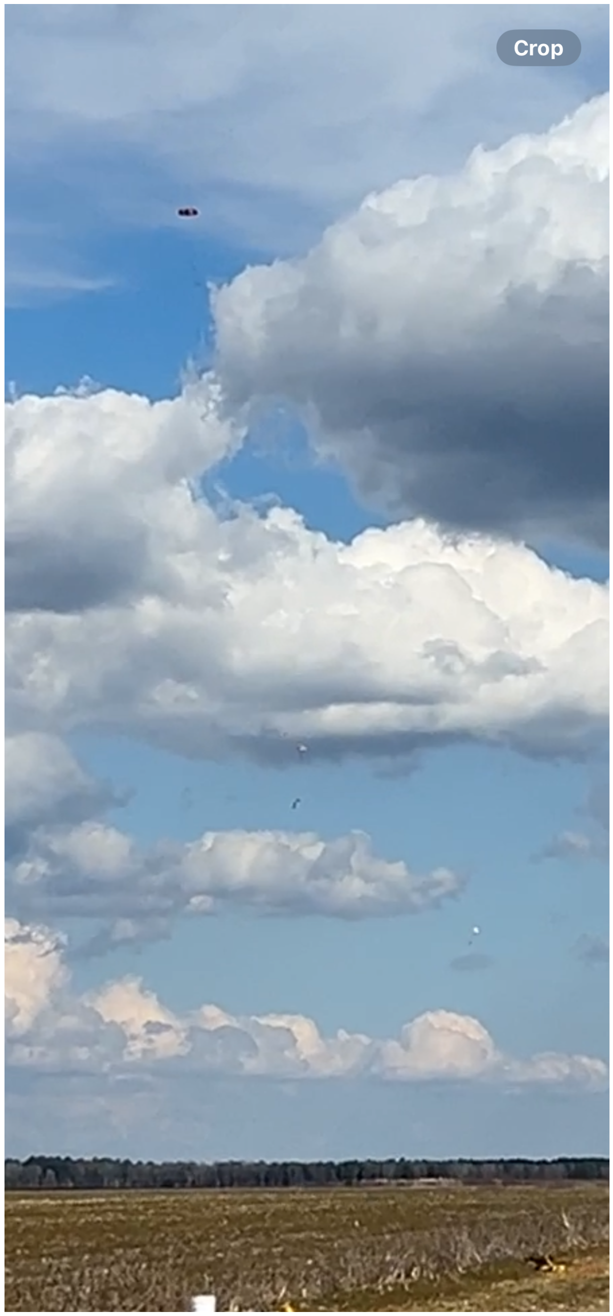

Figure 6.6: Descent After Main Ejection

The image obtained from launch of the recovery events was not very high in quality, so the events are hard to discern from it. See Section 3.5.6 for an image of the designed drogue recovery. In Figure 6.6, you can see the launch vehicle under main parachute in the top left (larger black dot), the nose cone under its parachute with the tethered sail deployment bay in the middle (white dot), and the payload mass simulator falling under its parachute at the bottom right (lower white dot). Note that drogue recovery, main recovery, nose cone recovery, and payload recovery all worked nominally during descent. The team will obtain better images of all recovery events for PDR.

The launch vehicle had no major damage upon landing, despite the fin-can landing in an irrigation ditch and getting filled with mud and water. Due to the high winds, the main parachute was still deployed at landing, and it dragged the fin-can and main parachute bay across the launch field a little bit, dragging it through the irrigation ditch and getting stuck. After successful recovery, the vehicle was checked for interior damage and signs that the black powder charges completely detonated. No interior damage was found, and all charges detonated as intended. All recovery harnesses were not tangled during deployment, descent, or landing. No parachutes were damaged from black powder ejection charges. Once again, the only minor issue was the main parachute dragging the launch vehicle across the field. Overall, it was a very successful recovery with no real damage, as all recovery components functioned as intended. Shown below are images of the separated components as they landed. Note that the launch vehicle is not where it originally landed after descent, as it was dragged across the field until the team could tie the main parachute up.

Figure 6.7: Launch Vehicle Landing while Main Parachute still deployed

Figure 6.8: Launch Vehicle Landing

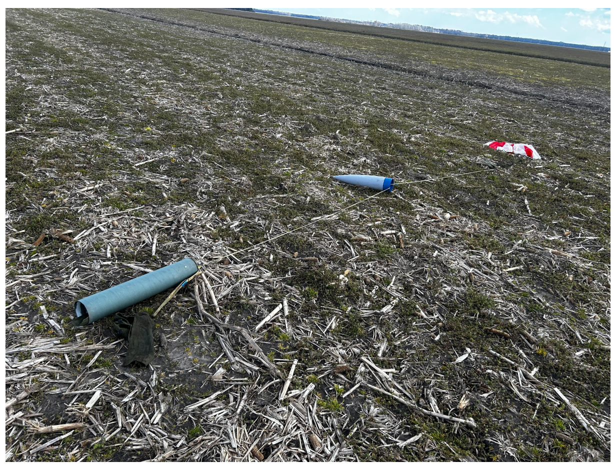

Figure 6.9: Nose Cone Landing

Figure 6.10: Payload Mass Simulator Landing

Altimeter Data

Shown below is the RRC3 primary altimeter data from the VDF flight. An apogee of 4204 ft was recorded by the primary altimeter, but the altitude spiked to 4247 ft at the drogue recovery event, so the peak of the graph is at 4247 ft. Additionally, the altitude does not reach zero feet. When the launch vehicle landed, the main parachute was still deployed and dragged the launch vehicle across the field for a considerable distance. This is concluded to be the reason the data is skewed. As a result, the descent time was obtained from the recorded video of the launch. From the video, the launch vehicle (fin-can and main parachute bay) had a descent time of 76 seconds, and the nose cone had a descent time of 61 seconds. The drogue rate from the altimeter reads 82 ft/s, which is considerably slower than the calculated 112.82 ft/s. This leads to the conclusion that the descent velocity calculations need to be revised such that the drag of the bluff body of the vehicle is accounted for.

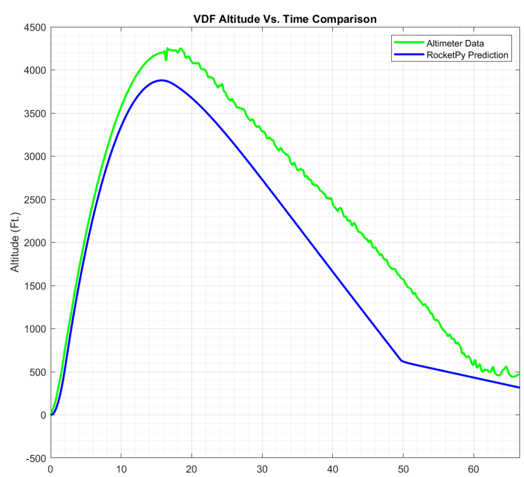

Figure 6.11: Primary Altimeter Altitude vs Time Compared to RocketPy Simulation.

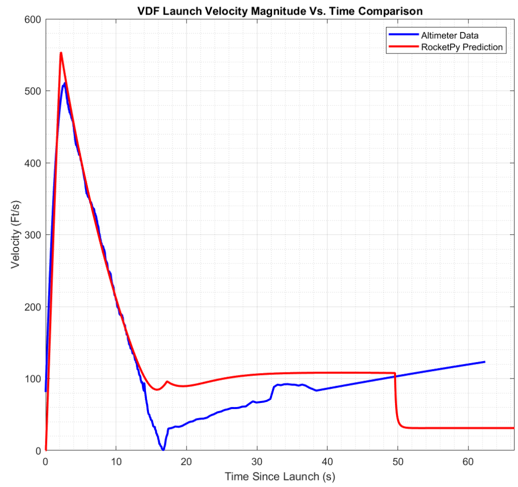

Figure 6.12: Primary Altimeter Velocity vs Time Compared to RocketPy Simulation.

The raw altimeter data from the RRC3 and the Quasar can be viewed in Appendix B and Appendix C respectively.

6.1.4 Subscale Comparison

The launch vehicle recovery mirrored the results of subscale with the payload deployment system operating as expected. The payload mass simulator, with a better mass distribution compared to subscale, improved the confidence in the full-scale's stability margin when loaded with the operational payload. The aerodynamic simulations functioned as intended, but with a larger discrepancy in predicted versus flown apogee, which is being investigated for testing during VDF. Overall, all success criteria for the launch vehicle were met, proving the design, construction, and analysis methodology.

6.1.5 Lessons Learned

This launch was the second run-through of the full-scale checklist and some steps were either incorrect, lacked necessary detail, or were skipped entirely. These inconsistencies in the checklist procedure were noted and will be fixed for the payload demonstration flight on March 23rd, 2024.

The wind conditions of launch day and the size of the launch vehicle's main parachute caused the main and fin can sections of the launch vehicle to be dragged significantly further from its initial landing location. The final landing conditions in this report have been reported from the location to which the launch vehicle was dragged to. During future launches, the approximate initial landing location will be noted and the recovery team will act swiftly to foul the main parachute to prevent the sections from dragging further.

Figure 6.13: Damaged payload mass simulator.

The only thing that received any amount of damage was the payload mass simulator. As seen in Figure 6.13, the forward bulkhead was pushed inward due to the forces it experienced during launch. It is uncertain whether the force of launch or the force of main deployment is what caused this damage, or if it was damaged upon landing, but both the forward and aft mass simulator bulkheads will be rebuilt and reinforced to prevent structural failure from happening again.

The measured apogee from the VDF flight experienced significant deviation from the expected value, which was not seen during the subscle flight. Due to the validated drag profile of the exterior contour of the launch vehicle, along with the wind speeds during the launch, the deviation from the predicted value is thought to have come from the lack of specification of the launch rail orientation at the Bayboro launch field. Depending on the direction of a launch rail cant, the apogee can vary greatly, as shown in Figure 6.14 below.

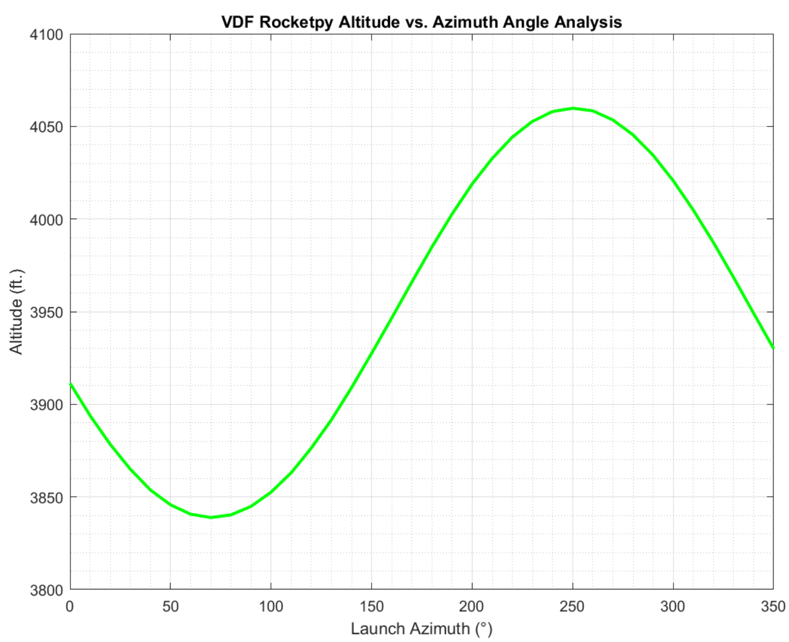

Figure 6.14: Predicted apogee vs. azimuth angle for VDF.

6.1.6 Plan of Action

The full-scale launch vehicle will fly once more before the final competition launch for the payload demonstration flight on March 23rd, 2024. Between the submission of this document and March 23rd, 2024, the payload will be complete and fully tested to determine its flight-worthiness. The full-scale checklist will be edited to streamline the launch day assembly process and an more steps will be added to describe the assembly and integration of the payload device.

New bulkheads of a thicker ply will be constructed for the mass simulator in case it needs to be reused in future launches of the full-scale launch vehicle.

The launch rail's orientation will be measured and specified in simulations before the addition of ballast for the PDF in March and the difference between measured and predicted apogee will be observed to verify the cause of the discrepancy from VDF.

6.2 Payload Demonstration Flight

The payload demonstration flight was not completed in tandem with the vehicle demonstration flight due to delays in payload construction therefore the payload demonstration flight will take place on the backup date, March 23rd, 2024. The launch plan remains the same from the VDF. The team will perform another ejection test prior to the PDF to ensure that the charges are sufficient for separation with the space that the payload device will take up in the bay. After all payload tests and ejection tests are complete and deemed successful, the team will travel to Paul Farm, Bayboro, NC to complete the PDF. The results from the PDF will be available in the FRR Addendum as will the results of any incomplete payload verification tests.

7 Project Plan

7.1 Launch Vehicle Testing

Table 7.1 summarizes all launch vehicle verification tests, the requirement(s) each test verifies, and the required facilities and personnel for the completion of the tests. The test schedule for all of the launch vehicle and payload tests can be viewed in Figure 7.20. All 11 launch vehicle verification tests have been complete.

Table 7.1: Launch Vehicle Tests

Test	Requirement(s) Verified	Required Facilities	Required Personnel	Complete? (Y/N)
Subscale Ejection Test	NASA SL Req. 3.2, RF 5	Flat Outdoor Area	Recovery Lead, Team Lead, Safety Officer	Yes
Subscale Demonstration Flight	NASA SL Req. 2.18	FAA Approved Launch Field	Team Lead, Safety Officer	Yes
GPS Operational Test	RF 4	Mode of Transportation	Recovery Lead	Yes
Altimeter Testing	RF 3	Vacuum Container	Recovery Lead	Yes
G10 Fin Durability Test	LVF 4	HPRC Lab	Structures Lead	Yes
Rivet Shear Loading Test	LVF 5	Universal Testing Machine	Structures Lead	Yes
Shear Pin Shear Loading Test	LVF 6	Universal Testing Machine	Structures Lead	Yes
Nose Cone Bulkhead Tensile Test	LVD 3	Universal Testing Machine	Structures Lead	Yes
AV Bay Bulkhead Tensile Test	LVD 3	Universal Testing Machine	Structures Lead	Yes
Full-scale Ejection Testing	NASA SL Req. 3.2, RF 5	Flat Outdoor Area	Recovery Lead, Team Lead, Safety Officer	Yes
Vehicle Demonstration Flight	NASA SL Req. 2.19.1	NAR/Tripoli Sanctioned Launch Field	Team Lead, Safety Officer	Yes

7.1.1 Subscale Ejection Test

Ejection testing ensures that the black powder charges calculated are sufficient in separating the appropriate sections of the fully assembled subscale launch vehicle for parachute deployment and ensures a safe and successful recovery during launch. The subscale ejection test verifies NASA SL Requirement 3.2 and Team Derived Requirement RF 5. This test was completed on November 14th, 2023. Table 7.2 below defines the success criteria for this test.

Table 7.2: Subscale Ejection Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Complete and vigorous separation of AV bay and drogue parachute bay/fin can	Yes
Complete and vigorous separation of nose cone and main parachute/payload bay	Yes
No damage to launch vehicle	Yes
No damage to recovery materials and hardware	Yes

Controllable Variables

- Ejection charge size

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- All launch vehicle assembly tools identified in the launch procedure (Section 5.3)
- Subscale launch vehicle, fully assembled
- Safety glasses
- Fireproof gloves
- Fire extinguisher
- Ejection testing wires with battery clip attached
- Charged 9V battery

Procedure

The field assembly checklist is used to assemble to launch vehicle in its launch day configuration (See Section 5.3). The items below are required changes to the launch procedure to conduct this test.

- The AV sled and recovery electronics are not placed in the AV bay.
- Only the primary blast caps are filled with black powder.
- The E-match wires are not cut, but are instead threaded through the pin switch hole

After the launch vehicle has been assembled, the steps below are followed.

1. The launch vehicle is placed horizontally on a piece of foam outdoors. Ensure that forward and aft ends of the vehicle are at least 3 feet away from walls or obstructions and that the vehicle is laying as flat as possible on the foam.
2. Any walls directly in front of or behind the vehicle are protected with another piece of foam.
3. All team members retreat to a safe distance of at least 10 feet away from the sides of the launch vehicle.
4. Ensure battery is not connected to battery clip.
5. One designated team member, equipped with safety glasses and fireproof gloves, approaches the launch vehicle to secure the ejection testing wires to the wires labeled ”drogue” on the exterior of the vehicle.
6. The team member retreats to a safe distance.
7. Ensure that everyone is wearing safety glasses and that no one is standing behind or in front of the launch vehicle.
8. The team member conducts a verbal countdown.
9. The team member connects a 9V battery to the connector, detonating the drogue ejection charge.
10. The team member and safety officer approach the vehicle, and, with fireproof gloves on, ensure adequate separation of the sections and dumb out the contents of each section. Put out any sparks and check the source of any smoke.

11. Repeat Steps 4-10 with the ejection testing wires secured to the wires labeled ”main.”

Results

After the third ejection test, adequate separation of the drogue and main charges was achieved. The primary drogue charge was determined to be 1.5 grams with 4 sheer pins connecting the sections and primary main charge was determined to be 2.75 grams with 2 sheer pins connecting the sections. Nose cone and mass simulator were properly propelled from the rest of the launch vehicle.

7.1.2 Subscale Demonstration Flight

The subscale demonstration flight ensures that the launch vehicle's design functions as predicted on a smaller scale. It confirms that the structural integrity, aerodynamic design, and recovery system are successful and do not have to be modified for full-scale application. A successful subscale demonstration flight verifies NASA SL Requirement 2.18. This test was completed on November 18th, 2023. Table 7.3 below defines the success criteria for this test.

Table 7.3: Subscale Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
Launch vehicle departs launch rail and travels vertically until motor burnout	Yes
Main and fin can launch vehicle sections deploy at least one parachute during decent	Yes
Nose cone separates from the rest of launch vehicle	Yes
All launch vehicle sections endure only minimal damage and retain integrity to safely re-launch	Yes

Controllable Variables

- Motor selection
- Ejection charge sizing
- Altimeter selection
- Launch vehicle weight

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled launch vehicle
- All tools and hardware identified in the launch procedure.

Procedure

The subscale launch day procedure is similar to the procedure listed in Section 5.3.2.

Results

All subscale systems worked as expected and the subscale launch vehicle was recovered without damage. An apogee of 1444 ft was predicted and the altimeter measured an apogee of 1439 ft. Upon post-launch inspection, the LED on the nose cone sled was lit green which indicated that the RF signal was received during descent.

7.1.3 GPS Operational Test

The GPS operational test ensures that the GPS is functioning correctly before launch and can successfully locate the launch vehicle after it is launched. This test verifies Team Derived Requirement RF 4. This test was completed on February 12th, 2024. Table 7.4 below defines the success criteria for this test.

Table 7.4: GPS Operational Test Success Criteria

Success Criteria	Achieved (Yes/No)
GPS receiver accurately locates the transmitter within a range of 100 feet	Yes
GPS transmitter and receiver stay active and powered on for at least 1 hour	Yes

Controllable Variables

- Distance
- Location
- Voltage
- Type of Transmitter and Receiver

Required Facilities, Equipment, Tools, and Software

- Eggtimer Quasar GPS Transmitter
- Big Red Bee 900 Transmitter
- Eggfinder LCD Receiver
- Nose Cone Receiver (for BRB900)
- 2 cell LiPo battery
- 1 cell LiPo battery
- 4 AA batteries
- Mode of transportation

Procedure

1. Power on the GPS transmitter and receiver.
2. Ensure the receiver is connected to the transmitter.
3. One person stays in a designated spot with the receiver (still connected to the transmitter).
4. A second person drives to a different location with the transmitter.
5. Once the second person is at the secondary location, the transmitter is used to record their coordinates.

6. The person with the receiver records the coordinates displayed on the receiver from the transmitter.
7. The person with the transmitter repeats steps 4 and 5 at least 3 times while the person with the receiver stays in the same location.
8. Once complete, the person with the receiver and the person with the transmitter will compare the two sets of coordinates.
9. After the experiment, the GPS transmitter and receiver will stay on until one of the batteries runs out.
10. Record the time it takes for one of the batteries to run out.

Results

There were two trackers tested for the launch vehicle, the BRB900 and the Eggtimer Quasar. The locations used for the testing were various spots around NC State's campus to get different coordinates. One thing to note, the BRB900, while it still transmitted coordinates, did not transmit coordinates within 100 ft. of the actual location. This is believed to be due to the fact that this tracker is recycled from previous years. However, Table 7.5 compares the two sets of coordinates for the Quasar and the difference between them.

Table 7.5: GPS Operational Results

Location	Transmitted	Range
35.77128, 78.67399	35.77116, -78.67375	79.728 ft.
35.77236, 78.67759	35.77240, -78.67755	19.008 ft.
35.77343, 78.67368	35.77346, 78.67370	12.672 ft.

7.1.4 Altimeter Testing

The altimeter test ensures that both primary and secondary altimeters used on the full-scale launch vehicle operate properly and are programmed correctly before launch. This test verifies Team Derived Requirement RF 3. This test was completed on February 20th, 2024. Table 7.6 below defines the success criteria for this test.

Table 7.6: Altimeter Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Drogue and main deployment lights light up at their appropriate times given the change of pressure in the chamber	Yes
Flight data of test indicates that drogue and main charges deployed	Yes

Controllable Variables

- Pressure
- Altimeter selection

Required Facilities, Equipment, Tools, and Software

- RRC3 altimeter
- Eggtimer Quasar
- Altimeter cable

- Lab computer
- 9V battery
- Handmade Altimeter Test System (HATS)
- Pressure vessel
- Vacuum pump

Procedure

1. The RRC3 altimeter is programmed using the MissleWorks mDAC program on the lab computer.
2. The altimeter is connected to the HATS.
3. The altimeter and HATS are placed into the pressure vessel.
4. The pressure vessel is sealed.
5. Slowly increase the pressure in the pressure vessel.
6. Slowly decrease the pressure in the pressure vessel to atmospheric pressure and watch the HATS to ensure that drogue and main deployment lights are lighting up at the right times. If the lights are not lighting up, first check that the pressure is sealed properly.
7. Remove the altimeter and HATS from the pressure vessel and connect to the lab computer to check that the flight data recorded indicates drogue and main deployment.
8. Program the Eggtimer Quasar on a cell phone, following the manufacturer's instructions, and repeat Steps 2-7 with the Quasar.

Results

All success criteria were met for both the primary and secondary altimeters. In fact, both were tested several times successfully before VDF. The drogue and main lights on the LED board lit up at the appropriate pressure for apogee and main deployment flawlessly. These deployment altitudes were confirmed on the mDACS software for the primary altimeter, and the IP address for the secondary altimeter.

7.1.5 G10 Fin Durability Test

The G10 fin durability test was designed to ensure that the tips of the full-scale vehicle's fins will not experience cracking or breakage in the event of a direct impact on the ground. The drop test will only be conducted in the grass given that the launch vehicle will exclusively launch in grass fields. This test verifies Team Derived Requirement LVF 4. This test was completed on the Oval lawn on February 14, 2024. Table 7.7 below defines the success criteria for this test.

Table 7.7: G10 Fin Durability Test Success Criteria

Success Criteria	Achieved (Yes/No)
Fin shows minimal to no damage upon hitting the ground at greater than or equal to the predicted impact kinetic energy of the launch vehicle's fin can.	Yes

Controllable Variables

- Fin shape
- Fin size
- Fin material
- Amount of ballast
- Height at which the fin is released

Required Facilities, Equipment, Tools, and Software

- Full scale G10 fiberglass test fin (1/8 in. thick)
- 12 ft. 1515 launch rail
- 1515 Delrin rail buttons
- 1/4 in. stainless steel threaded rods
- Ballast
- Cell phone cameras
- Video editing software

Test Setup

Figure 7.1: G10 fiberglass fin drop test setup.

Procedure

1. Fix rail buttons, threaded rods, and any ballast to the fin.
2. Slide the fin onto the launch rail and add a quick-release clamp directly underneath it.
3. Raise the launch rail and secure it to the bicycle stand.
4. Adjust the launch rail until it is 90 degrees with respect to the ground and confirm with a level (to simulate the worst possible landing configuration)
5. Start recording from multiple angles.
6. Pull the cord on the quick-release clamp to release the fin
7. Stop and save all recordings.
8. Inspect the fin for damage.
9. Repeat for a total of five trials.
10. Analyze timestamps of the recordings in video editing software.
11. Calculate velocity using timestamps and known fin height.
12. Calculate kinetic energy using velocity and fin mass.

Results

The target kinetic energy for this test was approximately 63.89 ft-lb. Given that the fin tip would start dropping at a height of about 10.96 ft. above ground level, the mass of the fin required to achieve an equivalent kinetic energy had to be about 0.181 slugs. After analyzing the footage of the drop tests, the timestamps were recorded. Using these timestamps and the known height, the velocity was calculated in ft/s. Using this velocity and the known mass, the kinetic energy was calculated. For trials 1, 2, and 5, a kinetic energy greater than the target kinetic energy was achieved with no damage. Trials 3 and 4 achieved just below the target energy, again with no damage. The kinetic energy data is shown below in Figure 7.2.

Trial #	Recording Time (s)	Gravity (ft/s^2)	Mass (slugs)	Distance (ft)	Velocity (ft/s)	Target KE (lbf-ft)	KE Achieved (lbf-ft)	KE Ratio
1	0.83	32.2	0.181219	10.95833	26.726	63.89	64.72046994	1.012998434
2	0.85	32.2	0.181219	10.95833	27.37	63.89	67.87710775	1.062405819
3	0.82	32.2	0.181219	10.95833	26.404	63.89	63.1703353	0.9887358788
4	0.8	32.2	0.181219	10.95833	25.76	63.89	60.12643455	0.9410930435
5	0.83	32.2	0.181219	10.95833	26.726	63.89	64.72046994	1.012998434

Figure 7.2: Kinetic energy achieved from G10 fiberglass fin drop tests.

Figure 7.3 shows what the G10 fiberglass fin looked like after five consecutive drop tests. While the fins were dirty from stabbing into the ground, they took no damage.

Figure 7.3: Condition of G10 fiberglass fin after five consecutive drop tests.

7.1.6 Rivet Shear Loading Test

Nylon push-clip rivets are used to secure non-separating sections together during flight. The rivet shear loading test ensures that the rivets used will withstand a predicted load of 25 pounds with a factor of safety greater than or equal to 2 during flight and recovery events. If the rivets fail, the amount of rivets used between non-separating sections of the launch vehicle will be increased. This test verifies Team Derived Requirements LVF 5. This test was completed on January 30th, 2024. Table 7.8 below defines the success criteria for this test.

Table 7.8: Rivet Shear Loading Test Success Criteria

Success Criteria	Achieved (Yes/No)
Rivets have a calculated factor of safety >2	Yes
Rivets do not break under a 25 lb load	Yes

Controllable Variables

- Size of rivets
- Type of rivets
- Number of rivets
- Applied force

Required Facilities, Equipment, Tools, and Software

1. 6 x 8 mm (about 1/2 in. x 0.3 in.) Nylon push clip rivets
2. 1/8 in. thick 6061 aluminum shear plates

3. 1/4 in. stainless steel quick links
4. Tensile testing machine in NC State's Structural Mechanics Lab

Test Setup

The test setup shown below in Figure 7.4 shows the Nylon push-clip rivet inserted into the aluminum shear plates that are connected to the Tensile testing machine using stainless steel quick links.

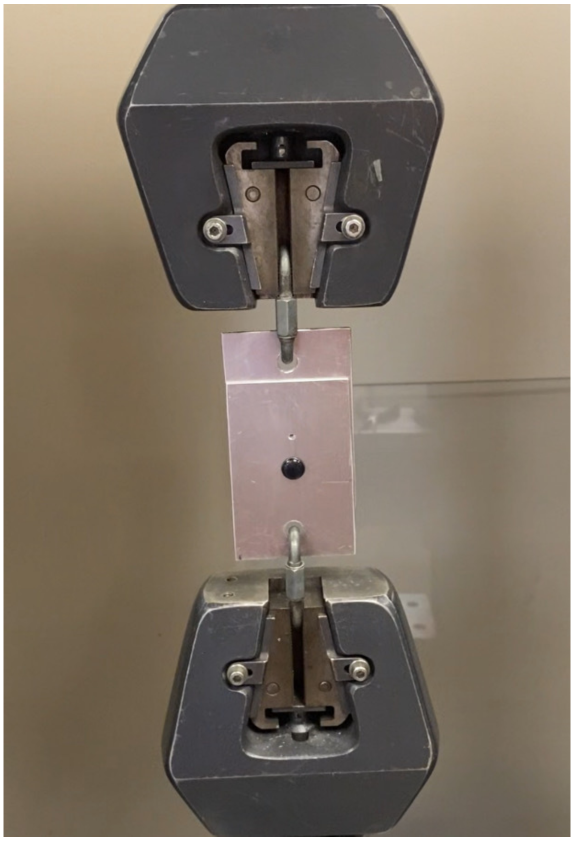

Figure 7.4: Shear loading test setup for Nylon rivets.

Procedure

1. Insert rivet into its respective hole in both aluminum shear plates.
2. Attach each of the quick links to the tensile testing machine.
3. Increase the loading on the tensile testing machine until the rivet breaks or the machine is maxed out.
4. Record the maximum loading the rivet experienced before failure or termination of the test.
5. Calculate the factor of safety and ensure that it is greater than or equal to 2.

Results

The ultimate loads for the three Nylon push-clip rivets that were tested are tabulated in Figure 7.5

below. In Figure 7.6, these values were used to calculate the average ultimate load per rivet. This average ultimate load was determined to be about 224 lb. Given that the expected load per rivet is approximately 7.5 lb, this yields a factor of safety of 29.9. Therefore, these rivets are more than capable of keeping the non-separating sections of the launch vehicle together. Furthermore, Figure 7.7 shows that even after the shear testing, the rivets remained mostly intact.

Fastener	Ultimate Load (lb)
Rivet 1	219.6
Rivet 2	233.6
Rivet 3	220.1

Figure 7.5: Ultimate load data for Nylon push-clip rivet shear test.

Component	Quantity Tested	Quantity on Relevant LV Section	Expected Load Per Component (lb)	Average Ultimate Load (lb)	Factor of Safety
Nylon Push Clip Rivets	3	4	7.5	224.4333333	29.92444444

Figure 7.6: Average ultimate load data for Nylon push-clip rivet shear test.

Figure 7.7: Broken Nylon push-clip rivets after testing.

7.1.7 Shear Pin Shear Loading Test

The 4-40 Nylon shear pins are used to secure separating sections together during flight. The shear pin shear loading test ensures the shear pins fail under the manufacturer's specified loading and allow black powder charges to separate the launch vehicle. If the shear pins do not fail at expected loads, the number of shear pins used between separating sections will be changed. This test verifies Team Derived Requirements LVF 6. This test was completed on January 30th, 2024. Table 7.9 below defines the success criteria for this test.

Table 7.9: Shear Pin Shear Loading Test Success Criteria

Success Criteria	Achieved (Yes/No)
Shear pins fail within a range of 35-40 lb.	Yes

Controllable Variables

- Size of shear pins
- Type of shear pins
- Number of shear pins
- Applied force

Required Facilities, Equipment, Tools, and Software

1. 4-40 x 1/2 in. Nylon shear pins
2. 1/8 in. thick 6061 aluminum shear plates
3. 1/4 in. stainless steel quick links
4. Tensile testing machine in NC State's Structural Mechanics Lab

Test Setup

The test setup shown below in Figure 7.4 shows the Nylon push-clip rivet inserted into the aluminum shear plates that are connected to the Tensile testing machine using stainless steel quick links.

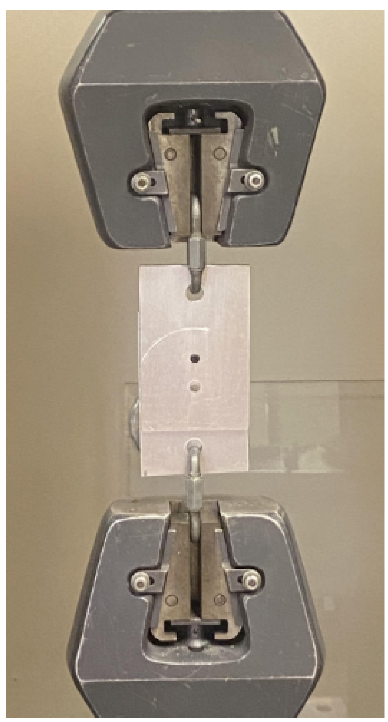

Figure 7.8: Shear loading test setup for Nylon shear pins.

Procedure

1. Insert shear pin into its respective hole in both aluminum shear plates.
2. Attach each of the quick links to the tensile testing machine.
3. Increase the loading on the tensile testing machine until the shear pin breaks.
4. Record the maximum loading the shear pin experienced before failure or termination of the test.

Results

The ultimate loads for the three Nylon shear pins that were tested are tabulated in Figure 7.10 below. In Figure 7.11, these values were used to calculate the average ultimate load per shear pin. This average ultimate load was determined to be about 39.4 lb. Given that the maximum expected load per shear pin is approximately 11.25 lb, this yields a factor of safety of roughly 3.5. This high safety factor enables the number of shear pins to be decreased to two, which will allow for smaller black powder charges for ejection testing and flights. This increases the expected load per shear pin to 22.5 lb and yields an acceptable safety factor of about 1.75. Therefore, these shear pins are both capable of keeping the separating sections of the launch vehicle together during flight and have a shear load within an acceptable range for ejection. Figure 7.7 shows the broken shear pins after the tests were conducted.

Figure 7.9: Broken Nylon shear pins after testing.

Fastener	Ultimate Load (lb)
Shear Pin 1	41.9
Shear Pin 2	37
Shear Pin 3	39.2

Figure 7.10: Ultimate load data for Nylon shear pin shear test.

Component	Quantity Tested	Quantity on Relevant LV Section	Expected Load Per Component (lb)	Average Ultimate Load (lb)	Factor of Safety
4/40 Nylon Shear Pins	3	4	11.25	39.36666667	3.499259259

Figure 7.11: Average ultimate load data for Nylon shear pin shear test.

7.1.8 Nose Cone Bulkhead Tensile Test

The removable nose cone bulkhead (see Section 3.2.2) is used as an attachment point for both the payload deployment bay (see Section 4.4) and for the nose cone parachute recovery harnesses. The AV bay bulkheads are used as an attachment point for the drogue and main parachute recovery harnesses. The bulkhead tensile test ensures that the nose cone and AV bay bulkheads can withstand their predicted loads with a factor of safety greater than or equal to 2. If either bulkhead fails this test, the thickness of the respective bulkhead will be increased and the test repeated. This test verifies Team Derived Requirement LVD 3. This test completed on February 7th, 2024. Table 7.10 defines the success criteria for this test.

Table 7.10: Nose Cone Bulkhead Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
Nose cone bulkhead has a calculated factor of safety >2	Yes
Nose cone bulkhead centering ring has a calculated factor of safety >2	Yes
Nose cone bulkhead suffers no visible damage under a 281.56 lb. load	Yes

Controllable Variables

- Bulkhead width
- Bulkhead material
- U-bolt size
- Placement of U-bolt
- Force applied

Required Facilities, Equipment, Tools, and Software

- 2 U-bolts
- Nose cone bulkhead test piece
- Nose cone bulkhead centering ring test piece
- Epoxy
- 8 nuts
- 8 washers
- Short length of 1” shock cord
- Tensile testing machine in NC State’s Structural Mechanics Lab

Procedure

1. Follow steps in Section 3.4.2 to construct a test nose cone and AV bay bulkhead as it would be constructed for use in the full-scale launch vehicle.
2. Attach nose cone bulkhead test piece to centering ring using four 1/4 in.-20 x 1/2 in. bolts.
3. Insert the U-bolts on the same side of the bulkhead and secure with 4 nuts for each U-bolt.
4. Place the bulkhead test piece into the bottom clamp of the tensile testing machine.
5. Secure the U-bolts into the top clamp using Kevlar shock cord.
6. Ensure that the universal testing machine is tared and is reading properly.
7. Apply force in steps of 10 lb, allowing the test piece to settle for 5-10 seconds between each application.
8. Continue applying force until the bulkhead fails.
9. Record at what force the bulkhead fractured and any noticeable defections throughout the experiment.

Results

This testing was completed until failure using the Instron Tension & Compression Testing Machine in NCSU's Structural Mechanics Lab. The point of failure ended up being the epoxied joint on the top bulkhead. Figure 3.80 shows the initial test setup while Figure 7.12 shows the aftermath. Finally, Table 7.11 shows the force at which the bulkhead failed and the factor of safety.

Table 7.11: Nose Cone Bulkhead Results

Required Force	Maximum Force	Factor of Safety
281.56 lb.	1248 lb.	7.6

Figure 7.12: Nose cone bulkhead after testing.

7.1.9 Avionics Bay Bulkhead Tensile Test

The AV bay bulkheads are used as an attachment point for the drogue and main parachute recovery harnesses. The bulkhead tensile test ensures that the AV bay bulkheads can withstand their predicted loads with a factor of safety greater than or equal to 2. If the AV bulkhead fails this test, the thickness of the AV bulkhead will be increased and the test repeated. This test verifies Team Derived Requirement LVD 3. This test is planned for February 6th, 2024. Table 7.12 below defines the success criteria for this test.

Table 7.12: AV Bay Bulkhead Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
AV bay bulkhead has a calculated factor of safety >2	Yes
AV bay bulkhead suffers no visible damage under a 122.61 lb. load	Yes

Controllable Variables

- Bulkhead width
- Bulkhead material
- U-bolt size
- Placement of U-bolt
- Force applied

Required Facilities, Equipment, Tools, and Software

- 1 U-bolt
- AV bay bulkhead test piece
- Epoxy
- 4 nuts
- 4 washers
- Short length of 1” shock cord
- Tensile testing machine in NC State’s Structural Mechanics Lab

Procedure

1. Follow steps in Section 3.4.2 to construct a test AV bay bulkhead as it would be constructed for use in the full-scale launch vehicle.
2. Insert the U-bolt into the bulkhead test piece and secure with 4 nuts.
3. Place the bulkhead test piece into the bottom clamp of the tensile testing machine.
4. Secure the U-bolts into the top clamp using Kevlar shock cord.
5. Ensure that the universal testing machine is tared and is reading properly.
6. Apply force in steps of 10 lb, allowing the test piece to settle for 5-10 seconds between each application.
7. Continue applying force until the bulkhead fails.
8. Record at what force the bulkhead fractured and any noticeable defections throughout the experiment.

Results

This testing was completed until failure using the RSL Tension and Compression Testing Machine in NCSU’s Structural Mechanics Lab. The point of failure was a fracture in the bulkhead along the U-bolt mounting. Figure 3.79 shows the initial test setup while Figure 7.13 shows the bulkhead folding inward due to the tensile force. Finally, Table 7.13 shows the force at which the bulkhead failed and the factor of safety.

Table 7.13: AV Bay Bulkhead Results

Required Force	Maximum Force	Factor of Safety
122.61 lb.	950 lb.	4.3

Figure 7.13: Nose cone bulkhead after testing.

7.1.10 Full-scale Ejection Testing

Ejection testing ensures that the black powder charges calculated are sufficient in separating the appropriate sections of the fully assembled full-scale launch vehicle for parachute deployment and ensures a safe and successful recovery during launch. The full-scale ejection test verifies NASA SL Requirement 3.2 and Team Derived Requirement RF 5. This test was completed on February 19th, 2024. Table 7.14 below defines the success criteria for this test.

Table 7.14: Full-scale Ejection Testing Success Criteria

Success Criteria	Achieved (Yes/No)
Complete and vigorous separation of AV bay and drogue parachute bay/fin can	Yes
Complete and vigorous separation of nose cone and main parachute/payload bay	Yes
No damage to launch vehicle	Yes
No damage to recovery materials and hardware	Yes

Controllable Variables

- Ejection charge size

Required Facilities, Equipment, Tools, and Software

- HPRC Lab
- All launch vehicle assembly tools identified in the launch procedure (Section 5.3)
- Full-scale launch vehicle, fully assembled
- Safety glasses
- Fireproof gloves
- Fire extinguisher
- Ejection testing wires with battery clip attached
- Charged 9V battery

Procedure

The field assembly checklist is used to assemble to launch vehicle in its launch day configuration (See Section 5.3). The items below are required changes to the launch procedure to conduct this test.

- The AV sled and recovery electronics are not placed in the AV bay.
- Only the primary blast caps are filled with black powder.
- The E-match wires are not cut, but are instead threaded through the pin switch hole

After the launch vehicle has been assembled, the steps below are followed.

1. The launch vehicle is placed horizontally on a piece of foam outdoors. Ensure that forward and aft ends of the vehicle are at least 3 feet away from walls or obstructions and that the vehicle is lying as flat as possible on the foam.
2. Any walls directly in front of or behind the vehicle are protected with another piece of foam.
3. All team members retreat to a safe distance of at least 10 feet away from the sides of the launch vehicle.
4. Ensure battery is not connected to battery clip.
5. One designated team member, equipped with safety glasses and fireproof gloves, approaches the launch vehicle to secure the ejection testing wires to the wires labeled ”drogue” on the exterior of the vehicle.
6. The team member retreats to a safe distance.
7. Ensure that everyone is wearing safety glasses and that no one is standing behind or in front of the launch vehicle.
8. The team member conducts a verbal countdown.
9. The team member connects a 9V battery to the connector, detonating the drogue ejection charge.
10. The team member and safety officer approach the vehicle, and, with fireproof gloves on, ensure adequate separation of the sections and dump out the contents of each section. Put out any sparks and check the source of any smoke.
11. Repeat Steps 4-10 with the ejection testing wires secured to the wires labeled ”main.”

Results

All success criteria were met for the first ejection test. However, the drogue black powder charge of 2.5 was too large, and seemed excessive. In addition, the main black powder charge of 4.5 worked, but the team felt it would be better to increase the charge so the deployment bay can separate with ease. As a result, the drogue charge was lowered to 2.0, the main charge was increased to 5.0, and another ejection test was conducted. All success criteria were met for the second ejection test with a drogue charge size of 2.0, and a main charge size of 5.0. Each section was completely separated, and an image of the main separation is shown below.

Figure 7.14: Full-scale main parachute ejection charge

7.1.11 Vehicle Demonstration Flight

The full-scale demonstration flight confirms the structural integrity, aerodynamic design, and recovery system are successful and do not need modifications for use during competition launch. This test verifies NASA SL Requirement 2.19.1. This test was completed on February 24th, 2024. Table 7.15 below defines the success criteria for this test.

Table 7.15: Full-scale Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
Launch vehicle departs launch rail and travels vertically until motor burnout.	Yes
Main and fin can launch vehicle sections deploy at least one parachute during decent.	Yes
Nose cone separates from the rest of launch vehicle.	Yes
All launch vehicle sections endure only minimal damage and retain integrity to safely re-launch.	Yes

Controllable Variables

- Motor selection
- Ejection charge sizing
- Altimeter selection
- Launch vehicle weight

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled full-scale launch vehicle
- All tools and hardware identified in the launch procedure (Section 5.3).

Procedure

See Section 5.3.2

Results

See Section 6.1

7.2 Payload Testing

Table 7.16 summarizes payload verification tests, the requirement(s) each test verifies, and the required facilities and personnel for the completion of the tests. The test schedule for all of the launch vehicle and payload tests can be viewed in Figure 7.20. Only 4 out of 8 payload verification tests have been complete as of the date of submission of this document. The remaining 4 tests will be complete prior to the payload demonstration flight.

Table 7.16: Payload Tests

Test	Requirement(s) Verified	Required Facilities	Required Personnel	Complete? (Y/N)
Subscale Launch SAIL Deployment Test	NASA SL Req. 2.18, PF 2	FAA Approved Launch Field	Payload Systems Lead	Yes
Rotor Blade/Landing Leg Deployment Test	PF 4, PD 3	Deployment system, large, open outdoor area	Payload Electronics Lead	No
Rotor Blade Adhesion Strength Test	PF 6	Applied Test Systems 1620C	Payload Structures Lead	Yes
Landing Leg Bending Test	PD 3	HPRC lab	Payload Structures Lead	No
RF Signal Test	PF 2	Launch field	Payload Systems Lead	Yes
Latch Tensile Test	PF 3	Universal Testing Machine	Payload Systems Lead	Yes
Thrust Verification Test	PF 5, PD 4	Thrust stand	Payload Electronics Lead	No
Payload Demonstration Flight	NASA SL Req. 2.19.2	NAR/Tripoli Sanctioned Launch Field	Payload Systems Lead, Payload Structures Lead, Payload Electronics Lead	No

7.2.1 Subscale Launch SAIL Deployment Test

The subscale launch SAIL deployment test ensures that the recovery system designed to deploy the sail from the launch vehicle during flight operates properly and ensures that the RF receiver can receive signals from the transmitter during the launch vehicle's descent. This test verifies NASA SL Requirement 2.18 and Team Derived Requirement. This test was completed on November 18th, 2023. Table 7.17 below defines the success criteria for this test.

Table 7.17: Subscale Launch SAIL Deployment Test Success Criteria

Success Criteria	Achieved (Yes/No)
SAIL mass simulator exits the main bay during recovery	Yes
SAIL mass simulator remains attached to nose cone under parachute during descent	Yes
LED connected to RF receiver is lit up upon post-flight inspection	Yes

Controllable Variables

- Recovery system design
- Parachute and recovery harness packing
- Ejection charges
- RF transmitter and receiver separation distance
- RF receiver location within launch vehicle

Required Facilities, Equipment, Tools, and Software

- RF receiver and transmitter
- Laptop computer
- SAIL mass simulator
- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled launch vehicle
- All tools and hardware identified in the launch procedure (Section 5.3).

Procedure

See the steps for Nose Cone Assembly in the Launch Procedure (Section 5.3).

Results

Upon post-flight inspection, the LED retained in the nose cone of the subscale launch vehicle was lit green, indicating that the RF signal was received by the receiver during descent.

7.2.2 Rotor Blade and Landing Leg Deployment Test

The rotor blade and landing leg deployment test ensures that the rotor blade and landing leg spring-loaded deployment systems operate as expected once deployed from the payload deployment bay. If the rotor blades and landing legs do not deploy within 1 second of exiting the deployment bay, the release mechanism for the blades and legs will be modified before the Payload Demonstration Flight. This test verifies Team Derived Requirements PF 4 and PD 3. This test is planned to be complete between March 4th, 2024 and March 23rd, 2024. Table 7.18 below defines the success criteria for this test.

Table 7.18: Rotor Blade/Landing Leg Bend Test Success Criteria

Success Criteria	Achieved (Yes/No)
The rotor blades and landing legs deploy within 1 second of exiting the deployment bay.	TBD

Controllable Variables

- Release height

Required Facilities, Equipment, Tools, and Software

- Assembled SAIL
- Deployment system
- Camera

- Crash pad

Procedure

1. Place the SAIL inside of the deployment bay.
2. Raise the deployment bay approximately 6 ft. off the ground.
3. Set crash pad underneath deployment bay.
4. Place the camera so that it has a view of both the deployment bay and the crash pad.
5. Start recording.
6. Send command to drop the SAIL from the deployment bay.
7. Analyze footage to determine the time to full rotor/landing leg deployment.

Results

This test has yet to be completed. The fiberglass tube has not arrived, thus making the test difficult to perform. The results of this test will be included in the FRR Addendum upon completion.

7.2.3 Rotor Blade Adhesion Strength Test

The rotor blade adhesion strength test ensures that the adhesive used to bind sections of the rotor blade is strong enough to withstand the SAIL's forces of operation. In the event of failure, a new adhesive will be researched and the test repeated. If no alternative adhesive is found, the construction of the rotor blades may be subject to change. This test verifies Team Derived Requirement PF 6. This test was completed on January 23rd, 2024. Table 7.19 below defines the success criteria for this test.

Table 7.19: Rotor Blade Adhesion Strength Test Success Criteria

Success Criteria	Achieved (Yes/No)
Rotor blade does not fracture at adhesion interfaces under a 300 lb. load	Yes

Controllable Variables

- Blade chord
- Machine loading
- Type of adhesive

Required Facilities, Equipment, Tools, and Software

- Instron 6800 Tensile Testing Machine
- 5,000 pound load cell

Procedure

1. Clamp the propeller blade at equidistant locations such that the joint is in the middle. This is done on the testing rig.
2. Apply the 5,000 pound load cell.

3. Stretch the propeller blade in increments of 20 pounds and document the displacement until 300 lbs.
4. Stretch the propeller blade in increments of 5 pounds until failure.

Results

The software for the Instron 6800 was having difficulties and thus could not retrieve meaningful displacement data. However, since the rotor blade test article is wrapped in a polymer composite, it is brittle, meaning there is little yield and thus, little plastic deformation. This incurs fracture near yield strength.

No noticeable yielding occurred up until 300 lbs. of force, meaning that the success criteria was met. It eventually fractured at a mounting hole under 517 lbs. of force. This fracture can be seen below in Figure 7.15.

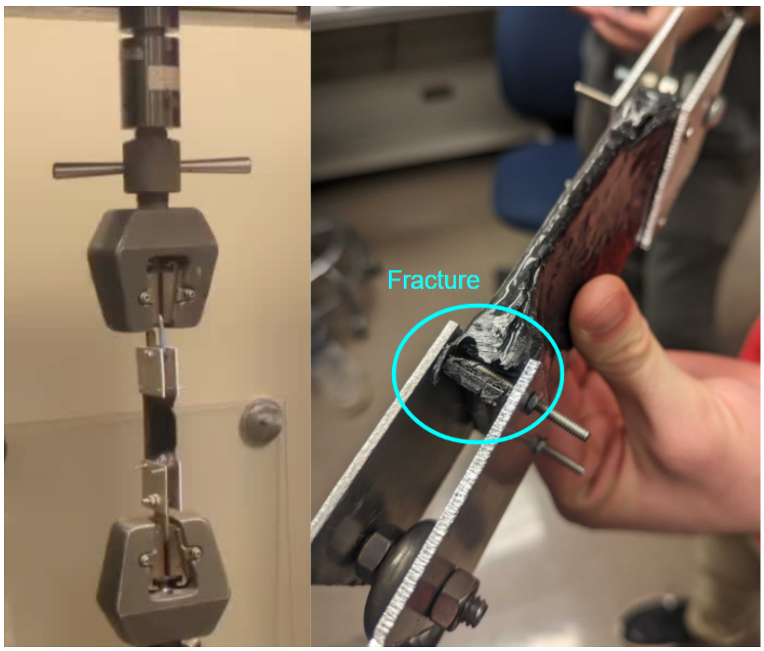

Figure 7.15: Tensile Testing Setup and Rotor Blade Fracture

7.2.4 Landing Leg Bend Test

The landing leg bend test ensures that the SAIL landing legs can withstand the force of impact with the ground after descent at predicted velocities. Upon failure, the material, construction, and/or configuration of the landing legs will be changed and the test repeated. This test verifies Team Derived Requirements PF 7 and PD 3. This test is planned for March 8th, 2024. Table 7.20 below defines the success criteria for this test.

Table 7.20: Landing Leg Bend Test Success Criteria

Success Criteria	Achieved (Yes/No)
Landing leg suffers minimum deformation under a 50 lb. load	TBD

Controllable Variables

- Load applied
- Landing leg material
- Landing leg construction
- Landing leg configuration

Procedure

1. Place the extended leg assembly on a flat surface.
2. Measure the height of the assembly.
3. Apply 20 pounds of weight to the top of the assembly.
4. Measure the height of the assembly.
5. Repeat Steps 3 and 4 at increments of 5 lb. up to 50 lb. or until failure.

Required Facilities, Equipment, Tools, and Software

- 100 pounds of weight
- Assembled legs and payload body

Results

This test has yet to be completed. The fiberglass tube has not arrived, thus making the test difficult to perform. The results of this test will be included in the FRR Addendum upon completion.

7.2.5 RF Signal Testing

The RF signal testing verify the operational range of the manual release command and motor startup command, as well as the supplied power to the transmitter. This test will satisfy Team Derived Requirement PF 2. This test was completed on February 24th, 2024. Table 7.21 below defines the success criteria for this test.

Table 7.21: RF Signal Test Success Criteria

Success Criteria	Achieved (Yes/No)
The servo turns for every distance that the release command is sent.	Yes
The servo turns inside of the deployment bay for every distance the command is sent.	Yes
The servo turns with at least 7.4V.	Yes

Controllable Variables

- Transmitter and receiver separation distance
- Location of receiver in launch vehicle
- Supplied voltage

Required Facilities, Equipment, Tools, and Software

- Bayboro launch field
- 2 XBee RF Modules
- 2 XBee Explorer Boards
- Laptop computer
- Micro USB cable
- Arduino Nano Every
- 2 cell Li-Po battery
- Buck converter
- Breadboard
- Wires for connections
- SAIL deployment bay

Procedure

1. Supply power to XBee receiver and transmitter.
2. Place the receiver a specified distance away from the transmitter, between 100 ft and 2500 ft.
3. Send command using transmitter to open latch.
4. Verify that servo has turned.
5. Repeat Steps 1-4 with the receiver inside the deployment bay to test if signal is blocked.

Results

The latch electronics successfully received the command at the distances specified, up to 2500 ft. Based on drift distance calculations for the launch vehicle, this indicates that the SAIL will be able to release at the maximum calculated drift distance. This is true even with the deployment bay possibly blocking the signal.

7.2.6 Latch Tensile Test

The latch tensile test will verify the maximum load the latch can withstand during operation, as well as the power required to open the latch using a servo. This test satisfies Team Derived Requirement PF 3. This test was completed on February 22nd, 2024. Table 7.22 below defines the success criteria for this test.

Table 7.22: Latch Tensile Test Success Criteria

Success Criteria	Achieved (Yes/No)
The latch does not open and/or fracture under a load of 100 lb. without being opened manually	Yes
The servo turns the manual release under a load of 100 lb. and opens the latch	No

Controllable Variables

- Tensile load
- Type of electric latch

Required Facilities, Equipment, Tools, and Software

- Tensile testing machine in NC State's Structural Mechanics Lab
- Camlock rotary latch
- Shock cord

Procedure

1. Secure Southco latch to tensile testing machine.
2. Attach shock cord to latch opening.
3. Close latch
4. Set tensile load.
5. Prepare servo using micro controller.
6. Open the latch using the servo.
7. Repeat Steps 1-5 for each load, from 5 lb to 100 lb.

Results

The Southco latch was able to successfully withstand the max 100 lb force load on the testing machine, and the servo was also able to open the latch at an applied load of 10 lb. The latch was not, however, able to open under higher loads. Due to slight deflections of the corner brackets securing the latch, the servo was unable to reach the latch manual release switch. While this does not satisfy one of the success criteria for the test, it does not invalidate the team derived requirement PF 3. During flight, the latch will not experience such high sustained loads, making deflection of the corner brackets unlikely. Additionally, considering that the latch will not need to release the SAIL under a higher load than the weight of the SAIL, the test verified that the SAIL will be able to safely release the SAIL under its own weight. To further increase the reach of the servo arm to the latch release switch, a single nut was attached to the latch release switch. This will allow for a more generous tolerance during servo operation. The testing setup for the latch tensile test is shown in Figure 7.16.

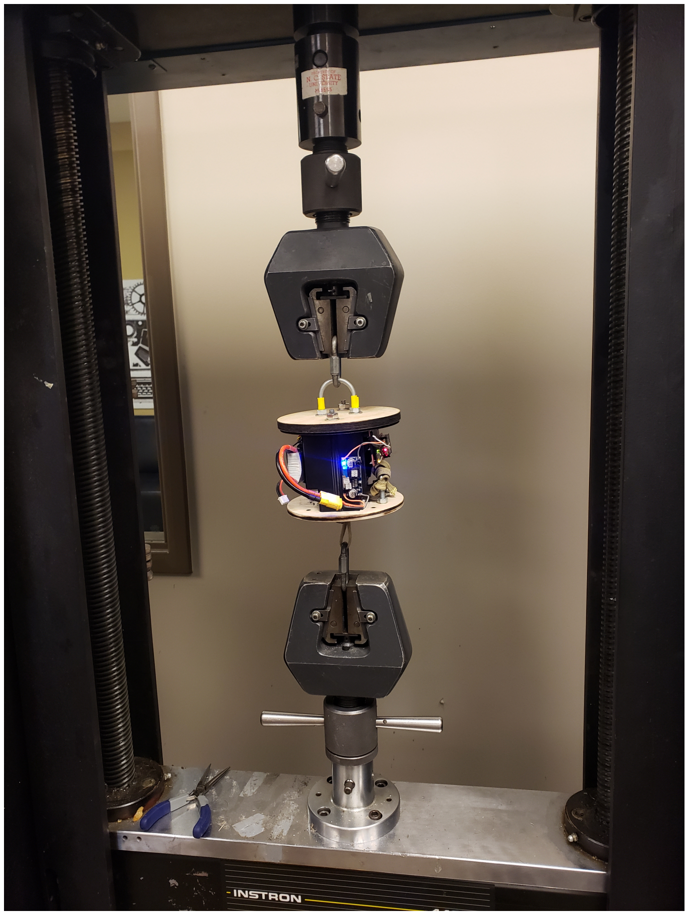

Figure 7.16: Setup for Latch Strength Test

7.2.7 Thrust Verification Test

The thrust verification test ensures that the SAIL generates enough thrust to safely descend to the ground. This test verifies Team Derived Requirement PF 5 and PD 4. Due to delays during fabrication of the gearbox, this test has not been conducted at the time of writing. This test is now planned for March 8th, 2024. Table 7.23 below defines the success criteria for this test.

Table 7.23: Thrust Verification Test Success Criteria

Success Criteria	Achieved (Yes/No)
The SAIL generates at least 7.7 lbs of thrust.	TBD

Controllable Variables

- Rotor blade shape
- Rotor blade size
- RPM

Required Facilities, Equipment, Tools, and Software

- Assembled rotor blade system
- Adafruit Feather
- Potentiometer
- Scale
- Stand
- Electronic speed controller
- Li-Po battery

Procedure

1. Secure the assembled rotor blade system to the stand.
2. Connect the ESC to the brushless motor.
3. Clear all personnel from the test area.
4. Connect the potentiometer to the Adafruit Feather.
5. Set the potentiometer to the off position.
6. Connect the battery to the ESC.
7. Set the potentiometer to 1000 RPM.
8. Record the scale readout.
9. Repeat steps 7-8 until the thrust equals 8 lbf.
10. Set the potentiometer to the off position.
11. Disconnect the battery.

Results

This test has yet to be completed due to difficulties in assembling the gearbox. The results of this test will be included in the FRR Addendum upon completion.

7.2.8 Payload Demonstration Flight

The payload demonstration flight ensures that all payload subsystems operate as designed during flight of the full-scale launch vehicle. This test verifies NASA SL Requirement 2.19.2. This launch is planned for March 23rd-24th, 2024. Table 7.24 below defines the success criteria for this test.

Table 7.24: Payload Demonstration Flight Success Criteria

Success Criteria	Achieved (Yes/No)
SAIL deployment bay separates from the rest of the launch vehicle with the nose cone at 800 ft.	TBD
RSO gives verbal permission for SAIL deployment	TBD
SAIL released from deployment bay on command	TBD
SAIL rotors and landing legs deploy	TBD
Minimum damage to SAIL is observed in post-flight analysis	TBD

Controllable Variables

- SAIL weight
- SAIL rotor motor
- Ejection charges

Required Facilities, Equipment, Tools, and Software

- Tripoli Range Safety Officer
- NASA SL Competition mentor(s)
- FAA approved launch field
- 15-15 launch rail
- Launch controller
- Assembled full-scale launch vehicle
- Assembled SAIL
- SAIL deployment bay
- RF transmitter and receiver
- Laptop computer
- All tools and hardware identified in the launch procedure (Section 5.3).

Procedure

The procedure for payload demonstration flight will be similar to the procedure of the vehicle demonstration flight (Section 5.3.2). Edits will be made to the deployment bay checklist when the fully configured payload is available for integration.

Results

The results of this test will be included in the FRR Addendum upon completion. See Section 6.2 for the PDF plan.

7.3 Requirements Compliance

7.3.1 Competition Requirements

Table 7.25: 2023-2024 NASA Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
General Requirements						
1.1	Students on the team SHALL do 100% of the project, including design, construction, written reports, presentations, and flight preparation, with the exception of assembling the motors and handling black powder (or any variant of ejection charges) or preparing and installing electric matches (to be done by the team's mentor). Teams SHALL submit new work. Excessive use of past work SHALL merit penalties.	Members of NC State's High-Powered Rocketry Club fabricate a solution to the criteria given in the Student Launch Handbook, implementing past ideas while developing new ones.	Inspection	Project Management	Verified	Students on the team use original work done by the team to complete the project.
1.2	The team SHALL provide and maintain a project plan to include, but not limited to, the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The Project Management Team, consisting of the Team Lead, Vice President, Integration Lead, Treasurer, Secretary, Safety Officer, Webmaster, and Social Media Lead manage the tasks related to this requirement.	Inspection	Project Management	Verified	See Section 7.5 for the project timeline.
1.3	Team members who will travel to the Huntsville Launch SHALL have fully completed registration in the NASA Gateway system before the roster deadline.	The Team Lead determines the team members attending Huntsville and ensures team members register and their application status is "submitted" in the NASA Gateway system no later than October 27th, 2023.	Inspection	Project Management	Verified	A list of team members attending is provided with the CDR submission.
1.3.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The Project Management Team determines the students that have been actively engaged to invite them to competition.	Inspection	Project Management	Verified	Team members that have been actively assisting the senior design group will be eligible to attend launch week.
1.3.2	Team members SHALL include one mentor (see Requirement 1.13).	The Team Lead invites the mentor(s) identified in Section 1.1.3 to attend competition.	Inspection	Project Management	Verified	Team mentors are listed in Section 1.1.3.
1.3.3	Team members SHALL include no more than two adult educators.	The Team Lead invites the adult educator(s) shown in Section 1.1.3 to attend competition.	Inspection	Project Management	Verified	See Section 1.1.3 for team mentors and advisors.

1.4	Teams SHALL engage a minimum of 250 participants in Educational Direct Engagement STEM activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events SHALL occur between project acceptance and the FRR addendum due date. A template of the STEM Engagement Activity Report can be found on pages 86 – 89.	The Outreach Lead offers STEM engagement opportunities to K12 students for the duration of project development and submits STEM Engagement Activity Reports within two weeks of the event.	Inspection	Project Management	Verified	The Outreach Lead has engaged over 250 participants and is continuing outreach events.
1.5	The team SHALL establish and maintain a social media presence to inform the public about team activities.	The Webmaster and Social Media Officer collaborate to maintain our website and social media presence to educate the public about activities and events held by the team. Our social media platforms include, but are not limited to: our club website, TikTok, Facebook, and Instagram.	Inspection	Project Management	Verified	Any form of social media in relation to the team has been sent to the NASA project management team.
1.6	Teams SHALL upload all deliverables to the designated NASA SL Box submission portal by the deadline specified in the handbook for each milestone. No PDR, CDR, and FRR milestone documents SHALL be accepted after the due date and time. Teams that fail to submit the PDR, CDR, and FRR milestone documents SHALL be eliminated from the project.	The Team Lead uploads all documents to the designated NASA SL Box submission portal by the deadline specified.	Inspection	Project Management	Verified	CDR, PDR, and FRR have been submitted to the NASA SL Box submission portal by the designated deadlines.
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) SHALL be provided action items to be completed following their review and SHALL be required to address action items in a delta review session. After the delta session the NASA management panel SHALL meet to determine the team's status in the program and the team SHALL be notified shortly thereafter.	If a milestone review is not completed satisfactorily, the team completes any action items given and attends the delta review session to maintain their status in the program.	Inspection	Project Management	Verified	The team satisfactorily completes each milestone review and submits before the deadline.
1.8	All deliverables SHALL be in PDF format.	The Team Lead sends all deliverables in PDF format to the NASA Project Management Team.	Inspection	Project Management	Verified	All documents are changed to PDF format before submission.
1.9	In every report, teams SHALL provide a table of contents including major sections and their respective sub-sections.	The Team Lead creates and adjusts a table of contents in every report.	Inspection	Project Management	Verified	A table of contents is included in every report as seen in the Table of Contents above.

1.10	In every report, the team SHALL include the page number at the bottom of the page.	The team uses a template which displays the page number at the bottom of each page for every report.	Inspection	Project Management	Verified	The page number will be included at the bottom of the page in every report as seen in this document.
1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	The team obtains the equipment needed to attend a video teleconference with the review panel.	Inspection	Project Management	Verified	The team will continue to obtain and test any equipment needed to perform a video teleconference with the review panel.
1.12	All teams attending Launch Week SHALL be required to use the launch pads provided by Student Launch's launch services provider. No custom pads SHALL be permitted at the NASA Launch Complex. At launch, 8 ft. 1010 rails and 12 ft. 1515 rails SHALL be provided. The launch rails SHALL be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant SHALL depend on Launch Day wind conditions.	The Aerodynamics Lead designs a launch vehicle that utilizes 8 ft. 1010 rails or 12 ft. 1515 rails. The Structures Lead builds the launch vehicle according to these specifications.	Inspection	Aerodynamics, Structures	Not Verified	The team plans to use the launch pads provided for Launch Day.

1.13	Each team SHALL identify a “mentor.” A mentor is defined as an adult who is included as a team member who SHALL be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor SHALL maintain a current certification and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the launch vehicle for liability purposes and must travel with the team to Launch Week. One travel stipend SHALL be provided per mentor regardless of the number of teams he or she supports. The stipend SHALL only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The Team Leader determines a qualified adult to mentor the team throughout project development and attend Launch Week.	Inspection	Project Management	Verified	See Section 1.1.3 for team mentors.
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The team records the number of hours spent working on each milestone and documents this in the designated report.	Inspection	Project Management	Verified	See Section 1.1.4 pertaining to time spent on FRR.
Vehicle Requirements						
2.1	The vehicle SHALL deliver the payload to an apogee altitude between 4,000 and 6,000 ft. above ground level (AGL). Teams flying below 3,500 ft. or above 6,500 ft. on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	The Aerodynamics and Structures Leads design a launch vehicle to deliver the payload to an apogee between 4,000 and 6,000 ft. AGL. The team fabricates the launch vehicle as designed.	Analysis, Demonstration	Aerodynamics, Structures	Not Verified	See Section 1.2.3 for launch day target apogee.
2.2	Teams SHALL declare their target altitude goal at the PDR milestone. The declared target altitude SHALL be used to determine the team’s altitude score.	The Aerodynamics Lead reports the target altitude goal by October 26, 2023 in the PDR milestone.	Inspection	Aerodynamics	Verified	See Section 1.2.3 for official target apogee.

2.3	The launch vehicle SHALL be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The Recovery and Structures Lead design a recovery system that prevents the launch vehicle from being damaged upon ground impact.	Demonstration	Recovery, Structures	Verified	See Section 1.2.4 for the recovery design.
2.4	The launch vehicle SHALL have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The Aerodynamics and Recovery Leads design the launch vehicle to have no more than four independent sections.	Inspection	Aerodynamics, Recovery	Verified	See Section 3.2 to view independent sections.
2.4.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 2 airframe diameters in length (one body diameter of surface contact with each airframe section).	The Aerodynamics Lead designs the coupler/airframe shoulders at in-flight separation points at least 2 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures	Verified	See Section 3.2 for the launch vehicle design.
2.4.2	Coupler/airframe shoulders which are located at non-in-flight separation points SHALL be at least 1.5 airframe diameters in length (0.75 body diameter of surface contact with each airframe section.)	The Aerodynamics Lead designs the coupler/airframe shoulders at non-in-flight separation points at least 1.5 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures	Verified	See Section 3.2 for the launch vehicle design.
2.4.3	Nose cone shoulders which are located at in-flight separation points SHALL be at least 0.5 body diameters in length.	The Aerodynamics Lead designs the nose cone shoulders at in-flight separation points to be a minimum of 0.5 body diameter in length.	Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
2.5	The launch vehicle SHALL be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The Project Management Team and Safety Officer creates a launch day checklist that can be completed within two hours.	Demonstration	Project Management, Safety	Not Verified	The team will continue to practice launch vehicle assembly before competition.
2.6	The launch vehicle and payload SHALL be capable of remaining in launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	The Project Management Team and Safety Officer ensure functionality of electrical components for a minimum of three hours by monitoring power consumption.	Demonstration	Project Management, Safety	Not Verified	The team tests powered electronics as outlined in Section 7.
2.7	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system. The firing system SHALL be provided by the NASA-designated launch services provider.	The Project Management Team and Safety Officer pick a motor from a designated launch services provider that can be ignited by a 12-volt direct current firing system.	Demonstration	Project Management, Safety	Verified	See Section 3.2.8 for the selected motor.

2.8	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The Project Management Team and Safety Officer design the launch vehicle such that no external circuitry or special ground support equipment is needed for launch.	Demonstration	Safety	Verified	No use of external circuitry will be used as shown in Section 3.2.
2.9	Each team SHALL use commercially available e-matches or igniters. Hand-dipped igniters SHALL not be permitted.	The Project Management Team and Safety Officer utilize commercially available e-matches and igniters.	Inspection	Project Management, Safety	Verified	The team uses commercially available e-matches or igniters for ejection testing and vehicle launches.
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 purchased solid motor propulsion system with APCP certified by NAR, TRA, and/or CAR.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.10.1	Final motor choice SHALL be declared by the Critical Design Review (CDR) milestone.	The Aerodynamics Lead states the finalized motor choice in the CDR milestone by January 8, 2024.	Inspection	Aerodynamics	Verified	See section 3.2.8 for the final motor choice.
2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment SHALL not be approved. A penalty against the team's overall score SHALL be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The Project Management Team requests approval from NASA RSO for a motor changed after the CDR milestone deadline.	Inspection	Project Management	Verified	The team has no intention of changing the current motor viewed in Section 1.2.2.
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The Aerodynamics Lead designs the launch vehicle to use a single motor propulsion system.	Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Ns (L-class).	The Aerodynamics Lead picks a motor that does not exceed a total impulse of 5,120 Ns.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The Structures Lead gets RSO approval for any on-board pressure vessels.	Inspection	Structures	Verified	No pressure vessels are used on the launch vehicle as seen in Section 3.2.
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The Structures Lead provides design documentation in each milestone report supporting a minimum factor of safety of 4:1.	Analysis, Inspection	Structures	Verified	See section 3.2 for the launch vehicle design.

2.13.2	Each pressure vessel SHALL include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	The Structures Lead picks pressure vessels which include a pressure relief valve system that sees the full pressure of the tank and can withstand the maximum pressure and flow rate of the tank.	Analysis, Inspection	Structures	Verified	No pressure vessels are used on the launch vehicle as seen in Section 3.2.
2.13.3	The full pedigree of the tank SHALL be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The Structures Lead describes the entire history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and name of the person or entity administering each pressure event.	Inspection	Structures	Verified	No pressure vessels are used on the launch vehicle as seen in Section 3.2.
2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The Aerodynamics Lead designs the launch vehicle to have a minimum static stability margin of 2.0 at the rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6 for the projected stability margin.
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5:1.	The Aerodynamics Lead designs the launch vehicle to have a minimum thrust to weight ratio of 5:1.	Analysis, Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.16	Any structural protuberance on the launch vehicle SHALL be located aft of the burnout center of gravity. Camera will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the launch vehicle's stability.	The Aerodynamics Lead designs the launch vehicle to have any protuberances located aft of the burnout center of gravity. If camera's are included, the Aerodynamics Lead will prove the housings cause minimal aerodynamic effect on the launch vehicle's stability.	Analysis, Inspection	Aerodynamics	Verified	See Section 3.2 for the launch vehicle design.
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 ft/s at rail exit.	The Aerodynamics Lead designs the launch vehicle to reach a minimum velocity of 52 ft/s at the rail exit.	Analysis	Aerodynamics	Verified	See Section 3.6 for the projected velocity of the launch vehicle.

2.18	All teams SHALL successfully launch and recover a subscale model of their launch vehicle prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data SHALL be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	The Project Management Team launches a subscale model of the launch vehicle before CDR using an impulse motor of class E or higher. The Project Management Team and Safety Officer successfully recovers the subscale and reports flight data in the CDR milestone by January 8, 2024.	Demonstration	Project Management, Safety	Verified	Details of the successful subscale flight are outlined in the CDR report.
2.18.1	The subscale model should resemble and perform as similarly as possible to the full scale model. However, the full scale SHALL not be used as the subscale model.	The Aerodynamics Lead designs a subscale model that performs similarly to the full scale model.	Inspection	Aerodynamics	Verified	Details pertaining to the subscale design and performance are outlined in the CDR report.
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The Recovery Lead attaches an altimeter to record the apogee altitude of the subscale model.	Inspection	Recovery	Verified	The subscale altimeters can be viewed in the CDR report.
2.18.3	The subscale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and fabricate a new subscale launch vehicle that meets the criteria for this year's project.	Inspection	Aerodynamics, Structures	Verified	The subscale vehicle was newly constructed for this year's competition.
2.18.4	Proof of a successful subscale flight SHALL be supplied in the CDR report.	The Project Management Team shows proof of successful subscale flight in the CDR report by January 8, 2024.	Inspection	Project Management	Verified	Details of the successful subscale flight are outlined in the CDR report.
2.18.4.1	Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead makes an altimeter flight profile graph which displays all altitudes recorded from liftoff through landing.	Analysis	Recovery	Verified	Subscale altimeter flight profile graphs are included in the CDR report.
2.18.4.2	Quality pictures of the "as-landed" configuration of all sections of the launch vehicle SHALL be included in the CDR report. This includes but is not limited to nose cone, recovery system, airframe, and booster.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the CDR milestone by January 8, 2024.	Analysis, Demonstration	Project Management, Recovery	Verified	The landed configuration of each section of the subscale launch vehicle is included in the CDR report.

2.18.5	The subscale launch vehicle SHALL not exceed 75% of the dimensions (length and diameter) of the designed full scale launch vehicle (if the full scale launch vehicle is a 4 in. diameter, 100 in. length rocket, your subscale SHALL not exceed 3 in. diameter and 75 in. in length).	The Aerodynamics and Structures Lead design the subscale launch vehicle to not exceed 75% of the dimensions used for the full scale launch vehicle.	Inspection	Aerodynamics, Structures	Verified	Details of the subscale design are outlined in the CDR report.
2.19.1	**Vehicle Demonstration Flight**. All teams SHALL successfully launch and recover their full scale launch vehicle prior to FRR in its final flight configuration. The launch vehicle flown SHALL be the same launch vehicle flown at competition launch. Requirements 2.19.1.1-9 SHALL be met during the Vehicle Demonstration Flight:	The Project Management Team launches and recovers the full scale vehicle, to be flown for competition, in its final flight configuration before the FRR milestone.	Demonstration	Project Management	Verified	See Section 6.1 for the successful Vehicle Demonstration Flight.
2.19.1.1	The vehicle and recovery system SHALL function as designed.	The Project Management Team identifies no abnormalities in the performance of the vehicle and recovery system.	Demonstration	Project Management	Verified	See Section 6.1 pertaining to successful recovery events.
2.19.1.2	The full scale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and build a new full scale launch vehicle, meeting the criteria for this year's project.	Inspection	Aerodynamics, Structures	Verified	See Section 3.2 for the launch vehicle design.
2.19.1.3.1	If the payload is not flown during the Vehicle Demonstration Flight, mass simulators SHALL be used to simulate the payload mass.	The Structures Lead installs mass simulators to mimic payload mass if the payload is not flown during VDF.	Inspection	Structures	Verified	See Section 6.1 pertaining to the payload mass simulator.
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the launch vehicle as the missing payload mass.	The Structures Lead installs mass simulators at the approximate location on the launch vehicle as the missing payload if the payload is not flown during VDF.	Inspection	Structures	Verified	See Section 6.1 pertaining to the placement of the payload mass simulator.
2.19.1.4	If the payload changes the external surfaces of the launch vehicle (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.	The Payload Team activates systems during VDF if the payload changes the external surface or manages the total energy of the vehicle.	Inspection	Payload	Verified	The payload design does not change the external surfaces of the launch vehicle.
2.19.1.5	Teams SHALL fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	The Aerodynamics Lead selects the same motor for both competition launch and the VDF. If the selected motor cannot be flown for VDF due to extenuating circumstances, the Project Management Team requests a waiver for an alternative motor in advance.	Inspection	Aerodynamics, Project Management	Verified	The motor selection can be viewed in Section 3.2.8.

2.19.1.6	The launch vehicle SHALL be flown in its fully ballastsed configuration during the full scale test flight. Fully ballastsed refers to the maximum amount of ballasts that SHALL be flown during the competition launch flight. Additional ballasts SHALL not be added without a re-flight of the full scale launch vehicle.	The Aerodynamics Lead determines the fully ballastsed configuration. The Structures Lead installs the needed ballasts for the full scale test.	Inspection	Aerodynamics, Structures	Verified	See section 6.1 pertaining to ballast used during VDF.
2.19.1.7	After successfully completing the full scale Vehicle Demonstration Flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The Project Management Team does not allow any further modifications of the launch vehicle or its components after VDF without NASA and RSO approval.	Inspection	Project Management	Verified	The launch vehicle will not be changed due to a successful VDF.
2.19.1.8	Proof of a successful Vehicle Demonstration Flight SHALL be supplied in the FRR report.	The Project Management Team provides proof of successful VDF in the FRR report.	Inspection	Project Management	Verified	See section 6.1.
2.19.1.8.1	Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead provides complete altimeter data acquired from the VDF in the FRR milestone.	Inspection	Recovery	Verified	See section 6.1.3 for VDF altimeter flight data.
2.19.1.8.2	Quality pictures of the ”as-landed” configuration of all sections of the launch vehicle SHALL be included in the FRR report. This includes but is not limited to nose cone, recovery system, airframe, and booster.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the FRR milestone.	Inspection	Project Management, Recovery	Verified	See section 6.1 pertaining to the as landed configuration.
2.19.1.9	The Vehicle Demonstration Flight SHALL be completed by the FRR submission deadline. No exceptions SHALL be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The Project Management Team completes the VDF by the FRR submission deadline. If re-flight is necessary, the team submits an FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Verified	See Section 6.1.
2.19.2	**Payload Demonstration Flight**. All teams SHALL successfully launch and recover their full scale launch vehicle containing the completed payload prior to the Payload Demonstration Flight deadline. The launch vehicle flown SHALL be the same launch vehicle to flown at competition launch. Requirements 2.19.2.1-4 SHALL be met during the Payload Demonstration Flight.	The Project Management Team launches and recovers the full scale launch vehicle containing the completed payload before the PDF deadline.	Inspection	Project Management	Not Verified	See Section 7.5 for the projected timeline and projected date of PDF.

2.19.2.1	The payload SHALL be fully retained until the intended point of deployment (if applicable). All retention mechanisms SHALL function as designed, and the retention mechanism SHALL not sustain damage requiring repair.	The Integration and Payload Leads ensure the payload is fully retained until the intended point of deployment, with each retention mechanism functioning as designed and not sustaining damage during flight.	Inspection	Integration, Payload	Not Verified	See Section 4.4.3 for the SAIL deployment method.
2.19.2.2	The payload flown SHALL be the final, active version of the payload.	The Project Management and Payload Teams ensures the payload flown during the PDF is the final active version of the payload.	Inspection	Project Management, Payload	Not Verified	The payload has yet to be fully constructed or flown.
2.19.2.3	If Requirements 2.19.2.1-2 are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum SHALL not be required.	The Project Management Team verifies all requirements are met for the VDF and are submitted prior to the FRR deadline. If all requirements are not met, the team performs an additional flight for PDF and submits the FRR Addendum.	Inspection	Project Management	Verified	The team plans to complete the aforementioned requirements by the FRR Addendum deadline as outline in Section 7.5.
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline.	The Project Management Team ensures the PDF is completed by the FRR Addendum deadline.	Inspection	Project Management	Not Verified	See Section 7.5 for the projected timeline and projected date of PDF.
2.20	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR.	The Project Management Team submits an FRR Addendum if the team completes the PDF or NASA required re-flight after the submission of the FRR.	Inspection	Project Management	Verified	The team will submit an FRR Addendum as PDF will take place after the FRR deadline.
2.20.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline SHALL not be permitted to fly a final competition launch.	The Project Management Team ensures PDF and re-flight completion before the FRR Addendum deadline.	Inspection	Project Management	Not Verified	See section 6.1 for successful VDF.
2.20.2	Teams who complete a Payload Demonstration Flight which is not successful may petition the NASA RSO for permission to fly the payload at the final competition launch. Permission SHALL not be granted if the RSO or the Review Panel have any safety concerns.	The Project Management Team petitions the NASA RSO for permission to fly the payload at the final competition launch if the PDF is not successful.	Demonstration	Project Management	Not Verified	See section 7.5 for the projected PDF.

2.21	The team's name and launch day contact information SHALL be in or on the launch vehicle airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information SHALL be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	The Project Management Team includes the team name and launch day contact information on the launch vehicle airframe, and any sections that separate during flight, such that it can be retrieved without the need to open or separate the vehicle.	Inspection	Project Management	Verified	The team name and contact information is included on the airframe of each separating section.
2.22	All Lithium Polymer batteries SHALL be sufficiently protected from impact with the ground and SHALL be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	The Project Management Team and Safety Officer clearly mark all lithium polymer batteries as a fire hazard and sufficiently protects them from impact with the ground.	Analysis, Inspection	Project Management, Safety	Verified	See Section 3.5.3 pertaining to battery suspension.
2.23.1	The launch vehicle SHALL not utilize forward firing motors.	The Aerodynamics Lead selects a motor that is not forward firing.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The Aerodynamics Lead selects a motor that does not utilize motors that expel titanium sponges.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The Aerodynamics Lead selects a motor that is not hybrid.	Inspection	Aerodynamics	Verified	The final motor choice can be seen in Section 3.2.8.
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The Aerodynamics Lead designs the launch vehicle to be launched on a single motor.	Inspection	Aerodynamics	Verified	See Section 3.2 regarding launch vehicle design.
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The Structures Lead fabricates a motor retention system that does not use friction fitting to hold the motor.	Inspection	Structures	Verified	See Section 3.2.9 for motor retention design.
2.23.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The Aerodynamics Lead designs the launch vehicle so that it does not reach Mach 1 at any point in flight.	Analysis	Aerodynamics	Verified	See Section 3.6 for the predicted vehicle velocity.
2.23.7	Vehicle ballasts SHALL not exceed 10% of the total unballastsed weight of the launch vehicle as it would sit on the pad (i.e. a launch vehicle with an unballastsed weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballasts).	The Aerodynamics Lead designs the launch vehicle such that vehicle ballasts does not exceed 10% of the total unballastsed weight of the launch vehicle.	Analysis, Inspection	Aerodynamics	Verified	See Section 3.6 pertaining to the addition of ballasts.
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The Recovery and Payload Leads choose onboard transmitters that do not exceed 250 mW of power (per transmitter).	Analysis	Recovery, Payload	Verified	The GPS transmitters can be viewed in Section 3.5.

2.23.9	Transmitters SHALL not create excessive interference. Teams SHALL utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The Recovery and Payload Leads select transmitters that create minimal interference. The Safety Lead ensures the use of unique frequencies to mitigate interference with other teams.	Analysis, Demonstration	Recovery, Payload, Safety	Verified	The transmitters can be viewed in Section 3.5.
2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the launch vehicle. Use of lightweight metal SHALL be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The Structures Lead fabricates the launch vehicle to have the minimal amount of metal used in the construction of the vehicle.	Inspection	Structures	Verified	See Section 3.4 for the launch vehicle materials.
Recovery Requirements						
3.1	The full scale launch vehicle SHALL stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	The Recovery Team ensures the launch vehicle is configured to fire a drogue parachute at apogee and a main parachute no later than 500 ft. AGL for both halves of the launch vehicle.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to parachute deployment.
3.1.1	The main parachute SHALL be deployed no lower than 500 ft.	The Recovery Team ensures the main parachute deployment charge is programmed to fire prior to reaching 500 ft. for any and all independently descending launch vehicle segments.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to parachute deployment.
3.1.2	The apogee event SHALL contain a delay of no more than 2 seconds.	The Recovery Team designs a recovery system that has an apogee event delay of no more than 2 seconds.	Demonstration	Recovery	Verified	See Section 3.5 pertaining to recovery design.
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	The Recovery Team designs a recovery system that does not utilize motor ejection.	Inspection	Recovery	Verified	See Section 3.5.7 pertaining to parachute ejection.
3.2	Each team SHALL perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale launch vehicles.	The Recovery Team performs ejection tests prior to each launch, confirming all recovery electronics are performing correctly.	Demonstration	Recovery	Verified	See Section 7.1.10 pertaining to ejection testing.

3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by Vehicle Demonstration Flight data, stays under 65 ft-lbf will be awarded bonus points.	The Recovery Team designs a recovery system such that the maximum kinetic energy experienced by the heaviest section of the launch vehicle does not exceed 65 ft-lbf.	Analysis	Recovery	Verified	See Section 3.6.6 for kinetic energy calculations.
3.4	The recovery system SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of launch vehicle recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The Recovery Team designs a recovery system that uses primary and secondary altimeters for any and all AV bays.	Inspection	Recovery	Verified	See Section 3.5.3 for altimeter selection.
3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The Recovery Team designs a recovery system that uses a separate, dedicated power supply, utilizing commercially available batteries, for any and all AV bays.	Inspection	Recovery	Verified	See Section 3.5.3 for the altimeter power supply.
3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the launch vehicle is in the launch configuration on the launch pad.	The Recovery Team designs a recovery system that uses pin switches to activate any and all altimeters from the exterior of the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5.3 for the altimeter arming method.
3.7	Each arming switch SHALL be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The Recovery Team designs a recovery system that uses arming switches that can be locked in the ON position for launch.	Inspection	Recovery	Verified	See Section 3.5.3 for the arming method.
3.8	The recovery system, including GPS and altimeters, electrical circuits SHALL be completely independent of any payload electrical circuits.	The Recovery Team designs a recovery system containing recovery electronics that are completely independent of the payload electronics.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The Recovery Team designs a recovery system that uses removable shear pins such that separable sections of the launch vehicle are secured together on the pad and during launch.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.10	Bent eyebolts SHALL not be permitted in the recovery subsystem.	The Recovery Team designs a recovery system that does not use any bent eyebolts.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.

3.11	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The Recovery Team designs a recovery system containing parachutes that does not allow any separately descending segment of the launch vehicle to drift more than a 2,500 ft radius from the launch pad.	Analysis, Demonstration	Recovery	Verified	See Section 3.6.8 regarding wind drift calculations.
3.12	Descent time of the launch vehicle SHALL be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by Vehicle Demonstration Flight data, stays under 80 seconds SHALL be awarded bonus points.	The Recovery Team designs a recovery system containing parachutes that allows any separately descending segments of the launch vehicle to safely land within 80 seconds of launch.	Analysis, Demonstration	Recovery	Verified	See Section 3.6.7 for the calculated descent time.
3.13	An electronic GPS tracking device SHALL be installed in the launch vehicle and SHALL transmit the position of the tethered vehicle or any independent section to a ground receiver.	The Recovery Team designs a recovery system containing a GPS tracking device that transmits the position of each independent section of the launch vehicle.	Inspection, Demonstration	Recovery	Verified	See Section 3.5.3 for the tracking system.
3.13.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic GPS tracking device.	The Recovery Team installs GPS tracking devices on any independent sections that land untethered to the launch vehicle.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.13.2	The electronic GPS tracking device(s) SHALL be fully functional during the official competition launch.	The Recovery Team tests GPS devices to ensure they remain completely functional during the official launch competition.	Inspection, Demonstration	Recovery	Not Verified	See Section 7.1.3 for testing of launch vehicle GPS trackers.
3.14	The recovery system electronics SHALL not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The Recovery Team designs a recovery system containing recovery electronics that are not affected by any other on-board electronic device.	Inspection, Demonstration	Recovery	Not Verified	See Section 3.5 for the recovery design.
3.14.1	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 Team designs an AV bay containing altimeters in a compartment that is physically separate from any other radio frequency transmitting or magnetic wave-producing devices.	Inspection	Recovery	Verified	See Section 3.5.3 for the avionics placement.
3.14.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The Recovery Team designs an AV bay containing recovery electronics that is shielded from all other onboard transmitting devices.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
3.14.3	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 Team designs an avionics bay containing recovery electronics that is shielded from all other onboard magnetic wave generating devices.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.

3.14.4	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 Team designs an AV bay containing recovery electronics that is shielded from all other onboard devices that may adversely affect the proper operation of the recovery system electronics.	Inspection	Recovery	Verified	See Section 3.5 for the recovery design.
Payload Requirements						
4.1	**SL Payload Mission Objective** — College/University Division — Teams SHALL design a STEMnauts Atmosphere Independent Lander (SAIL). SAIL is an in-air deployable payload capable of safely retaining and recovering a group of 4 STEMnauts in a unique predetermined orientation without the use of a parachute or streamer. The landing SHALL occur under acceptable descent and landing parameters for the safe recovery of human beings. A STEMnaut SHALL be defined as a non-living crew member, to be physically represented as the team chooses, and is assumed to have human astronaut survivability metrics. The method(s)/design(s) utilized to complete the payload mission SHALL be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to a proposed payload.	The Payload and Integration Teams design a payload that is capable of safely returning the STEMnauts from the flight, follows all safety, FAA and NAR requirements, and is in accordance with the spirit of the competition.	Demonstration	Payload Electronics, Payload Structures, Payload Systems, Integration	Verified	See Section 1.3 for the payload design.
4.2.1	Teams SHALL not use parachutes or streamers that are commercially available or custom made. A parachute is defined as an open-faced canopy whose primary function is to reduce descent speed or increase drag. A streamer is defined as a long, narrow strip of material (typically affixed at one end) whose primary function is to reduce descent speed or increase drag.	The Payload Structures Team designs a SAIL that does not utilize any parachutes or streamers for recovery operations.	Inspection	Payload Structures	Verified	See Section 4.4.3 for the SAIL release system.
4.2.2	The SAIL SHALL be a minimum of 5 lbs inclusive of the jettisoned or separated landing capsule and the 4 STEMnauts.	The Payload Structures Team designs a SAIL that has a final weight of at least 5 lbs.	Inspection	Payload Structures	Verified	See Section 4.4.2 for the SAIL design.

4.2.3	Deployment of the SAIL SHALL occur between 400 and 800 ft. AGL. See Requirement 4.3.3 for deployment/jettison of payloads.	The Payload Structures, Recovery, and Integration Teams ensure SAIL ejection is designed to be within 400 and 800 ft. AGL.	Demonstration	Payload Structures, Recovery, Integration	Verified	See Section 4.4.3 for the SAIL deployment method.
4.2.4	The team SHALL pre-determine and land in a unique landing orientation to be verified by NASA personnel in Huntsville or by a non-affiliated NAR/TRA rep for at-home launches.	The Payload Teams design a SAIL that has a clear and defined landing orientation.	Demonstration	Payload Electronics, Payload Structures, Payload Systems	Not Verified	See Section 4.1 pertaining to landing orientation.
4.2.5	Teams SHALL design and implement a method of retention and ingress/egress for the STEMnauts.	The Payload Teams design a SAIL that retains the STEMnauts and allows easy access to the crew cabin for ingress/egress operations.	Inspection	Payload Electronics, Payload Structures, Payload Systems	Verified	See Section 4.4.2 for the the payload design.
4.2.6	Teams SHALL determine acceptable descent and landing parameters, to be approved by NASA, and design their lander to meet those requirements.	The Payload Teams design a SAIL that has a final landing speed of 15 mph (according to criteria for NASA's Orion spacecraft) and limits angular velocity so that the STEMnauts experience a maximum of 3gs (according to NASA's Space Shuttle launch criteria).	Demonstration	Payload Electronics, Payload Structures, Payload Systems	Verified	See Section 4.1 for the success criteria.
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	The Payload, Recovery, and Integration Teams ensure that no energetics are used outside of in-flight recovery operations.	Inspection	Payload Structures, Recovery, Integration	Verified	See Section 4.4.2 for the payload design.
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The Safety Team reviews the SAIL design throughout the design process to ensure compliance with all FAA and NAR rules and regulations.	Inspection	Safety	Verified	See Section 4.2 pertaining to all safety regulations.
4.3.3	Any payload experiment element that is jettisoned during the recovery phase SHALL receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	The Payload Systems and Safety Teams ensure that payload is not jettisoned without receiving RSO authorization.	Demonstration	Payload Systems, Safety	Not Verified	See Section 4.4.3 for the SAIL release system.
4.3.4	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 Systems and Safety Teams ensures that any UAS that is deployed during the descent phase of flight is tethered to the vehicle and released on command after RSO permission is received.	Demonstration	Payload Systems, Safety	Verified	Payload is not classified as a UAS as outlined in Section 4.2.

4.3.5	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; see https://www.faa.gov/uas/faqs).	The Payload and Safety Teams ensure that any UAS is flown in full compliance with FAA regulations.	Inspection	Payload Electronics, Payload Structures, Payload Systems, Safety	Verified	See Section 4.2 pertaining to UAS status.
4.3.6	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	The Payload and Safety Teams ensure that any UAS weighing more than .55 lbs is registered with the FAA and the registration number is clearly marked on the vehicle.	Inspection	Payload Structures, Payload Systems, Payload Electronics, Safety	Verified	See Section 4.2 pertaining to UAS status.
Safety Requirements						
5.1	Each team SHALL use a launch and safety checklist. The final checklists SHALL be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Checklists are included in the FRR and are used during LRR and Launch Day activities.	Validation of Records	All	Verified	See Section 5.3 for the current launch and safety checklist. The final checklist used during launch day will be included in FRR.
5.2	Each team SHALL identify a student Safety Officer who will be responsible for all requirements in Section 5.3.	The student Safety Officer, Megan Rink, is responsible for requirements listed in Section 5.3.	Validation of Records	Safety	Verified	The team has identified the student Safety Officer for the 2023-2024 year.
5.3.1.1	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during design of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities.
5.3.1.2	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during construction of vehicle and payload components.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities, tracking injuries with an incident report sheet.
5.3.1.3	The designated Safety Officer SHALL monitor team activities with an emphasis on safety during assembly of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer has and will continue to monitor team activities, tracking injuries with an incident report sheet.
5.3.1.4	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during ground testing of vehicle and payload.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer is present for all ejection tests and tracks any injuries with an incident report sheet.
5.3.1.5	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during subscale launch test(s).	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The safety checklists for subscale launch can be viewed in the CDR report and full scale checklists in Section 5.3.

5.3.1.6	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during full scale launch test(s).	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	See Section 5.3 for the current launch and safety checklist.
5.3.1.7	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during competition launch.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Not Verified	The Safety Officer is listed to attend the competition launch.
5.3.1.8	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer assists and attends recovery activities.
5.3.1.9	The designated student Safety Officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The student Safety Officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety	Verified	The Safety Officer monitored previous STEM engagement activities and will continue to do so for future events.
5.3.2	The designated student Safety Officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The Safety Team writes and implements procedures and checklists for assembling, launching, and recovering the launch vehicle.	Demonstration	Safety	Verified	See section 5.3 pertaining to full scale checklists.
5.3.3	The designated student Safety Officer SHALL manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The student Safety Officer manages all safety documentation for the team.	Inspection	Safety	Verified	See Section 5 for safety documentation.
5.4	During test flights, teams SHALL abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams SHALL communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The Safety Team ensures all local rocketry club rules and regulations are followed by all team members.	Demonstration	Safety	Not Verified	The team has previously and will continue to abide by local RSO guidelines during test flights.
5.5	The team SHALL abide by all rules set forth by the FAA.	The Safety Team ensures all rules from the FAA are followed.	Demonstration	Safety, Project Management	Verified	The Safety Officer ensures team members follow FAA regulations at all times.
Final Flight Requirements						

6.1	Teams SHALL conduct the final flight in Huntsville during Launch Week, NASA Launch Complex, by the applicable deadlines as outlined in the Timeline for NASA Student Launch.	The team completes final flight at the NASA Launch Complex by the deadline given in the timeline for NASA Student Launch.	Demonstration	Project Management	Not Verified	See Section 7.5 for the project timeline.
6.1.1	Teams SHALL not show up at the NASA Launch Complex outside of launch day without permission from the NASA management team.	The team requests permission from the NASA management team if needing to show up at the NASA Launch Complex outside of launch day.	Demonstration	Project Management	Not Verified	The team plans to show up to the NASA Launch Complex on launch day.
6.1.2	Teams SHALL complete and pass the Launch Readiness Review conducted during Launch Week.	The team completes and passes the Launch Readiness Review.	Inspection; Demonstration	Project Management	Not Verified	The team plans to prepare for LRR prior to launch week.
6.1.3	The team mentor SHALL be present and oversee launch vehicle preparation and launch activities.	The team mentor oversees all launch activities.	Demonstration	Team Mentor	Not Verified	The team mentor has and will continue to oversee launch related activities.
6.1.4	The scoring altimeter SHALL be presented to the NASA scoring official upon recovery.	The recovery lead presents the scoring altimeter to the NASA scoring official.	Demonstration	Recovery	Not Verified	The Recovery Lead is responsible for altimeter recovery.
6.1.5	Teams SHALL launch only once. Any launch attempt resulting in the launch vehicle exiting the launch pad, regardless of the success of the flight, SHALL be considered a launch. Additional flights beyond the initial launch, SHALL not be scored and SHALL not be considered for awards.	The team launches the launch vehicle only once.	Inspection; Demonstration	Project Management	Not Verified	The team plans to perform extensive testing to ensure launch vehicle success as outlined in Section 7.

7.3.2 Team Derived Requirements

Table 7.26: Launch Vehicle Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
LVF 1	The launch vehicle SHALL be designed with removable ballasts.	Design changes made to the vehicle or payload after the PDR milestone may dictate a modification to the total ballasts of the vehicle.	Ballasts is not permanently mounted to the vehicle allowing for removal or addition with hand tools.	Inspection	Verified	See Section 3.6 pertaining to ballasts and Section 3.2.6 for the removable fin system.
LVF 2	The launch vehicle apogee verification SHALL be conducted by no less than 3 separate analysis programs.	Multimodal analysis of the apogee of the vehicle will increase the confidence in the apogee declared in the competition.	At least three different analysis programs are used in the development of a target apogee for the launch vehicle.	Inspection	Verified	See Section 3.6 regarding apogee calculations.
LVF 3	Vehicle Demonstration Flights SHALL be completed at least 3 weeks prior to NASA Student Launch Week.	In the event the launch vehicle sustains heavy damage, this gives adequate time to make any repairs before competition.	The date of the VDF is at least 3 weeks before the start of NASA Student Launch Week.	Demonstration	Verified	See section 6.1 for VDF.
LVF 4	Fins SHALL experience minimum damage hitting the ground at greater than or equal to the predicted impact kinetic energy of the launch vehicle's fin can.	As the launch vehicle lands, the fins will need to sustain minimal damage in case of a re-launch.	The fins are tested to determine how much damage, if any, is inflicted when dropped at the impact kinetic energy.	Inspection, Demonstration	Verified	See Section 7.1.5 for fin test results.
LVF 5	Rivets SHALL have a factor of safety greater than or equal to 2.	The rivets are responsible for holding non-separating launch vehicle sections together during flight and must be reliable.	Rivets used on the launch vehicle are tested and only used if the factor of safety is greater than or equal to 2.	Inspection, Demonstration	Verified	See Section 7.1.6 for test results.
LVF 6	Shear pins SHALL fail under a range of 35-40 lb loads.	The shear pins are responsible for holding separating launch vehicle sections together during flight and must be reliably fail to separate desired sections with black powder charges.	Shear pins used on the launch vehicle are tested and only used if they fail reliably under a 35 ± 1 lb. load.	Inspection, Demonstration	Verified	See Section 7.1.7 for test results.
Design Requirements						
LVD 1	The launch vehicle SHALL have four symmetrical fins.	Maximizing the aerodynamic surface area of the fins will increase the fin control authority of the launch vehicle's trajectory, reducing the risk of launch vehicle instability during flight as well as ensure the CG is centered.	The launch vehicle has four symmetrical fins mounted to the removable fin system.	Inspection	Verified	See Section 3.2.7 for the fin design.

LVD 2	The launch vehicle SHALL be designed with fins that do not contain curved geometry.	Complex fin geometry reduces the manufacturability of the fins increasing the amount of labor and cost of producing flight and critical spares of the fins.	The fins contain a linear external profile.	Inspection	Verified	See Section 3.2.7 pertaining to the fin design.
LVD 3	Bulkheads SHALL not fracture under tensile stress less than the maximum shock force.	Bulkheads are in place for structural integrity as well as parachute and shock cord attachments. Thus, the bulkheads need to withstand any forces experienced during flight.	The fabricated bulkheads will are made with a material strong enough to withstand shock forces.	Inspection, Demonstration	Verified	See Section 7.1 for bulkhead test results.
LVD 4	The motor tube SHALL be supported by at least 2 centering rings.	Provides adequate support to the motor tube when the motor is experiencing forces during launch.	The launch vehicle has three centering rings supporting the motor tube.	Inspection	Verified	See Section 3.2.9 pertaining to motor retention.
LVD 5	The launch vehicle SHALL have a stability margin between 2.0 and 3.0 upon rail exit.	A stability margin of 2.0 or greater is needed per NASA Requirement 2.14. With a maximum stability of 3.0, undesired weather cocking can be avoided when launching in high winds.	The estimated launch vehicle stability will be between 2.0 and 3.0.	Analysis	Verified	See Section 3.6 for expected stability margin of the launch vehicle design.
LVD 6	The launch vehicle stability margin SHALL maintain a variability of no more than 0.75 calibers between the subscale and full scale vehicle.	Modification of the launch vehicle's center of pressure and center of gravity by more than 5 percent of the launch vehicle's length degrades the validity of subscale testing.	The stability of the subscale and full scale launch vehicle evaluate to a difference of no more than 0.75 calipers.	Analysis	Verified	See Section 3.6 for expected stability margin of the launch vehicle design.
LVD 7	The launch vehicle SHALL not exceed a maximum velocity of Mach 0.7.	High launch vehicle atmospheric loading increases the risk of structural component and payload hardware damage.	Simulations dictate a maximum launch vehicle velocity of no more than Mach 0.7.	Analysis	Verified	See Section 3.6 for the calculated velocity.
LVD 8	The Launch vehicle SHALL not exceed a maximum instantaneous acceleration of 14 G's during flight.	High acceleration of the vehicle during flight increases the risk of structural safety margin degradation along with the risk of payload hardware damage.	Simulations dictate a maximum launch vehicle acceleration of no more than 14 G's of acceleration during the entire flight profile.	Analysis	Verified	See Section 3.6 for performance predictions.
LVD 9	The launch vehicle SHALL use no more than 4 pounds of ballasts in the nose cone.	Volume constraints within the nose cone of the launch vehicle dictate a finite amount of ballasts that can reasonably be placed within the section.	The ballasts measurement of the full scale vehicle is at or below 4 pounds.	Inspection	Verified	See Section 3.6 pertaining to ballasts.
LVD 10	The launch vehicle SHALL be developed with a methodology for altering the final mass of the vehicle by at least 0.25 lb on the day of launch.	Variability of wind speeds on the day of launch may dictate the addition of additional ballasts to compensate for cosine losses of total apogee.	A system for the alteration of the final vehicle mass by at least 0.25 lb is incorporated into the vehicle.	Inspection	Verified	See Section 3.6 pertaining to ballasts and Section 3.2.6 for the removable fin system.

LVD 11	The launch vehicle SHALL be designed to minimize cyclical angle of attack oscillations during liftoff.	Minimization of cyclical oscillations of the launch vehicle during flight will improve the probability of the vehicle achieving the target apogee.	Specific targeted analysis is presented in the CDR regarding design decisions made to minimize cyclical angle of attack oscillations	Inspection	Verified	See Section 3.2 pertaining to launch vehicle design.

Table 7.27: Recovery Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
RF 1	All batteries (9 V and LiPos) SHALL be fully charged before every flight.	The tracker may not sufficiently work or black powder might not be properly ignited if there is insufficient voltage.	All batteries will be determined as fully charged before being inserted into the AV sled.	Inspection, Analysis	Not Verified	Fully charged 9 V batteries and LiPos were utilized during subscale launch and VDF and will be used for future full scale flights.
RF 2	The secondary black powder charges SHALL be 0.5 grams larger than the primary charge.	The secondary charges are in place if the primary charges do not initially separate the sections of the launch vehicle. The secondary charges have to be larger than the primary charges to ensure complete separation during flight.	The black powder added to the secondary blast cap will be 0.5 grams more than the amount in the primary blast cap.	Inspection	Verified	See Section 3.5.7 for ejection charge sizing.
RF 3	Altimeter testing SHALL be successful and accurate before any vehicle launch.	Altimeters are detrimental to ensuring parachute deployment at desired altitudes and therefore needs to precisely measure the vehicle height.	All altimeters are tested and only placed on the AV sled if working properly.	Analysis, Demonstration	Verified	See Section 7.1.4 for altimeter test results.
RF 4	Any GPS used on the launch vehicle SHALL detect the vehicle within 100 ft. of its actual location.	The launch vehicle may not be recovered if the tracker does not accurately locate the section.	Any tracker used in the launch vehicle is tested to ensure it detects the transmitter location within 100 ft.	Demonstration	Verified	See Section 7.1.3 for tracker test results.
RF 5	Successful ejection testing, meaning separation of launch vehicle sections, SHALL be completed before any launch.	Ejection testing ensures the black powder charges are strong enough to break the shear pins and separate the vehicle sections.	The vehicle is not launched until sections are separated during ejection testing.	Demonstration	Verified	See Section 7.1.10 for full-scale ejection testing results.
RF 6	All shock cord SHALL be accordion folded before being placed into the launch vehicle.	This type of folding prevents the shock cord from being tangled while stored within the launch vehicle.	All shock cord will be accordion folded before being attached to U-bolts and placed inside the launch vehicle.	Inspection, Demonstration	Verified	The Project Manager and Recovery Lead verify that shock cord has been properly folded, and will continue to do so for future full scale launches.
RF 6.1	After folding, all shock cord SHALL be loosely secured with a rubber band.	To keep shock cord properly folded until separation, a rubber band is used to keep the shock cord from unraveling. Additionally, the rubber band is tied loosely in order to allow the shock cord to come apart during separation.	All shock cord is folded in half and secured with a rubber band after being accordion folded.	Inspection	Verified	The project manager and Recovery Lead verify that the shock cord is secured with a rubber band, and will continue to do so for future full scale launches.

RF 7	Parachute shroud lines SHALL be detangled before folding the parachute.	Tangled shroud lines may prevent the parachute from fully opening during descent.	Parachute shroud lines will be detangled to the point they are mostly separated from other shroud lines before folding the parachute.	Inspection, Demonstration	Verified	Shroud lines are detangled prior to folding the parachutes.
RF 8	Parachutes SHALL be folded accordion style and tightly rolled before being placed within the launch vehicle.	By folding the parachutes this way, it allows the parachute to open fully during descent while keeping them compact when placed in the launch vehicle.	All parachutes are folded accordion style and tightly rolled before being inserted into the launch vehicle.	Inspection, Demonstration	Verified	The parachutes will continue to be properly folded before or on launch day.
Design Requirements						
RD 1	A deployment bag SHALL be used to protect the main parachute from ejection gasses.	If exposed to ejection gasses, the main parachute may burn/melt causing the parachute to fail. Additionally, the deployment bag prevents the main parachute shock cords from tangling with other shock cords within the launch vehicle.	The main parachute will be fully inserted into a deployment bag before being put into the launch vehicle.	Inspection	Verified	See Section 3.5 pertaining to parachute protection.
RD 2	Drogue and payload parachutes SHALL be wrapped in Nomex cloth.	If exposed to ejection gasses, the parachutes may burn/melt causing the parachutes to fail.	The drogue and payload parachutes will be fully wrapped inside a Nomex cloth before being attached to the respective shock cords and bays.	Inspection	Verified	See Section 3.5 pertaining to Nomex cloth.
RD 3	U-Bolts SHALL be used for all shock chord connections.	Using U-bolts disperses the shock to multiple points, increasing bulkhead stability.	U-bolts are used on every bulkhead as an anchor point for the recovery harness.	Inspection	Verified	U-bolts will be added to bulkheads for shock chord connections.
RD 4	Threaded quick-links SHALL be used for all recovery harness and U-bolt connections.	Threaded quick links are easy to install around U-bolts and are unlikely to detach during flight.	Quick links will be used to attach any recovery harness to its respective U-bolt.	Inspection	Verified	Threaded quick links will be used to attach recovery harnesses during launch vehicle assembly.
RD 4.1	All quick links used for recovery harness and U-bolt connections SHALL be wrapped in electrical tape at the threaded link.	Quick links are the only thing holding the recovery harnesses to the U-bolts. Therefore, to prevent them from unscrewing when experiencing flight forces, electrical tape is used to keep the quick links fastened.	All quick links will be wrapped in electrical tape during launch vehicle assembly.	Inspection, Demonstration	Verified	Adding electrical tape onto the quick links is a step on the checklist for previous and future launches.
Environmental Requirements						
RE 1	Protective insulation SHALL be biodegradable.	In the case insulation falls out of the launch vehicle, the insulation used will have no negative environmental consequences.	There will be verification of biodegradable insulation before inserting into the parachute bays.	Inspection	Verified	See Section 3.5 for insulation use.

RE 2	Rubber bands used for shock cord folding SHALL be biodegradable.	The rubber bands will fall off the shock cord during separation. Thus, the rubber bands used will have no negative environmental impacts.	The rubber bands purchased will be verified as biodegradable before using them for shock cord.	Inspection	Verified	The rubber bands that have been purchased for club use are biodegradable.

Table 7.28: Payload Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
PF 1	All electronic components in the launch vehicle SHALL be removable.	With removable electronics, easier adjustments can be made to the payload design.	No electronic components within the launch vehicle are fixed in place.	Inspection, Demonstration	Verified	See Section 4.6 pertaining to payload electronics.
PF 2	The RF transmitter and receiver for release SHALL have an operational range of at least 2500 ft.	While the SAIL will be deployed at a maximum of 800 ft, the possibility of wind drift increases the chance of a large distance between the receiver and transmitter. This minimum specification will allow for the release latch to be operational over long distances.	Before inserting the transmitter and receiver in the SAIL, it will be tested and verified to have an operational range of at least 2500 ft.	Inspection, Demonstration	Verified	See Section 7.2.5 for RF transmitter results.
PF 3	The SAIL deployment latch SHALL withstand up to 100 lb. of tensile force.	The latch must not release the SAIL while experience forces during flight until given the command to do so.	The latch used can withstand at least 100 lb. of tensile force.	Inspection, Demonstration	Verified	See Section 7.2.6 for the testing results of the SAIL deployment latch.
PF 4	Rotor blades and landing legs SHALL immediately deploy after leaving the deployment bay.	Extended rotor blades are needed to immediately produce thrust while the landing legs need to be extended to create drag and ensure vertical landing orientation.	The rotor blades and landing legs are designed to immediately extended after exiting the deployment bay.	Demonstration	Not Verified	See Section 4.4.3 for the SAIL deployment method.
PF 5	The SAIL rotor blades SHALL produce up to 8 lb. of thrust.	The rotor blades need to produce enough thrust to counteract the weight of the SAIL, but only needs to generate enough thrust to slow the SAIL's descent.	The motor and propeller blades are designed to allow the rotors to produce up to 8 lb. of thrust.	Analysis, Demonstration	Not Verified	See Section 7.2.7 for testing procedures of the rotor blades.
PF 6	Adhesion methods used for propeller blade sections SHALL withstand at least 300 lb.	During the SAIL's descent, the propeller blades must remain intact to produce lift and spin at the desired RPM.	A strong adhesive is used to connect the propeller blade sections.	Inspection, Demonstration	Verified	See Section 7.2.3 for the rotor blade adhesion results.
PF 7	SAIL landing legs SHALL withstand a force of 35 lb during impact with the ground.	To remain in its upright orientation, the SAIL landing legs must be able to withstand the force of impact with the ground during landing.	The landing legs are designed to withstand the forces of impact during landing.	Inspection, Demonstration	Not Verified	See Section 7.2.4 for the testing procedures of the landing legs.
Design Requirements						
PD 1	The SAIL SHALL land with an impact velocity of less than 15 mph.	Having a descent velocity greater than 15 mph increases risk to the STEMnauts by applying greater G forces and higher velocity upon landing.	The rotor blades produce enough thrust to maintain a descent velocity less than or equal to 15 mph.	Analysis, Demonstration	Not Verified	See Section 4.4.2 pertaining to the SAIL propulsion methods.

PD 2	The SAIL SHALL not experience more than 3 G's of sustained centripetal forces or 6 G's of force for 1 second during the descent.	Having more than 3 G's of centripetal force and a maximum of 6 G's increases risk to the STEMnauts during descent.	Contra-rotating blades spinning at a similar RPM will help minimize spinning of the SAIL.	Analysis, Demonstration	Not Verified	See Section 4.3 pertaining to survivability metrics.
PD 3	The SAIL SHALL land in a vertical orientation resting on the extended landing legs.	Landing in a vertical orientation reduces risk to STEMnauts upon landing at a higher velocity. Resting upon the landing legs prevents the hub from tipping over.	The landing legs span wider than the base of the hub to provide sufficient support upon landing.	Inspection, Demonstration	Not Verified	See Section 4.4.2 pertaining to the landing legs.
PD 4	The contra-rotating rotor blades SHALL rotate at the same RPM.	This eliminates rotation caused by imbalanced aerodynamic torque on the rotors.	The contra-rotating rotors will be designed to work off one motor to ensure the rotors are operating at the same RPM.	Analysis, Demonstration	Not Verified	See Section 4.4.2 pertaining to gearbox assembly.
PD 5	The SAIL SHALL be a maximum of 8 lb. in total.	Keeping the weight at a reasonable value facilitates a lightweight launch vehicle and improves the performance of the rotor blades.	The SAIL will be a minimum of 5 lb., as per NASA Requirement 4.2.2, and a maximum of 8 lb.	Inspection	Not Verified	See Section 4.4.2 pertaining to the payload weight breakdown.

Table 7.29: Safety Team Derived Requirements

ID	Description	Justification	Success Criteria	Verification Method	Status	Status Description
Functional Requirements						
SF 1	Epoxy SHALL cure for at least 24 hours.	The chances of structural failure increases when using uncured epoxy as it weakens the structural integrity of the launch vehicle.	Parts using epoxy are labeled and untouched until the time and date shown on the label.	Inspection	Verified	Current fabrication procedures resulted in at least 24 hours of curing for all epoxied parts.
SF 2	Persons working with or around power tools SHALL wear safety glasses.	Wearing PPE during power tool operation reduces the risk of skin and eye injury from debris.	Safety glasses provided for every working HPRC member are located in the rocketry lab's PPE closet.	Inspection	Verified	25 pairs of safety glasses are kept in the PPE closet which exceeds lab capacity.
SF 3	Persons working with explosive liquids and/or powders SHALL wear nitrile gloves, safety glasses, and particulate masks.	Wearing PPE when working with hazardous liquids and/or powders reduces the risk of skin and eye injury from debris.	Gloves, safety glasses, and masks provided for every working HPRC member are located in the rocketry lab's PPE closet.	Inspection	Verified	7 boxes of nitrile gloves, 25 pairs of safety glasses, and 2 cases of masks are kept in the PPE closet which exceeds lab capacity.
SF 4	When attending the launch field, all personnel SHALL maintain a walking pace.	Walking at a steady pace decreases the risk of falling, tripping, or slipping.	Members attending launch day will maintain a steady walking place while on the launch field.	Inspection	Verified	Team members have and will continue to be briefed before launches on launch field safety and etiquette.
SF 5	Hazards labeled orange or red during risk assessment SHALL be decreased to yellow or green by CDR.	Filtering frequent and/or potentially dangerous hazards allows for a more durable launch vehicle and payload system.	After mitigation, all hazards included in CDR will fall in the yellow or green zones.	Inspection	Verified	All potential hazards fall in the green or yellow zones.
SF 6	All hazardous or flammable liquids and powders SHALL be stored in the flame cabinet when not in use.	Storing hazardous powders and liquids in a fireproof cabinet reduces risk of injury to students and lab equipment.	Hazardous liquids and powders remain in the flame cabinet unless actively being used by a team member.	Inspection	Verified	All hardeners, resins, lubricants, cleaners, aerosol paints, black powder, oxidizers, and igniters used by the team are stored in a JUSTRITE Flammable Liquid Storage Cabinet.
SF 7	Persons observing ejection testing SHALL stand at least 5 ft. to the side of the launch vehicle.	During ejection testing, the distance at which the launch vehicle separates or the effects of the black powder explosion are unknown. As a safety precaution, all observers should be at a safe distnace away.	During ejection testing, spectators do not stand in front or less than 5 ft. away from the launch vehicle.	Inspection	Verified	The Safety Officer is present during any ejection testing to ensure onlookers maintain a safe distance away.
SF 8	Persons attending SAIL deployment demonstrations SHALL refrain from being directly under the deployment bay.	The SAIL is dropped out of the deployment bay. Thus, in the event the rotors do not produce enough thrust, there is risk of injury.	Personnel attending SAIL deployment experimentation will refrain from being directly under the deployment bay.	Inspection, Demonstration	Not Verified	Once SAIL deployment experimentation takes place, everyone will remain a safe distance from the deployment drop site.

SF 9	SAIL electronics SHALL contain a kill switch.	If the SAIL does not work as intended or risks harming onlookers, a kill switch eliminates the rotor blades from spinning.	A kill switch will be utilized to stop the SAIL's motor in any case deemed necessary.	Demonstration	Not Verified	A tested kill switch is integrated into the SAIL electronics.
SF 10	Buckets filled with sand SHALL be brought to launches if any electronics utilize LiPo batteries.	LiPo batteries are at risk of exploding which can be stifled by submerging the batteries in sand.	Pre filled sand buckets are brought to every vehicle launch.	Inspection	Verified	Buckets of sand are kept in the HPRC lab and brought to every launch.
SF 11	All energetics SHALL be stored in a locking energetics container during travel.	Energetics have the potential to combust and therefore need to be secured inside a fireproof container to ensure everyone's safety during transport.	Any explosive or combustible products are kept inside a locking energetics container when traveling to the launch site.	Inspection, Demonstration	Verified	The club owns a locking energetics container that remains in the lab and is used for transporting hazardous materials.
SF 12	Altimeters SHALL not be armed while connected to live black powder charges.	If altimeters are armed and connected to live black powder charges, there is risk of accidentally detonating the black powder.	The pull-pin switch used to disarm the altimeters will remain inserted until the rocket is ready to launch on the launch pad.	Inspection	Verified	The Safety Officer and Recovery Lead ensure the pull-pin switch remains inserted until the vehicle is on the launch pad.
Environmental Requirements						
SE 1	All trash SHALL be disposed of before leaving the launch site.	Leaving trash may be harmful to the launch field as not everything used throughout launch day is biodegradable.	The team brings garbage bags to the launch site to dispose of any trash.	Inspection, Demonstration	Verified	The team picks up and disposes of any trash found at the launch site.
SE 2	All non-hazardous electronics SHALL be disposed of in the designated electronic recycling buckets.	Electronics that are not properly disposed of may later cause harm to the environment by contributing to toxic pollutants.	All non-hazardous electronics will be disposed of in the yellow recycling buckets located on NC State's campus.	Demonstration	Verified	There are various recycling buckets located on campus for proper electronic disposal.
SE 3	Live energetics and disarmed LiPo batteries SHALL be disposed of at a waste disposal facility.	Hazardous electronics need to be properly disposed of prevent environmental harm and ensure the safety of club members.	The Safety Officer will transport any live energetics or LiPos to the nearest waste disposal facility.	Demonstration	Verified	The Safety Officer has identified the nearest facility as the Wake County Household Hazardous Waste Facilities.

7.4 Budget

Table 7.30 below details the year-long budget for the 2023-2024 Student Launch Competition.

Table 7.30: 2023-2024 NASA Student Launch Competition Budget

	Item	Quantity	Price Per Unit	Item Total
Subscale Structure	Plastic 4 in. 4:1 Ogive Nosecone	1	$ 29.80	$ 29.80
	4 in. Blue Tube	2	$ 43.95	$ 87.90
	4 in. Blue Tube Pre-Slotted	1	$ 53.50	$ 53.50
	4 in. Blue Tube Coupler	4	$ 12.31	$ 49.24
	AeroTech I435T-14A Motor	2	$ 80.24	$ 160.48
	Aero Pack 38mm Retainer	2	$ 29.17	$ 29.17
	AeroTech RMS-38/600 Motor Casing	1	$ 98.86	$ 98.86
	Standard Rail Button - 1010	2	$ 4.25	$ 8.50
	U-Bolts	4	$ 1.00	$ 4.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 564.55**
Full Scale Structure	6 in. Nosecone Fiberglass Ogive 4:1	1	$ 149.99	$ 149.99
	6 in. G12 Fiberglass Tube (48 in.)	2	$ 228.00	$ 456.00
	AeroTech High-Power L1940X Motor	2	$ 289.99	$ 579.98
	Aero Pack 75mm Retainer	1	$ 59.50	$ 59.50
	AeroTech RMS-75/3840 Motor Casing	1	$ 526.45	$ 526.45
	Domestic Birch Plywood 1/8”x2x2	5	$ 57.99	$ 289.95
	G-10 Fiberglass Sheet Stock	2	$ 72.64	$ 145.28
	Large Rail Button -1515	2	$ 4.25	$ 8.50
	U-Bolts	8	$ 1.00	$ 8.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 2,464.75**
Payload	Carbon Fiber PETG Filament	1	$ 48.99	$ 48.99
	Unidirectional Carbon Fabric	2	$ 15.95	$ 31.90
	Aluminum Sheets	2	$ 13.35	$ 26.70
	PLA Filament	1	$ 25.00	$ 25.00
	Bevel Gear	2	$ 24.99	$ 49.98
	5.5 in. Blue Tube	1	$ 75.50	$ 75.50
	Aluminum Tube Leg	1	$ 19.88	$ 19.88
	Scorpion HKIV Motor	1	$ 320.00	$ 320.00
	Lithium Polymer Battery	1	$ 37.49	$ 37.49
	Cobra 150A ESC	1	$ 104.99	$ 104.99
	XTend 900 Modem	1	$ 283.20	$ 283.20
	MPM3610 Buck Converter	1	$ 5.95	$ 5.95
	Adafruit Feather	1	$ 19.95	$ 19.95
	ESC Programming Card	1	$ 11.95	$ 11.95
	Filament Binding Adhesive	1	$ 34.99	$ 34.99
	Misc. Nuts, Bolts, Springs, etc.	1	$ 298.39	$ 298.39
	Subtotal:			**$ 1,061.48**

Recovery and Avionics	Iris Ultra 96 in. Standard Parachute	1	$ 477.28	$ 477.28
	12 in. Compact Elliptical Parachute	1	$ 67.41	$ 67.41
	Eggtimer Quasar	2	$ 99.99	$ 199.98
	Eggtimer TX Transmitter	1	$ 70.00	$ 70.00
	6 in. Deployment Bag	2	$ 54.40	$ 108.80
	4 in. Deployment Bag	2	$ 47.30	$ 94.60
	18 in. Nomex Cloth	2	$ 26.40	$ 52.80
	13 in. Nomex Cloth	2	$ 17.60	$ 35.20
	5/8 in. Kevlar Shock Cord (per yard)	25	$ 6.99	$ 174.75
	3/16 in. Stainless Steel Quick Links	14	$ 6.98	$ 97.72
	Firewire Electric Match	16	$ 2.00	$ 32.00
	AeroTech Ejection Charge - 1.4g	24	$ 1.25	$ 30.00
	Small Nylon Shear Pins	40	$ 0.18	$ 7.20
	Subtotal:			**$ 1,447.74**
Miscellaneous	Paint	12	$ 18.00	$ 216.00
	West Systems 105 Epoxy Resin	2	$ 109.99	$ 219.98
	West Systems 206 Slow Hardener	2	$ 62.99	$ 125.98
	PLA 3D Printer Filament Spool	1	$ 26.00	$ 26.00
	ClearWeld Quick Dry 2-Part Epoxy	1	$ 20.28	$ 20.28
	Wood Glue	1	$ 7.98	$ 7.98
	Tinned Copper Wire Kit	1	$ 25.00	$ 12.00
	Zip Ties Pack	1	$ 6.59	$ 6.59
	Hook and Loop Strips Box	1	$ 10.00	$ 10.00
	9V Battery Pack	1	$ 12.00	$ 12.00
	Misc. Tape	1	$ 20.00	$ 20.00
	Estimated Shipping			$ 1,000.00
	Incidentals (replacement tools, hardware, safety equipment, etc.)			$ 1,500.00
	Subtotal:			**$ 3,197.79**
Travel	6 Person Student Hotel Rooms (# Rooms)	2	$ 1,418.24	$ 2,836.48
	Student Hotel Rooms (# Rooms)	4	$ 1,326.24	$ 5,304.96
	Mentor Hotel Rooms – 4 nights (# Rooms)	2	$ 556.03	$ 1,112.06
	NCSU Van Rental (# Vans)	3	$ 798.00	$ 2,394.00
	Subtotal:			**$ 11,647.50**
Promotion	T-Shirts	40	$ 15.00	$ 600.00
	Polos	15	$ 25.00	$ 375.00
	Stickers	500	$ 0.43	$ 215.00
	Subtotal:			**$ 1,190.00**
Total Expenses:				**$ 21,573.81**

As highlighted in Figure 7.17, our expenses can be divided into different sub-sections with travel funds taking up the majority of our spending for this year.

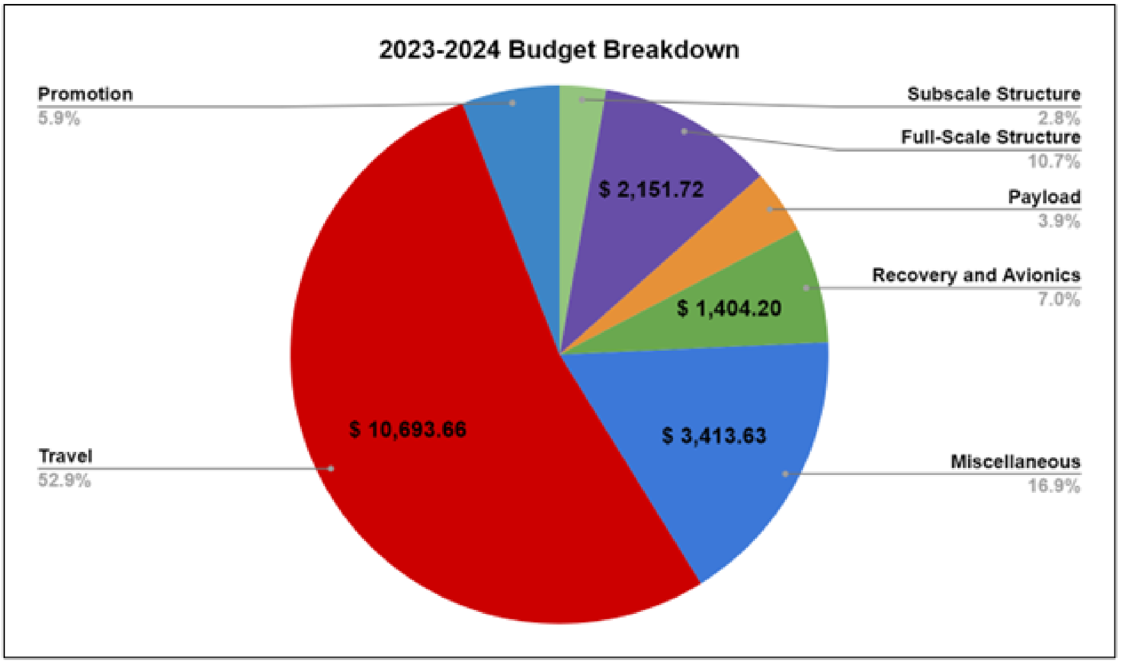

Figure 7.17: 2023 - 2024 Budget Breakdown

7.4.1 Funding Plan

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

NC State's Student Government Association's (SGA) Appropriations Committee is responsible for distributing university funding to nearly 600 different organizations on campus. Each semester the application process consists of a proposal where the club outline's what they are requesting from SGA, how much money they estimate to receive from other sources, and the anticipated club expenses for the academic year. The club then meets with representatives from SGA and give a presentation outlining club activities and the overall benefit the club provides the university. SGA then collectively allocates money to each organization on campus. In the 2022-2023 academic year, HPRC received $1,592.00 from SGA; $796.00 in the fall semester and $796.00 in the spring semester. For this academic year, a request of $2,000 was submitted for the fall semester and another $2,000 request will be submitted in the spring semester, assuming SGA regulations and budget remain the same.

The Educational and Technology Fee (ETF) is an NC State University fund that allocates funding for academic enhancement through student organizations. In the 2022-2023 academic year, HPRC received $3,000 from ETF and the club anticipates to receive $3,000 for this academic year. This funding will be used primarily to pay for the team's faculty advisors' travel costs.

Student travel costs will primarily be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurricular activities at NC State. Based on the 2022-2023 academic year, it is estimated HPRC will receive $8,000 this year.

In addition to funding through NC State organizations, North Carolina Space Grant is a large source of HPRC's funds. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club of the amount awarded. In previous academic years, this has been the maximum amount of $5,000, which will be available for use starting November 2023.

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

$1,000 in gifts of kind this academic year.

These totals are listed in Table 7.31 below, which outlines the projected costs and incoming revenue for the 2023-2024 academic year.

Table 7.31: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$3,000	$3,000
Engineering Enhancement Fund	$0	$8,000	$8,000
NC State Student Government	$2,000	$2,000	$4,000
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$500	$500	$1,000
Total Funding:			**$22,000.00**
Total Expenses:			**$21,573.81**
Difference:			**$297.13**

7.5 Project Timelines

Table 7.32: NASA SL Competition Dates and Deadlines

Date/Deadline	Event/Task
14 August 2023	Request for Proposal released
11 September 2023	Proposal due at 8am CST
4 October 2023	Awarded proposals announced
5 October 2023	PDR Q&A
26 October 2023	PDR packet due at 8am CST
9 November 2023	PDR video teleconference
7 December 2023	CDR Q&A
8 January 2023	subscale flight deadline
8 January 2023	CDR packet due at 8am CST
16 January - 6 February 2023	CDR video teleconferences
8 February 2023	FRR Q&A
4 March 2023	Vehicle Demonstration Flight deadline
4 March 2023	FRR packet due at 8am CST
11-19 March 2023	FRR video conferences
1 April 2023	Payload Demonstration Flight deadline
1 April 2023	Vehicle Demonstration Flight (reflights only)
1 April 2023	FRR Addendum due at 8am CDT
1 April 2023	Launch window opens for teams not traveling to Huntsville
4 April 2023	Launch Week Q&A
10 April 2023	Arrival in Huntsville
11-12 April 2023	Launch week events
13 April 2023	Launch day
14 April 2023	Backup launch day
23 April 2023	PLAR due at 8am CDT (Huntsville attendees)
30 April 2023	Launch window closes for teams not traveling to Huntsville

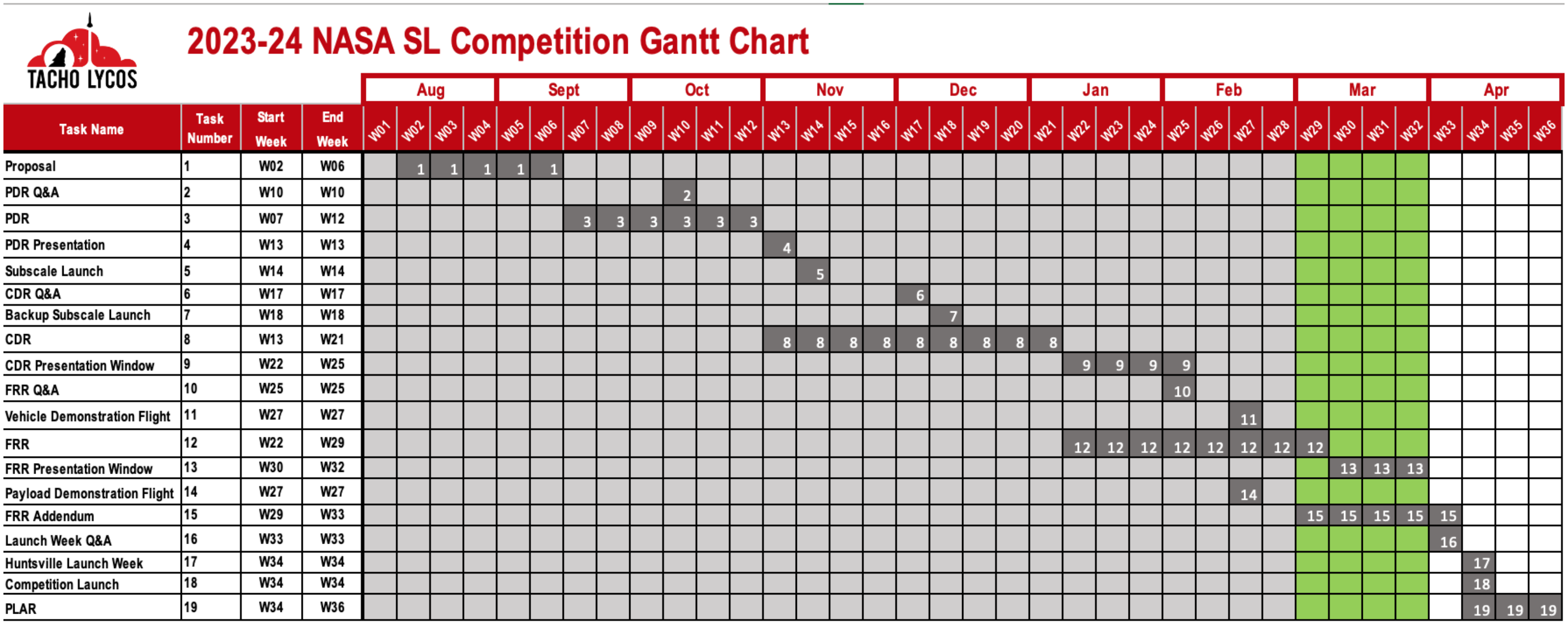

Figure 7.18: SL Competition Gantt chart.

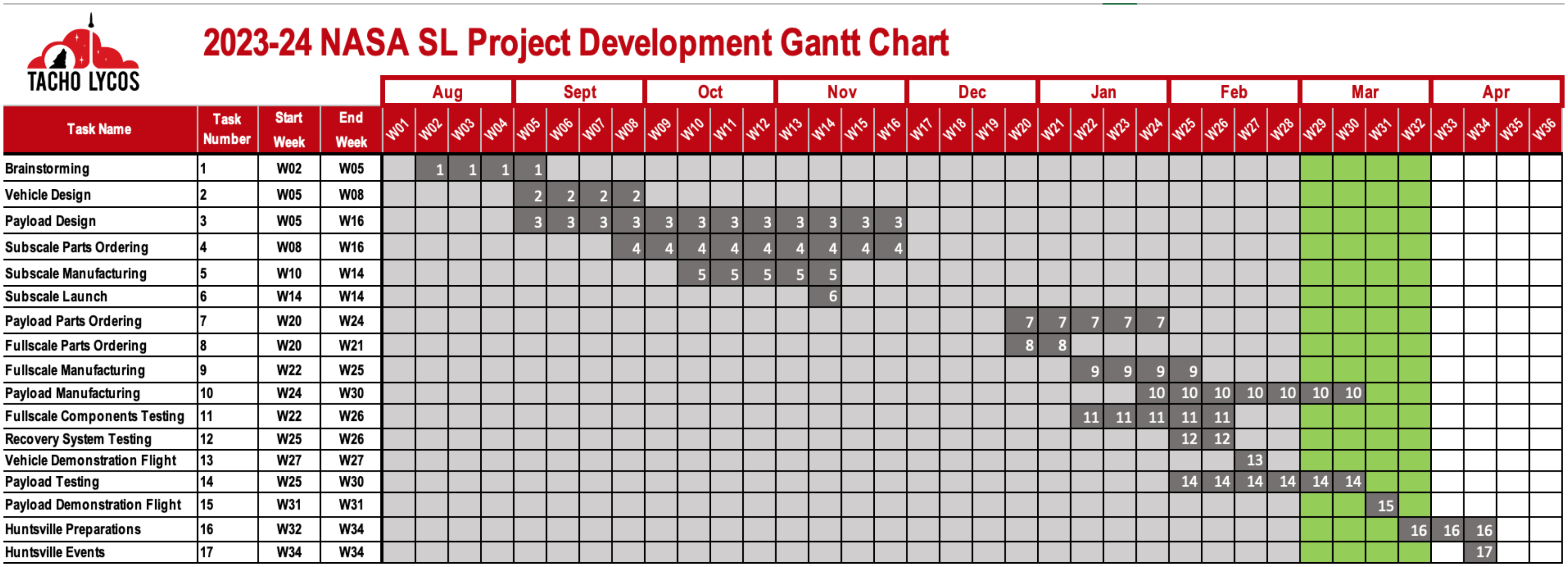

Figure 7.19: SL Development Gantt chart.

TACHO LYCOS

2023-24 NASA SL Project Development Gantt Chart

Task Name	Task Number	Start Week	End Week	Nov				Dec				Jan				Feb				Mar			
				W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32
Subscale Ejection Test	1	W14	W14		1																		
Subscale Demo Flight	2	W15	W15			2																	
Subscale SAIL Deployment Test	3	W15	W15			3																	
Rivet Shear Loading Test	4	W22	W22										4										
Shear Pin Shear Loading Test	5	W22	W22										5										
Rotor Blade Adhesion Strength Test	6	W24	W24												6								
Nose Cone Bulkhead Tensile Test	7	W25	W25													7							
AV Bay Bulkhead Tensile Test	8	W25	W25													8							
G10 Fin Durability Test	9	W26	W26														9						
Full-scale Ejection Test	10	W26	W26														10						
GPS Operational Test	11	W26	W26														11						
Latch Tensile Test	12	W27	W27															12					
RF Signal Test	13	W27	W27															13					
Altimeter Testing	14	W27	W27															14					
Vehicle Demo Flight	15	W27	W27															15					
Landing Leg Bend Test	16	W29	W29																	16			
Rotor and Leg Deployment Test	17	W30	W30																		17		
Thrust Verification Test	18	W30	W30																		18		
Payload Demo Flight	19	W31	W31																			19	

Figure 7.20: SL Development Gantt chart.

Table 7.33: Payload Build Schedule

March						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
-	-	-	-	-	**3/1**	**3/2**
-	-	-	-	-	-	VARTM remaining rotor blades
3/3	**3/4**	**3/5**	**3/6**	**3/7**	**3/8**	**3/9**
-	Water jet hub spaces	Assemble hubs	Finish gear box assembly	Cut out view window in fiberglass tube	Thrust verification test	-
3/10	**3/11**	**3/12**	**3/13**	**3/14**	**3/15**	**3/16**
-	Spring Break	Spring Break	Spring Break	Spring Break	Spring Break	Spring Break
3/17	**3/18**	**3/19**	**3/20**	**3/21**	**3/22**	**3/23**
-	PDF Ejection test, payload deployment test	Test altimeters	-	-	Launch day prep and packing	PDF Launch

Table 7.34: HPRC Spring Semester Lab Meeting Times

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Launch Day (Select Weekends)	**SL Vehicle Meeting** (6-7pm)	**Experimental Meeting** (6:30-8pm)	**SL Payload Meeting** (6-7:30pm)	**SL Integration Meeting** (3-5:30pm); **Safety Meeting** (5:30-6pm); **SL Vehicle Meeting** (6-7pm); **General Body Meetings** (7:30-8:30pm)	**Experimental Meeting** (3-4:30pm)	**Launch Day** (Select Weekends)

Table 7.35: Outreach Events and Estimated Participants

Event Name	Date	Estimated Participants
Brentwood Elementary	October 17th, 2023	84
Christina Koch Bottle Rockets	October 24th, 2023	50
Fred Old's Elementary	October 27th, 2023	45
Joyner Science Go Rounds	November 8th, 2023	83
Apex Friendship High School	December 5th, 2023	70
Lacy Elementary STEM Night	January 25th, 2024	150
Astronomy Days	February 3rd-4th, 2024	500
Museum of Life and Science Engineers Day	March 2nd, 2024	300
Washington Elementary Math and Science Night	March 7th, 2024	80
	TOTAL:	1362

Table 7.32 lists the 2024 NASA SL Competition deliverable deadlines and Figure 7.18 depicts the competition timeline in a Gantt chart for easy visualization. Figure 7.19 details the development plan for the 2024 NASA SL project.The deadlines in gray have already passed as of the date of submission of this report. Figure 7.20 details the testing schedule for all the tests planned in Sections 7.1 and 7.2. The deadlines in green are the next set of deadlines the team will be actively working under for the next deliverable, the Flight Readiness Review (FRR) Addendum. Table 7.33 contains the schedule to complete payload construction. Table 7.34 contains HPRC's weekly lab meeting schedule. These are all of the times the team members are in the lab actively working on deliverables together. Table 7.35 lists the outreach events that the team has already completed (in green) and the events planned after the date of submittal of this report (in yellow) along with the estimated number of participants total and for each event.

References

[1] A technique for the calculation of the opening-shock forces for several types of solid cloth parachutes. URL: https://doi.org/10.2514/6.1973-477.
[2] BRB900 GPS Telemetry System. URL: http://old.bigredbee.com/docs/BLGPS/brb_lcd6.pdf.
[3] Eggtime Quasar FAQ's. URL: https://eggtimerrocketry.com/quasar/.
[4] FAA AC No. 91-57A. URL: https://www.faa.gov/documenTLibrary/media/Advisory_Circular/AC_91-57A_Ch_1.pdf.
[5] Pull Pin Switch Kit. URL: https://www.labratrocketry.com/product-page/pull-pin-switch-kit.
[6] RRC3 Altimeter System. URL: https://www.missileworks.com/rrc3.
[7] Scorpion HKIV-4035. URL: https://www.scorpionsystem.com/catalog/helicopter/motors_4/hkiv-40/HKIV_4035_330/.

Appendices

A Vehicle Demonstration Flight Checklist

Checklist begins on next page.

SHAKE N' BAKE

2024 Vehicle Demonstration Flight

Launch Day Checklists

HIGH-POWERED ROCKETRY CLUB

TACHO LYCOS

This checklist completed by: Hanna McDaniel

On: 2 / 24 / 24

Checklist Legend

PPE Required - In procedure, the highlighted step signifies that PPE is needed for the steps following.

Explosives/Energetics - DANGER!

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

NOTE: First 3 checklists are night before checklists. Then the count starts again at the AV bay assembly checklist for launch day checklists.

BEGIN NIGHT-BEFORE CHECKLIST

1. E-MATCH INSTALLATION

Required Personnel		Confirmation
Student Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Personnel 1	Cameron Brown	CB
Personnel 2	Katelyn Yount	KY

Required Materials			
Item	**Quantity**	**Location**	
Red Bulkhead (Fwd AV)	1	Recovery Box	✓
Blue Bulkhead (Aft AV)	1	Recovery Box	✓
Blue tape	1	LD Toolbox (Top Drawer)	✓
E-Match	4	LD Toolbox (Top Drawer)	✓
Scissors	1	LD Toolbox (Top Drawer)	✓
Needle Nose Pliers	1	LD Toolbox (Middle Drawer)	✓
Wire Strippers	1	LD Toolbox (Middle Drawer)	✓
Terminal block screwdriver (small black Lincoln Lab case, blue flathead screwdriver)	1	LD Toolbox (Middle Drawer)	✓

Note: The following steps are to be followed on Bulkheads 2 and 3 simultaneously.

Bulkhead 2 uses labels **MP** and **MS**. Bulkhead 3 uses labels **DP** and **DS**.

Procedure		
Number	**Task**	**Completion**
1.1	Unscrew all *UNOCCUPIED* terminal blocks on **Bulkhead 2** and **Bulkhead 3**.	✓
1.2	Take four **e-matches** and trim the e-matches to approximately 6.5 inches in length from the red cap using wire cutters.	✓
1.3	Remove each red plastic protective **e-match** cover by sliding it down the e-match wire.	✓

1.4	Feed one **e-match** through the **MP** (Bulkhead 2) wire hole, with the e-match head on the side with the blast caps, and another **e-match** through the **MS** wire hole.	✓
1.5	Feed one **e-match** through the **DP** (Bulkhead 3) wire hole, with the e-match head on the side with the blast caps, and another **e-match** through the **DS** wire hole.	✓
1.6	Flip **Bulkhead 2** over and use a fingernail to separate the two e-match wires. Do the same for the two e-matches on **Bulkhead 3**.	✓
1.7	Use wire strippers to strip 1 inch of insulation from the end of each **e-match** wire.	✓
1.8	Bend the exposed **e-match** wire sections into a loop.	✓
1.9	Place **e-match** wire loops into the **MP** and **MS** terminal block, one into each unoccupied block. Place the other **e-match** wire loops into the **DP** and **DS** terminal block, one into each unoccupied block.	✓
1.10	Tighten the screws on the **MP, MS, DP**, and **DS** terminal blocks.	✓
1.11	Verify **e-match** security by lightly tugging on the wires coming out of the **MP**, **MS, DP,** and **DS** terminal blocks.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.12	Place each **e-match** head into its designated blast cap (**MP, MS, DP,** and **DS**).	✓
1.13	Bend each **e-match** wire such that the head lies flat against the bottom of each blast cap.	✓
1.14	Bend each **e-match** wire such that it is flush with the inner and outer walls of each blast cap.	✓
1.15	Using **blue tape**, tape each **e-match** wire to the outside of its respective blast cap.	✓
1.16	Using **blue tape**, tape each **e-match** wire to the bulkhead.	✓
1.17	Confirm that the **e-matches** in the **MP**, **MS, DP,** and **DS** connect to the correct terminal blocks (**MP, MS, DP,** and **DS** terminal blocks).	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.18	Confirm that all bulkhead and wiring labels are still visible.	✓

2. MAIN BLACK POWDER

Required Personnel		Confirmation
Student Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Personnel 1	Cameron Brown	CB
Personnel 2	Katelyn Yount	KY

Required Materials			
Item	**Quantity**	**Location**	✓
Red Bulkhead (Fwd AV)	1	AV Bulkhead Box	✓
Funnel	1	LD Toolbox (Top Compartment)	✓
8x11" Copy Paper	1	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	✓
Main Primary Charge (5.0 g)	1	AV HDX Box	✓
Main Secondary Charge (5.5 g)	1	AV HDX Box	✓

Procedure		
Number	**Task**	**Completion**
2.1	Confirm that all members within the assembly tent are wearing **safety glasses** (black powder).	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
2.2	Confirm that members handling black powder are wearing **nitrile gloves**.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State

2.3	Place the bottom of the **funnel** into the **MP** blast cap and carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head.	✓
2.4	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
2.5	Lift the **e-match** head so that it rests just on top of the black powder.	✓
2.6	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
2.7	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 of blue tape greater than 1 mm, but leave no gaps.	✓
2.8	Wrap **blue tape** around the outside wall of the blast cap to keep the top layers of tape tight and fold the excess tape to be flush with the top of the blast cap.	✓
2.9	Confirm all edges of the **MP** blast cap are covered with **blue tape**.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
2.10	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.	✓
2.11	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
2.12	Lift the **e-match** head so that it rests just 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 pieces 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 overlaps of blue tape greater than 1 mm, but leave no gaps.	✓
2.15	Confirm all edges of the **MS** blast cap are covered with **blue tape**.	Safety Officer Confirm: SL 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 **2.3-2.9** or **2.10-2.16** 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	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Personnel 1	Cameron Brown	CB
Personnel 2	Katelyn Yount	KY

Required Materials			
Item	**Quantity**	**Location**	
Blue Bulkhead (Aft AV)	1	-	✓
Funnel	1	LD Toolbox (Top Compartment)	✓
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	✓
Drogue Primary Charge (2.0 g)	2	AV HDX Box	✓
Drogue Secondary Charge (2.5 g)	2	AV HDX Box	✓
Anti-static bag	1	-	✓

Procedure		
Number	**Task**	**Completion**
3.1	Confirm that all members within the assembly tent are wearing **safety glasses** (black powder).	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
3.2	Confirm that members handling black powder are wearing **nitrile gloves**.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State

3.3	Place the bottom of the **funnel** into the **DP** blast cap and carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head.	✓
3.4	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
3.5	Lift the **e-match** head so that it rests just on top of the black powder.	✓
3.6	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
3.7	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.	✓
3.8	Confirm all edges of the **DP** blast cap are covered with **blue tape**.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
3.9	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.	✓
3.10	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.	✓
3.11	Slowly lift the **funnel** and tap it so the black powder falls into the blast cap only.	✓
3.12	Lift the **e-match** head so that it rests on top of the black powder.	✓
3.13	Fill the remaining space in the blast cap with fingertip-sized pieces of **paper towel**. The paper towel pieces should fill the space, but not be packed in tightly.	✓
3.14	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 overlaps greater than 1mm, but leave no gaps.	✓
3.15	Confirm all edges of the **DS** blast cap are covered with **blue tape**.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
3.16	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.	✓
3.17	Place a sheet of **white copy paper** on the assembly table and turn the bulkhead over above the paper.	✓

3.18.1	Confirm that **no black powder has leaked** onto the copy paper.	✓
3.18.2	**If black powder has leaked**, wipe copy paper clean and repeat checklist items **3.3-3.9** or **3.10-3.16** depending on which charge leaked, then repeat checklist items **3.17-3.18.1.**	✓
3.19	Use **plumber's putty** to seal any holes in the bulkhead.	✓
3.20	Wrap the entire bulkhead in an **anti-static bag**.	✓

END NIGHT-BEFORE CHECKLIST

BEGIN LAUNCH DAY CHECKLIST

1. AVIONICS BAY ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Recovery Lead	Braden Rueda	BR
Personnel 1	Cameron Brown	CB
~~**Personnel 2**~~		

Required Materials			
Item	**Quantity**	**Location**	
Red Bulkhead (main)	1	Energetics Box	✓
Blue Bulkhead (drogue)	1	Energetics Box	✓
AV Sled (assembled)	1	Recovery Box	✓
Pull Pin Switch	2	AV Sled	✓
RRC3 Altimeter	1	AV Sled	✓
Eggtimer Quasar	1	AV Sled	✓
AV Bay Section	1	-	✓
9V Battery	1	AV HDX Box	✓
2S 7.4 V LiPo	1	Lipo Bag	✓
¼ inch Nuts	4	Structures HDX Box	✓
¼ inch Washers	2	Structures HDX Box	✓
7/16" Wrench	1	LD Toolbox	✓
Adjustable Wrench	1	LD Toolbox	✓
Multimeter	1	LD Toolbox	✓
AV Receiver	1	Recovery Box	✓
Hot Glue Gun	1	LD Toolbox	✓
Safety Glasses	1	PPE Toolbox	✓
Plumber's Putty	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
1.1	Use the **multimeter** to test the voltage of the primary **9V battery**.	Note Voltage: 9.52V

1.2	**If the battery measures below 9V**, replace with a fresh battery and repeat checklist item **1.1**.	✓
1.3	Ensure that **pull pin switch** is inserted in both altimeters.	✓
1.4	Connect the 9V battery to the RRC3 battery clip in its battery compartment on the **AV sled** and secure with **zip tie.**	✓
1.5	Connect the **Lipo** to the Quasar battery connector.	✓
1.6	Pull out Quasar **pull pin**.	✓
1.7	Turn on the **AV receiver**.	✓
1.8	Wait for one minute and verify connection on **AV receiver**.	Recovery Lead Confirm: BR
1.9	Replace the Quasar **pull-pin switch**.	✓
1.10	Confirm all members within the assembly tent are wearing **safety glasses** (packed charges).	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.11	Remove **Blue Bulkhead** from its anti-static bag.	✓
1.12	Lightly tug on the wires coming out of the **DP** and **DS** terminal blocks on **Blue Bulkhead** to verify security.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.13	Slide **AV sled** onto the threaded rods secured to **Blue Bulkhead.** Make sure the altimeters are on the side of the bulkhead that reads "Electronics!"	✓
1.14	Lightly tug on the **DP** and **DS** wires oconnected to the **altimeters** to verify security.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.15	While pointing the blast caps away from personnel, connect the **drogue primary** and **drogue secondary** wire clips together. Connect wire clips to matching colors.	✓
1.16	Lightly tug on the wire connection between the **AV sled** and **Blue Bulkhead** to verify security.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.17	Pull out both **pull-pin switches**.	✓

1.18	Slide the **AV bay** over the **AV sled**, using the gold alignment marks on the **Blue Bulkhead** to line up the pull-pin switches to the holes in the switch band.	✓
1.19	Replace both **pull-pin switches** to their appropriate holes (facing blue bulkhead, primary on right, secondary on left).	✓
1.20	Remove **Red Bulkhead** from its anti-static bag.	✓
1.21	Lightly tug on the wires coming out of the **MP** and **MS** terminal blocks on **Red Bulkhead** to verify security.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.22	While pointing the blast caps away from personnel, connect the **main primary** and **main secondary** wire clips together. Connect wire clips to matching colors.	✓
1.23	Lightly tug on the wire connection between the **AV sled** and **Red Bulkhead** to verify security.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.24	Remove primary **pull pin switch**. Confirm that the proper beeps are sounding from the altimeter and that altimeter has continuity. If altimeter does not have continuity, take the sled out of the AV bay to troubleshoot. Restart at **Step 1.12**. If peeps are sounding properly, continue to next step.	Recovery Lead Confirm: BR
1.25	Remove secondary **pull pin switch**. Confirm that the proper beeps are sounding from the altimeter and that altimeter has continuity. If altimeter does not have continuity, take the sled out of the AV bay to troubleshoot. Restart at **Step 1.12**. If peeps are sounding properly continue to next step.	Recovery Lead Confirm: BR
1.26	Slide the **Red Bulkhead** onto the threaded rods, ensuring that the **MS** terminal block aligns with the altimeters (gold alignment marks), until the bulkhead is snug with the coupler. <u>Note</u>: Avoid pinching wires.	✓
1.27	Secure **Red Bulkhead** to the **AV bay** coupler with **two ¼ inch washers** and **two ¼ inch hex nuts** (one on each threaded rod). Tighten with **wrench** until snug.	✓
1.28	Use a **small screwdriver** to probe the **pressure ports** on the **AV bay** switch band to confirm they are clear.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State
1.29	Confirm all nuts are snug and **AV bay** is properly aligned	Recovery Lead Confirm: BR

			Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State

2. NOSE CONE ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Syanne Large	SL
Recovery Lead	Braden Rueda	BR
Personnel 1	Cameron Brown	CB
~~**Personnel 2**~~		

Required Materials			
Item	**Quantity**	**Location**	✓
Nose Cone	1	-	✓
Removable Nose Cone Bulkhead	1	Recovery Box	✓
Nose Cone Sled (w/ tracker)	1	Recovery Box	✓
3.7 V Lipo	1	Lipo Bag	✓
Phillips Head Screwdriver	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
2.1	Retrieve **nose cone sled** (tracker already attached) and insert **Lipo battery** into its slot.	✓
2.2	Secure **battery** to the nose cone sled with **zip ties**.	✓
2.3	Connect the **3.7V Lipo battery** to the **Big Red Bee 900**	✓
2.4	Turn on **receiver**.	✓
2.5	Wait for one minute and verify connection on **receiver**.	Recovery Lead Confirm: BR
2.6	Slide **nose cone sled** onto **nose cone bulkhead** threaded rods.	✓
2.7	Secure **nose cone sled** to threaded rods by screwing and tightening **two ¼ inch nuts** (one nut pure threaded rod) onto the forward end of the threaded rods.	✓
2.8	Verify that **nose cone sled** does not move up/down on the threaded rods.	Recovery Lead Confirm: BR

2.9	Insert **nose cone sled** and **nose cone bulkhead** into the **nose cone**. Secure with **¼ inch-20 x ¾ inch bolts.**	✓
2.10	Pull on **nose cone bulkhead** U-bolts to verify that the removable bulkhead remains in place under force.	Safety Officer Confirm: SL Safety Officer High-Powered Rocketry NC State

3. FINCAN ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Structures Lead	Cameron Brown	CB
Personnel 1		
Personnel 2		

Required Materials			
Item	Quantity	Location	
Fin Can	1	-	✓
Removable Fin System	1	Recovery Box	✓
Aft Rail Button	1	Structures HDX (RFS to Airframe)	✓
#8-32 x ½ inch Screws and washers	7	Structures HDX (RFS to Airframe)	✓
Phillips Screwdriver	1	LD Toolbox	✓

Procedure		
Number	Task	Completion
4.1	Ensure that there is a sufficient gap between the top of each fin and the bulkhead, that all bolts through the removable fin slats are tightened, that the fins do not wobble, and that added ballasts are not in the way.	Structures Lead Confirm: CB
4.2	Slide **removable fin system** into **fin can**. Align all L bracket holes with airframe holes.	✓
4.3	Confirm that **motor tube** can be inserted without obstruction.	Structures Lead Confirm: CB
4.4	Insert **aft rail button** into bottom hole aligned with forward rail button.	✓
4.5	Insert **7 #8-32 screws** into the holes between the fins to secure the **removable fin system** to the airframe.	✓
4.6	Confirm that rail buttons and screws are tight.	Structures Lead Confirm: CB

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

4. DEPLOYMENT BAY ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Payload Systems Lead	Michael Wax	MW
Personnel 1		
Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	
3/32 allen key	1	Payload Box	✓
M4 0.7mm x 12mm screws	4	Payload Box	✓
Deployment bay electronics sled	1	Payload Box	✓
Electronics breadboard	1	DB Sled	✓
Arduino	1	DB Sled	✓
XBee	1	DB Sled	✓
Buck Converter	1	DB Sled	✓
Servo	1	DB Sled	✓
Two cell Lipo battery	1	Payload Box	✓
XBee on XBee explorer board	1	Payload Box	✓
USB to Mini-USB cord	1	Payload Box	✓
Laptop	1	–	✓
SAIL mass simulator	1	Payload Box	✓
Deployment Bay	1	–	✓
Zip ties	4	Payload Box	✓
Payload Parachute	1	Recovery Box	✓
Small Deployment Bag	1	Recovery Box	✓
Payload Parachute Shock Cord	1	Recovery Box	✓
Quicklink (yellow)	1	Recovery Box	✓

Procedure		
Number	**Task**	**Completion**
4.1	Plug in the free transmitter **XBee** into the **laptop** using the **USB to Mini-USB cable**.	✓
4.2	Open the command window on the **laptop**.	✓
4.3	CD to the folder named "PotatoStation."	✓

4.4	Check the port name for the XBee. Use the port name that is linked to "USB Serial Port".	✓
4.5	Open the PotatoStation GUI by running main.py.	✓
4.6	Confirm that the GUI window opens. There should be a motor control window, a serial console to the left, and the latch status to the right.	✓
4.7	Next, manually push the servo horn to be parallel with the servo body. This is to prevent the servo from maxing out when the Lipo is plugged in.	✓
4.8	Plug in the 2 cell Lipo battery to the connector attached to the buck converter.	✓
4.9	Arm the latch by pressing the button in the top right of the window with a red skull on it. Make sure the XBee, Arduino, and Servo are communicating by pressing the big button with a man falling. The servo should rotate to about 90 degrees, then rotate back to its original position. An LED on the Arduino should also be lit up to the color orange. Test this a few times. **NOTE: IF THE SERVO MAXES OUT, DEPLOY AS SOON AS POSSIBLE TO PREVENT OVERHEATING**. When you initially plug in the lipo, the servo may max out. Be ready to open latch before plugging in.	✓
4.10	Once the servo is confirmed to be working, place the **Lipo** in the depression on the sled. Use four **zip ties** to secure it in place.	✓
4.11	Trim the **zip ties** as necessary.	✓
4.12	Take the **electronics sled** and slide it on the two threaded rods. The breadboard should be on the same side as the U-bolt. Place the top bulkhead on the threaded rods and screw on the two ¼" nuts. Tighten the nuts so that the bulkhead is flush against the sled.	✓
4.13	Close the latch. You can access it by using the opening in the bottom bulkhead.	✓
4.14	Send the test command again using the GUI. Ensure that the servo turns and the latch opens.	Payload Systems Lead Confirm: ✓ MW
4.15	Take the **shock cord** labeled PLP and loop it through the U-bolt on the payload mass simulator.	✓
4.16	Thread the **payload parachute** quicklink through both end loops of the PLP **shock cord**. Tighten the quicklink. Secure the quicklink connection with **electrical tape**.	✓

4.17	Connect a yellow quicklink to the loop of **shock cord** connected to the DB latch. Tighten the quicklink. Secure the quicklink connection with electrical tape.	✓
4.18	Take the loop of DB latch **shock cord** and loop it through the **payload mass simulator** U-bolt. Ensure that the quicklink for the parachute is on the side of the shock cord loop that is connected permanently.	✓
4.19	Use an allen key to feed the opposite end of **shock cord** through the open latch. Close the latch manually. Pull on shock cord/payload mass simulator. Confirm that latch is secure.	Payload Systems Lead Confirm: MW
4.20	Lower the payload **mass simulator**, payload parachute **deployment bag**, and **deployment bay electronics** into the deployment bay **tube**. The payload **parachute** and **shock cord** need to go in alongside the payload mass simulator.	✓
4.21	Move electronics bulkhead around, ensuring that the holes on the deployment bay are aligned to the internal L-brackets.	✓
4.22	Place four **washers** on the **M4 screws** and screw them into the holes with the allen key.	✓
4.23	Lift the **deployment bay** and hold it above the ground by the U-bolt. Confirm that bulkhead is secured to the bay.	Payload Systems Lead Confirm: MW

5. MAIN BAY RECOVERY ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Payload Electronics Lead	Franklin Rice	FSR
Personnel 1	Cameron Brown	CB
Personnel 2	Michael Wax	MW

Required Materials			
Item	**Number**	**Location**	
Nose Cone	1	-	✓
AV Bay	1	-	✓
Main/Payload Bay	1	-	✓
Safety Glasses	6	PPE Toolbox	✓
Main Parachute (96 in)	1	Recovery Box	✓
Nose Cone Parachute (48 in)	1	Recovery Box	✓
Nomex Cloth	1	Recovery Box	✓
Deployment Bag	1	Recovery Box	✓
Main Parachute Shock Cord (MP)	1	Recovery Box	✓
Nose Cone Parachute Shock Cord (NP)	1	Recovery Box	✓
Payload Shock Cord (PL)	1	Recovery Box	✓
Deployment Bag Shock Cord (BAG)	1	Recovery Box	✓
Payload Mass Simulator	1	Recovery Box	✓
Quicklinks	?	Recovery Box	✓
Shear Pins	3	AV HDX Box	✓
Electrical Tape	1	AV HDX Box	✓
Super Lube	1	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
5.1	Fold the length of **NC shock cord** between end loops accordion-style with 8-inch lengths.	✓
	Confirm the shock cord is folded accordion-style.	Payload Electronics Confirm: FSR

	Fold the accordion folds in half and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
5.2	Firmly grasp the **nose cone parachute** and remove the rubber band securing the drogue parachute.	✓
5.3	Confirm all **rubber bands** are removed from drogue parachute and shroud lines.	Team Lead Confirm: HM
5.4	Connect a **green quicklink** to the **NC parachute** and through the **Nomex** cloth. Do not tighten.	✓
5.5	Connect one end of the **NC shock cord** to the **green quicklink**. Tighten the quicklink. Secure quicklink connection with **electrical tape**.	✓
5.6	Wrap the **Nomex** cloth around the **nose cone parachute** like a burrito, continuing to firmly grasp the nose cone parachute. Wrap a **rubber band** around the folded up Nomex with the parachute inside to hold everything in place.	Payload Electronics Confirm: FSR
5.7	Connect a **green quicklink** to the remaining free loop of the NC **shock cord** and connect it to the green nose cone bulkhead **U-bolt**. Tighten the quicklink. Secure connection with electrical tape.	✓
5.8	Connect a **yellow quicklink** to one end of the deployment bay **shock cord** and connect it to the yellow **U-bolt** on the deployment bay. Tighten quicklink. Secure connection with **electrical tape.**	✓
5.9	Connect a **yellow quicklink** to the remaining free end of the deployment bay **shock cord.** Do not tighten.	✓
5.10	Pass deployment bay **shock cord** through the aft end of main/payload bay to the forward end.	✓
5.11	Attach the **yellow quicklink** to the yellow nose cone bulkhead **U-bolt**. Tighten quicklink. Secure connection with **electrical tape**.	✓
5.12	Insert **deployment bay** into aft end of payload bay, bulkhead facing. Have a person on the other end of the main\payload bay to ensure that the deployment bay **shock cord** remains taut.	✓
5.13	Reach into the open end of the deployment bay and ensure that payload contents are pushed as far into the bay as possible.	✓

5.14	**Remove rubber band** from Nomex wrapped **nose cone parachute** (Team Lead: place rubber band on wrist). Firmly grasping the wrapped parachute, slide the rest of the shock cord and drogue parachute into the fin can.	Team Lead Confirm: HM
5.15	Fold nose cone **parachute** in half and push it into the remaining space of the deployment bay.	✓
5.16	Accordion fold the remaining deployment bay **shock cord**.	✓
	Confirm the shock cord is folded accordion-style.	Payload Electronics Confirm: FSR
5.17	Fold the accordion folds in half and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
5.18	Put the **deployment bay** in the **nose cone coupler** before pushing the two sections together.	✓
5.19	Slide **nose cone** and **main/payload bay** together using alignment marks.	✓
5.20	Ensure that holes line up properly.	✓
5.21	Insert two **nylon shear pins** into opposite holes. Secure with **electrical tape**.	✓
5.22	Take main parachute **deployment bag** and loop the deployment bag **shock cord** through the deployment bag cord.	✓
5.23	Connect **yellow quicklink** to the two ends of the deployment bag **shock cord**. Then attach quicklink to yellow deployment bay **U-bolt**. Tighten quicklink. Secure the quicklink connection with **electrical tape**.	✓
5.24	Tighten deployment bag **shock cord** quicklink to the deployment bay **U-bolt**.	✓
5.25	**Remove rubber band** from Nomex wrapped **main parachute deployment bag** (Team Lead: place rubber band on wrist). Firmly grasping the wrapped parachute, and insert into main bay.	Team Lead Confirm: HM
5.26	Tighten **red quicklink** from MP **shock cord** to the **main parachute**. Tighten quicklink. Secure connection with electrical tape.	✓
5.27	Confirm all members within the assembly tent are wearing **safety glasses** (packed charges).	Safety Officer Confirm: SL

NC State
High-Powered Rocketry
Safety Officer

5.28	Tighten other red quicklink from MP **shock cord** to the red **U-bolt** on the **AV bay** bulkhead.	✓
5.29	Liberally apply **lube** to the **AV bay coupler** and to the inside of the **aft main/payload bay**.	✓
5.20	Insert a generous handful of **insulation** into the aft end of the **main/payload bay**.	✓
5.21	Insert AV bay into the main bay using alignment marks.	✓

6. DROGUE RECOVERY ASSEMBLY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Structures Lead	Cameron Brown	CB
Personnel 1	Braden Rueda	BR
~~**Personnel 2**~~		

Required Materials			
Item	**Quantity**	**Location**	
Fin Can Assembly	1	-	✓
AV Bay Assembly	1	-	✓
Safety Glasses	1	PPE Toolbox	✓
Drogue Parachute (15 in)	1	Recovery Box	✓
Small Nomex Sheet	1	Recovery Box	✓
Drogue Parachute Shock Cord (DP 1-3)	1	Recovery Box	✓
Quicklink (#1-3)	3	Recovery Box	✓
Shear Pins	4	AV HDX Box	✓
Blue Tape	1	LD Toolbox	✓
Rubber Bands	2	LD Toolbox	✓

Procedure		
Number	**Task**	**Completion**
4.1	Confirm that all members within the assembly tent are wearing safety glasses (charges loaded).	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
4.2	Fold the length of **shock cord** between the loops accordion-style with 8-inch lengths.	✓
4.3	Confirm the shock cord is folded accordion-style.	Structures Lead Confirm: CB
4.4	Fold the accordion folds in half and secure the length of shock cord with a single **rubber band**. Two fingers should fit snugly under the rubber band.	✓
4.5	Attach the hole in the **Nomex** sheet to **blue quicklink** and to the **drogue parachute**. Do not tighten.	✓

4.6	Firmly grasp the **drogue parachute** and remove the rubber band securing the drogue parachute.	✓
4.7	Confirm all rubber bands are removed from drogue parachute and shroud lines.	Team Lead Confirm: HM
4.9	Wrap the **Nomex** cloth around the drogue parachute like a burrito, continuing to firmly grasp the **drogue parachute**. Wrap a **rubber band** around the folded up Nomex with the parachute inside to hold everything in place.	✓
4.10	Attach a **blue quicklink** to each end loop of the **drogue shock cord**. Do not tighten.	Structures Lead Confirm: CB
4.11	Attach the longer end of the drogue **shock cord** to the fin can **bulkhead** U-bolt via **quicklink**. Tighten quicklink. Secure connection with **electrical tape**.	✓
4.12	Attach the shorter end of the drogue **shock cord** to the **AV bay** U-bolt via **quicklink**. Tighten quicklink. Secure connection with **electrical tape**.	✓
4.13	Insert two handfuls of insulation into the fin can/drogue bay.	✓
4.14	Slide the fin can and AV sections together using alignment marks.	✓
4.15	Confirm that the sections are properly aligned and holes are clear.	Structures Lead Confirm: CB
4.16	Insert two **#4-40, ½-inch long nylon shear pins** in opposite holes. Secure with electrical tape.	✓

7. MOTOR ASSEMBLY

Required Personnel		Confirmation
L3 Mentor	Alan Whitmore/Jim Livingston	JL
Aerodynamics Lead	Matthew Simpson	MS
Personnel 1		
Personnel 2		

Required Materials			
Item	**Quantity**	**Location**	
Aerotech J500G Reload Kit	1	Motor Box	✓
Aerotech RMS 38/720 Motor Casing	1	Motor Box	✓
Motor Igniter	1	LD Toolbox	✓
Lube	1	LD Toolbox	✓
Needle Nose Pliers	1	LD Toolbox	✓
Baby Wipes	1	LD Toolbox	✓
Sharpie Marker	1	LD Toolbox	✓
Blue Tape	1	LD Toolbox	✓
Nitrile Gloves	2	PPE Toolbox	✓
Paper Towels	1	Recovery Box	✓

NOTE: Follow all manufacturer procedures for assembling the motor!

Procedure		
Number	**Task**	**Completion**
6.1	Gather all **materials** and **L3 mentor** at table and **receive permission** to begin motor assembly from mentor.	✓
6.2	Ensure that personnel constructing motor are wearing **nitrile gloves**.	Aero Lead Confirm: MS
6.3	Use **Lube** to lightly grease included **O-Rings** identified by motor manual.	✓
6.4	Use **Lube** to lightly grease **threads** on motor casing.	✓
6.5	Install **smoke grain** into **insulator tube** with **spacer** until snug.	✓
6.6	Use **Lube** to lightly grease one end of the **smoke grain**.	✓
6.7	Install **smoke grain** into **forward closure**, greased side facing forward, until snug.	✓

6.8	Install forward seal disk **O-Ring** on **forward seal disk.**	✓
6.9	Install **forward seal disk** and **O-Ring** into one **end of motor liner** until snug.	✓
6.10	Install **three propellant grains** into motor liner.	✓
6.11	Install **motor liner** into **motor casing**, holding the liner centered within the casing.	✓
6.12	Install **forward O-Ring** into forward end of motor casing. The O-Ring MUST be seated against the forward end of the forward seal disk assembly.	✓
6.13	Install the **forward closure** with smoke grain assembly onto the forward end of the motor casing, on top of the forward O-Ring. Tighten until finger tight.	✓
6.14	Install **aft nozzle** on the aft end of the motor casing.	✓
6.15	Install **aft O-Ring** onto aft nozzle.	✓
6.16	Install **aft closure** onto aft O-Ring.	✓
6.17	Install **aft closure assembly** into **aft end of motor casing**. Tighten until finger tight. NOTE: **There will be exposed threads** when the aft closure is snug.	✓
6.18	Install **nozzle cap** with a corner cut.	✓
6.19	Prepare motor **ignitor**.	✓
6.20	Hold **ignitor** wire along the side of the motor casing.	✓
6.21	Designate appropriate length by marking **ignitor** wire with **Sharpie**.	✓
6.22	Separate ends of **ignitor** wire.	✓
6.23	Strip ends of **ignitor** wire with **wire strippers**.	✓
6.24	Coil **ignitor** wire back into original orientation.	✓
6.25	Tape **ignitor** to side of casing.	✓
6.26	Thank the mentor for assisting with motor assembly.	✓
6.27	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 7.2!**	✓

8. FINAL MEASUREMENTS

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Aerodynamics Lead	Matthew Simpson	MS
Personnel 1	Cameron Brown	CB
Personnel 2	Braden Rueda	BR

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

Number	Task	Completion
7.1	Unscrew **motor retainer**.	✓
7.2	Slide **motor casing** into **motor tube**.	✓
7.3	Secure motor casing using **motor retainer** screw.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
7.4	Measure the **center of pressure** of the launch vehicle. This point is **77.65 inches** from the tip of the nose cone. Ensure tape measure is straight and not following the curvature of the nose cone.	✓
7.5	Use a **circular sticker** or blue tape **labeled "CP"** to mark the center of pressure of the launch vehicle.	✓
7.6	Using the **rope** and **fish scale**, locate the **center of gravity** of the launch vehicle. Tie the rope around the launch vehicle and move the rope until the launch vehicle balances.	✓
7.7	Record the **weight** of the launch vehicle using the **fish scale**.	Record weight here: 50.1 lb

7.8	Use a **circular sticker** or blue tape **labeled "CG"** to mark the center of gravity of the launch vehicle.	✓
7.9	**Measure the center of gravity's distance** from the tip of the nose cone using the tape measure. Ensure the tape measure is straight.	Record CG location here: 63.5in
7.10	Calculate the **stability margin** using the formula (CP-CG)/D. This is (77.65 - CG)/4. <u>**The stability margin must be at least 2.0**</u>.	Record stability margin here: 2.293 Team Lead Confirm: HM
7.11	Load the **field recovery box** with the items required by **Checklist 8: Launch Pad**.	✓
7.12	Team Lead: Confirm that there are FOUR rubber bands around wrist.	Team Lead Confirm: HM
7.13	Proceed to the **RSO desk**.	✓

9. LAUNCH PAD

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Recovery Lead	Braden Rueda	BR
Structures Lead	Cameron Brown	CB
Personnel 1	Franklin Rice	FSR
Personnel 2	Matthew Simpson	MS

Required Materials			
Item	**Quantity**	**Location**	~~**Completion**~~
Launch Vehicle (assembled)	1	-	✓
Motor Ignitor	1	Field Recovery Box	✓
Lube	1	LD Toolbox	✓
Nitrile Gloves	1	PPE Box	✓
Heavy Duty Gloves	2	PPE Box	✓
Safety Glasses	1	PPE Box	✓
Adjustable Wrench	1	LD Toolbox	✓
Rubber Bands	6	LD Toolbox	✓
Phone	1	-	✓
Wire Cutters	1	LD Toolbox	✓
Wire Strippers	1	LD Toolbox	✓
Blue Tape	1	LD Toolbox	✓
Fire Extinguisher	1	Field Recovery Box	✓

Number	Task	Completion
8.1	Confirm with **RSO** that field conditions are **safe for launch**.	✓
8.2	Submit **flight card** to RSO for review.	✓
8.3	Proceed to the **launch pad**.	✓
8.4	**Record coordinates** of launch pad.	✓

8.5	Confirm **blast deflector** is mounted on launch rail.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
8.6	Carefully slide the **launch vehicle** onto the **launch rail**.	✓
8.7	Visually confirm the launch vehicle **slides smoothly** along the rail.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
8.8	**If there is resistance in sliding along the rail,** remove the launch vehicle, apply **lube** to the launch rail, then repeat items 8.6 and 8.7	✓
8.9	Rotate **launch rail** into the **upright** position and **lock** into place.	✓
8.10	Orient the **launch rail** such that it is pointed **5 degrees away from spectators**.	✓
8.11	Confirm the launch rail is **locked.**	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
8.12	Take **team pictures** as necessary.	✓
8.13	All **non-essential personnel leave** the launch pad.	✓
8.14	Confirm that all remaining individuals are wearing **safety glasses.**	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
	Altimeter Arming Procedure:	
8.15	Pull **pin switch** out of **secondary altimeter slot.**	✓
8.16	Confirm **secondary altimeter** is programmed correctly using **Appendix B – Secondary Beep Sheet.**	✓
8.17	Pull **pin switch** out of **primary altimeter** slot.	✓
8.18	Confirm **primary altimeter** is programmed correctly using **Appendix A – Primary Beep Sheet.**	✓
8.19	Confirm **both altimeters** are powered on with **full continuity.**	Safety Officer: SL Safety Officer High-Powered Rocketry NC State

Ignitor Installation Procedure		✓
8.20	**Insert ignitor** fully into the motor.	✓
8.21	**Tape ignitor** into place at the bottom of the launch vehicle.	✓
8.22	Confirm that **launch pad power is turned off**.	✓
8.23	Connect **ignitor wires to launch pad power.**	✓
8.24	Confirm **launch pad continuity**, measurement should read between 1.5 and 3.5.	✓
8.25	All personnel **navigate to safe location** behind the launch table.	✓
8.26	Pass the **primary checklist** and **field recovery toolbox** to the **Safety Officer.**	✓
8.27	Inform the **RSO** the team is **ready for launch**.	✓
8.28	**Launch!**	✓

10. FIELD RECOVERY

Required Personnel		Confirmation
Team Lead	Hanna McDaniel	HM
Safety Officer	Shyanne Large	SL
Recovery Lead	Braden Rueda	BR
Payload Electronics Lead	Frank Rice	FSR
Personnel 1	Matthew Simpson	MS
Personnel 2	Cameron Brown	CB
Personnel 3	Michael Wax	MW
~~Personnel 4~~		

Required Materials			
Item	**Quantity**	**Location**	
Nitrile Gloves	1	Field Recovery Box	✓
Heavy Duty Gloves	1	Field Recovery Box	✓
Safety Glasses	5	Field Recovery Box	✓
Adjustable Wrench	1	Field Recovery Box	✓
Rubber Bands	6	Field Recovery Box	✓
Phone	1	Field Recovery Box	✓
Wire Cutters	1	Field Recovery Box	✓
Wire Strippers	1	Field Recovery Box	✓
Blue Tape	1	Field Recovery Box	✓
Fire Extinguisher	1	Field Recovery Box	✓
Pull Pin Switch	1	Field Recovery Box	✓

Procedure		
Number	**Task**	**Completion**
9.1	Confirm that all personnel are wearing **safety glasses**.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
9.2	Confirm that all personnel handling the launch vehicle are wearing **nitrile gloves**.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
9.3	Approach the launch vehicle on foot.	✓
9.4	**If a parachute is open and pulling the launch vehicle**, follow items **9.5-9.7**. Otherwise, proceed to item **9.8**.	✓
9.5	Approach the parachute from the billowed side.	✓

9.6	Use hands and body to pull down the parachute by the CANOPY. **Do not grab the shroud lines or shock cord.**	✓
9.7	Repeat for second parachute if necessary.	✓
9.8	**If the launch vehicle appears to be on fire or smoking**, use the **fire extinguisher** to put out the flame.	✓
9.9	Use a **rubber band** to secure the **main parachute**.	✓
9.10	Use a **rubber band** to secure the **drogue parachute**.	✓
9.11	Use a **rubber band** to secure the **nose cone parachute**.	✓
9.12	**Take pictures** of the landing configuration before moving any piece of the launch vehicle.	✓
9.13	Equip **heavy-duty gloves** before handling any section of body tube.	Safety Officer: SL Safety Officer High-Powered Rocketry NC State
9.14	Carefully pick up the **forward end of the main/payload bay** just enough to inspect the forward AV bulkhead for **un-blown black powder** charges.	✓
9.15	Inspect the aft AV bulkhead for **un-blown black powder** charges.	✓
9.16	Listen to the **altimeters** and **record flight data** using **Appendix C - Post-Flight Beep Sheet.**	✓
9.17	**Power off both altimeters** by inserting the **pull pin switch** into the **AV bay**.	✓
9.18	**Record the coordinates** of the final resting position of the launch vehicle.	✓
9.19	**Take pictures of any damage** to the launch vehicle.	✓
9.20	Inspect for and **collect non-biodegradable waste** from the landing site.	✓
9.21	Collect each launch vehicle section and return to the launch site.	✓

APPENDIX A – PRIMARY BEEP SHEET

RRC3

NOTE: There is a quick low beep between each line

The Beeps: What do they mean	Expected Output
Drogue only- 1 beep repeating every 5 seconds Main only- 2 beeps repeating every 5 seconds Drogue and Main- 3 beeps repeating every 5 seconds (for Dual Deploy)	3 beeps repeating every 5 seconds, no need to record.

APPENDIX B – SECONDARY BEEP SHEET

Eggtimer Quasar

The Beeps: What do they mean	Expected Output
Beeps every 60 seconds while unarmed	Beep every 60 seconds, no need to record.
Continuous trill when armed	Continuous trill, no need to record.

APPENDIX C – POST-FLIGHT BEEP SHEET

The Beeps: What do they mean	Primary Beeps	Expected Output
A three to six-digit number representing the peak altitude in feet	4247	Should be approximately ~~1500 ft.~~ 4000 ft Record.
Low buzz signaling sequence is complete	✓	Ignore, currently not important.

The Beeps: What do they mean	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	4274	Should be approximately ~~1500 ft.~~ 4000 ft Record.
Long pause signaling sequence us complete	✓	Ignore, currently not important.

APPENDIX D - EMERGENCY PROCEDURES

PREMATURE BLACK POWDER IGNITION

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

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

LAUNCH RAIL COLLAPSE AT LAUNCH

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

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

Once Hazard is Clear:

- FOLLOW FIELD RECOVERY CHECKLIST

CATASTROPHE AT TAKE OFF

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

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

BALLISTIC DESCENT

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

If Persons are Injured:

- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

FAILED MOTOR IGNITION

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

NO IGNITOR CONTINUITY

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

If No Continuity Persists:

- SEEK RSO DIRECTION
- CHANGE LAUNCH PAD

BLACK POWDER SPILL

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

MISSING REQUIRED TOOL

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

If Unable to Resolve:

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

RAPID WEATHER CHANGE AT LAUNCH

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

PARACHUTE UNFOLDS DURING ASSEMBLY

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

HARDWARE DAMAGE POST-LANDING

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

B Primary Altimeter Raw Data

Below is the raw VDF flight data collected from the RRC3 altimeter.

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
0.00	1.223976E-05	1003.90	0	74.84	-	9.315441
0.05	8.25382	1003.60	7.857143	74.84	-	9.315441
0.10	22.01237	1003.10	20.95238	74.84	-	9.315441
0.15	33.0222	1002.70	31.42857	74.84	-	9.315441
0.20	44.03727	1002.30	41.90476	74.84	-	9.315441
0.25	55.05421	1001.90	52.38095	74.84	-	9.315441
0.30	71.58883	1001.30	68.14286	74.84	-	9.315441
0.35	79.85831	1001.00	76	74.84	-	9.315441
0.40	88.12979	1000.70	83.85714	74.84	-	9.315441
0.45	99.16269	1000.30	94.38095	74.84	-	9.315441
0.50	112.958	999.80	107.5238	74.84	-	9.315441
0.55	126.7589	999.30	120.6667	74.84	-	9.315441
0.60	137.8026	998.90	131.1905	74.84	-	9.315441
0.65	148.8516	998.50	141.7143	74.84	-	9.315441
0.70	170.9586	997.70	162.7619	74.84	-	9.315441
0.75	184.7831	997.20	175.9048	74.84	-	9.315441
0.80	198.6131	996.70	189.0952	74.84	-	9.315441
0.85	215.2175	996.10	204.9048	74.84	-	9.315441
0.90	242.9079	995.10	231.2857	74.84	-	9.315441
0.95	262.3033	994.40	249.7619	74.84	-	9.315441
1.00	281.7114	993.70	268.2381	74.84	-	9.315441
1.05	301.1306	993.00	286.7143	74.84	-	9.315441
1.10	326.1146	992.10	302.6667	74.84	-	9.315441
1.15	348.3371	991.30	310.7143	74.84	-	9.315441
1.20	370.5741	990.50	321.4286	74.84	-	9.315441
1.25	384.4799	990.00	324.1905	74.84	-	9.315441
1.30	403.9578	989.30	332.2857	74.84	-	9.315441
1.35	423.4469	988.60	335.0952	74.84	-	9.315441
1.40	442.9455	987.90	345.8095	74.84	-	9.315441
1.45	462.4569	987.20	356.5238	74.84	-	9.315441
1.50	484.7687	986.40	367.2381	74.84	-	9.315441
1.55	507.0969	985.60	375.381	74.84	-	9.315441
1.60	535.0261	984.60	388.8571	74.84	-	9.315441
1.65	560.1809	983.70	402.2857	74.84	-	9.315441
1.70	590.9534	982.60	421.0476	74.84	-	9.315441
1.75	618.9515	981.60	426.6667	74.84	-	9.315441
1.80	646.9729	980.60	440.1905	74.84	-	9.315441
1.85	672.2108	979.70	451.0476	74.84	-	9.315441
1.90	703.085	978.60	464.619	74.84	-	9.315441
1.95	725.5555	977.80	459.619	74.84	-	9.315441
2.00	750.852	976.90	465.2381	74.84	-	9.315441
2.05	776.1691	976.00	470.8571	74.84	-	9.315441
2.10	801.5051	975.10	476.5238	74.84	-	9.315441
2.15	824.0409	974.30	474.1905	74.84	-	9.315441
2.20	849.4109	973.40	477.1905	74.84	-	9.315441
2.25	871.9804	972.60	477.4762	74.84	-	9.315441
2.30	900.2116	971.60	491.1429	74.84	-	9.315441

(continued from previous page)

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
2.35	922.8132	970.80	494.0952	74.84	-	9.315441
2.40	948.2573	969.90	499.7619	74.84	-	9.315441
2.45	970.8926	969.10	502.7619	74.84	-	9.315441
2.50	996.373	968.20	508.4762	74.84	-	9.315441
2.55	1019.039	967.40	508.8095	74.84	-	9.334889
2.60	1041.722	966.60	509.1429	74.84	-	9.334889
2.65	1064.418	965.80	504.1429	74.84	-	9.334889
2.70	1087.129	965.00	501.8095	74.84	-	9.334889
2.75	1109.856	964.20	494.1905	74.84	-	9.334889
2.80	1135.443	963.30	491.9048	74.84	-	9.334889
2.85	1158.202	962.50	486.9048	74.84	-	9.334889
2.90	1180.976	961.70	484.5238	74.84	-	9.334889
2.95	1203.766	960.90	476.8571	74.84	-	9.334889
3.00	1226.573	960.10	477.1905	74.84	-	9.334889
3.05	1249.394	959.30	474.8095	74.84	-	9.334889
3.10	1275.085	958.40	475.1905	74.84	-	9.334889
3.15	1297.94	957.60	472.8095	74.84	-	9.334889
3.20	1323.668	956.70	475.8571	74.84	-	9.334889
3.25	1349.417	955.80	476.2381	74.84	-	9.334889
3.30	1378.05	954.80	482.0476	74.84	-	9.334889
3.35	1400.973	954.00	476.9524	74.84	-	9.334889
3.40	1423.912	953.20	477.2857	74.84	-	9.334889
3.45	1446.866	952.40	474.9048	74.84	-	9.334889
3.50	1469.838	951.60	475.1905	74.84	-	9.315441
3.55	1489.948	950.90	470.0476	74.84	-	9.315441
3.60	1512.949	950.10	470.381	74.84	-	9.315441
3.65	1533.085	949.40	467.9524	74.84	-	9.315441
3.70	1556.116	948.60	468.2857	74.84	-	9.315441
3.75	1579.16	947.80	468.619	74.84	-	9.315441
3.80	1602.22	947.00	468.9048	74.84	-	9.315441
3.85	1622.412	946.30	463.7619	74.84	-	9.315441
3.90	1645.501	945.50	464.0952	74.84	-	9.315441
3.95	1665.719	944.80	461.6667	74.84	-	9.315441
4.00	1685.948	944.10	459.2381	74.84	-	9.315441
4.05	1706.188	943.40	456.8095	74.84	-	9.315441
4.10	1729.337	942.60	457.1429	74.84	-	9.315441
4.15	1749.603	941.90	451.9524	74.84	-	9.315441
4.20	1772.782	941.10	452.2857	74.84	-	9.315441
4.25	1793.074	940.40	447.0952	74.84	-	9.315441
4.30	1813.38	939.70	441.9048	74.84	-	9.315441
4.35	1833.698	939.00	433.9524	74.84	-	9.315441
4.40	1854.028	938.30	431.5238	74.84	-	9.315441
4.45	1874.371	937.60	429.0476	74.84	-	9.315441
4.50	1894.725	936.90	426.5714	74.84	-	9.315441
4.55	1915.092	936.20	424.0952	74.84	-	9.315441
4.60	1935.472	935.50	424.381	74.84	-	9.315441
4.65	1955.864	934.80	421.9048	74.84	-	9.315441
4.70	1979.184	934.00	424.9048	74.84	-	9.315441
4.75	1999.602	933.30	422.381	74.84	-	9.315441
4.80	2020.033	932.60	419.9048	74.84	-	9.315441

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
4.85	2037.554	932.00	414.619	74.84	-	9.315441
4.90	2058.009	931.30	414.8571	74.84	-	9.315441
4.95	2075.55	930.70	409.5714	74.84	-	9.315441
5.00	2096.027	930.00	409.8571	74.84	-	9.315441
5.05	2113.588	929.40	407.2857	74.84	-	9.315441
5.10	2137.019	928.60	410.3333	74.84	-	9.315441
5.15	2154.601	928.00	405.0476	74.84	-	9.315441
5.20	2175.127	927.30	405.3333	74.84	-	9.315441
5.25	2192.729	926.70	400	74.84	-	9.315441
5.30	2213.278	926.00	400.2381	74.84	-	9.315441
5.35	2230.9	925.40	397.6667	74.84	-	9.315441
5.40	2251.472	924.70	397.9048	74.84	-	9.315441
5.45	2269.116	924.10	395.3333	74.84	-	9.315441
5.50	2286.768	923.50	392.7619	74.84	-	9.334889
5.55	2304.429	922.90	390.1905	74.84	-	9.334889
5.60	2325.046	922.20	390.4286	74.84	-	9.334889
5.65	2342.729	921.60	387.8571	74.84	-	9.334889
5.70	2360.419	921.00	385.2857	74.84	-	9.334889
5.75	2378.119	920.40	379.9524	74.84	-	9.334889
5.80	2395.83	919.80	377.381	74.84	-	9.334889
5.85	2410.595	919.30	371.9524	74.84	-	9.334889
5.90	2431.278	918.60	375	74.84	-	9.334889
5.95	2449.015	918.00	372.4286	74.84	-	9.334889
6.00	2466.762	917.40	372.619	74.84	-	9.334889
6.05	2481.558	916.90	367.1905	74.84	-	9.334889
6.10	2499.324	916.30	367.381	74.84	-	9.334889
6.15	2517.097	915.70	361.9524	74.84	-	9.334889
6.20	2534.882	915.10	362.1429	74.84	-	9.334889
6.25	2552.674	914.50	359.5238	74.84	-	9.334889
6.30	2567.508	914.00	356.9048	74.84	-	9.334889
6.35	2585.318	913.40	354.2857	74.84	-	9.334889
6.40	2603.138	912.80	354.4762	74.84	-	9.334889
6.45	2620.967	912.20	351.9048	74.84	-	9.334889
6.50	2638.806	911.60	352.0952	74.84	-	9.334889
6.55	2653.679	911.10	349.4286	74.84	-	9.315441
6.60	2671.535	910.50	349.619	74.84	-	9.315441
6.65	2686.422	910.00	344.1905	74.84	-	9.315441
6.70	2701.316	909.50	341.5238	74.84	-	9.315441
6.75	2716.217	909.00	338.8571	74.84	-	9.315441
6.80	2734.105	908.40	339.0476	74.84	-	9.315441
6.85	2752.005	907.80	339.2381	74.84	-	9.315441
6.90	2766.928	907.30	339.381	74.84	-	9.315441
6.95	2784.844	906.70	336.7143	74.84	-	9.315441
7.00	2799.782	906.20	334.0476	74.84	-	9.315441
7.05	2814.727	905.70	331.381	74.84	-	9.315441
7.10	2829.678	905.20	331.5238	74.84	-	9.315441
7.15	2844.636	904.70	328.8571	74.84	-	9.315441
7.20	2862.595	904.10	329.0476	74.84	-	9.315441
7.25	2874.572	903.70	323.5238	74.84	-	9.315441
7.30	2892.547	903.10	323.7143	74.84	-	9.315441

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
7.35	2907.533	902.60	323.8571	74.84	-	9.315441
7.40	2922.526	902.10	321.1905	74.84	-	9.315441
7.45	2937.526	901.60	318.5238	74.84	-	9.315441
7.50	2952.532	901.10	315.8095	74.84	-	9.334889
7.55	2964.541	900.70	310.2381	74.84	-	9.334889
7.60	2979.559	900.20	310.381	74.84	-	9.334889
7.65	2994.584	899.70	307.7143	74.84	-	9.334889
7.70	3009.616	899.20	307.8571	74.84	-	9.334889
7.75	3021.647	898.80	305.1429	74.84	-	9.334889
7.80	3036.691	898.30	305.2857	74.84	-	9.334889
7.85	3051.742	897.80	302.5714	74.84	-	9.334889
7.90	3063.787	897.40	297	74.84	-	9.334889
7.95	3078.85	896.90	297.1429	74.84	-	9.334889
8.00	3090.906	896.50	291.5714	74.84	-	9.334889
8.05	3102.967	896.10	288.8095	74.84	-	9.334889
8.10	3118.047	895.60	288.9524	74.84	-	9.334889
8.15	3133.135	895.10	289.0952	74.84	-	9.334889
8.20	3145.209	894.70	286.3333	74.84	-	9.334889
8.25	3157.289	894.30	280.7619	74.84	-	9.334889
8.30	3172.394	893.80	283.7143	74.84	-	9.334889
8.35	3184.482	893.40	278.0952	74.84	-	9.334889
8.40	3199.6	892.90	278.1905	74.84	-	9.334889
8.45	3211.7	892.50	275.4286	74.84	-	9.334889
8.50	3223.804	892.10	272.6667	74.84	-	9.334889
8.55	3235.911	891.70	269.9048	74.84	-	9.315441
8.60	3251.052	891.20	272.9048	74.84	-	9.315441
8.65	3263.171	890.80	270.1429	74.84	-	9.315441
8.70	3278.324	890.30	270.2381	74.84	-	9.315441
8.75	3290.451	889.90	267.4762	74.84	-	9.315441
8.80	3302.583	889.50	267.5714	74.84	-	9.315441
8.85	3314.721	889.10	264.8095	74.84	-	9.315441
8.90	3326.861	888.70	262.0476	74.84	-	9.315441
8.95	3335.969	888.40	259.2381	74.84	-	9.315441
9.00	3351.156	887.90	259.381	74.84	-	9.315441
9.05	3360.272	887.60	256.5714	74.84	-	9.315441
9.10	3375.47	887.10	259.5714	74.84	-	9.315441
9.15	3384.592	886.80	253.8571	74.84	-	9.315441
9.20	3396.757	886.40	251.0476	74.84	-	9.315441
9.25	3408.928	886.00	251.1429	74.84	-	9.315441
9.30	3421.104	885.60	251.2381	74.84	-	9.315441
9.35	3430.239	885.30	245.5714	74.84	-	9.315441
9.40	3445.468	884.80	248.5714	74.84	-	9.315441
9.45	3454.609	884.50	242.9048	74.84	-	9.315441
9.50	3466.802	884.10	243	74.84	-	9.334889
9.55	3478.997	883.70	243.0952	74.84	-	9.334889
9.60	3488.147	883.40	240.2857	74.84	-	9.334889
9.65	3500.352	883.00	237.4762	74.84	-	9.334889
9.70	3509.508	882.70	234.6667	74.84	-	9.334889
9.75	3521.721	882.30	231.8571	74.84	-	9.334889
9.80	3530.883	882.00	229	74.84	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
9.85	3543.104	881.60	229.0476	74.84	-	9.334889
9.90	3555.327	881.20	229.0952	74.84	-	9.334889
9.95	3564.498	880.90	226.2381	74.84	-	9.334889
10.00	3573.674	880.60	226.3333	74.84	-	9.334889
10.05	3582.85	880.30	220.619	74.84	-	9.334889
10.10	3595.088	879.90	223.619	74.84	-	9.334889
10.15	3604.271	879.60	217.9048	74.84	-	9.334889
10.20	3613.456	879.30	218	74.84	-	9.334889
10.25	3622.643	879.00	215.1905	74.84	-	9.334889
10.30	3631.833	878.70	212.381	74.84	-	9.334889
10.35	3641.025	878.40	209.5238	74.84	-	9.334889
10.40	3653.286	878.00	212.4762	74.84	-	9.334889
10.45	3662.484	877.70	206.7143	74.84	-	9.334889
10.50	3671.685	877.40	206.7619	74.84	-	9.334889
10.55	3680.89	877.10	203.9048	74.84	-	9.334889
10.60	3690.095	876.80	201.0476	74.84	-	9.334889
10.65	3696.235	876.60	198.1905	74.84	-	9.334889
10.70	3708.514	876.20	198.2857	74.84	-	9.334889
10.75	3717.728	875.90	198.3333	74.84	-	9.334889
10.80	3726.946	875.60	195.4762	74.84	-	9.334889
10.85	3733.09	875.40	192.619	74.84	-	9.334889
10.90	3742.312	875.10	189.7619	74.84	-	9.334889
10.95	3751.534	874.80	186.9048	74.84	-	9.334889
11.00	3760.76	874.50	187	74.84	-	9.334889
11.05	3766.912	874.30	184.0952	74.84	-	9.334889
11.10	3779.218	873.90	187.0476	74.84	-	9.334889
11.15	3785.374	873.70	181.2381	74.84	-	9.334889
11.20	3794.608	873.40	181.2857	74.84	-	9.334889
11.25	3803.847	873.10	181.3333	74.84	-	9.334889
11.30	3810.006	872.90	178.4286	74.84	-	9.334889
11.35	3816.167	872.70	175.5238	74.84	-	9.334889
11.40	3825.41	872.40	175.5714	74.84	-	9.334889
11.45	3834.658	872.10	172.7143	74.84	-	9.334889
11.50	3840.822	871.90	169.8095	74.84	-	9.334889
11.55	3850.074	871.60	169.8571	74.84	-	9.334889
11.60	3856.241	871.40	166.9524	74.84	-	9.334889
11.65	3865.498	871.10	167	74.84	-	9.334889
11.70	3871.667	870.90	167	74.84	-	9.334889
11.75	3880.928	870.60	164.0952	74.84	-	9.334889
11.80	3887.101	870.40	161.1905	74.84	-	9.334889
11.85	3893.276	870.20	158.3333	74.84	-	9.334889
11.90	3902.541	869.90	161.2857	74.84	-	9.334889
11.95	3908.72	869.70	158.4286	74.84	-	9.334889
12.00	3914.899	869.50	155.5714	74.84	-	9.334889
12.05	3921.08	869.30	152.6667	74.84	-	9.334889
12.10	3930.353	869.00	155.619	74.84	-	9.334889
12.15	3936.537	868.80	149.8095	74.84	-	9.334889
12.20	3942.721	868.60	149.8571	74.84	-	9.334889
12.25	3948.906	868.40	146.9524	74.84	-	9.334889
12.30	3955.093	868.20	144.0476	74.84	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
12.35	3961.281	868.00	144.0952	74.84	-	9.334889
12.40	3967.471	867.80	144.1429	74.84	-	9.334889
12.45	3973.661	867.60	141.2381	74.84	-	9.334889
12.50	3979.851	867.40	138.3333	74.84	-	9.334889
12.55	3986.044	867.20	138.381	74.84	-	9.315441
12.60	3992.239	867.00	135.4762	74.84	-	9.315441
12.65	3998.434	866.80	135.5238	74.84	-	9.315441
12.70	4004.63	866.60	132.619	74.84	-	9.315441
12.75	4010.826	866.40	132.6667	74.84	-	9.315441
12.80	4017.025	866.20	129.7619	74.84	-	9.315441
12.85	4020.125	866.10	126.8571	74.84	-	9.315441
12.90	4026.324	865.90	126.8571	74.84	-	9.315441
12.95	4029.426	865.80	121	74.84	-	9.315441
13.00	4035.628	865.60	121	74.84	-	9.315441
13.05	4041.83	865.40	121	74.84	-	9.315441
13.10	4048.034	865.20	121	74.84	-	9.315441
13.15	4051.138	865.10	115.1429	74.84	-	9.315441
13.20	4057.342	864.90	115.1429	74.84	-	9.315441
13.25	4063.55	864.70	115.1429	74.84	-	9.315441
13.30	4066.655	864.60	112.1905	74.84	-	9.315441
13.35	4072.862	864.40	112.1905	74.84	-	9.315441
13.40	4075.968	864.30	109.2381	74.84	-	9.315441
13.45	4082.179	864.10	109.2381	74.84	-	9.315441
13.50	4085.284	864.00	106.2857	74.84	-	9.315441
13.55	4091.497	863.80	106.2857	74.84	-	9.315441
13.60	4094.603	863.70	103.3333	74.84	-	9.315441
13.65	4097.711	863.60	100.381	74.84	-	9.315441
13.70	4103.924	863.40	100.381	74.84	-	9.315441
13.75	4107.033	863.30	97.42857	74.84	-	9.315441
13.80	4110.14	863.20	94.47619	74.84	-	9.315441
13.85	4113.25	863.10	91.52381	74.84	-	9.315441
13.90	4116.357	863.00	91.52381	74.84	-	9.315441
13.95	4119.466	862.90	88.57143	74.84	-	9.315441
14.00	4125.685	862.70	91.52381	74.84	-	9.315441
14.05	4128.796	862.60	88.57143	74.84	-	9.315441
14.10	4135.015	862.40	88.57143	74.84	-	9.315441
14.15	4135.015	862.40	82.66666	74.84	-	9.315441
14.20	4138.126	862.30	82.66666	74.84	-	9.315441
14.25	4141.237	862.20	79.71429	74.84	-	9.315441
14.30	4144.349	862.10	76.7619	74.84	-	9.315441
14.35	4147.46	862.00	76.7619	74.84	-	9.315441
14.40	4150.571	861.90	73.80952	74.84	-	9.315441
14.45	4153.685	861.80	73.80952	74.84	-	9.315441
14.50	4156.796	861.70	70.85714	74.84	-	9.315441
14.55	4159.91	861.60	70.85714	74.84	-	9.315441
14.60	4163.022	861.50	67.90476	74.84	-	9.315441
14.65	4166.135	861.40	67.90476	74.84	-	9.315441
14.70	4166.135	861.40	64.95238	74.84	-	9.315441
14.75	4169.25	861.30	62	74.84	-	9.315441
14.80	4172.363	861.20	62	74.84	-	9.315441

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
14.85	4175.478	861.10	62	74.84	-	9.315441
14.90	4175.478	861.10	59.04762	74.84	-	9.315441
14.95	4178.592	861.00	59.04762	74.84	-	9.315441
15.00	4181.706	860.90	59.04762	74.84	-	9.315441
15.05	4181.706	860.90	53.14286	74.84	-	9.315441
15.10	4184.822	860.80	53.14286	74.84	-	9.315441
15.15	4184.822	860.80	47.23809	74.84	-	9.315441
15.20	4187.937	860.70	50.19048	74.84	-	9.315441
15.25	4187.937	860.70	47.23809	74.84	-	9.315441
15.30	4191.053	860.60	47.23809	74.84	-	9.315441
15.35	4194.168	860.50	47.23809	74.84	-	9.315441
15.40	4194.168	860.50	44.28571	74.84	-	9.315441
15.45	4194.168	860.50	41.33333	74.84	-	9.315441
15.50	4197.284	860.40	41.33333	74.84	-	9.334889
15.55	4197.284	860.40	38.38095	74.84	-	9.334889
15.60	4197.284	860.40	35.42857	74.84	-	9.334889
15.65	4197.284	860.40	32.47619	74.84	-	9.334889
15.70	4200.402	860.30	32.47619	74.84	-	9.334889
15.75	4200.402	860.30	32.47619	74.84	-	9.334889
15.80	4200.402	860.30	29.52381	74.84	-	9.334889
15.85	4200.402	860.30	26.57143	74.84	-	9.334889
15.90	4203.518	860.20	26.57143	74.84	-	9.334889
15.95	4203.518	860.20	26.57143	74.84	-	9.334889
16.00	4203.518	860.20	23.61905	74.84	-	9.334889
16.05	4203.518	860.20	20.66667	74.84	-	9.334889
16.10	4203.518	860.20	20.66667	74.84	-	9.334889
16.15	4203.518	860.20	17.71428	74.84	-	9.334889
16.20	4203.518	860.20	17.71428	74.84	Drogue	9.334889
16.25	4203.518	860.20	14.7619	74.84	-	9.334889
16.30	4159.91	861.60	-26.76191	74.84	-	9.334889
16.35	3964.375	867.90	-215.9524	74.84	-	9.334889
16.40	4097.711	863.60	-91.90476	74.84	-	9.334889
16.45	4237.824	859.10	41.52381	74.84	-	9.334889
16.50	4234.702	859.20	38.57143	74.84	-	9.334889
16.55	4234.702	859.20	35.61905	74.84	-	9.334889
16.60	4237.824	859.10	38.57143	74.84	-	9.334889
16.65	4234.702	859.20	35.61905	74.84	-	9.334889
16.70	4234.702	859.20	35.61905	74.84	-	9.334889
16.75	4234.702	859.20	32.66667	74.84	-	9.334889
16.80	4234.702	859.20	32.66667	74.84	-	9.334889
16.85	4234.702	859.20	32.66667	74.84	-	9.334889
16.90	4234.702	859.20	32.66667	74.84	-	9.334889
16.95	4234.702	859.20	29.71428	74.84	-	9.334889
17.00	4231.583	859.30	26.76191	74.84	-	9.334889
17.05	4231.583	859.30	26.76191	74.84	-	9.334889
17.10	4228.463	859.40	23.80952	74.84	-	9.334889
17.15	4228.463	859.40	23.80952	74.84	-	9.334889
17.20	4228.463	859.40	23.80952	74.84	-	9.334889
17.25	4228.463	859.40	23.80952	74.84	-	9.334889
17.30	4225.344	859.50	20.85714	74.84	-	9.334889

(continued from previous page)

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
17.35	4225.344	859.50	62.38095	74.84	-	9.334889
17.40	4225.344	859.50	248.619	74.84	-	9.334889
17.45	4225.344	859.50	121.619	74.84	-	9.334889
17.50	4228.463	859.40	-8.857142	74.84	-	9.334889
17.55	4228.463	859.40	-5.904762	74.84	-	9.334889
17.60	4228.463	859.40	-5.904762	74.84	-	9.334889
17.65	4225.344	859.50	-11.80952	74.84	-	9.334889
17.70	4225.344	859.50	-8.857142	74.84	-	9.334889
17.75	4228.463	859.40	-5.904762	74.84	-	9.334889
17.80	4225.344	859.50	-8.857142	74.84	-	9.334889
17.85	4222.226	859.60	-11.80952	74.84	-	9.334889
17.90	4212.87	859.90	-20.71428	74.84	-	9.334889
17.95	4203.518	860.20	-29.61905	74.84	-	9.334889
18.00	4197.284	860.40	-35.57143	74.84	-	9.334889
18.05	4200.402	860.30	-29.66667	74.84	-	9.334889
18.10	4206.636	860.10	-23.71428	74.84	-	9.334889
18.15	4215.989	859.80	-11.85714	74.84	-	9.334889
18.20	4222.226	859.60	-5.904762	74.84	-	9.334889
18.25	4231.583	859.30	3	74.84	-	9.334889
18.30	4244.063	858.90	14.90476	74.84	-	9.334889
18.35	4250.306	858.70	23.80952	74.84	-	9.334889
18.40	4250.306	858.70	23.80952	74.84	-	9.334889
18.45	4240.943	859.00	14.90476	74.84	-	9.334889
18.50	4244.063	858.90	17.85714	74.84	-	9.334889
18.55	4247.185	858.80	17.85714	74.84	-	9.334889
18.60	4244.063	858.90	14.90476	74.84	-	9.334889
18.65	4234.702	859.20	6	74.84	-	9.334889
18.70	4219.106	859.70	-5.904762	74.84	-	9.334889
18.75	4209.753	860.00	-14.80952	74.84	-	9.334889
18.80	4206.636	860.10	-20.71428	74.84	-	9.334889
18.85	4209.753	860.00	-14.80952	74.84	-	9.334889
18.90	4215.989	859.80	-5.904762	74.84	-	9.334889
18.95	4206.636	860.10	-5.904762	74.84	-	9.334889
19.00	4175.478	861.10	-26.66667	74.84	-	9.334889
19.05	4147.46	862.00	-47.38095	74.84	-	9.334889
19.10	4144.349	862.10	-53.28571	74.84	-	9.334889
19.15	4147.46	862.00	-56.28571	74.84	-	9.334889
19.20	4141.237	862.20	-71.09524	74.84	-	9.334889
19.25	4141.237	862.20	-77.04762	74.84	-	9.334889
19.30	4144.349	862.10	-83	74.84	-	9.334889
19.35	4150.571	861.90	-89	74.84	-	9.334889
19.40	4156.796	861.70	-89.04762	74.84	-	9.334889
19.45	4159.91	861.60	-86.09524	74.84	-	9.334889
19.50	4150.571	861.90	-86.09524	74.84	-	9.334889
19.55	4147.46	862.00	-92	74.84	-	9.334889
19.60	4153.685	861.80	-89.04762	74.84	-	9.334889
19.65	4147.46	862.00	-92	74.84	-	9.334889
19.70	4144.349	862.10	-86.04762	74.84	-	9.334889
19.75	4131.905	862.50	-83.04762	74.84	-	9.334889
19.80	4119.466	862.90	-86	74.84	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
19.85	4113.25	863.10	-88.95238	74.84	-	9.334889
19.90	4103.924	863.40	-100.8095	74.84	-	9.334889
19.95	4097.711	863.60	-112.6667	74.84	-	9.334889
20.00	4094.603	863.70	-106.7143	74.84	-	9.334889
20.05	4091.497	863.80	-80	74.84	-	9.334889
20.10	4085.284	864.00	-59.23809	74.84	-	9.334889
20.15	4082.179	864.10	-59.23809	74.84	-	9.334889
20.20	4075.968	864.30	-68.09524	74.84	-	9.334889
20.25	4072.862	864.40	-65.14286	74.84	-	9.334889
20.30	4079.073	864.20	-59.23809	74.84	-	9.334889
20.35	4075.968	864.30	-65.14286	74.84	-	9.334889
20.40	4079.073	864.20	-68.09524	74.84	-	9.334889
20.45	4079.073	864.20	-74	74.84	-	9.334889
20.50	4079.073	864.20	-76.95238	74.84	-	9.334889
20.55	4082.179	864.10	-65.09524	74.84	-	9.354337
20.60	4082.179	864.10	-62.14286	74.84	-	9.354337
20.65	4079.073	864.20	-71	74.84	-	9.354337
20.70	4072.862	864.40	-71	74.84	-	9.354337
20.75	4069.758	864.50	-71	74.84	-	9.354337
20.80	4069.758	864.50	-59.14286	74.84	-	9.354337
20.85	4079.073	864.20	-38.42857	74.84	-	9.354337
20.90	4085.284	864.00	-26.61905	74.84	-	9.354337
20.95	4082.179	864.10	-20.66667	74.84	-	9.354337
21.00	4075.968	864.30	-20.66667	74.84	-	9.354337
21.05	4072.862	864.40	-20.66667	74.84	-	9.354337
21.10	4060.447	864.80	-29.52381	74.84	-	9.354337
21.15	4044.933	865.30	-38.38095	74.84	-	9.354337
21.20	4035.628	865.60	-44.28571	74.84	-	9.354337
21.25	4023.225	866.00	-50.19048	74.84	-	9.354337
21.30	4010.826	866.40	-59.04762	74.84	-	9.354337
21.35	4013.926	866.30	-62	74.84	-	9.354337
21.40	4010.826	866.40	-62	74.84	-	9.354337
21.45	4013.926	866.30	-62	74.84	-	9.354337
21.50	4013.926	866.30	-62	74.66	-	9.334889
21.55	4004.63	866.60	-70.85714	74.66	-	9.334889
21.60	4001.531	866.70	-76.7619	74.66	-	9.334889
21.65	4004.63	866.60	-73.80952	74.66	-	9.334889
21.70	4007.728	866.50	-67.90476	74.66	-	9.334889
21.75	4007.728	866.50	-62	74.66	-	9.334889
21.80	4007.728	866.50	-59.04762	74.66	-	9.334889
21.85	4001.531	866.70	-64.95238	74.66	-	9.334889
21.90	3992.239	867.00	-82.66666	74.66	-	9.334889
21.95	3992.239	867.00	-88.57143	74.66	-	9.334889
22.00	3986.044	867.20	-91.52381	74.66	-	9.334889
22.05	3979.851	867.40	-91.52381	74.66	-	9.334889
22.10	3973.661	867.60	-94.47619	74.66	-	9.334889
22.15	3961.281	868.00	-94.47619	74.66	-	9.334889
22.20	3942.721	868.60	-97.38095	74.66	-	9.334889
22.25	3933.444	868.90	-97.38095	74.66	-	9.334889
22.30	3924.17	869.20	-94.38095	74.66	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
22.35	3917.989	869.40	-88.47619	74.66	-	9.334889
22.40	3914.899	869.50	-94.38095	74.66	-	9.334889
22.45	3914.899	869.50	-91.42857	74.66	-	9.334889
22.50	3914.899	869.50	-94.38095	74.66	-	9.334889
22.55	3917.989	869.40	-91.42857	74.66	-	9.334889
22.60	3927.262	869.10	-73.7619	74.66	-	9.334889
22.65	3927.262	869.10	-70.80952	74.66	-	9.334889
22.70	3914.899	869.50	-85.52381	74.66	-	9.334889
22.75	3905.631	869.80	-97.28571	74.66	-	9.334889
22.80	3905.631	869.80	-97.28571	74.66	-	9.334889
22.85	3905.631	869.80	-97.28571	74.66	-	9.334889
22.90	3905.631	869.80	-91.38095	74.66	-	9.334889
22.95	3908.72	869.70	-79.57143	74.66	-	9.334889
23.00	3899.453	870.00	-88.38095	74.66	-	9.334889
23.05	3899.453	870.00	-82.47619	74.66	-	9.334889
23.10	3899.453	870.00	-76.57143	74.66	-	9.334889
23.15	3890.189	870.30	-79.47619	74.66	-	9.334889
23.20	3871.667	870.90	-85.28571	74.66	-	9.334889
23.25	3862.411	871.20	-76.42857	74.66	-	9.334889
23.30	3846.989	871.70	-82.2381	74.66	-	9.334889
23.35	3837.74	872.00	-82.2381	74.66	-	9.334889
23.40	3831.575	872.20	-82.19048	74.66	-	9.334889
23.45	3828.493	872.30	-82.19048	74.66	-	9.334889
23.50	3831.575	872.20	-79.2381	74.66	-	9.334889
23.55	3825.41	872.40	-85.09524	74.66	-	9.334889
23.60	3810.006	872.90	-102.7143	74.66	-	9.334889
23.65	3794.608	873.40	-126.1905	74.66	-	9.334889
23.70	3791.531	873.50	-129.1429	74.66	-	9.334889
23.75	3794.608	873.40	-114.4286	74.66	-	9.334889
23.80	3803.847	873.10	-96.80952	74.66	-	9.334889
23.85	3816.167	872.70	-85.09524	74.66	-	9.334889
23.90	3822.33	872.50	-79.2381	74.66	-	9.334889
23.95	3828.493	872.30	-73.38095	74.66	-	9.334889
24.00	3816.167	872.70	-88.09524	74.66	-	9.334889
24.05	3806.927	873.00	-88.09524	74.66	-	9.334889
24.10	3813.087	872.80	-82.2381	74.66	-	9.334889
24.15	3816.167	872.70	-79.28571	74.66	-	9.334889
24.20	3828.493	872.30	-58.71429	74.66	-	9.334889
24.25	3840.822	871.90	-29.33333	74.66	-	9.334889
24.30	3840.822	871.90	-20.52381	74.66	-	9.334889
24.35	3828.493	872.30	-17.61905	74.66	-	9.334889
24.40	3816.167	872.70	-20.57143	74.66	-	9.334889
24.45	3797.688	873.30	-32.33333	74.66	-	9.334889
24.50	3766.912	874.30	-58.71429	74.66	-	9.334889
24.55	3751.534	874.80	-76.33334	74.66	-	9.354337
24.60	3742.312	875.10	-79.2381	74.66	-	9.354337
24.65	3745.385	875.00	-61.66667	74.66	-	9.354337
24.70	3748.459	874.90	-44.09524	74.66	-	9.354337
24.75	3745.385	875.00	-44.04762	74.66	-	9.354337
24.80	3733.09	875.40	-58.71429	74.66	-	9.354337

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
24.85	3723.872	875.70	-76.28571	74.66	-	9.354337
24.90	3714.657	876.00	-96.7619	74.66	-	9.354337
24.95	3705.445	876.30	-111.381	74.66	-	9.354337
25.00	3696.235	876.60	-126	74.66	-	9.354337
25.05	3687.025	876.90	-123	74.66	-	9.354337
25.10	3677.821	877.20	-122.9524	74.66	-	9.354337
25.15	3674.753	877.30	-131.7143	74.66	-	9.354337
25.20	3668.618	877.50	-140.5238	74.66	-	9.354337
25.25	3662.484	877.70	-158.1429	74.66	-	9.354337
25.30	3659.418	877.80	-172.8095	74.66	-	9.354337
25.35	3653.286	878.00	-178.6667	74.66	-	9.354337
25.40	3647.155	878.20	-172.7619	74.66	-	9.354337
25.45	3644.091	878.30	-163.9048	74.66	-	9.354337
25.50	3644.091	878.30	-146.2857	74.66	-	9.334889
25.55	3647.155	878.20	-114.0476	74.66	-	9.334889
25.60	3656.351	877.90	-90.61905	74.66	-	9.334889
25.65	3659.418	877.80	-78.95238	74.66	-	9.334889
25.70	3668.618	877.50	-73.09524	74.66	-	9.334889
25.75	3668.618	877.50	-76	74.66	-	9.334889
25.80	3659.418	877.80	-81.85714	74.66	-	9.334889
25.85	3647.155	878.20	-81.80952	74.66	-	9.334889
25.90	3634.897	878.60	-84.71429	74.66	-	9.334889
25.95	3622.643	879.00	-87.61905	74.66	-	9.334889
26.00	3622.643	879.00	-78.85714	74.66	-	9.334889
26.05	3619.581	879.10	-73	74.66	-	9.334889
26.10	3616.517	879.20	-67.14286	74.66	-	9.334889
26.15	3607.332	879.50	-67.14286	74.66	-	9.334889
26.20	3601.209	879.70	-70.04762	74.66	-	9.334889
26.25	3585.908	880.20	-78.7619	74.66	-	9.334889
26.30	3570.614	880.70	-87.47619	74.66	-	9.334889
26.35	3570.614	880.70	-84.57143	74.66	-	9.334889
26.40	3567.557	880.80	-81.61905	74.66	-	9.334889
26.45	3564.498	880.90	-78.66666	74.66	-	9.334889
26.50	3564.498	880.90	-75.7619	74.66	-	9.334889
26.55	3564.498	880.90	-75.7619	74.66	-	9.334889
26.60	3564.498	880.90	-78.66666	74.66	-	9.334889
26.65	3564.498	880.90	-87.42857	74.66	-	9.334889
26.70	3564.498	880.90	-90.33334	74.66	-	9.334889
26.75	3564.498	880.90	-99.09524	74.66	-	9.334889
26.80	3555.327	881.20	-107.8095	74.66	-	9.334889
26.85	3552.271	881.30	-101.9524	74.66	-	9.334889
26.90	3558.385	881.10	-84.47619	74.66	-	9.334889
26.95	3558.385	881.10	-72.80952	74.66	-	9.334889
27.00	3558.385	881.10	-61.14286	74.66	-	9.334889
27.05	3552.271	881.30	-66.95238	74.66	-	9.334889
27.10	3546.159	881.50	-69.85714	74.66	-	9.334889
27.15	3546.159	881.50	-66.95238	74.66	-	9.334889
27.20	3546.159	881.50	-58.19048	74.66	-	9.334889
27.25	3543.104	881.60	-55.28571	74.66	-	9.334889
27.30	3546.159	881.50	-37.80952	74.66	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
27.35	3549.214	881.40	-20.33333	74.66	-	9.334889
27.40	3549.214	881.40	-20.33333	74.66	-	9.334889
27.45	3533.937	881.90	-32	74.66	-	9.334889
27.50	3521.721	882.30	-40.71429	74.66	-	9.334889
27.55	3521.721	882.30	-40.71429	74.66	-	9.334889
27.60	3515.614	882.50	-46.52381	74.66	-	9.334889
27.65	3497.302	883.10	-63.95238	74.66	-	9.334889
27.70	3482.048	883.60	-78.47619	74.66	-	9.334889
27.75	3482.048	883.60	-78.47619	74.66	-	9.334889
27.80	3466.802	884.10	-93	74.66	-	9.334889
27.85	3457.656	884.40	-93	74.66	-	9.334889
27.90	3454.609	884.50	-93	74.66	-	9.334889
27.95	3451.563	884.60	-101.7143	74.66	-	9.334889
28.00	3442.421	884.90	-110.4286	74.66	-	9.334889
28.05	3433.283	885.20	-119.1429	74.66	-	9.334889
28.10	3433.283	885.20	-113.3333	74.66	-	9.334889
28.15	3424.148	885.50	-116.2381	74.66	-	9.334889
28.20	3421.104	885.60	-119.1429	74.66	-	9.334889
28.25	3421.104	885.60	-119.1429	74.66	-	9.334889
28.30	3415.016	885.80	-122.0476	74.66	-	9.334889
28.35	3408.928	886.00	-130.7619	74.66	-	9.334889
28.40	3415.016	885.80	-127.8571	74.66	-	9.334889
28.45	3418.059	885.70	-124.9524	74.66	-	9.334889
28.50	3427.192	885.40	-101.6667	74.66	-	9.334889
28.55	3427.192	885.40	-90.04762	74.48	-	9.334889
28.60	3421.104	885.60	-95.85714	74.48	-	9.334889
28.65	3424.148	885.50	-87.14286	74.48	-	9.334889
28.70	3424.148	885.50	-69.71429	74.48	-	9.334889
28.75	3415.016	885.80	-63.90476	74.48	-	9.334889
28.80	3402.842	886.20	-75.47619	74.48	-	9.334889
28.85	3387.632	886.70	-75.42857	74.48	-	9.334889
28.90	3375.47	887.10	-78.28571	74.48	-	9.334889
28.95	3363.311	887.50	-86.95238	74.48	-	9.334889
29.00	3360.272	887.60	-86.95238	74.48	-	9.334889
29.05	3360.272	887.60	-78.2381	74.48	-	9.334889
29.10	3354.195	887.80	-75.33334	74.48	-	9.334889
29.15	3342.043	888.20	-86.90476	74.48	-	9.334889
29.20	3342.043	888.20	-78.19048	74.48	-	9.334889
29.25	3342.043	888.20	-75.28571	74.48	-	9.334889
29.30	3342.043	888.20	-75.28571	74.48	-	9.334889
29.35	3332.933	888.50	-78.14286	74.48	-	9.334889
29.40	3342.043	888.20	-63.66667	74.48	-	9.334889
29.45	3357.232	887.70	-55	74.48	-	9.334889
29.50	3351.156	887.90	-63.71429	74.48	-	9.334889
29.55	3348.118	888.00	-75.33334	74.48	-	9.334889
29.60	3335.969	888.40	-86.90476	74.48	-	9.334889
29.65	3335.969	888.40	-81.09524	74.48	-	9.334889
29.70	3326.861	888.70	-92.66666	74.48	-	9.334889
29.75	3317.755	889.00	-101.3333	74.48	-	9.334889
29.80	3311.685	889.20	-98.38095	74.48	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
29.85	3305.616	889.40	-92.57143	74.48	-	9.334889
29.90	3290.451	889.90	-92.52381	74.48	-	9.334889
29.95	3284.388	890.10	-86.71429	74.48	-	9.334889
30.00	3281.355	890.20	-78.04762	74.48	-	9.334889
30.05	3287.419	890.00	-69.38095	74.48	-	9.334889
30.10	3290.451	889.90	-66.47619	74.48	-	9.334889
30.15	3293.484	889.80	-57.76191	74.48	-	9.334889
30.20	3290.451	889.90	-49.09524	74.48	-	9.334889
30.25	3278.324	890.30	-60.66667	74.48	-	9.334889
30.30	3272.261	890.50	-66.42857	74.48	-	9.334889
30.35	3272.261	890.50	-66.42857	74.48	-	9.334889
30.40	3269.231	890.60	-60.66667	74.48	-	9.334889
30.45	3257.111	891.00	-80.85714	74.48	-	9.334889
30.50	3248.024	891.30	-104	74.48	-	9.334889
30.55	3238.94	891.60	-106.8571	74.48	-	9.334889
30.60	3217.751	892.30	-124.1429	74.48	-	9.334889
30.65	3208.676	892.60	-121.2381	74.48	-	9.334889
30.70	3205.649	892.70	-124.1429	74.48	-	9.334889
30.75	3205.649	892.70	-115.4762	74.48	-	9.334889
30.80	3205.649	892.70	-106.8095	74.48	-	9.334889
30.85	3208.676	892.60	-98.14286	74.48	-	9.334889
30.90	3211.7	892.50	-89.52381	74.48	-	9.334889
30.95	3211.7	892.50	-75.09524	74.48	-	9.334889
31.00	3217.751	892.30	-63.57143	74.48	-	9.334889
31.05	3217.751	892.30	-60.66667	74.48	-	9.334889
31.10	3208.676	892.60	-75.09524	74.48	-	9.334889
31.15	3208.676	892.60	-78	74.48	-	9.334889
31.20	3208.676	892.60	-80.90476	74.48	-	9.334889
31.25	3193.554	893.10	-92.38095	74.48	-	9.334889
31.30	3187.507	893.30	-86.57143	74.48	-	9.334889
31.35	3184.482	893.40	-83.66666	74.48	-	9.334889
31.40	3184.482	893.40	-83.66666	74.48	-	9.334889
31.45	3190.529	893.20	-75	74.48	-	9.334889
31.50	3190.529	893.20	-63.47619	74.48	-	9.334889
31.55	3184.482	893.40	-60.57143	74.48	-	9.334889
31.60	3172.394	893.80	-63.42857	74.48	-	9.334889
31.65	3166.351	894.00	-49	74.48	-	9.334889
31.70	3148.229	894.60	-57.57143	74.48	-	9.334889
31.75	3136.153	895.00	-66.19048	74.48	-	9.334889
31.80	3130.116	895.20	-71.95238	74.48	-	9.334889
31.85	3121.063	895.50	-80.57143	74.48	-	9.334889
31.90	3118.047	895.60	-86.33334	74.48	-	9.334889
31.95	3112.014	895.80	-94.95238	74.48	-	9.334889
32.00	3102.967	896.10	-103.5714	74.48	-	9.334889
32.05	3096.936	896.30	-115.0952	74.48	-	9.334889
32.10	3096.936	896.30	-115.0952	74.48	-	9.334889
32.15	3093.92	896.40	-109.2857	74.48	-	9.334889
32.20	3081.865	896.80	-120.7619	74.48	-	9.334889
32.25	3069.812	897.20	-132.2381	74.48	-	9.334889
32.30	3063.787	897.40	-123.5714	74.48	-	9.334889

(continued from previous page)

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
32.35	3063.787	897.40	-117.8095	74.48	-	9.334889
32.40	3066.8	897.30	-112.0952	74.48	-	9.334889
32.45	3072.825	897.10	-106.3333	74.48	-	9.334889
32.50	3084.877	896.70	-100.619	74.48	-	9.334889
32.55	3090.906	896.50	-94.85714	74.3	-	9.354337
32.60	3090.906	896.50	-89.09524	74.3	-	9.354337
32.65	3093.92	896.40	-74.71429	74.3	-	9.354337
32.70	3093.92	896.40	-68.95238	74.3	-	9.354337
32.75	3084.877	896.70	-60.33333	74.3	-	9.354337
32.80	3069.812	897.20	-63.14286	74.3	-	9.354337
32.85	3066.8	897.30	-60.23809	74.3	-	9.354337
32.90	3057.765	897.60	-60.23809	74.3	-	9.354337
32.95	3051.742	897.80	-63.09524	74.3	-	9.354337
33.00	3048.73	897.90	-60.19048	74.3	-	9.354337
33.05	3045.721	898.00	-54.42857	74.3	-	9.354337
33.10	3042.711	898.10	-51.52381	74.3	-	9.354337
33.15	3039.7	898.20	-54.38095	74.3	-	9.354337
33.20	3033.681	898.40	-57.23809	74.3	-	9.354337
33.25	3027.665	898.60	-51.47619	74.3	-	9.354337
33.30	3027.665	898.60	-40	74.3	-	9.354337
33.35	3027.665	898.60	-34.28571	74.3	-	9.354337
33.40	3021.647	898.80	-40	74.3	-	9.354337
33.45	3015.631	899.00	-48.57143	74.3	-	9.354337
33.50	3015.631	899.00	-54.33333	74.3	-	9.334889
33.55	3021.647	898.80	-60.09524	74.3	-	9.334889
33.60	3012.625	899.10	-74.42857	74.3	-	9.334889
33.65	3003.602	899.40	-83	74.3	-	9.334889
33.70	2997.591	899.60	-91.57143	74.3	-	9.334889
33.75	2994.584	899.70	-94.42857	74.3	-	9.334889
33.80	2985.569	900.00	-94.38095	74.3	-	9.334889
33.85	2979.559	900.20	-85.7619	74.3	-	9.334889
33.90	2967.545	900.60	-94.33334	74.3	-	9.334889
33.95	2949.529	901.20	-102.8571	74.3	-	9.334889
34.00	2937.526	901.60	-108.5714	74.3	-	9.334889
34.05	2922.526	902.10	-120	74.3	-	9.334889
34.10	2916.528	902.30	-122.8571	74.3	-	9.334889
34.15	2913.528	902.40	-122.8571	74.3	-	9.334889
34.20	2910.531	902.50	-122.8571	74.3	-	9.334889
34.25	2901.538	902.80	-125.7143	74.3	-	9.334889
34.30	2895.543	903.00	-125.7143	74.3	-	9.334889
34.35	2895.543	903.00	-125.7143	74.3	-	9.334889
34.40	2907.533	902.60	-114.2857	74.3	-	9.334889
34.45	2919.526	902.20	-97.14286	74.3	-	9.334889
34.50	2928.524	901.90	-82.85714	74.3	-	9.334889
34.55	2925.525	902.00	-85.71429	74.3	-	9.334889
34.60	2919.526	902.20	-97.14286	74.3	-	9.334889
34.65	2898.54	902.90	-108.5714	74.3	-	9.334889
34.70	2889.55	903.20	-108.5714	74.3	-	9.334889
34.75	2877.568	903.60	-114.2857	74.3	-	9.334889
34.80	2871.578	903.80	-117.1429	74.3	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
34.85	2862.595	904.10	-117.1429	74.3	-	9.334889
34.90	2856.608	904.30	-117.1429	74.3	-	9.334889
34.95	2847.629	904.60	-114.2857	74.3	-	9.334889
35.00	2838.652	904.90	-105.7143	74.3	-	9.334889
35.05	2835.661	905.00	-97.14286	74.3	-	9.334889
35.10	2835.661	905.00	-82.85714	74.3	-	9.334889
35.15	2835.661	905.00	-77.14286	74.3	-	9.334889
35.20	2838.652	904.90	-71.42857	74.3	-	9.334889
35.25	2841.645	904.80	-65.71429	74.3	-	9.334889
35.30	2844.636	904.70	-54.28571	74.3	-	9.334889
35.35	2850.621	904.50	-42.85714	74.3	-	9.334889
35.40	2850.621	904.50	-42.85714	74.3	-	9.334889
35.45	2853.614	904.40	-51.42857	74.3	-	9.334889
35.50	2847.629	904.60	-68.57143	74.3	-	9.354337
35.55	2841.645	904.80	-82.85714	74.3	-	9.354337
35.60	2841.645	904.80	-80	74.3	-	9.354337
35.65	2841.645	904.80	-74.28571	74.3	-	9.354337
35.70	2838.652	904.90	-57.14286	74.3	-	9.354337
35.75	2838.652	904.90	-48.57143	74.3	-	9.354337
35.80	2838.652	904.90	-37.14286	74.3	-	9.354337
35.85	2832.67	905.10	-37.14286	74.3	-	9.354337
35.90	2808.748	905.90	-51.33333	74.3	-	9.354337
35.95	2778.871	906.90	-74.09524	74.3	-	9.354337
36.00	2769.913	907.20	-74.04762	74.3	-	9.354337
36.05	2766.928	907.30	-68.33334	74.3	-	9.354337
36.10	2766.928	907.30	-65.47619	74.3	-	9.354337
36.15	2763.942	907.40	-68.33334	74.3	-	9.354337
36.20	2766.928	907.30	-65.47619	74.3	-	9.354337
36.25	2769.913	907.20	-65.47619	74.3	-	9.354337
36.30	2769.913	907.20	-68.33334	74.3	-	9.354337
36.35	2769.913	907.20	-71.19048	74.3	-	9.354337
36.40	2760.958	907.50	-85.42857	74.3	-	9.354337
36.45	2752.005	907.80	-93.95238	74.3	-	9.354337
36.50	2740.071	908.20	-108.1905	74.3	-	9.354337
36.55	2731.124	908.50	-111	74.3	-	9.334889
36.60	2734.105	908.40	-102.4286	74.3	-	9.334889
36.65	2728.143	908.60	-108.0952	74.3	-	9.334889
36.70	2725.16	908.70	-110.9524	74.3	-	9.334889
36.75	2725.16	908.70	-108.0952	74.3	-	9.334889
36.80	2725.16	908.70	-108.0952	74.3	-	9.334889
36.85	2728.143	908.60	-105.2381	74.3	-	9.334889
36.90	2725.16	908.70	-102.381	74.3	-	9.334889
36.95	2719.197	908.90	-85.28571	74.3	-	9.334889
37.00	2704.295	909.40	-71	74.3	-	9.334889
37.05	2683.445	910.10	-82.33334	74.3	-	9.334889
37.10	2671.535	910.50	-90.80952	74.3	-	9.334889
37.15	2671.535	910.50	-90.80952	74.3	-	9.334889
37.20	2674.511	910.40	-85.09524	74.3	-	9.334889
37.25	2674.511	910.40	-87.95238	74.3	-	9.334889
37.30	2677.489	910.30	-87.95238	74.3	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
37.35	2674.511	910.40	-90.80952	74.3	-	9.334889
37.40	2668.559	910.60	-96.47619	74.3	-	9.334889
37.45	2662.606	910.80	-93.61905	74.3	-	9.334889
37.50	2653.679	911.10	-93.61905	74.12	-	9.334889
37.55	2653.679	911.10	-82.2381	74.12	-	9.334889
37.60	2665.581	910.70	-62.38095	74.12	-	9.334889
37.65	2668.559	910.60	-62.38095	74.12	-	9.334889
37.70	2659.629	910.90	-65.2381	74.12	-	9.334889
37.75	2659.629	910.90	-62.38095	74.12	-	9.334889
37.80	2659.629	910.90	-62.38095	74.12	-	9.334889
37.85	2653.679	911.10	-68.04762	74.12	-	9.334889
37.90	2644.753	911.40	-79.42857	74.12	-	9.334889
37.95	2641.78	911.50	-79.38095	74.12	-	9.334889
38.00	2635.832	911.70	-79.38095	74.12	-	9.334889
38.05	2623.94	912.10	-76.52381	74.12	-	9.334889
38.10	2612.052	912.50	-68	74.12	-	9.334889
38.15	2606.108	912.70	-62.33333	74.12	-	9.334889
38.20	2600.167	912.90	-68	74.12	-	9.334889
38.25	2603.138	912.80	-68.04762	74.12	-	9.334889
38.30	2600.167	912.90	-70.85714	74.12	-	9.334889
38.35	2594.228	913.10	-79.38095	74.12	-	9.334889
38.40	2594.228	913.10	-76.52381	74.12	-	9.334889
38.45	2591.257	913.20	-73.66666	74.12	-	9.334889
38.50	2588.288	913.30	-70.80952	74.12	-	9.334889
38.55	2579.381	913.60	-70.7619	74.12	-	9.334889
38.60	2573.444	913.80	-76.42857	74.12	-	9.334889
38.65	2567.508	914.00	-93.42857	74.12	-	9.334889
38.70	2564.542	914.10	-99.09524	74.12	-	9.334889
38.75	2561.573	914.20	-93.38095	74.12	-	9.334889
38.80	2561.573	914.20	-93.38095	74.12	-	9.334889
38.85	2561.573	914.20	-93.38095	74.12	-	9.334889
38.90	2558.607	914.30	-90.52381	74.12	-	9.334889
38.95	2549.708	914.60	-90.47619	74.12	-	9.334889
39.00	2534.882	915.10	-101.8095	74.12	-	9.334889
39.05	2525.987	915.40	-104.619	74.12	-	9.334889
39.10	2514.135	915.80	-104.5714	74.12	-	9.334889
39.15	2505.248	916.10	-101.7143	74.12	-	9.334889
39.20	2511.171	915.90	-90.42857	74.12	-	9.334889
39.25	2517.097	915.70	-79.09524	74.12	-	9.334889
39.30	2520.062	915.60	-79.09524	74.12	-	9.334889
39.35	2520.062	915.60	-76.28571	74.12	-	9.334889
39.40	2511.171	915.90	-79.09524	74.12	-	9.334889
39.45	2514.135	915.80	-76.28571	74.12	-	9.334889
39.50	2511.171	915.90	-76.28571	74.12	-	9.354337
39.55	2502.285	916.20	-81.95238	74.12	-	9.354337
39.60	2499.324	916.30	-76.28571	74.12	-	9.354337
39.65	2502.285	916.20	-67.80952	74.12	-	9.354337
39.70	2511.171	915.90	-53.66667	74.12	-	9.354337
39.75	2508.209	916.00	-53.66667	74.12	-	9.354337
39.80	2514.135	915.80	-45.19048	74.12	-	9.354337

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
39.85	2514.135	915.80	-45.19048	74.12	-	9.354337
39.90	2487.479	916.70	-70.57143	74.12	-	9.354337
39.95	2454.93	917.80	-98.7619	74.12	-	9.354337
40.00	2434.233	918.50	-110	74.12	-	9.354337
40.05	2425.367	918.80	-104.2857	74.12	-	9.354337
40.10	2425.367	918.80	-95.80952	74.12	-	9.354337
40.15	2425.367	918.80	-84.52381	74.12	-	9.354337
40.20	2419.457	919.00	-81.66666	74.12	-	9.354337
40.25	2407.641	919.40	-98.52381	74.12	-	9.354337
40.30	2404.688	919.50	-107	74.12	-	9.354337
40.35	2401.736	919.60	-112.619	74.12	-	9.354337
40.40	2398.782	919.70	-115.4286	74.12	-	9.354337
40.45	2395.83	919.80	-109.7619	74.12	-	9.354337
40.50	2386.974	920.10	-121	74.12	-	9.354337
40.55	2381.071	920.30	-123.8095	74.12	-	9.334889
40.60	2372.219	920.60	-123.7619	74.12	-	9.334889
40.65	2366.319	920.80	-126.5714	74.12	-	9.334889
40.70	2363.368	920.90	-132.1905	74.12	-	9.334889
40.75	2369.268	920.70	-135.0476	74.12	-	9.334889
40.80	2378.119	920.40	-123.8095	74.12	-	9.334889
40.85	2389.925	920.00	-118.2381	74.12	-	9.334889
40.90	2398.782	919.70	-109.8095	74.12	-	9.334889
40.95	2392.877	919.90	-90.04762	74.12	-	9.334889
41.00	2395.83	919.80	-56.23809	74.12	-	9.334889
41.05	2392.877	919.90	-39.33333	74.12	-	9.334889
41.10	2398.782	919.70	-25.28572	74.12	-	9.334889
41.15	2407.641	919.40	-16.85714	74.12	-	9.334889
41.20	2392.877	919.90	-30.90476	74.12	-	9.334889
41.25	2375.169	920.50	-42.14286	74.12	-	9.334889
41.30	2375.169	920.50	-30.90476	74.12	-	9.334889
41.35	2369.268	920.70	-33.71429	74.12	-	9.334889
41.40	2354.521	921.20	-44.95238	74.12	-	9.334889
41.45	2339.78	921.70	-56.19048	74.12	-	9.334889
41.50	2319.154	922.40	-73.04762	73.94	-	9.334889
41.55	2307.374	922.80	-75.85714	73.94	-	9.334889
41.60	2301.485	923.00	-75.85714	73.94	-	9.334889
41.65	2292.655	923.30	-75.85714	73.94	-	9.334889
41.70	2298.542	923.10	-64.61905	73.94	-	9.334889
41.75	2298.542	923.10	-61.80952	73.94	-	9.334889
41.80	2301.485	923.00	-64.61905	73.94	-	9.334889
41.85	2301.485	923.00	-73.04762	73.94	-	9.334889
41.90	2292.655	923.30	-92.71429	73.94	-	9.334889
41.95	2283.826	923.60	-109.5714	73.94	-	9.334889
42.00	2272.057	924.00	-115.1429	73.94	-	9.334889
42.05	2263.234	924.30	-126.3333	73.94	-	9.334889
42.10	2251.472	924.70	-134.7143	73.94	-	9.334889
42.15	2248.533	924.80	-143.1429	73.94	-	9.334889
42.20	2251.472	924.70	-148.7619	73.94	-	9.334889
42.25	2254.413	924.60	-131.9048	73.94	-	9.334889
42.30	2257.353	924.50	-112.2381	73.94	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
42.35	2257.353	924.50	-112.2381	73.94	-	9.334889
42.40	2254.413	924.60	-109.4286	73.94	-	9.334889
42.45	2251.472	924.70	-98.19048	73.94	-	9.334889
42.50	2245.593	924.90	-89.7619	73.94	-	9.334889
42.55	2236.777	925.20	-78.47619	73.94	-	9.354337
42.60	2222.088	925.70	-81.2381	73.94	-	9.354337
42.65	2204.47	926.30	-92.38095	73.94	-	9.354337
42.70	2195.665	926.60	-92.33334	73.94	-	9.354337
42.75	2192.729	926.70	-100.7619	73.94	-	9.354337
42.80	2198.599	926.50	-95.19048	73.94	-	9.354337
42.85	2207.405	926.20	-89.61905	73.94	-	9.354337
42.90	2213.278	926.00	-84.04762	73.94	-	9.354337
42.95	2225.026	925.60	-64.42857	73.94	-	9.354337
43.00	2233.839	925.30	-47.61905	73.94	-	9.354337
43.05	2230.9	925.40	-39.23809	73.94	-	9.354337
43.10	2216.213	925.90	-44.85714	73.94	-	9.354337
43.15	2213.278	926.00	-36.47619	73.94	-	9.354337
43.20	2207.405	926.20	-39.23809	73.94	-	9.354337
43.25	2201.533	926.40	-47.61905	73.94	-	9.354337
43.30	2186.86	926.90	-64.38095	73.94	-	9.354337
43.35	2178.059	927.20	-75.57143	73.94	-	9.354337
43.40	2163.396	927.70	-89.52381	73.94	-	9.354337
43.45	2151.671	928.10	-97.90476	73.94	-	9.354337
43.50	2142.877	928.40	-103.4762	73.94	-	9.334889
43.55	2137.019	928.60	-103.4286	73.94	-	9.334889
43.60	2131.159	928.80	-100.619	73.94	-	9.334889
43.65	2122.373	929.10	-95	73.94	-	9.334889
43.70	2119.444	929.20	-81.04762	73.94	-	9.334889
43.75	2122.373	929.10	-69.85714	73.94	-	9.334889
43.80	2122.373	929.10	-67.04762	73.94	-	9.334889
43.85	2119.444	929.20	-75.42857	73.94	-	9.334889
43.90	2119.444	929.20	-83.80952	73.94	-	9.334889
43.95	2113.588	929.40	-94.95238	73.94	-	9.334889
44.00	2107.734	929.60	-111.7143	73.94	-	9.334889
44.05	2113.588	929.40	-114.5238	73.94	-	9.334889
44.10	2104.806	929.70	-120.0952	73.94	-	9.334889
44.15	2101.88	929.80	-108.9048	73.94	-	9.334889
44.20	2096.027	930.00	-111.6667	73.94	-	9.334889
44.25	2090.175	930.20	-111.6667	73.94	-	9.334889
44.30	2084.323	930.40	-111.6667	73.94	-	9.334889
44.35	2078.475	930.60	-103.2857	73.94	-	9.334889
44.40	2063.855	931.10	-108.8095	73.94	-	9.334889
44.45	2060.931	931.20	-97.61905	73.94	-	9.334889
44.50	2058.009	931.30	-89.19048	73.94	-	9.334889
44.55	2058.009	931.30	-80.80952	73.76	-	9.354337
44.60	2046.318	931.70	-86.38095	73.76	-	9.354337
44.65	2040.475	931.90	-86.38095	73.76	-	9.354337
44.70	2043.397	931.80	-75.2381	73.76	-	9.354337
44.75	2043.397	931.80	-72.42857	73.76	-	9.354337
44.80	2043.397	931.80	-75.2381	73.76	-	9.354337

(continued from previous page)

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
44.85	2040.475	931.90	-78	73.76	-	9.354337
44.90	2031.712	932.20	-83.52381	73.76	-	9.354337
44.95	2020.033	932.60	-94.66666	73.76	-	9.354337
45.00	2008.356	933.00	-100.2381	73.76	-	9.354337
45.05	2005.439	933.10	-97.42857	73.76	-	9.354337
45.10	2002.519	933.20	-105.7619	73.76	-	9.354337
45.15	2002.519	933.20	-97.38095	73.76	-	9.354337
45.20	2008.356	933.00	-89	73.76	-	9.354337
45.25	2014.194	932.80	-77.85714	73.76	-	9.354337
45.30	2025.871	932.40	-61.14286	73.76	-	9.354337
45.35	2031.712	932.20	-50	73.76	-	9.354337
45.40	2020.033	932.60	-55.57143	73.76	-	9.354337
45.45	1996.683	933.40	-63.90476	73.76	-	9.354337
45.50	1979.184	934.00	-77.80952	73.76	-	9.354337
45.55	1964.607	934.50	-88.95238	73.76	-	9.354337
45.60	1964.607	934.50	-88.95238	73.76	-	9.354337
45.65	1961.693	934.60	-80.57143	73.76	-	9.354337
45.70	1944.209	935.20	-91.66666	73.76	-	9.354337
45.75	1932.56	935.60	-105.5238	73.76	-	9.354337
45.80	1932.56	935.60	-105.5238	73.76	-	9.354337
45.85	1935.472	935.50	-102.7619	73.76	-	9.354337
45.90	1935.472	935.50	-100	73.76	-	9.354337
45.95	1938.383	935.40	-88.90476	73.76	-	9.354337
46.00	1944.209	935.20	-72.19048	73.76	-	9.354337
46.05	1941.297	935.30	-63.80952	73.76	-	9.354337
46.10	1938.383	935.40	-63.80952	73.76	-	9.354337
46.15	1935.472	935.50	-63.80952	73.76	-	9.354337
46.20	1918.004	936.10	-80.42857	73.76	-	9.354337
46.25	1909.271	936.40	-94.33334	73.76	-	9.354337
46.30	1897.635	936.80	-111	73.76	-	9.354337
46.35	1888.909	937.10	-130.4762	73.76	-	9.354337
46.40	1891.817	937.00	-133.2857	73.76	-	9.354337
46.45	1888.909	937.10	-124.9048	73.76	-	9.354337
46.50	1886	937.20	-105.4286	73.76	-	9.354337
46.55	1868.557	937.80	-105.381	73.94	-	9.334889
46.60	1859.84	938.10	-99.7619	73.94	-	9.334889
46.65	1851.122	938.40	-108.0476	73.94	-	9.334889
46.70	1851.122	938.40	-105.2857	73.94	-	9.334889
46.75	1856.933	938.20	-83.09524	73.94	-	9.334889
46.80	1865.65	937.90	-63.71429	73.94	-	9.334889
46.85	1859.84	938.10	-69.2381	73.94	-	9.334889
46.90	1859.84	938.10	-72	73.94	-	9.334889
46.95	1865.65	937.90	-66.47619	73.94	-	9.334889
47.00	1854.028	938.30	-80.28571	73.94	-	9.334889
47.05	1839.506	938.80	-99.66666	73.94	-	9.334889
47.10	1822.086	939.40	-113.4762	73.94	-	9.334889
47.15	1819.184	939.50	-113.4762	73.94	-	9.334889
47.20	1813.38	939.70	-116.2381	73.94	-	9.334889
47.25	1816.283	939.60	-96.85714	73.94	-	9.334889
47.30	1810.479	939.80	-94.04762	73.94	-	9.334889

(continued from previous page)

Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
47.35	1804.676	940.00	-88.47619	73.94	-	9.334889
47.40	1798.874	940.20	-85.66666	73.94	-	9.334889
47.45	1798.874	940.20	-88.42857	73.94	-	9.334889
47.50	1795.975	940.30	-88.42857	73.76	-	9.354337
47.55	1793.074	940.40	-88.42857	73.76	-	9.354337
47.60	1798.874	940.20	-66.28571	73.76	-	9.354337
47.65	1801.776	940.10	-55.23809	73.76	-	9.354337
47.70	1793.074	940.40	-55.23809	73.76	-	9.354337
47.75	1772.782	941.10	-74.57143	73.76	-	9.354337
47.80	1755.396	941.70	-96.66666	73.76	-	9.354337
47.85	1749.603	941.90	-110.4762	73.76	-	9.354337
47.90	1740.916	942.20	-113.2381	73.76	-	9.354337
47.95	1726.442	942.70	-127	73.76	-	9.354337
48.00	1723.548	942.80	-135.2857	73.76	-	9.354337
48.05	1720.653	942.90	-127	73.76	-	9.354337
48.10	1717.76	943.00	-115.9524	73.76	-	9.354337
48.15	1714.868	943.10	-102.1429	73.76	-	9.354337
48.20	1706.188	943.40	-107.6667	73.76	-	9.354337
48.25	1703.296	943.50	-104.9048	73.76	-	9.354337
48.30	1697.512	943.70	-113.1905	73.76	-	9.354337
48.35	1694.621	943.80	-110.4286	73.76	-	9.354337
48.40	1691.729	943.90	-107.6667	73.76	-	9.354337
48.45	1691.729	943.90	-102.1429	73.76	-	9.354337
48.50	1694.621	943.80	-99.38095	73.76	-	9.354337
48.55	1691.729	943.90	-99.38095	73.58	-	9.354337
48.60	1688.838	944.00	-99.38095	73.58	-	9.354337
48.65	1685.948	944.10	-107.6667	73.58	-	9.354337
48.70	1694.621	943.80	-102.1905	73.58	-	9.354337
48.75	1694.621	943.80	-93.90476	73.58	-	9.354337
48.80	1694.621	943.80	-74.57143	73.58	-	9.354337
48.85	1688.838	944.00	-63.52381	73.58	-	9.354337
48.90	1677.276	944.40	-69	73.58	-	9.354337
48.95	1671.498	944.60	-66.2381	73.58	-	9.354337
49.00	1662.829	944.90	-60.71429	73.58	-	9.354337
49.05	1657.053	945.10	-63.47619	73.58	-	9.354337
49.10	1645.501	945.50	-71.71429	73.58	-	9.354337
49.15	1633.954	945.90	-79.95238	73.58	-	9.354337
49.20	1631.068	946.00	-79.95238	73.58	-	9.354337
49.25	1628.183	946.10	-74.42857	73.58	-	9.354337
49.30	1625.296	946.20	-74.42857	73.58	-	9.354337
49.35	1622.412	946.30	-71.66666	73.58	-	9.354337
49.40	1622.412	946.30	-68.90476	73.58	-	9.354337
49.45	1622.412	946.30	-66.14286	73.58	-	9.354337
49.50	1613.757	946.60	-74.38095	73.58	-	9.334889
49.55	1599.338	947.10	-90.85714	73.58	-	9.334889
49.60	1593.571	947.30	-93.57143	73.58	-	9.334889
49.65	1587.806	947.50	-96.28571	73.58	-	9.334889
49.70	1584.924	947.60	-96.28571	73.58	-	9.334889
49.75	1582.041	947.70	-107.2857	73.58	-	9.334889
49.80	1579.16	947.80	-110.0476	73.58	-	9.334889

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Time	Altitude	Pressure	Velocity	Temperature	Events	Voltages
49.85	1576.278	947.90	-112.8095	73.58	-	9.334889
49.90	1576.278	947.90	-107.2857	73.58	-	9.334889
49.95	1576.278	947.90	-96.28571	73.58	-	9.334889

Secondary Altimeter Raw Data

Below is the raw VDF flight data collected from the Eggtimer Quasar altimeter.

T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
0.00	-4.00	-0.80	-16.00	0	0	0	0	0	0	0
0.05	19.00	3.16	79.20	0	0	0	0	0	0	0
0.10	50.00	12.53	187.36	0	0	0	0	0	0	0
0.15	39.00	17.82	105.89	0	0	0	0	0	0	0
0.20	51.00	24.46	132.71	0	0	0	0	0	0	0
0.25	12.00	21.97	-49.83	0	0	0	0	0	0	0
0.30	26.00	22.77	16.13	0	0	0	0	0	0	0
0.35	38.00	25.82	60.91	0	0	0	0	0	0	0
0.40	35.00	27.65	36.73	0	0	0	0	0	0	0
0.45	76.00	37.32	193.38	0	0	0	0	0	0	0
0.50	61.00	42.06	94.70	0	0	0	0	0	0	0
0.55	124.00	58.45	327.76	0	0	0	0	0	0	0
0.60	90.00	64.76	126.21	0	0	0	0	0	0	0
0.65	157.00	83.21	368.97	0	0	0	0	0	0	0
0.70	190.00	104.56	427.18	0	0	0	0	0	0	0
0.75	186.00	120.85	325.74	0	0	0	0	0	0	0
0.80	205.00	137.68	336.59	205	0	0	0	0	0	0
0.85	233.00	156.75	381.27	0	0	0	0	0	0	0
0.90	250.00	175.40	373.02	0	0	0	0	0	0	0
0.95	295.00	199.32	478.42	0	0	0	0	0	0	0
1.00	292.00	217.85	370.73	0	0	0	0	0	0	0
1.05	315.00	237.28	388.59	0	0	0	0	0	0	0
1.10	338.00	257.43	402.87	0	0	0	0	0	0	0
1.15	347.00	275.34	358.29	0	0	0	0	0	0	0
1.20	425.00	305.27	598.64	0	0	0	0	0	0	0
1.25	422.00	328.62	466.91	0	0	0	0	0	0	0
1.30	451.00	353.09	489.53	0	0	0	0	0	0	0
1.35	485.00	379.48	527.62	0	0	0	0	0	0	0
1.40	470.00	397.58	362.10	0	0	0	0	0	0	0
1.45	471.00	412.26	293.68	0	0	0	0	0	0	0
1.50	500.00	429.81	350.94	0	0	0	0	0	0	0
1.55	508.00	445.45	312.75	0	0	0	0	0	0	0
1.60	558.00	467.96	450.20	0	0	0	0	0	0	0
1.65	584.00	491.17	464.16	0	0	0	0	0	0	0
1.70	582.00	509.33	363.33	0	0	0	0	0	0	0
1.75	627.00	532.87	470.66	0	0	0	0	0	0	0
1.80	664.00	559.09	524.53	0	0	0	0	0	0	0
1.85	704.00	588.08	579.63	0	0	0	0	0	0	0
1.90	740.00	618.46	607.70	0	0	0	0	0	0	0
1.95	733.00	641.37	458.16	0	0	0	0	0	0	0
2.00	787.00	670.49	582.53	0	0	0	0	0	0	0
2.05	788.00	694.00	470.02	0	0	0	0	0	0	0
2.10	820.00	719.20	504.02	0	0	0	0	0	0	0
2.15	857.00	746.76	551.21	0	0	0	0	0	0	0
2.20	861.00	769.61	456.97	0	0	0	0	0	0	0
2.25	867.00	789.08	389.58	0	0	0	0	0	0	0
2.30	921.00	815.47	527.66	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
2.35	978.00	847.97	650.13	0	0	0	0	0	0	0
2.40	959.00	870.18	444.10	0	0	0	0	0	0	0
2.45	988.00	893.74	471.28	0	0	0	0	0	0	0
2.50	1017.00	918.39	493.03	0	0	0	0	0	0	0
2.55	1037.00	942.12	474.42	0	0	0	0	0	0	0
2.60	1058.00	965.29	463.54	0	0	0	0	0	0	0
2.65	1080.00	988.23	458.83	0	0	0	0	0	0	0
2.70	1113.00	1013.19	499.06	0	0	0	0	0	0	0
2.75	1113.00	1033.15	399.25	0	0	0	0	0	0	0
2.80	1155.00	1057.52	487.40	0	0	0	0	0	0	0
2.85	1176.00	1081.22	473.92	0	0	0	0	0	0	0
2.90	1201.00	1105.17	479.14	0	0	0	0	0	0	0
2.95	1222.00	1128.54	467.31	0	0	0	0	0	0	0
3.00	1232.00	1149.23	413.85	0	0	0	0	0	0	0
3.05	1276.00	1174.58	507.08	0	0	0	0	0	0	0
3.10	1295.00	1198.67	481.66	0	0	0	0	0	0	0
3.15	1310.00	1220.93	445.33	0	0	0	0	0	0	0
3.20	1321.00	1240.95	400.26	0	0	0	0	0	0	0
3.25	1366.00	1265.96	500.21	0	0	0	0	0	0	0
3.30	1373.00	1287.37	428.17	0	0	0	0	0	0	0
3.35	1431.00	1316.09	574.54	0	0	0	0	0	0	0
3.40	1430.00	1338.87	455.63	0	0	0	0	0	0	0
3.45	1485.00	1368.10	584.50	0	0	0	0	0	0	0
3.50	1472.00	1388.88	415.60	0	0	0	0	0	0	0
3.55	1513.00	1413.70	496.48	0	0	0	0	0	0	0
3.60	1532.00	1437.36	473.19	0	0	0	0	0	0	0
3.65	1555.00	1460.89	470.55	0	0	0	0	0	0	0
3.70	1571.00	1482.91	440.44	0	0	0	0	0	0	0
3.75	1605.00	1507.33	488.35	0	0	0	0	0	0	0
3.80	1634.00	1532.66	506.68	0	0	0	0	0	0	0
3.85	1634.00	1552.93	405.34	0	0	0	0	0	0	0
3.90	1687.00	1579.74	536.28	0	0	0	0	0	0	0
3.95	1706.00	1605.00	505.02	0	0	0	0	0	0	0
4.00	1738.00	1631.60	532.02	0	0	0	0	0	0	0
4.05	1749.00	1655.08	469.61	0	0	0	0	0	0	0
4.10	1735.00	1671.06	319.69	0	0	0	0	0	0	0
4.15	1783.00	1693.45	447.75	0	0	0	0	0	0	0
4.20	1837.00	1722.16	574.20	0	0	0	0	0	0	0
4.25	1809.00	1739.53	347.36	0	0	0	0	0	0	0
4.30	1842.00	1760.02	409.89	0	0	0	0	0	0	0
4.35	1889.00	1785.82	515.91	0	0	0	0	0	0	0
4.40	1876.00	1803.85	360.73	0	0	0	0	0	0	0
4.45	1876.00	1818.28	288.58	0	0	0	0	0	0	0
4.50	1936.00	1841.83	470.87	0	0	0	0	0	0	0
4.55	1951.00	1863.66	436.69	0	0	0	0	0	0	0
4.60	1943.00	1879.53	317.35	0	0	0	0	0	0	0
4.65	1978.00	1899.22	393.88	0	0	0	0	0	0	0
4.70	1985.00	1916.38	343.11	0	0	0	0	0	0	0
4.75	2023.00	1937.70	426.48	0	0	0	0	0	0	0
4.80	2041.00	1958.36	413.19	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
4.85	2054.00	1977.49	382.55	0	0	0	0	0	0	0
4.90	2071.00	1996.19	374.04	0	0	0	0	0	0	0
4.95	2117.00	2020.35	483.23	0	0	0	0	0	0	0
5.00	2153.00	2046.88	530.59	0	0	0	0	0	0	0
5.05	2111.00	2059.71	256.47	0	0	0	0	0	0	0
5.10	2119.00	2071.56	237.17	0	0	0	0	0	0	0
5.15	2187.00	2094.65	461.74	0	0	0	0	0	0	0
5.20	2174.00	2110.52	317.39	0	0	0	0	0	0	0
5.25	2187.00	2125.82	305.91	0	0	0	0	0	0	0
5.30	2229.00	2146.45	412.73	0	0	0	0	0	0	0
5.35	2231.00	2163.36	338.18	0	0	0	0	0	0	0
5.40	2269.00	2184.49	422.55	0	0	0	0	0	0	0
5.45	2291.00	2205.79	426.04	0	0	0	0	0	0	0
5.50	2298.00	2224.23	368.83	0	0	0	0	0	0	0
5.55	2333.00	2245.99	435.06	0	0	0	0	0	0	0
5.60	2345.00	2265.79	396.05	0	0	0	0	0	0	0
5.65	2389.00	2290.43	492.84	0	0	0	0	0	0	0
5.70	2389.00	2310.15	394.27	0	0	0	0	0	0	0
5.75	2395.00	2327.12	339.42	0	0	0	0	0	0	0
5.80	2439.00	2349.49	447.53	0	0	0	0	0	0	0
5.85	2433.00	2366.19	334.03	0	0	0	0	0	0	0
5.90	2444.00	2381.76	311.22	0	0	0	0	0	0	0
5.95	2457.00	2396.80	300.98	0	0	0	0	0	0	0
6.00	2459.00	2409.24	248.78	0	0	0	0	0	0	0
6.05	2511.00	2429.59	407.03	0	0	0	0	0	0	0
6.10	2520.00	2447.68	361.62	0	0	0	0	0	0	0
6.15	2549.00	2467.94	405.30	0	0	0	0	0	0	0
6.20	2576.00	2489.55	432.24	0	0	0	0	0	0	0
6.25	2566.00	2504.84	305.79	0	0	0	0	0	0	0
6.30	2571.00	2518.07	264.63	0	0	0	0	0	0	0
6.35	2606.00	2535.66	351.70	0	0	0	0	0	0	0
6.40	2601.00	2548.73	261.36	0	0	0	0	0	0	0
6.45	2655.00	2569.98	425.09	0	0	0	0	0	0	0
6.50	2647.00	2585.39	308.07	0	0	0	0	0	0	0
6.55	2705.00	2609.31	478.46	0	0	0	0	0	0	0
6.60	2700.00	2627.45	362.77	0	0	0	0	0	0	0
6.65	2715.00	2644.96	350.21	0	0	0	0	0	0	0
6.70	2745.00	2664.97	400.17	0	0	0	0	0	0	0
6.75	2756.00	2683.17	364.14	0	0	0	0	0	0	0
6.80	2752.00	2696.94	275.31	0	0	0	0	0	0	0
6.85	2779.00	2713.35	328.25	0	0	0	0	0	0	0
6.90	2803.00	2731.28	358.60	0	0	0	0	0	0	0
6.95	2818.00	2748.62	346.88	0	0	0	0	0	0	0
7.00	2832.00	2765.30	333.50	0	0	0	0	0	0	0
7.05	2848.00	2781.84	330.80	0	0	0	0	0	0	0
7.10	2847.00	2794.87	260.64	0	0	0	0	0	0	0
7.15	2867.00	2809.30	288.52	0	0	0	0	0	0	0
7.20	2855.00	2818.44	182.81	0	0	0	0	0	0	0
7.25	2863.00	2827.35	178.25	0	0	0	0	0	0	0
7.30	2918.00	2845.48	362.60	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
7.35	2947.00	2865.78	406.08	0	0	0	0	0	0	0
7.40	2951.00	2882.83	340.86	0	0	0	0	0	0	0
7.45	2936.00	2893.46	212.69	0	0	0	0	0	0	0
7.50	2958.00	2906.37	258.15	0	0	0	0	0	0	0
7.55	3004.00	2925.90	390.52	0	0	0	0	0	0	0
7.60	2987.00	2938.12	244.42	0	0	0	0	0	0	0
7.65	3004.00	2951.29	263.54	0	0	0	0	0	0	0
7.70	3018.00	2964.63	266.83	0	0	0	0	0	0	0
7.75	3056.00	2982.91	365.46	0	0	0	0	0	0	0
7.80	3062.00	2998.73	316.37	0	0	0	0	0	0	0
7.85	3076.00	3014.18	309.10	0	0	0	0	0	0	0
7.90	3083.00	3027.94	275.28	0	0	0	0	0	0	0
7.95	3101.00	3042.56	292.22	0	0	0	0	0	0	0
8.00	3110.00	3056.04	269.78	0	0	0	0	0	0	0
8.05	3180.00	3080.84	495.82	0	0	0	0	0	0	0
8.10	3156.00	3095.87	300.66	0	0	0	0	0	0	0
8.15	3188.00	3114.29	368.53	0	0	0	0	0	0	0
8.20	3213.00	3134.04	394.82	0	0	0	0	0	0	0
8.25	3164.00	3140.03	119.86	0	0	0	0	0	0	0
8.30	3214.00	3154.82	295.88	0	0	0	0	0	0	0
8.35	3268.00	3177.46	452.71	0	0	0	0	0	0	0
8.40	3226.00	3187.17	194.17	0	0	0	0	0	0	0
8.45	3255.00	3200.73	271.33	0	0	0	0	0	0	0
8.50	3230.00	3206.59	117.07	0	0	0	0	0	0	0
8.55	3249.00	3215.07	169.65	0	0	0	0	0	0	0
8.60	3299.00	3231.86	335.72	0	0	0	0	0	0	0
8.65	3285.00	3242.48	212.58	0	0	0	0	0	0	0
8.70	3318.00	3257.59	302.06	0	0	0	0	0	0	0
8.75	3338.00	3273.67	321.65	0	0	0	0	0	0	0
8.80	3332.00	3285.34	233.32	0	0	0	0	0	0	0
8.85	3317.00	3291.67	126.66	0	0	0	0	0	0	0
8.90	3398.00	3312.94	425.33	0	0	0	0	0	0	0
8.95	3370.00	3324.35	228.26	0	0	0	0	0	0	0
9.00	3372.00	3333.88	190.61	0	0	0	0	0	0	0
9.05	3436.00	3354.30	408.49	0	0	0	0	0	0	0
9.10	3402.00	3363.84	190.79	0	0	0	0	0	0	0
9.15	3430.00	3377.07	264.63	0	0	0	0	0	0	0
9.20	3394.00	3380.46	67.71	0	0	0	0	0	0	0
9.25	3438.00	3391.97	230.17	0	0	0	0	0	0	0
9.30	3448.00	3403.17	224.13	0	0	0	0	0	0	0
9.35	3466.00	3415.74	251.30	0	0	0	0	0	0	0
9.40	3471.00	3426.79	221.04	0	0	0	0	0	0	0
9.45	3481.00	3437.63	216.84	0	0	0	0	0	0	0
9.50	3476.00	3445.31	153.47	0	0	0	0	0	0	0
9.55	3471.00	3450.45	102.77	0	0	0	0	0	0	0
9.60	3504.00	3461.16	214.22	0	0	0	0	0	0	0
9.65	3528.00	3474.52	267.38	0	0	0	0	0	0	0
9.70	3525.00	3484.62	201.90	0	0	0	0	0	0	0
9.75	3564.00	3500.50	317.52	0	0	0	0	0	0	0
9.80	3543.00	3509.00	170.01	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
9.85	3570.00	3521.20	244.01	0	0	0	0	0	0	0
9.90	3619.00	3540.76	391.21	0	0	0	0	0	0	0
9.95	3599.00	3552.41	232.97	0	0	0	0	0	0	0
10.00	3608.00	3563.52	222.37	0	0	0	0	0	0	0
10.05	3611.00	3573.02	189.90	0	0	0	0	0	0	0
10.10	3620.00	3582.42	187.92	0	0	0	0	0	0	0
10.15	3645.00	3594.93	250.34	0	0	0	0	0	0	0
10.20	3638.00	3603.55	172.27	0	0	0	0	0	0	0
10.25	3656.00	3614.04	209.81	0	0	0	0	0	0	0
10.30	3671.00	3625.43	227.85	0	0	0	0	0	0	0
10.35	3662.00	3632.74	146.28	0	0	0	0	0	0	0
10.40	3703.00	3646.79	281.03	0	0	0	0	0	0	0
10.45	3681.00	3653.64	136.82	0	0	0	0	0	0	0
10.50	3692.00	3661.31	153.46	0	0	0	0	0	0	0
10.55	3691.00	3667.25	118.76	0	0	0	0	0	0	0
10.60	3716.00	3677.00	195.01	0	0	0	0	0	0	0
10.65	3740.00	3689.60	252.01	0	0	0	0	0	0	0
10.70	3715.00	3694.68	101.61	0	0	0	0	0	0	0
10.75	3736.00	3702.94	165.29	0	0	0	0	0	0	0
10.80	3737.00	3709.75	136.23	0	0	0	0	0	0	0
10.85	3793.00	3726.40	332.98	0	0	0	0	0	0	0
10.90	3783.00	3737.72	226.39	0	0	0	0	0	0	0
10.95	3799.00	3749.98	245.11	0	0	0	0	0	0	0
11.00	3769.00	3753.78	76.09	0	0	0	0	0	0	0
11.05	3802.00	3763.43	192.87	0	0	0	0	0	0	0
11.10	3804.00	3771.54	162.29	0	0	0	0	0	0	0
11.15	3806.00	3778.43	137.84	0	0	0	0	0	0	0
11.20	3838.00	3790.35	238.27	0	0	0	0	0	0	0
11.25	3875.00	3807.28	338.61	0	0	0	0	0	0	0
11.30	3825.00	3810.82	70.89	0	0	0	0	0	0	0
11.35	3824.00	3813.46	52.71	0	0	0	0	0	0	0
11.40	3849.00	3820.57	142.17	0	0	0	0	0	0	0
11.45	3838.00	3824.05	69.74	0	0	0	0	0	0	0
11.50	3858.00	3830.84	135.79	0	0	0	0	0	0	0
11.55	3853.00	3835.27	88.63	0	0	0	0	0	0	0
11.60	3861.00	3840.42	102.91	0	0	0	0	0	0	0
11.65	3890.00	3850.34	198.33	0	0	0	0	0	0	0
11.70	3919.00	3864.07	274.66	0	0	0	0	0	0	0
11.75	3915.00	3874.25	203.73	0	0	0	0	0	0	0
11.80	3945.00	3888.40	282.98	0	0	0	0	0	0	0
11.85	3938.00	3898.32	198.38	0	0	0	0	0	0	0
11.90	3939.00	3906.46	162.71	0	0	0	0	0	0	0
11.95	3936.00	3912.37	118.16	0	0	0	0	0	0	0
12.00	3929.00	3915.69	66.53	0	0	0	0	0	0	0
12.05	3944.00	3921.35	113.23	0	0	0	0	0	0	0
12.10	3978.00	3932.68	226.58	0	0	0	0	0	0	0
12.15	3965.00	3939.15	129.26	0	0	0	0	0	0	0
12.20	3990.00	3949.32	203.41	0	0	0	0	0	0	0
12.25	3973.00	3954.05	94.73	0	0	0	0	0	0	0
12.30	3991.00	3961.44	147.78	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
12.35	3985.00	3966.15	94.23	0	0	0	0	0	0	0
12.40	4002.00	3973.32	143.38	0	0	0	0	0	0	0
12.45	3999.00	3978.46	102.71	0	0	0	0	0	0	0
12.50	4009.00	3984.57	122.16	0	0	0	0	0	0	0
12.55	4043.00	3996.25	233.73	0	0	0	0	0	0	0
12.60	4026.00	4002.20	118.98	0	0	0	0	0	0	0
12.65	4019.00	4005.56	67.19	0	0	0	0	0	0	0
12.70	4038.00	4012.05	129.75	0	0	0	0	0	0	0
12.75	4014.00	4012.44	7.80	0	0	0	0	0	0	0
12.80	4042.00	4018.35	118.24	0	0	0	0	0	0	0
12.85	4073.00	4029.28	218.59	0	0	0	0	0	0	0
12.90	4067.00	4036.83	150.87	0	0	0	0	0	0	0
12.95	4066.00	4042.66	116.70	0	0	0	0	0	0	0
13.00	4098.00	4053.73	221.36	0	0	0	0	0	0	0
13.05	4040.00	4050.98	-54.91	0	0	0	0	0	0	0
13.10	4088.00	4058.39	148.07	0	0	0	0	0	0	0
13.15	4080.00	4062.71	86.46	0	0	0	0	0	0	0
13.20	4060.00	4062.17	-10.83	0	0	0	0	0	0	0
13.25	4092.00	4068.13	119.33	0	0	0	0	0	0	0
13.30	4102.00	4074.91	135.46	0	0	0	0	0	0	0
13.35	4081.00	4076.13	24.37	0	0	0	0	0	0	0
13.40	4123.00	4085.50	187.50	0	0	0	0	0	0	0
13.45	4104.00	4089.20	74.00	0	0	0	0	0	0	0
13.50	4099.00	4091.16	39.20	0	0	0	0	0	0	0
13.55	4120.00	4096.93	115.36	0	0	0	0	0	0	0
13.60	4100.00	4097.54	12.29	0	0	0	0	0	0	0
13.65	4109.00	4099.83	45.83	0	0	0	0	0	0	0
13.70	4161.00	4112.07	244.67	0	0	0	0	0	0	0
13.75	4133.00	4116.25	83.73	0	0	0	0	0	0	0
13.80	4149.00	4122.80	130.99	0	0	0	0	0	0	0
13.85	4157.00	4129.64	136.79	0	0	0	0	0	0	0
13.90	4179.00	4139.51	197.43	0	0	0	0	0	0	0
13.95	4160.00	4143.61	81.94	0	0	0	0	0	0	0
14.00	4150.00	4144.89	25.56	0	0	0	0	0	0	0
14.05	4193.00	4154.51	192.44	0	0	0	0	0	0	0
14.10	4188.00	4161.21	133.96	0	0	0	0	0	0	0
14.15	4180.00	4164.97	75.17	0	0	0	0	0	0	0
14.20	4194.00	4170.77	116.13	0	0	0	0	0	0	0
14.25	4233.00	4183.22	248.91	0	0	0	0	0	0	0
14.30	4169.00	4180.38	-56.88	0	0	0	0	0	0	0
14.35	4184.00	4181.10	14.50	0	0	0	0	0	0	0
14.40	4202.00	4185.28	83.59	0	0	0	0	0	0	0
14.45	4190.00	4186.22	18.88	0	0	0	0	0	0	0
14.50	4173.00	4183.58	-52.90	0	0	0	0	0	0	0
14.55	4177.00	4182.26	-26.32	0	0	0	0	0	0	0
14.60	4191.00	4184.01	34.95	0	0	0	0	0	0	0
14.65	4199.00	4187.01	59.96	0	0	0	0	0	0	0
14.70	4215.00	4192.61	111.96	0	0	0	0	0	0	0
14.75	4209.00	4195.89	65.58	0	0	0	0	0	0	0
14.80	4215.00	4199.71	76.46	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
14.85	4172.00	4194.17	-110.83	0	0	0	0	0	0	0
14.90	4195.00	4194.33	3.33	0	0	0	0	0	0	0
14.95	4224.00	4200.27	118.66	0	0	0	0	0	0	0
15.00	4208.00	4201.81	30.94	0	0	0	0	0	0	0
15.05	4248.00	4211.05	184.75	0	0	0	0	0	0	0
15.10	4228.00	4214.44	67.79	0	0	0	0	0	0	0
15.15	4209.00	4213.35	-21.76	0	0	0	0	0	0	0
15.20	4209.00	4212.48	-17.41	0	0	0	0	0	0	0
15.25	4234.00	4216.79	86.07	0	0	0	0	0	0	0
15.30	4212.00	4215.83	-19.14	0	0	0	0	0	0	0
15.35	4237.00	4220.06	84.69	0	0	0	0	0	0	0
15.40	4248.00	4225.65	111.75	0	0	0	0	0	0	0
15.45	4237.00	4227.92	45.40	0	0	0	0	0	0	0
15.50	4212.00	4224.74	-63.68	0	0	0	0	0	0	0
15.55	4226.00	4224.99	5.06	0	0	0	0	0	0	0
15.60	4216.00	4223.19	-35.96	0	0	0	0	0	0	0
15.65	4238.00	4226.15	59.24	0	0	0	0	0	0	0
15.70	4226.00	4226.12	-0.62	0	0	0	0	0	0	0
15.75	4238.00	4228.50	47.51	0	0	0	0	0	0	0
15.80	4231.00	4229.00	10.01	0	0	0	0	0	0	0
15.85	4260.00	4235.20	124.00	0	0	0	0	0	0	0
15.90	4251.00	4238.36	63.20	0	0	0	0	0	0	0
15.95	4238.00	4238.29	-1.44	0	0	0	0	0	0	0
16.00	4256.00	4241.83	70.85	0	0	0	0	0	0	0
16.05	4207.00	4234.86	-139.32	0	0	0	0	0	0	0
16.10	4207.00	4229.29	-111.46	0	0	0	0	0	0	0
16.15	4279.00	4239.23	198.84	0	0	4279	0	0	0	0
16.20	4247.00	4240.79	31.06	0	0	0	0	0	0	0
16.25	4252.00	4243.03	44.85	0	0	0	0	0	0	0
16.30	4242.00	4242.82	-4.11	0	0	0	0	0	0	0
16.35	4216.00	4237.46	-107.29	0	0	0	0	0	0	0
16.40	4003.00	4190.57	-937.83	0	0	0	0	0	0	0
16.45	4180.00	4188.45	-42.27	0	0	0	0	0	0	0
16.50	4240.00	4198.76	206.18	0	0	0	0	0	0	0
16.55	4212.00	4201.41	52.95	0	0	0	0	0	0	0
16.60	4232.00	4207.53	122.36	0	0	0	0	0	0	0
16.65	4251.00	4216.22	173.89	0	0	0	0	0	0	0
16.70	4248.00	4222.58	127.11	0	0	0	0	0	0	0
16.75	4261.00	4230.26	153.69	0	0	0	0	0	0	0
16.80	4226.00	4229.41	-17.05	0	0	0	0	0	0	0
16.85	4268.00	4237.13	154.36	0	0	0	0	0	0	0
16.90	4252.00	4240.10	59.49	0	0	0	0	0	0	0
16.95	4256.00	4243.28	63.59	0	0	0	0	0	0	0
17.00	4270.00	4248.63	106.87	0	0	0	0	0	0	0
17.05	4238.00	4246.50	-42.50	0	0	0	0	0	0	0
17.10	4233.00	4243.80	-54.00	0	0	0	0	0	0	0
17.15	4242.00	4243.44	-7.21	0	0	0	0	0	0	0
17.20	4260.00	4246.75	66.24	0	0	0	0	0	0	0
17.25	4214.00	4240.20	-131.01	0	0	0	0	0	0	0
17.30	4249.00	4241.96	35.20	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
17.35	4239.00	4241.37	-11.85	0	0	0	0	0	0	0
17.40	4214.00	4235.90	-109.48	0	0	0	4214	0	0	0
17.90	4212.00	4231.12	-9.56	0	0	0	0	0	0	0
18.40	4225.00	4229.89	-2.45	0	0	0	0	4225	0	0
18.90	4233.00	4230.51	1.24	0	0	0	0	0	0	0
19.40	4133.00	4211.01	-39.01	0	0	0	0	0	0	0
19.90	4106.00	4190.01	-42.00	0	0	0	0	0	0	0
20.40	4081.00	4168.21	-43.60	0	0	0	0	0	0	0
20.90	4043.00	4143.17	-50.08	0	0	0	0	0	0	0
21.40	4027.00	4119.93	-46.47	0	0	0	0	0	0	0
21.90	3996.00	4095.15	-49.57	0	0	0	0	0	0	0
22.40	3903.00	4056.72	-76.86	0	0	0	0	0	0	0
22.90	3937.00	4032.77	-47.89	0	0	0	0	0	0	0
23.40	3865.00	3999.22	-67.11	0	0	0	0	0	0	0
23.90	3796.00	3958.57	-81.29	0	0	0	0	0	0	0
24.40	3839.00	3934.66	-47.83	0	0	0	0	0	0	0
24.90	3731.00	3893.93	-81.46	0	0	0	0	0	0	0
25.40	3635.00	3842.14	-103.57	0	0	0	0	0	0	0
25.90	3640.00	3801.71	-80.86	0	0	0	0	0	0	0
26.40	3567.00	3754.77	-93.89	0	0	0	0	0	0	0
26.90	3582.00	3720.22	-69.11	0	0	0	0	0	0	0
27.40	3570.00	3690.17	-60.09	0	0	0	0	0	0	0
27.90	3496.00	3651.34	-77.67	0	0	0	0	0	0	0
28.40	3428.00	3606.67	-89.34	0	0	0	0	0	0	0
28.90	3428.00	3570.94	-71.47	0	0	0	0	0	0	0
29.40	3340.00	3524.75	-92.37	0	0	0	0	0	0	0
29.90	3330.00	3485.80	-77.90	0	0	0	0	0	0	0
30.40	3261.00	3440.84	-89.92	0	0	0	0	0	0	0
30.90	3225.00	3397.67	-86.34	0	0	0	0	0	0	0
31.40	3190.00	3356.14	-83.07	0	0	0	0	0	0	0
31.90	3146.00	3314.11	-84.05	0	0	0	0	0	0	0
32.40	3065.00	3264.29	-99.64	0	0	0	0	0	0	0
32.90	3070.00	3225.43	-77.72	0	0	0	0	0	0	0
33.40	3001.00	3180.54	-89.77	0	0	0	0	0	0	0
33.90	2977.00	3139.84	-81.42	0	0	0	0	0	0	0
34.40	2898.00	3091.47	-96.73	0	0	0	0	0	0	0
34.90	2877.00	3048.57	-85.79	0	0	0	0	0	0	0
35.40	2823.00	3003.46	-90.23	0	0	0	0	0	0	0
35.90	2839.00	2970.57	-65.78	0	0	0	0	0	0	0
36.40	2748.00	2926.05	-89.03	0	0	0	0	0	0	0
36.90	2730.00	2886.84	-78.42	0	0	0	0	0	0	0
37.40	2696.00	2848.67	-76.34	0	0	0	0	0	0	0
37.90	2663.00	2811.54	-74.27	0	0	0	0	0	0	0
38.40	2602.00	2769.63	-83.82	0	0	0	0	0	0	0
38.90	2586.00	2732.91	-73.45	0	0	0	0	0	0	0
39.40	2523.00	2690.92	-83.96	0	0	0	0	0	0	0
39.90	2525.00	2657.74	-66.37	0	0	0	0	0	0	0
40.40	2411.00	2608.39	-98.70	0	0	0	0	0	0	0
40.90	2362.00	2559.11	-98.56	0	0	0	0	0	0	0
41.40	2387.00	2524.69	-68.85	0	0	0	0	0	0	0

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T	Alt	FAlt	FVeloc	LDA	LowV	Apogee	N-O	Drogue	Main	AUX
41.90	2317.00	2483.15	-83.08	0	0	0	0	0	0	0
42.40	2246.00	2435.72	-94.86	0	0	0	0	0	0	0
42.90	2204.00	2389.38	-92.69	0	0	0	0	0	0	0
43.40	2206.00	2352.70	-73.35	0	0	0	0	0	0	0
43.90	2157.00	2313.56	-78.28	0	0	0	0	0	0	0
44.40	2089.00	2268.65	-89.82	0	0	0	0	0	0	0
44.90	2052.00	2225.32	-86.66	0	0	0	0	0	0	0
45.40	2010.00	2182.26	-86.13	0	0	0	0	0	0	0
45.90	1952.00	2136.20	-92.10	0	0	0	0	0	0	0
46.40	1905.00	2089.96	-92.48	0	0	0	0	0	0	0
46.90	1873.00	2046.57	-86.79	0	0	0	0	0	0	0
47.40	1840.00	2005.26	-82.63	0	0	0	0	0	0	0
47.90	1745.00	1953.21	-104.10	0	0	0	0	0	0	0
48.40	1709.00	1904.36	-97.68	0	0	0	0	0	0	0
48.90	1692.00	1861.89	-84.95	0	0	0	0	0	0	0
49.40	1660.00	1821.51	-80.76	0	0	0	0	0	0	0
49.90	1576.00	1772.41	-98.21	0	0	0	0	0	0	0
50.40	1534.00	1724.73	-95.36	0	0	0	0	0	0	0
50.90	1492.00	1678.18	-93.09	0	0	0	0	0	0	0
51.40	1426.00	1627.75	-100.87	0	0	0	0	0	0	0
51.90	1401.00	1582.40	-90.70	0	0	0	0	0	0	0
52.40	1343.00	1534.52	-95.76	0	0	0	0	0	0	0
52.90	1314.00	1490.41	-88.21	0	0	0	0	0	0	0
53.40	1254.00	1443.13	-94.57	0	0	0	0	0	0	0
53.90	1213.00	1397.10	-92.05	0	0	0	0	0	0	0
54.40	1116.00	1340.88	-112.44	0	0	0	0	0	0	0
54.90	1125.00	1297.71	-86.35	0	0	0	0	0	0	0
55.40	1057.00	1249.57	-96.28	0	0	0	0	0	0	0
55.90	999.00	1199.45	-100.23	0	0	0	0	0	0	0
56.40	949.00	1149.36	-100.18	0	0	0	0	0	0	0
56.90	877.00	1094.89	-108.94	0	0	0	0	0	0	0
57.40	858.00	1047.51	-94.76	0	0	0	0	0	0	0
57.90	784.00	994.81	-105.40	0	0	0	0	0	0	0
58.40	724.00	940.65	-108.32	0	0	0	0	0	0	0
58.90	721.00	896.72	-87.86	0	0	0	0	0	0	0
59.40	698.00	856.97	-79.49	0	0	0	0	0	698	0
59.90	607.00	806.98	-99.99	0	0	0	0	0	0	0
60.40	569.00	759.38	-95.19	0	0	0	0	0	0	0
60.90	524.00	712.31	-94.15	0	0	0	0	0	0	0
61.40	6.00	571.05	-282.52	0	0	0	0	0	0	0
61.90	15.00	459.84	-222.42	0	0	0	0	0	0	0
62.40	4.00	368.67	-182.33	0	0	0	0	0	0	0