PURDUE SPACE PROGRAM

Project Wolf Critical Design Review

Purdue University
500 Allison Road
West Lafayette, IN 47906
7 January, 2025

Table 1: Abbreviations and Acronyms

Abbreviation/Acronym	Definition
AGCS	Avionics Ground Control Station
AGL	Above Ground Level
BIDC	Bechtel Innovation Design Center
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
CONOPS	Concept of Operations
FEA	Finite Element Analysis
FMEA	Failure Modes and Effects Analysis
MFSS	Motor and Fin Support Structure
MC	Mission Criteria
NASA	National Aeronautics and Space Administration
NAR	National Association of Rocketry
OTG	On The Go
PDR	Preliminary Design Review
PPE	Personal Protection Equipment
PSP	Purdue Space Program
PTC	Purdue Technology Center
RAC	Risk Assessment Code
R&D	Research and Development
R&VP	Requirements and Verification Planning
RSO	Range Safety Officer
SL	Student Launch
TLA	Top Level Assembly
TRA	Tripoli Rocketry Association
WDM	Weighted Decision Matrix

1.1 Team Summary

Table 1.1.1: Team Summary

Team Name	Purdue Space Program Student Launch
Mailing Address	500 Allison Road, West Lafayette, IN 47906
2025 Team Mentor	Christopher Nilsen
2025 Mentor Contact Info	cnilsen@purdue.edu, (813) 442-0891
2025 Mentor TRA Certifications	TRA 12041, Level 3 Certified
Launch in Huntsville?	Yes
Total People-Hours Spent on Milestone	37 People - Hours
Team Instagram	@psp.studentlaunch
Team Facebook	purduesl
Team Website	https://purdueseds.space/student-launch/

1.2 Launch Vehicle Summary

Table 1.2.1: Launch Vehicle Summary

Vehicle Name	Luna-Tic
Official Target Altitude	4,772’
Chosen Primary Motor	Loki Research L930
Chosen Secondary Motor	Loki Research L1482
Predicted Vehicle Total Mass	35.7 lb
Vehicle Total Length	99.60”
Vehicle Outer Diameter	5.15”
Number of Independent Sections	3
Number of Fins	3
Booster Section Length/Mass	25” / 8.82 lb
Recovery Section Length/Mass	44.7” / 9.52 lb
Payload Section Length/Mass	29.90” / 9.56 lb
Vehicle Recovery System	Dual Deployment, Apogee and 700 ft AGL
Rail Size	10”

1.3 Payload Summary

The payload consists of two subsystems. The first, the STEMnaut Capsule Radio Frequency Transmitter (STEMCRaFT), is responsible for satisfying Requirement 4.1. The STEMCRaFT consists of the sensor package, the STEMnaut capsule, and the radio transmission system. This design eliminates the need for external systems, such as a deployable vehicle. The second, the integration and retention system, ensures that the STEMCRaFT remains securely in place within the airframe and payload coupler. This system consists of a mounting plate sandwiched between two rings that hold the sensor package and battery in place, and the capsule is bolted to one of the rings. The rings are then bolted to the payload coupler airframe. The integration system satisfies Requirements S.P.5 and S.P.7.

2 Changes Made Since Preliminary Design Review

2.1 Changes Made to Vehicle Criteria

There were some design changes made to the launch vehicle since Preliminary Design Review (PDR) to account for feedback during the PDR presentation session and further refinement of the launch vehicle's design. The first design change was the total length of the launch vehicle. There was an increase of 4" to the total length of the launch vehicle which is now 99.6". The sections that increased in length were the lower recovery airframe section and the booster section. The lower recovery airframe increased by 3" to now equal 21". The booster section had an increase in length of 1" to now equal 25". The lower recovery airframe section length was increased to allow for more space of the drogue parachute inside the launch vehicle. There were some difficulties packing the subscale parachute so the team decided to increase the length of the airframe for the full-scale to ensure proper packing methods. The booster airframe was increased to account for the bulkhead at the motor casing. The team also decided on the shock cord lengths to be 40' for drogue and then 60' for main. The team decided to go on the longer side to avoid parachute collision issues that the team faced last year. Finally, the fins changed from using a NACA 0008 airfoil to a NACA 0012 airfoil. This change was made because a fin flutter test was conducted on the fin with NACA 0008 airfoil which failed at the fin tip after 14 lbf was applied across the fin. This is unacceptable as it violates Requirement S.C.22, which mandates the fin to be able to withstand a force of 50 lbf. After the PDR presentation, the team remeasured the casing with the bulkhead and determined another inch to the booster airframe to ensure clearance and ensure that the secondary payload coupler bulkhead would not collide with the motor casing bulkhead. This increase in length did affect the stability of the launch vehicle. The static stability of the launch vehicle went from 3.56 cals to a stability of 3.7 cals after the increase in length and change in fin airfoil type. The team decided that this change in stability was negligible as it met both Requirements S.C.12 and C.2.14.

2.2 Changes Made to Payload Criteria

As stated in the PDR, the payload has two subsystems, the STEMCRaFT and the integration and retention system, which work together to accomplish the payload objective. However, the design of the individual subsystems have changed. The STEMCRaFT has transitioned from a sled design to concentric rings that are bolted to the payload coupler and a capsule for the STEMnauts. The team decided to move away from the sled design from CDR due to ease of manufacturing, accessibility, and ensuring that the team was able to meet all requirements since there were concerns about the components being fully encapsulated during PDR.

The transmission system of the payload has also changed since the PDR. For the transmission antenna, there will be four .31" slits made into the airframe which will allow for arms to extend after landing. These arms will be reinforced with the fiberglass removed when the slits were cut. This addition was made to ensure a clear transmission of the data, overcoming any geographic obstacles and satisfying Requirement S.P.4.

2.3 Changes Made to Project Plan

The project plan has had minimal changes since the PDR. The largest changes to the project plan has been the shifting of dates due to student schedules and university breaks. The most notable date change was that of the subscale date. The subscale launch was rescheduled to November 17th, 2024, deviating from both the originally proposed and backup launch dates.

3 Vehicle Criteria

3.1 Mission Statement and Criteria

3.1.1 Mission Statement

The mission of Project Wolf is to develop a fully reusable launch vehicle that is able to reach an apogee of 4772’ with the purpose of safely delivering the STEMCRaFT throughout flight to a landing site. The STEMCRaFT will have the ability to transmit at least three pieces of landing site data via radio transmission back to ground control. This will be done by using students’ engineering skills acquired throughout their careers at Purdue University, Purdue Space Program, research experience, and industry experience.

3.1.2 Mission Success Criteria

The team has developed mission criteria (MC) that will determine if the flight on launch day will be considered a success. Most of these success criteria are the same as PDR. The team did add MC2 as the team now knows the official competition altitude and determined that the launch vehicle should reach close to that value to be a success.

Table 3.1.2.1 Mission Success Criteria

Criteria ID	Criteria	Justification	Metric
MC1	The launch vehicle will successfully achieve an apogee between 4000 and 6000 ft.	Reaching this apogee meets Requirement C.2.1 of achieving an apogee between 4,000 and 6000 ft. The selected motor should put the launch vehicle in that range.	Apogee, ft.
MC2	The launch vehicle will reach an altitude ±1000’ of the competition altitude of 4772’	Reaching this apogee will satisfy criterion MC1 while also aligning with the objective of proximity to the competition apogee.	Apogee, ft
MC3	The launch vehicle will have successful deployment of both drogue and main parachute during descent	Proper deployment of the drogue and main parachutes is critical for a safe and controlled descent.	The number of recovery systems deployed is equal to the number of recovery systems on board
MC4	The launch vehicle will be fully recoverable and reusable	Having a fully reusable launch vehicle satisfies Requirement A.2.3.	Number of damaged components

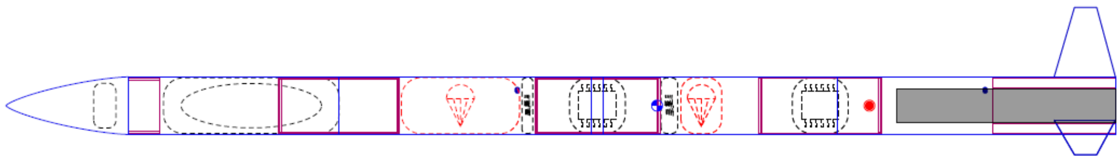
MC5	All components will be strong enough to endure the forces of flight	It is paramount that the launch vehicle can take the forces of flight to ensure the safety of everyone at the launch competition.	A safety factor of at least 1.5 for all parts
MC6	The launch vehicle will land softly and in a manner deemed safe	Soft landings are crucial to prevent damage to the vehicle and the payload. Requirement A.3.3 requires each independent section to be below 75 ft-lbf.	Descent kinetic energy
MC7	The payload will successfully collect and relay temperature, elapsed time, and apogee after landing.	The primary goal of the payload is to collect and transmit the selected data points to satisfy Requirement P.4.2.1.	Number of data points collected
MC8	The STEMCRaFT will protect all STEMnaut passengers during the entire flight	Protecting the STEMnauts during flight is critical to demonstrate the STEMCRaFT's safety per Requirement P.4.1.	Max g-force

3.1.3 Launch Vehicle Alternatives

3.2 Chosen Alternative

3.2.1 Top Level Assembly Design

Rocket Design



Rocket
Stages: 1
Mass (with motor): 35.7 lb
Stability: 3.7 cal / 19.1 %
CG: 58.447 in
CP: 77.51 in

L930-LW-0

Altitude	4819 ft
Flight Time	85.7 s
Time to Apogee	18.1 s
Optimum Delay	14.1 s
Velocity off Pad	62.5 ft/s
Max Velocity	586 ft/s
Velocity at Deployment	124 ft/s
Landing Velocity	14.3 ft/s

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Motor Wt	Size
L930-LW	895 N	3.95 s	1123 N	3534 Ns	5.64:1	4 lb	2.99/19.6 in

Figure 3.2.1.1: Chosen Top-Level Alternative OpenRocket

The chosen top level assembly design of the launch vehicle out of the three alternative designs presented in PDR is the 5” airframe diameter with a secondary payload coupler. This design was chosen over the 4” diameter design due to the motor restrictions and to ensure that the launch vehicle can meet all National Aeronautics and Space Administration (NASA) altitude requirements. The 4” design would also be harder for integration for the avionics, payload, and research and development (R&D) subteams. The team also decided to include the secondary payload coupler to allow for the R&D subteam, hence why the launch vehicle without the secondary payload coupler was not chosen. The secondary payload coupler allows the R&D subteam to have a space on the launch vehicle to be able to collect specific data for projects the team would like to develop such as airbrakes. The static stability of the launch vehicle is 3.7 cal which meets the Requirement C.2.14. This stability is lower than what the team had in previous years, however the goal for this year is to get a static stability as close to 3.0. This goal was set to prevent weathercocking but still maintain a stability above the minimum of 2.0 set by NASA.

The top level assembly (TLA) includes three different sections. These sections are the booster section, the recovery section, and the payload section. The booster section will include the booster airframe, the Motor Fin Support Structure (MFSS), the secondary payload section and the lower recovery section. The design of the MFSS will include a retainer plate to hold in the launch vehicle motor, a thrust plate, and a centering plate. The fins will be an airfoiled trapezoidal design. The fins have a root cord of 5.5” and a height of 6.2”. An airfoil design was chosen to reduce the drag of the airfoil and the manufacturing process will allow for this. The airfoil chosen for the fin was originally a NACA 0008 design before it was changed to a NACA 0012 design out of concern for fin deformation during landing which was discovered during the fin flutter test.

The second section of the launch vehicle is the recovery section. This section includes the avionics coupler, lower recovery, and upper recovery. The avionics coupler is where the avionics sled is held and the energetics for separation. The separation of the launch vehicle is located between the lower recovery section and avionics coupler and between the upper recovery and the payload coupler.

The last section of the launch vehicle includes the payload coupler, the payload airframe, and the nosecone. This is where the payload will be housed inside the launch vehicle. This will include the integration system and the STEMCRaFT, further described in Section 4.

The full vehicle cross-sectional assembly is shown below, with each independent section shown in a different color . The nosecone is shown in red, the payload section is yellow, the recovery section is green, and the booster section is blue.

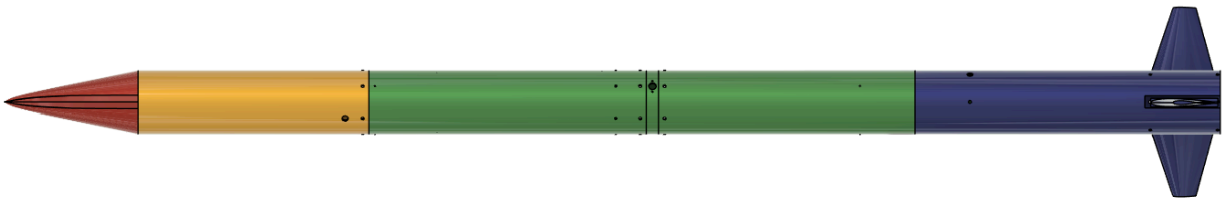


Figure 3.2.1.2: TLA of the Launch Vehicle Side View

3.2.2 Nosecone

Three alternatives were considered for the nosecone. A conic, an elliptical, and a Haack series nosecone were considered. All simulations returned fairly similar results but the Haack series was ultimately selected. The two most important factors when considering which nosecone to choose were overall aerodynamics and internal storage space. The team decided that the

Haack series scored the highest on aerodynamics and second in internal storage space so it was selected.

3.2.3 Airframe

The launch vehicle's airframe is composed of several subsections, including the payload, upper recovery, lower recovery, and booster, all joined by couplers such as those for the lower recovery, avionics, and payload. Two design alternatives were proposed for the airframe. Design 1 excluded the new R&D payload, omitting the lower recovery airframe and coupler. In contrast, Design 2 incorporated the R&D payload, along with the lower recovery airframe and coupler. The team selected Design 2 to accommodate the new R&D payload and drogue parachute. Following PDR, modifications were made to Design 2, including extending the booster airframe by 1” to accommodate the bulkhead at the motor casing and lengthening the lower recovery airframe to 21” to house a drogue parachute.

3.2.4 Motor Fin Support Structure

Due to the R&D payload being implemented in the final launch vehicle, MFSS alternative 2 for the centering plate has been chosen. This is the Centering Plate which has the 3 radial outer slots cut all the way through. This is different from alternative 1, which had the cutouts only partially cut through. The reasons why alternative 2 was chosen are to save more weight, as the safety factor is already extremely high, and because the pressure-regulating properties of the solid back surface of alternative 1 is not needed with the R&D Payload present in its place. The pressure regulation was initially needed to allow the shear pins to break and the sections to separate.

3.2.5 Fins

Since PDR there have been significant changes made to the chosen alternative. This section will discuss the chosen alternative as it was in PDR, while other sections will discuss the most recently modified version. The team decided to utilize the fin alternative previously designated as the third alternative for the 5” airframe with a R&D payload. This alternative was selected as it best matched the chosen top level alternative.

With the original design, the fin featured a NACA 0008 airfoil with a root chord of 5.5”, tip chord of 2”, a height of 6.2”, and a sweep length of 1.82”. This was paired with the matching insert, which is best described in two parts. The mounting bracket and trapezoidal interior. The mounting bracket joins the fin to the MFSS with a rectangular shape of 5.5” and 0.95”. The trapezoid has a height of 4.33” off the bracket, with a frame thickness of 0.5” and an outer angle of 102 degrees and a symmetric shape. Finally the top length of the interior is 1.38”. These original measurements are shown in the technical drawings below, same as in the PDR.

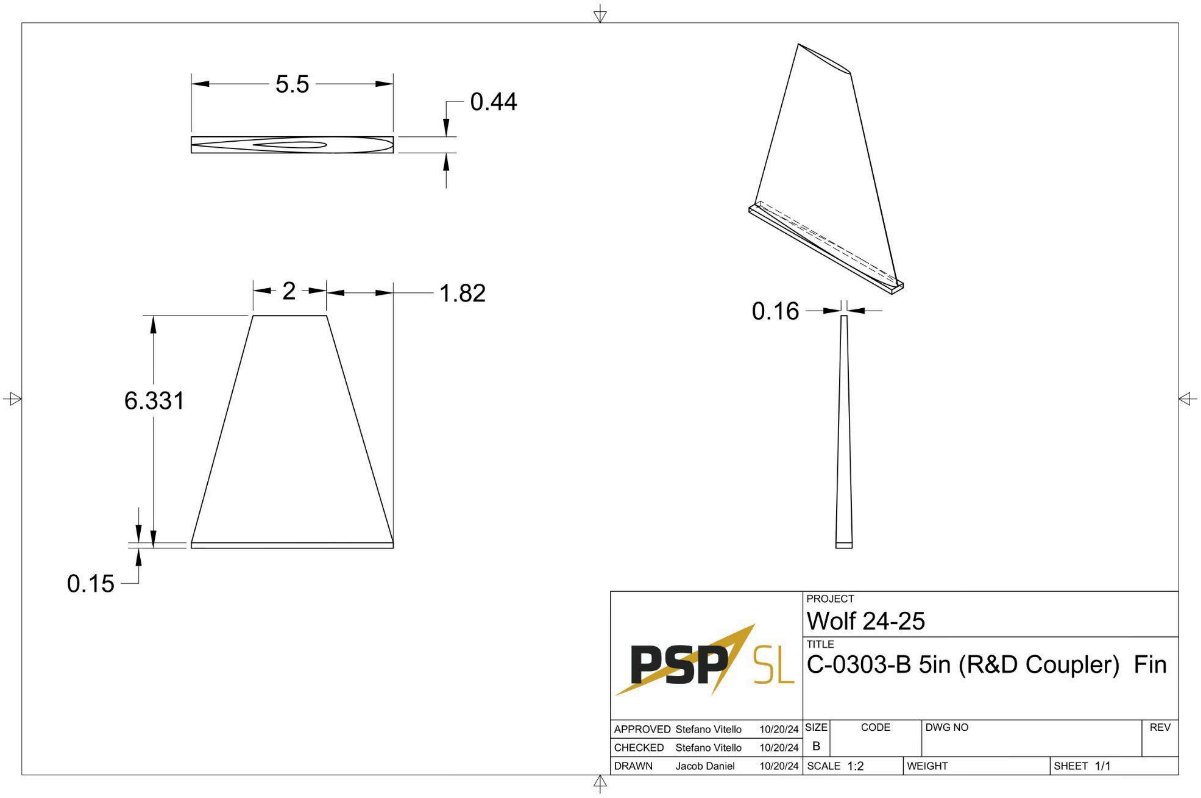


Figure 3.2.5.1: Former Design of The Chosen Fin Alternative

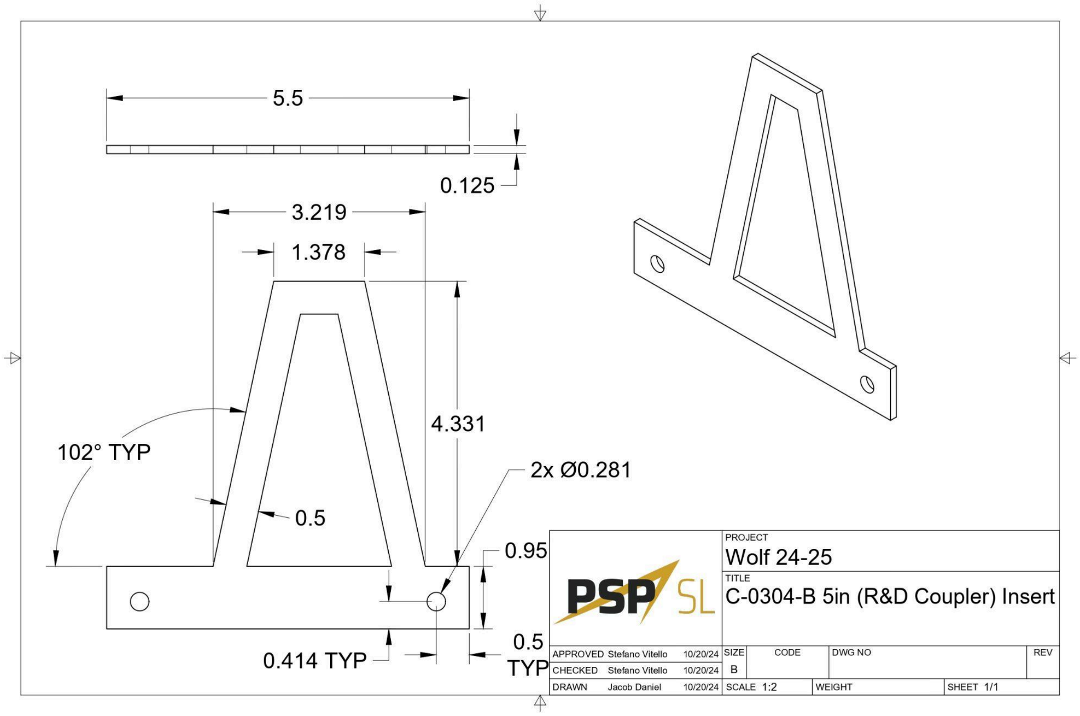


Figure 3.2.5.2: Former Design of The Chosen Fin Insert Alternative

3.3 Final Components

3.3.1 Booster Section

The Booster Section houses the MFSS and transfers the thrust of the motor to the rest of the launch vehicle. The booster section is comprised of the Booster Airframe, MFSS, and fins. It has a total length of 25’’ and a total mass of 8.82 lbm.

3.3.1.1 Motor Fin Support Structure

The MFSS is the system to hold the motor and the fins into the airframe, while evenly transferring the force of the motor through the airframe to prevent catastrophic failure. It also ensures proper alignment of the motor and fins, preventing unwanted horizontal thrust vectors and the flight characteristics from being unpredictable. No component design changes have been made since PDR due to extremely high safety factors and feasible manufacturability, which is discussed in sections below.

Table 3.3.1.1.1: MFSS Assembly Components

Component	Quantity	Material	Mass per piece (lbm)	Total Mass (lbm)	Manufacturing
Thrust Plate	1	Aluminum 6061-T6	0.2459	0.2459	CNC Milled
Centering Plate	1	Aluminum 6061-T6	0.1737	0.1737	CNC Milled
Motor Retainer Plate	1	Aluminum 6061-T6	0.0931	0.0931	Waterjet
Fin Insert	3	G10 Fiberglass	0.0696	0.2088	Waterjet
Fin Spacer	6	G10 Fiberglass	0.0044	0.0264	Waterjet
18-8 Stainless Steel Socket Head Screw, 1/4-20 Thread Size, 3/4 in. Long	6	18-8 Stainless Steel	0.0141	0.0846	Off-the-shelf

18-8 Stainless Steel Hex Nut, 1/4-20 Thread Size	6	18-8 Stainless Steel	0.0078	0.0468	Off-the-shelf
18-8 Stainless Steel Button Head Hex Drive Screw, 1/4-20 Thread Size, 7/8 in. long	6	18-8 Stainless Steel	0.0129	0.0774	Off-the-shelf
18-8 Stainless Steel Socket Head Screw, 6-32 Thread Size, 3/4 in. Long	3	18-8 Stainless Steel	0.0036	0.0108	Off-the-shelf
18-8 Stainless Steel Hex Nut, 6-32 Thread Size	3	18-8 Stainless Steel	0.0022	0.0066	Off-the-shelf
Total Component Mass (lbm)				0.7215	
Total Fasteners Mass (lbm)				0.2526	
Total Assembly Mass (lbm)				0.9741	

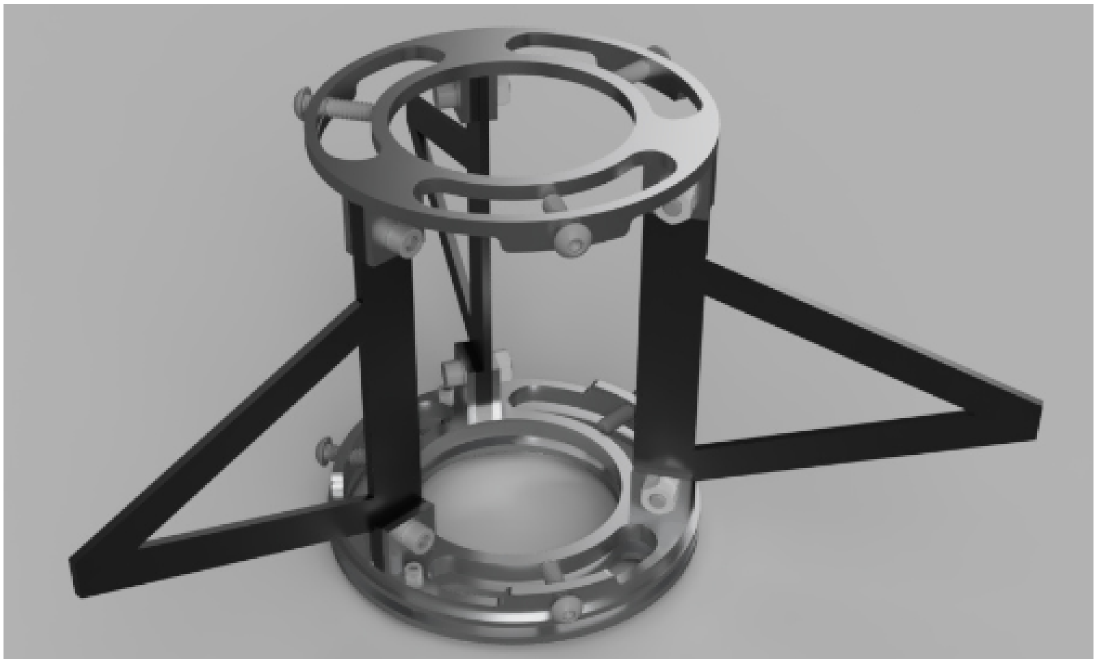


Figure 3.3.1.1.1: MFSS Assembly Computer-Aided Design (CAD) Model Render

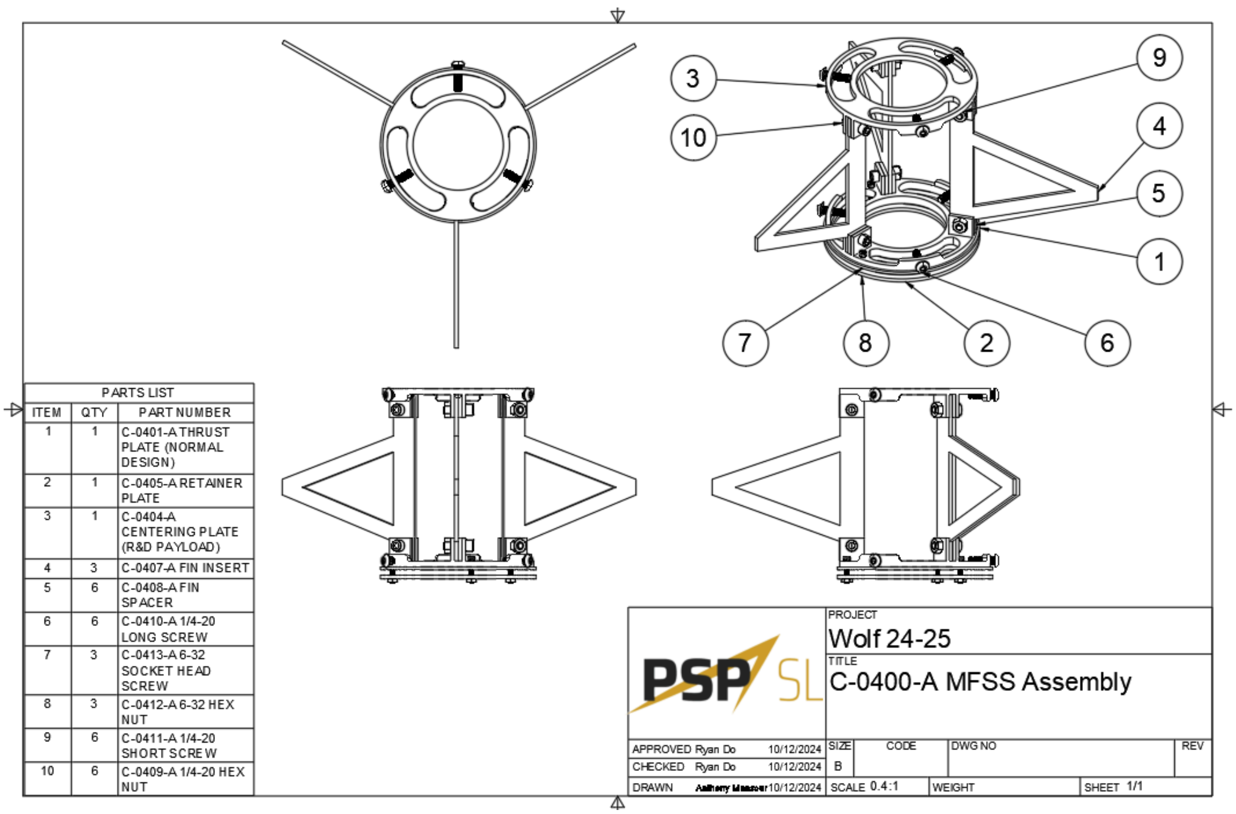


Figure 3.3.1.1.2*: MFSS Assembly Technical Drawing (Sheet 1)*

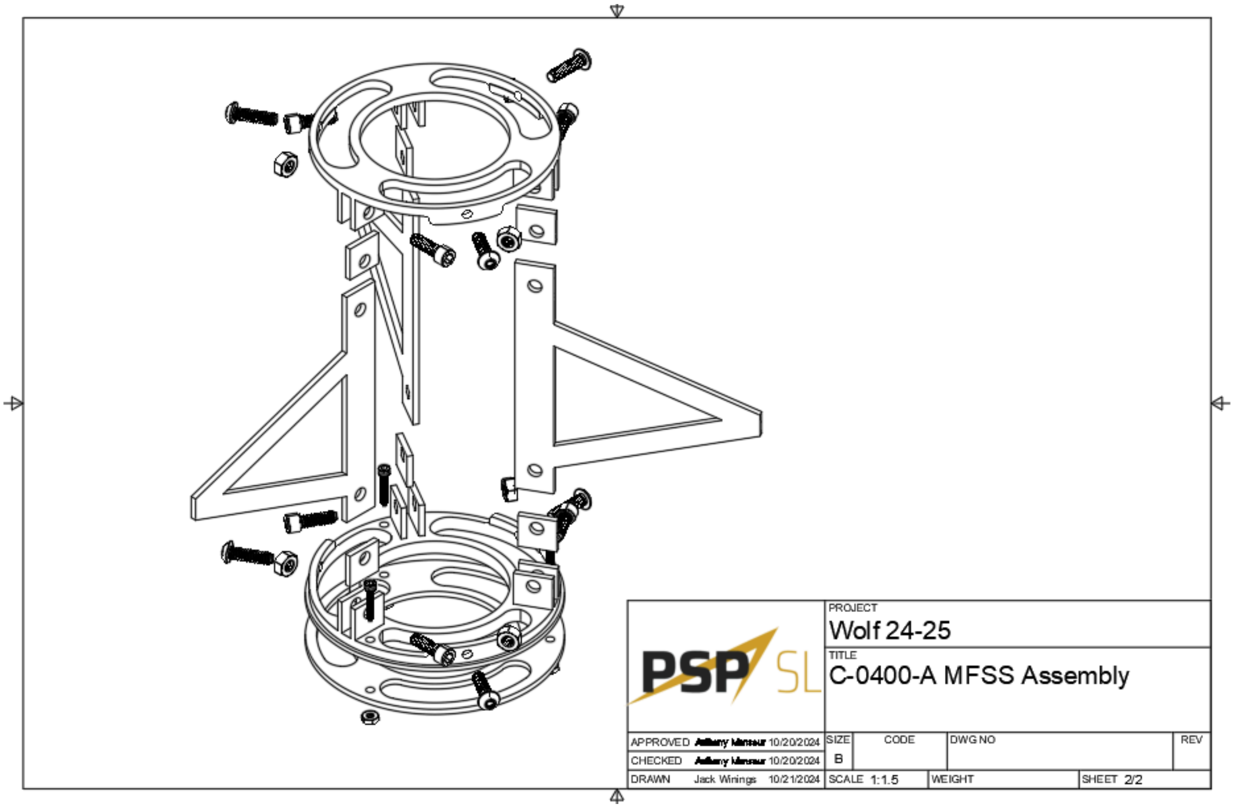


Figure 3.3.1.1.3*: MFSS Assembly Technical Drawing (Sheet 2)*

3.3.1.1.1 Retainer Plate

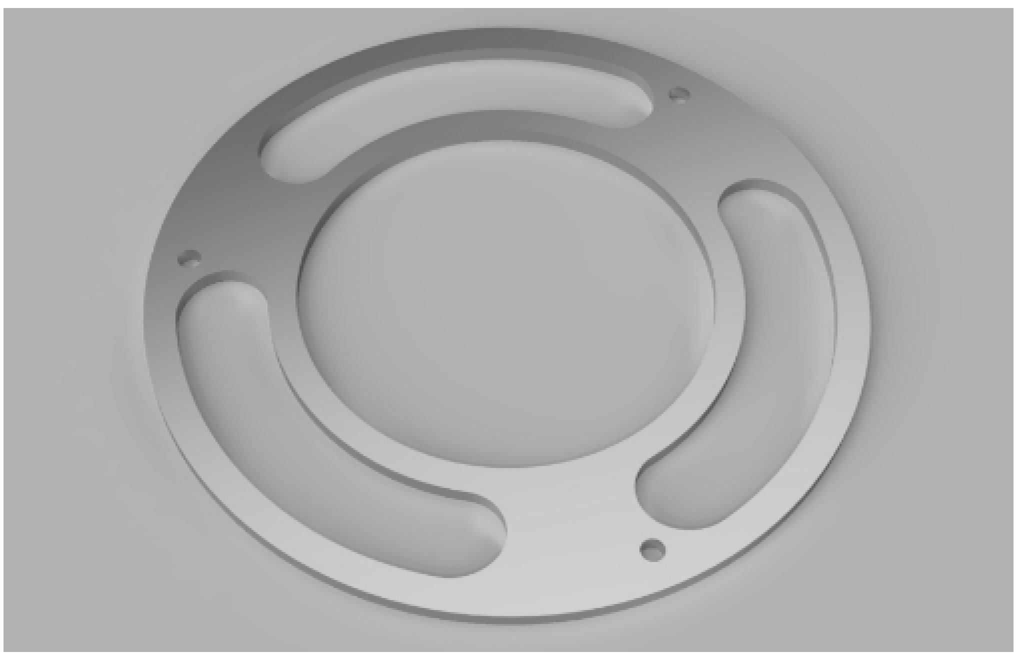


Figure 3.3.1.1.1.1: Motor Retainer Plate CAD Model Render

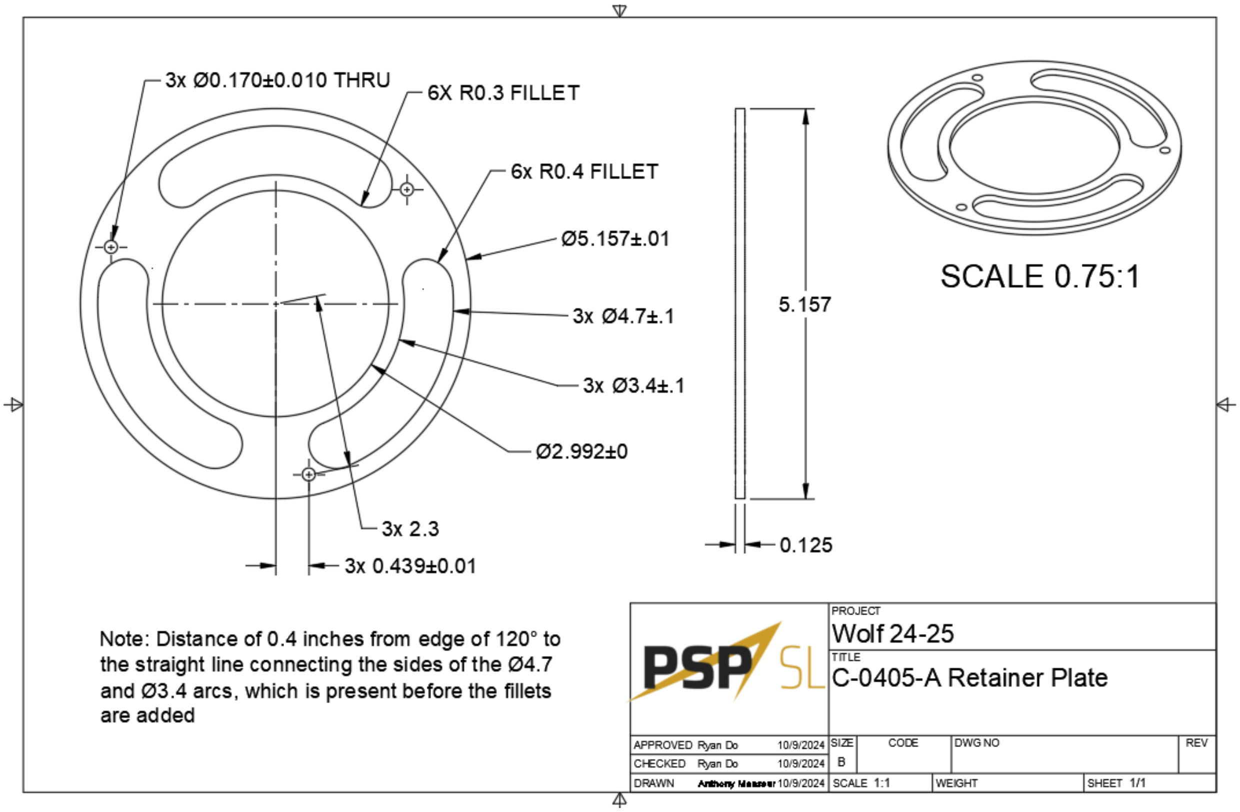


Figure 3.3.1.1.1.2: Motor Retainer Plate Technical Drawing

3.3.1.1.2 Thrust Plate

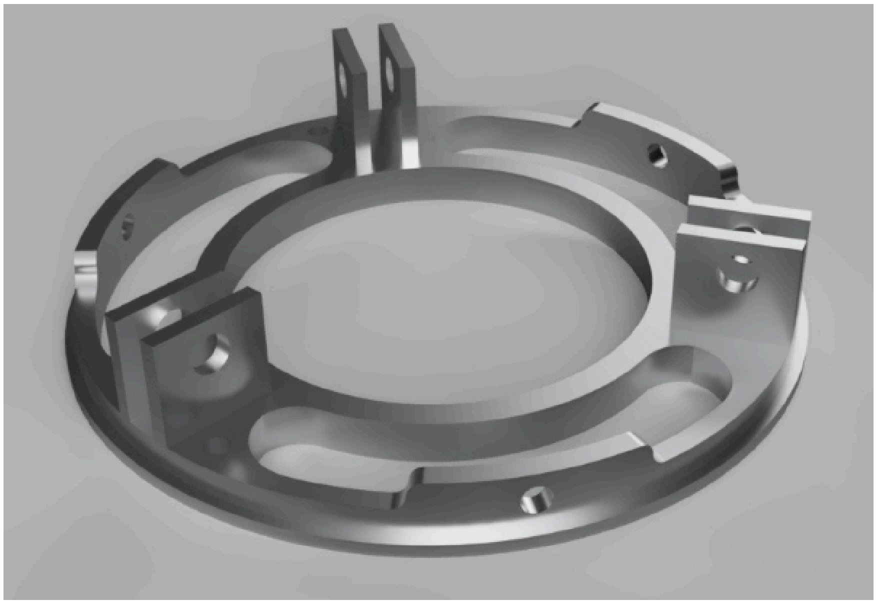


Figure 3.3.1.1.2.1: Thrust Plate CAD Model Render

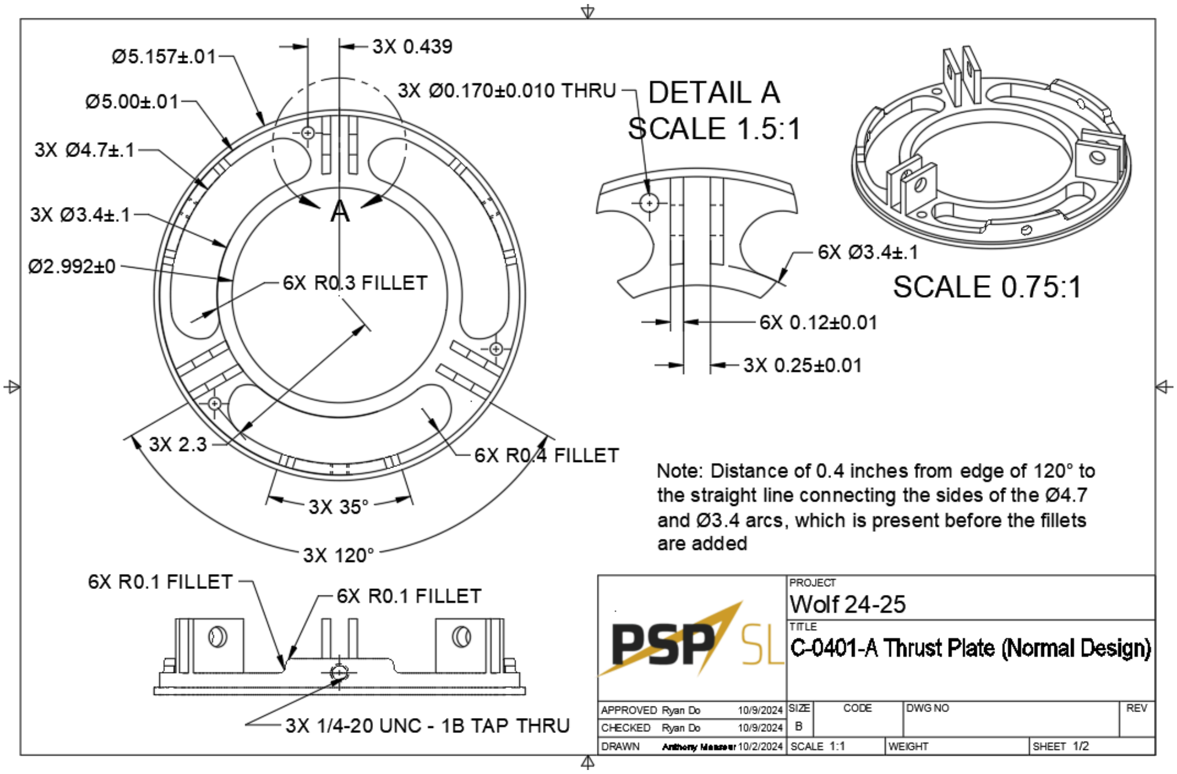


Figure 3.3.1.1.2.2: Thrust Plate Technical Drawing (Sheet 1)

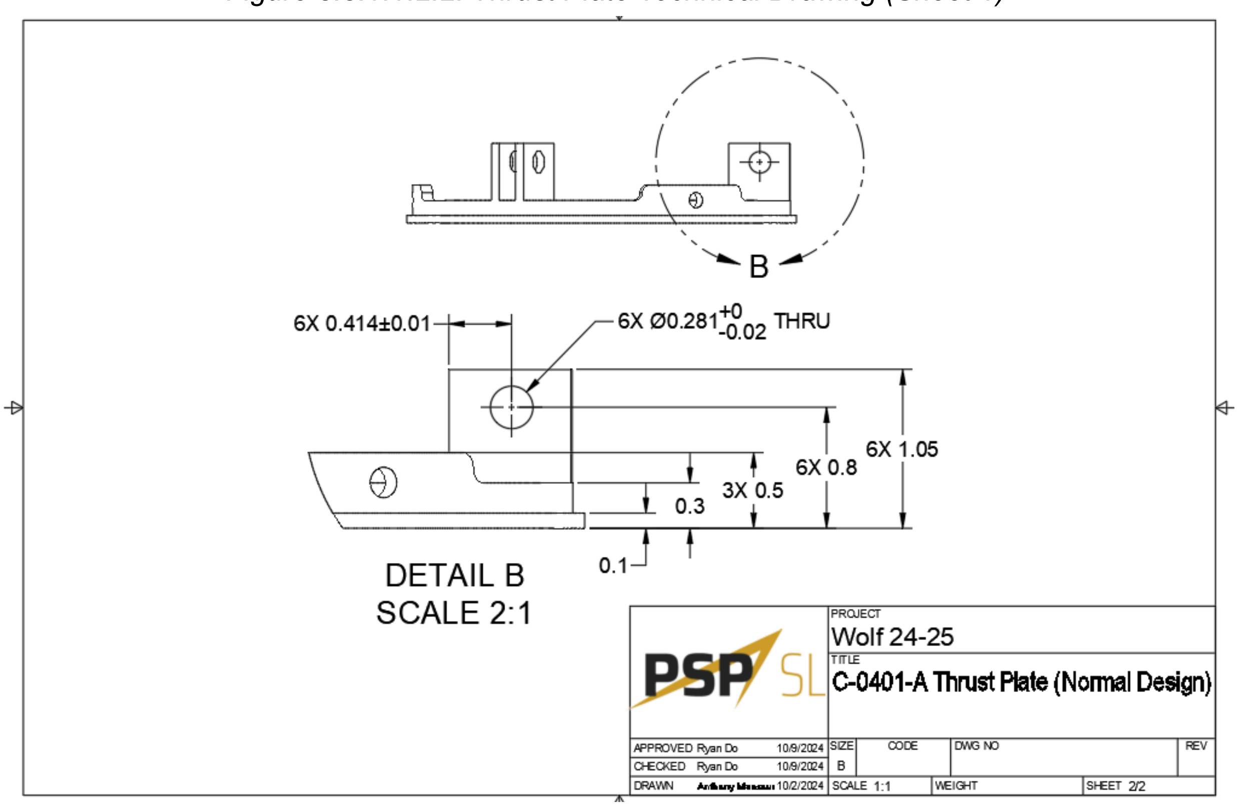


Figure 3.3.1.1.2.3: Thrust Plate Technical Drawing (Sheet 2)

3.3.1.1.3 Centering Plate

As previously specified in section 3.2.1, the R&D payload design has been chosen due to the R&D payload being present in the final launch vehicle design. This means that more weight can be saved by fully cutting through the 3 radial weight saving slots, instead of only partially for the "No R&D Payload" design. This is because the pressure regulation of this solid surface is not needed with the R&D Payload present in the final design. The pressure regulation was initially needed to allow the spear pins to break and the sections to separate.

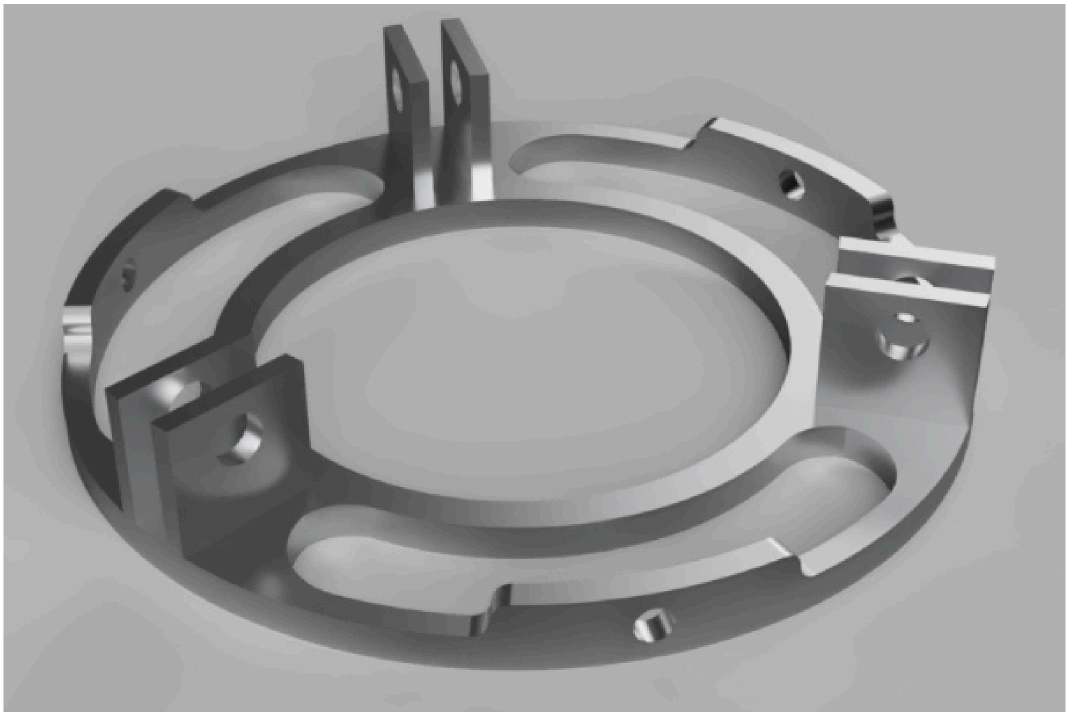


Figure 3.3.1.1.3.1: Centering Plate CAD Model Render

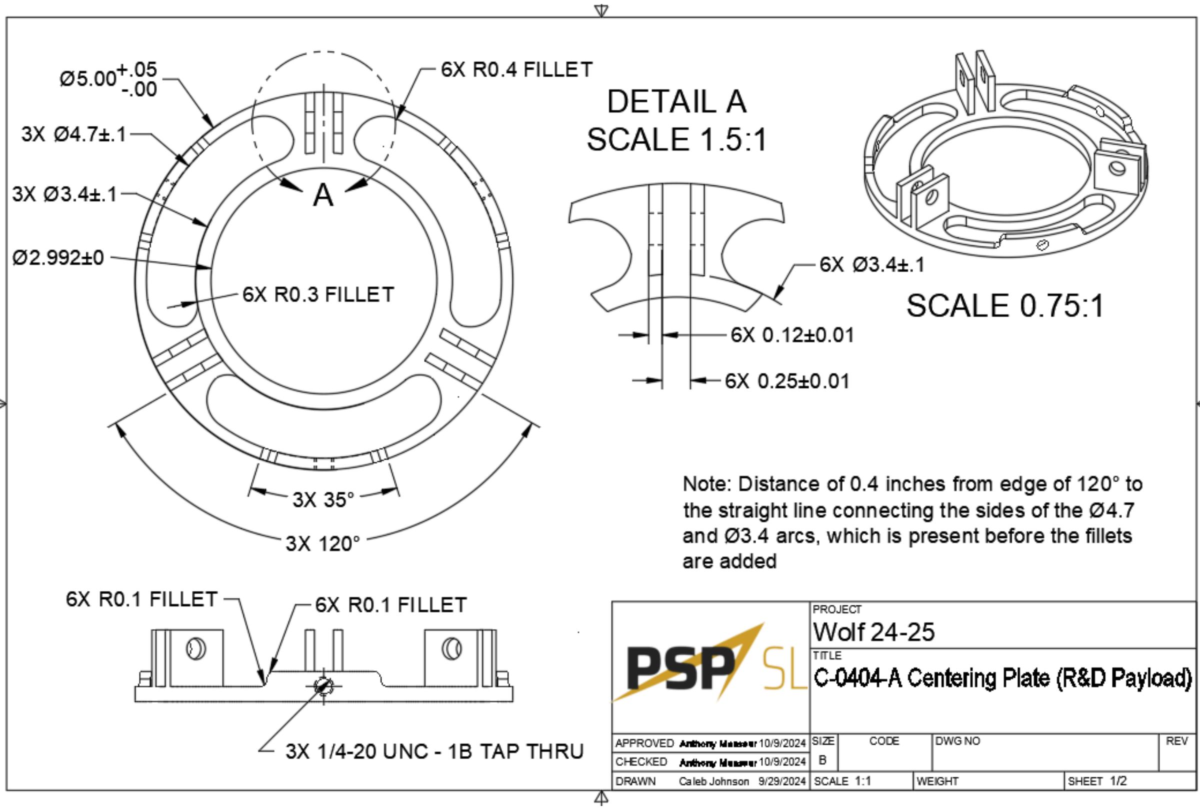


Figure 3.3.1.1.3.2: Centering Plate Technical Drawing (Sheet 1)

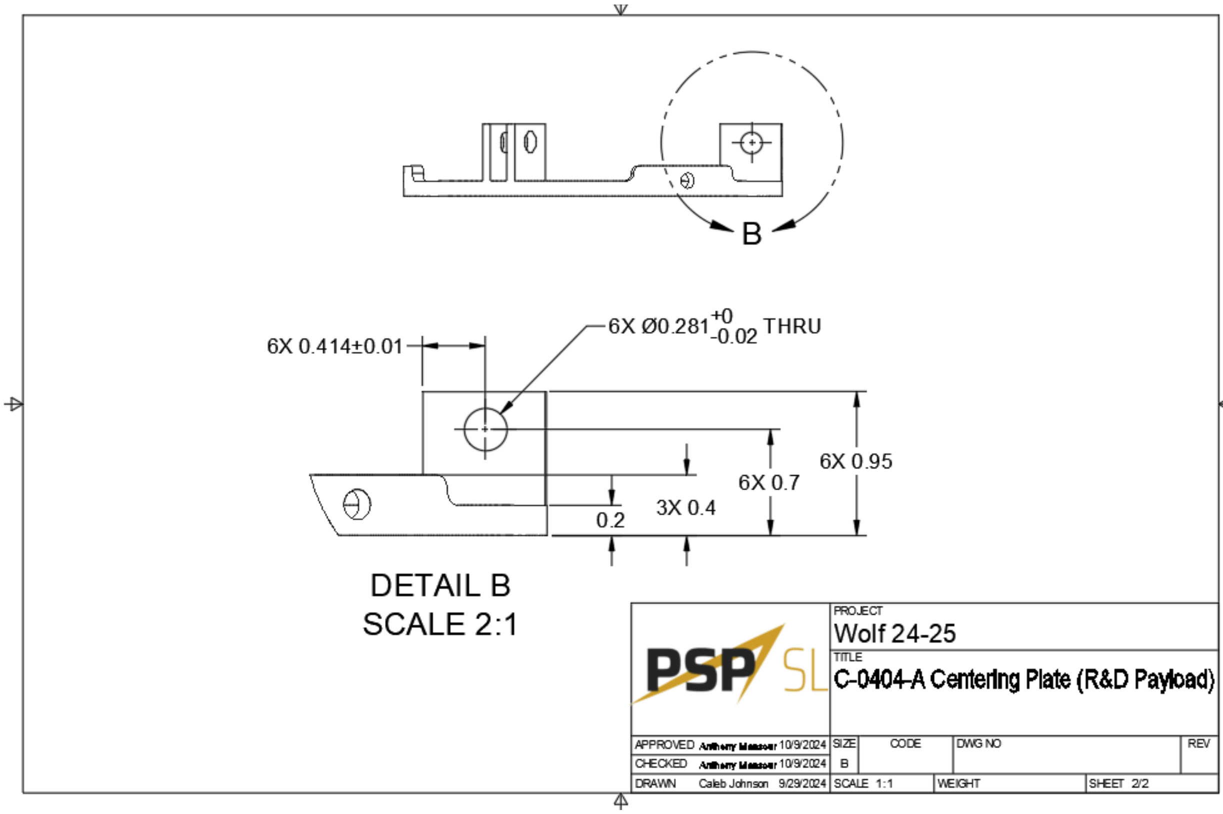


Figure 3.3.1.1.3.3: Centering Plate Technical Drawing (Sheet 2)

3.3.1.2 Fins

Since the PDR, some changes have been made to the selected alternative. In PDR, the chosen alternative was the third fin alternative. This design has largely remained, but some small changes were necessary. The original design was given a NACA 0008 airfoil. It, as aforementioned, had a root chord and tip chord of 5.5” and 2” respectively. A height of 6.2” and a sweep length of 1.82”. Additionally, the root thickness was 0.44” and the tip thickness was 0.16“. The insert which fits inside the fin has similar dimensions and shape described hereafter. Once again, the insert is best described in two parts: the bracket and trapezoidal interior. The insert bracket has dimensions seen as 5.5” wide and 0.95” tall. There are two mounting holes with a diameter of 0.28” cut out 0.41” high and 0.5” from the sides for the purpose of fitting threaded quarter inch screws. The interior trapezoid has a frame thickness of 0.5”, with a height of 4.33”. The angle between the top of the bracket and the side of the frame is at 102 degrees. Finally the top width is 1.38”.

During analysis of the fin, it was found that the fin could not handle the expected forces applied to it and thus failed. The error was attributed to the distance between the outside of the fin and the insert being too thin. As a result, NACA 0012 airfoil was used. Airfoiled fins were chosen over traditional fin designs to optimize the aerodynamic performance of the launch vehicle. Unlike flat fins, airfoiled fins reduce drag and improve stability by streamlining airflow around the vehicle, which is critical for maintaining control during flight. The selection of a NACA airfoil, specifically transitioning from the NACA 0008 to the NACA 0012, reflects the need for a thicker fin capable of withstanding the expected forces while preserving the aerodynamic benefits.
The dimensions of the new fin can be seen in the technical drawings below. The root chord is 5.17” with a tip chord of 1.88”. The height stays the same at 6.2“. The sweep length along the leading edge is 1.82” and the trailing edge is 1.47”. Furthermore the root thickness is 0.66” and the tip thickness is 0.32”. Because of the fact that there is a gap between the airframe and the MFSS there is a piece attached to the fin to fill that gap. It has a width of 5.50” and height of 0.71” and a thickness of 0.13”. There is a bit cut out for the insert to go from the fin to the MFSS where it is attached. The insert is similar to the old one. The bracket piece that attaches to the MFSS and the shape is the same. The start of the trapezoid is initially offset by 0.54”. The frame thickness remains the same at 0.5”. The internal angle of the leading edge is 76 degrees and the trailing edge is 77 degrees. Also the height is 5.80” with a top width of 1.05”.

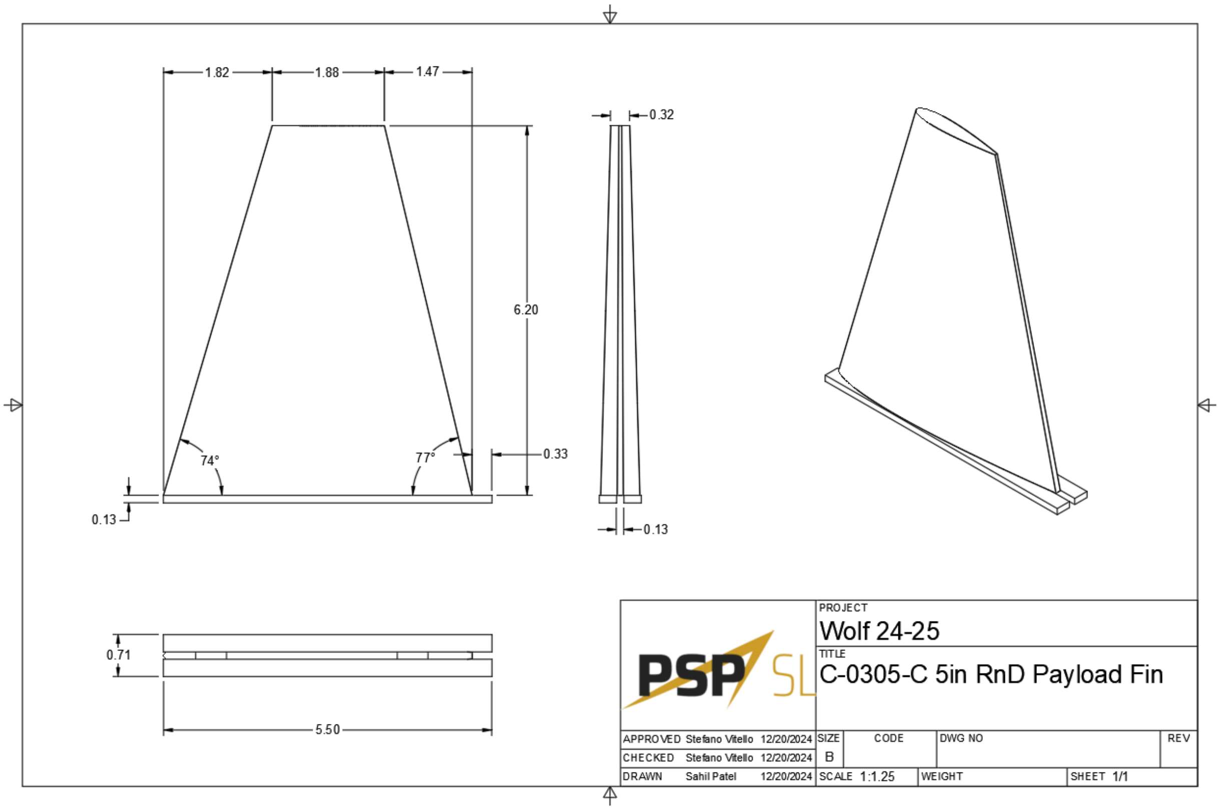


Figure 3.2.1.2.1: 5in Fin Technical Drawing

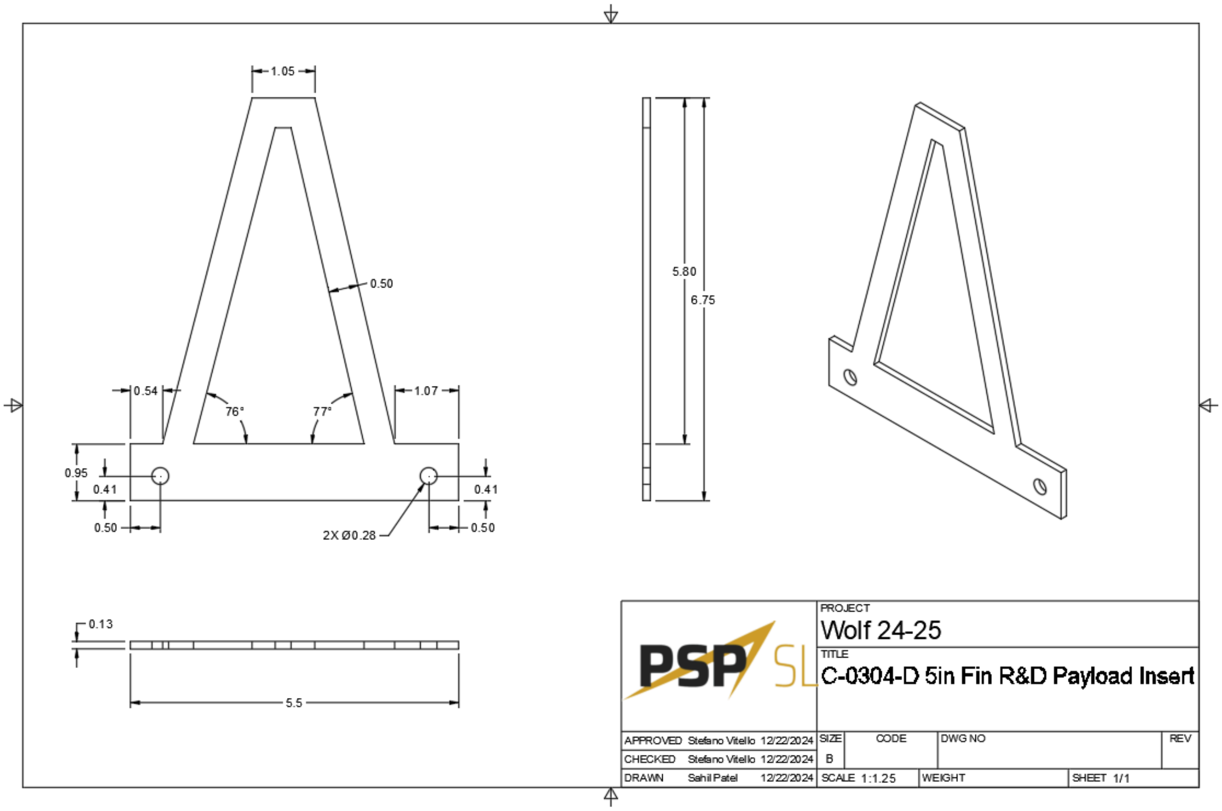


Figure 3.2.1.2.2: 5in Fin Insert Technical Drawings

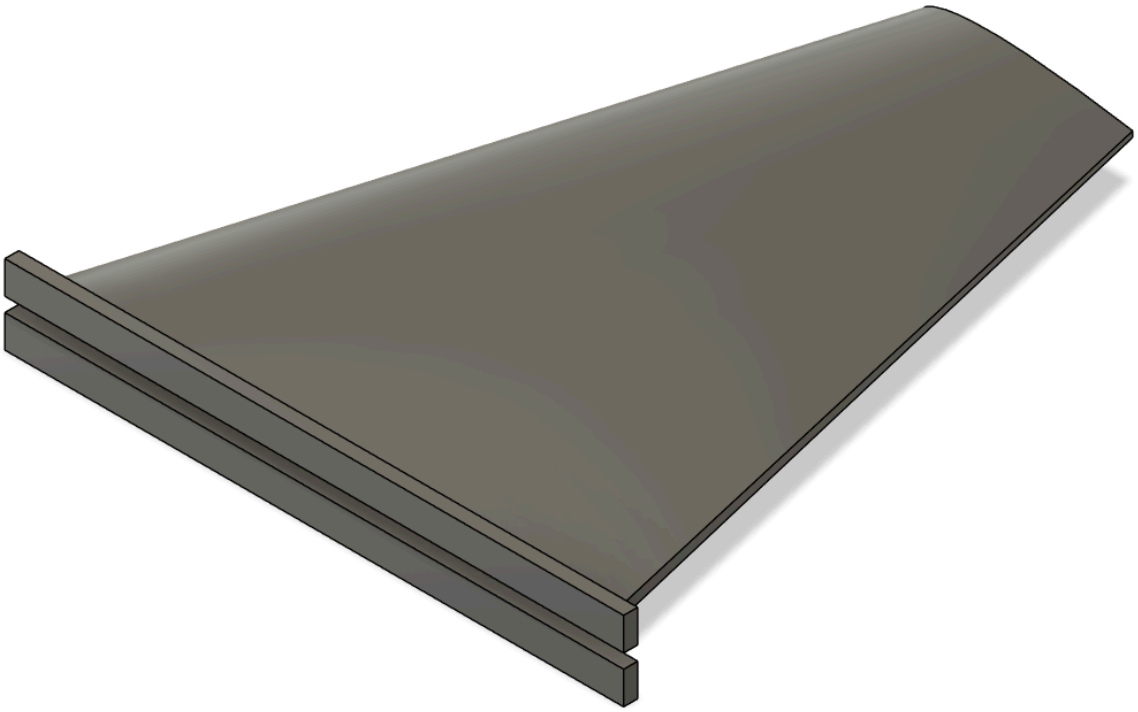


Figure 3.2.1.2.3: 5in Fin CAD Model

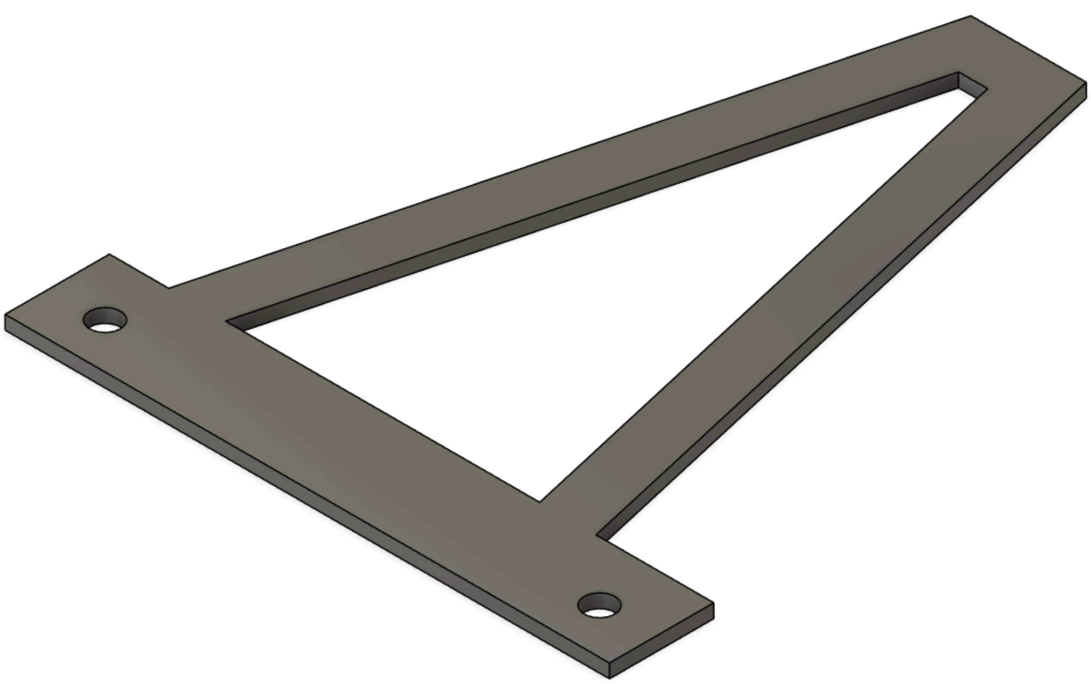


Figure 3.2.1.2.4: 5in Insert CAD Model

3.3.1.3 RnD Coupler

Figure 3.3.2.1.1: Lower Recovery Coupler CAD Model

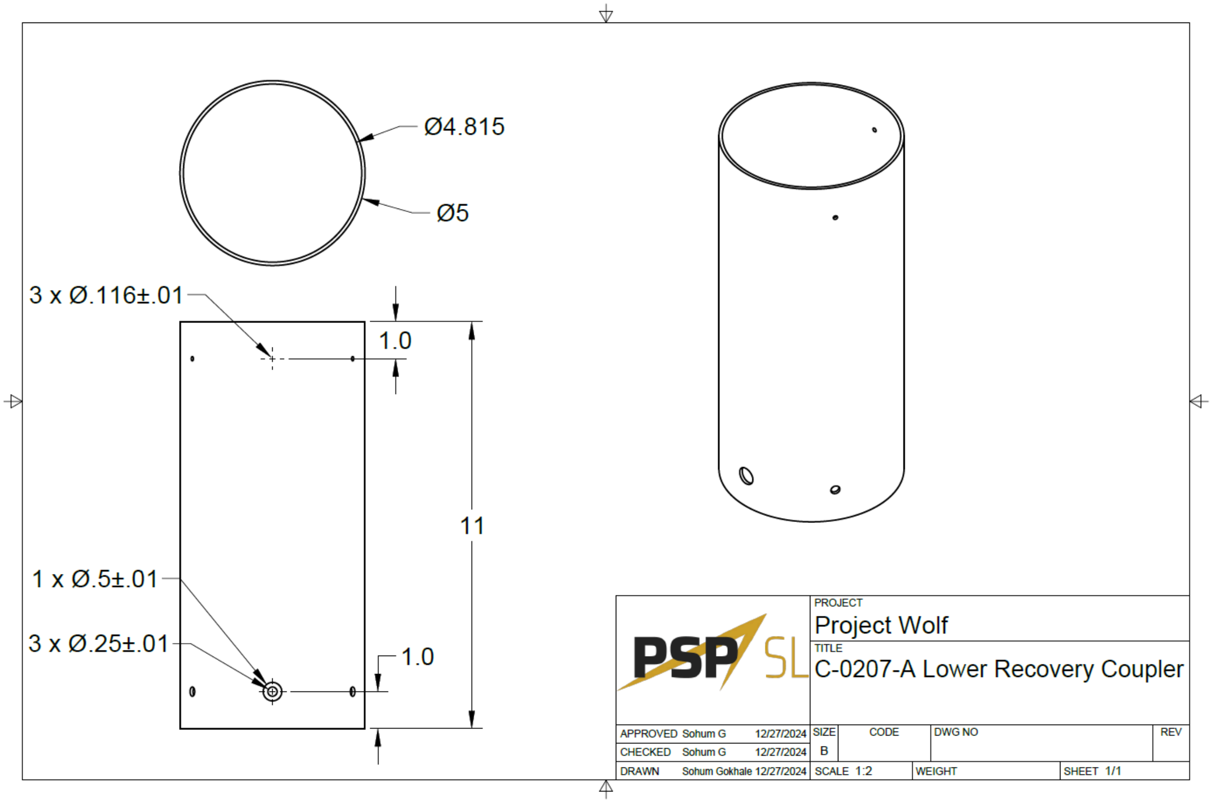


Figure 3.3.2.1.2: Lower Recovery Coupler Technical Drawing

The 11" long RnD coupler section is designed to house the secondary payload, which will gather additional data beyond what is provided by the sensors in the primary payload. The coupler has an inner diameter of 4.815" and an outer diameter of 5", meeting requirement S.C.11. It includes three 0.116" diameter shear pin holes that align with the lower recovery airframe. Additionally, the coupler features three evenly spaced 0.25" diameter holes for mounting to the booster airframe and a single 0.5" diameter key switch hole that aligns with the corresponding key switch hole on the booster airframe.

3.3.1.4 Booster Airframe

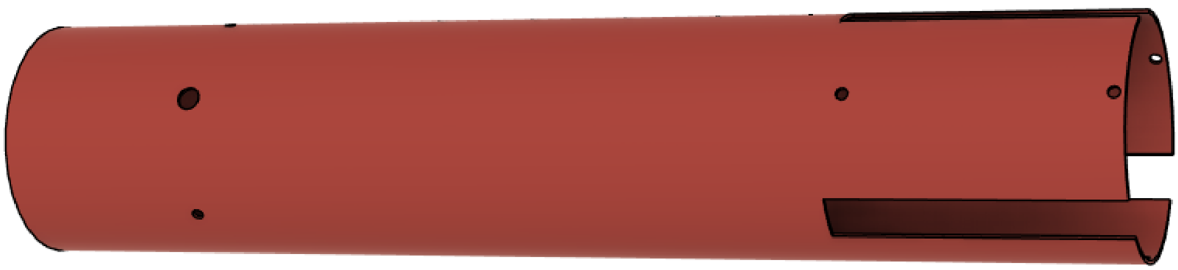


Figure 3.4.1.3.1: Booster Airframe CAD Model

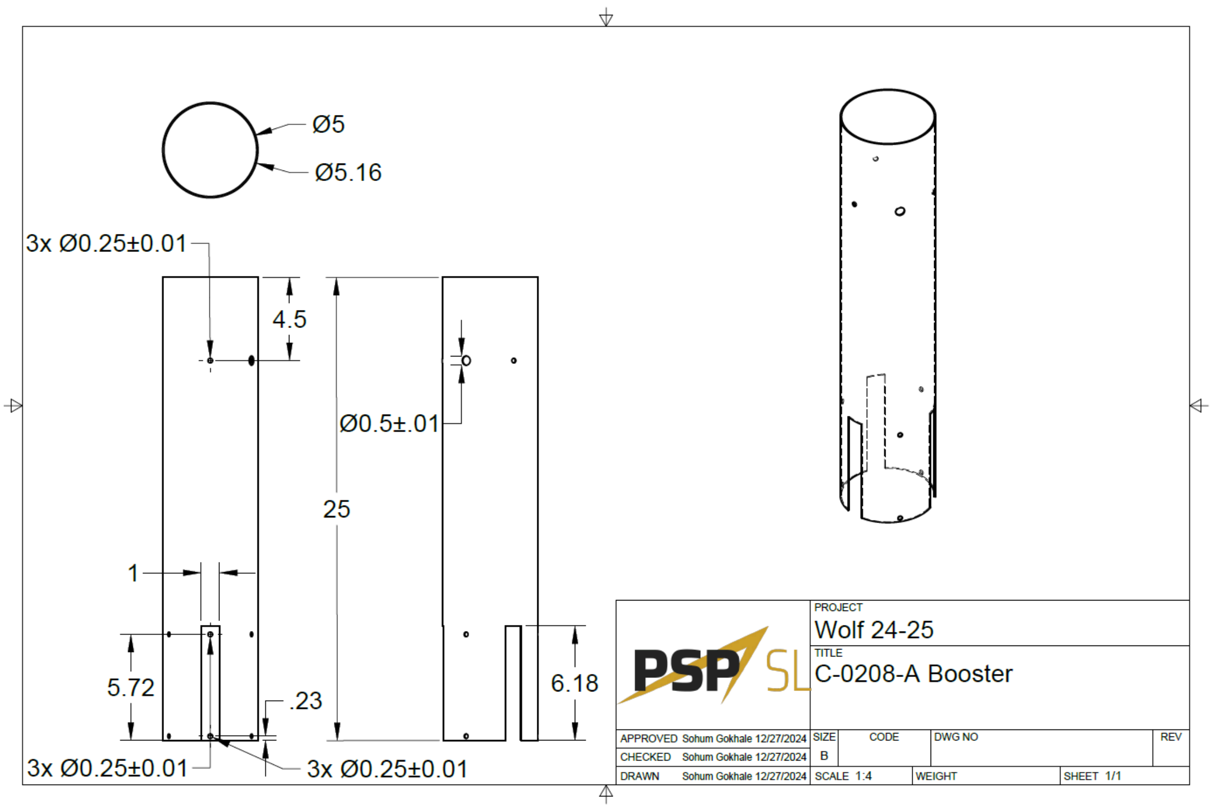


Figure 3.4.1.3.2: Booster Airframe Technical Drawing

The Booster Airframe houses the MFSS, which is used to hold the motor and fins, as required by Requirement S.C.8. It is constructed of G12 fiberglass to allow for high strength and low weight. The airframe has an inner diameter of 5'' and an outer diameter of 5.16'' with a total length of 25''. The airframe has six 0.25'' holes around the bottom of the airframe to mount the MFSS. They are in sets of three radially spaced with one set 0.23'' away from the bottom edge of the airframe while the other set of three is 5.72'' away from the bottom. The bottom section of the airframe has three 1’’ wide, 6.18’’ long rectangular slots cut out to accommodate the fins. Near the top of the airframe, there are an additional three 0.25’’ holes spaced radially 4.5’’ away from the top of the airframe along with one 0.5’’ key switch hole. These holes are used to mount the booster to the lower recovery coupler as well as provide access to a key switch inside the coupler.

3.3.2 Lower Recovery Section

The lower recovery section consists of just the lower recovery airframe. This airframe contains the drogue parachute and is connected to the booster airframe via the RnD coupler and shear pins which will break at apogee to deploy the drogue parachute.

3.3.2.1 Lower Recovery Airframe

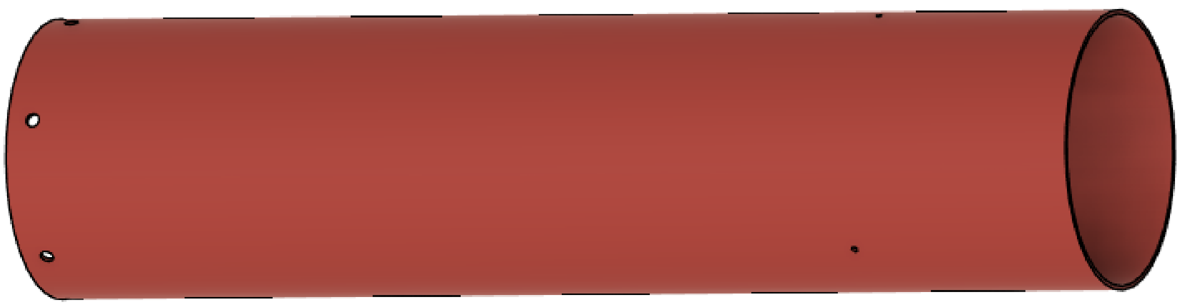


Figure 3.3.2.2.1: Lower Recovery Airframe CAD Model

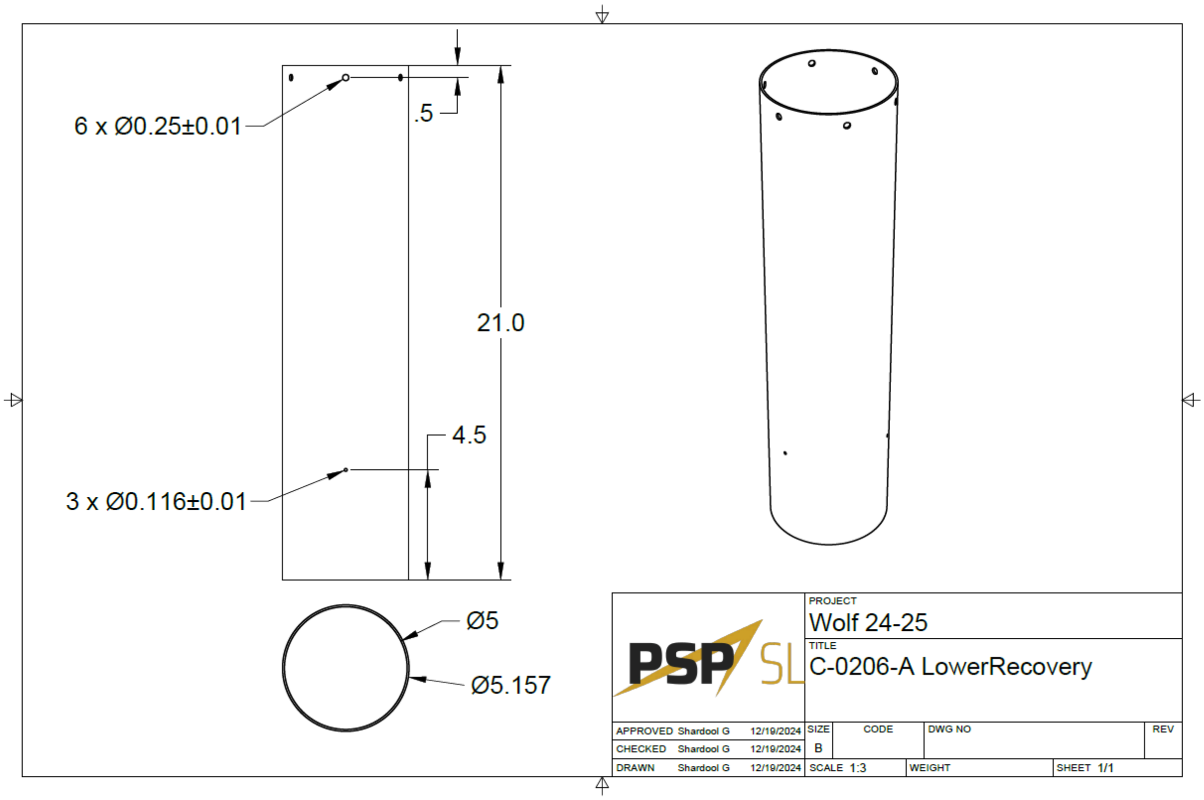


Figure 3.3.2.2.2: Lower Recovery Airframe Technical Drawing

The lower recovery airframe, constructed from G12 fiberglass, is designed to house the drogue parachute. It has a total length of 21", an outer diameter of 5.157", and an inner diameter of 5", meeting the specifications of Requirement S.C.11. The airframe features six evenly spaced radial holes, each 0.25" in diameter, located 0.5" from the top. Additionally, it includes three evenly spaced shear pin holes, each 0.116" in diameter, positioned 4.5" from the bottom.

3.3.3 Upper Recovery Section

3.3.3.1 Upper Recovery Airframe

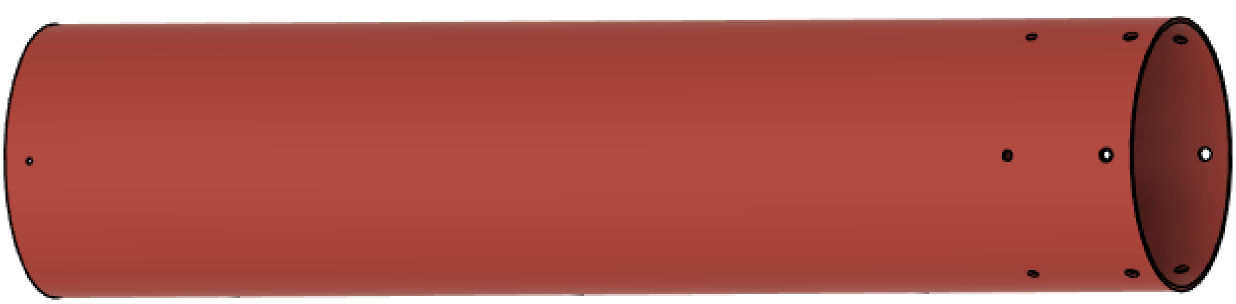


Figure 3.3.3.1.1: Upper Recovery Airframe CAD Model

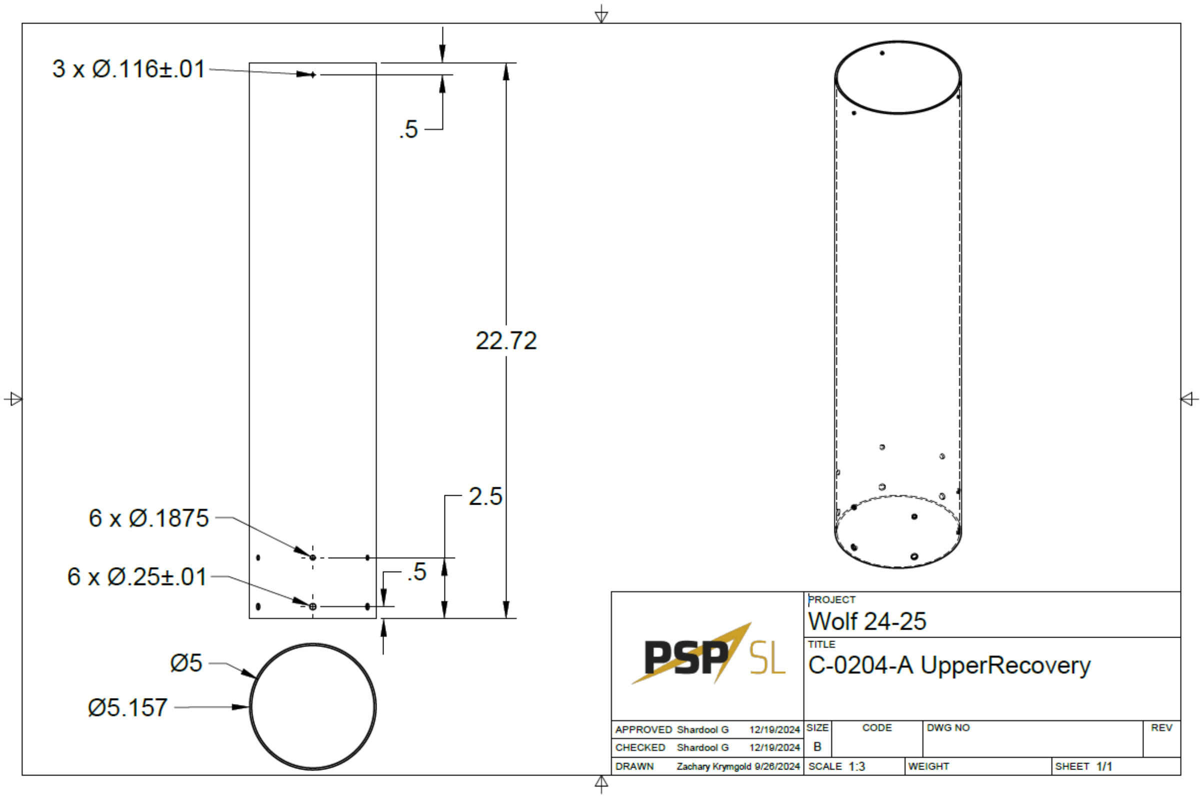


Figure 3.4.3.1.2: Upper Recovery Airframe Technical Drawing

The upper recovery airframe is a cylindrical tube with an outer diameter of 5.15 inches and an inner diameter of 5 inches in accordance with Requirement S.C.11. The upper recovery airframe has a length of 22.72 inches and contains 15 holes, 3 radially symmetric 0.25 inch holes on one end, and 12 holes on the other end of the tube, 6 radially symmetric 0.25 inch holes and 6 radially symmetric 0.1875 inch static pressure holes.

3.3.3.2 Avionics Coupler

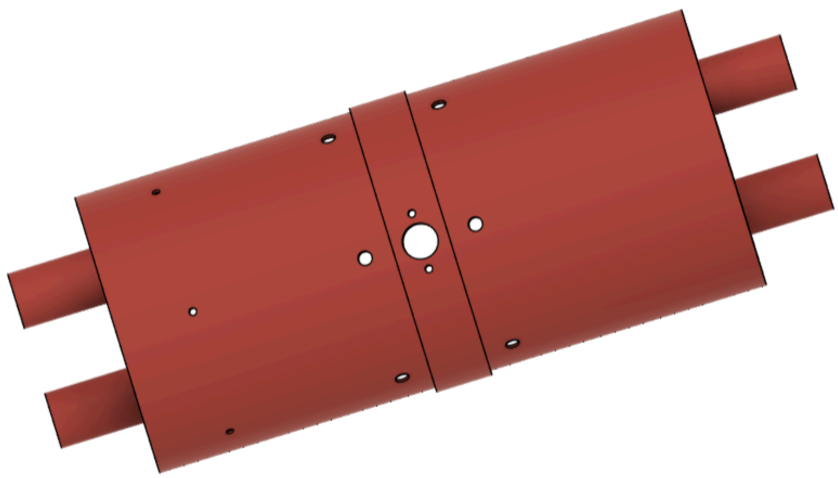


Figure 3.3.3.2.1: Avionics Coupler CAD Model

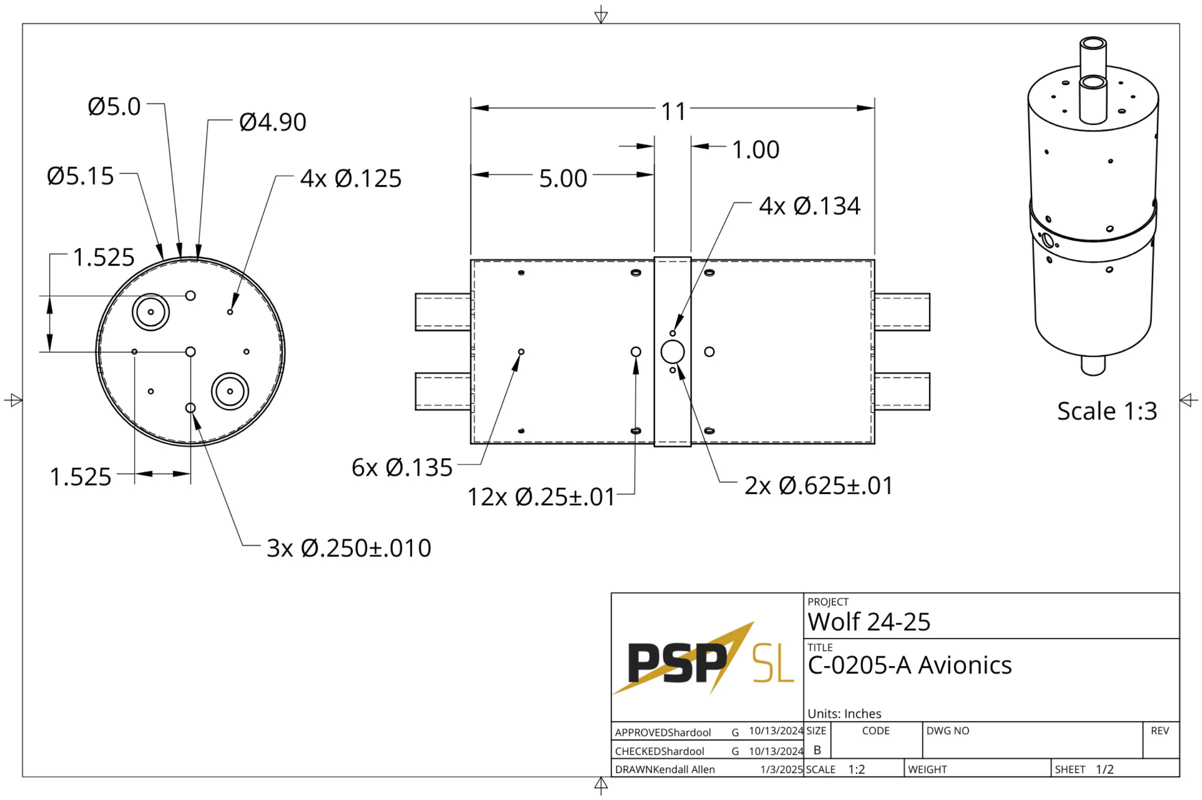


Figure 3.4.3.2.2: Avionics Coupler Technical Drawing (Sheet 1)

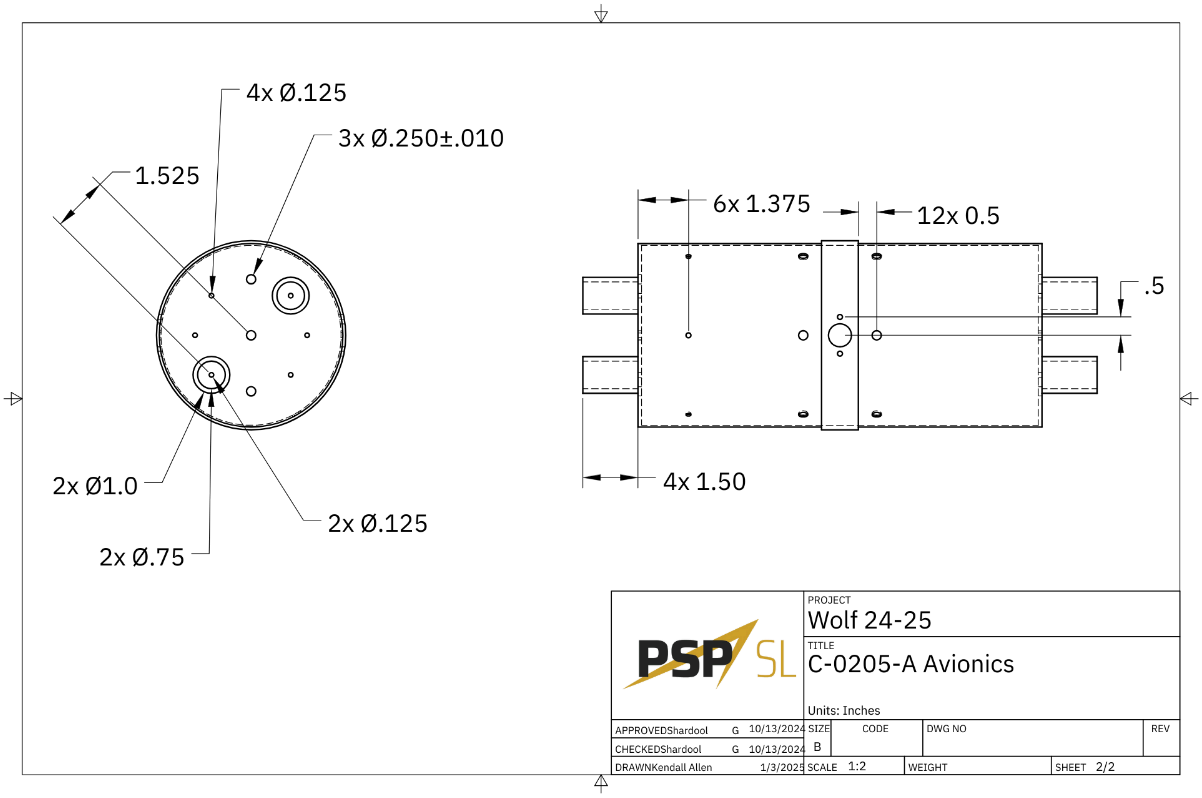


Figure 3.4.3.2.3: Avionics Coupler Technical Drawing (Sheet 2)

The avionics coupler serves as an in-flight separation point and contains the avionics systems of the launch vehicle. Not much has changed in this component since PDR. The avionics coupler is 11” long, with a diameter of 4.998” and a wall thickness of 0.098”. The length of the coupler is approximately 2.2 times greater than the airframe diameter, satisfying Requirement C.2.4.1. The switch band has a diameter of 5”, and contains two 0.625” in diameter keyswitch holes, along with four total mounting holes, each 0.135” in diameter. There are twelve 0.25” in diameter holes located radially along each side of the coupler, located 0.5” from the edge of the switch band to connect the coupler to the upper and lower recovery sections. This hole size was chosen to standardize the connection points between the components of the launch vehicle, as per Requirement S.C.17. In addition to this, there are six static pressure holes located radially around the top half of the coupler, 0.135” in diameter. Each end of the coupler is capped with a bulkhead, containing separation charge tubes with a 1” outer diameter, 0.75” inner diameter, and a length of 1.5”. The bulkheads have six holes radially, four static pressure holes and two 0.25” mounting holes, with an additional 0.25” hole in the center. The coupler is secured by two 12” threaded rods.

3.3.4 Payload Section

3.3.4.1 Payload Coupler

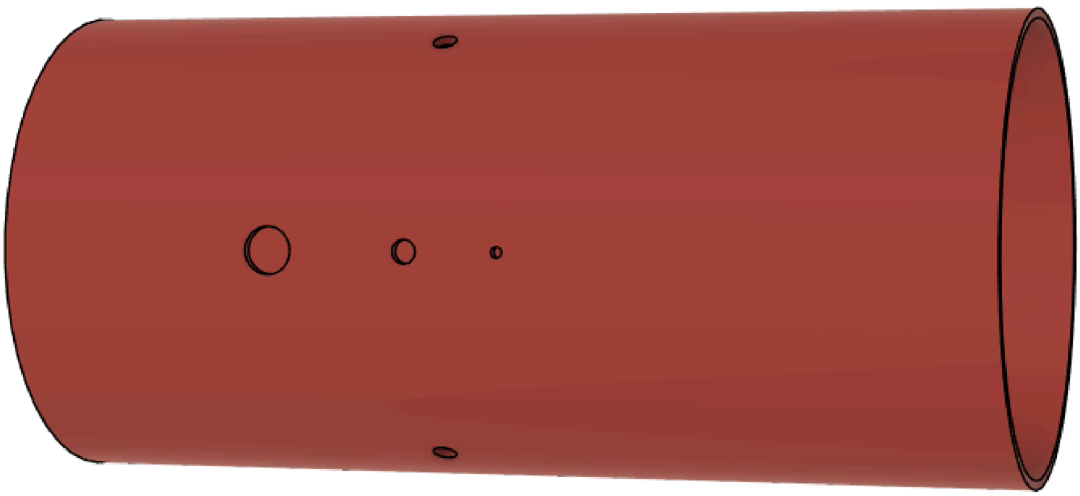


Figure 3.4.4.1.1: Payload Coupler CAD Model

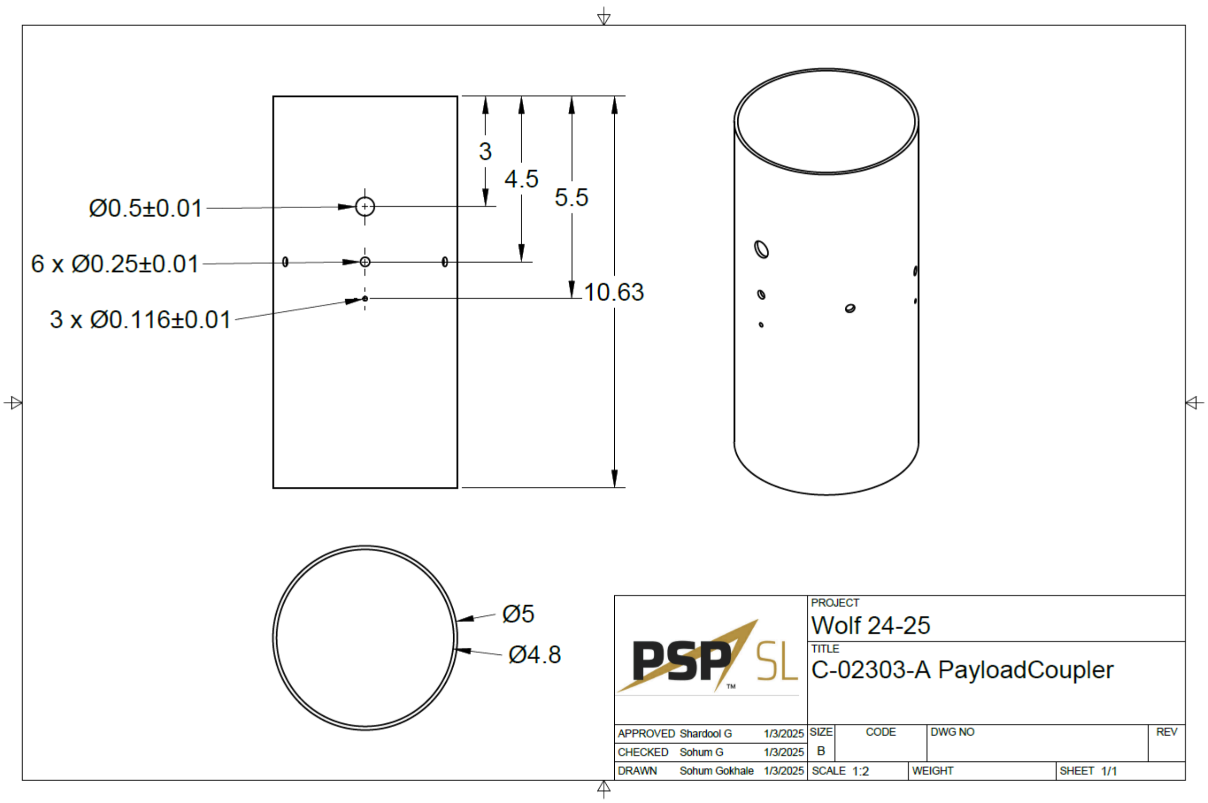


Figure 3.4.4.1.2: Payload Coupler Technical Drawing

The payload coupler connects the payload airframe to the upper recovery airframe. It is made of G12 fiberglass with a total length of 10.63’’ to satisfy the NASA coupler length requirements (C.2.4.1 and C.2.4.2). It has an inner diameter of 4.8’’ and an outer diameter of 4.998’’. The airframe has six 0.25’’ holes to mount to the payload airframe and three 0.116’’ holes to accommodate shear pins to attach to the Upper Recovery airframe. These holes are radially patterned with the 0.25’’ holes 4.5’’ away from the upper edge of the coupler and the 0.116’’ holes at 5.5’’ away. There is also a 0.5’’ hole for a key switch that is housed inside the payload airframe 3’’ away from the upper edge of the coupler.

3.3.4.2 Payload Airframe

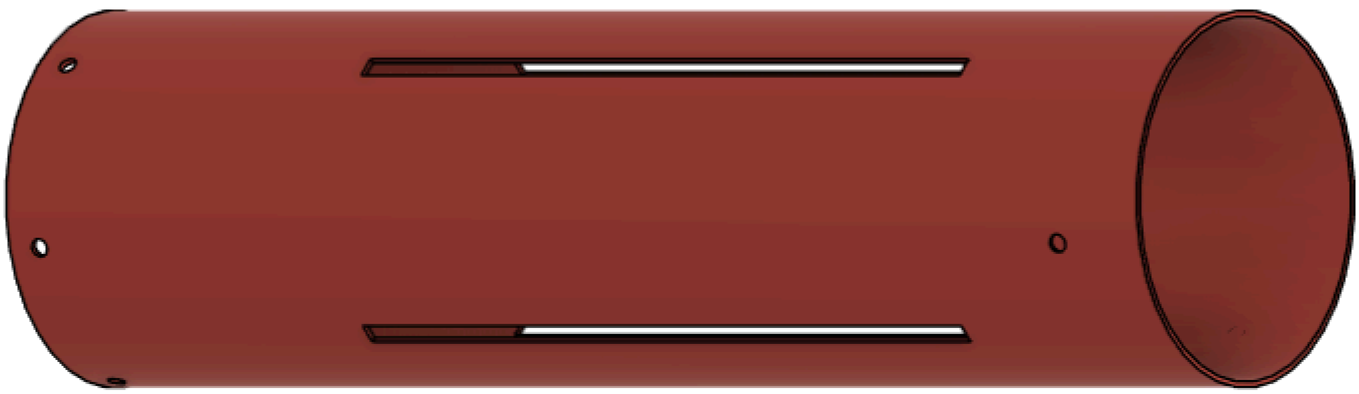


Figure 3.4.4.2.1: Payload Airframe CAD Model

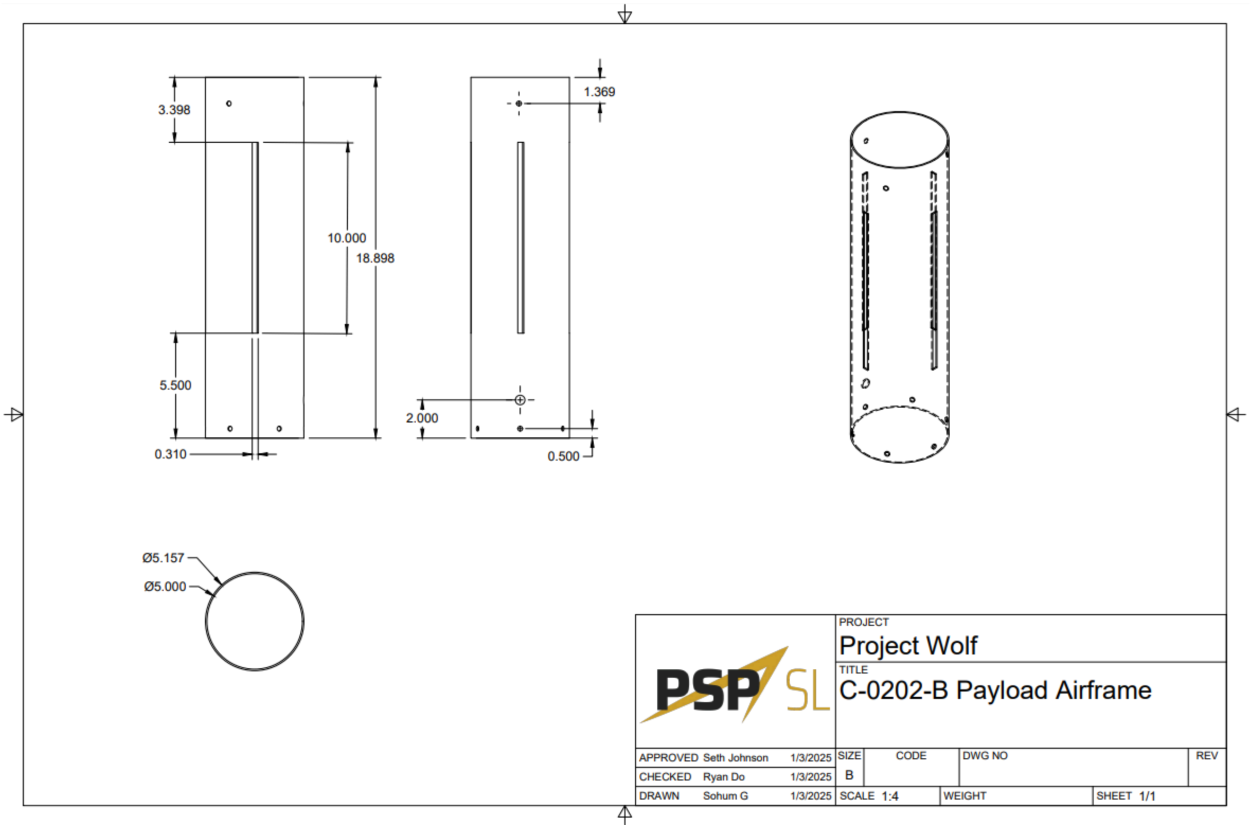


Figure 3.4.4.2.2: Payload Airframe Technical Drawing

The payload airframe, constructed from G12 fiberglass, is designed to house the primary payload of the launch vehicle. It has a total length of 18.9", an outer diameter of 5.157", and an inner diameter of 5", meeting the specifications of Requirement S.C.11. The airframe includes six 0.25" diameter holes located 0.5" from the bottom, used for mounting the payload tube to the payload coupler. Additionally, it features a single 0.5" diameter key switch hole positioned 2" from the bottom.

3.3.4.3 Nosecone

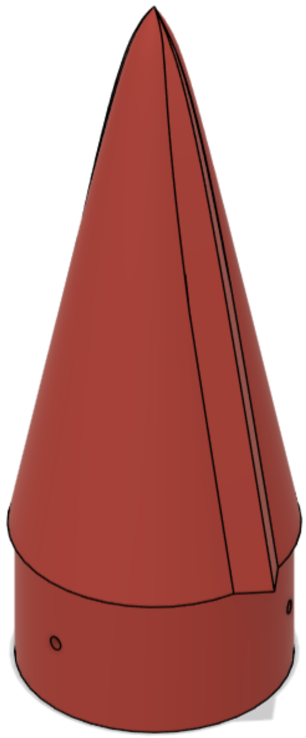


Figure 3.3.4.3.1: Nosecone CAD Model

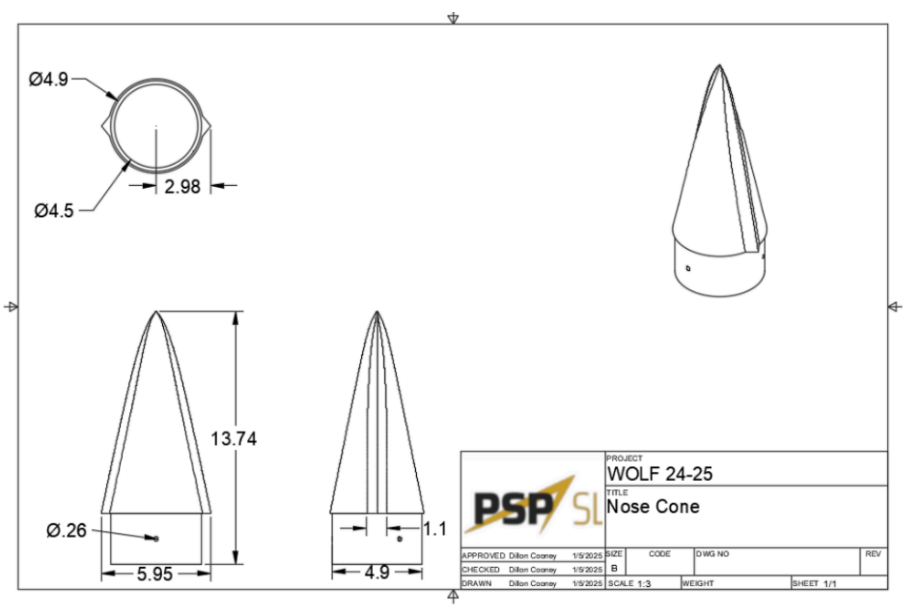


Figure 3.3.4.3.2: Nosecone Technical Drawing

The nosecone is a Haack series shape with two flanges that will house cameras as described in section 3.7.4.1. The shoulder has a length of 2.756" which satisfies Requirement C.2.4.3 as it is

0.55 times that of the airframe diameter. The inside of the nosecone is to house the electronics for the nosecone camera. The nosecone is to be 3D printed according to Requirement S.C.18. The nosecone will also have a wet layup put on after the model is printed. It will have a similar process described for the fins as it will use bidirectional fiberglass sheets and resin to reinforce the strength of nosecone.

3.4 Points of Separation

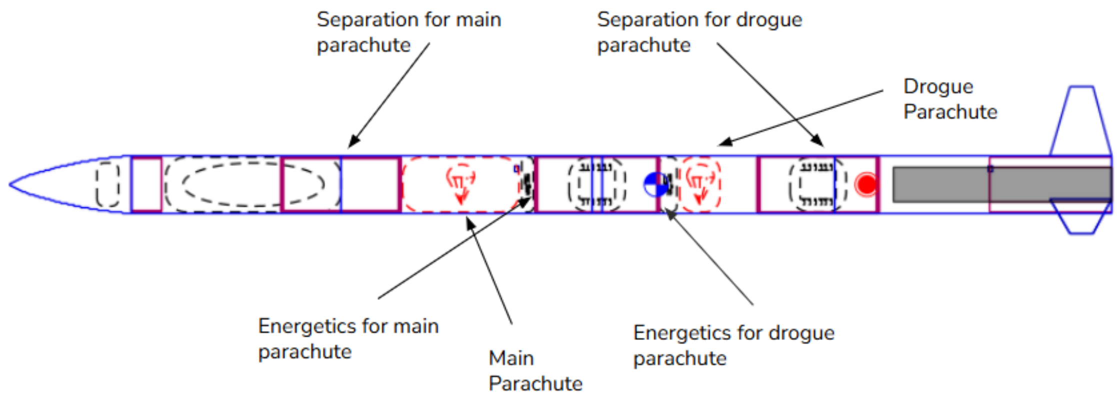


Figure 3.4.1: Locations of Energetic Materials and Separation Points

As shown in Figure 3.4.1, there are currently two separation points on the designed launch vehicle for the 2024-2025 NASA Student Launch (SL) Competition. This differs from previous years due to new payload mission requirements set by NASA for the 2024-2025 competition. The separation point related to the deployment of the drogue parachute is located at the point where the top of the booster airframe and the R&D coupler is connected. The separation point related to the deployment of the main parachute is located at the point where the bottom of the payload airframe and payload coupler is connected. For both separation points, the energetic material necessary for deployment of the parachute is located on the bulkplates of the avionics coupler with the main parachute being deployed using energetics on the top bulkplate of the avionics coupler and the drogue parachute being deployed using energetics on the bottom bulkplate of avionics coupler. The deployment of the parachutes happens when the energetic material is ignited which then builds up pressure in the airframe. The shear pins located at the separation points will be unable to hold up against the pressure buildup causing the airframe components to split, and thus the deployment of the parachutes will occur.

In the previous year, a pressurization bulkplate was placed in between the avionics airframe and booster airframe to ensure proper pressure buildup at the separation point for successful deployment of the drogue parachute. The reason for this bulkplate was due to the MFSS being hollow thus causing pressure loss as the pressurized air would then flow out the bottom of the launch vehicle. For this year's launch vehicle design, a secondary payload dubbed the R&D payload is placed inside the R&D coupler which is located at the top of the booster section. This payload's purpose is to store flight data for usage in the development of an airbrake system for future use. With the addition of the R&D coupler, a pressurization bulkplate is no longer necessary as the R&D coupler can help build up pressure inside the airframe for successful drogue parachute deployment hence why this year’s design lacks one.

3.5 Manufacturability

3.5.1 Motor Fin Support Structure

The only manufacturing change since PDR is changing how the fin spacers are manufactured. As each is a simple fiberglass rectangle with a hole in it, water cutting was originally going to be used. Water cutting was used to cut out the rectangular profiles, but due to the risk of delamination and the holes being quite small, it was not possible to use water cutting for the hole profiles. Consequently, a drill press has been used instead, carefully marking the hole location for each before drilling.

As for the retainer plate, it is 0.125” thick, therefore an aluminum 6061-T6 sheet of the same thickness from Online Metals is used as stock. An improvement from previous years is using a precision milled and ground sheet, resulting in a near-constant thickness throughout, fulfilling Requirement S.C.2. This prevents the sheet from being too thick in places, which would not allow the laser to penetrate fully. The CAD file is exported in the .dwg format, then cut at the Bechtel Innovation Design Center (BIDC) metal laser cutter.

Due to the thrust and centering plate being extremely similar, they can be manufactured in nearly the same way. Aluminum 6061-T6 cylinder stocks from Coremark Metals are used. For both, the length is 5”, to ensure extra clamping area for the CNC. Diameters of 5.25” and 5” are used for the thrust and centering plates respectively. This is due to the thrust plate having the outer lip extruded, so the 5.25” is milled down to the airframe diameter.

The primary operation for both plates is done on the Haas UMC-500 at the BIDC. From the perspective of the MFSS assembly, the features on the inner face of these plates are machined, but without fully cutting through, to prevent damage to the bottom of the Setrite 3-Jaw Chuck workholding. To further specify, this “perspective of the MFSS assembly” can be seen on Figure 3.3.1.1.1 and/or 3.3.1.1.2.

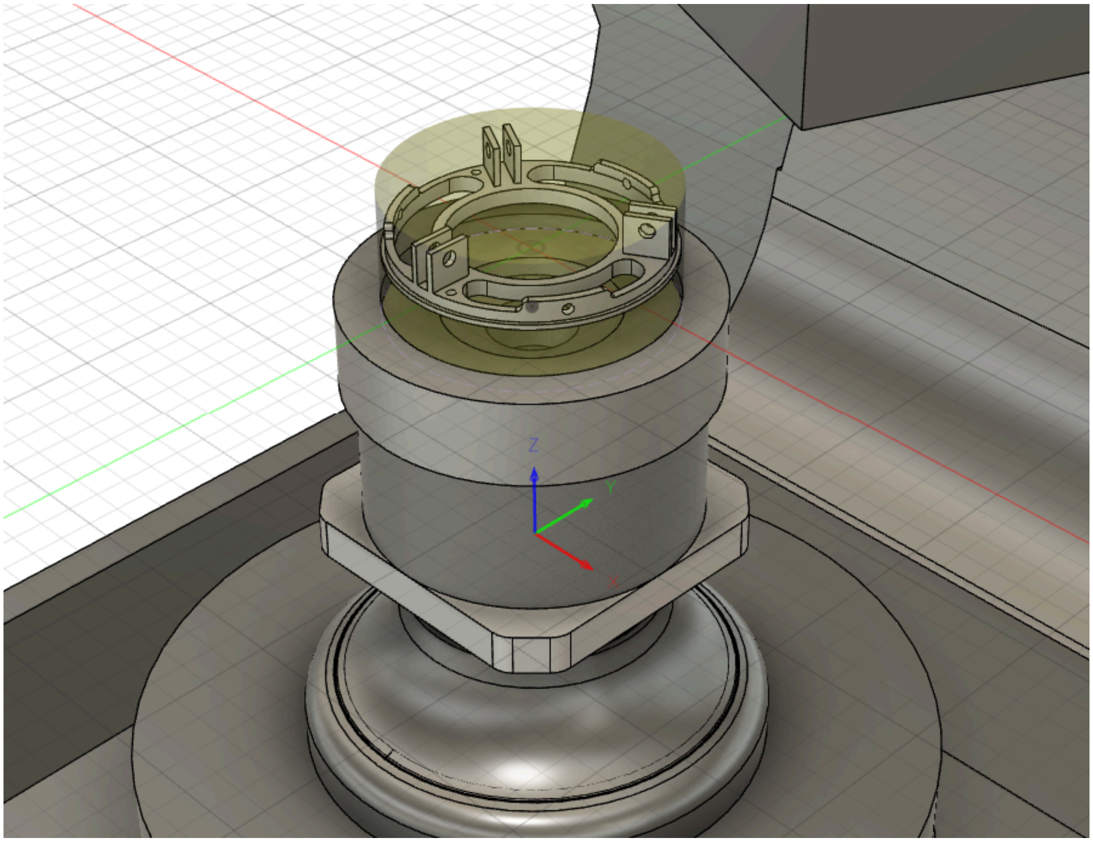


Figure 3.5.1.1: Thrust and Centering Plates Operation 1 Setup

The plates then must be oriented upside-down to clear the remaining material, in which a soft jaws workholding is used, which was custom manufactured in previous years, and fulfilling Requirement S.C.20. The workholding is switched to the soft jaws, and the same UMC-500 is used to drill the screw holes connecting the thrust and retainer plates, and clearing the area previously clamped.

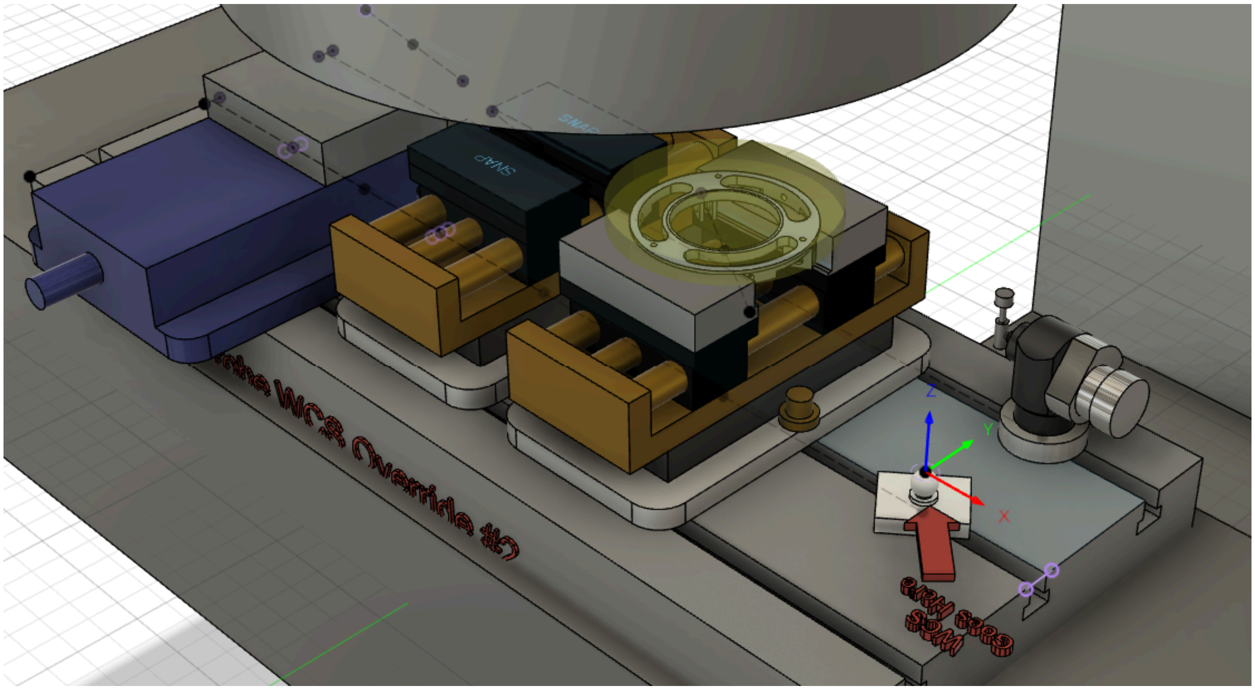


Figure 3.5.1.2: Thrust and Centering Plates Operation 2 Setup

3.5.2 Fins

To begin with, a mold must be acquired for casting the fin within. This is done by utilizing a stereolithography 3D printer to produce a very high definition positive of the fin. This is suspended within a box which enables silicone to be cast around the 3D printed fin. Once hardened, the 3D printed fin is removed and leaves a negative of the fin. From here a fiberglass insert is required, which is optimally produced via waterjet cutter for precision and accuracy. This insert is suspended within the negative of the mold, where the selected resin is cast around the insert (see section 3.6.2.2.). Once the resin is hardened it is removed from the mold. This yields a nearly complete fin, from here a fiberglass layup is required to finish the production. This is done by utilizing fiberglass hardener to adhere and solidify fiberglass sheets to the exterior of the resin, creating a proper composite material which has repeatedly proven its efficacy in previous competitions.

For the duration of the process, numerous parts are created to assist with the manufacture of the fin. The process of casting the resin requires the most amount of supporting equipment, primarily two boxes and what is referred to as a ‘sled’. The first box is a solid box, utilized for casting the liquid silicone and creating the primary mold. The second box is a skeletonized variant which enables the application of lubricant between the walls of the box and mold, easing removal of the mold and subsequent fin. The ‘sled’ piece is a mount that mates the insert and 3D printed positive to the box, suspending it within the necessary location for consistent and effective production.

Figure 3.5.2.1: Solid Mold Casting Box (Bottom) And 3D Printed Fin Positive (Purple/Top) Affixed To Casting Sled (Green/Top)

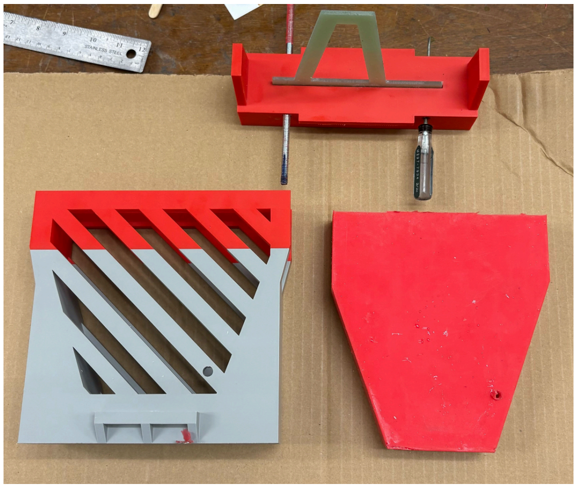


Figure 3.5.2.2: Skeletonized Box (Left), Casting Sled (Top/Red), Fiberglass Insert (Top/Green), and Silicon Mold (Right)

3.5.3 Nosecone

The nosecone will be 3D printed using ASA as described in section 3.6.2.5. It will be printed in three separate sections to account for the available print volume of the 3D printer. This will also reduce the print time it will take to get the three sections. These three sections will then be connected via resin. Once the resin cures, the team will do a wet fiberglass layup. It will be a similar process as described of how the fiberglass layup is done for the fins in section 3.5.2. The team will use bidirectional fiberglass sheets and resin.

3.5.4 Airframe

The team has optimized the manufacturing process for the airframe. The team has developed 3-D printed jigs made of PLA that will slip around the airframe piece that will already have holes printed into them. This is to ensure that all the holes line up and that when drilling the drill will stay straight. The team has also designed all the airframe pieces to be either two, three or six holes, this way the team can use a hexagonal prism design for the jigs. The reason to use the hexagonal prism is to allow the team to lay the airframe and the jig on a flat surface and ensure that the airframe piece will not roll during the manufacturing process. The team has also included a lip at the end of the jigs. This was to ensure that proper heights are accounted for when it came to the holes of the airframe. These jigs allow for easy manufacturing of the subscale airframe and will simplify the manufacturing process of the full-scale airframe. Figures 3.5.4.1 and 3.5.4.2 show the CAD model and technical drawing of the avionics coupler jig respectively. Figure 3.5.4.3 shows all the printed jigs utilized in the manufacturing of the subscale airframe and then Figure 3.5.4.4 shows the jigs being utilized by team members.

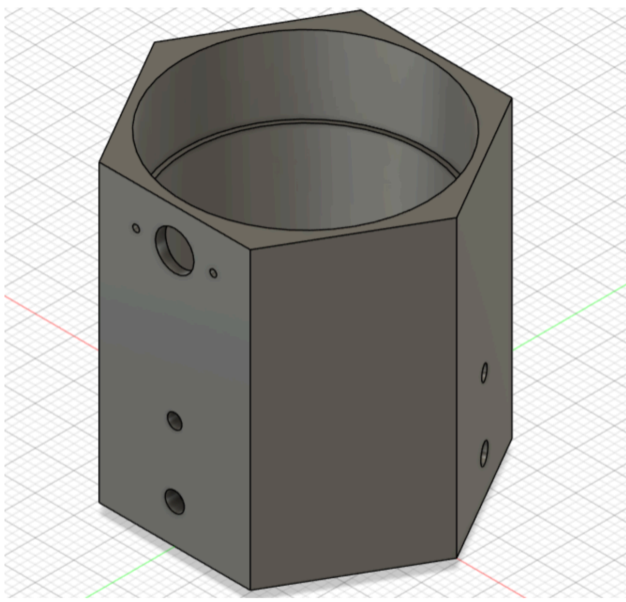


Figure 3.5.4.1: Subscale Avionics Jig CAD Model

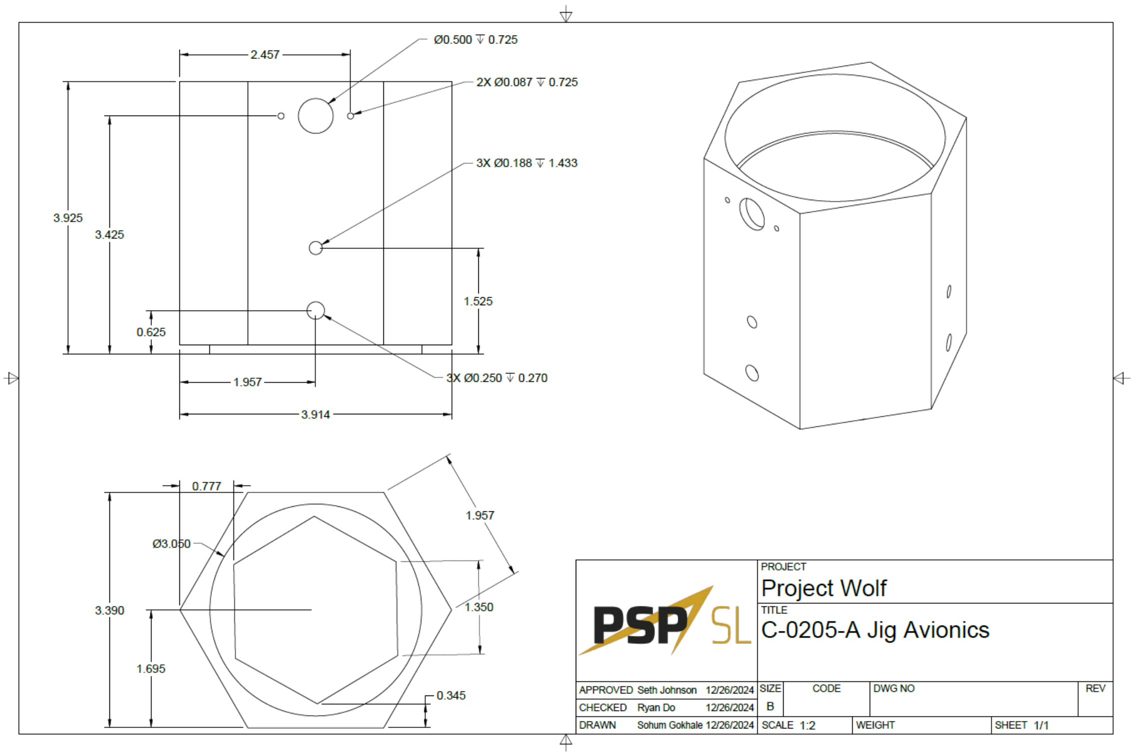


Figure 3.5.4.2: Subscale Avionics Coupler Jig Technical Drawing

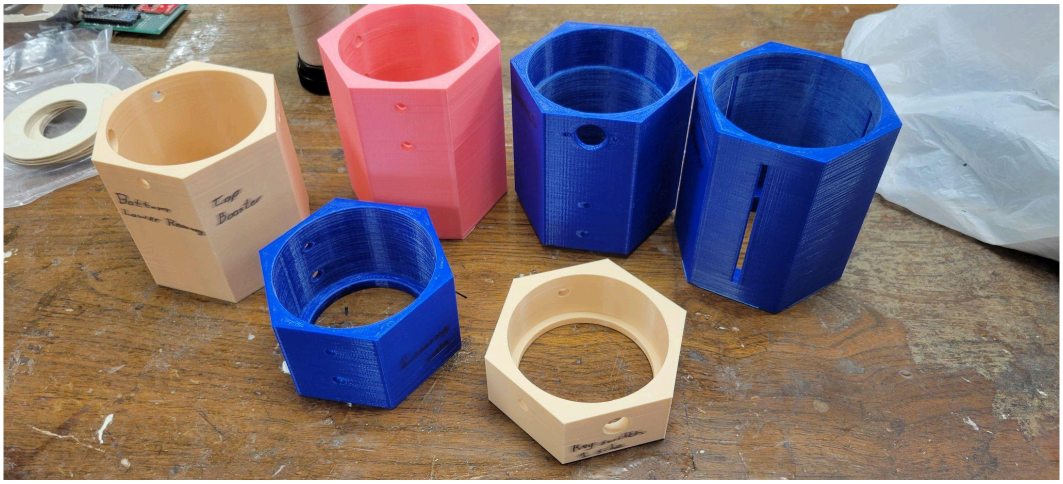


Figure 3.5.4.3: Jigs Used For Subscale Manufacturing

Figure 3.5.4.4: Team Members Using Jigs For Subscale Manufacturing

3.6 Design Integrity

3.6.1 Fins

3.6.1.1 Fin Shape and Style

With respect to the shape and style of the fin, nothing major has changed since the selection was made within PDR. The fin has a trapezoidal shape similar to previous years. The root chord has a length of 5.5”, the tip chord with a length of 2”, a height of 6.2”, and a sweep angle of 16.4°. This sweep angle translates into a sweep length of 1.82”. These fin characteristics were chosen so that the center of pressure of the launch vehicle remains at the bottom end of the R&D coupler which is necessary for the R&D payload inside the coupler to obtain meaningful flight data. The trailing edge of the fin has been truncated slightly to remove the fine edge which will make the actual manufactured fin to have a tip chord of 1.88” and a root chord of 5.17”. This is because having a thin sharp edge for the trailing edge leads to easy breakage of the edge, which causes an unevenness in the design and a chance for damage to propagate throughout the fin.

When considering the airfoil, a major revision was made in the choice of airfoil since PDR. During the physical testing of the fin for fin flutter analysis, detailed in the next section, the fin failed at a significantly lower applied force than expected. After analysis of the failure, the conclusion was made that the failure was largely a result of the fiberglass insert not traversing a large enough amount of the interior of the fin. This was a result of the fact that the fin was too thin to properly support the insert inhabiting a larger portion of the fin's interior. To rectify this problem, the fin's airfoil was altered from a NACA 0008 to a NACA 0012, increasing the thickness by 50%. The increase in thickness enabled a proper redesign of the insert to account for the previous failure, such is detailed in the final component Section 3.4.1.2.

The choice of a NACA 0012 airfoil was made for a few reasons. In the case of the latter two numbers, this choice is made by the necessary thickness to hold the internal insert structure, as mentioned above. In the case of the former two numbers, the double zeros, this is due to the desirability of a symmetric airfoil. In the case of the launch vehicle, adding a camber to the airfoil would inevitably lead to a lifting action on the fins. Such a lifting action, placed about the aft of the launch vehicle would lead to a decrease in stability, and higher unreliability in the design. As a result, a symmetric airfoil is chosen, leading to the choice of the NACA 0012 designation.

3.6.1.2 Fin Flutter

As previously mentioned in the PDR, the fin flutter analysis that had been performed on the fin is suboptimal due to the large number of assumptions and composite material. As such, a more complete and acceptable fin flutter test or analysis is required for satisfactory proof of the capability of the design. This improved test is done by mounting the fin specimen in a cantilever manner, whereupon a force is tip loaded and the deflection is measured. Further the tip then has a moment applied where then the angular deflection is also measured. These values allow for the fin to be modeled as a combination of a torsional and bending spring, where there constants are given by the equations $K_\alpha = \frac{P_\alpha d}{\theta}$ and $K_H = \frac{P_H}{\delta_t}$ respectively. That is where P_H is the force applied, and δ_t is the measured deflection for the simple bending. Further, P_α is the force applied at distance d for the moment, where theta is the angular deflection measured. Further, some values must be determined for the analysis. Those are: the mass m, the polar inertia of the cross section I_α for the rotation about the height axis, S_α the coupling inertia, the cross sectional area S, the distance from the center of lift x_{ac}, dynamic pressure q, lift curve slope $C_{L\alpha}$, and the harmonic motion ω. These values are gathered from simple measurements, the dimensions of the design, or from the conditions of the analysis. Once these values are attained, they can be placed into the determinate equation, which can then be solved for omega:

$$(m\omega^2 - K_h)(I_\alpha\omega^2 - K_\alpha + C_{L\alpha}qSx_{ac}) - S_\alpha\omega^2(S_\alpha\omega^2 - C_{L\alpha}qS) = 0$$

Omega can then be analyzed for when the motion of the fin begins to become unstable. This is seen easier when the equation is broken into pieces, and the relation is shown as such. Given that, the equation can be broken apart as follows:

$$C = (K_hK_\alpha - K_hC_{L\alpha}qSx_{ac}),\ \text{A} = (A = mI_\alpha - S_\alpha^{\ 2})$$

$$B = (S_{\alpha}C_{L\alpha}qS + mC_{L\alpha}qSx_{ac} - mK_{\alpha} + I_{\alpha}K_{h})$$

These portions can then be utilized to find the relation $B^2 < 4AC$, where the relation can be noted from the simple quadratic equation for when its root becomes imaginary. This means that the relation between B, A, and C is dependent upon the dynamic pressure placed upon the fins. The dynamic pressure is dependent upon the air density and velocity of the airflow. Given the relatively low decrease in density for the duration of the flight, the density can be assumed to be a constant. This further increases the reliability of the analysis as the higher density leads to a higher dynamic pressure and a lower calculated point of failure. As a result the independent variable becomes the velocity of the fin, allowing for the 4AC section of the inequality to be brought over to the left side. The equation can then be analyzed for when it becomes negative, dependent upon the velocity, subsequently gaining the fin flutter velocity.

The specimen utilized for the analysis has been observed to fail the physical testing. Such will be discussed later in section 6.1.2. As it stands, the failure of the fin during testing prevents any acceptable analysis to be done, and indicated the need for alteration of the design as well as further preliminary analysis. As a result, the fin design was modified. Due to the inability to produce a newly designed fin within the timeframe given, another fin flutter analysis has been performed via Computational Fluid Dynamics (CFD). This was previously avoided due to the relatively high skill and computational requirements, but was deemed necessary for satisfactory analysis.

When conducting the CFD analysis of the fins to obtain the fin flutter velocity, many assumptions and round offs were made in the process. To start off, fin flutter is an observed aerodynamic phenomenon where the fin will constantly bend back and forth due to aerodynamic forces. With continuous oscillation of bending of fins, the fins will eventually break apart and fail mid flight. When the fins undergo an oscillating deformation of about a third of its total height, this will be considered catastrophic deformation. In this current case, catastrophic deformation occurs when it reaches a value of 2.067” or 0.0525 meters. With the usage of Ansys Finite Element Analysis (FEA) as seen in Figure *3.6.1.2.1* a shear force of 1000 newtons was applied over the top of the fin, and on the edge of the fin. The forces were set up in this manner to imitate aerodynamic forces creating torsion and bending moments on the fin in flight. Using 1000 newtons, the maximum deformation of the fin will have a value of 0.0495 meters which is close to the value of catastrophic deformation. With this obtained force, it is then calculated that the force per unit length is 6350 newtons. Using this force unit span, it is now possible to obtain the pressure applied to the fin. An assumption made now is that the pressure is applied to the leading edge of the fin. From this, the team can then calculate the pressure itself by multiplying the force unit span applied to the fin to the frontal area of the fin which resembles the shape of a box. This box has a height of 0.66” and a length of 6.2” which means that the pressure applied is 2405312.67 Pa. The next step is to continuously tweak the boundary conditions of the fluid domain around the fin until the obtained pressure is applied to the fin as a maximum value. Using a flow velocity of 1372 m/s, the variable residual plot was obtained as shown in Figure *3.6.1.2.2* and the pressure contour in Figure *3.6.1.2.3*. The obtained residuals plot indicates convergence below 1 of all the variables meaning that the values obtained adequately fulfills the continuous navier-stokes equations and is accurate. Looking at the pressure contour plot, the maximum applied pressure on the fin is 2158000 Pa which isn't exactly the same as the calculated applied pressure from earlier but is of the same magnitude and close enough. This means that the fin flutter velocity is estimated to be around 1372 m/s or Mach 4 at sea-level.

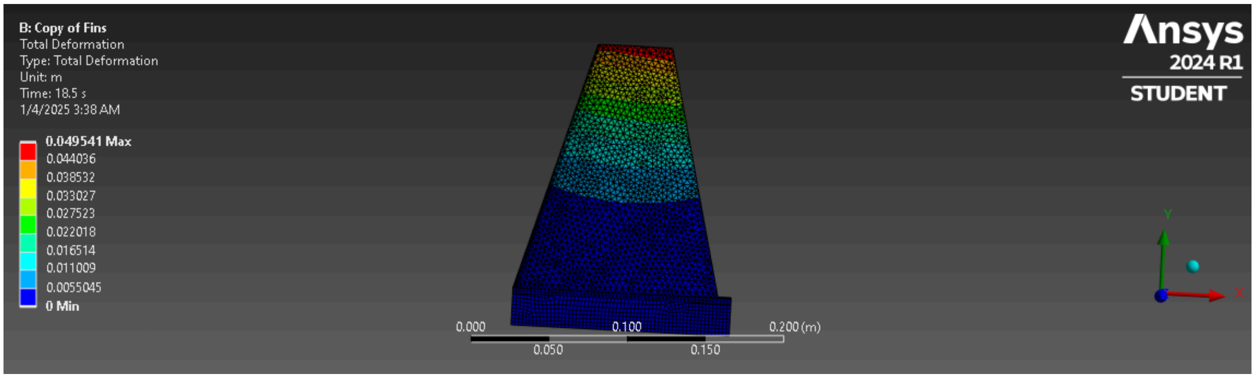
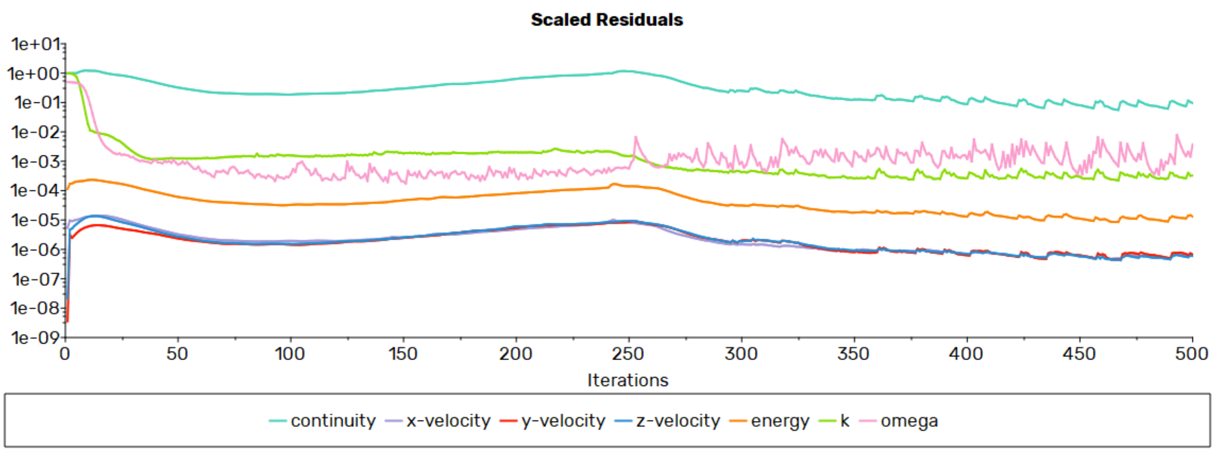


Figure 3.6.1.2.1: Catastrophic Deformation of Fins

Figure



3.6.1.2.2: Residuals Plot for Flow Computation of Fins

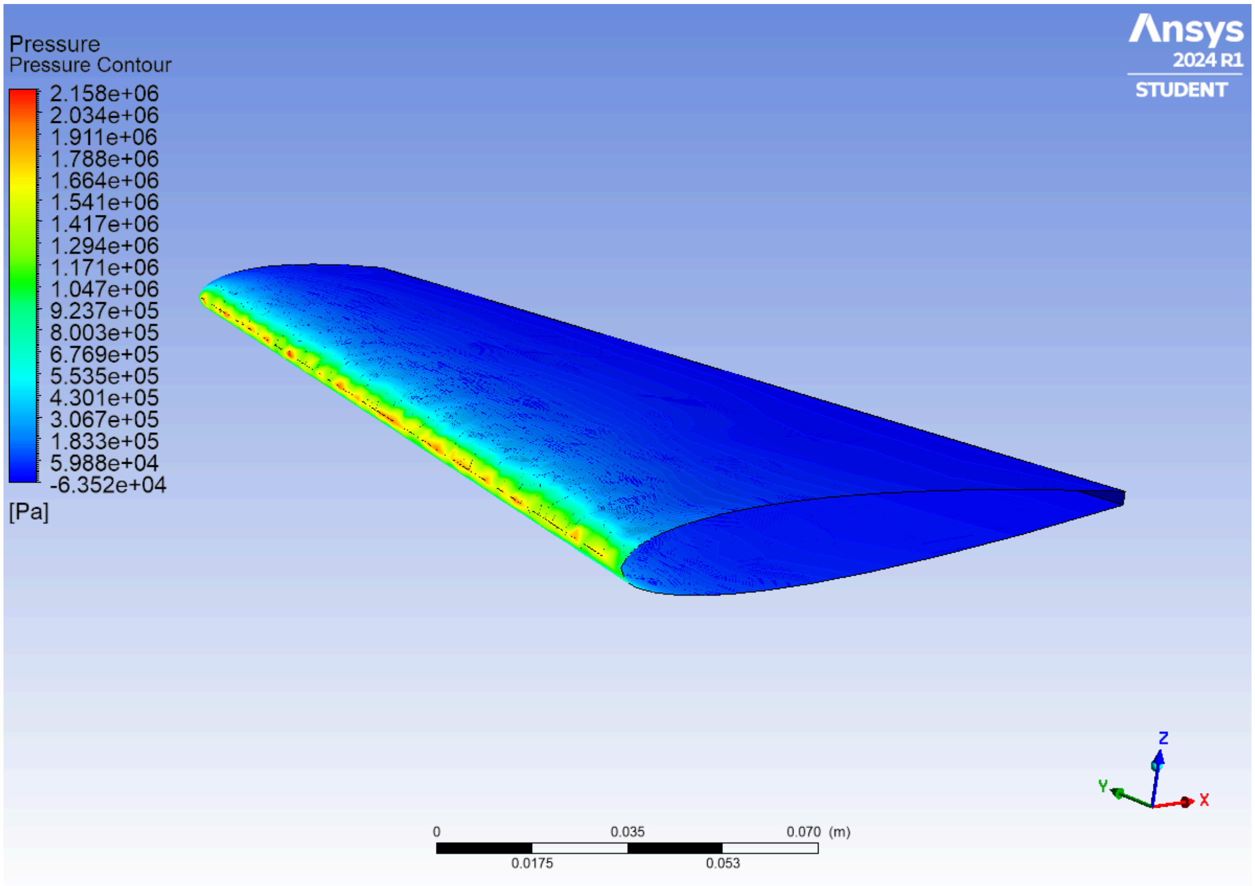


Figure 3.6.1.2.3: Pressure Contour of Fins

3.6.1.3 Fin FEA

Given the significant changes since the PDR, it was deemed necessary to reevaluate the integrity of the design of the fins. Here this has taken the form of another set of simulations to find the performance and safety of the design and materials. These simulations are the same two simulations as detailed in previous documentation, that is, the inclusion of a face-on tip loaded impact to simulate landing as well as a pressure applied to the leading edge of the fin to simulate the pressure as a result of the flight. Added onto these two simulations, a new third simulation has been introduced to account for the failure mode seen in the failed fin flutter analysis. This is a sideways shear force applied at the tip of the fin to simulate a sideways landing impact. The force of landing, as well as the pressure of flight, had to be recalculated to account for the changes in vehicle design and performance.

With respect to the landing force applied within the simulation, the same formula from PDR was applied using the new values seen in the current design of the launch vehicle. As detailed in section 3.8.3, the landing velocity is found to be 15 feet per second. As detailed in Section 3.4.1, the booster section mass is seen as approximately 0.389 slugs. These two values yield a landing momentum of about 5.828 slug-ft/s. As previously documented, accounting for a landing in soft dirt, the time of impact can be approximated as .1 seconds. Placing these values into the simple force equation, where F is force, m is the mass of the booster, v is the landing velocity, and t is the duration of the impact:

$$F = \frac{mv}{t}$$

The landing force is found to be 58.3 pounds force, or 259.23 Newtons for the use in ANSYS simulations.

For the calculation of the inflight pressure applied across the fin, a similar approach as seen in previous documentation was taken. This first required the acquisition of a Reynolds number, which was found using the dynamic viscosity at altitude, velocity of the launch vehicle, average chord length, and air density at altitude. These values were found to be 3.637E-7 slug-second/ft2, 585 ft/s, 3.75 in, and 20.48E-4 slug / ft3 respectively. This yielded, once again, a Reynolds number of approximately 30,000. Applying this along with a Mach number of .532 in XFlr, provided a standard analysis of the performance of the given NACA 0012 airfoil.

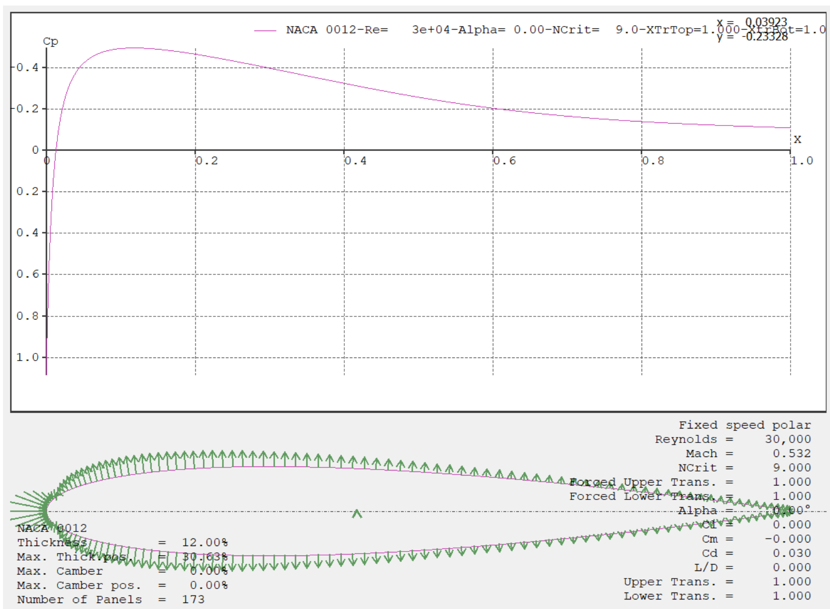


Figure 3.6.1.3.1: XFlr5 NACA0012 Airfoil Simulation

XFlr provided a Coefficient of Pressure of .0182 which was then used in the Coefficient of Pressure equation shown below to acquire the pressure across the airfoil. The team assumed incompressible flow due to that the launch vehicle at max velocity has a mach number of around 0.5. Once again using the aforementioned values, the small change in flight velocity yielded a pressure similar to previous calculations at approximately 37kPa, or 5.37 Psi. For the purposes of further testing the redesigned fin, a pressure of 40kPa was applied in the simulations to increase certainty in performance.

$$C_{P_T} = \frac{\frac{1}{2}\rho V^2 + P_S}{\frac{1}{2}\rho V_\infty^2}$$

Figure 3.6.1.3.2: Coefficient of Pressure Equation

Where, Cp is the coefficient of pressure, rho is the density, V is the velocity, Ps is the static pressure, and V_∞ is free stream velocity. As seen below, the first set of images indicate the sideways landing impact shear force, while the second set of images indicate the face-on landing impact normal force. In the case of the shear force, it is observed that a factor of safety of approximately 1.8 is calculated for a maximum deformation of about 13mm or .51”. This is gained by a stress of 24.2E6Pa, or 24.2MPa, or approximately 3.5kPsi. This clearly indicates the absolute necessity of the redesign that the fins underwent since PDR, in which the improved design reaches a factor of safety of 1.8 for the simulation creating the same failure mode as observed in the physical testing. In the case of the face on impact, simulating a normal force applied on the tip of the fin, the redesign provides improved performance, though at a scale deemed negligible. This is seen by the original simulations providing a deformation of 0.0639mm, whereas the redesign simulation shows a deformation of 0.0262mm for a slightly increased impact force.

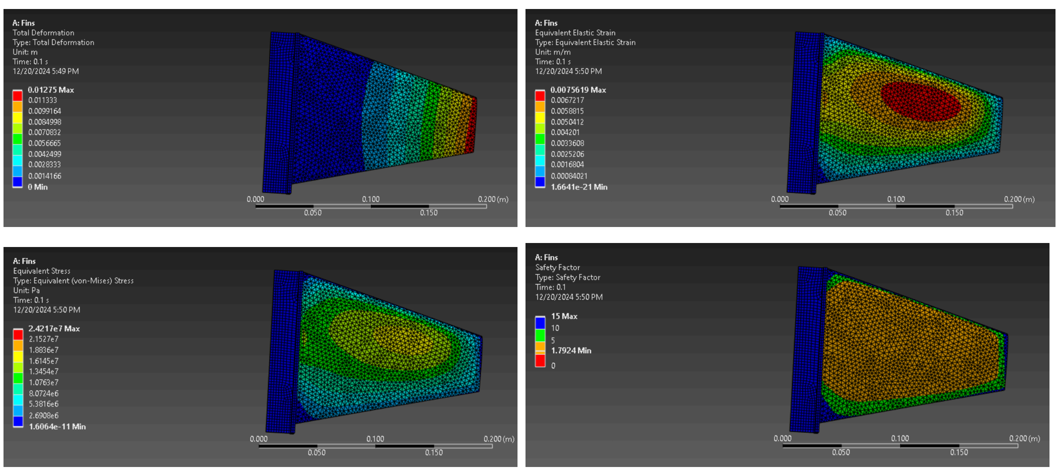
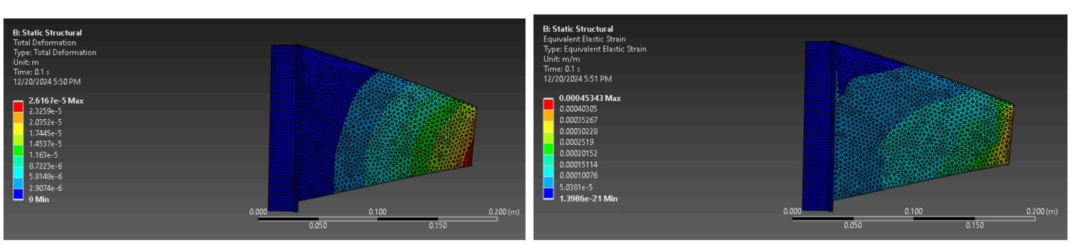


Figure 3.6.1.3.3: ANSYS Simulation For Sideways Landing Impact On Fin



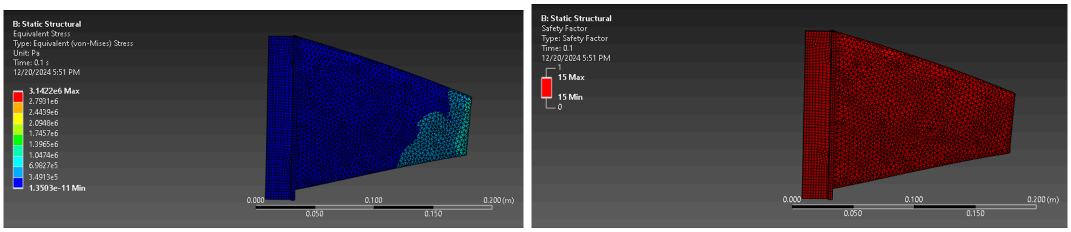


Figure 3.6.1.3.4: ANSYS Simulation For Head-On Landing Impact On Fin

Looking at the inflight pressure based simulations, ANSYS provided a maximum deformation of approximately .0313mm or 0.001232 inches for a maximum internal stress of 1.35MPa or 195.8Psi. This yields a factor of safety of 15 across the entirety of the fin, which is notably the maximum that the simulation outputs. These values and output images from ANSYS are visible below. This is comparable to the original design and simulations flight stress of approximately 2.64MPa, creating a maximum deformation of approximately .0321mm, though again still having a predicted factor of safety of 15+.

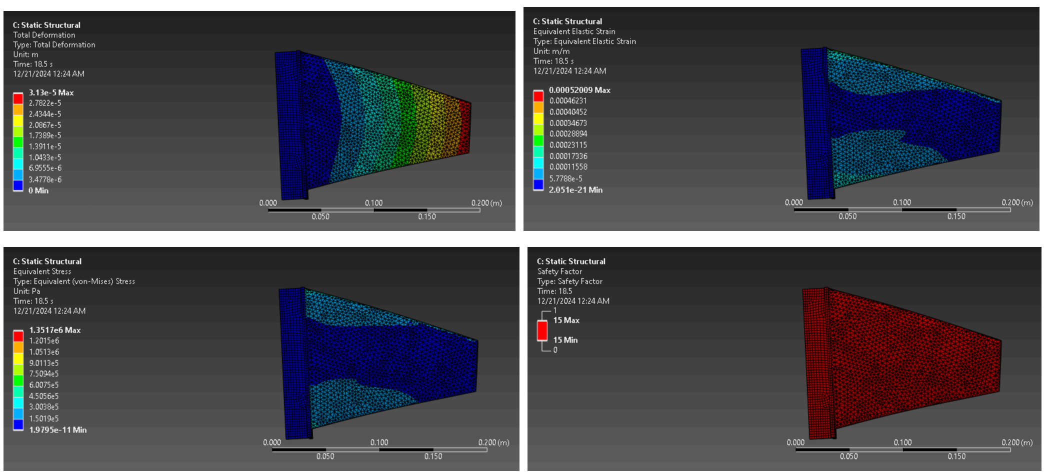


Figure 3.6.1.3.5: ANSYS Simulation For In-Flight Effect On Fin

3.6.2 Material Selection

3.6.2.1 Motor Fin Support Structure

The material choice from PDR has not changed for the MFSS. The material that will be used is Aluminum 6061-T6. This was chosen using a weighted decision matrix (WDM) that compared AL 6061-T6, 304 Stainless Steel, and Ti-AL-V4. The AL 6061-T6 was chosen based on the manufacturability of the material, the density, ultimate tensile strength and the cost of the material. The team also wanted to ensure that the material would satisfy the team derived Requirement S.C.3. The material selection of the MFSS was considered a top priority for the team as if there was a structural failure of the MFSS it would cause a catastrophic failure for the launch vehicle. The material properties of AL 6061-T6 that impact the design of the MFSS can be found in Table 3.6.2.1.1.

Table 3.6.2.1.1: AL 6061-T6 Properties

Material Property	Metric	English
Density	2.7 g/cm^3	0.0975 lb/in^3
Ultimate Tensile Strength	310 MPa	45000 psi
Modulus of Elasticity	68.9 GPa	10000 ksi
Shear Modulus	26 GPa	3770 ksi
Shear Strength	207 MPa	30000 psi

3.6.2.2 Fins

As detailed in the PDR, there were several alternative materials to select from in order to construct the fins. This included a fiberglass insert in either Nylon-12 or Epox-A-Cast 670HT resin, or plywood with a simple fiberglass wet layup. As previously determined, the G10 fiberglass insert in a cast Epox-A-Cast 670HT resin shell with a fiberglass wet layup was determined best via a WDM. Between the previous document and current writing, the team had considered the possibility of use of a plywood insert as opposed to fiberglass. This largely came as a result of the difficulty in acquiring access to a waterjet cutting machine. However, the consideration was found to be rather brief as easy access to said machine was found, and the improvement in performance of the fiberglass over the plywood despite a small increase in price. The final consideration came with the choice of fiberglass cloth, as multiple variants are easy to acquire. The major consideration came to a choice between bi-directional or randomized fibers. Based on previous work experience with both types of cloth, the team came to the conclusion that the use of bi-directional fibers would be optimal due to the active difficulty and problem of fraying with the randomized fibers. While this problem remains with bi-directional fibers, it is reduced in severity. Another significant issue found with the randomized fibers is its ability to contour to the shapes necessary is less than that of the bi-directional fibers. This creates a problem when wrapping the fin with the cloth.

3.6.2.3 Bulkplates

The material for the bulkplates for the couplers are made of fiberglass G10. This was chosen due to the commercial availability of fiberglass G10 and the low cost of the material. The supplier of both the airframe and couplers of the launch vehicle also supply bulkplates that have close tolerances to ensure proper fit of the bulkplates. The team decided on using those bulkplates rather than using materials due to already having that proper fit provided by the supplier. The other options that the team considered was 3-D printing the bulkplates out of PETG. The team decided on choosing the fiberglass G10 due to the higher strength than PETG. The material properties of G10 Fiberglass can be found in Table 3.6.2.3.1.

Table 3.6.2.3.1: G10 Fiberglass Material Properties

Material Property	Metric	English
Density	1.80 g/cc	.0650 lb/in^3
Tensile Strength	310 MPa	45000 psi
Flexural Strength	517 MPa	75000 psi
Compressive Strength	448 MPa	65000 psi

3.6.2.4 Airframe and Coupler

The team considered multiple material types for the airframe and the couplers of the launch vehicle. These included carbon fiber, G12 fiberglass, and PETG. The team could easily decide on not using PETG for the airframe of the launch vehicle due to the manufacturability of the material, since the team would have to use a 3-D printer to manufacture the airframe the team would need access to a printer large enough to print the large airframe sections. Purdue University does not currently have a printer large enough to handle such a task that is easily available to students. That would mean the team would either need to outsource the manufacturing of the airframe or have to purchase a printer large enough. Since the team would like to give learning and experience to its members the team decided against outsourcing and the price of such a large printer would be overly expensive causing the team not to go with PETG. This means that the team had to decide between either carbon fiber of G12 fiberglass. A WDM was created to decide between the two materials. The criteria for the materials considered were price, manufacturability, strength and the density of the material, as the team wants a high strength, low cost, and low weight option.

Table 3.6.2.4.1 Airframe Material WDM

Design Criteria		Design Options	
	Weights	Carbon Fiber	G12 Fiberglass
Price	2	1	2
Manufacturability	4	1	2
Strength	5	1	2
Density	3	2	1
Total		17	25
Choice Made			

As seen in the WDM, the material that the team will be using for the airframe and coupler parts are G12 Fiberglass. The use of G12 fiberglass will ensure that the launch vehicle's airframe will be able to withstand the forces of flight and landing. With the maximum landing kinetic energy that the team predicts in section 3.8.3, the team concludes that that the landing force will not cause the airframe to not buckle upon landing.

3.6.2.5 Nosecone

The material selection for the nosecone of the launch vehicle will be 3D printed ASA. In previous years the team decided against the use of ASA due to the toxic fumes that could be produced. However as seen in both Section 5, Safety, and Section 6.3.1, Budget, the team has been able to mitigate the safety hazard using proper Personal Protection Equipment (PPE). There were many concerns from last year with the team having to remanufacture the nosecone of the launch vehicle due to the PETG nosecone failing. With the increased budget to acquire the proper PPE, the team is able to manufacture using ASA, which has both a higher impact and UV resistance than that of PETG. The choice to 3D print the nosecone was due to the shape of the nosecone. The choice for the design on the nosecone can be found in Section 3.2.5. The material properties of the nosecone can be found below in Table 3.6.2.5.1.

Table 3.6.2.5.1: Material Properties of ASA

Material Properties	ASA
Ultimate Tensile Strength	29.4 - 75.5 MPa
Yield Tensile Strength	15.0 - 83.4 MPa
Flexural Modulus	0.220 - 5.85 GPa

The team is also planning on doing a fiberglass wet layup around the ASA nosecone. The team will use bidirectional fiberglass cloth similar to that of the wet lay ups of the for the fins of the launch vehicle. This will reinforce the nosecone and overall strengthen the design.

3.6.3 Motor Mounting and Retention

3.6.3.1 Thrust Plate FEA

The safety factor for the MFSS was found by conducting FEA through ANSYS assuming the maximum stress that each component can experience. FEA for the thrust plate was performed using the maximum thrust of the motor. Remote displacements were placed on the inner edge of the inner ring and the top of the outer extruding lip. Fixed supports were also placed on the airframe holes. The first remote displacement was defined by the following: Movement and rotation was prohibited in the x and y directions, but allowed in the z direction. The second remote displacement disallowed all displacements and rotations, except for allowing z-rotation. The maximum motor force, of 1136.7 N, was applied to the bottom surface. The FEA shows that the minimum safety factor is 6.8, which far surpasses Requirement S.C.1.

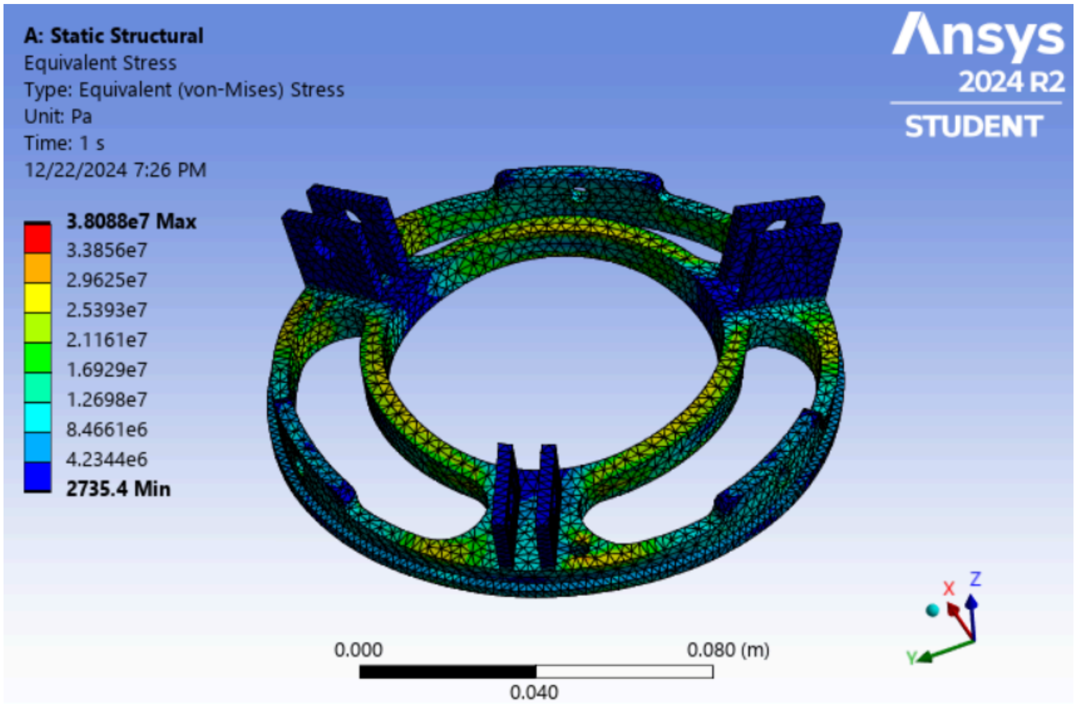


Figure 3.6.3.1.1: Thrust Plate Equivalent (von-Mises) Stress

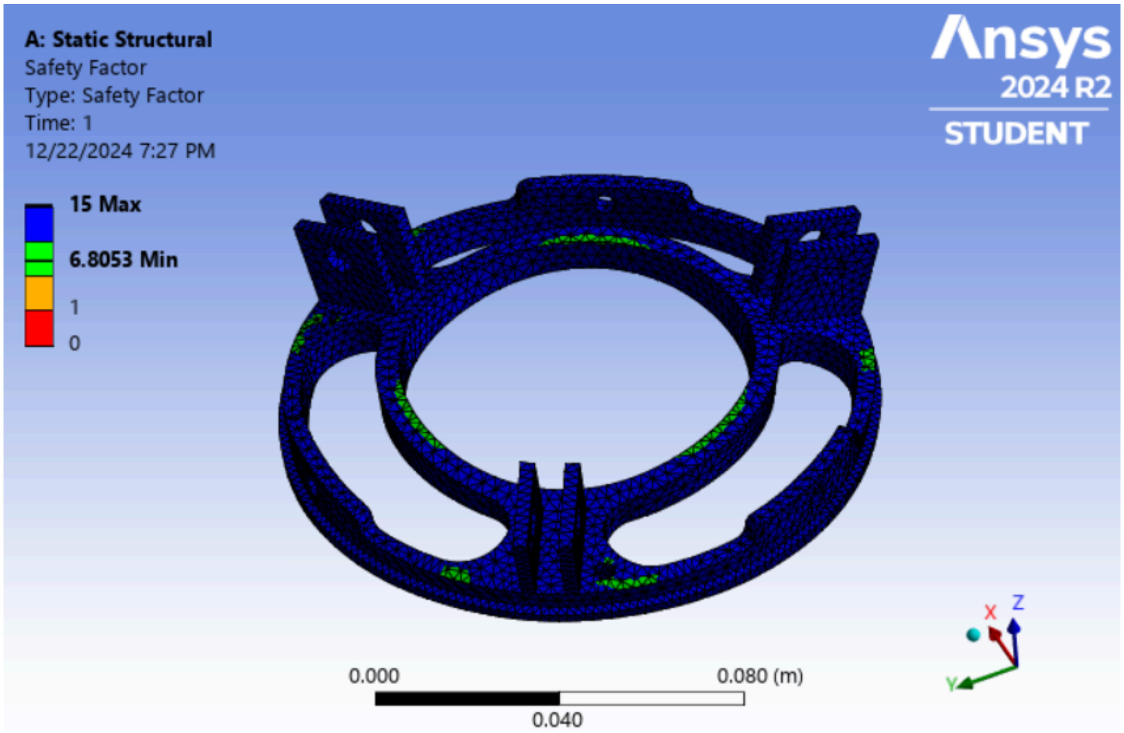


Figure 3.6.3.1.2: Thrust Plate Safety Factor

3.6.3.2 Centering Plate FEA

The conditions for FEA for the centering plate was given that the thrust plate failed, exerting the maximum force on the centering plate. A remote displacement was placed on the inner edge of the inner ring of the centering plate. Using this remote displacement, movement and rotation was prohibited in the x and y directions, but was allowed in the z direction. Additionally, fixed supports were placed on the airframe holes and the outer edge, since it is fastened to the airframe. The deformation scales were amplified to better show FEA results. The maximum motor force, of 1136.7 N, was applied to the top of the centering plate, resulting in a minimum stress safety factor of 13.484. This minimum stress safety factor surpasses a minimum stress safety factor of 1.5 specified in Requirement S.C.1.

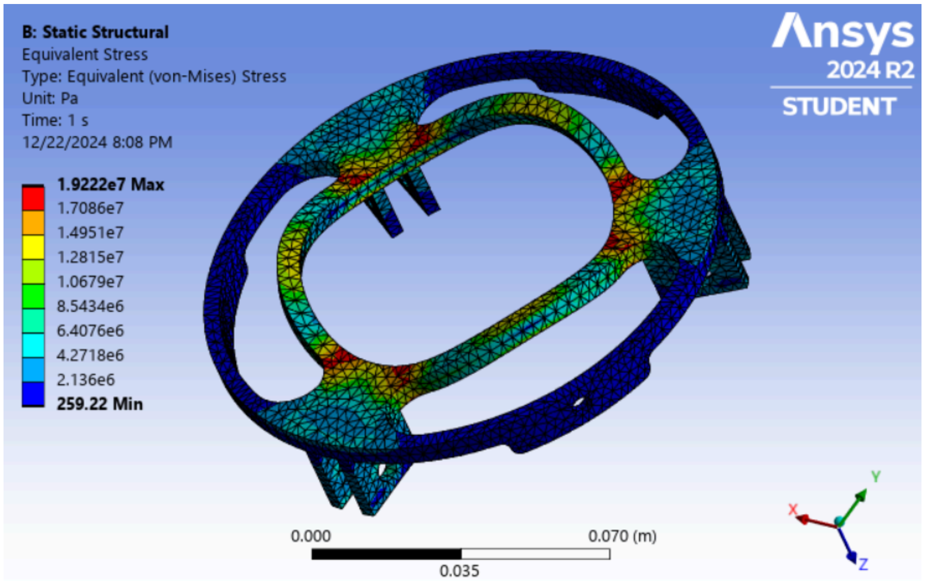


Figure 3.6.3.2.1: Centering Plate Equivalent (von-Mises) Stress

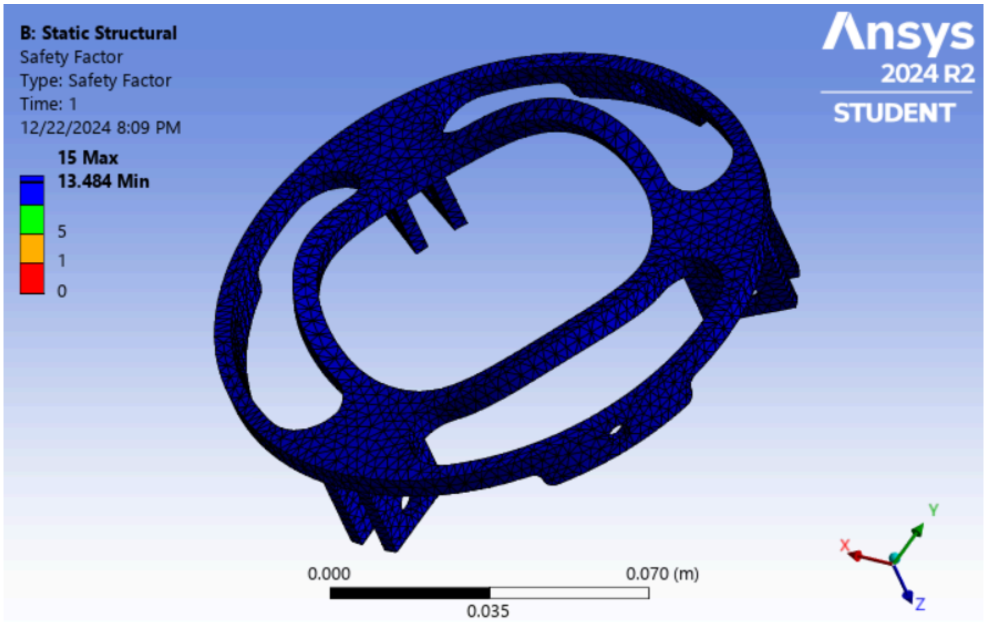


Figure 3.6.3.2.2: Centering Plate Safety Factor

3.6.3.3 Retainer Plate FEA

Given that when the launch vehicle is in motion, the retainer plate does not experience any force by the motor, the analysis was performed based on data from the landing. This is due to the fact that the retainer plate experiences first impact with the ground during landing. Using the equation

$$F = \frac{mv}{t}$$

(where F is force, m is mass, v is speed, and t is time) to calculate the force applied to the retainer plate during ground impact, and a rough assumption that it is 0.1 seconds for soft dirt, which would deform during the collision more than other materials, the resulting calculated force was 494 N. This value of t is low in order to model the impact as near-instantaneous, in alignment with this assumption. The minimum stress safety factor was 2.28, surpassing Requirement S.C.1. Additionally, as can be seen on Figure *3.6.3.3.1*, the deformation was very little, fulfilling Requirement S.C.10.

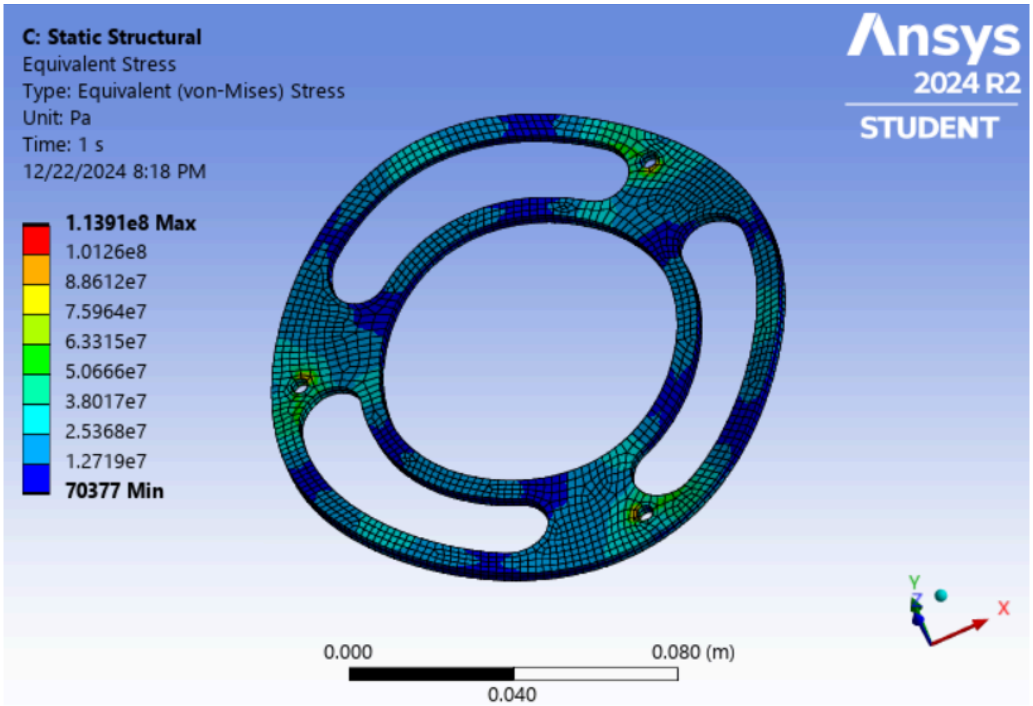


Figure 3.6.3.3.1: Retainer Plate Equivalent (von-Mises) Stress

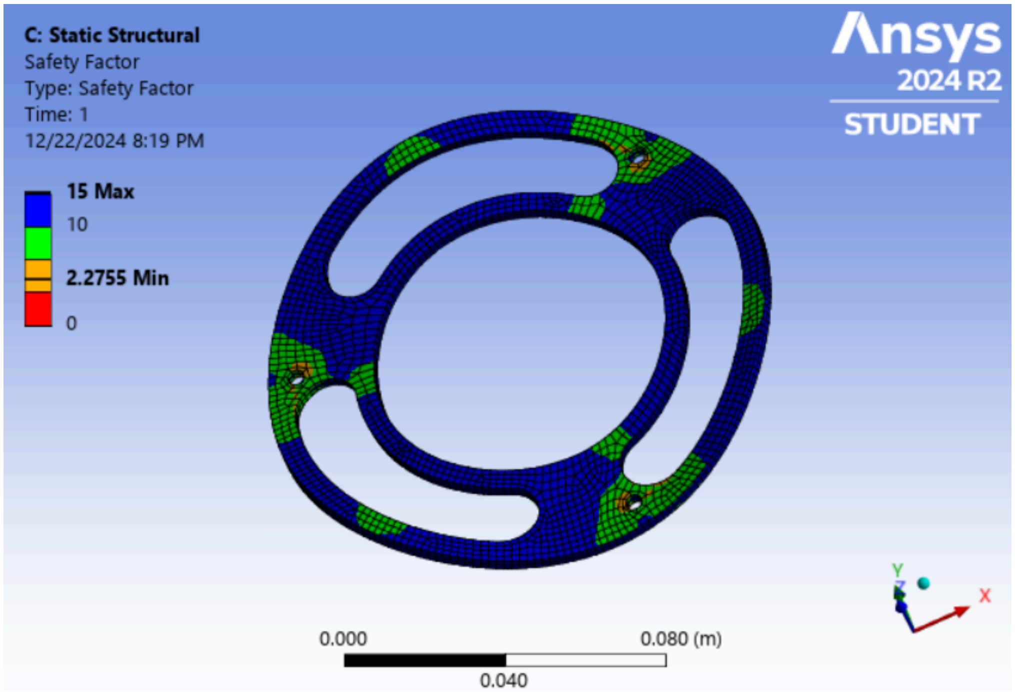


Figure 3.6.3.3.2: Retainer Plate Safety Factor

3.6.3.4 MFSS Assembly

The FEA for the MFSS assembly used the same individual constraints as each part. The retainer plate and fasteners had to be deleted due to Ansys errors, but the results should still be accurate. The deformation scale in both Figures 3.6.3.4.1 and 3.6.3.4.2 has been exaggerated to better show the results. Due to the safety factor being about 12.8, as seen in Figure 3.6.3.4.2, Requirement S.C.1 is fulfilled once again.

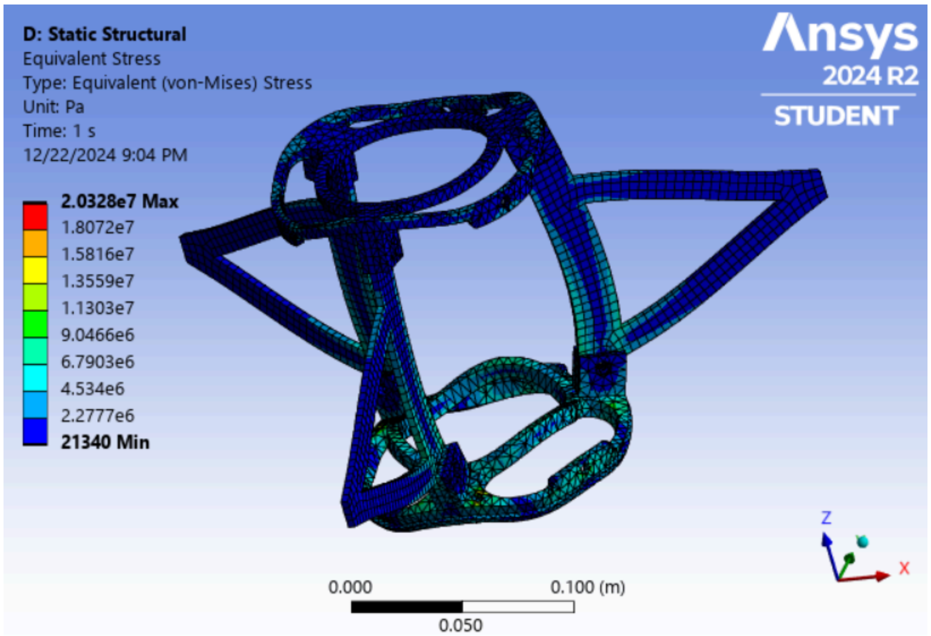


Figure 3.6.3.4.1: MFSS Assembly Equivalent (von-Mises) Stress

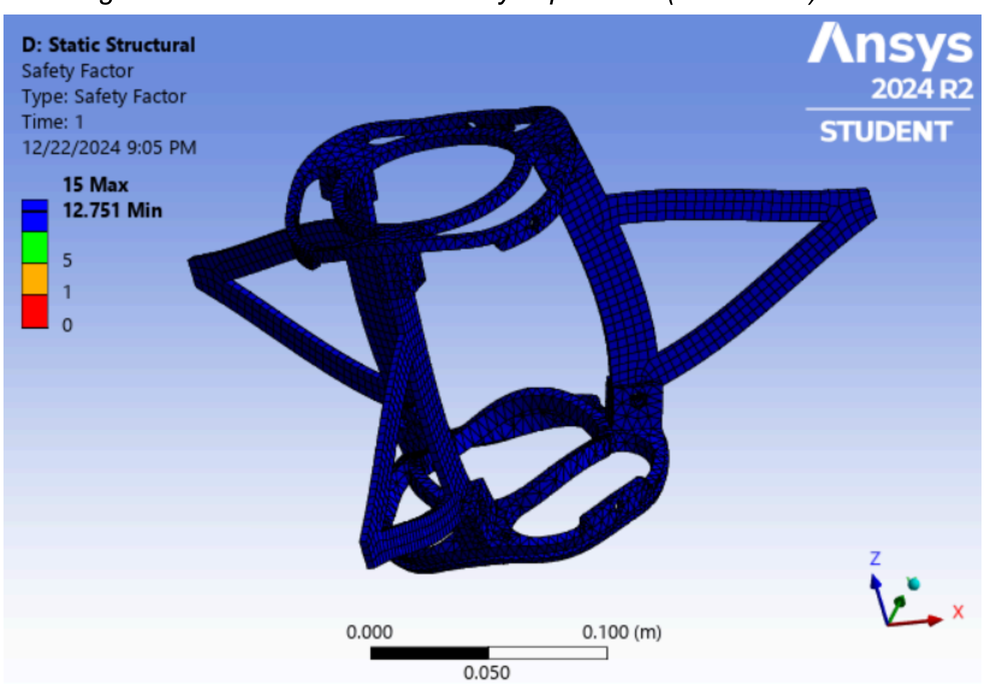


Figure 3.6.3.4.2: MFSS Assembly Safety Factor

3.6.4 full-scale CFD

A CFD simulation was conducted on the full-scale assembly of the launch vehicle to model and predict flight performance when at maximum predicted speed which was indicated to be 586 ft/s as given by OpenRocket as shown in Section 3.2.1. The CFD simulation was first set up by encapsulating the launch vehicle in a fluid domain in the shape of a cube that is 5 meters across all dimensions as shown in Figure 3.6.4.1. With the set fluid domain, the simulation was run utilizing a SST k-omega turbulence model. An assumption made when setting the boundary conditions of the fluid domain is using an ideal gas model for air at sea level conditions. Another assumption made during the simulation is that all the other sides of the fluid domain were assumed to be a farfield indicating normal atmospheric conditions at those locations far away from the launch vehicle. When running the simulation, a residual plot was obtained as shown in Figure 3.6.4.2 showing how accurate various variables are and how well they satisfy the continuous Navier-Stokes equations. In the residual plot, it is seen that various flow parameters have residuals that converge to a value less than 1 indicating a decent approximation after 1500 iterations.

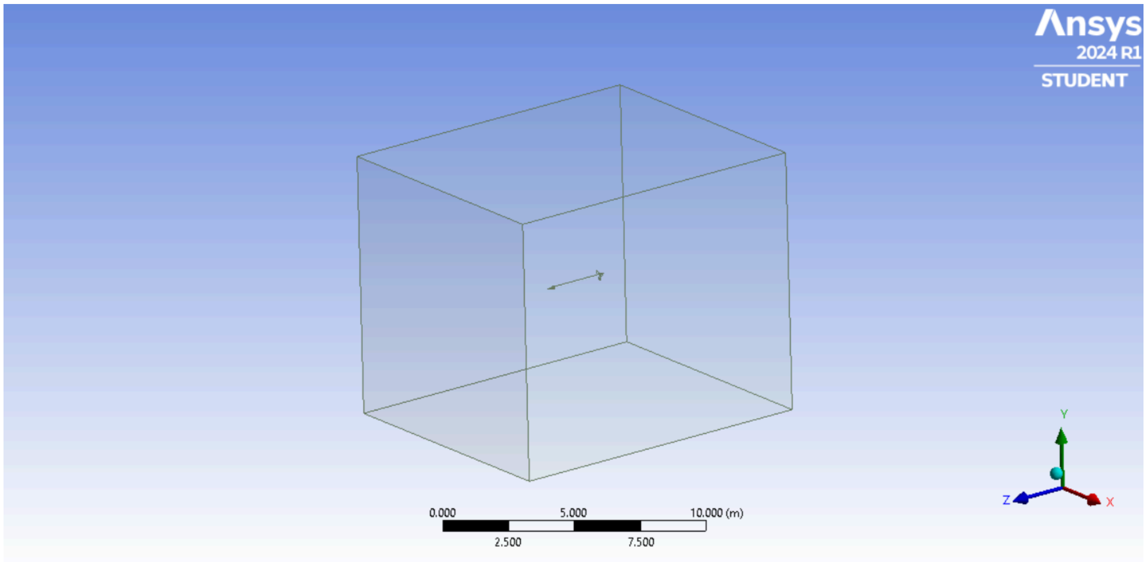


Figure 3.6.4.1: Flow Domain Geometry

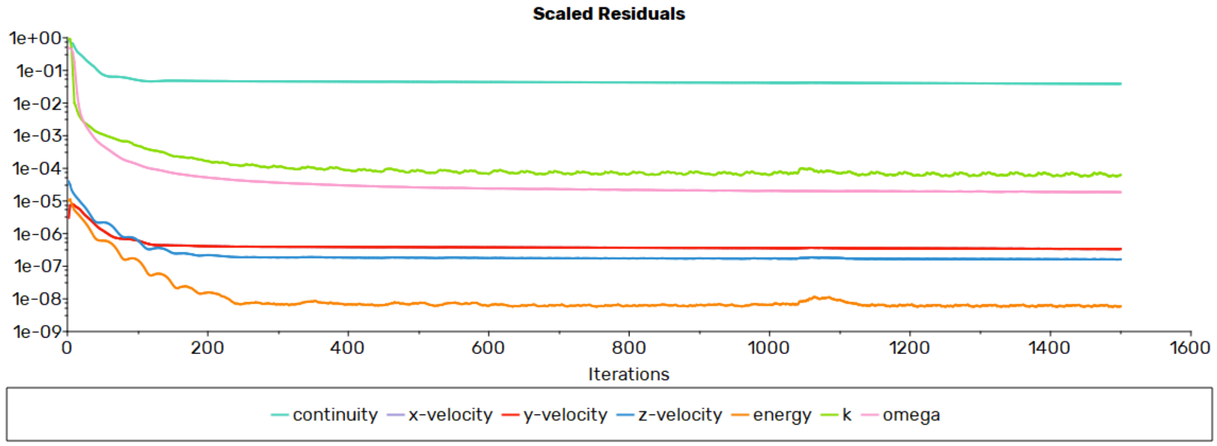


Figure 3.6.4.2: Residuals Plot for Flow Computation of Full-Scale

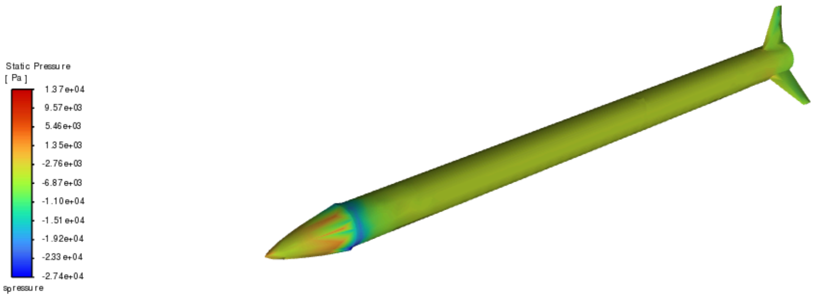


Figure 3.6.4.3: Static Pressure along Full-Scale Launch Vehicle

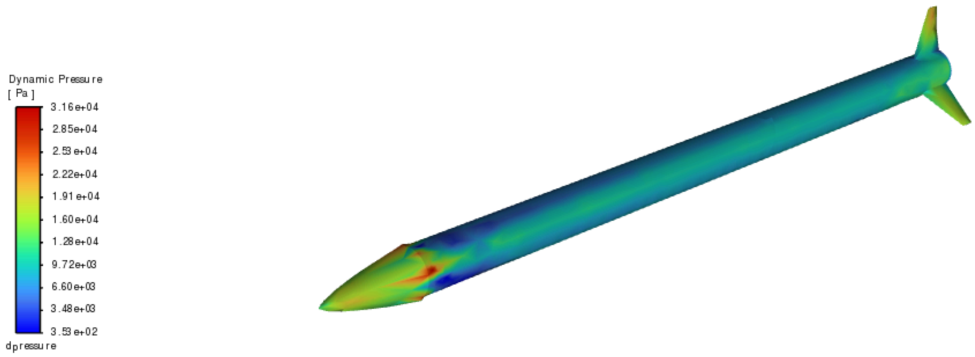


Figure 3.6.4.4: Dynamic Pressure along Full-Scale Launch Vehicle

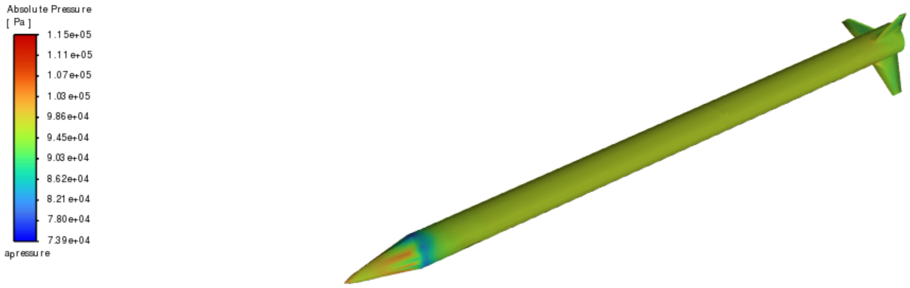


Figure 3.6.4.5: Absolute Pressure along Full-Scale Launch Vehicle

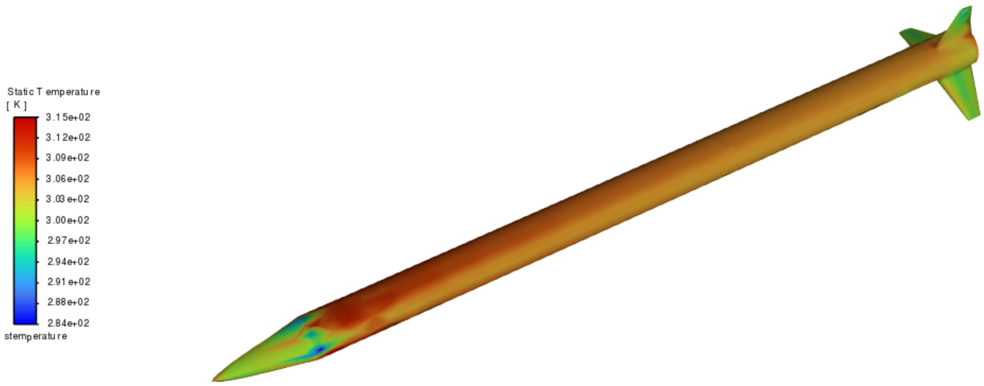


Figure 3.6.4.6: Static Temperature along full-scale Launch Vehicle

Looking at the static, dynamic, and absolute pressure contour of the launch vehicle as shown in Figures 3.6.4.3, 3.6.4.4, and 3.6.4.5, no abnormal values were obtained further reinforcing the CFD approximation of the flight performance of the launch vehicle at maximum predicted speed. It is shown that the maximum value of the absolute pressure occurs at the nosecone tip and has a value similar to that of the atmospheric pressure showing that the nosecone is not at risk of major and permanent deformation during flight. Looking at Figure 3.6.4.6, the maximum temperature is 315 Kelvin which is lower than the melting temperature of ASA which has a melting temperature above 443.15 Kelvin. This shows that the nosecone of the launch vehicle is not at risk of melting due to friction drag.

3.6.5 Mass of Vehicle and Sub-Sections

The estimated mass of the launch vehicle is 35.7 lbm. This is based on the predicted values given by OpenRocket based on the mass material selected and the dimensions of each section. Once the construction of the full-scale components has happened the team will determine the actual mass of the launch vehicle. The mass of each section and the total mass can be found in Section 3.6.5.1.

Table 3.6.5.1 Launch Vehicle and Components Mass

Component(s)	Mass (lbm)
Nosecone	2.33
Camera Bay	1.01
Payload	6.22
Upper Recovery (w/ main parachute)	5.22
Avionics	2.68
Lower Recovery (w/ drogue parachute)	1.62
Booster (w/o fins, MFSS, motor, R&D Payload)	3.53
R&D Payload	2.66
MFSS	0.97
Fins	1.63
Motor (w/ propellant)	7.9
Propellant	4.2
Estimated Total	**35.7**

3.6.6 Subscale Flight Results

3.6.6.1 Subscale Mission Statement

The mission of the subscale launch vehicle is to provide the team with the experience of going through the manufacturing process while also verifying the structural design and the simulations created by the team. The subscale launch vehicle will also serve as a testbed for the primary and secondary payloads. The subscale launch also served as a test flight for the Altus Metrum Telemetrum to confirm testing data.

3.6.6.2 Scaling of Launch Vehicle

The subscale was designed to demonstrate the feasibility of the final full-scale launch vehicle by showcasing the structural and aerodynamic stability of the launch vehicle. The subscale launch vehicle was also designed so that all the sections were the same as the full-scale. This was so that both the payload and R&D teams had the ability to test each subteams' sensor packages. The OpenRocket model can be seen in Figure 3.6.6.2.1.

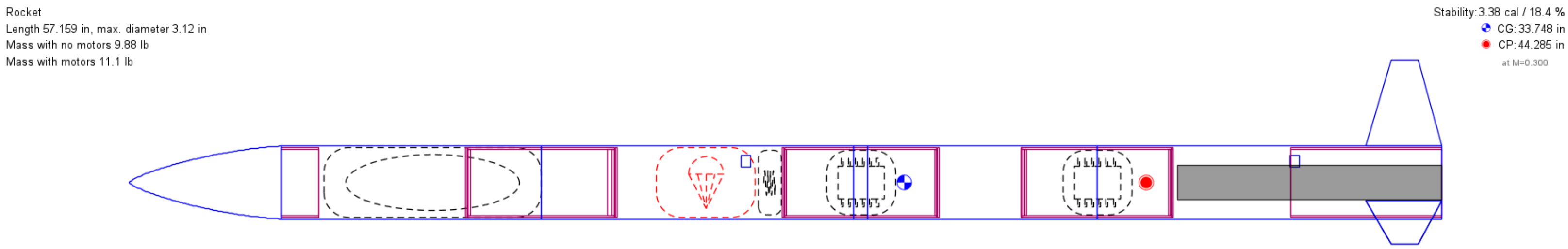


Figure 3.6.6.2.1: Subscale Launch Vehicle OpenRocket

To achieve both the mission and goals of the subscale launch vehicle a 60% scaling factor was used on the diameter and the lengths of each section. This was to accomplish Requirement G.2.18.5, as to not go over that 75% maximum scaling factor. The team also decided on a 60% scaling factor for the manufacturability of the subscale launch vehicle. Since the full-scale launch vehicle will utilize a 5" airframe, a scaling factor of 60% will allow the team to utilize a 3" airframe. This is also to satisfy Requirement G.2.18.5, while still allowing the team to find airframe parts that are commercially available. The subscale is also made up of all the same sections as the full-scale to ensure the structural stability. This includes a booster, lower recovery, upper recovery, and payload airframe and a secondary payload, avionics, and payload coupler. However, the team decided on only using one parachute for the subscale which causes the launch vehicle to only have one separation point. The separation point occurs between the upper recovery and the avionics coupler. The separation occurs with the use of a black powder ejection rather than using the motor ejection, since there is a coupler above the motor. A parachute of 3' was utilized for the launch vehicle due to the team wanting to demonstrate a similar landing kinetic energy. The team also decided on a Loki Research I-377 motor. This was due to the availability and it meeting all NASA and team subscale requirements. There was also the size restriction of the subscale vehicle meaning that the team only considered motors with a diameter of 38mm. The thrust curve of the Loki Research I-377 motor can be found in Figure 3.6.6.2.2.

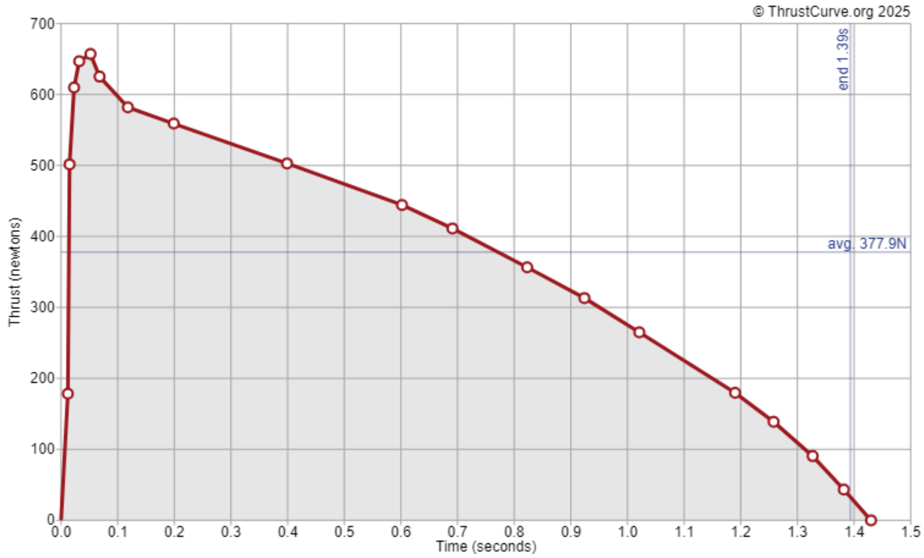


Figure 3.6.6.2.2: Loki Research I-377 Thrust Curve

3.6.6.3 Launch Day Conditions and Predictions

The team launched the subscale launch vehicle on November 17th, 2024 at 10:00 am in West Lafayette, IN. The temperature was 54° Fahrenheit, a humidity of 83%, a pressure of 14.39 psi, and a wind speed of 7.4 mph. The team predicted an altitude of 1858 feet at apogee based on simulations using the launch day conditions. An overview of the simulations is below along with graphs of the altitude, velocity and acceleration from the simulations as well as a comparison of the simulated data with real data.

Figure 3.6.6.3.1: Subscale Launch Vehicle on the Pad

Table 3.6.6.3.1 Summary of subscale simulations with launch day conditions.

Simulation Method	Apogee (ft)	Descent Time (s)	Landing Velocity (ft/s)	Maximum Velocity (ft/s)	Maximum Acceleration (ft/s^2)	Drift Distance From Apogee (ft)
OpenRocket	1858	47.6	39.2	347	457	476
RocketPy	1857	48.2	39.5	345	456	248

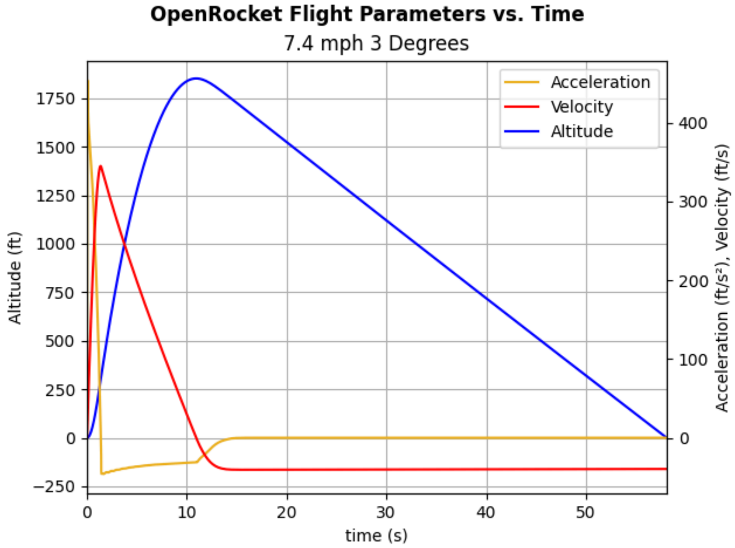


Figure 3.6.6.3.2: OpenRocket vertical altitude, acceleration, and velocity vs time for subscale launch conditions

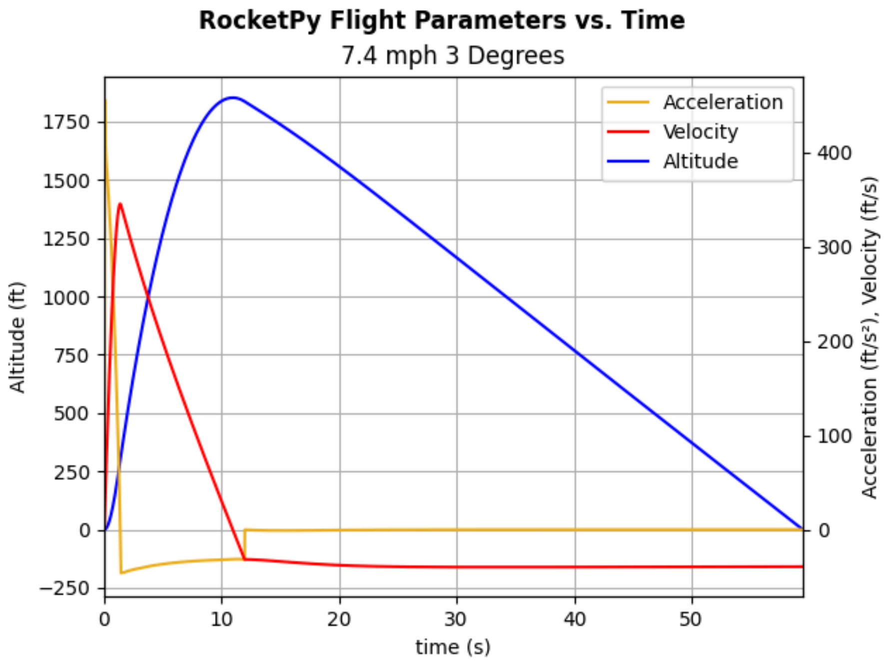


Figure 3.6.6.3.3: RocketPy vertical altitude, acceleration, and velocity vs time for subscale launch conditions

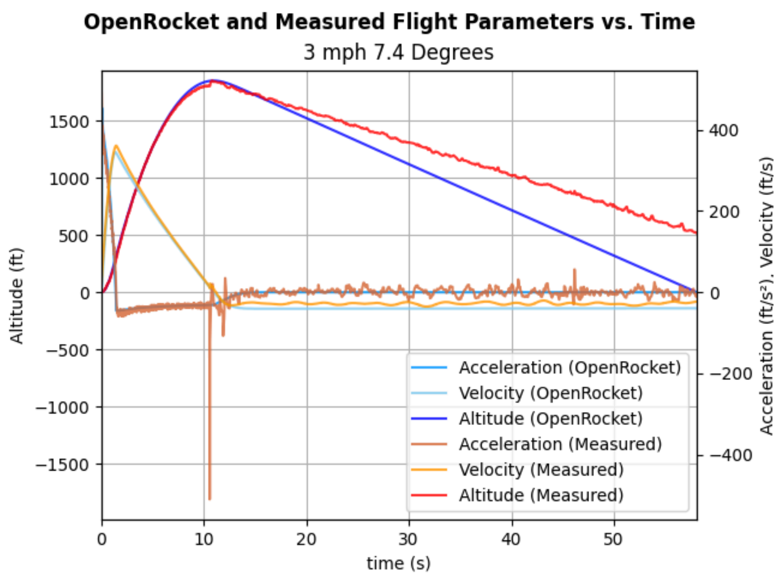


Figure 3.6.6.3.4: Comparison of OpenRocket data with measured data for altitude, velocity and acceleration of the subscale flight

3.6.6.4 Subscale Flight Data

The recovery system used the Altus Metrum Telemetrum as the GPS and altimeter for the subscale flight. The parachute deployed at 1806' with a reported apogee from the Telemetrum at 1851' as shown in the flight graph below.

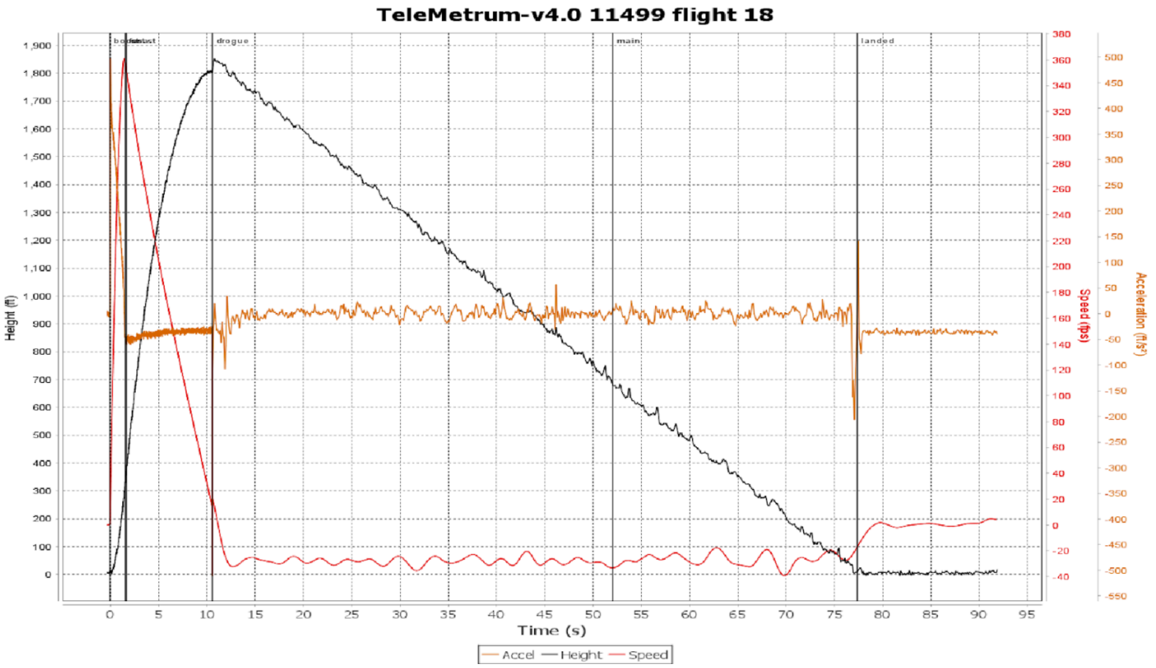


Figure 3.6.6.4.1: Telemetrum Subscale Flight Results

Table 3.6.6.4.1 Subscale Data Points

Apogee (ft)	Descent time (sec)	Landing Velocity (ft/s)	Maximum Velocity (ft/s)	Maximum Acceleration (ft/s^2)	Drift Distance (ft)
1851	41.5	23.0	361	497	2,301

3.6.6.5 Flight Reliability and Confidence

Several factors go into ensuring the reliability of the subscale simulations. First, as seen in Table 3.6.6.3.1, two simulation methods were used: OpenRocket and RocketPy, and these simulation methods gave very similar results to each other, despite the differences discussed in Section 3.8.6 in methodology. Both were run using the exact launch conditions of the subscale flight, including wind speed, temperature and altitude of the launch pad. This led to incredibly accurate results. The differences between the average of the two simulations and the real flight data is below.

Table 3.6.6.5.1 Percent Difference from Predicted and Actual

Apogee (ft)	0.3%
Descent Time (sec)	13.4%

Landing Velocity (ft/s)	41.6%
Maximum Velocity (ft/s)	3.9%
Maximum Acceleration (ft/s^2)	8.0%
Drift Distance (ft)	84.5%

The highest error is found in drift distance and landing velocity. This is explained by the difference between the way the wind is simulated and how wind acts in reality. In both simulation methods the wind is set to a constant value of constant direction for all altitudes. In reality wind changes quickly with both time and altitude, this has a small impact on the vehicles flight during ascent, and a large impact on the vehicle when it is under parachute. Large gusts of wind can blow the vehicle off course, and changes in the wind's direction and magnitude over time and altitude can cause the vehicle to blow far away from its predicted landing site. The other two data points with large error are descent time and landing velocity, which figure 3.6.6.3.3 can help explain. As seen in the figure, the vehicle descends far quicker in the simulations than it did in reality. A difference in mass wouldn't explain this, as that would also lead to differences in altitude, velocity and acceleration during ascent which was not observed. The most likely cause of this error is in the simulation of the parachute. The area of the parachute is accurate in the simulations based on measurement, which means the error must originate in the coefficient of drag of the parachute. The coefficient of drag used was 1.6 which was based on the manufacturer's documentation, but measurements were not taken to confirm this. For the full-scale vehicle, coefficient of drag of the parachutes can be determined by analysis of prior launches, which was not a method that could be done for subscale. This slow descent can also help explain the larger drift distance, as the longer the descent is, the further the vehicle will drift.

Both maximum velocity and maximum acceleration have error under 10% which indicates that the simulation is accurate when modeling the forces applied on the vehicle during ascent where both maximum velocity and maximum acceleration occur. This is corroborated by the incredibly low 0.3% difference in apogee, or 6 foot difference between the simulation and the subscale data. This level of error is low enough that errors from data collection would be enough to explain the difference. Descent is far harder to accurately simulate than ascent, and so while the high level of error between descent data and simulated data does require explanation and work to improve simulation methods, the extreme accuracy of the ascent data gives confidence that the simulations will be accurate to the full-scale launch.

3.6.6.6 Subscale Impact on Full-Scale Design

The subscale launch vehicle flight validated the team's ability to manufacture, test, and predict launch behavior. The team was able to learn important lessons when manufacturing the subscale with tolerancing 3D printed parts. There was one issue which was that the packing of the parachute was difficult. Since the packing volume is comparable to that of the full-scale and there was difficulty packing the parachute, it caused the team to decide to lengthen the lower recovery airframe piece by 1”. With the larger diameter and the longer airframe piece, the team is confident that the parachutes should fit into the launch vehicle.

3.7 Recovery Subsystems

3.7.1 Avionics and Recovery CONOPS

The avionics and recovery subteam operates with four phases for the Concept of Operations (CONOPS). These are Preparation, Initiation, Flight, and Retrieval. The Preparation phase is anything that happens in advance of the launch, within the days before and day of launch before the launch vehicle reaches the launch pad. Initiation is all procedures on the launch pad, where the on-board electronics will be powered on. The Flight phase begins when the motor ignites and continues until the moment the launch vehicle has landed. The Retrieval phase is all procedures once the launch vehicle has begun to descend under the parachutes.

3.7.1.1 Phase 1: Preparation

The preparation phase of the Avionics and Recovery CONOPS is anything done before launch leading up to when the altimeters within the launch vehicle are turned on. In the days before the launch, the altimeters will be configured to ensure the drogue and main parachute are deployed at their designated altitude. To ensure that the parachutes will deploy and the ejection charges are the correct amount, the launch vehicle will undergo black powder ejection testing. Additionally, all altimeters will be subjected to vacuum testing to verify the system will work and the deployment charges will be triggered at the proper altitudes. Following this, the altimeters will be implemented on the avionics sled. The avionics coupler will also undergo final assembly after this step with the switches being assembled onto the sled. The altimeters will each be connected to their own independent battery and switch. Additionally, the primary altimeter will be connected to the primary ejection charges for the main and drogue parachutes. The redundant altimeter will be connected to the redundant charges for the main and drogue parachutes. Following complete assembly of the avionics bay, the coupler will be integrated into the launch vehicle. Following integration of the avionics coupler, the shock cords will be attached to their designated bulkheads for tethering. The parachutes, and parachute heat shielding will be packed and integrated within the separation points of the launch vehicle.

3.7.1.2 Phase 2: Initiation

When the launch vehicle is successfully placed on the launch pad, the initiation phase will begin by turning on the altimeters separately via the two independent switches. The Altus Metrum Telemetrum altimeter will be turned on first, followed by the PerfectFlite StratoLogger CF. Both altimeters will give a series of beeps indicating system readiness for main and drogue parachutes that will be checked against the beeps provided in the altimeter manuals. At the Avionics Ground Control Station (AGCS), the Altus Metrum Teledongle will be connected to a laptop at the launch pad. Once the connection is confirmed, the team will also turn on the nosecone cameras for live-streaming and data collection. When the team returns back to the viewing area, the laptop will remain connected to ensure live flight data is collected including deployment status, apogee, live altitude, and vehicle position.

3.7.1.3 Phase 3: Flight

During flights, the complete avionics systems will be monitoring altitude of the launch vehicle for proper initiation of the deployment charges upon reaching apogee. The primary altimeters will ignite the primary ejection charge for the drogue parachute at apogee and the redundant altimeter will ignite the redundant charge two seconds after apogee. The main parachute will be deployed at 700' above ground level (AGL) with the primary ejection charge. The redundant charge will be ignited at 600' AGL by the secondary altimeter to ensure the main parachute is deployed to be below the impact velocity requirement.

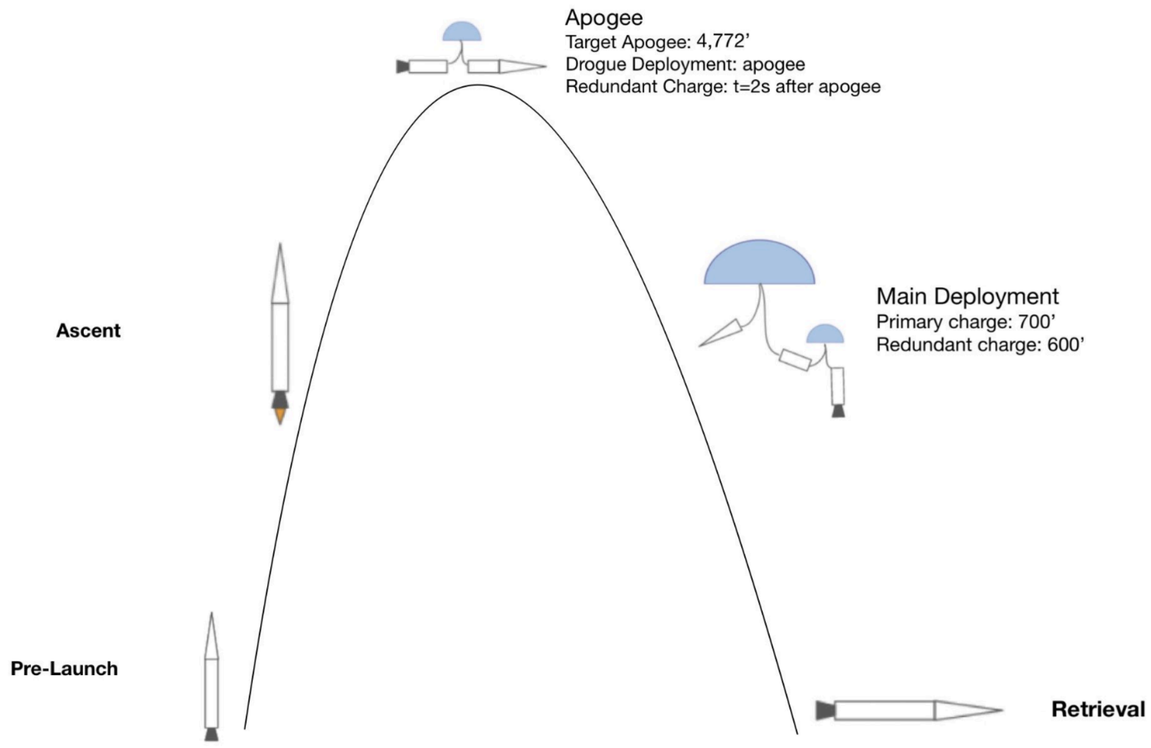


Figure 3.7.1.3.1: Predicted Flight Profile

3.7.1.4 Phase 4: Retrieval

Upon deployment of the parachutes, the launch vehicle shall be tracked visually at all times. In the case that physical sight or line of sight is lost, the GPS tracking within the primary altimeter will be used to establish landing location to begin physical retrieval. Once the team has arrived at the landing location, pictures will be taken to record the events and orientation of landing for reference. Either the safety lead or avionics and recovery lead will approach the launch vehicle to inspect if all black powder charges have deployed. Altitude will be recorded from the beeps given by the altimeters. Following this, the avionics bay will be turned off and the team will recover the launch vehicle. All data from the altimeters will be transferred to a laptop. Analysis of this data will occur within the days after the flight to calculate highest apogee and descent analytics.

3.7.2 Chosen Components

3.7.2.1 Altimeter Sled

The altimeter sled is designed to hold the recovery electronics. The overall design intends to decrease the day-of assembly time of the sled and increase the security of the components within it. The sled is designed to incorporate the key switches into the sled so that the altimeters can be wired to the switches before the avionics coupler is integrated with the full launch vehicle. This was a key feature of the design as compared to previous iterations, and is meant to decrease the assembly time on the pad and increase the security of the avionics wiring. The sled will be 3D printed to incorporate the complex geometry needed to incorporate the key switches into the sled. The sled will be made out of PETG, which is a stronger filament alternative to PLA. This will ensure the avionics sled can withstand flight forces and remains reusable in case of hard impact. The switch holders are located in the center of the sled on opposing ends to line up with the key switch holes on the switch band at the center of the avionics coupler.

One side of the sled holds the batteries, and the other side holds the altimeters. This allows a corresponding altimeter and battery to be located directly opposing each other on the sled, helping with wire management. The batteries will be labelled and retained inside their own compartments, satisfying team requirement S.A.4. Each compartment includes a lid that will be attached with heat set inserts and M3 screws. Each battery will be held with high friction tape at the bottom of the compartment, and with zip ties that will go through the sled and hold the battery in place. This set-up allows extra protection for the batteries and ensures they will remain secure inside the avionics sled with large forces, satisfying the team-based requirement S.A.12.

The avionics sled layout also ensures that the Altus Metrum Telemetrum altimeter will be oriented horizontally with respect to the upright launch vehicle. The altimeters will sit on standoffs that fasten into heat set inserts in the sled. This allows the altimeters to be raised off the sled, leaving room for the battery zipties below, while keeping them securely in place on the sled. The sled itself will be located on two 13” long ¼-20 threaded rods. The sled will be centered on the rods and constrained with a washer and two ¼-20 hex nuts on each end. This assembly, including the altimeters, batteries, key switches, wiring, threaded rods, washers, and hex nuts will be able to be quickly inserted into the avionics coupler. The coupler will then be closed with the bulkheads, and a washer and two hex nuts will be put on each threaded rod to secure the coupler. The retention features are summarized in Table 3.7.2.1.1.

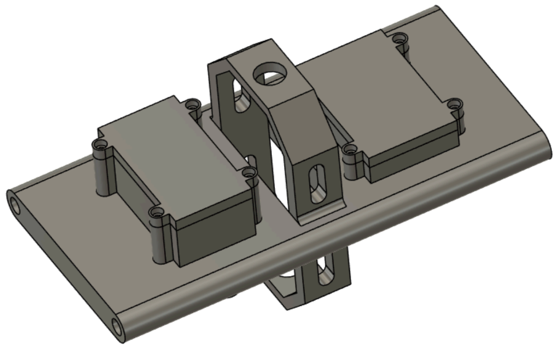


Figure 3.7.2.1.1: Altimeter Sled CAD Model

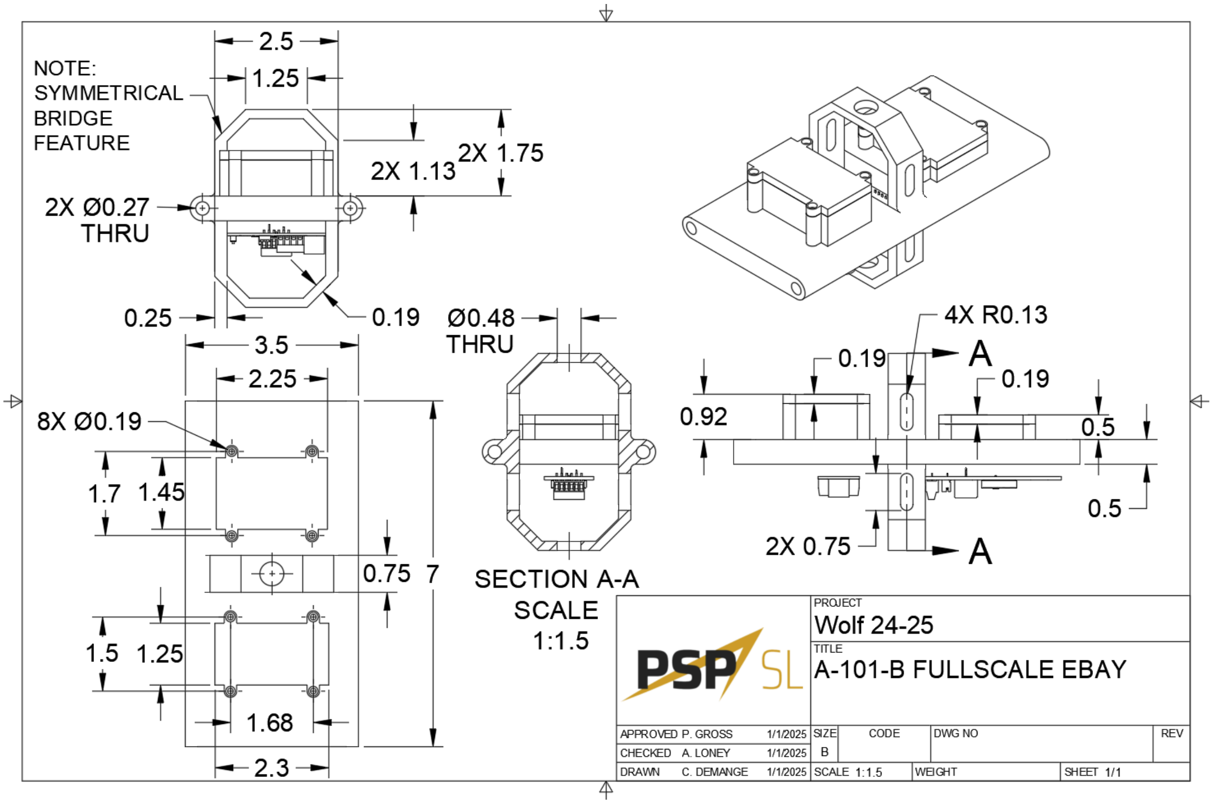


Figure 3.7.2.1.2: Altimeter Sled Drawing

Table 3.7.2.1.1: Altimeter Sled Components and Retention Features

Component	Retention Feature
Altimeters	M3 screws and heat set inserts on standoffs

Batteries	Labeled compartment with M3 screws and heat set inserts
	High friction tape
	Zip ties
Key Switch	Key switch bridge
	Threaded insert and washer
Sled	¼-20 threaded rods, washer, and two ¼-20 hex nuts
	Avionics coupler, bulkheads, washer, and two ¼-20 hex nuts

3.7.2.2 Ejection Charges and Deployment Mechanisms

To satisfy Requirement A.3.1, the team will be using a dual deploy system that utilizes FFFFg black powder. The main parachute will be deployed using a cannon deployment and the drogue parachute will use a modified gravity-assisted cannon deployment method. The parachutes are packed in the sections that are attached to the separation points using 0.190" braided Kevlar shock cords and removable shear pins as according to Requirement A.3.9.

The cannon deployment method shoots the parachute out of the open end of the airframe like a cannon. Since the drogue parachute uses a modified cannon deployment, it will not be ejected out of the airframe. The section will still pressurize and separate, however, the drogue parachute will be deployed with the help of gravity. To pressurize the sections, the team will use e-matches that will ignite a black powder charge, at a predetermined altitude as sensed by the altimeters, creating high pressures in the sections and shearing the shear pins, allowing for separation. FFFFg powder charges were chosen by the team over FFFg powder because it has a smaller grain size and ignites easier. The calculations for the size of the black powder charges are shown below. Ground tests will be done before every flight to refine these numbers and ensure the amount of black powder used is sufficient to separate the airframe, in accordance with Requirement A.3.2.

The total ejection charge calculations use the force needed to shear one pin and the total pressure on the bulkhead. To find the force needed to shear a shear pin, multiply the cross-sectional area ($Area_{Pin}$) of a 4-40 shear pin, as selected by the team (radius 0.056 in.), by the shear strength of nylon (τ_{Nylon}):

$$A_{Pin} = \pi R_{Pin}^{2}$$

$$A_{Pin} = 3.1415 * (0.056\, in)^{2} = 0.009852\, in^{2}$$

$$F_{Pin,\, Failure} = A_{Pin} * \tau_{Nylon}$$

$$F_{Pin,\, Failure} = 0.009852\, in^{2} * 10000\, psi = 98.52\, lbf$$

Next, to find the total pressure on the bulkheads, divide the force required to shear three shear pins by the area of the bulkhead, which is 5” in diameter:

$$3 * F = 3 * 98.52\, lbf = 295.56\, lbf$$

$$A_{Bulkhead} = \pi R_{Bulkhead}^{2}$$

$$A_{Bulkhead} = 3.1415 * (2.5\, in)^2 = 19.634\, in^2$$

$$P_{Bulkhead} = \frac{4*F_{Pin,\,Failure}}{A_{Bulkhead}} = \frac{295.56\, lbf}{19.634\, in^2} = 15.053\, psi$$

Then, the grams (G) of black powder can be found with the following equation.

$$G = \frac{P_{Bulkhead} * \pi(D_{Airframe}/2)^2 * L_{Airframe}}{266*3300} *454*1.2$$

The pressure on the bulkhead for three shear pins, diameter, and length of the airframe section to be pressurized are multiplied together. These numbers are then divided by 266 (gas constant) and this result is then multiplied by the combustion temperature of black powder (T = 3300 ℉). This gives a result in pounds which is then converted into grams by multiplying by 454. Finally, there is a multiplied factor of safety of 1.2 for uncertainties in black powder and section sizes. This number is then rounded to the nearest 0.5 gram for the ease of packing the charges. These calculations will give the size of the primary charge.

To find the redundant charge, add an additional 0.5 grams of black powder to ensure the section will separate. Additionally, to confirm the redundant charge will produce a pressure that is safe for the launch vehicle, the equation given above can be rearranged to solve for the pressure on the bulkhead from the charge.

$$P_{Bulkhead} = \frac{G_{max}*266*3300}{\pi(D_{Airframe}/2)^2 * L_{Airframe} *454*1.2}$$

Table 3.7.2.2.1: Ejection Charge Quantities and Pressures Produced

Charge	Airframe Length (in)	Charge Quantity (g)	Pressure (psi)
Main Primary	12.7	2.5	16
Main Redundant	12.7	3	19
Drogue Primary	5.2	1	15
Drogue Redundant	5.2	1.5	23

The values of the primary and redundant charges for the main and drogue parachutes are shown in Table 3.7.2.2.1, with the length used in calculations and the pressure generated. The calculated values of black powder will be verified through ground testing prior to a flight.

3.7.3 Recovery Hardware

3.7.3.1 Parachutes

The final decisions for the recovery system included a 120” Rocketman parachute for the main deployment and a 24” Rocketman parachute for the drogue deployment. Based on various calculations for parachute diameter using approximated weight distributions, the best sizing was about 9.610’ for the main parachute and about 20” for the drogue parachute. For calculating the main parachute diameter, the equations for drag and kinetic energy are utilized simultaneously to produce the following equation:

$$d_{main} = \sqrt{\frac{4m_v m_s g}{\pi E C_d \rho}}$$

where m_v is the mass of the vehicle, m_s is the mass of the heaviest section, g is gravity, E is the total kinetic energy, C_d is the coefficient of drag, and ρ is density. The kinetic energy component was implemented into the final computation in order to consider the 65 ft-lbf impact kinetic energy bonus requirement. The equation was slightly adjusted to account for calculating the dimension using Imperial units and launch vehicle weights.

$$d_{main} = \sqrt{\frac{4w_v w_s}{\pi E C_d \rho g}}$$

where w_v is the mass of the vehicle and w_s is the mass of the heaviest section. A similar calculation was used to determine the diameter of the drogue. However, the descent velocity was used instead of the impact kinetic energy since the drogue diameter is not dependent on that energy parameter. The equation is as follows:

$$d_{drogue} = \sqrt{\frac{8m_v g}{C_d \rho v^2 \pi}}$$

where v is the descent velocity. Considering the weight of the launch vehicle to compute the diameter using Imperial units, the equation can be written as follows:

$$d_{drogue} = \sqrt{\frac{8w_v}{C_d \rho v^2 \pi}}$$

where w_v is the mass of the vehicle. The simulations performed using the OpenRocket at various conditions also confirmed similar parachute diameters necessary to meet the descent requirements. After using computational methods to identify the optimal parachute sizes, various vendors were considered including Rocketman, Fruity Chutes, and SkyAngle. SkyAngle was eliminated due to the lack of information about its product specifications and reliability. Potential parachute options around the calculated dimensions from both Rocketman and Fruity Chutes were compared, considering various factors such as material, cost, diameter, and descent statistics. For the main parachute selection, the best choice was the 120” Rocketman parachute primarily due to its superiority in cost, dimension, and descent rate. Selecting a parachute with a slightly higher diameter than calculated will ensure that the launch vehicle is safely recovered within an acceptable margin of error.

Table 3.7.3.1.1: WDM for Main Parachute

Design Criteria	Design Options					
Main Parachute Criteria	Baseline Measurements	9ft (108”) Rocketman	10ft (120") Rocketman	12ft (144") Rocketman	10ft (120”) Fruity Chutes	12ft (144”) Fruity Chutes
Price	$350	5	5	5	3	2
Sizes	10 ft	3	5	4	5	4
Materials	ripstop nylon	5	5	5	5	5
Packing Volume	190 in^3	5	5	4	4	3
Descent Rate	20 fps	4	4	3	4	3
Cd	1.75	4	4	4	4	5
Totals		26	28	25	25	22
Choice Made						

A similar design matrix was used to select the drogue parachute, considering similar criteria such as cost, material, dimensions, and descent statistics. Although the 24” Rocketman drogue and the 20” Fruity Chutes were both deemed ideal options, the accessibility for the Rocketman brand is much more reliable and cost-effective. The Fruity Chutes drogue is no longer in stock and has a very vague wait time. Additionally, the larger drogue will ensure the launch vehicle is in the proper orientation when descending from apogee. Previously, the 18” drogue used on last year’s launch vehicle had less drag than the booster section which caused the vehicle to fall in the vertical orientation. This positioning caused the main parachute deployment to fail due to its collision with the upper sections. Since this year's launch vehicle has similar weight and dimensions, selecting a slightly larger drogue addresses lessons learned from past mistakes.

Table 3.7.3.1.2: WDM for Drogue Parachute

Design Criteria	Design Options					
Final Parachute (Drogue)	Baseline Measurements	24" Rocketman	36" Rocketman	18" Fruity Chutes	20" Fruity Chutes	24" Fruity Chutes
Price	$70	4	3	3	3	3
Sizes	21"	4	3	2	5	4
Materials	Ripstop Nylon	5	5	5	5	5
Packing	11 in^3	4	3	5	4	4

Volume						
Descent Rate	15 fps	5	4	4	4	5
Descent Time	80 s	4	3	5	5	4
Cd	0.65	5	5	4	5	5
Totals		31	26	28	31	30
Choice Made						

3.7.3.2 Heat Shielding

In order to protect the parachutes from the ejection charge gases, the team will have to utilize heat shielding in the form of heat-retardant blankets. These blankets will be made of Nomex and will wrap fully around the parachute during packing to prevent heat and soot from reaching the parachutes. The blankets will also help the parachute eject out of the airframe because it keeps the parachute wrapped and packed neatly which reduces the chances of the parachute getting caught inside the airframe and helps it slide out easier. The team decided to use Nomex for the blankets because it weighs less than Kevlar and is easier to work with while also having almost the same heat resistance. The smallest blanket will be used to pack the drogue parachute and the larger blanket will protect the main parachute.

3.7.3.3 Shock Cords

The recovery system shock cords will be made of 0.125” wide tubular Kevlar. Because Kevlar is very strong, with a rating of 3600 lb, the team decided that Kevlar shock cords are best suited to withstand the shock of parachute deployment. Additionally, it is rated heat resistant to 800ºF, so it will withstand the heat of ejection charge gasses. The width ⅜” of was determined to be thick enough that the shock cord would not zipper or shear from rubbing on the open ends of the airframe. This width is also small enough that it will minimize the space taken up when packed as the diameter of the launch vehicle limits packing space. A 40 ft shock cord will be used to tether the drogue parachute to the booster and recovery sections. A 60 ft shock cord will tether the main parachute to the recovery section to the payload section.

3.7.3.4 Attachment Hardware

The launch vehicle sections will remain tethered together by the recovery system shock cords. There will be four attachment points within the launch vehicle for the shock cords: the payload coupler lower bulkhead, both the upper and lower bulkhead of the avionics coupler and the upper bulkhead of the R&D coupler. These attachment points will consist of 0.25’’ stainless steel eye-bolts, which are strength rated to 500 lbs, that are screwed into and secured to the bulkheads. The shock cord will be connected to these eye-bolts using 0.25” stainless steel quick links with a strength rating of 880 lbs. Starting from the attachment point on the R&D coupler, approximately two-thirds up the length of the shock cord, the shock cord will have a loop tied into it with a quick link. The shroud lines for the drogue parachute and the Nomex protection blanket for the drogue parachute will be attached to this quick link. Similarly, two-thirds up the length of the shock cord attached to the upper bulkhead of the avionics coupler will have a loop and quick link. The shroud lines and Nomex protection blanket for the main parachute will both be attached to this quick link.

3.7.4 Electrical Components

3.7.4.1 Nosecone Cameras

The launch vehicle shall utilize a camera system in the nosecone. As shown in Figure 3.7.4.2.1, the system consists of a Raspberry Pi 3B+ connected to an Arducam Mini OV5647 Camera Module, an Ultra Tiny GC0307 USB Camera, a Digi XBee 3 Pro module, an AKK X2-ultimate video transmitter, a battery, and a key switch.

To improve upon the previous year's system, upgraded antennas will be utilized to increase the theoretical range of the system. The On The Go (OTG) Receiver used at the AGCS for live stream video reception will use a combination of an omnidirectional antenna and the new VAS Avenger XR18 Directional Antenna to provide a combination of improved range and stability. The AKK transmitter used for live stream video transmission will have an upgraded TrueRC X-AIR MK. II Antenna to improve transmission strength and negate polarization loss between this antenna and the receiving antenna.

The purpose of the camera system is to provide stored and live-streamed video flight data. Each camera has a unique purpose. The camera module records 1080p video, which is stored locally and used for flight analysis and outreach at a later date. The USB camera records 640 x 480p video that is live-streamed to the AGCS for real-time confirmation of flight milestones and outreach. Both cameras are aft-facing, an orientation that has provided useful video since 2021.

During launch vehicle initiation, the team will turn the key switch to “on” to power the nosecone camera system. Five minutes before launch, the team will send the “start recording” signal from an XBee transmitter at the AGCS. When the XBee receiver receives this signal, the two cameras will start recording video. During flight, the video footage from the USB camera will be live streamed from the launch vehicle via the AKK X2-ultimate video transmitter, and received at the AGCS with the OTG FPV Monitor receiver. During retrieval, the team will download the stored video footage from the camera module. Live streamed video is a unique feature of Project Wolf that enables the team to see real-time video footage of the launch vehicle during flight.

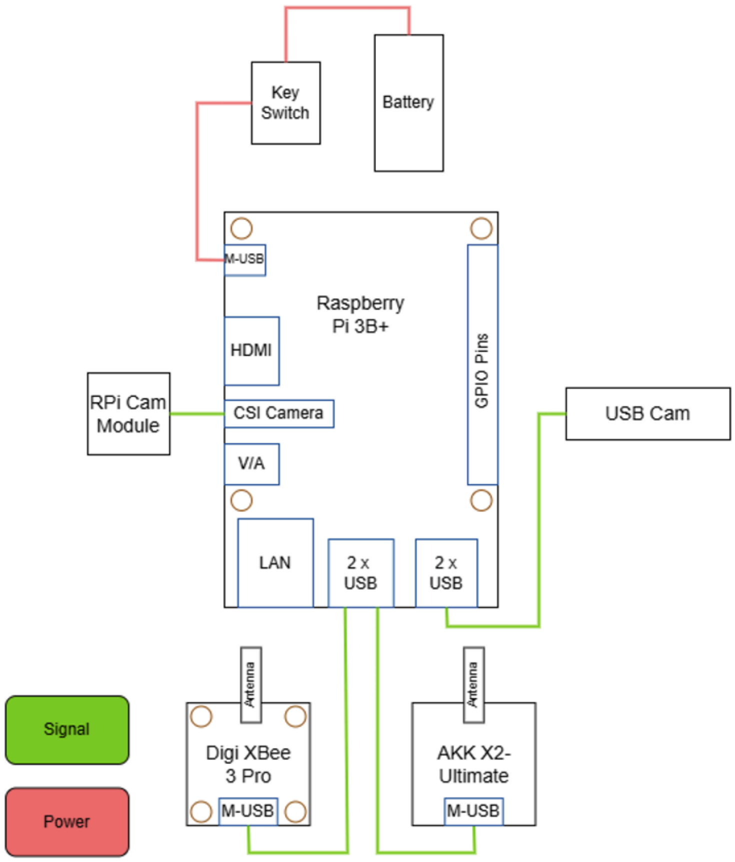


Figure 3.7.4.1.1: Wiring diagram of nosecone cameras

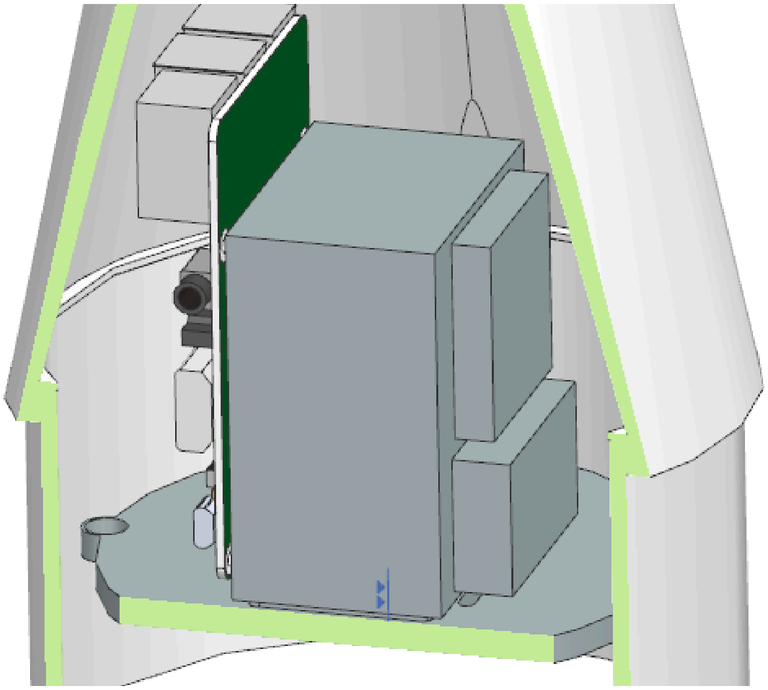


Figure 3.7.4.1.2: Cross-Sectional View of Nosecone Camera System within Nosecone

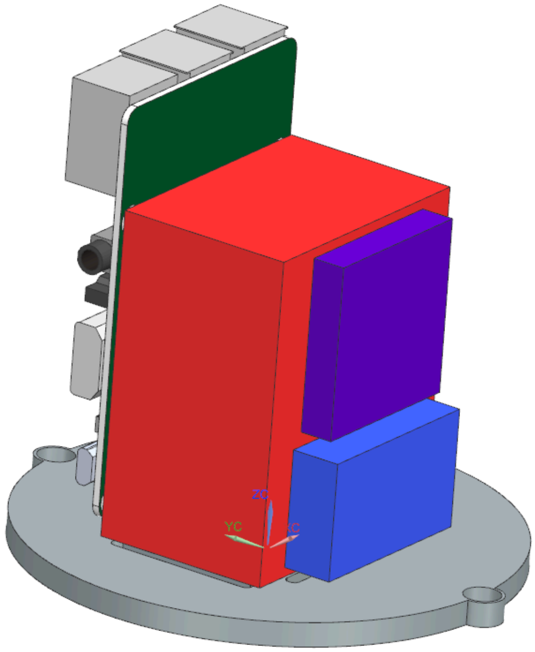


Figure 3.7.4.1.3: View of Nosecone Camera System

3.7.4.2 Altimeters

The team selected the Altus Metrum Telemetrum as the primary altimeter due to its advantage over other options and its reliability during testing. It was selected over contenders Featherweight BlueRaven and the Marsa33 Altimeter due to its ability to store 40 minutes of flight data, its compatibility with Windows OS, and the team's past success with the Telemetrum. The BlueRaven does not work with Windows OS, making flight data analysis challenging, and the Marsa33 had unclear flight memory capabilities.

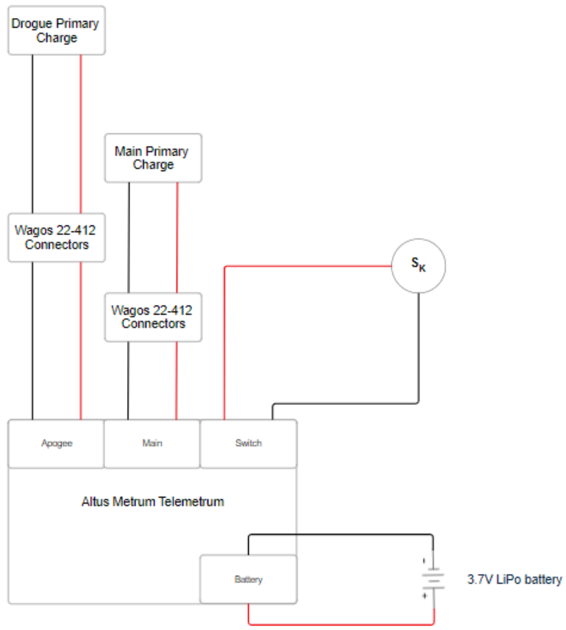


Figure 3.7.4.2.1: Primary Altimeter Wiring Diagram

Additionally, the Telemetrum performed well in vacuum testing. In order to meet Requirement S.A.25 to deploy parachutes at the correct altitudes, vacuum testing examined whether the Telemetrum fired the drogue charge at apogee and the main charge at 700'. As demonstrated in Figure 3.7.4.2.1, the Telemetrum accurately identified these altitudes, releasing the drogue at an apogee of 4728 feet and the main parachute at 704 feet.

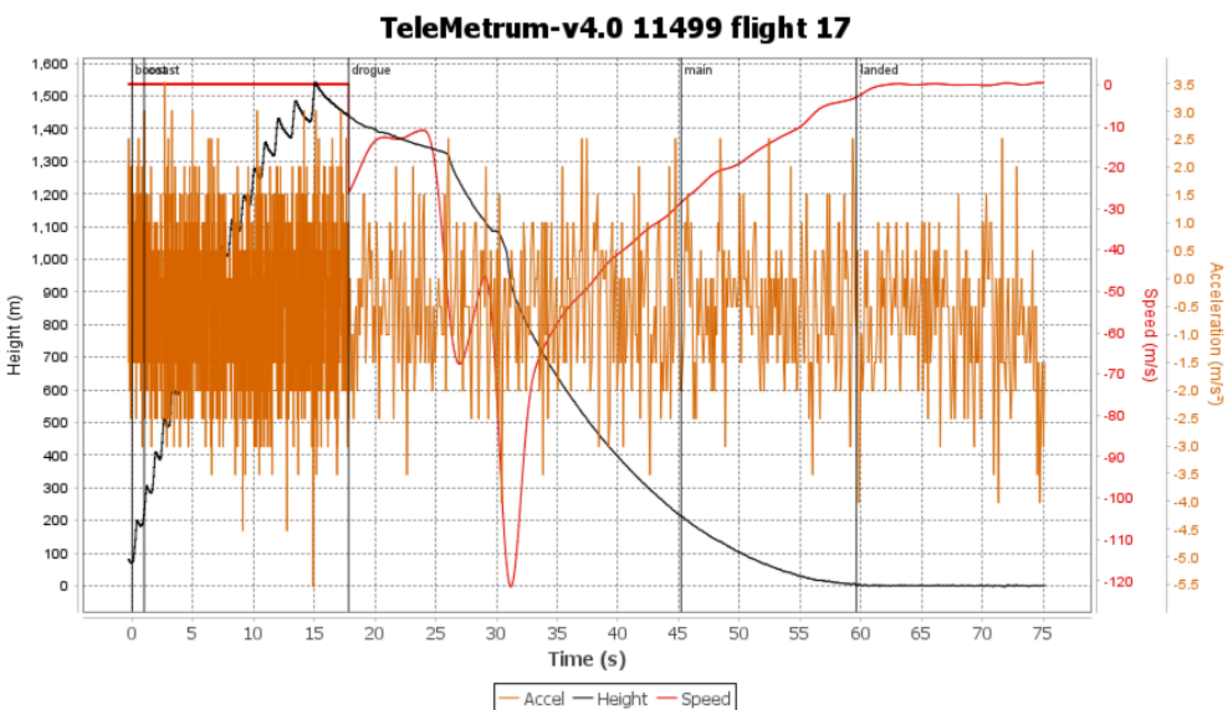


Figure 3.7.4.2.2: Telemetrum Vacuum Testing Results

The Telemetrum also performed well during the subscale flight. As demonstrated in Figure 3.7.4.2.2, the Telemetrum successfully released the drogue at a height of 1804 feet, and successfully released the main parachute at a height of 687 feet.

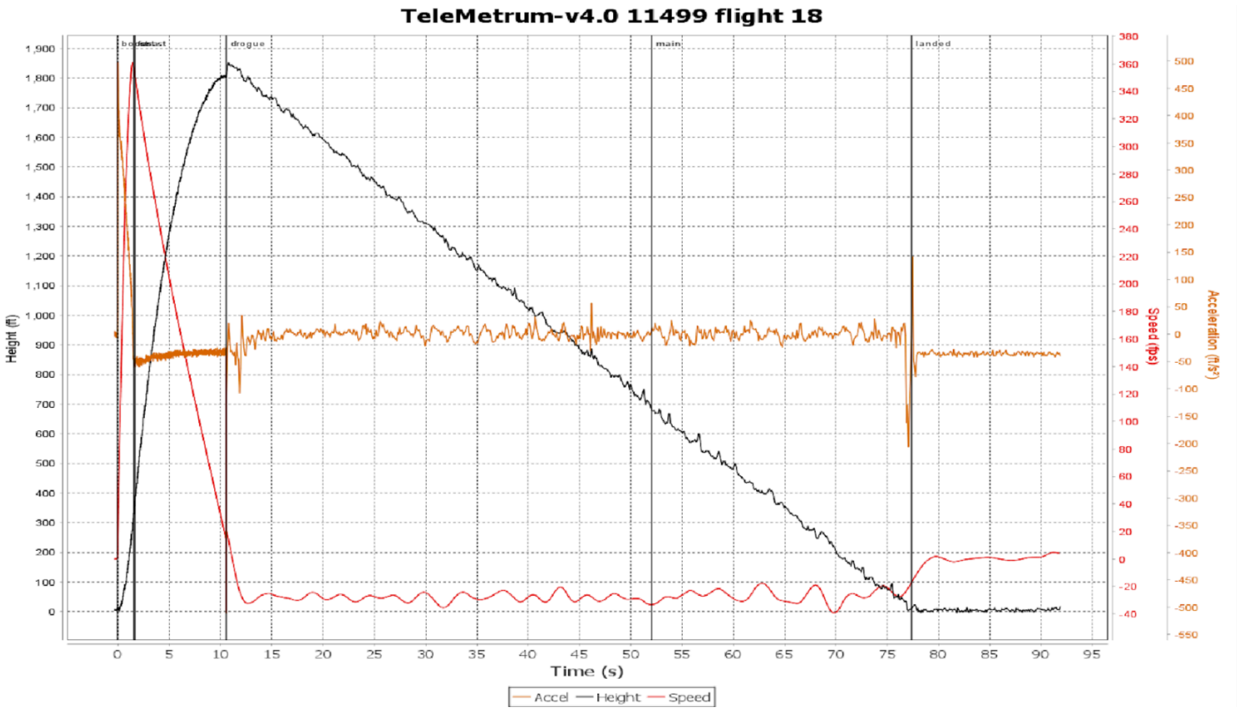


Figure 3.7.4.2.3: Telemetrum Subscale Flight Results

Next, the team selected the PerfectFlite StratologgerCF as the redundant altimeter. It was selected over contenders PerfectFlite Firefly and MissileWorks RRC2+ due to its lower price, pyro outputs, compatibility with Windows OS, and superior flight memory. The PerfectFlite Firefly lacks two pyro outputs for two parachutes (Requirement S.A.19), and the RRC2+ is more expensive and has less flight memory than the Stratologger.

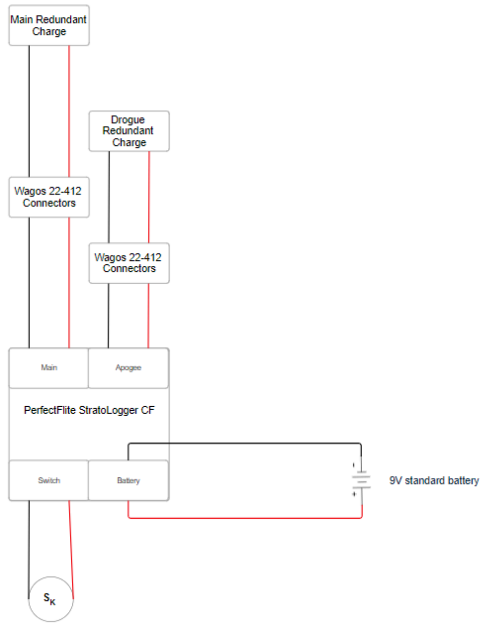


Figure 3.7.4.2.4: Redundant Altimeter Wiring Diagram

Vacuum testing for the Stratologger tested if the Stratologger fired the drogue redundant charge two seconds after apogee (a delay from when the primary altimeter should fire), and the main redundant charge at 600".

Both the Telemetrum and the Stratologger meet Requirement A.3.4 because they are barometric altimeters. Both meet Requirement A.3.5 because each has their own dedicated power supply: the Telemetrum uses a 3.7V LiPo battery, and the Stratologgery uses a 9V standard battery. Additionally, the altimeters meet Requirement S.A.9 because each altimeter has its own independent circuit, to ensure parachute ejection occurs even if one circuit fails. Both altimeter circuits are set up to meet Requirement S.A.5, in which each circuit can only be armed or disarmed by a switch. Finally, both altimeters meet Requirement S.A.21 by having the capability to store at least two flights in case flight data cannot be accessed between flights. Additionally, with the live tracking of the Telemetrum using the Teledongle, the team can immediately download the data after flight from the Telemetrum without needing to plug the altimeter into a computer.

3.7.4.3 GPS Tracker

To meet team Requirement S.A.27, the primary altimeter has GPS capability. The Telemetrum was selected as the primary altimeter, and it receives GPS data at a frequency of 434.55MHz, starting in channel 0. The GPS on the Telemetrum will assist the team in locating the launch vehicle during retrieval. The GPS is housed in the avionics sled in the avionics bay. Since all parts of the launch vehicle are tethered together, only one GPS is needed to transmit the location of the launch vehicle for NASA Requirement A.3.13. The Telemetrum's GPS successfully relayed location coordinates during the subscale flight.

3.7.4.4 Switches

The team has decided to use key switches as the method of pre-launch activation of the deployment system batteries. The switches will be integrated into the avionics sled and are accessible from the outside of the airframe. The switches must also be secure from the flight forces. Compared to all other considerations for switches, the team decided to use key switches because they were the most secure and easiest to integrate. A key switch was used during subscale to activate the Altus Metrum Telemetrum. This flight was used to prove key switches were secure enough to withstand the flight forces of the launch vehicle.

3.7.4.5 Connectors

The team has elected to use Wago 221-412 connectors as the connection point from the altimeters to the ejection charge e-matches on the other side of the bulkhead. There will be four connectors on both the upper and lower bulkheads of the avionics coupler, equaling eight total connectors within the launch vehicle. These connectors were used during the team's subscale launch and have been proven to hold the wires securely and ensure continuity throughout flight. Additionally, these connectors are temperature tested by the manufacturer and can withstand the temperatures of the ejection charge ignition, which was proven as well during the subscale flight.

3.8 Mission Performance Predictions

3.8.1 Flight Profile Simulations

All flight simulations were run using OpenRocket and checked using a custom Python program using the RocketPy library. Both methods employ numerical integration of the equations of motion and both allow for six degrees of freedom in their simulations. OpenRocket uses the Runge-Kutta method of fourth order for its numerical integration, while RocketPy uses the Adams-Bashforth and BDF methods through the Python library SciPy. All simulations were run using the International Standard Atmosphere, launched at sea level, using a 144" launch rod, from a launch site location of 28.6° North, -80.6° East. The five graphs below are OpenRocket simulations of altitude, vertical velocity, and vertical acceleration for launch angles between 0° and 20°, and wind speeds between 0 mph and 20 mph. The launch angles for each wind speed were chosen based on simulation data and experience from prior launches to minimize drift distance from the launch pad. The section masses can be found in table 3.8.1.1, as these were the values utilized for the simulations.

Table 3.8.1.1: Launch Vehicle Mass and Component Mass

Component(s)	Mass (lbm)
Nosecone	2.33
Camera Bay	1.01
Payload	6.22
Upper Recovery (w/ main parachute)	5.22
Avionics	2.68
Lower Recovery (w/ drogue parachute)	1.62
Booster (w/o fins, MFSS, motor, R&D Payload)	3.53
R&D Payload	2.66
MFSS	0.97
Fins	1.63
Motor (w/ propellant)	7.9
Propellant	4.2
Estimated Total	**35.7**

Table 3.8.1.2 Flight Profile Simulations Overview

Simulation Method	Launch Conditions	Figure Number
OpenRocket	0 mph 5 deg	3.8.1.1
OpenRocket	5 mph 5 deg	3.8.1.2
OpenRocket	10 mph 7.5 deg	3.8.1.3
OpenRocket	15 mph 7.5 deg	3.8.1.4
OpenRocket	20 mph 10 deg	3.8.1.5
RocketPy	0 mph 5 deg	3.8.1.6
RocketPy	5 mph 5 deg	3.8.1.7
RocketPy	10 mph 7.5 deg	3.8.1.8
RocketPy	15 mph 7.5 deg	3.8.1.9
RocketPy	20 mph 10 deg	3.8.1.10

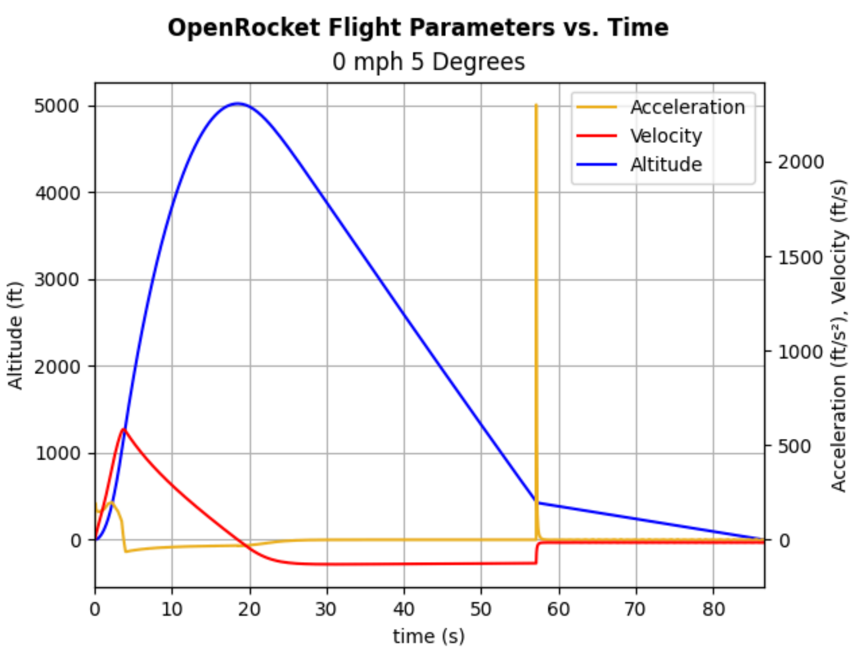


Figure 3.8.1.1: OpenRocket vertical altitude, acceleration, and velocity vs time for 0 mph wind speed and 5° launch angle

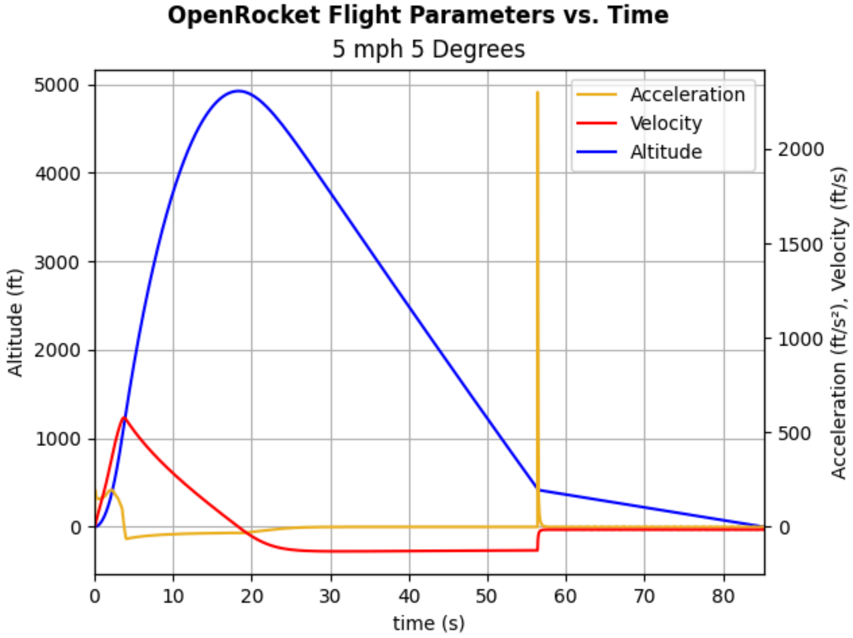


Figure 3.8.1.2: OpenRocket vertical altitude, acceleration, and velocity vs time for 5 mph wind speed and 5° launch angle

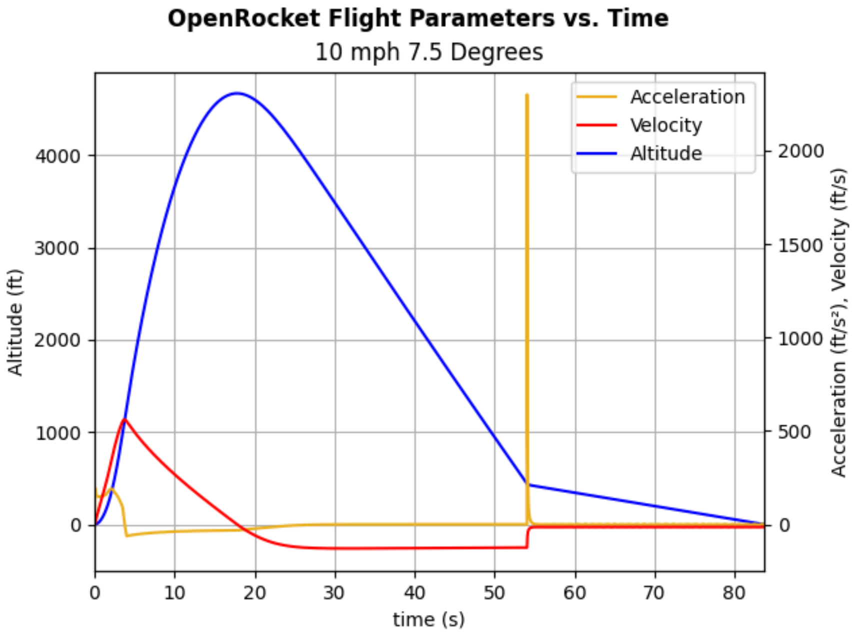


Figure 3.8.1.3: OpenRocket vertical altitude, acceleration, and velocity vs time for 10 mph wind speed and 7.5° launch angle

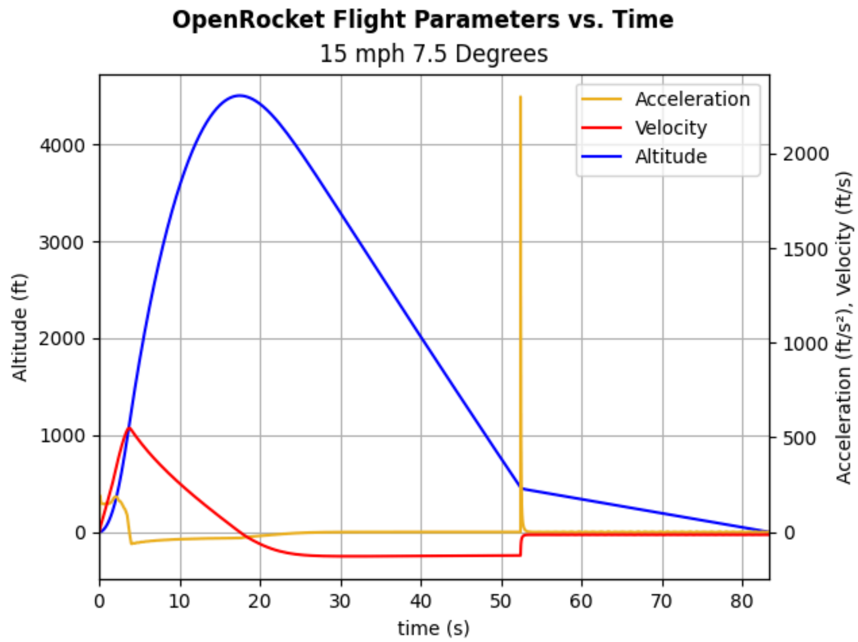


Figure 3.8.1.4: OpenRocket vertical altitude, acceleration, and velocity vs time for 15 mph wind speed and 7.5° launch angle

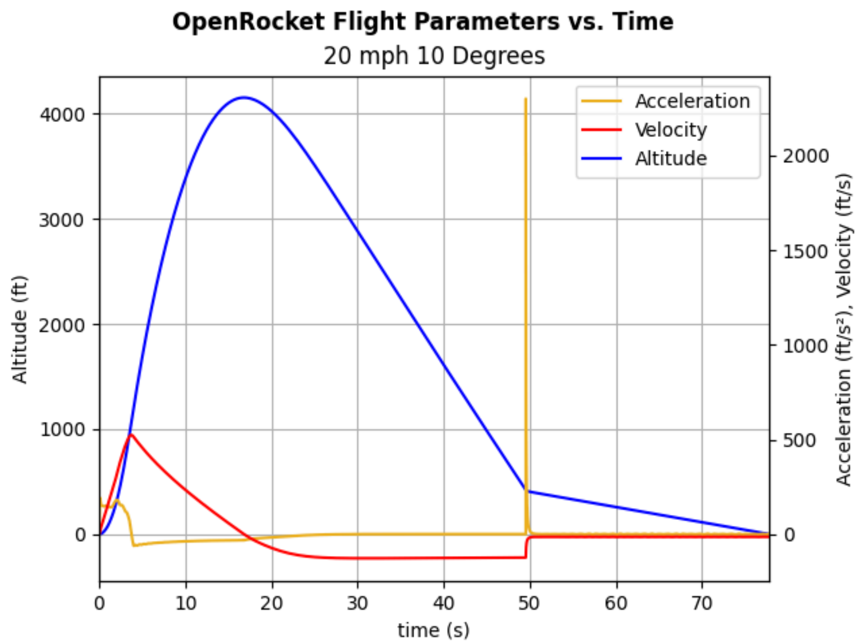


Figure 3.8.1.5: OpenRocket vertical altitude, acceleration, and velocity vs time for 20 mph wind speed and 10° launch angle

The next five figures are RocketPy simulations of altitude, vertical velocity and vertical acceleration for launch angles between 0∘ and 20∘, and wind speeds between 0 mph and 20 mph.

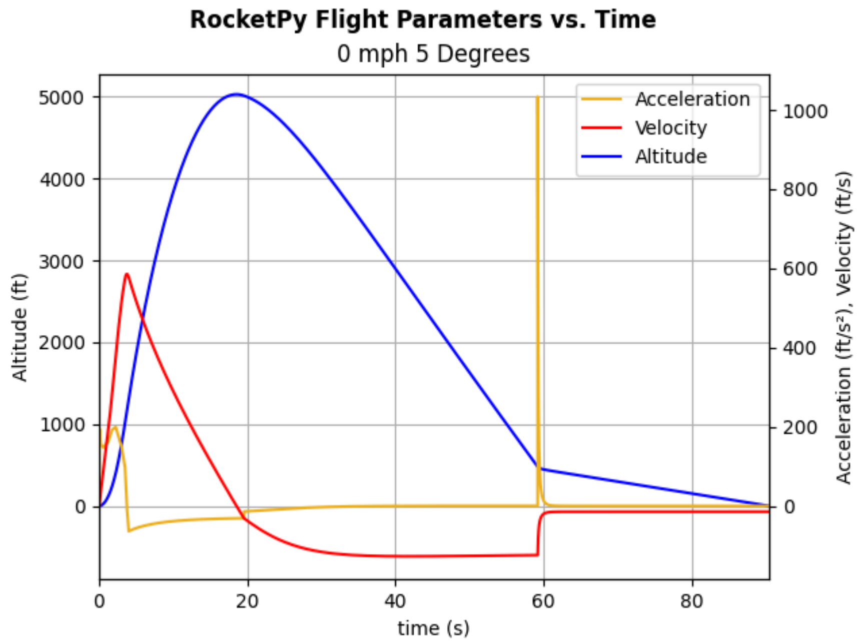


Figure 3.8.1.6: RocketPy vertical altitude, acceleration, and velocity vs time for 0 mph wind speed and 5° launch angle

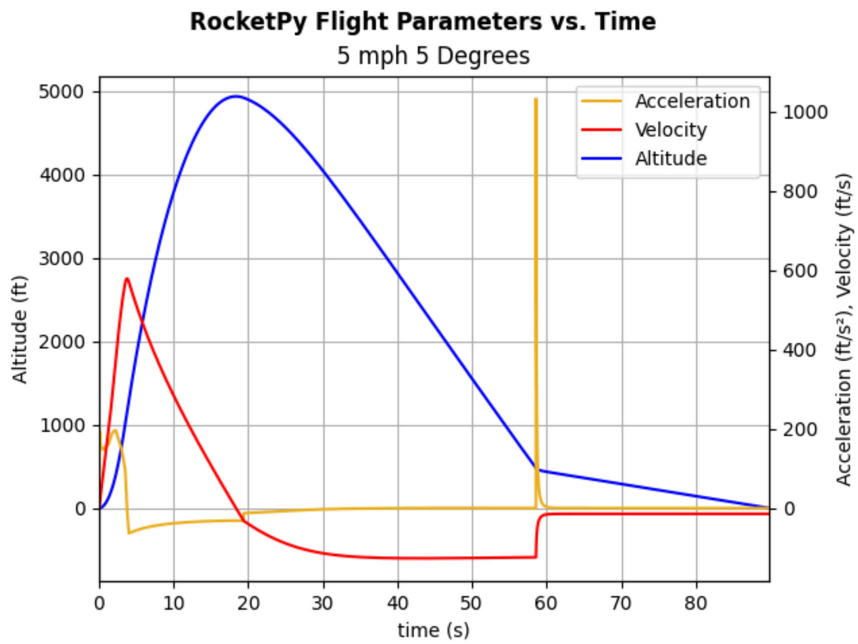


Figure 3.8.1.7: RocketPy vertical altitude, acceleration, and velocity vs time for 5 mph wind speed and 5° launch angle

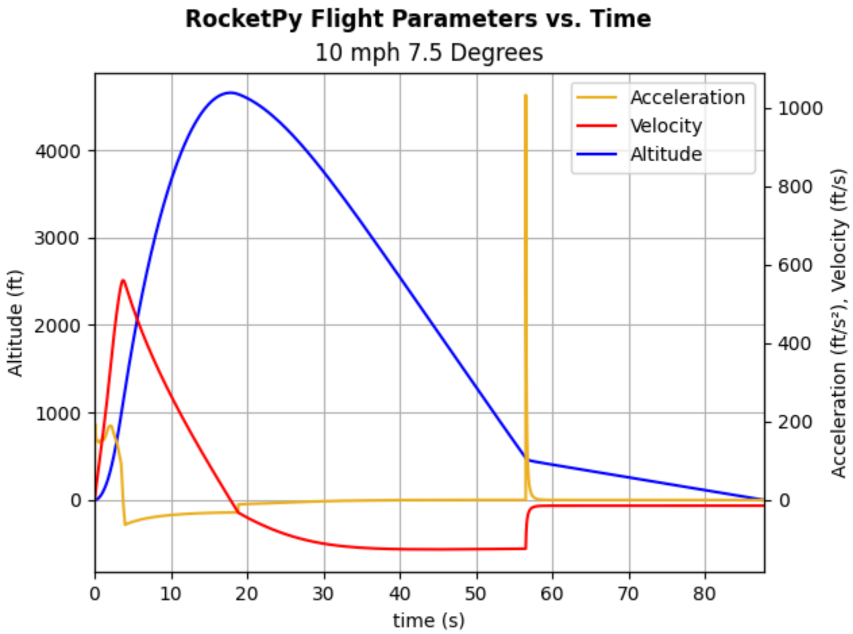


Figure 3.8.1.8: RocketPy vertical altitude, acceleration, and velocity vs time for 10 mph wind speed and 7.5° launch angle

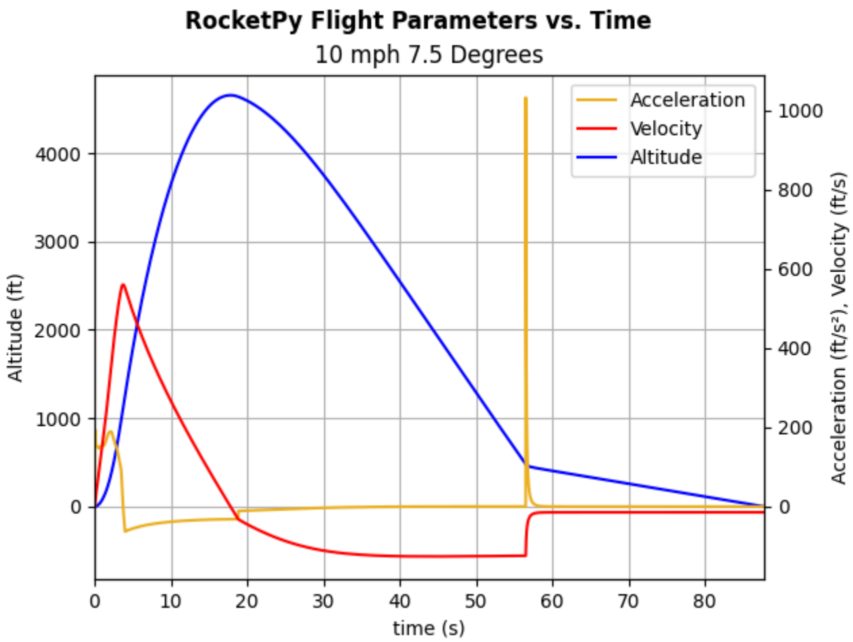


Figure 3.8.1.9: RocketPy vertical altitude, acceleration, and velocity vs time for 15 mph wind speed and 7.5° launch angle

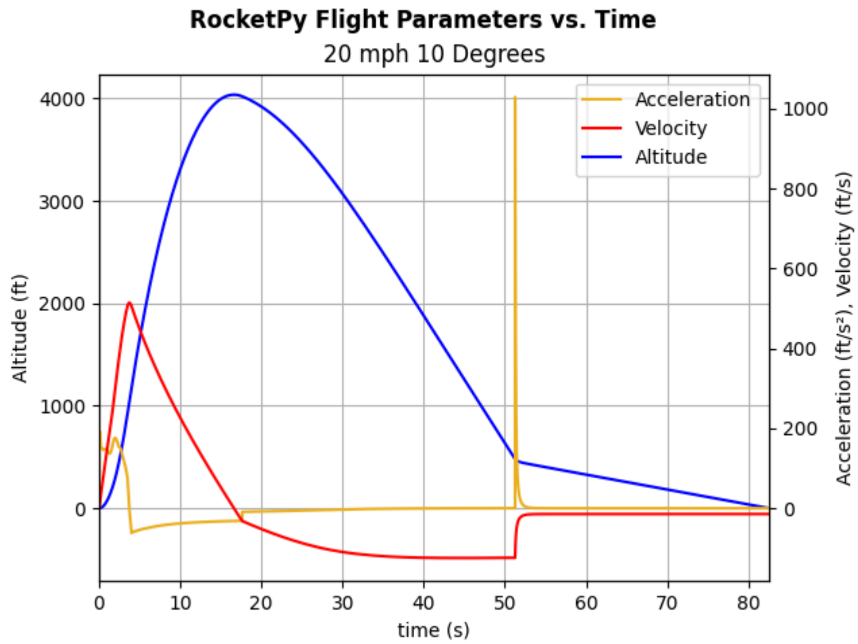


Figure 3.8.1.10: RocketPy vertical altitude, acceleration, and velocity vs time for 20 mph wind speed and 10° launch angle

For all simulations, the thrust generated by the motor was simulated using a thrust curve, which gives a measured thrust value for time-steps throughout the burn of the motor. The thrust curve used to simulate the L930-LW-0 motor in the launch vehicle is found below.

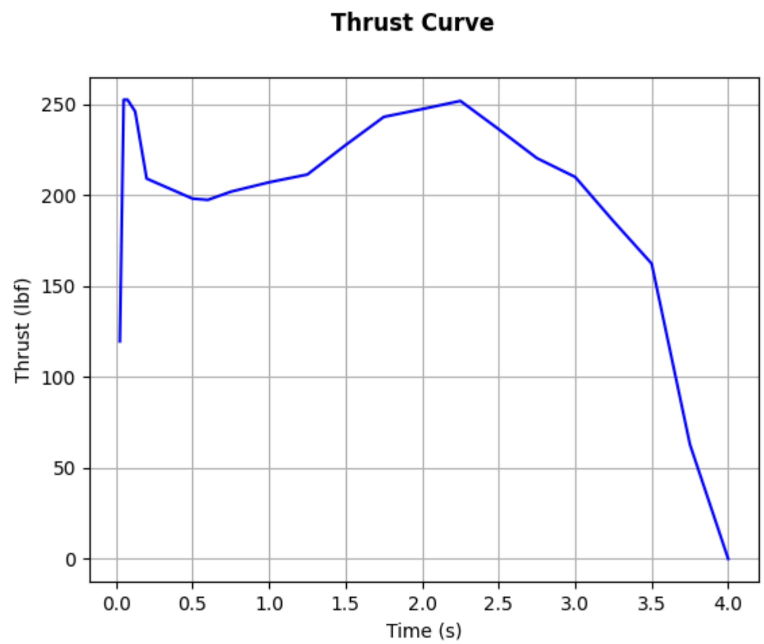


Figure 3.8.1.11 Thrust curve for L930-LW-0 motor used in simulations

3.8.2 Stability Margins

3.8.2.1 Static Stability

To ensure the vehicle's stability, the static stability margin was considered. The static stability margin directly correlates and can be used as a measure of the magnitude of the stabilizing moments on the vehicle. A low static stability will cause the vehicle to be slow to orient in the direction of freestream which could lead to the vehicle moving off course. A high static stability will lead to the vehicle quickly orienting into the freestream. This can be problematic in the event of a sudden gust of wind as the vehicle will wind cock and snap off course. Static stability is a simple measurement gained by dividing the distance between the center of pressure and the center of gravity by the diameter of the airframe. When considering low and high stabilities, the team has found that stabilities under 2.5 and over 4.5 are to be avoided.

The static stability margin of the launch vehicle was simulated in both OpenRocket and RocketPy with the following conditions: zero-degree angle of attack to accurately measure static margin and a Mach number of 0.07 to simulate the vehicle’s speed off the rail. These programs use the Barrowman Equations to estimate the center of pressure of the vehicle which is compared to the center of gravity to find the stability margin. OpenRocket estimated a static stability margin of 3.64 calibers while RocketPy estimated a static stability margin of 3.66 calibers. Figure 3.8.2.1.1 showing the Center of Pressure (CP) and Center of Gravity (CG) positions as simulated by both OpenRocket and RocketPy, followed by Figure 3.8.2.1.2 which shows the exact locations of the CP and CG as simulated by these programs.

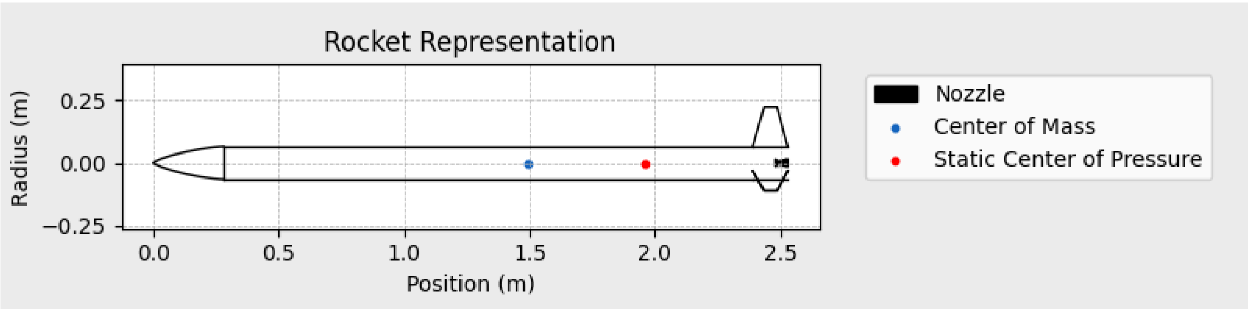


Figure 3.8.2.1.1: Launch Vehicle with CP and CG displayed from RocketPy

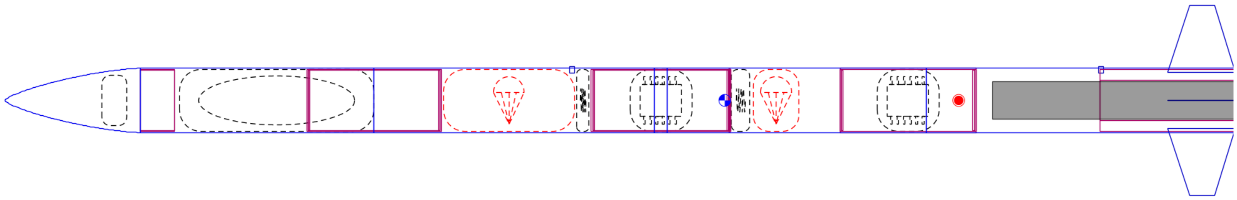


Figure 3.8.2.1.2: Launch vehicle with CP displayed in Red and CG displayed in blue from OpenRocket

The locations of the Coefficient of Pressure and Coefficient of Gravity are seen in Table 3.8.2.1.1, as measured from the tip of the vehicle.

Table 3.8.2.1.1: Simulated CP and CG locations as measured from the nose

Simulation Method	CP Location (in. from nose)	CG Location (in. from nose)
OpenRocket	77.20	58.45
RocketPy	77.18	58.96

3.8.3 Landing Kinetic Energy

In order to ensure the safety of the STEMnauts and the integrity of the vehicle, as well as stay within mission guidelines, the kinetic energy of each independently tethered section of the vehicle at landing was calculated using this formula:

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

With m being the mass of the section and v being the velocity of the section. The velocity was calculated using OpenRocket and RocketPy, with both programs giving a maximum velocity at landing of 14.5 ft/s. The mass of each section was found through measurement of the design. The weight and landing kinetic energy of each section are shown below.

Table 3.8.3.1: Weight and Max Kinetic Energy at Landing of Each Independent Vehicle Section

Vehicle Section	Weight (lbs.)	Maximum Kinetic Energy at Landing (ft-lbf)
Payload	9.56	31.24
Recovery	7.93	25.91
Booster	14.0	45.74

The payload section consists of the payload and nosecone, the recovery section consists of the upper recovery section, along with the avionics bay and the booster section consists of the motor, MFSS,, and the lower recovery system. The highest landing kinetic energy of a section is that of the booster, with a maximum kinetic energy of 45.74 ft-lbf, which is below the team's target of 65 ft-lbf.

3.8.4 Descent Time

Descent times were simulated using OpenRocket and RocketPy given different launch conditions. All simulations gave descent times under the competition requirement and team goal of 90 seconds (A.3.12). The team calculated the descent times with the reported coefficient of drag given by the parachute manufacturers. There is a known discrepancy with Rocketman parachutes reported CD being above what it is in reality, and the team has accounted for this with a safety margin in the team’s simulations. The team expects based on this margin that the team will still meet the descent time requirements. Additionally, the team will be doing drop tests on the parachutes before the first launch of the full-scale launch vehicle to gather an accurate CD that will be used in the simulations for that launch. Table 3.8.4.1 shown below features the descent times.

Table 3.8.4.1: Launch Vehicle Simulated Descent Times From OpenRocket and RocketPy

Wind speed and Launch Angle	Descent time from OpenRocket (sec)	Descent time from RocketPy (sec)
0 mph 5°	68.0	71.9
5 mph 5°	66.9	71.5
10 mph 7.5°	65.9	69.9
15 mph 7.5°	65.9	68.7
20 mph 10°	61.0	65.9

3.8.5 Drift Distance

The drift distance of the vehicle is measured as the distance between the apogee of flight and the location of landing as the apogee is assumed to be directly over the launch site. There are two ways this can be calculated. Both OpenRocket and RocketPy provide trajectory simulations that can accurately predict the drift distance of the vehicle under a parachute, but the value can also be estimated by multiplying the descent time by the wind speed. These two methods will give very different results, however both are useful to analyze. Table 3.8.5.1 shows the simulated and estimated drift distances according to the descent times and trajectories provided by OpenRocket and RocketPy, followed by an example of a simulated trajectory from RocketPy of a 10 mph wind speed, 7.5° launch angle launch.

Table 3.8.5.1: Launch Vehicle Drift Distance Simulations and Estimations

Wind speed and Launch Angle	Distance from OpenRocket Simulated Trajectory (ft)	Distance from OpenRocket Descent time and wind speed (ft)	Distance from RocketPy Simulated Trajectory (ft)	Distance from RocketPy Descent time and wind speed (ft)
0 mph 5°	299	0	613	0
5 mph 5°	49	491	425	524
10 mph 7.5°	347	967	375	1025
15 mph 7.5°	759	1450	85	1511
20 mph 10°	999	1789	69	1933

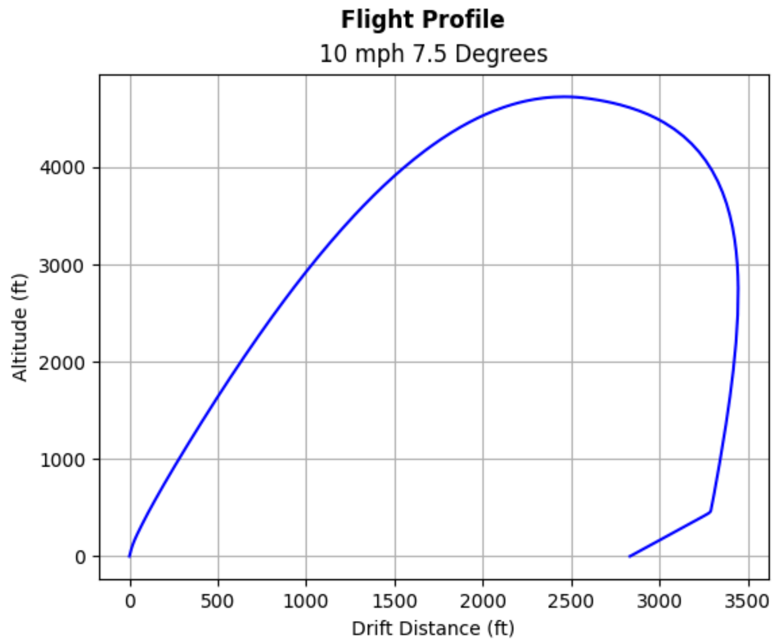


Figure 3.8.5.1: Flight Profile simulated by RocketPy for 10 mph wind speed and 7.5° launch angle

As seen in Figure 3.8.5.1 the momentum of the launch vehicle after the drogue is deployed in the simulations leads to a continued motion into the wind followed by slow acceleration in the direction of the wind under the drogue, and finally a constant velocity in the direction of the wind under the main parachute. This gives a far lower drift distance than the estimations based on wind speed and descent time which do not account for the initial momentum, or the different drag values for these distinct stages of descent. The maximum drift distance allowed is 2,500' which is above the maximum drift distance measured from any of the methods used, the highest of which is a drift distance of 1,933' for a launch into 20 mph wind with a 10° launch angle as estimated by multiplying the descent time simulated by RocketPy with the wind speed.

3.8.6 Simulations Comparisons

Both OpenRocket and RocketPy are very similar programs, both use numerical integration to solve the equations of motion and both provide a six degree of freedom simulation, however the way the two programs achieve this has minor differences. These differences are explored below for stability margin, kinetic energy at landing, descent time, drift distance, and apogee.

Starting with static stability, the difference between the two methods was 0.02 calibers, which is a 0.5% difference. This is an incredibly minor difference which is explained by slight differences between the programs in the position of the center of mass. This is due to the fact that RocketPy requires a manual entry of a center of mass of both the motor and the vehicle without a motor, while OpenRocket does this automatically, The manually entered data of RocketPy will have different input values than the automatically generated data of OpenRocket which leads to slightly different center of mass positions.

Maximum landing kinetic energy is identical between the two simulation methods. This does not give the full picture, however. Landing kinetic energy is determined by the velocity at landing, which was consistently found to be 14.5 ft/s by RocketPy, while OpenRocket had different values for each launch condition with a maximum of 14.5 ft/s. These values ranged from 14.1 ft/s to 14.5 ft/s. This variation is most likely caused by the way that OpenRocket handles lateral velocity and wind speed – which will be explored further in the drift distance section – as the variation increases with wind speed. This means that the actual maximum difference between the two simulation methods is found for the condition of 20 mph wind speed and 10° launch angle, where OpenRocket gives a kinetic energy at landing of 43.3 ft-lbf while RocketPy gives a value of 45.74 ft-lbf for a difference of 5.3%

In terms of descent time, the largest error between the two methods was found in the most extreme launch conditions of 20 mph wind and 10° launch angle. OpenRocket gave a value of 61 seconds while RocketPy gave a value of 65.9 seconds. This is a difference of 4.9 seconds or 8%. This error is primarily due to differences in how OpenRocket and RocketPy handle the opening and drag characteristics of parachutes. When given an altitude for a parachute to release, OpenRocket will simulate the time it takes for a parachute to open after deployment. This is shown in the OpenRocket graphs as a large spike in acceleration when the launch vehicle is at an altitude of ~378 ft given a parachute deployment at 540 feet. This is in contrast with RocketPy which simulates chute deployment and opening at the exact moment altitude reaches 540 feet. This is somewhat counteracted by adding a small delay of 0.5 seconds to the deployment of the main parachute in RocketPy to simulate the time needed to open, but this delay is not the same as the delay in OpenRocket, leading to the launch vehicle descending under main for longer in RocketPy than in OpenRocket.

The largest error between the two methods is the drift distance from trajectory simulations. The error between simulations for drift distance from multiplying wind speed and descent time will be identical to the error between simulations for descent time because there is a direct linear correlation between the two values. The maximum error for drift distance can once again be found at the most extreme launch conditions of 20 mph wind speed and a 10° launch angle. OpenRocket gives a value of 999’ while RocketPy gives a value of 69’ which is a difference of 930’ or 93%. This error is very large but it can be explained by differences in drag and slight differences in reaction calculations. For a better understanding of what is taking place in these simulations, flight profiles of the 20 mph 10° launch for both OpenRocket and RocketPy are provided below.

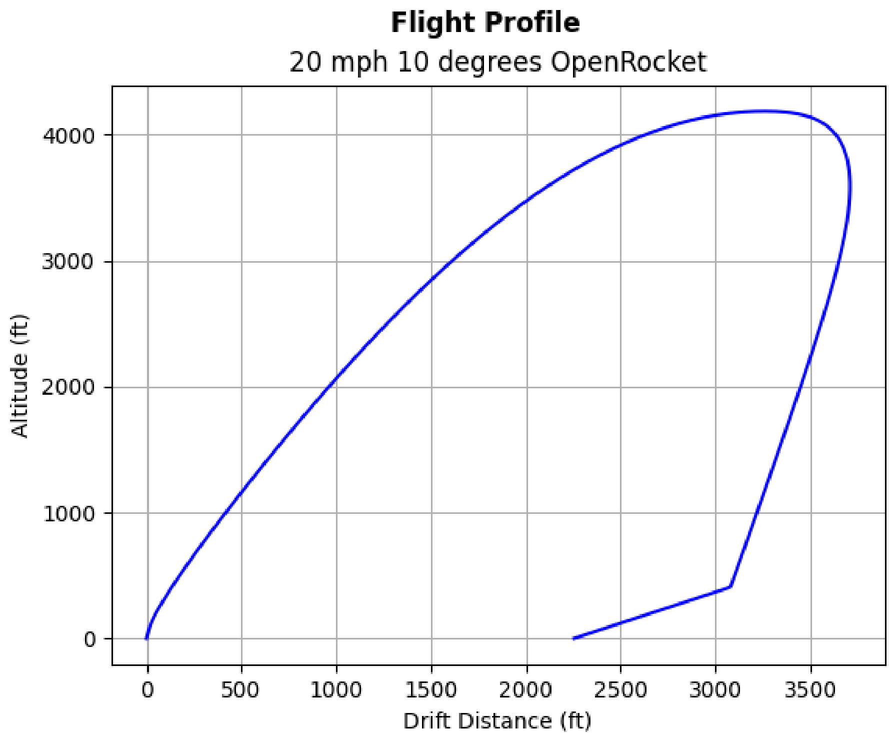


Figure 3.8.6.1: Flight profile of 20 mph wind speed 10° launch angle flight from OpenRocket

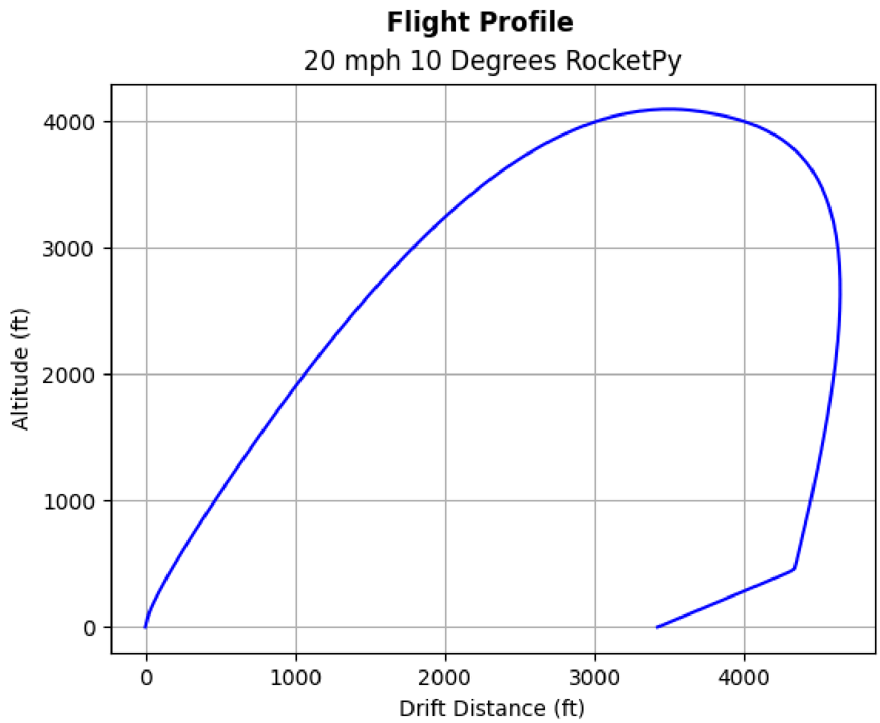


Figure 3.8.6.2: Flight profile of 20 mph wind speed 10° launch angle flight from RocketPy

In the OpenRocket simulation, the vehicle is carried a short distance into the wind while experiencing a large lateral acceleration in the direction of the wind. In the RocketPy simulation, the vehicle's momentum takes it further into the wind and the lateral acceleration is far lower. This leads to the vehicle being carried by the wind far past its position at apogee in the OpenRocket simulation, while in the RocketPy simulation, it is brought back only a small distance past the position of apogee. At apogee for the 20 mph wind speed 10° launch angle simulations, OpenRocket gives a lateral velocity value of 272 ft/s, while RocketPy gives a value of 292 ft/s. This difference in velocity provides an increase in momentum which somewhat explains the increased drift into the wind simulated by RocketPy. The much larger part of this difference comes from the difference in drag characteristics between the two simulations. Lateral drag on the parachute and vehicle causes an acceleration in the direction of the wind. This acceleration when under drogue is highest at drogue deployment and then decreases logarithmically. Both simulations provide a similar shape for this acceleration curve, however the peaks are far different. The lateral acceleration at apogee in OpenRocket is 82.7 ft/s^2 while the lateral acceleration at apogee in RocketPy is 45.2 ft/s^2 which is a difference of 45%. This large difference in acceleration is caused by a difference in lateral drag force, and leads to the vehicle traveling much further into the wind under drogue in the RocketPy simulations than in the OpenRocket simulations.

The largest difference in apogee is again found at the 20 mph wind speed 10° launch angle condition, with a difference of 118' or 2.8% between the two simulation methods. This is a very small difference which can be explained by the differences in the inputs for each simulation, as RocketPy requires manual entry of data that OpenRocket generates automatically. It can also be explained by small differences in simulation, as the two systems use entirely different methods of numerical integration, and one could be marginally more accurate under certain conditions.

Overall, the two simulations provide very similar outputs for most parameters, only greatly disagreeing on drift distance. These similarities show the veracity of the predictions made by OpenRocket and confirm that the design will perform as planned. Tables 3.8.6.1-3.8.6.3 shows the maximum differences between the two simulation methods followed by an overview of the data provided by both programs.

Table 3.8.6.1: Maximum Difference Between Simulation Methods For Each Parameter

Parameter	Maximum difference
Stability	0.5%
Landing Kinetic Energy	5.3%
Descent Time	8.0%
Drift Distance	93%
Apogee	2.8%

Table 3.8.6.2: Summary of OpenRocket Simulations

Wind Speed (mph)	Launch Angle (degrees)	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	5018	68.0	43.9	62.6	299
5	5	4925	66.9	45.1	62.5	49
10	7.5	4668	65.9	44.5	62.6	347
15	7.5	4503	65.9	45.7	62.6	759
20	10	4155	61.0	43.3	62.7	999

Table 3.8.6.3: Summary of RocketPy Simulations

Wind Speed (mph)	Launc h Angle	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	5028	71.9	45.7	62.1	613
5	5	4932	71.5	45.7	62.1	425
10	7.5	4657	69.9	45.7	62.1	375
15	7.5	4455	68.7	45.7	62.1	85
20	10	4037	65.9	45.7	62.2	69

3.8.7 Official Competition Apogee

The target apogee for the launch vehicle is 4,772' AGL, which was determined by taking a weighted average of the simulated apogees with weights for different launch conditions based on historical wind speed data at the launch site. All future references to altitude will be AGL.

Five wind speeds were selected for analysis, 0 mph, 5 mph, 10 mph, 15 mph, and 20 mph, and appropriate launch angles into the wind were selected to maximize stability and minimize distance from the launch site. These wind speeds were given to the team via the NASA handbook. The simulated apogees are below as well as their average which was used in the final calculation.

Table 3.8.7.1: Simulated Apogee from OpenRocket and RocketPy

Launch Parameters:	Final Apogee from OpenRocket (ft)	Final Apogee from RocketPy (ft)	Average (ft)
0 mph wind, 5° launch angle	5018	5028	5023
5 mph wind, 5° launch angle	4925	4932	4929
10 mph wind, 7.5° launch angle	4668	4657	4663
15 mph wind, 7.5° launch angle	4503	4455	4478
20 mph wind, 10° launch angle	4155	4037	4096

Weights for each wind speed were determined using the average wind speed in Huntsville, Alabama from 10 A.M. to 1 P.M. on May 4th from 2005-2024. The weights are seen below

Table 3.8.7.2: Weights for Wind Speed Conditions Based on Historical Data

Weight	Wind Speed (mph)
.2	0 mph
.35	5 mph
.25	10 mph
.15	15 mph
.05	20 mph

These weights were multiplied by the average simulated apogee for the respective launch condition to obtain the final predicted competition apogee when launched from Huntsville

4 Payload Criteria

4.1 Chosen Payload Alternative

After careful deliberation, designs for each major payload subsystem have been selected from the options in the PDR. Each of these systems is outlined below, as well as their motivations for selection.

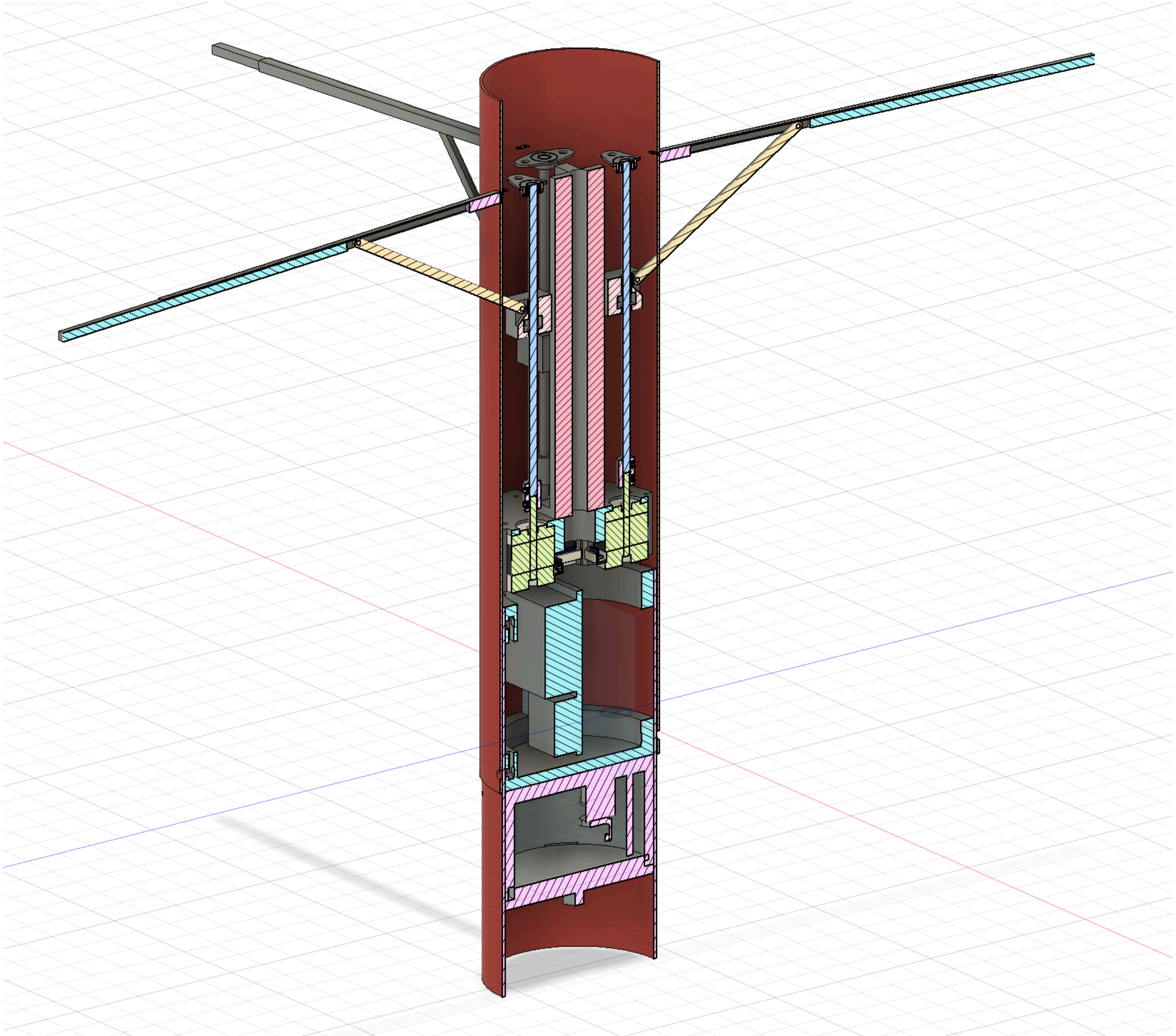


Figure 4.1.1: Payload Top-Level Assembly

Table 4.1.1: Payload Subsystem Overview

Subsystem	Name	Function
STEMCRaFT	4.1.2 Radio Transmission System	Transmit relevant landing site data to a NASA-owned receiver
STEMCRaFT	4.1.3 STEMnaut Capsule	Transport 4 STEMnauts from Earth to the launch vehicle's destination
STEMCRaFT	4.1.4 Sensor Package	Collect relevant landing site data
Integration and Retention	4.1.5 Integration and Retention System	Interface between the STEMCRaFT and the rest of the launch vehicle

4.1.1 Summary

The payload consists of two essential subsystems that work together to ensure mission success. The first subsystem, the STEMnaut Capsule Radio Frequency Transmitter (STEMCRaFT), is responsible for securely housing four STEMnauts, collecting flight and landing site data, and transmitting this data via radio frequency to a NASA receiver upon landing. The STEMCRaFT consists of three main components: the sensor package, which collects and stores landing site data; the STEMnaut capsule, which ensures the safety of the STEMnauts during the flight and landing; and the radio transmission system, which transmits the data via an internal antenna located within the airframe. This design eliminates the need for external systems, such as a deployable vehicle. These elements together satisfy Requirement P.4.1.

The second subsystem, the integration and retention system, ensures that the STEMCRaFT remains securely in place within the airframe and payload coupler. This system consists of a mounting plate sandwiched between two rings that hold the electrical components of the STEMCRaFT in place, namely the sensor package and corresponding battery. The rings are then bolted to the airframe to ensure that it remains stationary during the mission. The integration system satisfies Requirements S.P.5 and S.P.7.

4.1.2 Radio Transmission System

The primary goal of the Radio Transmission System (RTS) is to transmit data from the STEMCRaFT to the NASA receiver at the base station. This transmission is required to be via radio on a frequency determined on launch day within the 2m band (approximately 144-148MHz). Due to the fact that the landing location and orientation are uncertain and could be quite far away from the NASA receiver, it is desirable to make the transmitter as powerful as possible, to ensure a good connection.

Due to the fact that high-gain antennas are typically around the size of half the wavelength of the signal band (in this case 1 meter), a directional antenna is not realistic in this instance.

Therefore, a vertical quarter-wave monopole antenna is a desirable antenna configuration, due to its simplicity, omni-directionality (in the horizontal plane), and strength.

The electrical portion of the RTS is based around the SR_FRS_4WV chip from SunriseDigit. This chip was chosen for several reasons. First, it fulfills Requirement 4.2.6 that forbids transmissions above 5W, while still being substantially powerful at 4W. Secondly, the PTT pin can be used to toggle a “sleep mode” which is useful for power conservation until it is time to transmit data at the landing site. Furthermore, the chip is capable of transmitting SMS data using standard UART protocol, which can be easily accomplished using the RX/TX pins of a microcontroller such as the Arduino Uno Rev3 used for the project. Lastly, the chip’s dimensions are 50x80x4.1mm, which allows it to fit easily within the cargo bay, and to easily interface with the arduino along a standard FH34 Series bus.

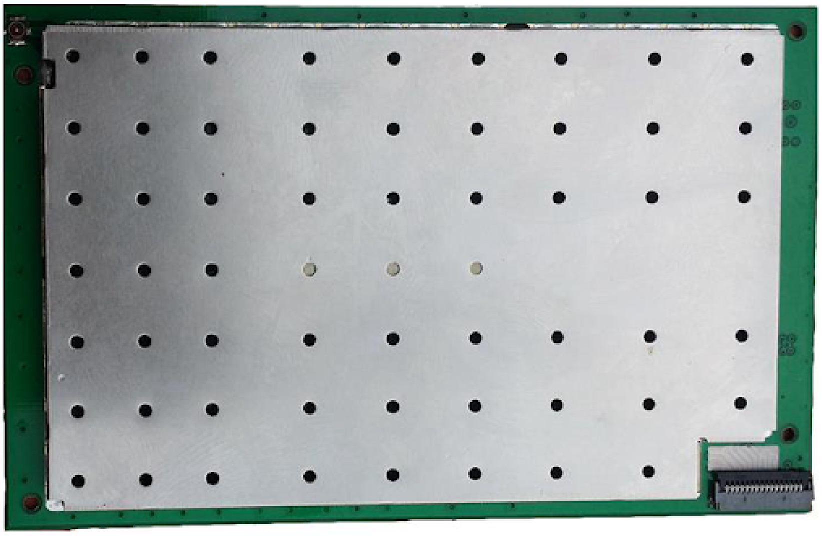


Figure 4.1.2.1: The SR_FRS_4WV VHF Transmitter

Similar offerings in radio chips, for example a SDR (software defined radio), were not as appealing due to their much larger cost and size relative to maximum output power. Furthermore, interfacing with an SDR with an Arduino would introduce additional undesired complexity, compared to interfacing with its UART protocol.

The mechanical portion of the RTS is based on a half-wave monopole antenna. Due to the uncertainty in landing orientation, it is essential to ensure it can deploy in any orientation the payload section lands in. To accomplish this, four separate extendable monopoles exist, ensuring at least one will always be able to deploy upright. Two horizontal ones can additionally be used to supplement the ground plane of the antenna, improving its performance.

4.1.3 STEMnaut Capsule

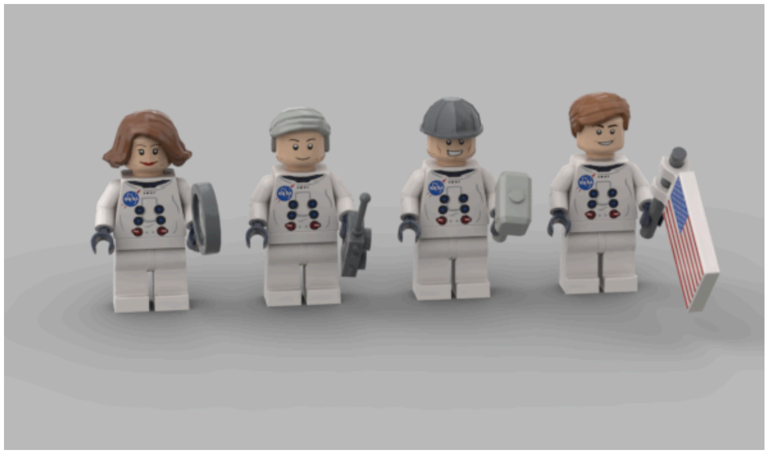


Figure 4.1.3.1: STEMnauts as LEGO® Minifigures

The team has chosen four LEGO minifigures to represent the STEMnauts, each of them resembling a famous figure important to Purdue's legacy and each of them serving a different role during the mission. From left to right in Figure 4.1.3.1, the STEMnauts are Mission Specialist Janice Voss, Pilot David Wolf, Passenger Purdue Pete (one of Purdue University's mascots), and Commander Neil Armstrong.

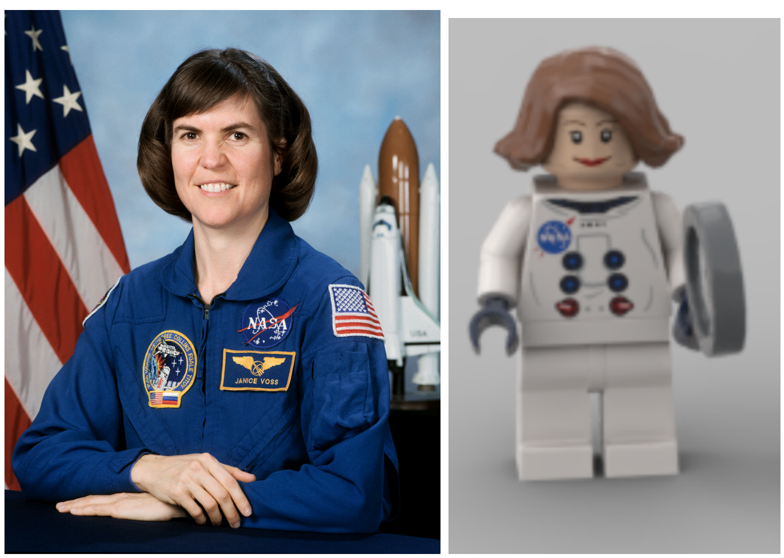


Figure 4.1.3.2: Janice Voss and her STEMnaut counterpart

Born in South Bend, Indiana, Janice Voss received her B.S. in Engineering Science from Purdue University at just the age of 19. On her first flight, STS-57, she became Purdue's first female astronaut and supervised 22 experiments in the Spacehab, the first commercial laboratory in space. Dr. Voss flew four more STS missions in her career, serving as a mission specialist on all five of them. On her last STS mission, STS-99, she and her crew worked to create what is still the most accurate topographical map of Earth's surface. She has spent over forty-nine days in space, traveling more than 18 million miles. Dr. Voss has been chosen as mission specialist for the Project Wolf mission.

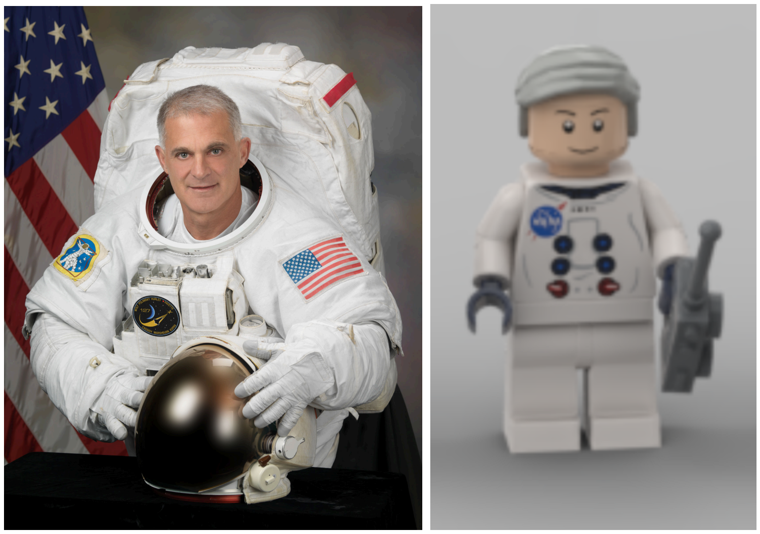


Figure 4.1.3.3: David Wolf and his STEMnaut counterpart

David Wolf was born in Indianapolis, Indiana, and received his BS in Electrical Engineering at Purdue University. After Purdue, he went to medical school and trained as a flight surgeon with the U.S. Air Force. Dr. Wolf has been on five STS missions and 7 spacewalks totalling over 47 hours of extravehicular activity. During STS-127 when Endeavor docked with the International Space Station, Dr. Wolf became a part of the record for most people aboard one spacecraft with 13 total people. Dr. Wolf also went through cosmonaut training in Russia to prepare for the NASA-Mir 6 mission. In that mission, he conducted experiments and studies for four months entirely in the Russian language and cast a ballot in a local Texas election, becoming the first American to vote from space. The team has chosen to name the SL project after David Wolf in honor of his record-breaking accomplishments, and has chosen him as the pilot of the team's mission.

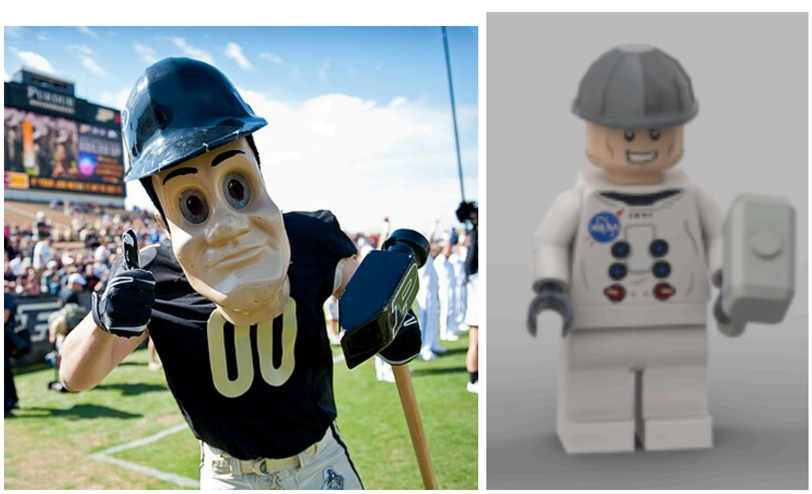


Figure 4.1.3.4: Purdue Pete and his STEMnaut counterpart

Not to be confused with the official school mascot, the Boilermaker Special, Purdue Pete is the athletic mascot of Purdue University. He was created by Purdue University's Bookstore in 1940 to be a fun character in various bookstore items. In 1956, Purdue Pete became a physical character, attending a pep rally before the Purdue v. Missouri football game. Growing in popularity over the years, Purdue Pete attends all sports events and makes appearances at community events. This year, Purdue Pete will be riding as a passenger on the Project Wolf mission.

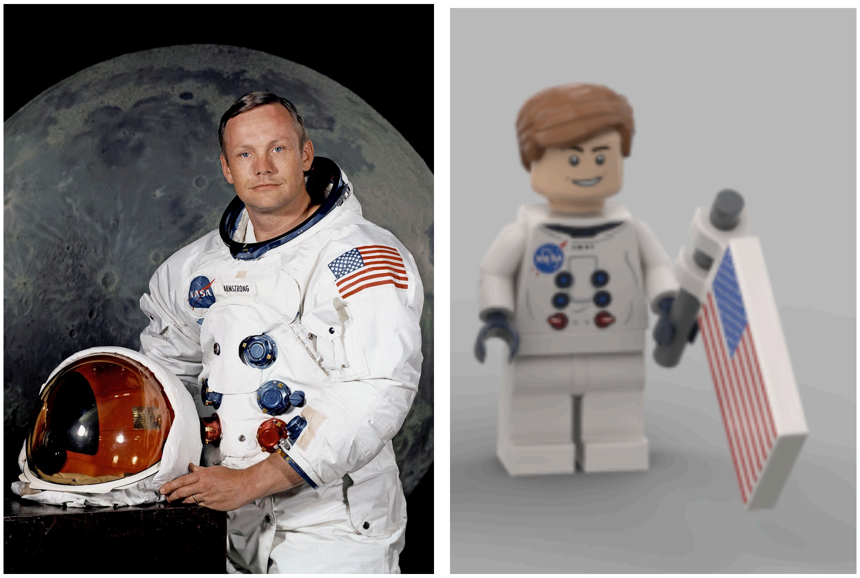


Figure 4.1.3.5: Neil Armstrong and his STEMnaut counterpart

Neil Armstrong was born in Wapakoneta, Ohio, and received his BS in Aeronautical Engineering at Purdue University. During the Korean War, he flew 78 missions as a naval aviator. Armstrong was a research test pilot and flew the hypersonic X-15 at Mach 5.7. Along with David Scott, Armstrong became the first to successfully dock two spacecraft in the Gemini 8 mission. His most famous achievement was becoming the first man on the Moon in the Apollo 11 mission. Due to his impressive resume and extensive flight experience, Mr. Armstrong has been chosen to be the commander for Project Wolf.

4.1.3.1 References

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4.1.4 Sensor Package

The sensor package component of the payload is the subsystem that collects the relevant landing site data once the launch vehicle has touched down, fulfilling part of Requirement P.4.1. At this point in time, the team has selected the following three data points for collection from Requirement P.4.2.1: the apogee reached, the temperature of the landing site, and the time of landing. The sensor package consists of an Arduino Uno Rev3, a 7.4V Li-ion Battery, an Adafruit ADXL345 Triple-Axis Accelerometer, an Adafruit BMP388 Barometric Altimeter, and a custom-made PCB.

Many sensors were considered for each data point, but eventually it was decided to use a barometric pressure sensor and an accelerometer to retrieve in-flight data. More detail on this is presented in section 4.4.2, the electronics review section.

After determining what sensors to use, the team ordered and retrieved the products. Everything was then situated on a breadboard and connected to the Arduino IDE. The code was then written over the next couple of weeks.

Preliminary tests were conducted by placing the breadboard, while still connected to the computer, in an elevator and travelling from the basement of the Neil Armstrong Hall of Engineering to the third floor and back to the basement. While it was not very similar to the flight conditions it would undergo during subscale and full-scale, it did allow the team to see if the code was working in the early stages of development.

After the initial tests were complete, the PCB was designed and ordered. The components were soldered on, and the battery was connected with a switch. This ensured the sensor package was ready for testing aboard the upcoming drone tests and the upcoming subscale flight.

To test the code once the components were assembled, a series of flight tests were carried out with a drone. The payload was attached to the drone with duct tape and a subscale flight was imitated as shown in Figure 4.1.4.1. The package was placed on the ground (launchpad), and after a countdown, the drone was flown straight up at high speeds. After it reached the intended test altitude of approximately 25 meters, it was brought down at lower speeds to imitate falling with a parachute. Once it reached the ground, the payload was attached to the computer and the second script was run to see the data on the flight.

Figure 4.1.4.1: Sensor Package Flight Test

Figure 4.1.4.2: Subscale Launch Integration

The sensor package was also flown on the subscale flight. Integration of the sensor package and its retention system is shown in figure 4.1.4.2. The flight was very successful, and the data retrieved proved to be mostly correct except for a few minor errors. More information on subscale flight results and data accuracy is in section 4.3.3 of the design review.

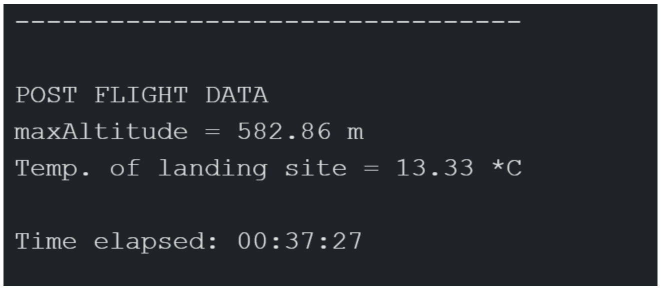

Figure 4.1.4.3: Sensor Package Data obtained from Subscale Flight

4.1.5 Integration and Retention System

As with any payload system, the integration and retention system is a crucial component of the team's chosen payload. The team's current retention system was originally created for the subscale launch vehicle. In order to fit the sensor package into the smaller allotted dimensions for the subscale launch vehicle, the original integration system design in PDR had to be altered. Instead of a payload sled with threaded rods running through it, the sensor package was fitted between two rings that aligned with the inner surface of the airframe. The rings were held together by a plate that also served as a flat surface to which the battery could be attached using velcro.

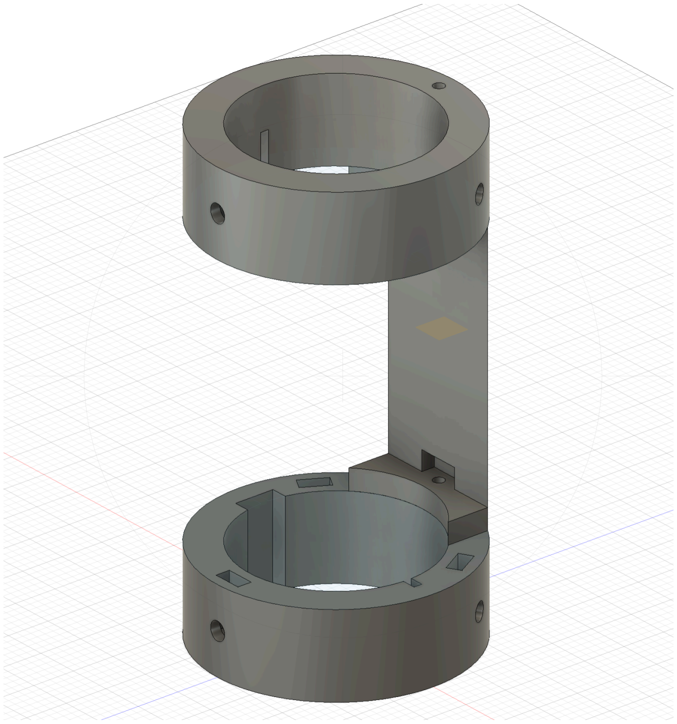

Figure 4.1.5.1: Integration and Retention System for Subscale

It was decided that further consideration would be put towards this new integration system design, since it was successful during the subscale launch, and set the team apart from the traditional sled design that the team has learned is common among other teams. For this design, the two ends of the sensor package fit inside notches in each of the rings. This prevents the sensor package from sliding along the length of the airframe or rotating within the airframe. The two rings are held together by a plate that is flat on one side to hold the battery and curved on the other to fit against the inside of the airframe.

The coupler is the most optimal location for the placement of the payload electronics and STEMnaut Capsule because all design options for the transmission antenna require the antenna to be placed in the payload bay. The payload coupler also allows for much more room for the ring integration system, and it provides a space where the system will not interfere with the mechanics of the antenna design.

This method of integration has proven to be successful in safely and securely embedding the payload system into the launch vehicle during the subscale launch, which is why the decision was made to further develop this design for the full-scale launch. Because there is more space allotted for full-scale than subscale, it is no longer necessary to restrict the payload integration system to holding just the sensor package and battery stacked on top of one another. Because of this, there is room for the sensor package, the battery, and the transmission electronics to all fit within the distance between the two rings and be attached to the same center connecting plate.

4.2 Payload CONOPS

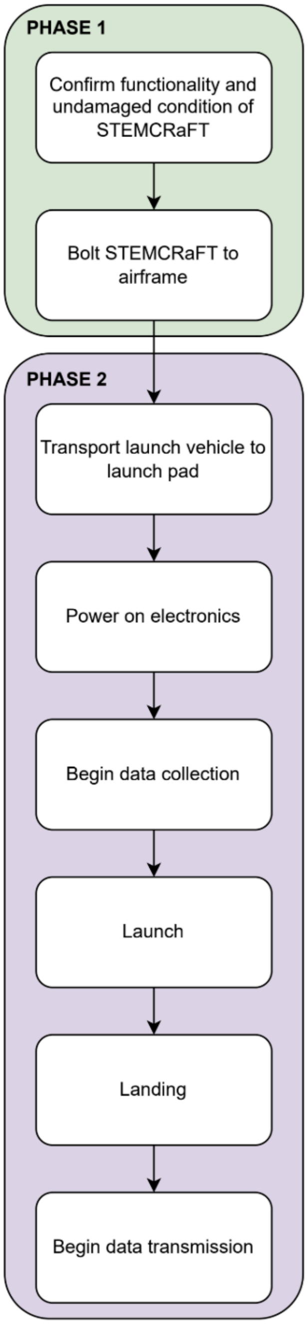

Figure 4.2.1: Payload CONOPS Flowchart

4.2.1 Phase 1

On launch day, the integration process will begin by verifying that the sled's integration system is intact and all components are functioning properly. This includes checking the placement of the PCB, ensuring the stabilization piece securely holds the rings together, and confirming that the battery is properly mounted. Once the sled system is verified, it will be integrated into the payload section and securely bolted to the airframe using threaded rods, ensuring a stable foundation for the entire system. Following the sled integration, the STEMCRaFT will be carefully positioned and secured within the payload section. The STEMCRaFT will be aligned to ensure that the sensor package, STEMnaut capsule, and radio transmission system are ready for activation.

4.2.2 Phase 2

After the payload system is transported to the launch pad, the electronics will be powered on, and the sensor package will begin collecting flight and landing site data. Once the vehicle lands, the team will focus on transmitting the collected data through the internal antenna located within the airframe. The data will then be sent to the NASA receiver, completing the data collection and transmission process. This sequence ensures the integration, launch, data collection, and post-landing data transmission are carried out seamlessly.

4.3 Payload Design Review

4.3.1 Radio Transmission System

The primary goal of the Radio Transmission System (RTS) is to transmit data from the STEMnaut Payload section to the NASA receiver at the base station. This is required to be via radio on an undetermined frequency within the 2m band (approximately 144-148MHz). Due to the fact that the launch location and the orientation of the launch vehicle once landed is unknown, the team has come up with a mechanical system that will optimize the chances of a clear transmission no matter the outcome of the landing. This fulfills requirement S.P.4.

A description of the electrical systems and the commands used for transmission is located in section 4.4.1, the electronics review section.

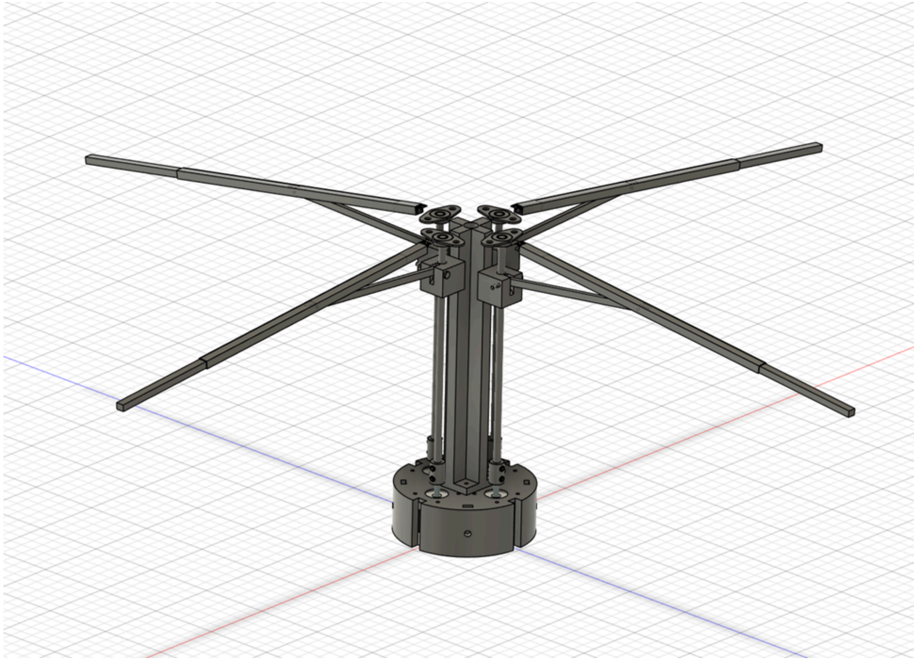

Figure 4.3.1.1: Transmission Deployment Apparatus

The deployable antenna is retained and deployed using the Transmission Deployment Apparatus (TDA) seen in Figure 4.3.1.1. The TDA consists of 4 separate antennas that are capable of being deployed independently. Upon landing and the determination of the landing orientation, the independence of antennas allows the antennas that are closest to parallel with the ground to deploy first and push the launch vehicle into a position where one of the undeployed antennas is approximately perpendicular to the ground. The two deployed antennas along with the undeployed downfacing antenna will then be in the required position to form the ground plane for transmission. At this point the final antenna can be deployed to be used for sending the transmission.

The deployment of the antennas is achieved by operating motors secured in a mount at the base of the payload section which is bolted to the airframe. To deploy an antenna, the motor rotates a lead screw to drive a block, prevented from rotating by a central guide, along the length of the payload section. A rod connected to the driven block is connected to a slider inside the antenna arm which forces the antenna arm to rotate outward as the block is driven as well as a slider inside the antenna arm to extend to achieve a greater extended length. The lead screws are secured by bearings at the top of the payload section and the transmission arms are attached using hinges both of which are bolted to the nosecone bulkplate.

This system requires slits to be cut in the payload bay section of the airframe in order for the arms to deploy upon landing. These slits are 0.31” thick and 10” in length. The transmission arms will be attached to 3D printed copies of the cut-out pieces of the airframe to ensure structural stability of the transmission arms as well as the stability of the launch vehicle during flight. The transmission arms and the attached 3D printed sections will be secured during flight to prevent premature deployment, which the team is aware would result in a disqualification. The team has also ensured that the slits in the airframe do not interfere with the payload coupler nor the nosecone lip, both of which attach to the payload bay. A sketch of the intended slits is pictured in Figure 4.3.1.2.

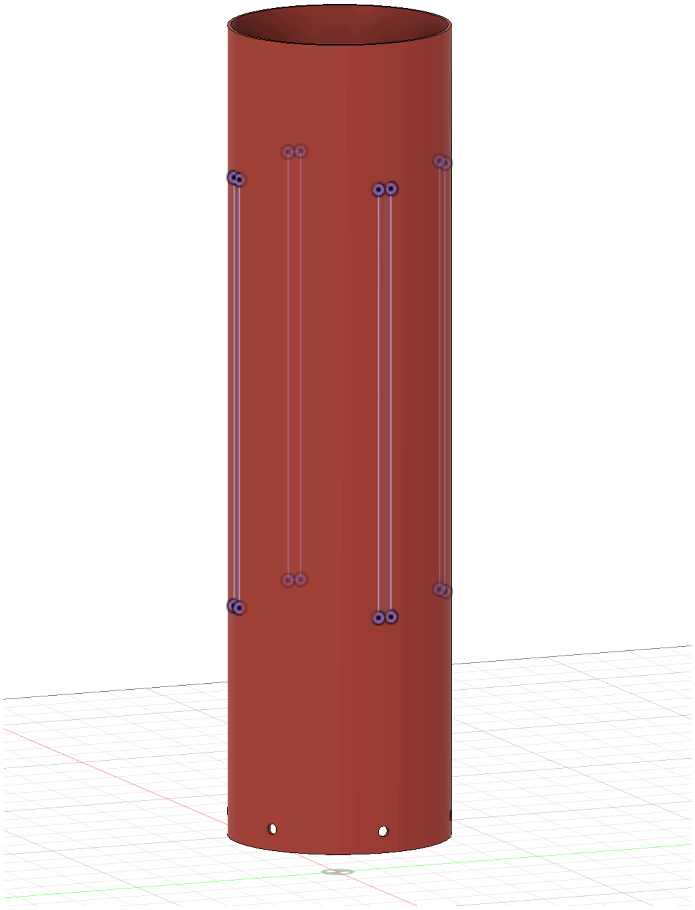

Figure 4.3.1.2: Marked Slits for Transmission Arms of TDA in the Payload Bay

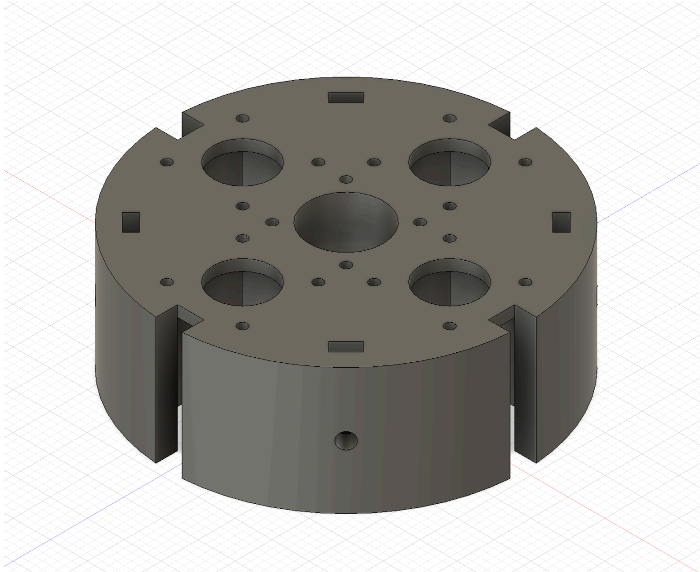

Figure 4.3.1.3: Motor Mount

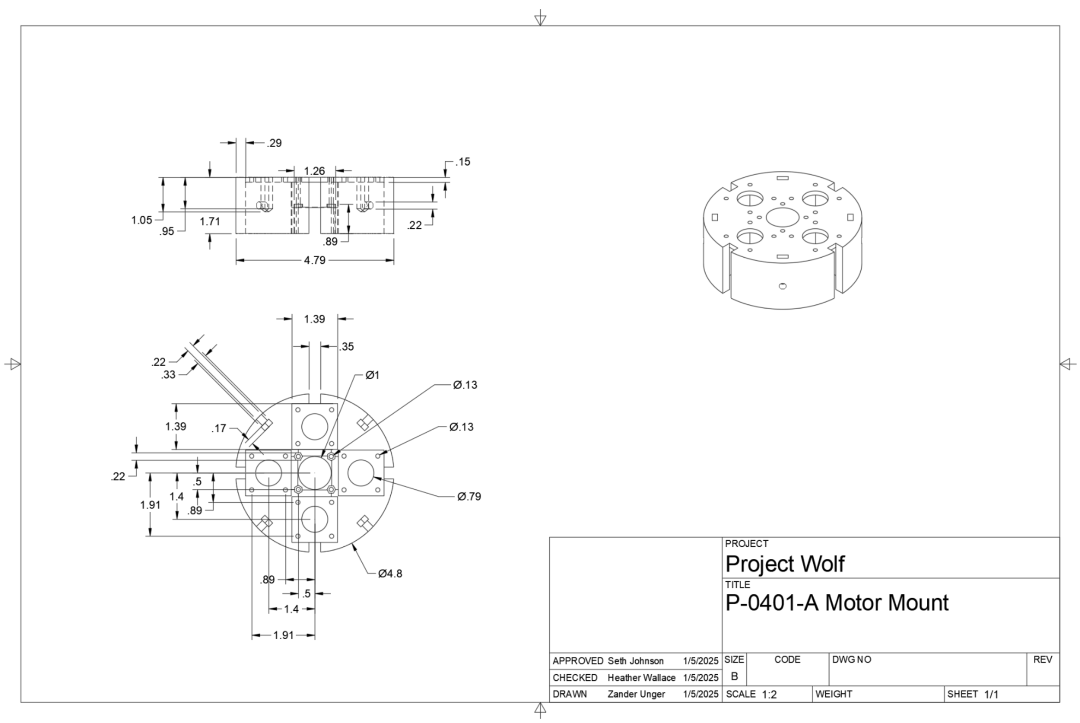

Figure 4.3.1.4: Motor Mount Drawing

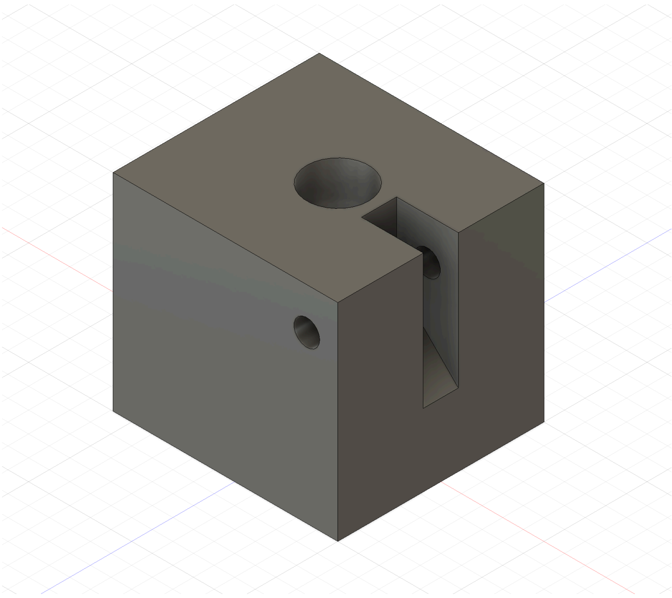

Figure 4.3.1.5: Drive Block

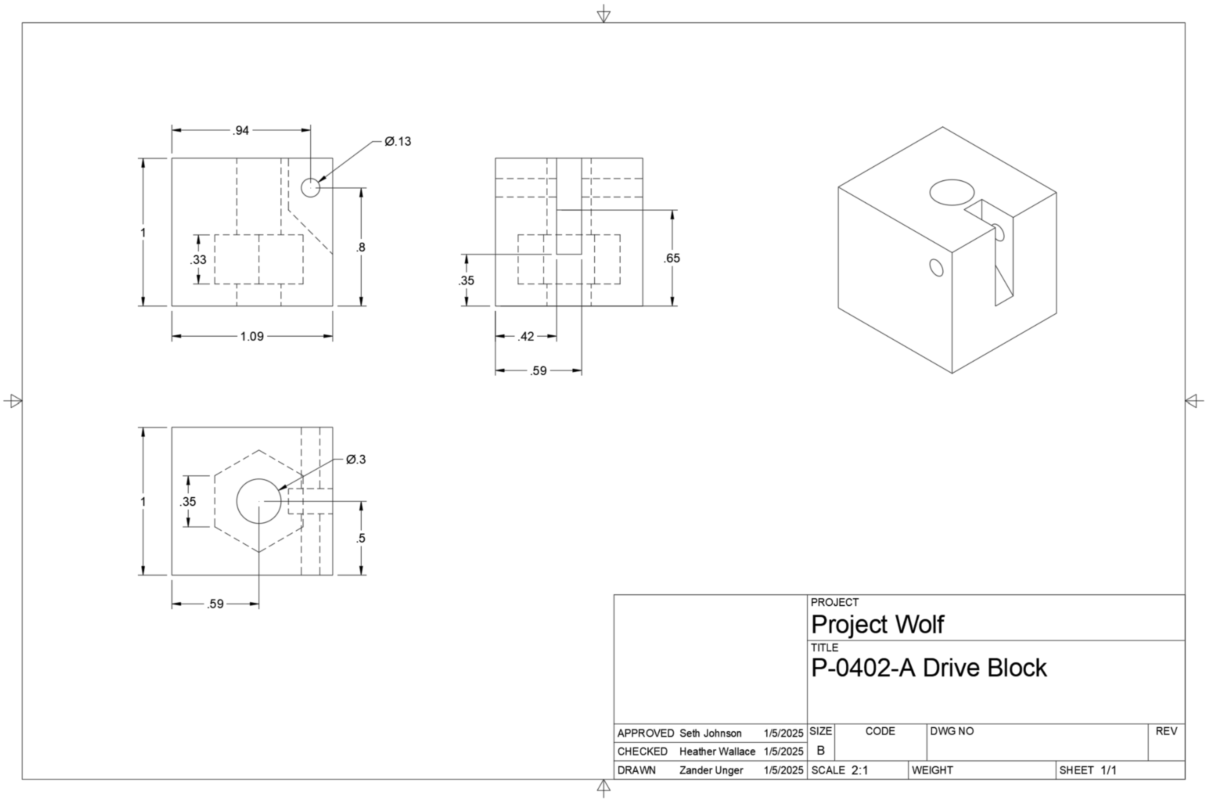

Figure 4.3.1.6: Drive Block Drawing

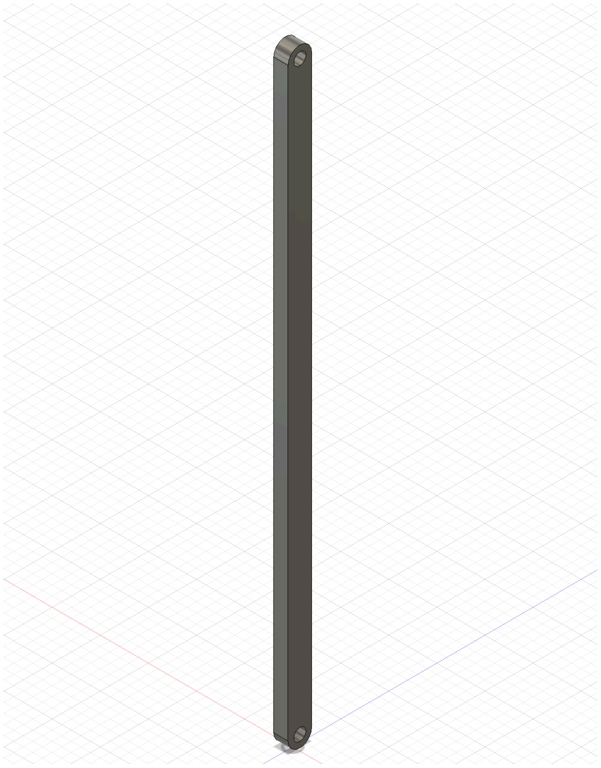

Figure 4.3.1.7: Push Rod

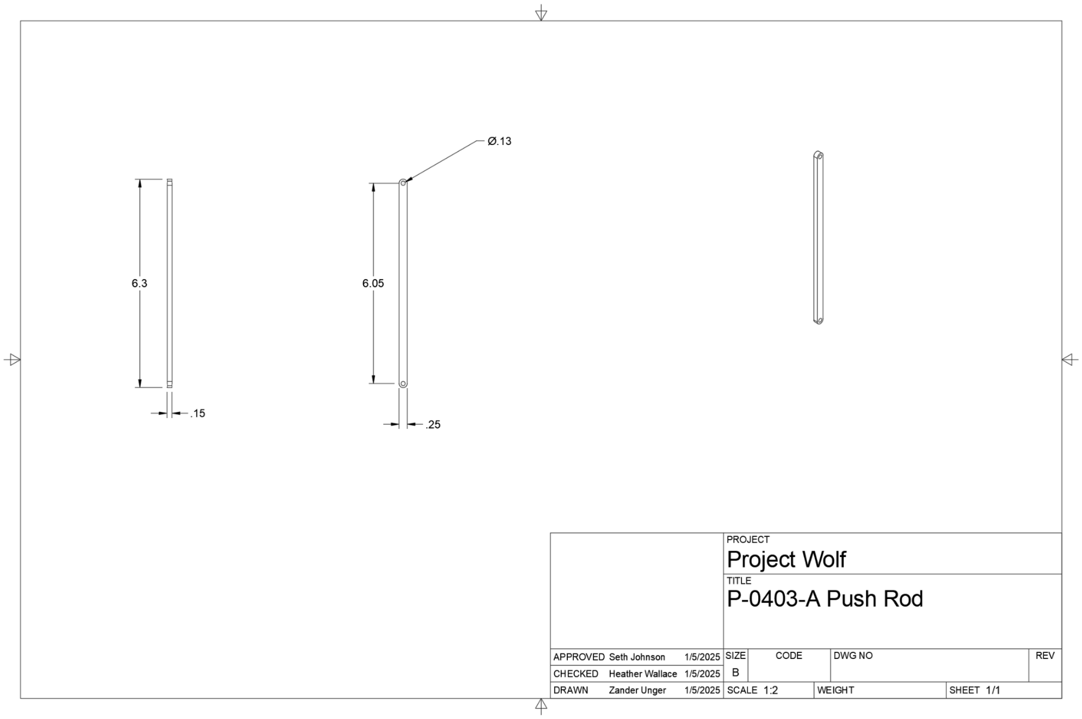

Figure 4.3.1.8: Push Rod Drawing

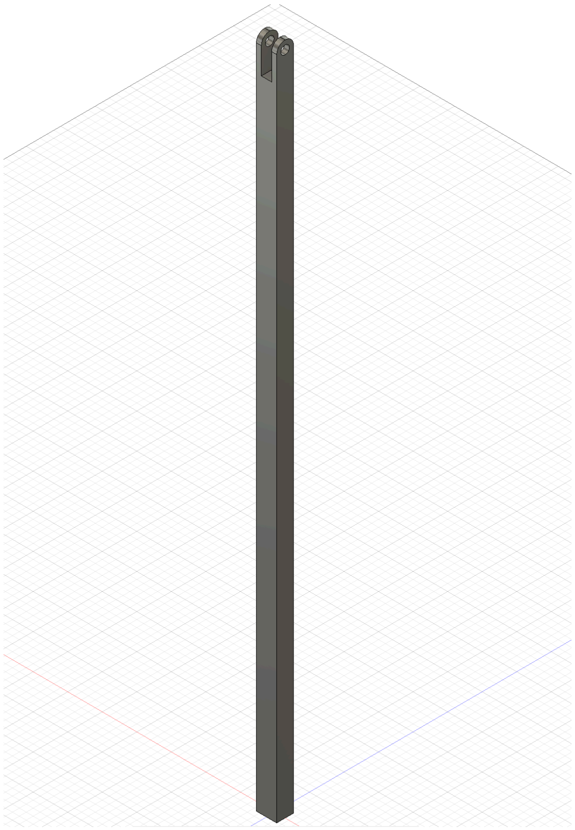

Figure 4.3.1.9: Slider

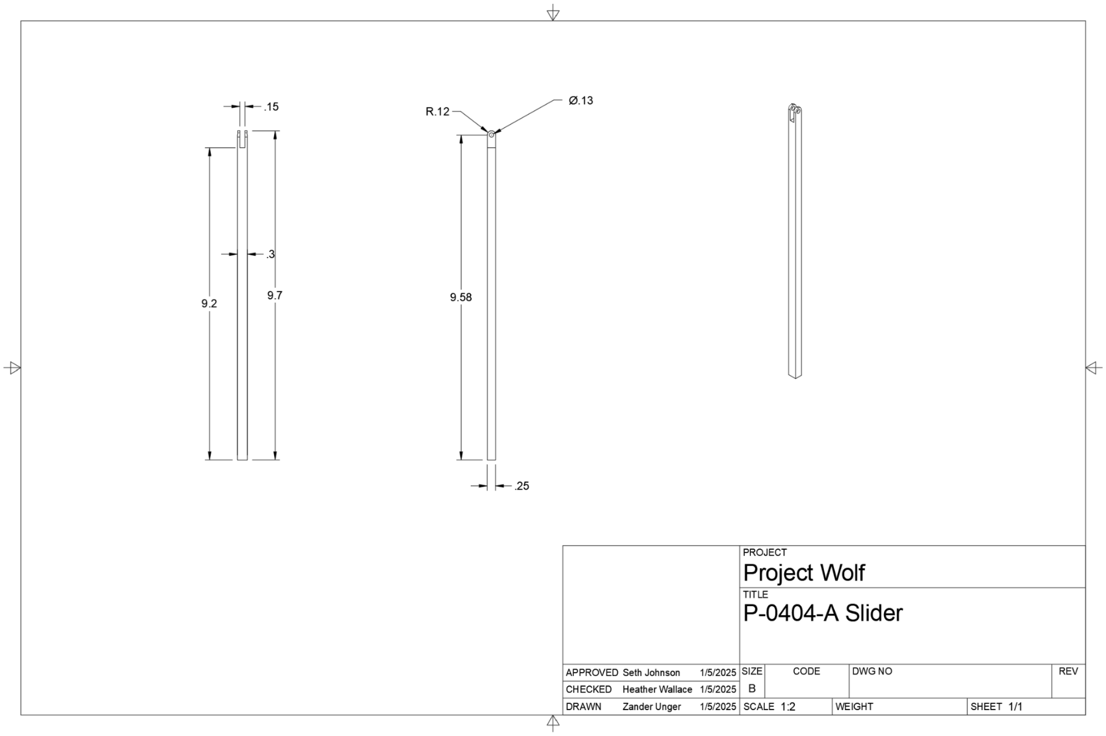

Figure 4.3.1.10: Slider Drawing

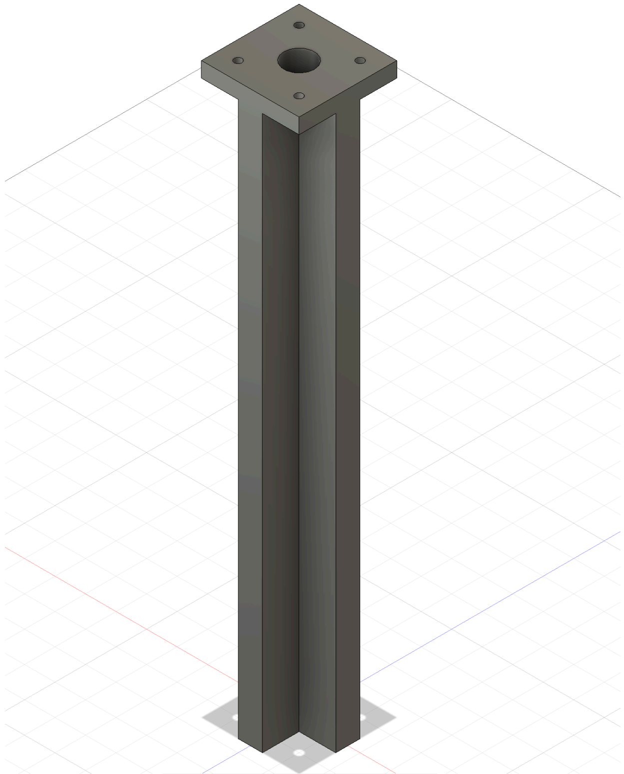

Figure 4.3.1.11: Drive Block Guide

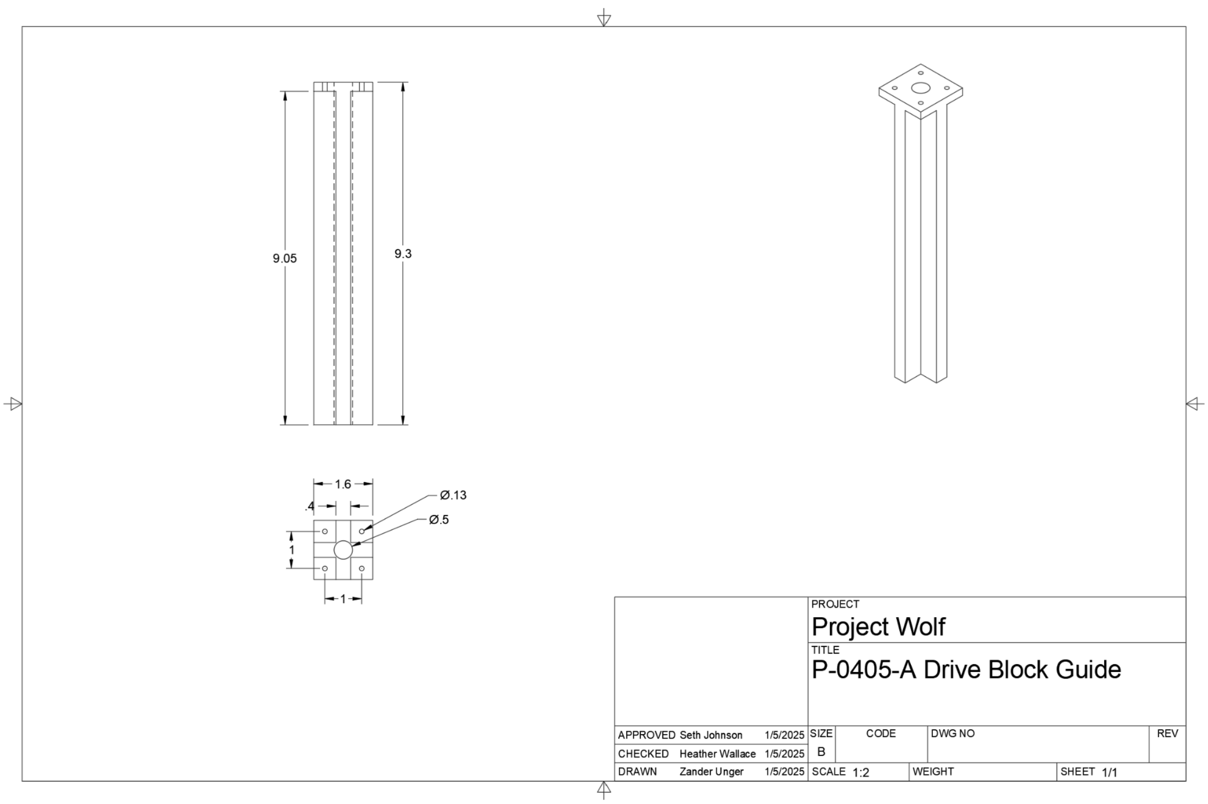

Figure 4.3.1.12: Drive Block Guide Drawing

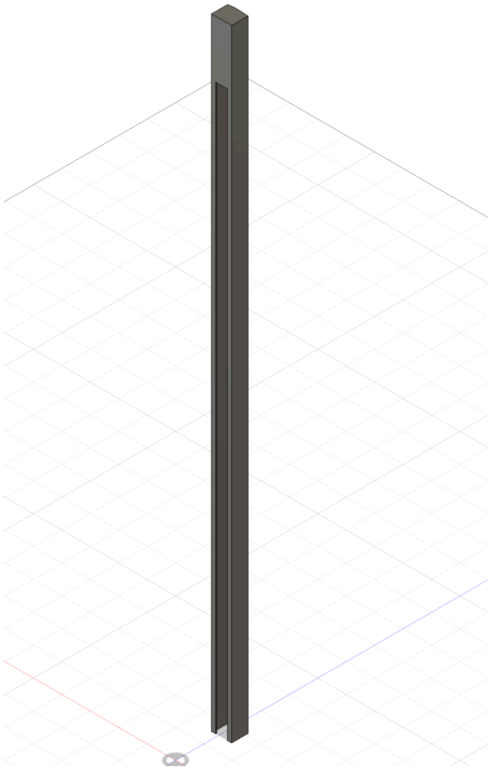

Figure 4.3.1.13: Transmission Arm

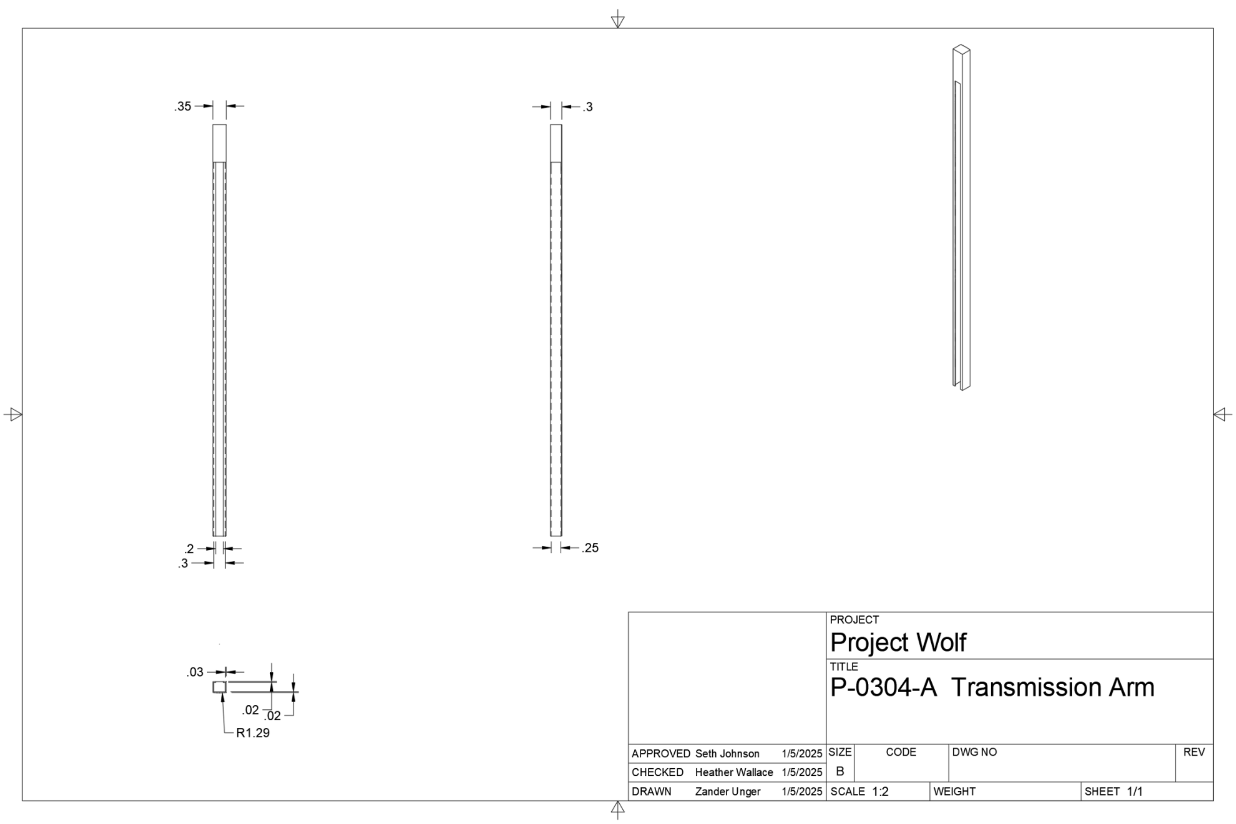

Figure 4.3.1.14: Transmission Arm Drawing

4.3.2 STEMnaut Capsule

An important part of the payload challenge this year is developing a STEMnaut Capsule capable of transporting the STEMnauts from Earth to the launch vehicle's destination safely and reliably. In keeping with these goals, the STEMnaut Capsule (constructed via 3D printing) is located just above the sensor and antenna package of the launch vehicle and is made to conform with the vehicle's fuselage. It is a 5" diameter by 3" tall cylinder with a lid on the top for easy ingress/egress of the STEMnauts. The lid simply slides into place, guided by three small notches on the interior wall of the capsule. These notches also ensure that the lid does not detach during launch. The capsule is secured to the coupler rings with screws.

As the main mission of the STEMnaut Capsule is to provide a place for the STEMnauts to ride on the launch vehicle, the capsule's interior is fitted with chairs oriented in the direction of the vehicle's velocity. This means the STEMnauts will be oriented with their backs parallel to the surface of the launchpad during departure. This is done because humans can best withstand G-forces from their chest to back (see Appendix D). From launch to landing, the capsule provides a smooth ride for the STEMnauts, delivering them safely to their destination.

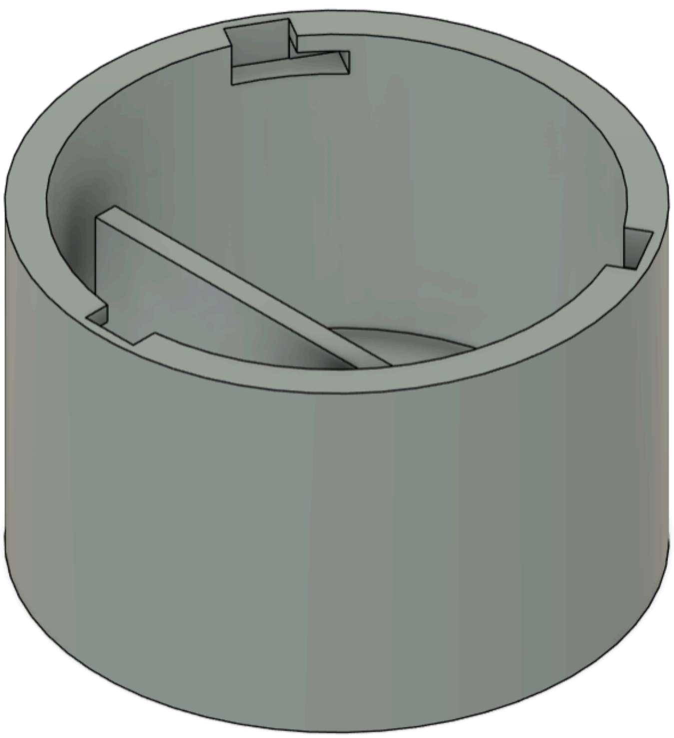

Figure 4.3.2.1: STEMnaut Capsule

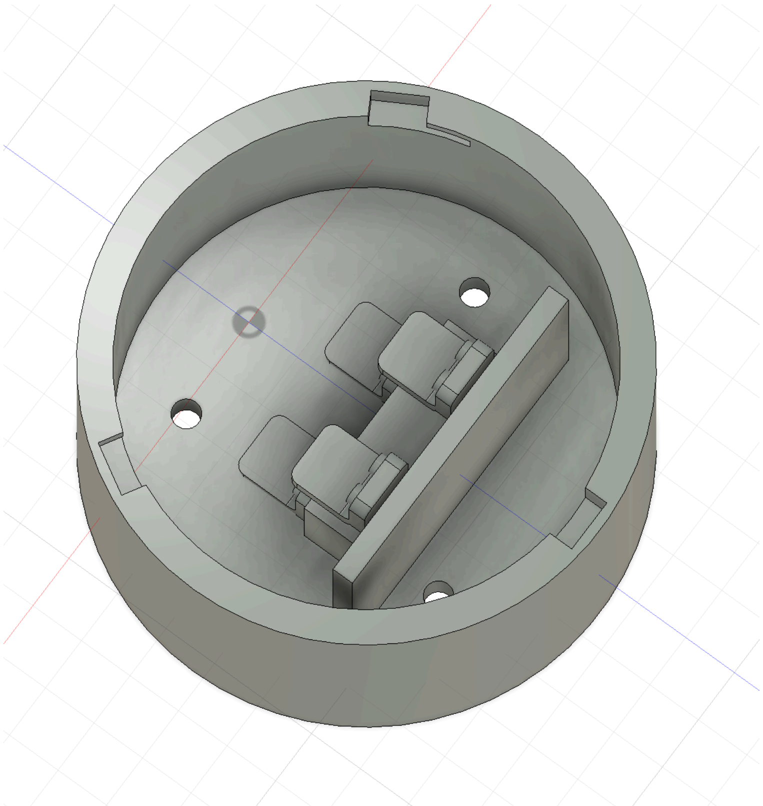

Figure 4.3.2.2 Internal View of STEMnaut Capsule

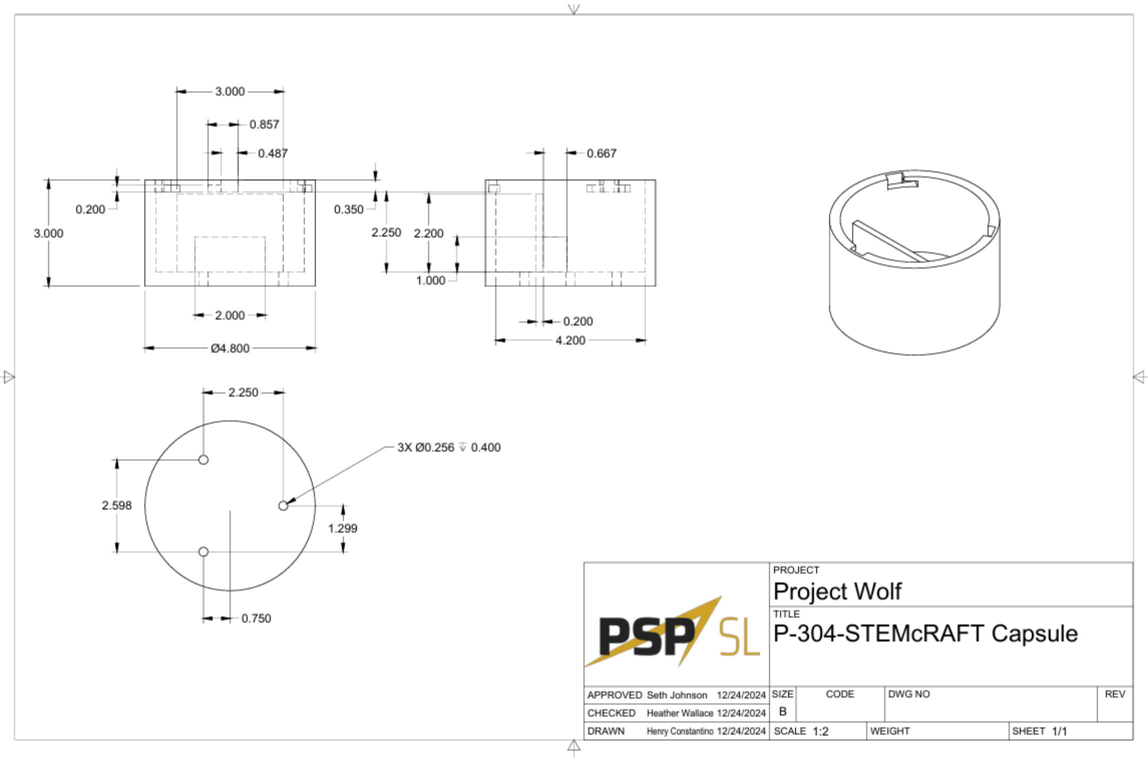

Figure 4.3.2.2: STEMnaut Capsule Technical Drawing

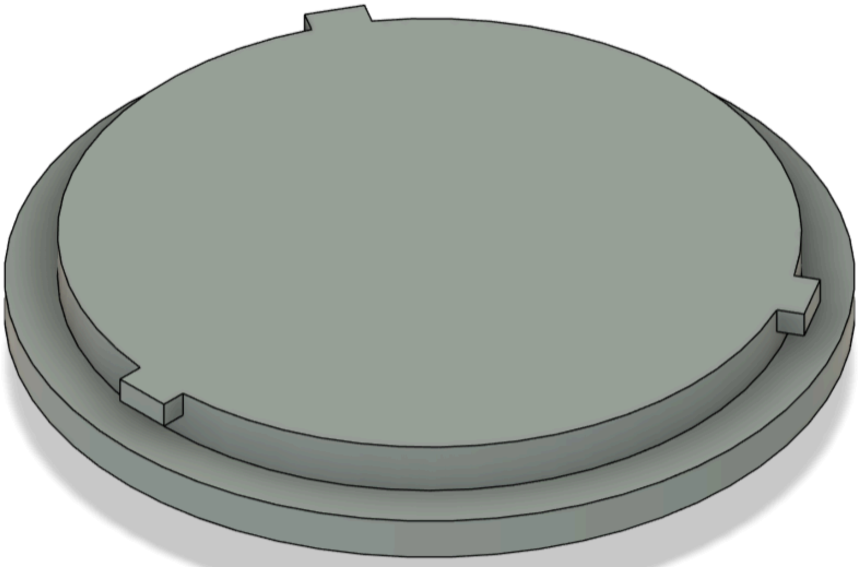

Figure 4.3.2.4: STEMnaut Capsule Lid

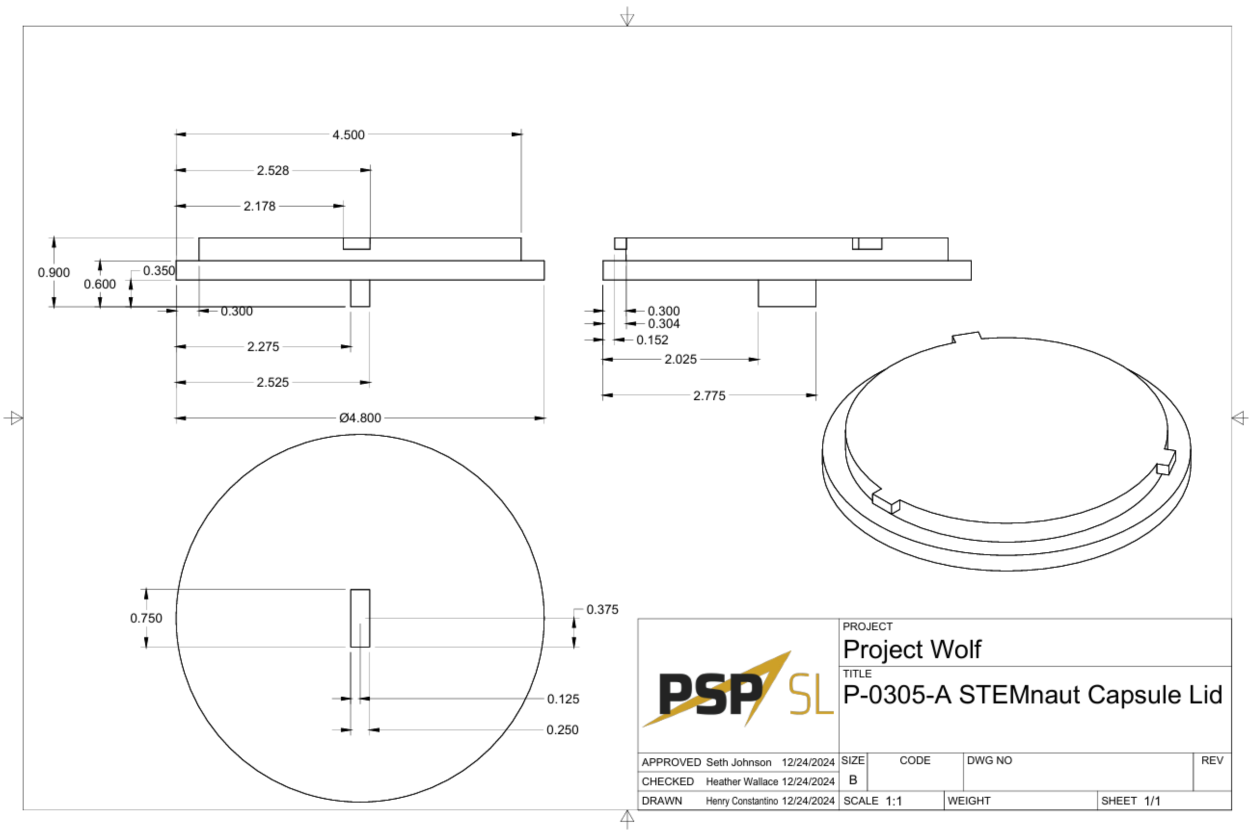

Figure 4.3.2.5: STEMnaut Capsule Lid Technical Drawing

4.3.3 Sensor Package

The sensor package and its battery are attached to a thin 3D printed mounting plate. This mounting plate is set on both ends to two rings, both of which are attached to the airframe Further details on the integration and retention of the sensor package are in Section 4.3.4. Further details on the electronics for the sensor package are located in Section 4.4.2, under the payload electronics review.

4.3.3.1 Subscale Flight Data

```
--------------------------------


POST FLIGHT DATA
maxAltitude = 582.86 m
Temp. of landing site = 13.33 *C

Time elapsed: 00:37:27
```

Figure 4.3.3.1.1: Sensor Package Data obtained from Subscale Flight

Table 4.3.3.1.1: Subscale Sensor Package Data compared to Validation Data

	Apogee (ft)	Temperature (*C)	Time Elapsed
Sensor Package	1912.27	13.33	00:37:27
Validation Data	1851	13.78	N/A
Percent Error	3.31%	3.27%	N/A

The alternative data the team compared the sensor package data was taken individually. The apogee was taken from Telemetrum data from the Avionics & Recovery team, and the temperature data point was taken using a handheld thermometer at the landing site. The landing site data obtained from subscale was fairly accurate, with percent error for apogee being 3.31% and percent error for temperature being 3.27%. This is a great starting point for the team to build off of in the next semester leading up to the full-scale flight. The difference in apogee most likely was caused by an inaccurate starting altitude measurement input by one of the team members before subscale launch vehicle integration, so the team has plans to test and improve upon the software so this does not happen again.

The team is aware that the “Time Elapsed” data point, collected to fulfill the required time of landing data point, is not in the correct format of hours, minutes, seconds and a timezone (e.g. 00:00:00 UTC), and was made aware of this during the CDR Q&A session. The team will address this issue in the upcoming months before the team’s full-scale flight.

4.3.3.2 Software

The code was written on Arduino IDE and utilizes numerous libraries. The screenshot below (Figure 4.3.3.2.1) shows which libraries must be installed.

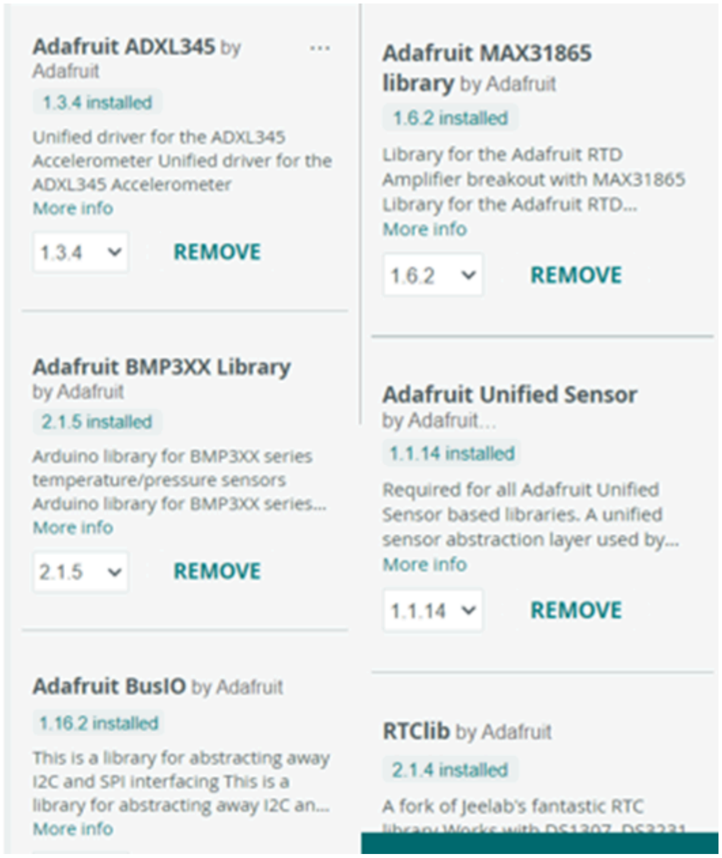

Figure 4.3.3.2.1: Necessary Libraries for Sensor Package Software

There are two scripts used in this project; the first script runs during the flight and the second is run after the flight, once the package is plugged into a computer, to retrieve and present the final data. Currently, there are a couple pieces that need to be manually entered into the script. First, the atmospheric pressure needs to be inputted at the beginning of the code. The corresponding line of code is below. This is an area of improvement that will be addressed in the second semester.

```
#define SEALEVELPRESSURE_HPA (995) //rep
```

Figure 4.3.3.2.2: Inserting Atmospheric Pressure

The value is typically around 995 (as shown in Figure 4.3.3.2.2) but to get an accurate reading one needs to place the payload at the launch site and complete the following steps in Arduino IDE:

1. Click “file”, “Examples”, “Adafruit BMP3XX Library”, “bmp3xx_simpletest”
2. After the script opens, find the section in Figure 4.3.3.2.3
3. Comment the first line of the code segment shown in Figure 4.3.3.2.3 and uncomment the third

```
if (!bmp.begin_I2C()) {   // hardware I2C mode, can pass in address & alt Wire
//if (! bmp.begin_SPI(BMP_CS)) {  // hardware SPI mode
//if (! bmp.begin_SPI(BMP_CS, BMP_SCK, BMP_MISO, BMP_MOSI)) {  // software SPI mode
  Serial.println("Could not find a valid BMP3 sensor, check wiring!");
  while (1);
}
```

Figure 4.3.3.2.3: Code Segment

```
//if (!bmp.begin_I2C()) {   // hardware I2C mode, can pass in address & alt Wire
//if (! bmp.begin_SPI(BMP_CS)) {  // hardware SPI mode
if (! bmp.begin_SPI(BMP_CS, BMP_SCK, BMP_MISO, BMP_MOSI)) {  // software SPI mode
  Serial.println("Could not find a valid BMP3 sensor, check wiring!");
  while (1);
}
```

Figure 4.3.3.2.4: Corrected Code Segment after completing steps 1-3.

4. Run the code, make sure you set serial monitor band to 115200 or change the code to your preferred band
5. The serial monitor will output the surrounding pressure to be replaced in the main code in the line shown in Figure 4.3.3.2.2
6. Next, a couple thresholds must be set based on the expected flight. First, the threshold to start the timer must be inputted. The corresponding code is shown below in Figure 4.3.3.2.5.

```
// check to see if flight has started, take note of start time
// replace "111" with correct value, run BMP388 sensor test to retrieve
if (accelMag > 15 && timestartcounter == 0 && currentAltitude > "111") {
  timestart = elapsedTime;
  timestartcounter = 1;
}
```

Figure 4.3.3.2.5: Code Segment

7. Replace the “111” with a value that will indicate the launch vehicle has begun flight (i.e. if stationary altitude is 1 meter, make it something above this so the package knows it is ascending). It is important to remember that once the script is running, any indication of

this will result in the timer starting so make sure to switch off the payload and only switch it back on once it is on the launchpad.

8. Finally, the max altitude threshold must be set. The corresponding code is shown below in Figure 4.3.3.2.6

```
//check to see if landing conditions are met, iterates 5 times
// replace "111" with correct values, these conditions are to make it so it knows its landed (i.e.
// run BMP388 sensor test to see the current altitude
if (accelMag <= currentaccelMag+.05 && accelMag >= currentaccelMag-.05 && maxAltitude >= 111) {
  counter = counter + 1;
}
```

Figure 4.3.3.2.6: Code Segment

9. Replace “111” in line 4 of Figure 4.3.3.2.6 with a value that will check if the launch vehicle has reached its apogee and returned to the ground (i.e. if the launch vehicle is going 100 meters in the air, make it ~75 meters).

The main script is now complete. On launch day, the package would be plugged into the computer and the script would be compiled and sent to the Arduino. Once the payload reaches the ground post-flight, it is plugged into a computer, without being turned off, and the post flight script is run. It outputs the final data of the flight.

The next step for the team in the design process is to connect the sensor package with the transmission system, which is under development and will be the main objective of the team in the month of January leading up to tue team’s full-scale flight.

4.3.4 Integration and Retention System

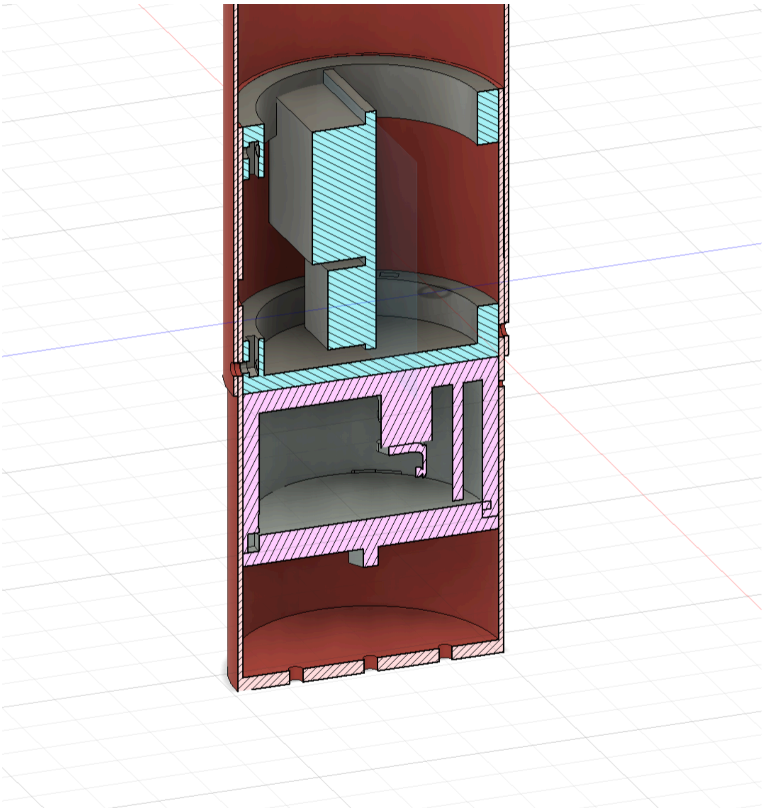

Figure 4.3.4.1: Integration and Retention Subassembly

Both the STEMnaut capsule as well as the sensor package are retained inside the airframe using two mount rings.The STEMnaut capsule is attached to the bottom mount rings via screws. The sensor package is mounted to a mounting plate and fastened between the bottom and top via notches in the rings. The sensor package and mount ring subassembly is then fastened to the airframe using embedded nuts in the rings and screws on the outside of the airframe. This retention system allows both the STEMnaut capsule and the sensor package to be secured using the same two mount rings which simplifies the system.

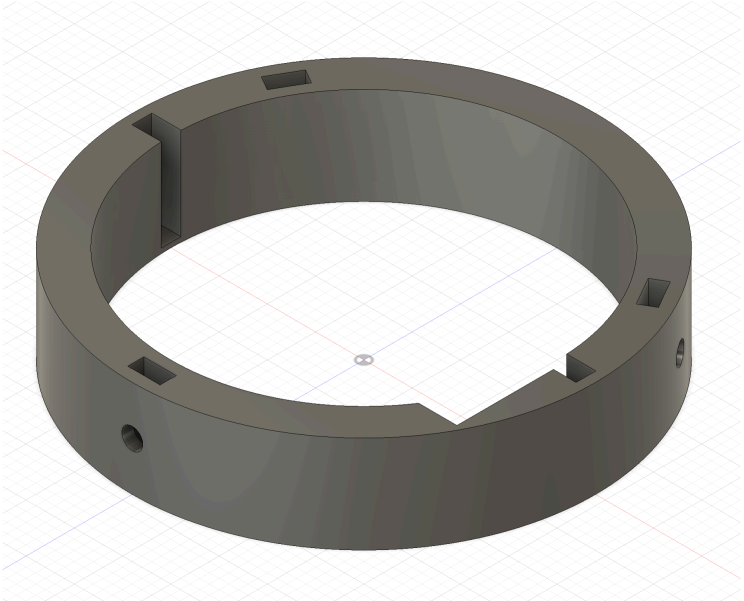

Figure 4.3.4.2: Integration and Retention Top Ring

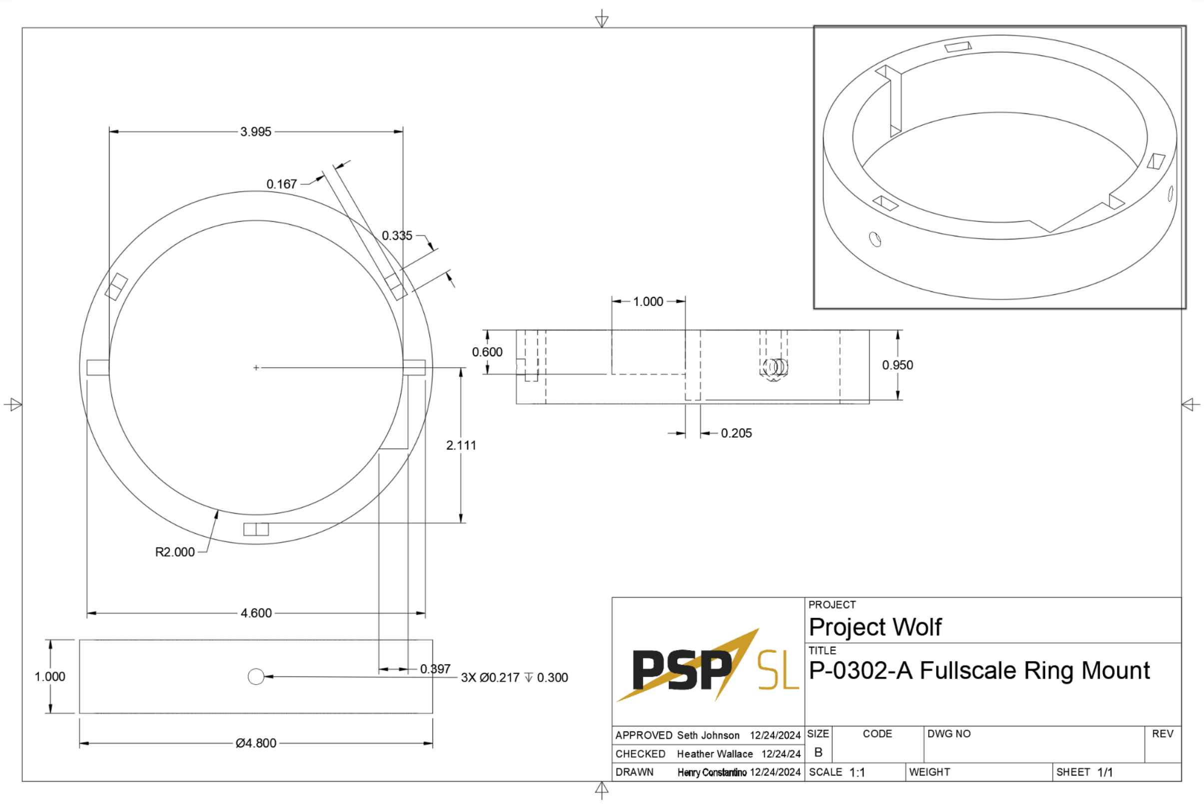

Figure 4.3.4.3: Integration and Retention Top Ring Drawing

The cutout on the side of the top ring is to make room for the Arduino Uno Rev3, which is the thickest electrical component in the sensor package. Since the STEMCRaFT is meant to fit in a tight area, cutting out a portion of the ring allows for greater spatial efficiency.

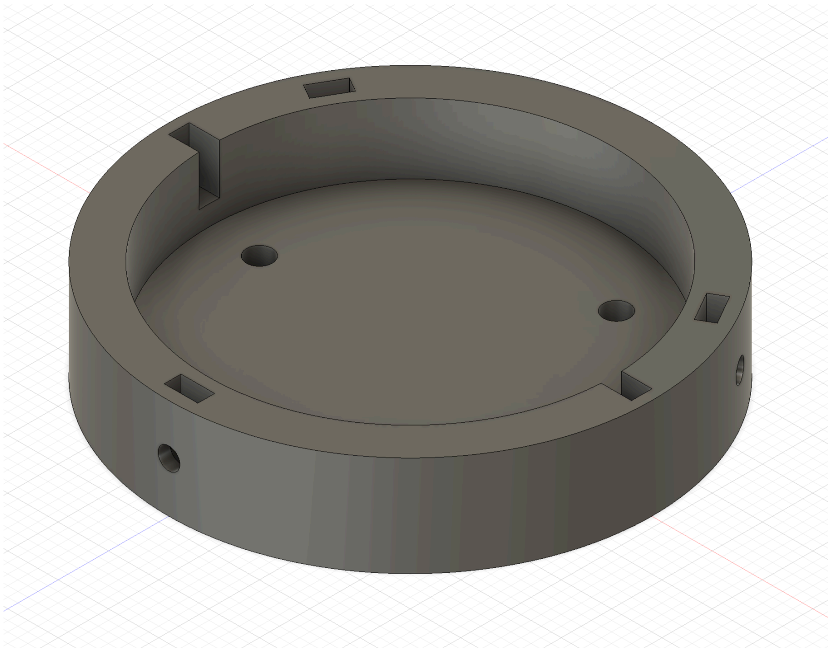

Figure 4.3.4.4: Integration and Retention Bottom Ring

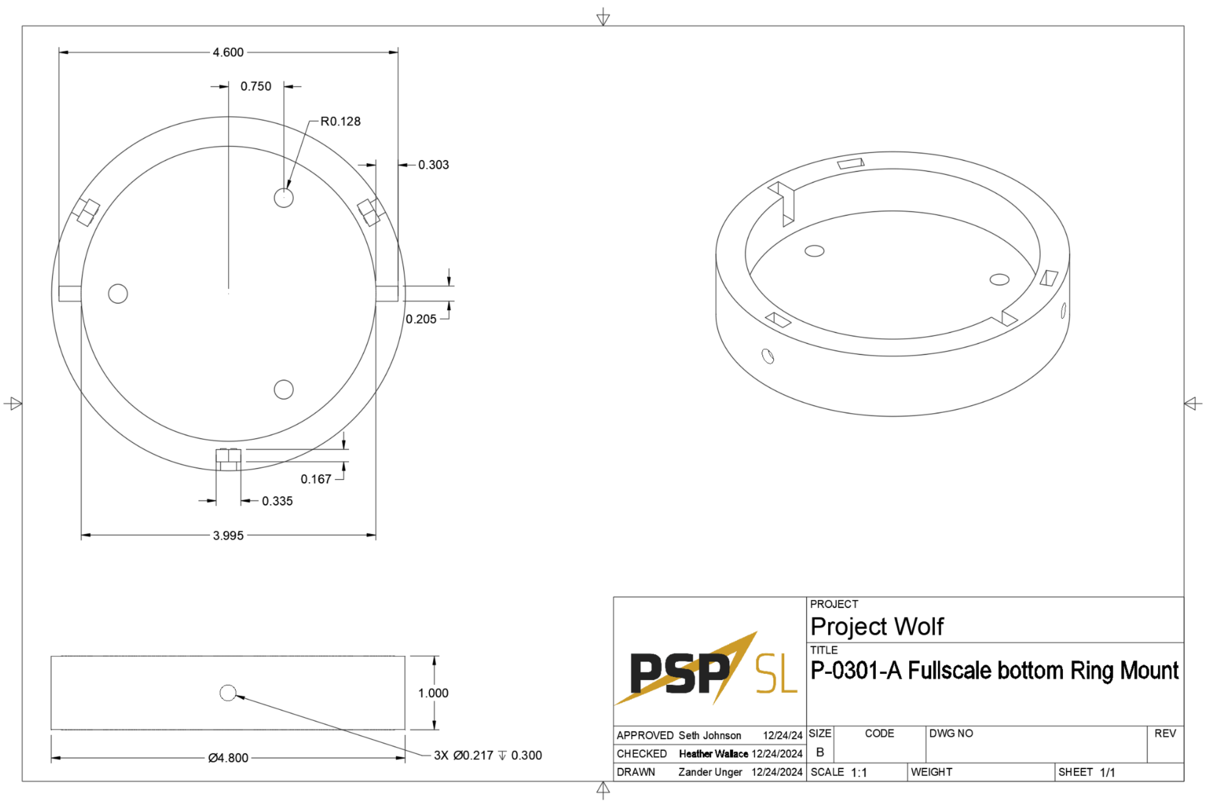

Figure 4.3.4.5: Integration and Retention Bottom Ring Drawing

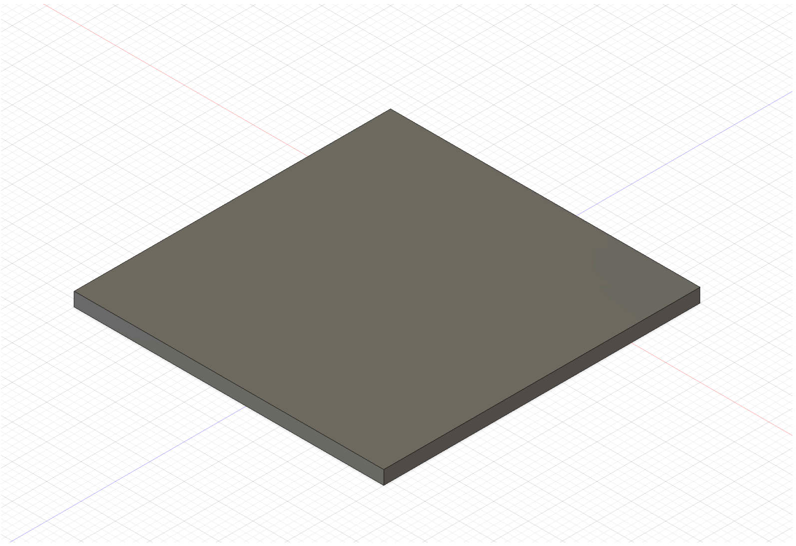

Figure 4.3.4.6: Mounting Plate

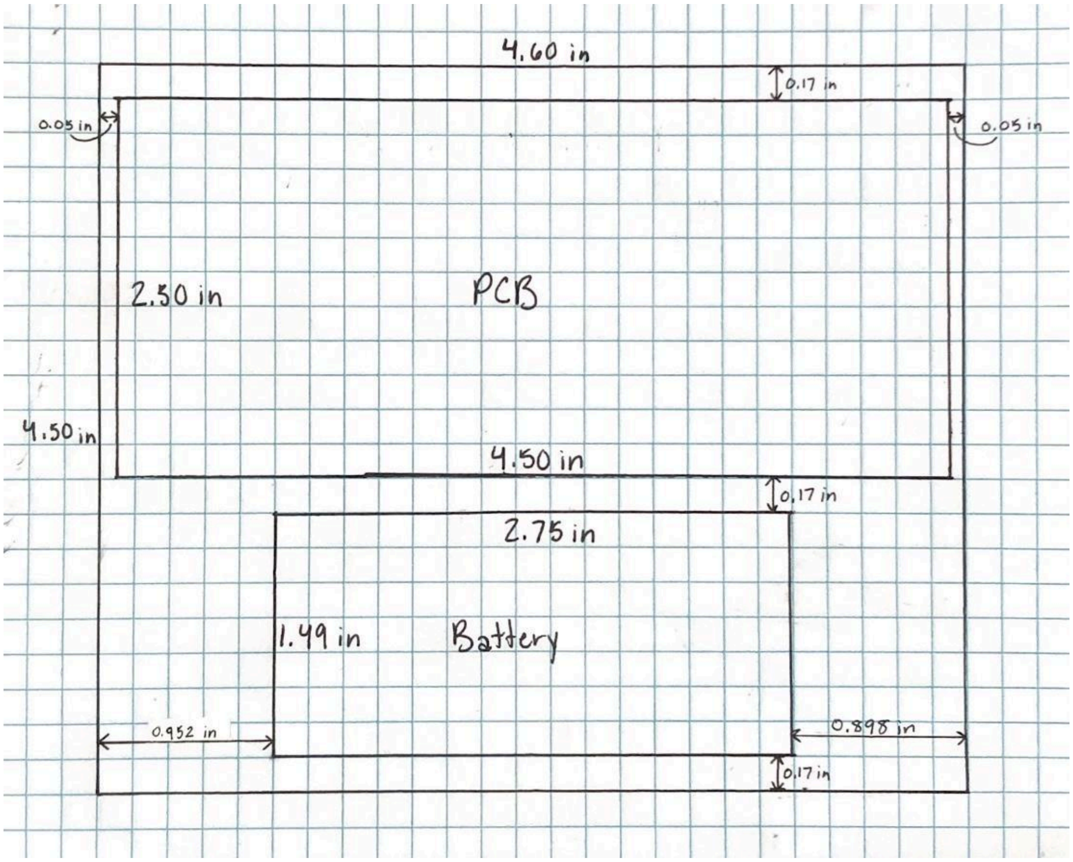

Figure 4.3.4.7: Mounting Plate Layout Sketch

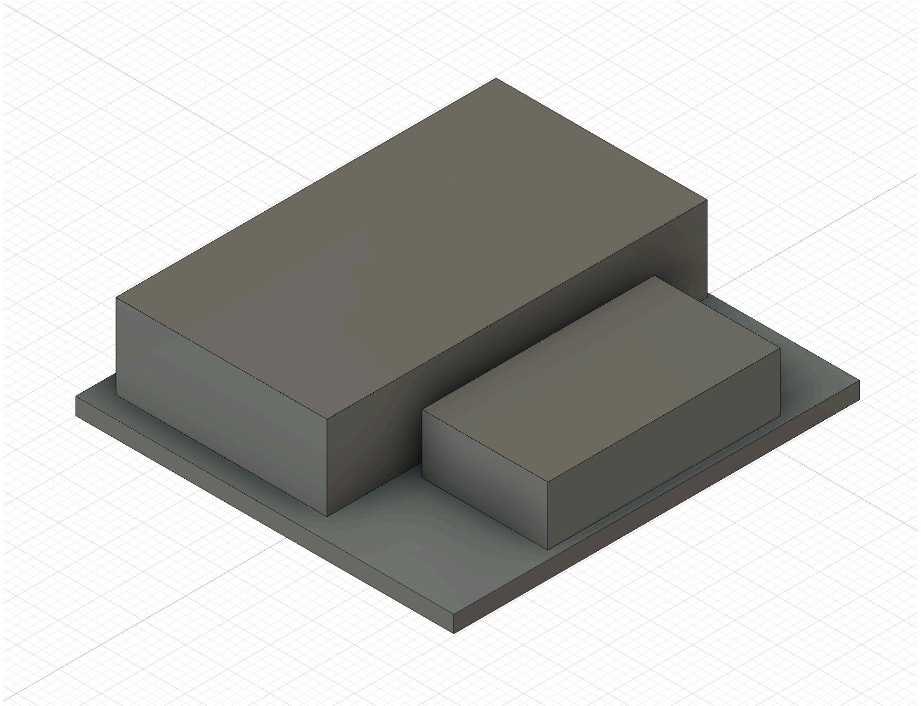

Figure 4.3.4.8: Mounting Plate with Simulated Thicknesses of Electrical Components

In Figure 4.3.4.8, the taller, thicker component is the PCB with all sensors and Arduino sautered to it, and the smaller component is the 7.4V Li-ion battery.

4.4 Payload Electronics Review

4.4.1 Radio Transmission System

Table 4.4.1.1: Pinout of the SR_FRS_4WV

Pin #	Description	Label
1	MIC input (not used)	MIC_IN
2	NC	NC
3	Program (not used)	VCC
4	GND	GND
5	1=receive, 0=transmit	PTT
6	TXD for UART	TXD
7	RXD for UART	RXD
8	1=inactive squelch control, 0=active squelch control	SQ

9	NC	NC
10	0=SLEEP MODE, 1=WORKING MODE	PDsN
11	Audio output (not used)	AF_OUT
12	Program port (not used)	P00
13	GND	GND
14	RF Power Select: NC: 4W, GND: 1W	H/L
15	Program port (not used)	P01
16	GND	GND

The SR_FRS_4WV is interfaced using the Arduino UNO with standard UART protocol. Specifically, using AT instructions. The format is to start the message with “AT” and end it with a carriage return <CR>. The response will be in the form of <CR><LF><response><LF><CR>. All data should be sent using standard ASCII with the exception of the length of the message to be sent in chars.

The first command of note is the AT+DMOGRP command. The useful functionality of this command is its ability to set a specific transmit frequency and transmit power. For example the command AT+DMOGRP=144.00000, 144.00000, 1, 1, \8b000, \8b000<CR> sets the transmit frequency to 144 MHZ, and the transmit power to high.

The other important command is AT+DMOMES. This is for sending a message. For example AT+DMOMES=\{8x5}HELLO will send HELLO. It is necessary for the length parameter to be a single byte hex value, which is the exception to the otherwise all ascii encoding protocol. Additionally for messages of odd length there is a requirement for an additional character to be added to the end of the UART transmission. The transmission has a maximum length of 80.

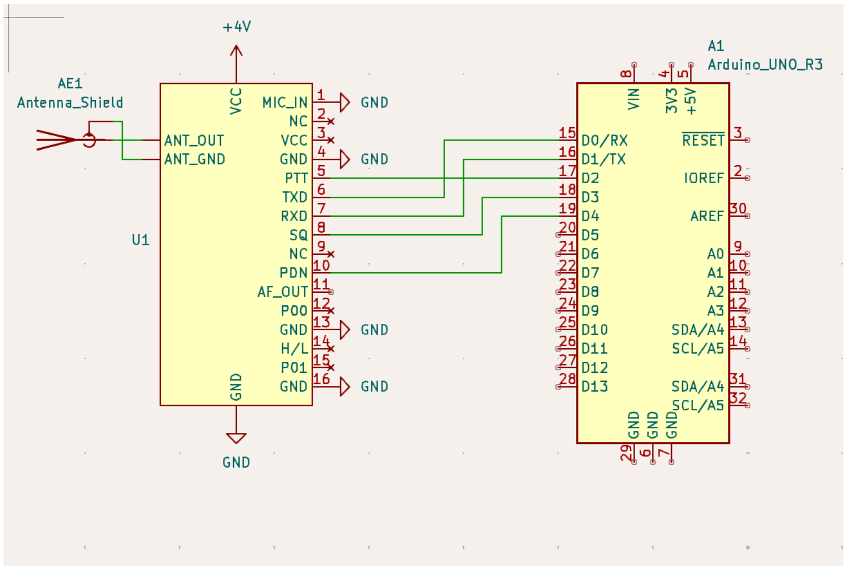

Figure 4.4.1.1: Connections from the SR_FRS_4WV to the Arduino Uno

The physical connections from the arduino to the SR_FRS_4WV consist of the UART DIO pins, as well as supplemental DIO pins to control receive/transmit mode, squelch control, and sleep mode. Furthermore the necessary power and ground connections are made to the battery. It is also necessary to ensure the arduino and SR_FRS_4WV share a common ground, which can be accomplished by connecting the grounds to one another.

4.4.2 Sensor Package

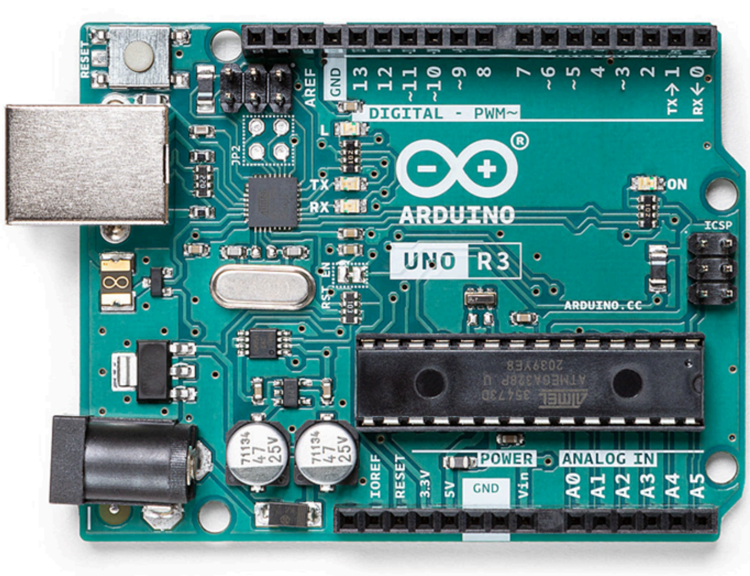

Figure 4.4.2.1: Arduino Uno Rev3

The Arduino Uno REV3 is a microcontroller board that manages and processes data from various sensors used on the team's sensor package. This board will allow the team to code various sensors allowing multiple streams of data from different servers. This board has multiple digital and analog pins which are more than enough for the team to connect the team's sensors either using the SPI or I2C method. It also has a USB port for ease of connection to a computer.

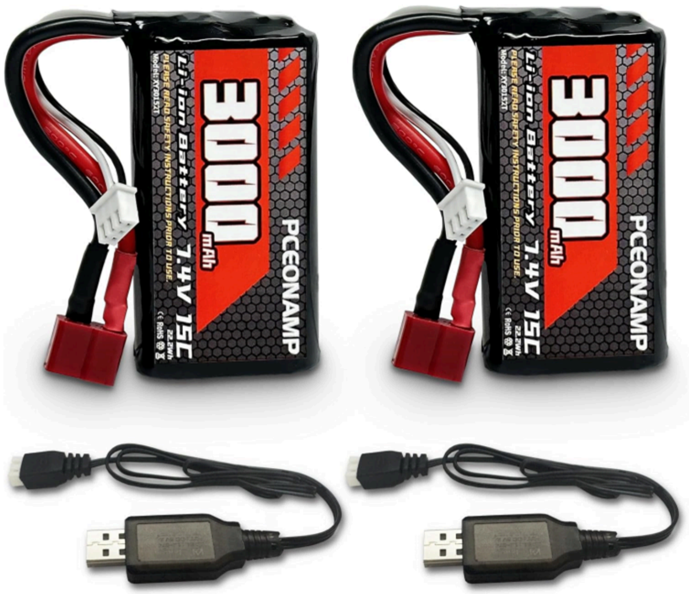

Figure 4.4.2.2: Li-ion Battery

The power source for the sensor package is a 7.4V Li-ion Battery with a 3000mAh capacity. This rechargeable battery provides a stable and reliable power supply for the Arduino Uno and connected sensors, ensuring consistent performance. Its high capacity of 3000mAh allows for extended operation, making it suitable for launch day requiring long runtime without frequent recharging.

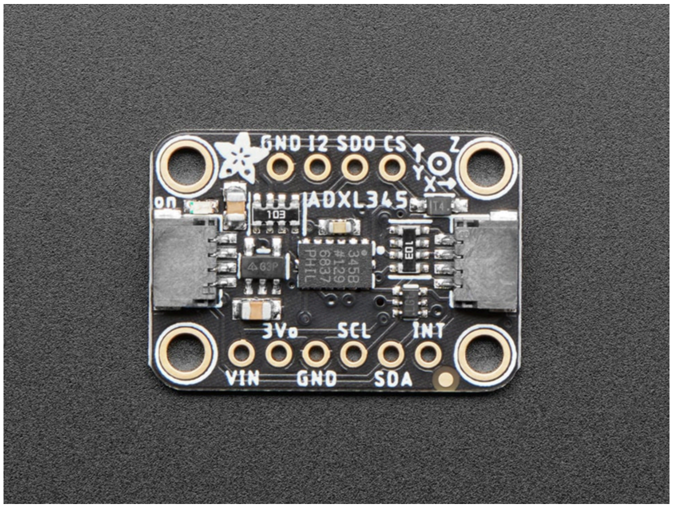

Figure 4.4.2.3: ADXL 345

The team used the Adafruit ADXL345 Triple-Axis Accelerometer, a highly sensitive and versatile sensor capable of measuring acceleration in three dimensions (X, Y, and Z). The ADXL345 communicates via I2C or SPI interfaces, making it easy to integrate with the Arduino Uno and ensuring fast, reliable data transfer.

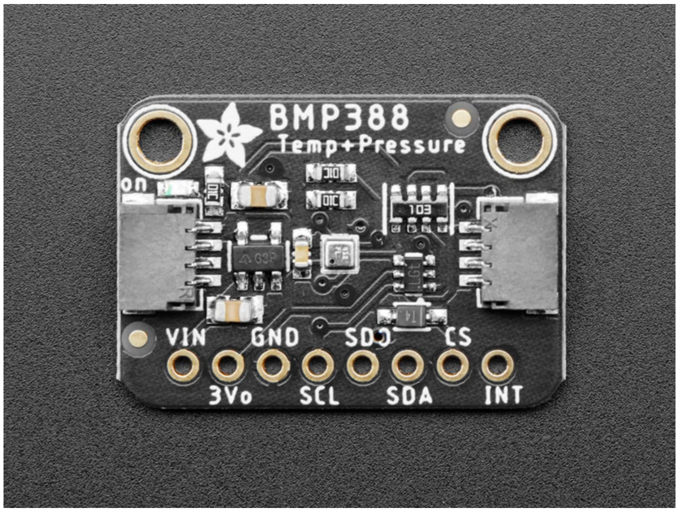

Figure 4.4.2.4: BMP 388 Barometric Altimeter

The sensor package utilizes the Adafruit BMP388, a precision barometric pressure and temperature sensor. This sensor is designed to provide highly accurate pressure measurements and temperature measurements making it ideal for applications such as altitude tracking and weather monitoring. The sensor communicates via I2C or SPI interfaces, ensuring seamless integration with the Arduino Uno for efficient data collection.

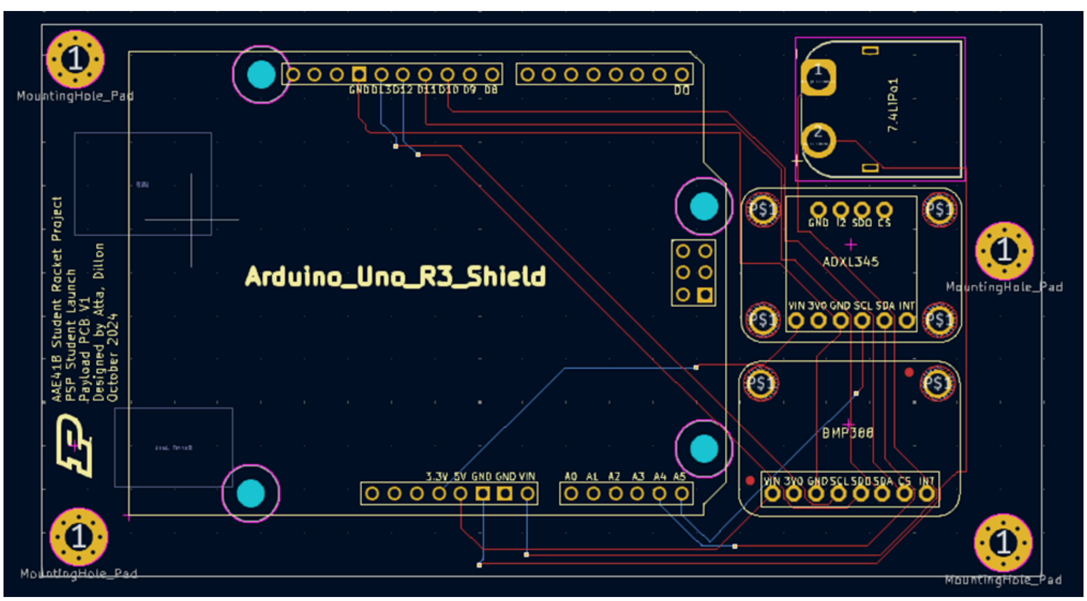

Figure 4.4.2.5: PCB Layout

To streamline the integration of all components, the sensors and supporting circuitry were designed and laid out on a custom PCB using KiCad. The Arduino Uno, Adafruit ADXL345 accelerometer, BMP388 pressure sensor, and other necessary components were incorporated into the PCB design to ensure efficient and compact assembly. The Arduino Uno's connections were also integrated into the design, allowing for a clean and organized system layout.

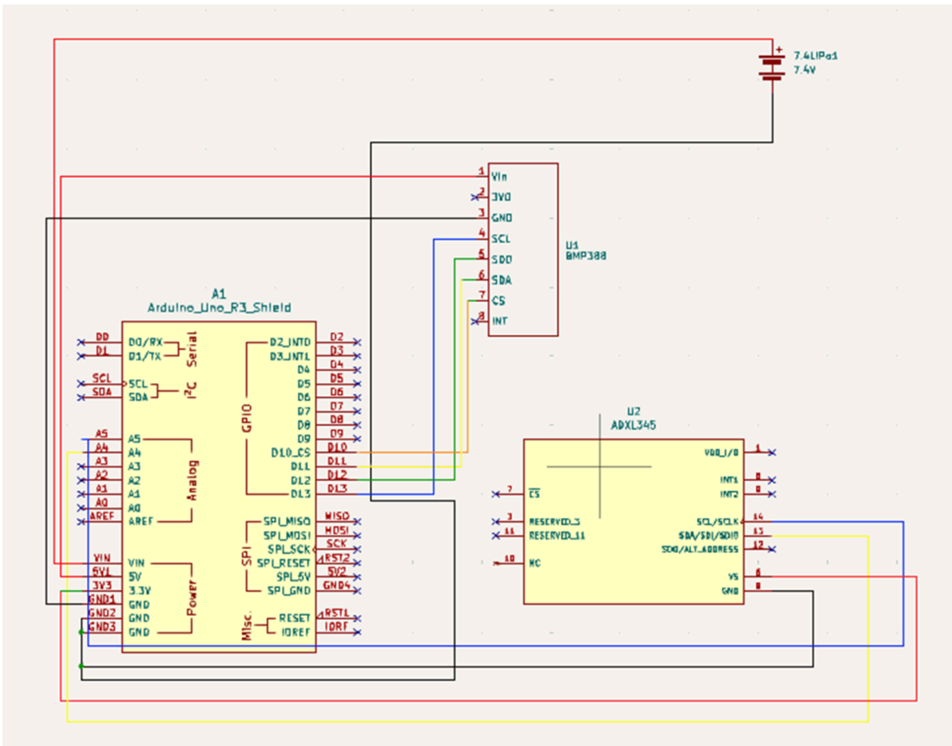

Figure 4.4.2.6: Sensor package schematic from KiCad

The electronic schematic for the sensor package was also designed using KiCad which was the initial step before designing the PCB. The Arduino Uno, Adafruit ADXL345 accelerometer, BMP388 pressure sensor, and other necessary components were incorporated into the PCB design to ensure efficient and compact assembly. The ADXL 345 was connected to the Arduino using an I2C configuration while the BMP388 was connected using a SPI configuration.

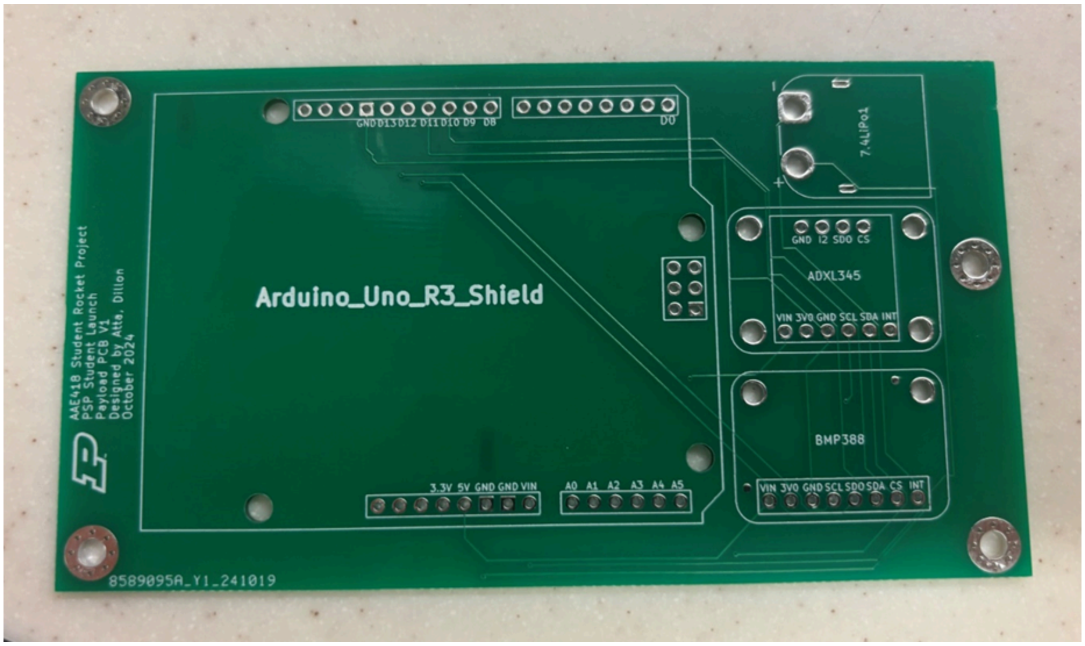

Figure 4.4.2.7: Final PCB Manufactured by JLCPCB

The final PCB, manufactured and delivered by JLCPCB, represents the fully realized design of the sensor package. Upon arrival, the board was carefully inspected and tested to ensure that all components functioned as intended. This professionally fabricated PCB integrates the Adafruit ADXL345 accelerometer, BMP388 pressure sensor, and Arduino Uno interface, along with all supporting circuitry, into a compact and efficient layout.

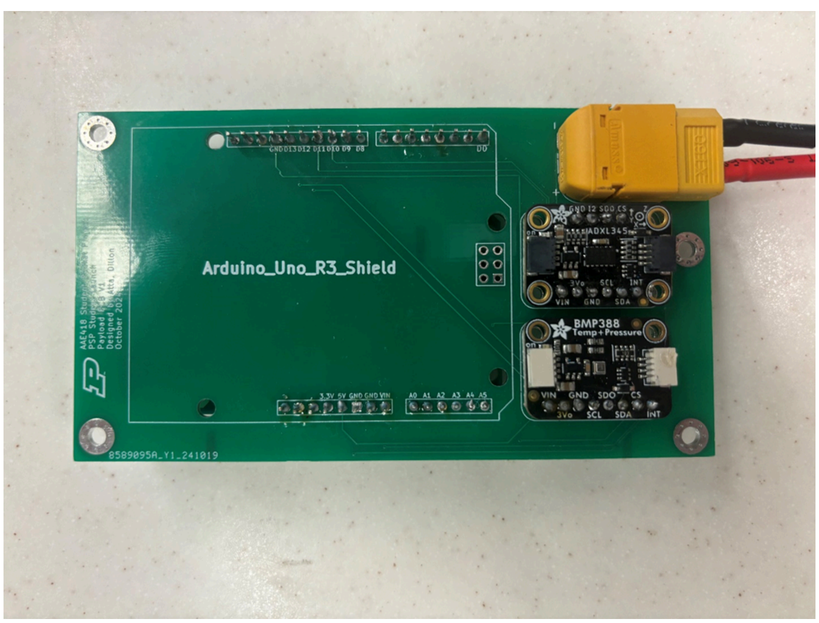

Figure 4.4.2.8: Soldered Components on the PCB

Finally, each component was carefully soldered onto the PCB. This assembly process ensured secure connections and proper placement of all components, laying the foundation for a fully functional sensor package.

4.5 Secondary Payload

Independent from the primary competition payload, a secondary payload has also been developed for the launch vehicle, henceforth referred to as the "R&D payload". This secondary payload resides within an 11" coupler section located just forward of the motor. It is entirely passive, providing an opportunity to gather flight data from independent sensors and assess launch stresses on trial components. The primary purpose of obtaining this information is to develop a baseline knowledge for airbrakes in future projects.

The designed R&D payload consists of an electronics sled with a barometric altimeter and accelerometer. The sensor data is logged via an Arduino MKRZero, and powered by a 2S LiPo battery. The entire sled is mounted within the coupler via two integrated nut rings, as seen in Figure 4.5.1. The LiPo battery is secured in an indent on the back side of the sled with a velcro strap, and is also appropriately marked as a fire hazard.

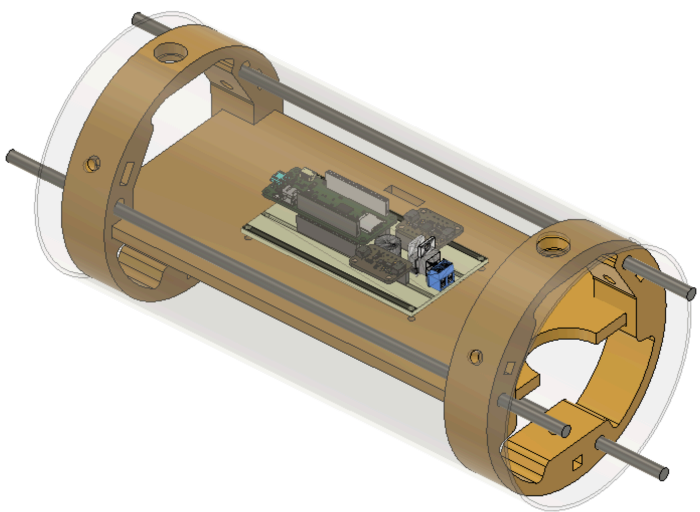

Figure 4.5.1: R&D Payload Sled

The coupler section fits between the booster and lower recovery airframes, attached with ¼"-20 bolts. A cross section of this integration can be seen in Figure *4.5.1*.

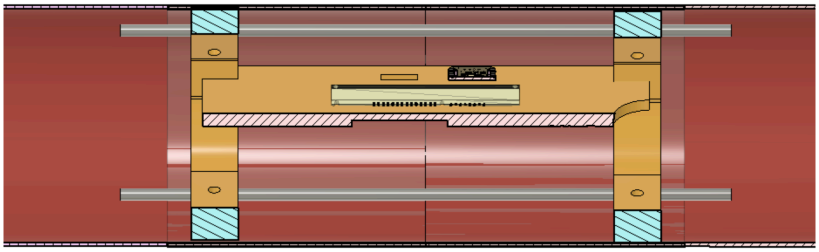

Figure 4.5.2: R&D Coupler Integration

The electronics present on the R&D sled are mounted on a custom PCB, an electrical schematic of which can be seen in Figure 4.5.3 below. Important features include the 5V regulator to manage the LiPo battery voltage, and the screw terminal for key switch. The R&D payload uses a key switch identical to the recovery system, so both can be powered on and off with a single key. To reiterate, this secondary R&D payload is entirely passive and serves only to gather data for the team.

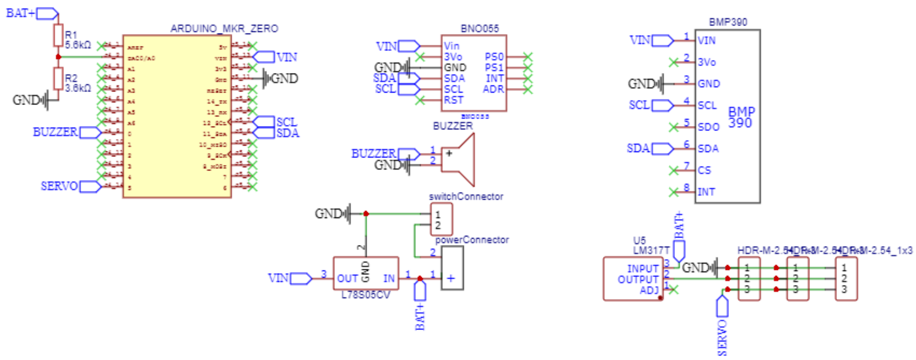

Figure 4.5.3: R&D Sensor Package Schematic

5 Safety

The Safety Officer of the 2024-2025 PSP-SL Team is Julia Spihlman. The Team Safety Officer holds responsibility for the safety and welfare of all team members and launch attendees throughout the competition cycle as per Requirement H.5.2 and H.5.3. The Team Safety Officer must possess a comprehensive understanding of all equipment and organizational guidelines for each facility utilized by the team during the competition cycle. Additionally, the Team Safety Officer is required to attend all meetings involving fabrication, testing, and/or assembly activities.

To increase technical expertise in the implementation of safety, each subteam (Avionics and Recovery, Construction, Payload, and R&D) has one delegated safety liaison. The safety liaisons aid the Team Safety Officer and help ensure safety within the team by monitoring and reporting subteam activities. In addition, subteam safety liaisons assist the Team Safety Officer in the creation of procedures using in-depth knowledge of their respective subteam.

5.1 Launch Concerns and Operation Procedures

For the preparation of all full-scale launches, the following procedures were created. The procedures in this section detail all action items that must be completed by each subteam prior, during, and post full-scale launch. Included in each set of procedures is a list of materials needed, which is broken up into items needed to construct the launch vehicle, peripheral items for operations, and tools needed for assembly. Each material list contains a column for items to be checked-off as present before beginning the procedures. Additionally, a list of necessary personnel is included with each set of procedures. Within the procedures, the “Step #” column uniquely labels each step. The “Action” column describes what must be done for each step, with hazards identified and highlighted using the key in Table 5.1.1. The “T/S #” column provides a reference to relevant Troubleshooting and Emergency Procedures at steps where such failure modes are most likely to occur. Finally, the “Verification” column exists for each step to be signed-off once completed. Within this column, there are steps at which certain required personnel must sign-off. These steps have the required personnel indicated in the “Verification” column. For safety, the PPE required for each set of steps is indicated and highlighted before the steps are listed.

Table 5.1.1: Procedure Caution Key

Hazard Type	Highlight Color
PPE or safety measure	
Explosive or energetic	

Within this section, a Beep Guide is also included. The Beep Guide serves as reference for the procedures, helping to translate the initialization beeps produced by the TeleMetrum and StratoLoggerCF altimeters, the post-flight readout beeps produced by the TeleMetrum and StratoLoggerCF altimeters, and the initialization beeps produced by the R&D sled sensors. The Beep Guide is listed in the “Action” column of steps in which it may need to be referenced.

Troubleshooting and Emergency Procedures are included at the end of this section to be completed in the event of a failure or accident. These procedures utilize the same hazard highlight color notation as seen in Table 5.1.1. Each failure mode or accident type is given a number within its title that is referenced within the "T/S #" column of the launch operation procedures.

5.1.1 Motor Preparation

Table 5.1.1.1: Motor Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
Propellant grains	3	
Tracking smoke grains	1	
Motor case with thrust ring	1	
Large retaining snap rings	2	
Small retaining snap ring	1	
Primary O-rings	3	
Tracking smoke O-ring	1	
Liner shoulder O-ring	1	
Forward bulkhead	1	
Graphite nozzle	1	
Nozzle washer	1	
Liner tube	1	
Tools		
Nitrile gloves	4	
Safety glasses	4	
O-ring lubricant	1	
Internal retaining ring pliers	1	
Small file	1	
Sharp knife	1	
Paper towel roll	1	

Personnel	
Role	**Name**
Project Manager (PM)	Seth Johnson
Project Engineer (PE)	Jacob Daniel
Team Safety Officer (TSO)	Julia Spihlman

Step #	Action	T/S #	Verification
	PPE: nitrile gloves & safety glasses		
1.1	CONFIRM all personnel that may interact with energetics are wearing PPE. **CAUTION**: failure to complete may cause hazardous material to come in contact with skin or eyes		TSO:
1.2	VERIFY all hardware pieces are clean of grease and soot.		PM:
1.3	EXAMINE inside ends of motor cases for any hazards that may cut/tear O-rings. *If present:* remove with a sharp knife or small file. **CAUTION (knife)**: maintain control of knife & cut away from body		
1.4	CREATE clean, dust-free surface with paper towels.		
1.5	APPLY thin layer of grease inside bulkhead, end of casing, and o-rings.		
1.6	PLACE O-rings on clean surface.		
1.7	POSITION tracking smoke O-ring onto tracking smoke grain. **CAUTION (smoke grain)**: fire & projectile hazard		
1.8	SPREAD thin layer of grease on back side of smoke grain.		
1.9	LOOSEN bolt at top end of bulkhead.		
1.10	PUSH tracking smoke grain into smoke well, paying mind to compressed O-ring.		
1.11	TIGHTEN head bolt.		
1.12	INSERT small retaining snap ring in smoke well. **CAUTION (snap ring)**: all personnel must wear safety glasses & be aware of installation, snap rings may become a projectile		
1.13	INSTALL all o-rings; insert larger, black, primary O-rings onto bulkhead, smaller 3/32” O-ring onto bulkhead shoulder, and orange primary O-ring onto nozzle.		
1.14	CONFIRM that inside corners of motor liner are chamfered smooth.		
1.15	APPLY thin layer of grease to inside end of motor liner.		
1.16	INSERT each propellant grain into motor liner. **CAUTION (propellant grain)**: fire & projectile hazard		
1.17	INSERT recessed shoulder of nozzle into nozzle end of liner tube; slide together, with liner tube first, into thrust ring end of motor case.		
1.18	PLACE stainless steel nozzle washer behind nozzle.		
1.19	INSTALL retaining ring using retaining ring pliers.		
1.20	POSITION assembled bulkhead into top of motor; carefully push straight until bulkhead shoulder O-ring is seated into end of liner.		
1.21	SECURE with second retaining ring; ensure that bulkhead and retaining ring are flush against each other.		
1.22	VERIFY both retaining rings are fully seated in their grooves.		
1.23	STORE motor in cool, dry location away from personnel until vehicle		TSO:

	integration. **CAUTION**: failure to complete this step may lower performance of motor or lead to premature ignition		

MOTOR PREPARATION COMPLETE?
PM:

5.1.2 Powder Charge Preparation

Table 5.1.2.1: Powder Charge Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
FFFFg black powder	8g	
E-matches	4	
Nitrile glove	1	
Small cable ties	8	
Tools		
Nitrile gloves	4	
Safety glasses	4	
Anti-static bag	1	
Scissors	1	
Wire strippers	1	
Gram scale	1	
Non-plastic funnel	1	
Permanent marker	1	

Personnel	
Role	**Name**
Avionics Lead (AL)	Payton Gross
Team Safety Officer (TSO)	Julia Spihlman
Avionics Support #1 (AS1)	–
Avionics Support #2 (AS2)	–

Step #	Action	T/S #	Verification
PPE: nitrile gloves & safety glasses			
2.1	CONFIRM all personnel that may contact energetics are wearing PPE. **CAUTION**: failure to complete may cause hazardous material to come in contact with skin or eyes		TSO:
2.2	CONFIRM no strong winds or nearby heat sources. **CAUTION**: failure to complete may cause ignition or scattering of energetics		TSO:
2.3	CUT 2”+ off the tips from four fingers of a nitrile glove.		
2.4	TRIM four e-matches to specified length. **CAUTION (e-match)**: fire & projectile hazard		

2.5	TWIST ends of wires together.		AL:
2.6	MEASURE 1g of FFFFg black powder. **CAUTION (black powder)**: fire & projectile hazard	**5**	
2.7	FUNNEL measured black powder into a trimmed fingertip of the nitrile glove. **CAUTION (black powder)**: fire & projectile hazard	**5**	
2.8	PLACE e-match in black powder. **CAUTION (e-match & black powder)**: fire & projectile hazard	**5**	
2.9	SECURE opening of glove tip with two cable ties.		TSO:
2.10	LABEL the quantity on a piece of tape wrapped around the e-match wire to indicate contents of 1g of black powder.		
2.11	REPEAT steps 2.6 - 2.10 for quantities of 1.5g, 2.5g, and 3g.		AL:
2.12	STORE all four charges in anti-static bag. **CAUTION**: failure to complete may cause premature ignition of energetics		TSO:

POWDER CHARGE PREPARATION COMPLETE?

AL:

5.1.3 Avionics and Recovery Preparation

Table 5.1.3.1: Avionics and Recovery Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
Black powder charges (in anti-static bag)	4	
3.7V LiPo battery (in fireproof bag)	1	
9V battery	1	
9V battery connector	1	
Key switch	2	
TeleMetrum altimeter	1	
StratoLoggerCF altimeter	1	
Avionics sled	1	
Avionics coupler	1	
Avionics bulkheads	2	
Bag of cellulose insulation	1	
60’ long, 0.375” tubular Kevlar shock cord	1	
40’ long, 0.375” tubular Kevlar shock cord	1	

Personnel	
Role	**Name**
Avionics Lead (AL)	Payton Gross
Team Safety Officer (TSO)	Julia Spihlman

Main parachute (120”)	1	
Drogue parachute (24”)	1	
Double Nomex blanket	1	
Single Nomex blanket	1	
Stainless steel quick links (0.25”)	6	
22 AWG stranded wire	92”+	
Nylon screws (4-40)	8	
Battery lid screws	8	
Threaded rods (0.25”-20)	2	
Hex nuts (0.25”-20)	16	
Washers (0.25” inner diameter)	4	
Peripheral Items		
Laptop with USB port & AltOS installed	1	
Micro-USB cable	1	
DT4UTx cable	1	
USB-B-USB-A cable	1	
Tools		
Nitrile gloves	4	
Key switch key	1	
Roll of green masking tape	1	
Roll of orange masking tape	1	
Tarp	1	
Wire stripper	1	
Pliers	1	
0.25” open-end wrench	1	
Terminal screwdriver	1	
Multimeter	1	

Step #	Action	T/S #	Verification
Day Before Launch - Charging Batteries			
3.1.1	VERIFY LiPo fireproof bag is used to protect LiPo battery when charging. **CAUTION**: failure to complete may increase likelihood of LiPo fire occurring		TSO:
3.1.2	CHARGE the LiPo battery to above 3.3V. **CAUTION (LiPo battery)**: possible explosive if overcharged		AL:
3.1.3	MEASURE voltage of 9V battery and VERIFY charge above 8V.		AL:

Programming TeleMetrum Altimeter			
3.2.1	CONNECT key switch and LiPo battery to TeleMetrum.		
3.2.2	CONNECT TeleMetrum to laptop using micro-USB cable.		
3.2.3	OPEN AltOS on laptop.		
3.2.4	SELECT “Configure Altimeter.”		
3.2.5	POSITION Telemetrum face up.		
3.2.6	TURN ON TeleMetrum.		
3.2.7	SELECT TeleMetrum as device.		
3.2.8	SELECT “Settings.”		
3.2.9	SET Altitude of Main Deploy to “700’.”		
3.2.10	SET Apogee Delay to “0 seconds.”		
3.2.11	SET Frequency to “435.550 MHz Channel 0.”		
3.2.12	SET Telemetry/RDF/APRS Enable to “Enabled.”		
3.2.13	SET Telemetry to a Baud rate of “9600.”		
3.2.14	SET APRS interval to “5.”		
3.2.15	SET Callsign.		
3.2.16	SET Maximum Flight Log Size kB to “8192.”		
3.2.17	SET Igniter Firing Mode to “Dual Deploy”.		
3.2.18	SET Pad Orientation to “Antenna Up.”		
3.2.19	VERIFY and SAVE settings.		AL:
3.2.20	SELECT “Save Flight Data.”		AL:
3.2.21	DELETE previous flights.		
3.2.22	TURN OFF TeleMetrum.		
3.2.23	INSERT LiPo battery into fireproof bag.		
Programming StratoLoggerCF Altimeter			
3.3.1	CONNECT DT4UTx cable to USB-B - USB-A cable.		
3.3.2	CONNECT DT4UTx cable to StratoLoggerCF data port.		
3.3.3	CONNECT USB-B - USB-A cable to laptop.		
3.3.4	CONNECT key switch and 9V battery to StratoLoggerCF.		
3.3.5	TURN ON switch.		
3.3.6	OPEN DataCap on laptop.		
3.3.7	SELECT “Altimeter.”		
3.3.8	SELECT “CommPort.”		
3.3.9	SELECT “Altimeter.”		

3.3.10	SELECT "Setup."		
3.3.11	VERIFY comm port set to "COM6."		AL:
3.3.12	SELECT "Settings."		
3.3.13	SET Preset to "600 ft" for main deployment and "2 sec" for delay of drogue deployment.		AL:
3.3.14	SET Siren Delay to "0 seconds".		AL:
3.3.15	SELECT "Update Alt."		
3.3.16	TURN OFF StratoLoggerCF.		
Preparing Parachutes			
3.4.1	TIE ⅓ of shock cord into an overhand loop at one end of the shock cord for both 60' and 40' shock cords.		
3.4.2	Z-FOLD every 10'' of shock cord.		
3.4.3	TAPE z-folds together with a loop of tape in middle, minimizing overlapping tape.		
3.4.4	CONNECT quick links to each of the six loops.		
3.4.5	MARK quick links on longer ends of shock cords with green tape .		
3.4.6	CREATE two z-folds in outer shroud lines of main parachute.		
3.4.7	TAPE z-folds together with a loop of tape in middle, minimizing overlapping tape.		
3.4.8	FOLD parachute into a long and thin form on tarp for protection.		AL:
3.4.9	CONNECT main parachute and double Nomex blanket to middle quick link of 60' shock cord.		
3.4.10	CONNECT drogue parachute and Nomex blanket to middle quick link of 40' shock cord.		
3.4.11	MARK closed quick links with orange tape.		
3.4.12	VERIFY configuration.		AL:
Assembling Avionics Bay			
PPE: nitrile gloves & safety glasses			
3.5.1	CONFIRM all personnel that may contact energetics are wearing PPE. **CAUTION**: failure to carry out may cause hazardous material to come in contact with skin or eyes		TSO:
3.5.2	PLACE 2.5g and 3g black powder charges into black powder canisters on upper bulkhead. **CAUTION (e-match & black powder)**: fire & projectile hazard	**5**	
3.5.3	PACK black powder canisters with cellulose insulation.		
3.5.4	TAPE opening of black powder canisters with masking tape to seal.		AL:
3.5.5	PLACE 1g and 1.5g black powder charges into black powder canisters on lower bulkhead.	**5**	

	CAUTION (e-match & black powder): fire & projectile hazard		
3.5.6	PACK black powder canisters with cellulose insulation.		
3.5.7	TAPE opening of black powder canisters with masking tape to seal.		AL:
3.5.8	PLACE e-match wires in appropriate terminal blocks.		
3.5.9	CUT four pieces of 3” 22 AWG stranded wire.		
3.5.10	TWIST two pairs of wires.		
3.5.11	CRIMP female male JST contacts onto one end of each wire for each set, then slide contacts into JST connector with wire sleeve at interface.		
3.5.12	CUT eight pieces of 10” 22 AWG stranded wire.		
3.5.13	TWIST four individual pairs of wire.		
3.5.14	SCREW a pair of 3” wires into Telemetrum terminals 1 and 2.		
3.5.15	SCREW a pair of 10” wires into Telemetrum terminals 3 and 4.		
3.5.16	SCREW a pair of 10” wires into Telemetrum terminals 5 and 6.		
3.5.17	SCREW pair of 3” wires into StratoLogger “SWITCH” terminals.		
3.5.18	SCREW pair of 10” wires into StratoLogger “MAIN” terminals.		
3.5.19	SCREW pair of 10” wires into StratoLogger “DROGUE” terminals.		
3.5.20	SCREW Telemetrum and StratoLoggerCF altimeters to respective altimeter sled mounting posts with nylon mounting screws.		
3.5.21	PLACE 3.7V LiPo and 9V batteries into appropriate altimeter sled housings.		
3.5.22	CONNECT 3.7V LiPo battery to TeleMetrum.		
3.5.23	CONNECT 9V battery to 9V battery connector.		
3.5.24	SCREW connector into StratoLoggerCF battery terminals.		
3.5.25	VERIFY continuity of TeleMetrum altimeter and battery by turning it on then off.		AL:
3.5.26	VERIFY continuity of StratoLoggerCF altimeter and battery by turning it on then off.		AL:
3.5.27	PLACE battery lids on appropriate batteries. **CAUTION:** failure to complete may increase likelihood of battery spreading fire		
3.5.28	SCREW on battery lids.		
3.5.29	VERIFY proper configuration of altimeter sled.		AL:
3.5.30	SCREW two hex nuts onto each threaded rod, 0.5” between bottom of rod and face of nuts.		
3.5.31	POSITION one washer on each threaded rod, on top of nuts.		
3.5.32	SLIDE lower bulkhead onto threaded rods with face of canisters resting on washers.		
3.5.33	SCREW two hex nuts onto each threaded rod with 0.5” between first hex nut and bulkhead.		

3.5.34	SLIDE altimeter sled onto threaded rods so it rests on hex nut with LiPo battery oriented upward.		
3.5.35	SCREW two hex nuts onto each threaded rod.		
3.5.36	PUSH main parachute wires from altimeters through each hole in lower bulkhead.		
3.5.37	ATTACH and SECURE main e-match connection wires into other ends of corresponding WAGO connectors onto exterior of lower bulkhead.		AL:
3.5.38	VERIFY key switch configuration is “off.” **CAUTION**: failure to complete may cause premature ignition of energetics	**4**	AL:
3.5.39	CONNECT both altimeters to their switch via JST connectors.		
3.5.40	CONNECT coupler and bulkhead, covering altimeter sled.		
3.5.41	VERIFY coupler configuration.		AL:
3.5.42	PUSH drogue parachute wires from each altimeter through appropriate hole in upper bulkhead.		
3.5.43	SLIDE upper bulkhead onto threaded rods.		
3.5.44	SCREW drogue e-match wires into respective ends of upper bulkhead exterior connectors.		AL:
3.5.45	PLACE a washer on each threaded rod.		
3.5.46	SCREW two hex nuts down each threaded rod.		AL:
3.5.47	TURN ON and TURN OFF keylock switch and listen for TeleMetrum initialization beeps. *See Beep Guide.*	**8**	AL:
3.5.48	TURN ON and TURN OFF keylock switch and listen for StratoLoggerCF initialization beeps. *See Beep Guide.*	**8**	AL:

AVIONICS AND RECOVERY PREPARATION COMPLETE?

AL:

5.1.4 Nosecone Camera Preparation

Table 5.1.4.1: Nosecone Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
12V LiPo Battery (in fireproof bag)	1	
Arducam Mini OV5647 camera module	1	
Ultra Tiny GC0307 USB camera	1	
Digi XBee 3 Pro module	2	

Personnel	
Role	**Name**
Avionics Lead (AL)	Payton Gross
Team Safety Officer (TSO)	Julia Spihlman
Nosecone Support #1 (NC1)	Luke Williams
Nosecone Support #2 (NC2)	Maggie McLeod

AKK X2-ultimate video transmitter	1	
Key switch	1	
Raspberry Pi 3B+	1	
OTG FPV Receiver	1	
AGCS	1	
Nosecone	1	
Standard 5.8GHz Antenna	2	
VAS Avenger XR18 Antenna	1	
TrueRC X-AIR MK. II Antenna	1	
5.8GHz Omnidirectional Antenna	1	
Peripheral Items		
Laptop with USB port	1	
Tools		
Key switch key	1	

Step #	Action	T/S #	Verification
	Day Before Launch - Charging Batteries		
4.1.1	VERIFY LiPo fireproof bag is used to protect the LiPo battery when charging. **CAUTION**: failure to complete may increase likelihood of LiPo fire occurring		TSO:
4.1.2	CHARGE LiPo battery to above 11.9V. **CAUTION (LiPo battery)**: possible explosive if overcharged		TSO:
	Assembling Camera System		
4.2.1	PUTTY two cameras to respective nosecone holes.		
4.2.2	WIRE 12V battery to the key switch.		
4.2.3	WIRE key switch to M-USB.		
4.2.4	WIRE RPi Cam Module to CSI Camera.		
4.2.5	CONNECT USB Cam to one of the two 2 x USB terminals.		
4.2.6	CONNECT M-USB of Digi XBee 3 Pro to the 2 x USB terminal that has not been connected to anything.		
4.2.7	CONNECT M-USB of AKK X2- Ultimate to the 2 x USB terminal where Digi XBee 3 Pro is connected.		
4.2.8	CONNECT TrueRC X-AIR MK. II Antenna to AKK X2-Ultimate		
4.2.9	CONNECT standard 5.8ghz antenna to Digi XBee 3 Pro		
4.2.10	SCREW nuts down threaded rods around 1.5in.		
4.2.11	PLACE e-plate down threaded rods to rest on nuts.		

4.2.12	SCREW nuts down threaded rods to secure e-plate.		
Assembling Camera GCS			
4.3.1	CONNECT VAS Avenger XR18 Antenna and Omnidirectional Antenna to OTG Receiver		
4.3.2	CONNECT OTG receiver to Laptop via USB		
4.3.3	CONNECT standard 5.8ghz antenna to GCS Digi XBee 3 Pro		
4.3.4	CONNECT GCS Digi XBee 3 Pro to Laptop via USB		
4.3.5	OPEN camera app on laptop and select USB2.0 camera.		
4.3.6	OPEN XCTU app on laptop.		
4.3.7	SCAN for connected devices and add XBEE.		
4.3.8	SCAN connected XBEE's network and connect e-plate XBEE.		
4.3.9	TURN key switch on to ensure all connections are valid then back off.		NC1:

NOSECONE CAMERA PREPARATION COMPLETE?

AL:

5.1.5 Payload Preparation

Table 5.1.5.1: Payload Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
STEMCRaFT	1	
STEMCRaFT Li-ion	1	
Antenna Transmission LiPo	1	
Main Payload Section with Radio Transmission Module	1	
UART connection cable	1	
Peripheral Items		
Laptop with SDR chip	1	
Test antenna	1	

Personnel	
Role	**Name**
Payload Lead (PL)	Heather Wallace
Team Safety Officer (TSO)	Julia Spihlman

Step #	Action	T/S #	Verification
	Day Before Launch - Charging Batteries		
5.1.1	VERIFY LiPo fireproof bag is used to protect LiPo battery when charging. **CAUTION**: failure to complete may increase likelihood of LiPo fire occurring		TSO:
5.1.2	CHARGE LiPo battery to above 3.3V. **CAUTION (LiPo battery)**: possible explosive if overcharged		PL:
	Electrical Assembly		
5.2.1	CONNECT and SECURE LiPo battery to Radio Transmission Module.		
5.2.2	CONNECT and SECURE LiPo battery to Radio STEMCRaFT.		
5.2.3	CONNECT STEMCRaFT to Radio Transmission Module via UART connection.		
	Test Phase		
5.3.1	CONFIGURE Laptop-basd SDR for set frequency.		
5.3.2	CONFIGURE Laptop-basd SDR for set frequency.		
5.3.3	SIMULATE Landing detection on STEMCRaFT.		
5.3.4	VERIFY Correct received APRS data packets from Laptop-based SDR.		PL:
5.3.5	RESET STEMCRaFT to landing detection mode.		
	Mechanical Assembly		
5.4.1	BOLT STEMCRaFT into payload coupler.		
5.4.2	BOLT motor mount of TDA to the lid of the coupler		
5.4.3	HOOK 3D printed covers of transmission arms to the airframe		
5.4.4	CONNECT payload bay to the payload coupler		
5.4.5	CONNECT transmission arms to hinges and sliders from the outside		
5.4.	VERIFY complete Payload Assembly.		PL:

PAYLOAD PREPARATION COMPLETE?

PL:

5.1.6 R&D Preparation

Table 5.1.6.1: R&D Preparation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
2S LiPo Battery (in fireproof bag)	1	
Coupler threaded rods	3	

Personnel	
Role	**Name**
R&D Lead (RDL)	Gabe Kurfman
Team Safety Officer (TSO)	Julia Spihlman

Coupler bulkplates	2	
Coupler tube	1	
R&D sensor sled	1	
32GB micro SD card	1	
Peripheral Items		
Micro USB to USB programming cord	1	
Micro SD card to USB adapter	1	
Tools		
7/16" open-end wrench	2	
5/32" Allen key	1	
M2 Allen key	1	

Step #	Action	T/S #	Verification
Day Before Launch			
6.1.1	FLASH PCB with latest flight software.		
6.1.2	VALIDATE beep sequence after software is uploaded. *See Beep Guide.*	**10**	
6.1.3	COMPLETE "toss test" by moving to open area and throwing R&D sled ~10 ft. upwards.		
6.1.4	VERIFY data logged from "toss test" matches short ascent profile.		
6.1.5	CLEAR data from SD card and reinsert into sled.		
6.1.6	VERIFY LiPo fireproof bag is used to protect LiPo battery when charging. **CAUTION**: failure to complete may increase likelihood of LiPo fire occurring		TSO:
6.1.7	CHARGE LiPo battery. **CAUTION (LiPo battery)**: possible explosive if overcharged		RDL:
Day of Launch, Before Transport to Field			
6.2.1	PLUG LiPo battery into PCB and secure with velcro strap.		
6.2.2	INSERT sled into R&D coupler section and assemble with x6 ¼-20 nuts.		
6.2.3	SWITCH key switch to ON position and verify beep sequence. *See Beep Guide.*	**10**	
6.2.4	PACK coupler section with bubble wrap and prepare for transport.		

R&D PREPARATION COMPLETE?

RDL:

5.1.7 Full Launch Vehicle Integration

Table 5.1.7.1: Full Launch Vehicle Integration Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
Booster airframe	1	
MFSS	1	
Fins	3	
0.25’’ button head screws	30	
R&D coupler with sled integrated	1	
0.116" diameter shear pins	6	
Lower recovery airframe	1	
Assembled avionics bay (contains energetics)	1	
Drogue parachute with shock cord and quicklinks attached	1	
Main parachute with shock cord and quicklinks attached	1	
Upper recovery airframe	1	
Payload coupler	1	
Payload airframe	1	
Nosecone with cameras integrated	1	
Motor	1	
ANSI #6 screws	6	
Peripheral Items		
Laptop with OpenRocket	1	
Tools		
Green masking tape roll	1	
0.25” hex screwdriver	1	
ANSI screwdriver	1	
Scale	1	

Personnel	
Role	**Name**
Project Manager (PM)	Seth Johnson
Project Engineer (PE)	Jacob Daniel
Team Safety Officer (TSO)	Julia Spihlman
Avionics Lead (AL)	Payton Gross
Construction Lead (CL)	Ryan Do
Payload Lead (PL)	Heather Wallace
R&D Lead (RDL)	Gabe Kurfman

Step #	Action	T/S #	Verification
7.1.1	VERIFY adequate weather conditions; air temperature must be >32°F and <95,°F wind speed must be <20 mph. **CAUTION**: failure to complete may result in damage to components or difficulty		TSO:

	recovering vehicle		
Booster Section			
7.2.1	ATTACH fins to MFSS.		
7.2.2	SCREW MFSS into booster airframe with six 0.25” button head screws.		
7.2.3	INSPECT R&D coupler for debris or residue on contact surfaces. *If present*: clean contact surface **CAUTION**: failure to complete may lead to separation failure		
7.2.4	SCREW R&D coupler into booster airframe with three 0.25” button head screws.		
Lower Recovery Section			
7.3.1	ATTACH quick link of longer end of drogue shock cord (tape indicator) to eyebolt on R&D coupler.		
7.3.2	ATTACH lower recovery airframe to R&D coupler with three shear pins, feeding drogue parachute through the airframe.		
7.3.3	TAPE shear pins in place. **CAUTION**: failure to complete may result in premature separation of launch vehicle.		
7.3.4	ATTACH quick link of shorter end of drogue shock cord (no tape indicator) to eyebolt on lower avionics bulkhead. **CAUTION (avionics bay)**: contains energetics, avoid excessive impact		
7.3.5	FLAG quick links with green tape, signifying closure.		AL:
7.3.6	PLACE drogue parachute and shock cord into lower recovery airframe with parachute completely covered by Nomex blanket. **CAUTION**: failure to cover parachute with Nomex blanket may result in heat damage		AL:
7.3.7	INSPECT avionics bay for debris or residue on contact surfaces. *If present*: clean contact surface **CAUTION**: failure to complete may lead to separation failure		
7.3.8	SCREW lower avionics bay into lower recovery airframe with six 0.25” button head screws. **CAUTION (avionics bay)**: contains energetics, avoid excessive impact		
Upper Recovery Section			
7.4.1	ATTACH quick link of longer end of main shock cord (tape indicator) to eyebolt on upper avionics bulkhead. **CAUTION (avionics bay)**: contains energetics, avoid excessive impact		
7.4.2	ATTACH upper recovery airframe to upper avionics bay, feeding main parachute through the airframe. **CAUTION (avionics bay)**: contains energetics, avoid excessive impact		
7.4.3	SCREW upper avionics bay into upper recovery airframe with six 0.25” button head screws. **CAUTION (avionics bay)**: contains energetics, avoid excessive impact		

7.4.4	ATTACH quick link of shorter end of main shock cord (no tape indicator) to eyebolt on payload bulkhead.		
7.4.5	FLAG quick links with green tape, signifying closure.		AL:
7.4.6	INSERT folded main parachute followed by shock cord into upper recovery airframe with parachute completely covered by Nomex blanket. **CAUTION**: failure to cover parachute with Nomex blanket may result in heat damage		AL:
7.4.7	INSPECT payload coupler for debris or residue on contact surfaces. *If present*: clean contact surface **CAUTION**: failure to complete may lead to separation failure		
7.4.8	ATTACH upper recovery airframe to payload coupler with three shear pins.		
7.4.9	TAPE shear pins in place. **CAUTION**: failure to complete may result in premature separation of launch vehicle.		
7.4.10	TURN ON and TURN OFF avionics key switch to listen for initialization beeps from each altimeter.	**8**	AL:
Payload Section			
7.5.1	SCREW payload coupler into payload airframe with six 0.25'' button head screws.		
7.5.2	SCREW nosecone into payload airframe with three 0.25'' button head screws.		
Finalizing Launch Vehicle			
7.6.1	VERIFY proper alignment and connection of rail buttons.		CL:
7.6.2	VERIFY motor is undamaged.		PM:
7.6.3	INSERT motor into MFSS.		
7.6.4	SCREW the motor retainer plate, below the motor casing lip, to thrust plate with three ANSI #6 screws.		
7.6.5	VERIFY proper alignment and securement of motor.		CL:
7.6.6	WEIGH fully integrated launch vehicle. WEIGHT:		CL:
7.6.8	SELECT launch rail angle per weather conditions and simulations. ANGLE:		AL:
7.6.9	VERIFY all components and materials necessary for launch are prepared for relocation to launch area.		

VEHICLE INTEGRATION COMPLETE?

PM:

5.1.8 Launch Initiation

Table 5.1.8.1: Launch Initiation Procedures

Materials		
Item	**Qty**	**Check**
Launch Vehicle Items		
Fully integrated launch vehicle	1	
Ignitor	1	
Extra AA battery for radio transmitter	1	
Peripheral Items		
Laptop with USB port and AltOS installed	1	
TeleMetrum antenna	1	
Teledongle	1	
Radio transmitter	1	
Laptop with USB port and XTCU installed	1	
Digi XBee 3 Pro module	1	
OTG FPV receiver	1	
Standard 5.8GHz Antenna	1	
VAS Avenger XR18 Antenna	1	
5.8GHz Omnidirectional Antenna	1	
Tools		
Key switch key	1	
Multimeter	1	

Personnel	
Role	**Name**
Project Manager (PM)	Seth Johnson
Project Engineer (PE)	Jacob Daniel
Team Safety Officer (TSO)	Julia Spihlman
Avionics Lead (AL)	Payton Gross
Construction Lead (CL)	Ryan Do
Payload Lead (PL)	Heather Wallace
R&D Lead (RDL)	Gabe Kurfman
Avionics Support #1 (AS1)	–
Nosecone Support #1 (NC1)	Luke Williams
Nosecone Support #2 (NC2)	Maggie McLeod

Step #	Action	T/S #	Verification
Positioning Launch Vehicle on Rail			
8.1.1	SLIDE launch vehicle onto launch rail.		
8.1.2	VERIFY correct connection of rail buttons.		
8.1.3	TURN ON nosecone key switch.		
8.1.4	VERIFY nosecone camera system initializes.		NC1:
8.1.5	ADJUST launch rail angle to that determined in Step 6.6.8.		
8.1.6	CONSTRUCTION: GO FOR LAUNCH?		CL:
Initializing R&D			
8.2.1	TURN ON payload key switch.		
8.2.2	VERIFY all systems initialize. *See Beep Guide.*	**10**	RDL:

8.2.3	PAYLOAD: GO FOR LAUNCH?		RDL:
Initializing Payload			
8.3.1	TURN ON payload switch.		
8.3.2	VERIFY all systems initialize.	**9**	PL:
8.3.3	PAYLOAD: GO FOR LAUNCH?		PL:
Initializing Avionics			
8.4.1	CLEAR all but essential personnel from launch pad (TSO, AL, AS1). **CAUTION**: failure to complete may lead to more personnel injury in the event of an accident		TSO:
8.4.2	VERIFY static port holes clear of debris. **CAUTION**: failure to complete may lead to altimeter reading inaccuracies		
8.4.3	TURN ON TeleMetrum key switch. **CAUTION (black powder charges)**: charges are now live explosives		
8.4.4	VERIFY TeleMetrum initialization beeps. *See Beep Guide.*	**8**	AL:
8.4.5	TURN ON StratoLogger key switch. **CAUTION (black powder charges)**: charges are now live explosives		
8.4.6	VERIFY StratoLogger initialization beeps. *See Beep Guide.*	**8**	AL:
8.4.7	AVIONICS: GO FOR LAUNCH?		AL:
Installing Ignitor			
8.5.1	SLIDE igniter through nozzle until touching smoke element. **CAUTION (motor)**: motor is now live	**3**	
8.5.2	TAPE ignitor into place. **CAUTION**: failure to complete may result in unsuccessful ignition		
8.5.3	TEST ignitor for continuity with multimeter.		PM:
8.5.4	PROJECT MANAGEMENT: GO FOR LAUNCH?		PM:
Setting Up Avionics Ground Station			
8.6.1	ASSEMBLE TeleMetrum antenna; longest prongs at bottom, shortest at top.		
8.6.2	PLUG TeleMetrum antenna into TeleDongle.		
8.6.3	PLUG TeleDongle into laptop with AltOS installed.		
8.6.4	OPEN AltOS.		
8.6.5	SELECT "Monitor Flight."		
8.6.6	SELECT "TeleDongle" device.		
8.6.7	CONTINUE to telemetry window.		
8.6.8	VERIFY frequency is set to "434.550 MHz Channel 0."		
8.6.9	VERIFY baud rate is set to "9600 baud."		
8.6.10	VERIFY TeleMetrum's live telemetry appears on screen.		

8.6.11	VERIFY every light is green.		
8.6.12	VERIFY battery.		
8.6.13	VERIFY battery voltage greater than 3.3V.		
8.6.14	VERIFY on-board Data Logging reads "ready to record."		
8.6.15	VERIFY greater than 4 GPS satellites in solution; this may take a moment.		
8.6.16	VERIFY GPS Ready reads "Ready".		
8.6.17	VERIFY launch area fills Site Map.		
Setting Up Nosecone Camera Ground Station			
8.7.1	CONNECT VAS Avenger XR18 Antenna and Omnidirectional Antenna to OTG Receiver.		
8.7.2	CONNECT OTG receiver to Laptop via USB.		
8.7.3	CONNECT standard 5.8ghz antenna to GCS Digi XBee 3 Pro.		
8.7.4	CONNECT GCS Digi XBee 3 Pro to Laptop via USB.		
8.7.5	OPEN camera app on laptop and select USB2.0 camera.		
8.7.6	OPEN XCTU app on laptop.		
8.7.7	SCAN for connected devices and add XBEE.		
8.7.8	SCAN connected XBEE's network and connect e-plate XBEE.		
8.7.9	SEND “start recording signal” from XBee transmitter from AGCS.		

VEHICLE INITIATION COMPLETE?

PM:

5.1.9 Flight

Table 5.1.9.1: Flight Procedures

Materials		
Item	**Qty**	**Check**
Peripheral Items		
Laptop with USB port and AltOS installed	1	
TeleMetrum antenna	1	
Teledongle	1	
Radio transmitter	1	
SoloGood FPV Monitor receiver	1	
Laptop with USB port and XTCU installed	1	
Digi XBee 3 Pro module	1	

Personnel	
Role	**Name**
Team Safety Officer (TSO)	Julia Spihlman
Avionics Lead (AL)	Payton Gross
Payload Lead (PL)	Heather Wallace
R&D Lead (RDL)	Gabe Kurfman
Avionics Support #1 (AS1)	–
Nosecone Support #1 (NC1)	Luke Williams
Nosecone Support #2 (NC2)	Maggie McLeod

OTG FPV receiver	1	
Standard 5.8GHz Antenna	1	
VAS Avenger XR18 Antenna	1	
5.8GHz Omnidirectional Antenna	1	
Tools		
First aid kit	1	
Fire extinguisher	1	
Camera	1	

Step #	Action	T/S #	Verification
Safety & Ignition			
9.1.1	PRESENT safety briefing to team prior to launch. **CAUTION**: failure to complete may result in more personnel injury in the event of an accident		TSO:
9.1.2	EXAMINE sky for objects and surroundings for potential fire. *If present*: immediately notify RSO and spectators **CAUTION**: failure to complete may result in more personnel injury in the event of fire	**2**	TSO:
9.1.3	CONDUCT 5-second countdown. **CAUTION**: failure to complete may result in more personnel injury in the event of an accident		TSO:
9.1.4	IGNITE launch vehicle motor.	**6, 7**	PM:
9.1.5	RECORD launch vehicle with camera for duration of flight.		
9.1.6	VISUALLY TRACK launch vehicle for duration of flight.	**1**	
Avionics Monitoring			
9.2.1	MONITOR launch vehicle trajectory via CONOPS.		
9.2.2	EXAMINE launch vehicle trajectory for off-nominal conditions. *If present*: alert RSO and spectators. **CAUTION**: failure to complete may result in more personnel injury in the event of an accident	**1**	
Payload Monitoring			
9.3.1	DETERMINE landing zone relative azimuth & range through visual information and/or avionics data.		
9.3.2	MONITOR Ground-Station APRS receiver for incoming data transmission.		
Nosecone Camera Monitoring			
9.4.1	RECEIVE live stream footage from USB camera via AKK X2-ultimate video transmitter.		

5.1.10 Retrieval

Table 5.1.10.1: Retrieval Procedures

Materials		
Item	**Qty**	**Check**
Tools		
First aid kit	1	
Fire extinguisher	1	
Nitrile gloves	7	
Safety glasses	7	
Key switch key	1	
Camera	1	

Personnel	
Role	**Name**
Project Manager (PM)	Seth Johnson
Project Engineer (PE)	Jacob Daniel
Team Safety Officer (TSO)	Julia Spihlman
Avionics Lead (AL)	Payton Gross
Payload Lead (PL)	Heather Wallace
R&D Lead (RDL)	Gabe Kurfman
Avionics Support #1 (AS1)	-
Nosecone Support #1 (NC1)	Luke Williams
Nosecone Support #2 (NC2)	Maggie McLeod

Step #	Action	T/S #	Verification
PPE: nitrile gloves & safety glasses			
10.1	VERIFY all personnel who may contact energetics are wearing appropriate PPE. **CAUTION**: failure to complete may result in hazardous material to come in contact with skin or eyes		TSO:
10.2	GATHER fire extinguisher and first aid kit. **CAUTION**: failure to complete may result in more personnel injury in the event of an accident		TSO:
10.3	APPROACH launch vehicle carefully until 15’ away. **CAUTION (terrain)**: watch surroundings for uneven ground or other obstacles		
10.4	VERIFY visually nominal landing.	**2, 11**	TSO:
10.5	INSPECT black powder canisters for undetonated charges. *If present*: clear landing area and contact RSO **CAUTION (black powder charges)**: live energetic **CAUTION**: failure to complete may result in severe personnel injury		AL:
10.6	RECORD beeps given by altimeters. *See Beep Guide.* Telemetrum: ______ StratoLogger: ______		AL:
10.7	TURN OFF avionics key switch.		AL:
10.8	PHOTOGRAPH landing configuration of launch vehicle.		

10.9	ALERT personnel that launch vehicle is safe to approach within 15’.		TSO:
10.10	TURN OFF nosecone camera key switch.		
10.11	TURN OFF R&D key switch.		
10.12	TURN OFF payload key switch.		
10.13	COLLECT all launch vehicle components. **CAUTION (motor)**: motor may still be hot and may cause burns if not handled with care **CAUTION**: failure to collect all pieces of launch vehicle may cause harm to environment		
10.14	RETURN components to ground station. **CAUTION (terrain)**: watch surroundings for uneven ground or other obstacles		

5.1.11 Beep Guide

Table 5.1.11.1: Altimeter Initialization Guide

Order	Beeps	Meaning
TeleMetrum Altimeter		
1	2-3 digit counts	Battery Voltage (to the tenth)
2	dit dah dah dit	Pad Mode
3	3 dits	Continuity
StratoLoggerCF Altimeter		
1	short siren, 1+ digit counts	Error Code
2	2 beeps	Preset #
3	5, 10, 10 beeps	Main Deploy Altitude (to the ones in feet)
4	1 long beep	Apogee Delay
5	3-6 digit counts	Previous Flight Apogee (ft)
6	2-3 digit counts	Battery Voltage (to the tenth)
7	3 beeps	Continuity

Table 5.1.11.2: Altimeter Post-Flight Readout Guide

Order	Beeps	Meaning
TeleMetrum Altimeter		
-	digit counts, dah for zero digit	Apogee (m)
StratoLoggerCF Altimeter		
1	3-6 digit counts	Apogee (ft)
2	2-5 digit counts	Maximum Velocity (mph)

Table 5.1.11.3: R&D Sled Initialization Guide

Beeps	Meaning
1 low, repeating	SD initialization failed or SD is missing
2 low, repeating	Pressure sensor initialization failed
3 low, repeating	Accelerometer initialization failed
3 high	Initialization complete
0 for >30s	Battery or continuity failure

5.1.12 Troubleshooting and Emergency Procedures

Table 5.1.12.1: Troubleshooting and Emergency Procedures

1) Ballistic Trajectory
CALL "scatter" *if launch vehicle has been in free-fall for greater than 4 seconds with no sign of parachute ejection.*
(**All Launch Spectators**) RUN away from launch vehicle for minimum of 20 seconds or until "all clear" is called.
EXAMINE personnel for injuries or burns. *If present:* administer first aid or call 911 if needed.

2) Launch Pad/Landing Site Fire
CLEAR area of personnel, flammable materials, & energetics.
EXTINGUISH any flames with fire extinguisher.
EXAMINE launch vehicle, any neighboring launch vehicles, ignition system *if on launch pad*, & surroundings for damage. *If present*: report findings to respective personnel or authorities.
EXAMINE personnel for injuries or burns. *If present:* administer first aid or call 911 if needed.

3) Premature Motor Ignition
TAKE COVER *if motor becomes projectile*.
CLEAR area of personnel, flammable materials, & energetics.
EXTINGUISH any flames with fire extinguisher.
EXAMINE personnel for injuries or burns. *If present:* administer first aid or call 911 if needed.

4) Unintended Black Powder Ignition
CLEAR area of personnel, flammable materials, & energetics.
EXTINGUISH any flames with fire extinguisher.
EXAMINE personnel for injuries or burns. *If present:* administer first aid or call 911 if needed.

5) Black Powder Spill
CLEAR area of personnel, flammable materials, & energetics
(**Clean-Up Personnel**) WEAR gloves & safety glasses.
FUNNEL black powder into its container by sweeping powder with gloved hand.
WIPE remaining black powder off surface with wet cleaning wipe.
EXAMINE personnel for eye or skin reactions from black powder. *If present:* thoroughly rinse skin or eyes.

6) Ignitor Discontinuity
DISARM launch controller.
WAIT minimum of 60 seconds before approaching launch vehicle.
(**Team Mentor**) APPROACH launch vehicle & INSPECT connections.
WEAR gloves *if handling used ignitors or motors.*
REPLACE ignitor *if discontinuity continues.*

7) Motor Failure
DISARM launch controller.
WAIT minimum of 60 seconds before approaching launch vehicle.
(**Team Mentor**) APPROACH launch vehicle
DISARM avionics bay
WEAR gloves *if handling used ignitors or motors.*
REPLACE motor *if necessary.*
DETERMINE whether launch reattempt is possible. *If possible*: return to launch initiation procedures.

8) Avionics Initialization Failure
TeleMetrum Altimeter
IF "dah dit dit dah": error in sensor calibration.
IF 2 dits: only main has continuity.
IF 1 dit: only drogue has continuity.
IF brap: no continuity (storage is full).
StratoLoggerCF Altimeter
IF short siren, 1+ digit counts: abnormal previous flight error code.
IF 4 beeps does not occur: preset failure.
IF 6, 10, 10 beeps do not occur: main deploy altitude is unknown.
IF one long beep does not occur: apogee delay was not set.
IF 2 beeps or 1 beep did not occur: no continuity.
IF 2 beeps: only main has continuity.
IF only 1 beep: only drogue has continuity.

9) Payload Initialization Failure
Sensor Package
IF no green light on sensor package: check charge on Li-ion battery and plug/unplug.
Radio Transmission System
IF APRS Packet fails to transmit to laptop SDR: restart RTS.
IF NO transmission still occurs: check RTS battery.
IF Antennae fail to deploy: check linear actuators properly configured.

10) R&D Initialization Failure
IF 1 low, repeating beep: SD initialization failed or SD is missing.
IF 2 Low, repeating beeps: pressure sensor initialization failed.
IF 3 Low, repeating beeps: accelerometer initialization failed.
IF no beeps for >30s: battery or continuity failure.

11) Unsafe Landing Site
ALERT RSO of landing site.
ALERT relevant authorities of the property, including power company *if in power lines*.
DO NOT retrieve launch vehicle or components *if in tall tree or power lines*.

5.2 Risk Assessment

To identify and evaluate potential hazards posed by the project, several hazard analyses were performed by the Team Safety Officer. Each area of the competition cycle and design process were considered in this analyses, including hazards posed to personnel, hazards posed to the goal of the project as a whole, hazards posed to and from the environment, and failure modes of the launch vehicle, its systems, and launch operations. These four types of hazards are broken up into the following tables, including Personnel Hazard Analysis, Failure Modes and Effect Analysis, Environmental Concerns, and Project Risk Assessment. For the Personnel Hazard Analysis, Failure Modes and Effect Analysis (FMEA), and Environmental Concerns tables, the rating scale for the severity of a hazard's consequence (C) and its likelihood (L) can be seen in Figure 5.2.1. This evaluation system was developed in accordance with the Risk Assessment Code (RAC) in Appendix C and created following the guidelines provided in S3001: Guidelines for Risk Management and ISO 31000:2018 - Risk Management as well as other NASA and industry documents.

Likelihood \ Consequence	1	2	3	4	5
5	6	16	20	23	25
4	5	13	18	22	24
3	4	10	15	19	21
2	2	8	11	14	17
1	1	3	7	9	12

Figure 5.2.1: RAC Diagram

Risks affecting the project's budget, resources, and timeline, as included in the Project Risk Assessment, were analyzed using a simplified version of the likelihood and consequence rankings in Figure 5.2.1. This simplified version of the RAC diagram can be seen in Figure 5.2.2.

Likelihood \ Consequence	1	2	3
3	4	7	9
2	2	6	8
1	1	3	5

Figure 5.2.2: RAC Diagram for Project Risk Assessment

Table 5.2.1 illustrates the ranges of combined consequence and likelihood RAC scores for both the original RAC used for the Personnel Hazard Analysis, Failure Modes and Effect Analysis, and Environmental Concerns and the simplified RAC used for the Project Risk Assessment, and their levels of acceptance by the team. For all hazards, mitigations and verifications have been put into place by the Team Safety Officer to minimize their consequence and likelihood. Extra measures will be taken to reduce all hazards to a post-mitigation and verification RAC score within the preferred and acceptable ranges.

Table 5.2.1: RAC Acceptance Levels

Acceptance Level	RAC Score Range	Project Risk RAC Score Range
Preferred	1-6	1-4
	7-10	
Acceptable	11-15	5-6
Unacceptable	16-19	7-9
	20-25	

In each of the following analysis tables, the column C-L 1 states the initial ratings of the severity of the consequence and likelihood for each hazard. The RAC 1 column then provides the initial risk score for the hazard. The C-L 2 and RAC 2 columns then state the final ratings of consequence severity and likelihood and final risk score, respectively, following the introduction and implementation of the proposed mitigations and verifications for each hazard. In each analysis table, the hazards are ranked in order of highest to lowest post-mitigation risk score for each hazard type or system to indicate hazards of greater significance to be aware of.

At this phase in the competition cycle, the majority of safety verifications have been introduced to the team. Verification means such as special instruction in procedures, design considerations, testing results, system drawings, and briefings have been utilized by the team to ensure the mitigation of hazards. During each of the team's weekly general meetings, a "Safety Minute" presentation is given to by the Team Safety Officer covering how to mitigate a different personnel hazard, such as proper PPE, best practices when working with energetics, fire safety and prevention, and more.

5.2.1 Personnel Hazard Analysis

Table 5.2.1.1: Personnel Hazard Analysis

Task	Hazard	Cause	Effect	C-L 1	RAC 1	Mitigations	Verification	C-L 2	RAC 2
Testing	**Excessive Ejection Charge Size**	Improper calculation or measurement of ejection charges.	Moderate to severe burns. Severe injury. Death.	5-3	21	Utilize team standard formula for calculation ejection charge sizing. Verify calculations with cross-reference between multiple personnel.	Avionics Lead and Team Safety Officer shall oversee the measurement of ejection charges during ground testing. **See section 3.7.2.2, Ejection Charges and Deployment Mechanisms.**	5-1	12
						PPE such as safety glasses, gloves, and masks in the absence of proper ventilation shall be worn during ejection charge ground testing.	Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches.		
	Electrocution	Improper wiring.	Mild to severe burns. Cardiac arrest.	5-2	17	Label all high-voltage equipment. Personnel must be grounded when working with high-voltage equipment. All wiring must be insulated.	Team Safety Officer shall perform regular inspection of high-voltage equipment to ensure labels are present.	5-1	12
	Unintended Black Powder Ignition	Accidental exposure to flame or heat source. Close proximity to significant electric charge.	Hearing damage. Mild to severe injury.	5-2	17	Store black powder in a cool, dry place away from heat. Label all containers storing black powder.	Team Safety Officer shall perform regular inspection of storage and handling practices.	3-2	11
						Safety glasses and gloves must be used by all personnel handling black powder. If space in which black powder is being handled does not have good ventilation, masks must be worn.	Team Safety Officer shall create and post a check-in and out form to monitor only permitted personnel handling black powder. Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches.		
						Provide resources for black powder safety.	Black powder safety covered in weekly "Safety Minute." **See Troubleshooting and Emergency Procedures, section 4.**		
	Black Powder Spill	Improper storage & handling. Wind guts.	Respiratory damage. Eye irritation. Skin irritation.	4-3	19	Store black powder in a cool, dry place away from heat. Label all containers storing black powder.	Team Safety Officer shall perform regular inspection of storage and handling practices.	1-3	4
						Safety glasses and gloves must be used by all personnel handling black powder. If space in which black powder is being handled does not have good	Team Safety Officer shall create and post a check-in and out form to monitor only permitted personnel handling black powder. Gloves, masks, and safety glasses shall be provided by the		

						ventilation, masks must be worn.	Team Safety Officer at all tests, work days, and launches.		
						Provide resources for black powder safety.	Black powder safety covered in weekly "Safety Minute." **See Troubleshooting and Emergency Procedures, section 5.**		
Construction	**Entanglement with Construction Equipment**	Loose hair, clothing, or jewelry. Improper equipment usage.	Moderate to severe injury.	5-4	24	Work-day attire shall consist of closed-toe shoes, tied back hair, removal of loose jewelry, shirts without loose sleeves, and long pants. Appropriate PPE such as gloves, masks, and safety glasses must be worn when using equipment.	Team Safety Officer shall perform checks for proper PPE and attire at the beginning of work days. Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches. Proper work day attire covered in weekly "Safety Minute."	5-1	12
						Personnel must be trained on each piece of construction equipment before being permitted to use it.	Online safety training must be completed by personnel in order to gain access to workspace in the BIDC.		
	Workspace Fire	Unintended ignition of flammable material. Electrical or equipment failure. Poor housekeeping. Poor ventilation.	Moderate to severe burns.	5-2	17	Inform personnel of location of fire exits and fire extinguishers in each workspace.	Locations of fire exits and fire extinguishers shall be announced by Team Safety Officer at beginning of work days. Fire safety and prevention shall be presented in weekly "Safety Minute."	5-1	12
	Eye Contact with Debris	Sawdust. Metal shavings. Glass fibers.	Eye irritation. Eye damage. Vision loss.	4-4	22	Safety glasses must be worn when working materials and components.	Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches. Team Safety Officer shall perform regular checks for proper PPE during work days.	4-1	9
	Inhalation of Byproducts	Epoxy resin. Sawdust. Solder flux. Fiberglass. PLA, PETG, & ASA filament.	Cough. Shortness of breath. Lung damage.	5-3	21	Masks shall be worn when working with epoxy resin or fiberglass, or when cutting materials.	Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches. Team Safety Officer shall perform regular checks for proper PPE during work days.	4-1	9
						3D printing shall be done in rooms of adequate ventilation and ASA shall be printed using an enclosure.	The team shall only utilize facilities equipped with proper ventilation to 3D print such as the PTC and the Purdue Rapid Prototyping Lab.		

						Soldering shall be done under a fan.	Subteam leads and Team Safety Officer shall monitor that only personnel that have undergone soldering training solder. Fans shall be available at all soldering stations.		
	Heavy Lifting	Improper lifting method. Moving & lifting heavy objects in the workplace.	Mild to severe muscle strain.	4-4	22	Personnel shall work together or use a dolly to move large and heavy items. Train personnel on proper posture and techniques for lifting and moving in accordance with OSHA standards.	Heavy lifting covered in weekly "Safety Minute."	3-1	7
	Loud Noise Exposure	Machinery. Power tools.	Hearing damage. Tinnitus.	5-3	21	Earmuffs or earplugs must be worn when working with machinery with an average noise level of 85 decibels or higher per OSHA standards.	Team Safety Officer shall ensure earplugs or earmuffs are available at all workspaces including the BIDC, PTC, and Potter Engineering Center.	3-1	7
	Falling Objects	Improper storage of materials & tools.	Bruising. Cuts. Mild to moderate injury.	4-3	19	Store items and materials in a maximally inert state to reduce the chances of falling. Storage shall be designed so dangerous/heavy tools/materials are not stored in high places.	Construction Lead shall perform inspection of storage practices at the end of each work day to ensure compliance and alert team of improper storage methods.	3-1	7
						Label storage locations of items.	Storage locations shall be allocated by Project Management at the beginning of the competition year in accordance with 5S practices.		
	Skin Contact with Epoxy	Resin spill. Improper resin cleanup.	Mild skin irritation. Allergic reaction.	3-3	15	Gloves must be worn when working with epoxy.	Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches. Team Safety Officer shall perform regular checks for proper PPE during work days.	2-1	3
	Contact with Heat Source	Touching recently worked vehicle components. Improper usage of soldering iron.	Moderate to severe burns.	4-3	19	Gloves must be worn when working with applicable tools, machinery, and components. Equipment and tools must be turned off when not in use. Soldering must only be done by trained personnel.	Gloves, masks, and safety glasses shall be provided by the Team Safety Officer at all tests, work days, and launches. Team Safety Officer shall perform regular checks for proper PPE during work days.	2-1	3
						Long pants and closed-toe shoes must be worn on work days.	Team Safety Officer shall check for proper attire at the beginning of each work day.		

							Proper work day attire covered in weekly "Safety Minute."		
	Slipping & Tripping Hazards	Improper storage & cleanup of materials & equipment. Unsecured cords & cables.	Bruising. Cuts. Mild to moderate injury.	4-3	19	Workspaces must have adequate lighting. Tape loose cords and wires out of the way of walkways.	The PTC, BIDC, and Potter Engineering Center will be utilized as workspaces by the team and have been approved by the Project Manager for these standards.	2-1	3
						Label storage locations for all items.	Storage locations shall be allocated by Project Management at the beginning of the competition year in accordance with 5S practices.		
						Brief personnel on proper cleanup procedures.	Construction Lead shall perform inspection of storage practices at the end of each work day to ensure compliance and alert team of improper storage methods. OSHA slips, trips, and falls prevention covered in weekly "Safety Minute."		
	Ergonomic Strain	Repetitive motions. Improper posture.	Muscle pain. Carpal tunnel syndrome.	2-4	13	Train personnel on proper posture and ergonomics for working in accordance with OSHA standards.	Posture and ergonomics covered in weekly "Safety Minute."	1-2	2
Launch	**Ballistic Trajectory**	Recovery system failure. Unawareness of vehicle descent.	Severe injury. Death.	5-3	21	Personnel must stay a minimum of 100 ft away from the launch pad per NAR Minimum Distance Table. Utilize a 5-second countdown as described in the NAR High Power Rocket Safety Code, section 6. All personnel must keep a heads up position during the entirety of the flight. Point at launch vehicle while airborne.	Team Safety Officer shall deliver a safety briefing highlighting these safety measures prior to each launch. **See Flight Procedures, step 9.1.1.**	5-1	12
						Procedures shall be made available for the event of a ballistic trajectory.	**See Troubleshooting and Emergency Procedures, section 1.**		
	Downed Power Lines	Vehicle collision with power lines.	Fatal electrocution.	5-2	17	Select launch site adequate distance away from power lines per NAR Minimum Safe Distance Table.	Primary launch location shall be the Purdue Dairy Farm and secondary shall be Indiana Rocketry Inc, Pence HP field, which both satisfy a minimum diameter of cleared area of 50 ft.	5-1	12
						Launch vehicle must not be recovered from power lines and authorities must be notified per the NAR High	**See Troubleshooting and Emergency Procedures, section 11.**		

						Power Rocketr Safety Code, section 13.			
	Premature Ignition	Short circuit. Improper motor & ignitor installation. Improper motor storage.	Moderate burns. Moderate to severe injury.	5-2	17	Prepare energetic devices only immediately prior to flight. Store energetic devices properly away from heat sources and handle them with care.	Warnings issued in procedures to handle energetic devices with care at appropriate steps. **See Motor Preparation Procedures, step 1.23.**	5-1	12
						Have procedures in place in case of premature ignition.	**See Troubleshooting and Emergency Procedures, section 3.**		
	Difficult Terrain	Uneven ground. Poisonous plants. Fast-moving water.	Mild to moderate injury. Infection. Drowning.	5-2	17	Notify all personnel of any potentially hazardous terrain. Set boundaries that shall not be crossed at the launch location before the launch operations begin and communicate these areas to attendees.	Team Safety Officer is responsible for notifying personnel of these dangers and overseeing the retrieval of the launch vehicle. **See Retrieval Procedures, step 10.3.**	4-1	9
						Do not attempt to recover launch vehicle from dangerous areas per the NAR High Power Rocketr Safety Code, section 13.	**See Troubleshooting and Emergency Procedures, section 11.**		
						Wear appropriate shoes and clothing for the launch site's terrain.	Team Safety Officer shall send reminder to personnel the day before launch of appropriate attire.		
	Low Temperature	Cold weather on launch day.	Hypothermia. Moderate to severe injury. Hospitalization.	5-3	21	Do not launch or hold work days outdoors on days of extreme cold temperatures less than 32°F.	Project Manager and Team Safety Officer shall monitor weather prior to any scheduled team event.	1-3	4
						Ensure personnel are properly dressed for cold weather.	The Project Manager and Team Safety Officer shall inform personnel before the event of expected weather and dismiss those who are not adequately dressed from the event.		
	High Temperature	Hot weather on launch day.	Heatstroke. Exhaustion. Hospitalization.	4-3	19	Do not launch or hold work days on days of extreme hot temperatures greater than 95°F as labeled as a danger by OSHA.	Project Manager and Team Safety Officer shall monitor weather prior to any scheduled team event.	1-3	4
						Ensure personnel drink adequate amounts of water.	Project Manager and Team Safety Officer shall provide or ensure water is available at the location of the event.		
	Launch Pad/Landing Site Fire	Motor malfunction.	Moderate burns.	3-2	11	Have readily available fire extinguisher at all times. Use protective ground tarp during assembly.	Team Safety Officer shall carry fire extinguisher throughout duration of launch day for increased accessibility.	2-1	3

		Dry grass & leaves on launch pad. Damage to components.				Stand adequate distance away from the launch vehicle during launch.	A Safety Briefing shall be presented by the Team Safety Officer before every launch instructing all personnel to stay a minimum of 100 ft away from the launch pad per NAR Minimum Distance Table.		
						Avoid crowding of unnecessary personnel near launch pad & landing site.	**See Launch Initiation Procedures, step 8.4.1 and Retrieval Procedures, step 10.3.**		
						Have procedures in place in case of fire.	**See Troubleshooting and Emergency Procedures, section 2.**		
	Hot Motor	Touching motor too soon after landing. Close proximity to vehicle on pad.	Mild to moderate burns.	3-2	11	Stand adequate distance away from the launch vehicle during launch.	A Safety Briefing shall be presented by the Team Safety Officer before every launch instructing all personnel to stay a minimum of 100 ft away from the launch pad per NAR Minimum Distance Table.	2-1	3
						Gloves must be worn when handling potentially hot motor.	**See Troubleshooting and Emergency Procedures, sections 6 and 7.**		
						Do not touch the motor during retrieval of the launch vehicle.	The Team Safety Officer shall warn all retrieval personnel to carefully handle the booster section. **See Retrieval Procedures, step 10.13.**		
	Jet Blast Projectiles	Uncleared launch pad. Close proximity to launch pad.	Mild to moderate injury.	3-2	11	Stand adequate distance away from the launch vehicle during launch.	A Safety Briefing shall be presented by the Team Safety Officer before every launch instructing all personnel to stay a minimum of 100 ft away from the launch pad per NAR Minimum Distance Table.	2-1	3

5.2.2 Failure Modes and Effect Analysis

Table 5.2.2.1: Failure Modes and Effects Analysis

Component	Failure Mode	Cause	Effect	C-L 1	RAC 1	Mitigations	Verification	C-L 2	RAC 2
Avionics & Recovery									
Ejection Charges	**Ejection Failure**	Faulty wiring. Inadequate ejection charge sizes.	Failure to shear pins. Absence of parachute deployment. Ballistic trajectory. Destruction of vehicle.	5-3	21	Utilize team standard formula for calculation ejection charge sizing. Verify calculations with cross-reference between multiple personnel.	Avionics Lead and Team Safety Officer shall oversee the measurement of ejection charges during ground testing. **See section 3.7.2.2, Ejection Charges and Deployment Mechanisms.**	5-1	12
						Test ejection charge design and sizes prior to launch.	Ejection charge ground testing must be successfully completed prior to launch. **See Figure 6.1.1.3: Black Powder Ejection Verification Test.**		
Batteries	**Power Loss**	Faulty wiring. Lack of charge. Overcharge. Old age.	Unprovoked ejection charges. Partial to total destruction of vehicle. Ballistic trajectory.	5-3	21	Properly charge batteries the day before launch.	**See Avionics and Recovery Preparation Procedures, step 3.1.2 and 3.1.3.**	5-1	12
						Test batteries prior to launch to ensure proper function.	Battery continuity testing must be successfully completed for both 9V battery and 3.7V LiPo battery prior to launch. **See Figure 6.1.1.1: Altimeter Continuity and Battery Drain Verification Test.**		
	Fire	Overcharge. Puncture. Overheating.	Battery destruction. Destruction of vehicle. Ballistic trajectory.	5-2	17	Properly charge batteries the day before launch.	**See Avionics and Recovery Preparation Procedures, step 3.1.2 and 3.1.3.**	5-1	12
						Design altimeter sled to contain housings for batteries to protect them from impact with the ground and label batteries as a fire hazard.	**See section 3.7.2.1: Altimeter Sled and Requirement S.A.4.**		
Altimeters	**Premature Ejection**	Faulty altimeter programming or wiring. Poor venting.	Premature stage separation. Loss of vehicle. High drift.	5-3	21	Check that static port holes are clear of debris prior to launch.	**See Launch Initiation Procedures, step 8.4.2.**	5-1	12
	Delayed Ejection	Faulty altimeter programming or wiring. Poor venting.	Excessive landing energy. Disqualification. Partial destruction of vehicle.	5-3	21	Test altimeters to ensure capability to ignite ejection charge at desired flight times prior to launch.	Altimeter vacuum testing must be successfully completed for both Telemetrum and Stratologger altimeters prior to launch. **See Figure 6.1.1.2: Altimeter Ejection Vacuum Verification Test.**	5-1	12

						Check that static port holes are clear of debris prior to launch.	**See Launch Initiation Procedures, step 8.4.2.**		
	Altimeter Failure	Improper programming. Faulty wiring. Altimeter defect.	Absence of parachute deployment. Partial to total destruction of vehicle. Ballistic trajectory.	5-2	17	Test altimeters to ensure maintenance of continuity throughout extreme temperatures and forces prior to launch.	Altimeter continuity and force testing must be successfully completed for both TeleMetrum and StratoLoggerCF altimeters prior to launch. **See Figure 6.1.1.1: Altimeter Continuity and Battery Drain Verification Test and Figure 6.1.1.5: Force Drop Verification Test.**	5-1	12
						Verify proper altimeter initialization prior to flight.	**See Launch Initiation Procedures, step 8.4.4 and step 8.4.6 and Troubleshooting and Emergency Procedures, section 8.**		
	Entanglement	Improper packing. Excessive ejection charge sizing. Inadequate parachute size.	Shock cord does not fully extend. Parachute does not fully inflate. Ballistic trajectory. Failed recovery.	5-3	21	Select a proper sized parachute to prevent unstable deployment. Test parachute to verify sizing.	**See section 3.7.3.1: Parachutes and Figure 6.1.1.4: Parachute Drop Verification Test.**	5-1	12
						The packing of parachutes and sealing of parachute chambers must be supervised.	Avionics Lead must sign-off the folding of the main parachute and insertion of main parachute into its chamber. **See Avionics and Recovery Preparation Procedures, step 3.4.8 and Full Launch Vehicle Integration Procedures, step 7.4.6.**		
						Utilize team standard formula for calculation ejection charge sizing. Verify calculations with cross-reference between multiple personnel.	Avionics Lead and Team Safety Officer shall oversee the measurement of ejection charges during ground testing. **See section 3.7.2.2, Ejection Charges and Deployment Mechanisms.**		
						Test ejection charge design and sizes prior to launch.	Ejection charge ground testing must be successfully completed prior to launch. **See Figure 6.1.1.3: Black Powder Ejection Verification Test.**		
	Deployment Failure	Improper packing.	Recovery failure. Partial to total destruction of vehicle.	5-3	21	The packing of parachutes and sealing of parachute chambers must be supervised.	Avionics Lead must sign-off the folding of the main parachute and insertion of main parachute into its chamber. **See Avionics and Recovery Preparation Procedures, step 3.4.8 and Full Launch Vehicle**	5-1	12

							Integration Procedures, step 7.4.6.		
	Breakage or Disconnection of Shock Cord	Weak shock cord. Faulty eye-bolt. Faulty quick link.	Loss of parachute. Recovery failure. Partial to total vehicle destruction.	5-2	17	Utilize shock cords made of material with high strength and heat ratings with adequate thickness.	Selected Kevlar shock cord has a strength rating of 3600 lb and is rated heat resistant to 800ºF. **See section 3.7.3.3: Shock Cords.**	5-1	12
						Utilize eye-bolts with high strength ratings.	Selected stainless steel eye-bolts are strength rated to 500 lbs. **See section 3.7.3.4: Attachment Hardware.**		
						Utilize quick links with high strength ratings.	Selected quick links have a strength rating of 880 lbs. **See section 3.7.3.4: Attachment Hardware.**		
	Breakage of Shroud Lines	Improper ejection. Previous flight or transportation damage.	Loss of parachute. Recovery failure. Partial to total vehicle destruction.	5-2	17	Only buy parachutes from reliable sources.	**See Table 3.7.3.1.1: WDM for Main Parachute.**	5-1	12
						Z-fold the shroud lines of the main parachute to prevent potential breakage upon deployment.	**See Avionics and Recovery Preparation Procedures, steps 3.4.6 and 3.4.7.**		
						Test parachute for proper function prior to launch.	Parachute drop test must be successfully completed for the main parachute prior to launch. **See Figure 6.1.1.4: Parachute Drop Verification.**		
	Heat Damage	Absence of Nomex blanket. Improper packing. Improper ejection charge size.	Recovery failure. Partial to total destruction of vehicle.	5-2	17	Utilize a Nomex blanket and allocate plenty of space for the drogue parachute in design. Confirm that the Nomex blanket entirely covers the parachute prior to launch.	Avionics Lead shall confirm the configuration of the main parachute and Nomex blanket. **See Full Launch Vehicle Integration Procedures, step 7.3.11 and section 3.2.2.6: Heat Shielding.**	5-1	12
Connectors	**Disconnection between E-Matches and Altimeters**	Faulty connector. Connection works loose.	Absence of parachute deployment. Ballistic trajectory. Destruction of vehicle.	5-2	17	Choose connectors that can withstand extreme temperatures of high altitude and ejection charge ignition.	The chosen connectors, Wago 221-412 connectors, have been temperature tested by the manufacturer to withstand such conditions. Wago 221-412 connectors were successfully used and held connection during subscale flight. **See section 3.7.4.5: Connectors.**	5-1	12
GPS	**Failure to Lock with Satellites**	Interference. Poor weather.	Loss of vehicle.	5-2	17	Test GPS during subscale launch to verify function for full-scale launch.	Telemetrum GPS successfully relayed launch vehicle location during subscale flight. **See section 3.7.4.3: GPS Tracker.**	5-1	12

						Ensure proper GPS lock and battery charge before flight.	**See Launch Initiation Procedures, steps 8.6.15 and 8.6.16.**		
Drogue Parachute	**Deployment Failure**	Improper packing.	Excessive landing energy. Recovery failure.	4-3	19	The packing of parachutes and sealing of parachute chambers must be supervised.	Avionics Lead must sign-off on the insertion of the drogue parachute into its chamber. **See Full Launch Vehicle Integration Procedures, step 7.3.6.**	4-1	9
	Breakage or Disconnection of Shock Cord	Weak shock cord. Faulty eye-bolt. Faulty quick link.	Loss of parachute. Excessive landing energy. Recovery failure.	4-2	14	Utilize shock cords made of material with high strength and heat ratings with adequate thickness.	Selected Kevlar shock cord has a strength rating of 3600 lb and is rated heat resistant to 800ºF. **See section 3.7.3.3: Shock Cords.**	4-1	9
						Utilize eye-bolts with high strength ratings.	Selected stainless steel eye-bolts are strength rated to 500 lbs. **See section 3.7.3.4: Attachment Hardware.**		
						Utilize quick links with high strength ratings.	Selected quick links have a strength rating of 880 lbs. **See section 3.7.3.4: Attachment Hardware.**		
	Breakage of Shroud Lines	Improper ejection. Previous flight or transportation damage.	Loss of parachute. Excessive landing energy. Recovery failure.	4-2	14	Only buy parachutes from reliable sources.	**See Table 3.7.3.1.2: WDM for Drogue Parachute.**	4-1	9
						Test parachute for proper function prior to launch.	Parachute drop test must be successfully completed for drogue parachute prior to launch. **See Figure 6.1.1.4: Parachute Drop Verification.**		
	Entanglement	Improper packing. Excessive ejection charge sizing. Inadequate parachute size.	Shock cord does not fully extend. Parachute does not fully inflate. Excessive landing energy. Recovery failure.	4-2	14	Select a proper sized parachute to prevent unstable deployment. Test parachute to verify sizing.	**See section 3.7.3.1: Parachutes and Figure 6.1.1.4: Parachute Drop Verification Test.**	4-1	9
						The packing of parachutes and sealing of parachute chambers must be supervised.	Avionics Lead must sign-off on the insertion of the drogue parachute into its chamber. **See Full Launch Vehicle Integration Procedures, step 7.3.6.**		
						Utilize team standard formula for calculation ejection charge sizing. Verify calculations with cross-reference between multiple personnel.	Avionics Lead and Team Safety Officer shall oversee the measurement of ejection charges during ground testing. **See section 3.7.2.2, Ejection Charges and Deployment Mechanisms.**		
						Test ejection charge design and sizes prior to launch.	Ejection charge ground testing must be successfully completed prior to launch.		

					14		**See Figure 6.1.1.3: Black Powder Ejection Verification Test.**		9
	Heat Damage	Absence of Nomex blanket. Improper packing. Improper ejection charge size.	Excessive landing energy. Recovery failure.	4-2	14	Utilize a Nomex blanket and allocate plenty of space for the drogue parachute in design. Confirm that the Nomex blanket entirely covers the parachute prior to launch.	Avionics Lead shall confirm the configuration of the drogue parachute and Nomex blanket. **See Full Launch Vehicle Integration Procedures, step 7.3.6 and section 3.2.2.6: Heat Shielding.**	4-1	9
Payload									
Battery	**Fire**	Overcharge. Puncture. Overheating.	Destruction of battery. Destruction of payload bay & sensors.	5-2	17	Properly charge batteries the day before launch.	**See Payload Preparation Procedures, step 5.1.2.**	5-1	12
	Power Loss	Faulty wiring. Lack of charge. Overcharge. Old age.	Lack of power to sensors. Lack of data collection. Unmet objectives.	4-4	22	Properly charge batteries the day before launch.	**See Payload Preparation Procedures, step 5.1.2.**	4-1	9
						Test battery to ensure capability of supplying power for duration of launch.	Battery must successfully complete life testing prior to launch. **See Figure 6.1.3.4: Battery Life Verification Test.**		
Radio Transmission System	**Transmitter Failure**	Faulty wiring. Interference.	Lack of data collection. Unmet objectives.	4-3	19	Test transmitter prior to launch to ensure adequate range capabilities.	Transmitter must successfully complete a range test prior to launch. **See Figure 6.1.3.1: Transmitter Range Test.**	4-1	9
Retention System	**Retention Assembly Failure**	Poor construction or design. Weak material.	Destruction of payload bay & sensors. Lack of data collection. Unmet objectives.	4-3	19	Test retention system over temperature to ensure it can withstand the extreme temperature of flight.	Retention system must successfully complete a temperature test prior to launch. **See Figure 6.1.3.3: Temperature Verification Test.**	4-1	9
Sensors	**Sensor Failure**	Faulty programming or wiring of pressure sensor, accelerometer, or Arduino.	Lack of data collection. Unmet objectives.	4-2	14	Organize and simplify wiring design to prevent wiring errors and disconnection.	Arduino, pressure sensor, and accelerometer will be mounted on a custom PCB, reducing need for physical wires. **See section 4.4.2: Sensor Package.**	4-1	9
						Test sensors to ensure performance at extreme conditions of flight.	Overall functionality test of sensors and test of function at high temperatures must be successfully completed prior to launch. **See Figure 6.1.3.2: Sensor Package Verification Test and Figure 6.1.3.3: Temperature Verification Test.**		

						Verify the Payload system correctly initializes prior to flight.	**See Launch Initiation Procedures, step 8.3.2 and Troubleshooting and Emergency Procedures, section 9.**		
Launch Vehicle Structure & Design									
Stability	**Instability**	Unbalanced design.	Unexpected flight path. Recovery failure.	5-3	**21**	Model and simulate launch vehicle to predict stability.	**See section 3.8.2: Stability Margins.**	5-1	**12**
						Measure the center of gravity and pressure of the assembled launch vehicle and confirm they are within tolerance of their desired locations.	Construction Lead shall be responsible for verification via simulation or alternative method that the model's center of gravity and center of pressure are in desirable locations and that the physical assembly conforms to the design.		
Nosecone	**Destruction of Nosecone**	Poor construction or design. Weak material.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	**21**	Conduct strength tests on the nosecone to ensure it can withstand landing forces and be reused without damage.	Strength test must be successfully completed by nosecone prior to launch. **See Figure 6.1.2.4: Nosecone Impact Strength Verification Test.**	5-1	**12**
MFSS	**Thrust Plate Failure**	Poor construction or design. Weak material. Previous flight damage.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	**21**	Test thrust plate with FEA to ensure the design meets the desired factor of safety. Confirm the constructed thrust plate is true to the design and manufactured within all tolerances.	Construction Lead shall oversee the testing and manufacturing of the MFSS. **See section 3.6.3.1: Thrust Plate FEA.**	5-1	**12**
	Centering Plate Failure	Poor construction or design. Weak material. Previous flight damage.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	**21**	Test centering plate with FEA to ensure the design meets the desired factor of safety. Confirm the constructed centering plate is true to the design and manufactured within all tolerances.	Construction Lead shall oversee the testing and manufacturing of the MFSS. **See section 3.6.3.2: Centering Plate FEA.**	5-1	**12**
	Retainer Plate Failure	Poor construction or design. Weak material. Previous flight damage.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	**21**	Test retainer plate with FEA to ensure the design meets the desired factor of safety. Confirm the constructed retainer plate is true to the design and manufactured within all tolerances.	Construction Lead shall oversee the testing and manufacturing of the MFSS. **See section 3.6.3.3: Retainer Plate FEA.**	5-1	**12**
						Conduct strength tests on retainer plate to ensure it can withstand landing forces and be reused without damage.	Strain test must be successfully completed by retainer plate prior to launch. **See Figure 6.1.2.3: Retainer Plate Strain Verification Test.**		

Fins	**Destruction of Fin**	Poor construction or design. Weak material.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	**21**	Conduct strength tests on fins to ensure it can withstand flight force and speed.	Fin flutter test and FEA must be successfully completed by all fins prior to launch. **See section 3.6.1.2: Fin Flutter, Figure 6.1.2.1: Fin Flutter Verification Test, and section 3.6.1.3: Fin FEA.**	5-1	**12**
	Loss of Fin	Disconnection of fin from insert.	Partial to total destruction of vehicle. Ballistic trajectory.	5-2	**17**	Verify that the MFSS will retain the fins under stress to the desired factor of safety.	Testing shall be completed via Ansys to ensure the MFSS strength to support the fins. **See section 3.6.3.4: MFSS Assembly.**	5-1	**12**
Airframe	**Premature Separation**	Loss or absence of shear pins.	Recovery failure. Ballistic trajectory.	5-3	**21**	Tape shear pins in place with masking tape following installation to prevent them from falling out during transportation to or set up on launch pad.	**See Full Launch Vehicle Integration Procedures, steps 7.3.3 and 7.4.9.**	5-1	**12**
	Failure to Separate	Excessively strong connection of stages. Debris on coupler contact surfaces.	Parachutes fail to deploy. Recovery failure. Partial to total destruction of vehicle.	5-2	**17**	Check the contacting surfaces of couplers for debris or residue that may increase separation difficulty prior to assembly.	**See Full Launch Vehicle Integration Procedures, steps 7.2.3, 7.3.7, and 7.4.7.**	5-1	**12**
						Utilize shear pins to hold stages together at separation points.	**See section 3.4: Points of Separation.**		
	Zippering	Excessive charge delay. Excessive landing energy. Inadequate shock cord.	Partial to total destruction of vehicle.	5-2	**17**	Ensure calculated ejection charges are properly sized and timed.	Altimeter vacuum testing must be successfully completed for both Telemetrum and Stratologger altimeters prior to launch. **See Figure 6.1.1.2: Altimeter Ejection Vacuum Verification Test.**	5-1	**12**
						Shock cord selection must be of adequate length and be able to completely absorb separation shock.	Selected Kevlar shock cord has a strength rating of 3600 lb. **See section 3.7.3.3: Shock Cords.**		
						Design recovery system to adequately slow the vehicle to a safe kinetic energy.	Descent simulation of the launch vehicle with OpenRocket found a maximum velocity of 14.5 ft/s at landing. **See section 3.8.3: Landing Kinetic Energy.**		
Bulkplates	**Destruction of Bulkplates**	Poor construction or design. Weak material.	Partial to total destruction of vehicle. Ballistic trajectory.	5-2	**17**	Choose materials according to material analysis and prior flight data. Confirm analysis with test launches.	Chosen G10 Fiberglass material has tensile strength of 45000 psi, flexural strength of 75000 psi, and compressive strength of 65000 psi. **See section 3.6.2.3: Bulkplates.**	5-1	**12**

Motor	**Detonation**	Motor defect. Improper assembly.	Partial to total destruction of vehicle.	5-2	17	Consider a motor's proneness to detonation during motor selection.	Project Manager and Construction Lead shall approve motor selection. Successful subscale flight with motor from Loki Research.	5-1	12
						Follow all provided assembly instructions for the motor.	**See section 5.1.1: Motor Preparation Procedures.**		
						Check the motor for damage prior to installation.	**See Full Launch Vehicle Integration Procedures, step 7.6.2.**		
	Unfastening	Improper retention.	Falling debris. Low apogee. Recovery failure.	5-2	17	Utilize positive retention mode rather than passive.	MFSS shall be utilized as positive retention. **See section 3.3.1.1: Motor Fin Support Structure.**	5-1	12
						Confirm before launch the motor is secured and aligned properly.	**See Full Launch Vehicle Integration Procedures, step 7.6.5.**		
	Improper Angle	Poor MFSS construction. Storage or transportation damage.	Low stability. Unexpected flight path.	4-2	14	Confirm that the MFSS is within acceptable tolerances. Confirm before launch the motor is secured and aligned properly.	**See Full Launch Vehicle Integration Procedures, step 7.6.5.**	4-1	9
	Unexpected Burn Time	Motor defect or damage. Improper storage.	Unexpected flight path. Low apogee. Recovery failure.	4-2	14	Select the motor from a reliable source.	Project Manager and Construction Lead shall approve motor selection. Successful subscale flight with motor from Loki Research.	4-1	9
						Properly store the motor prior to launch.	**See Motor Preparation Procedures, step 1.23.**		
						Check the motor for damage prior to installation.	**See Full Launch Vehicle Integration Procedures, step 7.6.2.**		
	Failure to Ignite	Motor defect. Improper storage.	Delay in launch time. Launch cancellation.	2-2	8	Select the motor from a reliable source.	Project Manager and Construction Lead shall approve motor selection. Successful subscale flight with motor from Loki Research.	2-1	3
						Properly store the motor prior to launch.	**See Motor Preparation Procedures, step 1.23.**		
Launch Support Equipment									
Launch Rail	**Disconnection of Launch Vehicle**	High wind speed. Improper rail button installation. Improper launch vehicle installation.	Partial to total destruction of vehicle. Ballistic trajectory.	5-2	17	Visually confirm rail button alignment prior to launch.	**See Full Launch Vehicle Integration Procedures, step 7.6.1**	5-1	12
						Confirm proper connection of launch vehicle to launch rail prior to launch.	**See Launch Initiation Procedures, step 8.1.2.**		

						Confirm proper function of launch rail with subscale launch.	Subscale launch resulted in success with no launch rail issues. **See section 3.6.6: Subscale Flight Results.**		
	High Friction	Improper launch rail setup. Improper rail button installation. Improper launch vehicle installation. High temperature and humidity.	Unexpected flight path. Low apogee. Failure to take flight.	2-3	10	Follow manufacturer's instructions for setting up the launch rail. Use lubrication on the launch rail as needed or for hot or humid weather conditions.	Project Manager shall oversee the proper setup of the launch rail and inspect for lubrication needs.	2-1	3
						Verify proper connection of launch vehicle to launch rail.	**See Launch Initiation Procedures, step 8.1.2.**		
Ignitor	**Discontinuity**	Ignitor defect. Lack of continuity.	Delay in launch time. Launch cancellation.	2-3	10	Test ignitor for continuity with multimeter following installation.	**See Launch Initiation Procedures, step 8.5.3.**	2-1	3
						Have procedures in place in case of ignitor discontinuity.	**See Troubleshooting and Emergency Procedures, section 6.**		
Launch Operations									
Launch Vehicle Components	**Damage to Components**	Improper storage during transportation. Careless handling during assembly.	Vehicle cannot fly. Decreased performance.	4-3	19	Have backup components for parts susceptible to breakage. Store components properly.	Subteam leads shall ensure subteam components are stored properly throughout the year and while in transit. Packing configuration of items shall be checked by Project Management prior to departure.	4-1	9
	Forgotten or Lost Components	Disorganized packing.	Delay in launch time.	2-5	16	A list of all necessary components shall be made prior to launch. Responsibility for each component shall be assigned to team personnel.	Packing list shall be created by Project Manager and Team Safety Officer prior departure for launch. Necessary items and tools for launch vehicle assembly including in procedures.	2-1	3
Flight Path	**Interference**	Planes. Birds. Loose balloons.	Destruction of vehicle. Ballistic trajectory. Delay in launch time.	5-5	25	Survey surrounding skies prior to launch for potential obstacles. Delay the launch if any obstacles are spotted per the NAR High Power Rocket Safety Code, section 9.	Team Safety Officer and Project Manager shall verify the skies are clear for launch. **See Flight Procedures, step 9.1.2.**	1-4	5
						Ensure an FAA waiver has been obtained for the designated launch area.	The Project Manager shall confirm the FAA waiver has been acquired and that a suitable test launch area has been selected.		

5.2.3 Environmental Concerns

Table 5.2.3.1: Environmental Hazard Analysis

Hazard Type	Hazard	Cause	Effect	C-L 1	RAC 1	Mitigations	Verification	C-L 2	RAC 2
Hazard from Environment	**Rough Terrain**	Trees. Water bodies. Mud. Rugged landscape. Vegetation.	Recovery difficulty or incapability. Damage to vehicle. External personnel such as fire department needed for vehicle entanglement in trees.	5-3	21	Select launch site that is relatively flat and easy to traverse. Launch in a direction that maximizes the distance between the intended trajectory's landing and area of rough terrain.	The Project Manager and Team Safety officer shall sign off on the launch location and trajectory prior to the launch. Indiana Rocketry Inc, Pence HP field and the Purdue Dairy Farm shall be used as test launch locations which consist of primarily open, flat land.	5-1	12
						Follow the NAR Minimum Distance Table and section 10 of the NAR High Power Rocket Safety Code.	Both test launch sites are in accordance with NAR standards with a minimum diameter of cleared area of 50 ft where trees do not pose a hazard.		
	Power Lines	Power line interference with landing trajectory of launch vehicle.	Recovery incapability. External personnel such as fire department or power company needed for vehicle entanglement.	5-2	17	Follow the NAR Minimum Distance Table and section 10 of the NAR High Power Rocket Safety Code.	Both test launch sites are in accordance with NAR standards with a minimum diameter of cleared area of 50 ft where power lines do not pose a hazard.	5-1	12
	High Wind Speed	Poor forecast. Mountainous geography.	Launch delay. Excessive drift. Difficulty recovering launch vehicle.	4-3	19	Launch shall not take place for wind speeds greater than 20 mph per the NAR High Power Rocket Code, section 9.	The Project Manager and the Team Safety Officer will monitor the weather. **See Full Launch Vehicle Integration Procedures, step 7.1.1.**	3-2	11
						Adjust launch angle within 20 degrees of vertical. Run simulations prior to launch with present wind speeds to determine the optimal launch angle.	**See Full Launch Vehicle Integration Procedures, step 7.6.8.**		
	Structures	Close proximity of structures to landing location.	Transmission interference.	4-3	19	Select launch site with minimal nearby structures.	Indiana Rocketry Inc, Pence HP field and the Purdue Dairy Farm shall be used as test launch locations which consist of primarily open, flat land.	4-1	9
						Follow the NAR Minimum Distance Table and sections 10 and 11 of the NAR High Power Rocket Safety Code.	Both test launch sites are in accordance with NAR standards with a minimum diameter of cleared area of 50 ft, wide open space, and at least 1500 ft away from occupied buildings.		

	High Temperature	Climate. Poor forecast. Low latitude. Low elevation.	Overheating of electronics. Warping of components. Battery degradation.	5-3	21	If the temperature at the time of the launch is greater than 95°F, the launch shall be delayed for optimal performance.	The Project Manager and the Team Safety Officer will monitor the weather. **See Full Launch Vehicle Integration Procedures, step 7.1.1.**	3-1	7
	Low Temperature	Climate. Poor forecast. High latitude. High elevation.	Change in launch vehicle rigidity & mass. Higher drag force on launch vehicle. O-ring failure. Cracking of components. Parachute stiffness. Battery capacity loss.	5-3	21	If the temperature at the time of the launch is less than 32°F, the launch shall be delayed for optimal performance.	The Project Manager and the Team Safety Officer will monitor the weather. **See Full Launch Vehicle Integration Procedures, step 7.1.1.**	3-1	7
	Humidity & Moisture	Climate. Poor forecast. Recent precipitation. Low altitude. Close proximity to water body.	Corrosion & rust formation on metal components, electronics, & batteries.	3-3	15	Store the launch vehicle and its components in a cool dry place.	Subteam leads shall check that subteam components are stored properly at the end of each work day. Motor shall be carefully stored when not in use. **See Motor Preparation Procedures, step 1.23.**	2-1	3
						Design launch vehicle with minimal usage of materials susceptible to rust.	Subteam leads shall approve all material choices in design.		
Hazard to Environment	**Fire Ignition**	Battery damage. Dry ground & debris at location of launch pad.	Start of wildfire. Damage to wildlife, vegetation, & landscape.	5-3	21	Components containing batteries must be designed with protective battery securements to protect batteries in case of impact with the ground and must be clearly labeled as a fire hazard.	The Team Safety Officer shall check all component designs with batteries and battery configurations prior to manufacturing to ensure they are appropriately protected.	5-1	12
						A fire extinguisher shall be on hand in case of fire.	The Team Safety Officer shall carry a fire extinguisher and notify personnel of its location on launch days.		
						Clear launch pad area of loose or dried vegetation prior to launch.	Team Safety Officer and Project Manager shall be responsible for the clearing of the launch pad prior to launch rail set-up.		
	Impact with Wildlife	Bird interference with flight trajectory, Launch vehicle landing on wildlife.	Lift-threatening injury of wildlife. Habitat disruption.	5-2	17	Launch shall not be conducted at known habitat locations of large groups of wildlife. Survey surrounding skies prior to launch for potential obstacles. Delay the launch if any	Team Safety Officer and Project Manager verify the skies are clear for launch. **See Flight Procedures, step 9.1.2.**	5-1	12

						obstacles are spotted per the NAR High Power Rocket Safety Code, section 9.			
	Impact with Structures	Recovery failure, structural failure, instability, or rail misalignment, leading to stray trajectory.	Repairable damage to structures.	4-2	14	Select launch site with minimal nearby structures.	Indiana Rocketry Inc, Pence HP field and the Purdue Dairy Farm shall be used as test launch locations which consist of primarily open, flat land.	4-1	9
						Follow the NAR Minimum Distance Table and sections 10 and 11 of the NAR High Power Rocket Safety Code.	Both test launch sites are in accordance with NAR standards with a minimum diameter of cleared area of 50 ft, wide open space, and at least 1500 ft away from occupied buildings.		
	Component Pollution	Breakage of launch vehicle components. Failure to retrieve all components.	Component materials slowly decompose in ground. Harm to wildlife & vegetation. Water contamination.	3-4	18	Fasten all components on the launch vehicle.	Construction Lead and Project Manager shall oversee and sign-off on the integration of the launch vehicle.	3-1	7
						Search the launch and landing sites for potentially detached parts. Check the launch vehicle to see if parts are missing upon retrieval.	**See Retrieval Procedures, step 10.13.**		
	Exhaust Pollution	APCP combustion of launch vehicle motor.	Small amounts of greenhouse gasses emitted into air, soil, & nearby water.	2-5	16	Ensure that the selected motor emits an acceptably low amount of pollution from the exhaust. Utilize blast deflector to prevent motor's exhaust from hitting ground per the NAR High Power Rocket Safety Code, section 7.	Team Safety Officer shall review the available motor specifications and pursue available information to determine the level of harm that may result from the exhaust byproducts.	1-5	6
	Battery Pollution	Battery puncture. Overcharge. Unprotected battery design.	Toxic chemical & heavy metal contamination of soil & nearby water.	3-3	15	Components containing batteries must be designed with protective battery securements to protect batteries in case of impact with the ground.	The Team Safety Officer shall check all component designs with batteries and battery configurations prior to manufacturing to ensure they are appropriately protected.	2-1	3
						Inspect batteries prior to launch vehicle assembly for punctures. Properly charge batteries prior to launch. Issue a caution to not overcharge batteries within procedures.	**See Avionics and Recovery Preparation Procedures, steps 3.1.1 and 3.1.2, Nosecone Preparation Procedures, step 4.1.2, Payload Preparation Procedures, step 5.1.2, and R&D Preparation Procedures, step 6.1.7.**		

	Impact with Terrain	Excessive kinetic energy of launch vehicle upon descent & landing.	Disturbance of wildlife & vegetation. Indentation & disfigurement of terrain.	2-3	10	Simulate launch vehicle landing to ensure safe landing kinetic energy.	OpenRocket simulation of the launch vehicle descent found a maximum velocity at landing of 14.5 ft/s. **See section 3.8.3: Landing Kinetic Energy.**	2-1	3
						Perform tests with parachutes to reduce likelihood of the parachutes failing to deploy.	**See Figure 6.1.1.4: Parachute Drop Verification Test.**		

5.2.4 Project Risk Assessment

Table 5.2.4.1: Project Risk Assessment

Hazard	Cause	Effect	C-L 1	RAC 1	Mitigations	Verification	C-L 2	RAC 2
Weather Delay	Poor weather conditions during test launches. Poor weather preventing transportation of personnel to workspace.	Disqualification. Lack of launch data. Construction delay. Launch delay.	3-2	8	Ensure there is adequate time after the scheduled test launches to reschedule in case of delay. Test systems as soon as possible.	The Project Manager and Team Safety Officer shall check the weather the day before a test or launch to ensure it is suitable for testing. The Project Manager shall verify the scheduled dates are in compliance.	3-1	5
Unavailability of Test Launch Site	Failure to organize proper area to launch or test. Failure to receive FAA waiver for launch.	Disqualification. Lack of launch data.	3-2	8	Secure a reliable test launch area and FAA waiver well in advance of the dates on which test launch data is required.	The Project Manager shall confirm the FAA waiver has been acquired and that a suitable test launch area has been selected. Indiana Rocketry Inc, Pence HP field and the Purdue Dairy Farm shall be used as test launch locations.	3-1	5
Inactivity / Low Availability of Personnel	Personnel unable or unwilling to work due to increase in classwork or other commitments.	Low attendance. Decreased body of personnel. Labor shortage. Construction delay.	3-2	8	Encourage communication regarding upcoming exams/commitments so work may be assigned accordingly. If possible, schedule work on time consuming/difficult tasks outside of midterm/final exam “season.”	Subteam leads shall keep track of their team members' exams/commitments and verify with those members that they have sufficient time to finish the work assigned to them, and shall reassign work to others if they do not.	3-1	3
Inadequate Funding	Improper budgeting & allocation of funds. Shortage of money raised.	Inability to purchase parts. Construction delay. Inability to launch. Inability to attend Huntsville competition.	3-2	8	Contact plenty of potential sponsors so the team’s funding goal will be surpassed. Check the budget periodically to ensure the team is on pace.	Business Lead shall verify potential sponsors have been contacted and that the budget is being followed, or else delegate the task to a team member. **See section 6.3: Finance.**	2-1	3

Major Testing Failure	Improper construction. Insufficient data collection in launch vehicle design.	Construction delay. Launch delay. Necessary repairs. New parts needed to be purchased. Lack of launch data. Disqualification.	2-2	6	Ensure specifications of parts used for testing meet the relevant factor of safety for the test being performed. Test procedures shall be available to personnel and entirely followed.	Subteam leads shall ensure parts being used meet their requirements. Subteam members shall ensure proper testing procedures are being followed or designate tasks to a member of the subteam. **See section 6.1: Testing Plan.**	2-1	3
Failure to Receive Components	Shipping delay. Out of stock items ordered.	Construction delay. Launch delay.	3-2	8	Order months in advance of when components will be needed. Talk with suppliers about lead time before purchasing.	Subteam leads shall confirm each component has been ordered through verification email, verbal confirmation, other.	2-1	3
Damage to or Loss of Parts	Testing failure. Careless handling during construction, transportation, or launch.	Construction delay. Necessary repairs. New parts needed to be purchased.	3-2	8	Have excess parts in case of loss or damage if financially viable. Follow transportation, launch, and construction safety procedures.	Subteam leads shall account for excess parts or designate this task to a subteam member. Subteam members shall ensure compliance with all safety procedures.	2-1	3
Rushed Work	Rapidly approaching deadlines. Unreasonable schedule expectations.	Failure during testing or launch due to lower quality of construction & less attention paid to test data.	3-2	8	Release deadlines far in advance of their due date with a time buffer before the work must be completed. Delegate people to each task.	A Gantt chart will be utilized to show due dates. **See section 6.4: Timeline.** Subteam leads shall verify all tasks have been assigned to a team member and that the team member is aware of the assignment	2-1	3
Construction Equipment Failure	Improper long-term maintenance of construction equipment. Improper use or storage of equipment.	Construction delay.	2-2	6	Refer to instruction manuals on how to use equipment prior to first time usage. Use tools only for tasks they are designed to be used for.	Trained personnel will be documented for each piece of equipment by the subteam lead. Procedures using equipment must be approved by the subteam lead.	2-1	3
Loss or Unavailability of Workspace	Construction. Building hazards. Loss of lab privileges.	Construction delay.	3-3	9	Follow the rules of the workspace. Have at least one secondary workspace available for relocation at all times.	Team Safety Officer shall check that all personnel in the workspace have the necessary certifications at the beginning of each work day. The team's primary workspace shall be in the PTC, with secondary workspaces available in Potter Engineering Center and the BIDC.	1-1	1

					Personnel shall be informed of and follow fire prevention practices in accordance with the U.S. Fire Administration.	Team Safety Officer shall deliver “Safety Minute” covering fire prevention.		
Insufficient Transportation	Insufficient funding. Limited space in transportation mode for all personnel to travel to launch site or workplace.	Loss of labor force. Team member morale loss. Low attendance of launches.	2-2	6	Ensure there is room in the budget for the transportation of all parties. Forms and lists of drivers and passengers shall be released at least 4 days prior to departure.	Subteam leads shall verify everyone on their subteam in need of transportation is on the list and that it has been sent.	1-1	1
Damage by Non-Team Members	Accidental damage caused by other workspace users.	Construction delay. Necessary repairs. New parts needed to be purchased.	2-2	6	Components shall only be stored in designated areas labeled “PSP SL.”	Subteam leads shall conduct a visual inspection of their worksite and storage spaces after every work day to verify compliance.	1-1	1
Damage in Transit	Careless handling of launch vehicle and components during transit.	Launch delay. Necessary repairs. New parts needed to be purchased.	2-2	6	Secure all items with appropriate padding. If applicable, orient items such that they are in a state of minimal potential energy to minimize instability and prevent tipping.	Subteam leads shall delegate responsibility for subteam components. Subteam leads shall verify components are appropriately positioned and stored prior to departure.	1-1	1

6 Project Plan

6.1 Testing Plan

In the team's Requirements and Verification Plan (R&VP) Table, subteam specific requirements marked with the "Testing" verification type are listed below. These are the requirements that must be verified by performing a full-scale assessment rather than an analysis or a subscale demonstration. This category holds the requirements either too complex to be verified by simpler means or too mission critical to be verified using an approximation.

6.1.1 Avionics and Recovery

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	1	In Progress	Altimeter Continuity and Battery Drain Test	S.A.1, S.A.2, S.A.3

Verification Plan Objective

This test will verify that the altimeters and their batteries will function across all likely launch temperatures, and that they will maintain continuity throughout flight. It will also verify that the batteries will supply usable voltage for the maximum expected duration of flight and pad time.

Success Criteria	Dependent Variables
Both altimeters must maintain continuity and receive adequate power from their respective batteries for 4 hours powered on in both temperature extremes, and the voltages of both batteries must remain the same after 18 hours powered off in warm weather. -- Warm-weather test: Must be above 70°F. -- Cold-weather test: Must be below 35°F. -- Every continuity measurement of both the StratoLoggerCF and the TeleMetrum altimeters must be 3 beeps (full dual-deployment continuity). -- In the powered-on test, the voltage of the 9V battery must not drop below 8V. -- In the powered-on test, the voltage of the 3.7V LiPo battery must not drop below 3.3V.	The dependent variables are the number of continuity beeps emitted by both the TeleMetrum and StratoLoggerCF altimeters and the voltages of both the 3.7V LiPo and 9V batteries.

Why is this necessary?	Test Articles
This test verifies that both altimeters will be able to maintain continuity and receive adequate power from their respective batteries for 4 hours (1 hour longer than the pad time of 3 hours) powered on in both temperature extremes, and the voltages of both batteries will remain the same after 18 hours powered off in warm weather.	StratoLoggerCF Altimeter, Telemetrum Altimeter, 9V Battery, 3.7V LiPo Battery

Test Equipment and Methodology

Test Equipment
StratoLoggerCF altimeter, TeleMetrum altimeter, 9V battery, 9V battery connector, 3.7V LiPo battery, two switches, wires, multimeter, screwdriver set

Methodology
Powered-On Test (Warm and Cold Weather)
1. The current temperature was recorded.
2. One new 9V battery will be connected to the StratoLoggerCF altimeter using a 9V battery connector, along with a switch.
3. The altimeter will be turned on with the switch and will go through its initialization routine. Then, the system will be left for 4 hours.
4. Every 0.5 hours (including at 0 hours and 4 hours), use a multimeter to record the voltage of the 9V battery. Also record the continuity beeps.
5. The procedure will be repeated with the 3.7V LiPo battery and the TeleMetrum altimeter. The voltage of the TeleMetrum can be recorded by switching it off and then on again and recording the initialization beeps (first set of beeps is ones place of voltage, second set of beeps is tenths place of voltage). This is because the multimeter cannot measure the 3.7V LiPo battery's voltage. The number of initialization beeps was then recorded as the voltage measured for that interval of time.
Note: The entire test will be conducted in both the warm and cold temperatures in order to verify that full continuity and adequate voltage supplied to the altimeters can consistently be achieved in both warm and cold weather.

Powered-Off Test (Warm Weather Only)
1. In warm weather only with the same setup as in the powered-on test, but with the altimeters powered off, a voltage reading of each battery will be taken before and after 18 hours of everything being wired together in flight configuration.

Potential Impact of Results

If both altimeters and batteries pass this test, it will be expected that the altimeters will have enough power to deploy the parachutes without problems during flight. The selection of these components would be confirmed. If one or both altimeters/batteries fail this test, a retest will occur for those components, and if necessary a new altimeter or battery will be considered.

Test Data

Warm Weather Trial: 71°F Altimeter/Battery	Reading 1 (0 hours)	Reading 2 (0.5 hours)	Reading 3 (1 hour)	Reading 4 (1.5 hours)

TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 5 (2 hours)	Reading 6 (2.5 hours)	Reading 7 (3 hours)	Reading 8 (3.5 hours)
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 8 (4 hours)			
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
Cold Weather Trial: >32.0°F Altimeter/Battery	Reading 1 (0 hours)	Reading 2 (0.5 hours)	Reading 3 (1 hour)	Reading 4 (1.5 hours)
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 5 (2 hours)	Reading 6 (2.5 hours)	Reading 7 (3 hours)	Reading 8 (3.5 hours)
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 8 (4 hours)			
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				

Powered Off Test: 71°F Altimeter/Battery	Reading 1 (Before 18 hours)	Reading 2 (After 18 hours)
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage		
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage		

Test Results			
Altimeter/Battery	Warm Weather: 71°F	Cold Weather: >32.0°F	Powered-Off Test: 71°F
TeleMetrum/3.7V LiPo			
StratoLoggerCF/9V			

Conclusions
This test will be completed in January 2025.

Figure 6.1.1.1 Altimeter Continuity and Battery Drain Verification Test

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	2	In Progress	**Altimeter Ejection Vacuum Test**	S.A.9, S.A.25

Verification Plan Objective
This test verifies that the altimeters are able to consistently ignite the ejection charges at specific times throughout flight, and the primary altimeter ignites the drogue and main charges with comfortable margins before the redundant altimeter.

Success Criteria	Dependent Variables
Both altimeters must ignite the drogue parachute e-matches at apogee (or 2s after apogee) and the main parachute e-matches at the correct altitude during descent. -- For the TeleMetrum altimeter, the magnitude of the difference between the apogee altitude and the altitude the drogue e-match ignites at must be less than 500' for all three trials. -- For the TeleMetrum altimeter, the altitude the main e-match ignites at must be between 700 ± 50' for all three trials. -- For the StratoLoggerCF altimeter, the drogue delay (the time between ignition of the TeleMetrum drogue e-match and ignition of the StratoLoggerCF drogue e-match) must be between 0.75 and 1.75s (as it is programmed to be 2s) for all three trials. -- For the StratoLoggerCF altimeter, the altitude the main e-match ignites at must be between 600 ± 50' for all three trials.	The dependent variable is the times in flight the e-matches are ignited by the TeleMetrum and StratoLoggerCF altimeters.
Why is this necessary?	**Test Articles**
This test verifies that both altimeters are able to ignite both ejection charges at the correct times in flight in order to ensure the successful recovery of the vehicle and validate the choices of altimeters.	StratoLogger CF Altimeter, Telemetrum Altimeter

Test Equipment and Methodology

Test Equipment

StratoLoggerCF altimeter, TeleMetrum altimeter, 9V battery, 9V battery connector, 3.7V LiPo battery, two switches, four LEDs, 2 mini breadboards, 4 resistors, screwdriver set, glass bowl, sheet of plexiglass, wine stopper, wine bottle air remover pump, plumber's putty, AltimeterOne altimeter, 1/2" drill bit, 1/4" drill bit. LEDs are being used in place of e-matches for this testing to conserve materials and lessen the hazards in testing.

Methodology

1. Using a 1/2" bit, drill one hole into the sheet of plexiglass. Place the wine stopper into this hole and seal the hole with a small ring of plumber's putty in order to prevent air from escaping.
2. Drill a smaller hole to the side of the previous hole using a 1/4" bit. This is a pressure release hole to simulate descent.
3. For each altimeter, connect an LED to the drogue and main outputs and a battery (9V for StratoLogger and 3.7V for Telemetrum) and switch to the altimeter.
4. Turn on the AltimeterOne and set it to Real Time.
5. Place the testing altimeter system and the AltimeterOne in a glass bowl at the same time. The switch should be hanging over the rim of the bowl to allow easy access to turn the altimeter on and off. If the testing altimeter is the Telemetrum, ensure that it is pointing up.
6. Place a large ring of plumbers' putty around the rim of the bowl and over the e-matches and switch wires. Rest the prepared sheet of plexiglass over the bowl and press down until there is a uniform seal around the entire perimeter. If necessary, extra plumbers' putty can be placed around the exposed wires to ensure a complete seal.
7. Use a small piece of plumbers' putty to seal the pressure release hole.
8. Switch the altimeters on and allow them to complete their initialization routines. It is important that these steps are completed after sealing the pressure release hole because if the chamber is sealed after the altimeters are switched on, they might detect the small drop in pressure and start the launch.
9. Remove air through the stopper using the wine bottle air remover pump. Once the vacuum reaches the expected apogee altitude as indicated by the digital display of the AltimeterOne, the drogue LED is expected to light up (or 2 seconds after apogee for the StratoLoggerCF altimeter).
10. Slightly lift the small piece of plumbers' putty in the second drilled hole in the plexiglass in order to slowly allow air back inside it. This will cause the altitude to decrease according to the AltimeterOne. The main LED is expected to light at pressures corresponding to an altitude of 700' (or 600' for the StratoLoggerCF altimeter).
11. Download the flight data to a computer for analysis
12. Repeat all the above two more times for a total of three trials for both altimeters.

Potential Impact of Results					
If both altimeters pass this test, no action will be required to correct the performance of e-match ignition, and it can be expected that the altimeters will eject the parachutes with no issues during launch. If one or both altimeters fail this test, a complete retest will need to be conducted on the altimeter(s) that failed in order to determine and correct the issue, and new altimeters may be considered.					
Test Data					
Telemetrum Trial	Apogee Altitude (ft)	Drogue Ignition Altitude (ft)	Main Ignition Altitude (ft)		
1	4595.34	4585.73	677.59		
2	4627.95	4478.67	719.69		
3	5752.49	5186.38	683.53		
4	5528.51	5178.02	700.62		
5	4819	4728.08	704.04		
StratoLoggerCF Trial	Apogee Altitude (ft)/Time Stamp in Data (sec)	Drogue Ignition Altitude (ft)/Time Stamp in Data (sec)	Main Ignition Altitude (ft)		
1	5321/15.6	4830/20.45	592		
2	4899/24.05	4851/24.35	Unable to retrieve main altitude		
3	4745/17.75	4725/19.60	592		
4	4844/18.25	4657/21.70	595		
Joint Trial	Time Stamp (From Recorded Video) of TeleMetrum Drogue Ignition (s)	Time Stamp (From Recorded Video) of StratoLoggerCF Drogue Ignition (s)	Main Ignition Altitude (ft) Telemetrum/Stratologger		
1					
2					
3					
Data Analysis					
Telemetrum Trial		Distance Between Apogee and Drogue Ignition (ft)	Distance Between Main Ignition and Expected Main Ignition (ft)		
1		9.61	22.41		
2		149.28	19.69		
3		566.11	16.47		
4		350.49	0.62		
5		90.92	4.04		
StratoLoggerCF Trial		Time between Apogee and Drogue Deployment	Distance Between Main Ignition and Expected Main Ignition (ft)		
1		4.85	8		
2		0.3	NA		
3		1.85	8		
4		3.45	5		
Test Results					
Altimeter	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
TeleMetrum	PASS	PASS	FAIL	PASS	PASS
StratoLoggerCF					
Results and Conclusions					
Failure on trial 3 of the Telemetrum was believed to be either human error or issue with the testing equipment following analysis of the testing video. StratologgerCF testing cannot be given an official pass/fail score without the joint test. As the team analyzes the data now, it has been determined a pass.					

Figure 6.1.1.2 Altimeter Ejection Vacuum Verification Test

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	3	Incomplete	**Black Powder Ejection Test**	S.A.13, S.A.14

Verification Plan Objective

This test verifies that the amount of black powder will properly separation the airframe sections, that the parachutes will be completely protected on all sides, and will slide out easily during ejection.

Success Criteria	Dependent Variables
Both the drogue and main black powder charges must separate their correct airframe sections the appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes. -- Black powder canister on the upper side of the avionics bay to separate the payload section: ignition must result in at least 6' of separation between the recovery section and the payload section for at least one amount of black powder equal to or greater than 2.5g. -- Black powder canister on the lower side of the avionics bay to separate the booster section: ignition must result in at least 6' of separation between the lower recovery section and the booster section for at least one amount of black powder equal to or greater than 1.5g.	The dependent variables are the amount of separation on the ground between the correct airframe sections for both the drogue and main parachute sides, whether any vehicle components are damaged, and whether the parachutes are fully ejected from the airframe.

Why is this necessary?	Test Articles
This test verifies that the amount of black powder will be appropriate to shear the pins and separate the airframe sectionsthe appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes. This ensures the successful recovery of the vehicle and validates the choices of all of these components.	Drogue and Main Ejection Systems

Test Equipment and Methodology

Test Equipment

Avionics bay, payload/upper section, booster section, screws, shear pins, screwdriver set, hex wrench set, black powder, gram scale, paper cup, disposable latex gloves, small zip ties, ematches, fireproof cellulose insulation, masking tape, 10' wires, main parachute, drogue parachute, Nomex blankets, 50' shock cord, 30' shock cord, quick links, rubber mallet, remote detonator, measuring tape

Methodology

1. Measure out 1.5g of black powder into a paper cup using a gram scale. Cut off a finger of a disposable latex glove and pour the black powder into it. Put an ematch inside the finger and zip-tie the end shut.
2. Pack the black powder canister with fireproof cellulose insulation. Place the prepared black powder into the black powder canister on the booster section side. Cover the canister with masking tape to seal in the cellulose insulation.
3. Connect the end of the ematch not in the glove to the WAGOs connector on the avionics bay.
4. Connect the 10' extension wire to the other end of the WAGOs connector.
5. Thread the extension wire through one of the avionics bay switch holes so it can be accessed outside the vehicle.
6. Attach the drogue parachute and its protective Nomex blanket to the 30' shock cord via the loop and quick link. It should be off-centered with the longer end attached to the eyebolt on the bulkhead of the booster section and the shorter end attached to the eyebolt on the bulkhead of the avionics bay toward the booster section.
7. Pack the main parachute, attached to the 50' shock cord, and its Nomex blanket into flight configuration in the upper recovery section.
8. Reconnect the avionics bay section, payload section, and booster section using screws and shear pins.
9. Connect the remote detonator to the extension wire.
10. Ensure everyone involved in testing is standing at least 40' away from the system. Once clear, do a count-down and then set off the remote detonator. The ejection charges are then expected to ignite and separate the two sections connected by shear pins.
11. If the sections did separate, the testing conductor will verify the launch vehicle body is safe before it is approached. Measure the distance between the sections in feet, using the tape measure.
12. If the required success criteria listed above is not met, repeat the procedure with an incremental increase of 0.5g per test until 6' of separation is achieved.
13. Record the minimum amount that achieves the success criteria as the ideal amount.

Potential Impact of Results

If both ejection systems pass this test, no action will be required to correct the performance of airframe separation, and it can be expected that the amount of black powder will successfully separate the correct airframe sections and eject the parachutes with no issues during launch. If one or both ejection systems fail this test, the following responses will be taken: repeat the procedure for the system(s) that was not successful with an incremental increase of 0.5g of black powder per test until 6' of separation is achieved.

Test Data

Black Powder Canister Side	Amount of Black Powder Used (g)	Distance Between the Two Sections	Damage to any vehicle components?	Parachute ejected?
Drogue				
Main				

Test Results

Black Powder Canister Side	Pass/Fail
Drogue	
Main	

Conclusions

This test is planned for early spring of 2024.

Figure 6.1.1.3 Black Powder Ejection Verification Test

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	4	In Progress	**Parachute Drop Test**	S.A.14

Verification Plan Objective

This test verifies that the parachute will open consistently within an appropriate distance range or time frame to allow for full deployment after ejection.

Success Criteria	Dependent Variables
The parachute must fully deploy within their respective maximum parameter. -- The elapsed time between the weight being dropped and the drogue parachute fully opening must be below 1.5 seconds for each trial. -- The final drop distance estimate for the subscale and main parachute to fully open should be less than 150'	The dependent variables are the elapsed time between the weight being dropped and the parachute fully opening and the final estimate for the total drop distance required for the main parachute to open fully, including shock cord extension.
Why is this necessary?	**Test Articles**
This test verifies that the parachute is able to fully deploy within its respective maximum parameter in order to ensure the successful recovery of the vehicle and validate the choices of parachutes.	Subscale parachute, drogue parachute, main parachute

Test Equipment and Methodology

Test Equipment
Subscale parachute, drogue parachute, main parachute Nomex blanket, 30' shock cord, 60' shock cord, bright orange tape, two quick links, 50lbm weight, old upper airframe, one smartphone for video recording

Methodology
1. Mark the 60' shock cord with bright orange tape in 5' increments. Drape the cord over the edge of the parking garage as a vertical distance marker.
2. On each floor of the parking lot, place bright orange tape horizontally in 1' increments up to 6' on each side of the central 60' shock cord.
3. Attach the drogue parachute to the center of a 30' shock cord via a loop and quick link. Tie the ends of the shock cord around the 50 lbm weight multiple times and secure it with a quick link.
4. Pack the drogue parachute in flight configuration with the Nomex blanket and into an old upper airframe.
5. Prepare a running stopwatch on a smartphone and place it in the frame of the smartphone that is aligned with the central shock cord recording the drop.
6. Hang the parachute over the edge of the parking garage and drop the weight off the top edge.
7. Repeat this procedure for a total of three drops of the drogue parachute.
8. Repeat this procedure three times for the subscale chute and main chute. These tests are not timed.

Analysis
1. For each drogue trial, record the elapsed time between the weight being dropped and the parachute opening.
2. For all subscale parachute trials, record the distance between the parachute leaving the airframe and it being fully opened. Do not include the extension of the shock cord in this value.
3. For the main parachute, record the distance between the parachute leaving the airframe and hitting the ground. Record and calculate the approximate percentage the parachute was open to just before hitting the ground.
4. Plot the "distance to open" values for the drogue and subscale parachute against the parachute surface areas from the hemispherical models. Use this data to create linear and exponential models.
5. For the main parachute, plot the percentage opened values against the precise drop distance. Create an exponential model from this data. Estimate the total drop distance required for the main parachute to fully open (100%) using the exponential model.
6. Input the surface area of the main parachute into the linear and exponential "distance to open" models for the drogue and subscale parachutes. Use these models to generate two more estimates of the total drop distance required for the main chute to open. Average the model estimate closest with the estimate from the main parachute percentage data.
7. Add the 30' extension of the shock cord to that calculated averaged estimate to produce a final estimate.

Potential Impact of Results

If each parachute passes this test, no action will be required to correct the deployment performance, and it can be expected that the parachutes will deploy with no issues during launch. If a parachute fails this test, a complete retest will need to be conducted on the parachute(s) that failed in order to determine and correct the issue, and new parachutes or packing methods may be considered.

Test Data

Parachute	Trial 1	Trial 2	Trial 3
Subscale (36" diameter) Distance to open (not including extension of shock cord)	19'	20'	25'
Drogue (15" diameter) Distance to open (not including extension of shock cord)	0:46 Second	0:6 Second	
Main (120" diameter) Distance to open (not including extension of shock cord)	1:50 Seconds	1:53 Seconds	1:50 Seconds

Test Results (Data Analysis Not Shown)			
Parachute	**Trial 1**	**Trial 2**	**Trial 3**
Subscale	PASS	PASS	PASS
Drogue	PASS	PASS	
Main	PASS	PASS	PASS
Conclusions			
The subscale parachute was tested on 11/16/2023. All trials resulted in the parachute fully deploying in less than 150', meeting the metric for successful test. The drogue parachute also met criteria due to deploying in less than 150' and 1:50 second threshold required for deployment. The main and drogue parachutes will be tested in early spring of 2024.			

Figure 6.1.1.4 Parachute Drop Verification Test

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	5	Incomplete	**Force Drop Test**	S.A.6, S.A.11

Verification Plan Objective
This test verifies that the key switch and other avionics components can withstand forces up to 100 pounds.

Success Criteria	Dependent Variables
All avionics components must withstand the drop test -- The key switch must not disengage after being exposed to the test forces -- All avionics components must not have any visual damage -- All avionics components and connections must work as intended after being exposed to the test forces	The dependent variable is the configuration of the key switch and the operability of the avionics components after the drop
Why is this necessary?	**Test Articles**
This ensures that the avionics system is robust and secure enough to withstand the forces of flight and landing without turning off or running into any other issues due to high forces	StratoLoggerCF Altimeter, Telemetrum Altimeter, 9V Battery, 3.7V LiPo Battery, Key Switch

Methodology
Test Equipment Fully assembled avionics section with all electronics onboard, ruler **Methodology** 1. Fully assemble the avionics section of the launch vehicle 2. Turn the key switch on and ensure electronics work as expected 3. Take the avionics section outside to a patch of bare dirt which best matches the ground conditions at Huntsville and measure a height of 3.5 ft. Dropping from this height will achieve a speed of 15 ft/s upon impact which is the terminal velocity of the launch vehicle under main parachute 4. Drop the avionics section from the height 5. Perform analysis and repeat steps 1-4 two more times to check consistency **Analysis** 1. Ensure that the key switch is still in the "on" configuration 2. Take the avionics bay out of the airframe and ensure no visual damage is done to its components 3. Ensure that the all avionics components are powered and working as intended
Potential Impact of Results
If the avionics section passes this test, then no design changes need to be made. If the avionics section fails this test, then new components will need to be selected and integrated into the avionics bay to ensure that the entire system can withstand the forces of flight and landing
Results and Conclusions

Figure 6.1.1.5 Force Drop Verification Test

6.1.2 Construction

*			Status	Verification Plan Title	Requirements Satisfied
VT	C	1	In Progress	Fin Flutter Test	S.C. 22

Verification Plan Objective

This test phsyically tests the capabilities of the fin design and material while also collecting data on its deformation per force. This enables further fin flutter analysis to verify maximum safe flight speed.

Dependent Variables	Test Articles
The two major dependent variables collected is the torsional and bending deformation measured per force and moment applied.	Fin specimen, camera, measuring/gridded background, adjustable weight, fin securing clamps, 1 foot rod.

Methodology

Test Equipment: Fin specimen for testing, adjustible weight attachable to fin, 1 foot long rod for generating moments also attachable to fin, clamps to secure fin in cantilever manner, gridded paper and camera for deflection measurement, Computer with MATLAB.

Test Procedure:
1. Mount fin in cantelever manner
2. Mount gridded background and camera to observe deflection of fin specimen
3. Attach weight to tip of fin and record deflection per force of weight
4. Relieve fin of tip load
5. Attach 1ft rod to fin, attach weight to opposite end of rod
6. Measure angular deflection per weight on rod for moment measurement
7. Acquire bending and torsional spring constants from data
8. Plug into fin flutter analysis code
9. Acquire fin flutter velocity

Potential Impact of Results

The fin should be capable of withstanding the same force as that of an expected landing impact. When code is finished and results analyzed, the fin flutter velocity should be higher than the expected flight velocity of the launch vehicle. These are the criteria for success. Should the fin specimen be unable to meet these criteria, it will necessitate a redesign of the fin for the safety and function of the launch vehicle. This can take the form in an alteration of the size of insert, thickness of the fin, material selection, or general fin sizing itself.

Results and Conclusions

Significant difficulty comes from attempting to make a numerical analysis of the test results. This is largely due to the fact that the fin specimen has, in fact, failed the test. When subjected to a load of approximately fourteen pounds the tip of the fin was at a nearly ninety degree angle, making a measure of deflection difficult. Upon a slight increase in force, the tip of the fin sheared off as a whole. It is observable in the test images that this does not indicate the capabilities of the whole fin, as the majority of the fin had minimal deflection while the specifically the tip failed. Inspecting the point of failure, the point of shear occurred exactly at the fiberglass insert, indicating a failure of the resin due to a lack of internal support. As such the fin has since been redesigned with a thicker airfoil enabling for the insert to span a larger portion of the volume.

Figure 6.1.2.1: Fin Flutter Verification Test

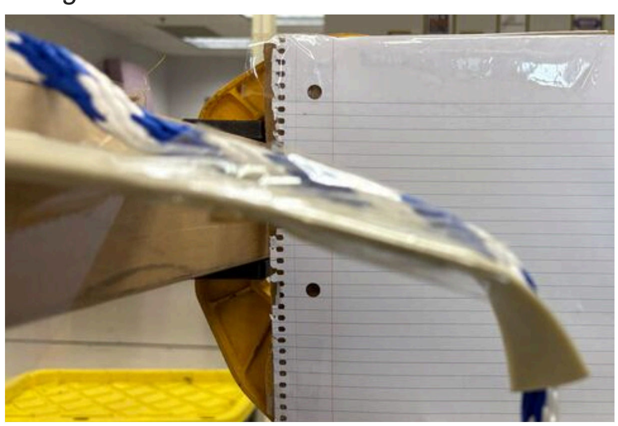

Figure 6.1.2.2: Fin Tip Loaded with 14 lbf, Tip Showing Signs of Significant Failure In Original Design

*			Status	Verification Plan Title	Requirements Satisfied
VT	C	2	In Progress	Retainer Plate Strain	S.C.10

Verification Plan Objective

The requirement is "Retainer plate of MFSS shall have a maximum strain of 0.01 after every launch for reusability." This test aims to find the strain due to the landing force on the retainer plate, ensuring it is below the 0.01 threshhold.

Dependent Variables	Test Articles
Original retainer plate diameter and final curved length after landing	Retainer plate and bendy ruler

Methodology

1. Measure the retainer plate diamater with the ruler before test launch
2. Assemble MFSS and conduct test launch
3. Measure the retainer plate curved length with the bendy ruler after the launch, taking into account the deflection which occurs. A common pitfall to avoid is having the ruler not hugging the curved surface closely, resulting in an innacurate measurement
4. Divide the final distance by the initial diamater to find stain. Compare this against the initial benchmark of 0.01.

Potential Impact of Results

If the strain is above 0.01, then the retainer plate will need to be re-manufactured to be thicker, thus withstanding more force before deflecting. If the strain is below 0.01, then it has been verfied that the retainer plate strength is sufficient for re-use across multiple launches.

Results and Conclusions

Verification plan still in progress, therefore this box will be filled after the testing has been completed.

Figure 6.1.2.3: Retainer Plate Strain Verification Test

*			Status	Verification Plan Title	Requirements Satisfied
VT	C	3	In Progress	Nosecone Impact Strength	S.C.21

Verification Plan Objective

This test ensures that the nosecone is able to withstand the force created when landing. The nosecone not fracturing upon landing is important because this will ensure that the manufacturing of multiple nosecones won't be necessary and also enable the nosecone to be reused in subsequent launches

Success Criteria

The nosecone must be able to withstand at least an impact of 18 kJ/m^2 which is exactly the impact force upon the landing of the launch vehicle. The nosecone has succesfully withstood an impact of 18 kJ/m^2 if its deformation after landing is less than 0.1 mm

Dependent Variables	Test Articles
Nosecone deformation	Nosecone, Camera, Ruler

Methodology

1. Take a picture of nosecone before launch whilst also measuring all nosecone dimensions
2. Assemble launch vehicle with nosecone attached
3. Take picture of nosecone after launch and compare with picture before launch for any noticable defects. If no noticiable defects are found, remeasure all nosecone dimensions to compare to nosecone dimensions before launch and calculate deformation to determine whether the launch test was successful or not

Potential Impact of Results

If the nosecone deformation is greater than 0.1 mm, the nosecone must be redisigned to be thicker in order to be able to withstand a higher impact force. If the nosecone has a deformation less than 0.1 mm, then it has been verified that the nosecone is able to withstand the landing impact and can be reused in subsequent launches.

Results and Conclusions

The test launch has yet to be completed and thus the verification plan is still in progress. This box will be updated once the test launch has been completed and the nosecone test has concluded.

Figure 6.1.2.4: Nosecone Impact Strength Verification Test

6.1.3 Payload

*			Status	Verification Plan Title	Requirements Satisfied
VT	P	1	Incomplete	Transmitter Range Test	P.4.1, S.P.4
Verification Plan Objective					
Satisfies requirement P.4.1 and S.P.4: The range data collected from this test will ensure that the landing site data can be clearly transmitted to the transceiver.					
Success Criteria				**Dependent Variables**	
The transceiver is able to receive data from the sensor package.				Transceiver connection	
Why is this Necessary?				**Test Articles**	
The landing site data must be able to be clearly transmitted to and received by the FTM-300DR transceiver used on launch day.				FTM-300DR transceiver/similar specification transceiver	
Methodology					
Test Equipment Transceiver, battery, airframe Methodology 1. Set up transceiver and ensure it transmits at a short distance (ideally this is the full payload electrical system but just the transceiver and battery will work) 2. Take the transceiver and payload airframe to a large open area with clear line of sight up to a mile 3. Place the transceiver inside the payload airframe 4. Take the receiver one mile from the location of the transceiver and check for signal strength 5. After test, collect all test equipment					
Potential Impact of Results					
If the transceiver cannot receive data, different materials must be chosen to construct the payload container. A different transmitter may also need to be selected.					
Results and Conclusions					
Verification plan still in progress, therefore this box will be filled after the testing has been completed.					

Figure 6.1.3.1: Transmitter Range Verification Test

*			Status	Verification Plan Title	Requirements Satisfied
VT	P	2	Incomplete	Sensor Package Test	P.4.1, P.4.2, S.P.5

Verification Plan Objective

Satisfies requirements P.4.1, P.4.2, and S.P.5: The durability data collected from this test will ensure the STEMcRAFT and its contents remain in operating condition during and after flight.

Success Criteria	Dependent Variables
STEMcRAFT remains intact and data from sensors indicate survivability of contents within.	Sensor and STEMcRAFT durability/functionality
Why is this Necessary?	**Test Articles**
The sensors are required to track, log, and transmit landing site data to the transceiver. This means any damage they suffer can affect data accuracy or transmission.	Sensor and STEMcRAFT

Methodology

Test Equipment
Fully assembled STEMcRAFT inside payload airframe section, ruler

Methodology
1. Integrate STEMcRAFT inside payload airframe section and ensure all electronics work as intended before test
2. Take STEMcRAFT outside to a patch of dirt similar to ground conditions at Huntsville
3. Measure a height of 3.5 ft which will ensure the payload section reaches 15 ft/s (speed of terminal velocity under drogue) upon landing
4. Drop the payload section
5. Perform analysis and repeat steps 1-4 two more times to check for constency

Analysis
1. Take STEMcRAFT outside of airframe
2. Check connections still have continuity and no electronics have any visual damage
3. Take data from the STEMcRAFT and ensure that no data was lost and data yields accurate results

Potential Impact of Results

If the sensors are indicated to be damaged or lose functionality throughout any part of testing, the STEMcRAFT will need to be redesigned to ensure proper protection.

Results and Conclusions

Verification plan still in progress, therefore this box will be filled after the testing has been completed.

Figure 6.1.3.2: Sensor Package Verification Test

*			Status	Verification Plan Title	Requirements Satisfied
VT	P	3	Incomplete	Temperature Test	S.P.8

Verification Plan Objective

Satisfies requirement S.P.8: This data collected from this test will be used to determine if the deployment system can properly function within temperatures up to 115 degrees Fahrenheit.

Success Criteria	Dependent Variables
STEMcRAFT and integration system continues to operate within temperatures up to 115 degrees Fahrenheit.	STEMcRAFT and integration system functionality
Why is this Necessary?	**Test Articles**
The payload will be subjected to high temperatures during flight as well as at the launch site and must still be able to function.	STEMcRAFT, Integration system

Methodology

Test Equipment
STEMcRAFT, metal rack, hot plate, thermal tarp, twist-tie, thermometer, receiver

1. Set up the STEMcRAFT and transmission system in the payload bay and coupler
2. Place the payload bay and coupler on a metal rack
3. Place the rack and payload bay on a hot plate
4. Cover with a thermal tarp and cinch off at the bottom
5. Place a thermometer through an opening, and ensure tarp is pressed flush against the thermometer
6. Turn on the hot plate
7. Monitor the thermometer until temperatures reach around 120 degrees Fahrenheit
8. Remove the payload bay and coupler from the hot plate
9. Initiate data collection
10. Set up the receiver and initiate transmission
11. Check to see if data was received and if data is accurate

Potential Impact of Results

If the sensors are indicated to be damaged or lose functionality throughout any part of testing, the STEMcRAFT will need to be redesigned to ensure proper protection.

Results and Conclusions

Verification plan still in progress, therefore this box will be filled after the testing has been completed.

Figure 6.1.3.3: Temperature Verification Test

*			Status	Verification Plan Title	Requirements Satisfied
VT	P	4	Incomplete	Battery Life Test	G.2.6, S.P.9
Verification Plan Objective					
Satisfies requirements G.2.6 and S.P.9: The data collected from this test will ensure that the sensor package system will be able to operate for an extended period of time.					
Success Criteria				**Dependent Variables**	
The STEMcRAFT battery is able to run for at least 3 hours.				Battery life	
Why is this Necessary?				**Test Articles**	
To ensure the battery is able to power the payload electronics for any extended period of time in which the vehicle is awaiting launch.				STEMcRAFT battery	
Methodology					
Test Equipment STEMcRAFT, timer Methodology 1. Turn on STEMcRAFT and timer at same time 2. Wait 3 hours and turn off STEMcRAFT and stop timer 3. Ensure that all data is logged for the entire duration of the test 4. Turn STEMcRAFT back on and restart timer 5. Log time where the STEMcRAFT battery is drained 6. Retrieve the STEMcRAFT data and determine how long the STEMcRAFT data records before loss of data or overwriting 7. Repeat steps 1-6 two more times to check for consistency					
Potential Impact of Results					
If the sensors are indicated to be damaged or lose functionality throughout any part of testing, the STEMcRAFT will need to be redesigned to ensure proper protection.					
Results and Conclusions					
Verification plan still in progress, therefore this box will be filled after the testing has been completed.					

Figure 6.1.3.4: Battery Life Verification Test

6.2 Requirements Verification

Since PDR, the R&VP Table has been updated with more subteam requirements as well as the addition of the verification ID for each requirement marked for "Testing". An overview of the R&VP table's layout was given in PDR. For completion, the following URL links to the team's R&VP Handbook which details the team's R&VP methods: https://tinyurl.com/PSP-SL-RandVP. Most incomplete requirements involve future events such as the full-scale flight and operations at the competition. The discontinued requirements are the requirements involving pressure vessels and unmanned aerial vehicles. Since the team is using neither, the conditions for these requirements are not met, justifying their discontinuation.

Table 6.2.1 R&VP Subsystem Designation

Subsystem	Letter	Mnemonic
Social, Business, Outreach, Documentation	N	Non-technical
Construction (Airframe and Propulsion)	C	Construction
Payload	P	Payload
Avionics and Recovery	A	Avionics
Research and Development (R&D)	R	Research
Standards, Guidelines	G	Guidelines
Systems, Project Management	M	Management
Safety	H	Health

The "Mission Critical" designation is reserved for requirements which are absolutely necessary to be satisfied for the vehicle to be flown.

PR: Prerequisite

- Requires the identification of subteam requirements which, if verified, guarantees the satisfaction of the given requirement.
- *This verification type requires at least one subordinate requirement.*

A: Analysis

- The use of mathematical modeling and analytical techniques to predict the suitability of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications.
- *This verification type requires analysis documentation.*

D: Demonstration

- Generally a basic confirmation of performance capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mock-ups.

I: Inspection

- The visual examination of a realized end product. Inspection is generally used to verify physical design features or specific manufacturer identification.

T: Testing

- Involves use of an end product to obtain detailed data needed to verify performance or provide sufficient information to verify performance through further analysis.
- *This verification type requires test plan documentation.*

See the R&VP Handbook for full descriptions and requirement standards.

Figure 6.2.1 R&VP Verification Methods

Table 6.2.2 NASA R&VP Table

							Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
G	1.1	☑	In Progress	NASA	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Student team members shall only be a part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit penalties.		☐	☐	☑	☐	☐		The team is currently ensuring that the design, construction, and assembly of each subsystem and the system as a whole is fully developped by the team and no independent third party. This is also true for all written reports, presentations, and other articles of documentatiion
G	1.2	☑	In Progress	NASA	The team will provide and maintain a project plan to include, but not limited to, the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.		☐	☐	☑	☐	☐		The team has developped a gantt chart for project milestones, a proposed budget, safety checklists, and FMEA tables. The team also includes its STEM engagement events in the timeline
G	1.3	☑	In Progress	NASA	Team members who will travel to the Huntsville Launch shall have fully completed registration in the NASA Gateway system before the roster deadline. Team members shall include:		☐	☐	☑	☐	☐	G.1.3.1, G.1.3.2, G.1.3.3	When the Huntsville launch date gets closer, project management will ensure that those in the team who are not already part of the NASA Gateway system are added
G	1.3.1	☑	In Progress	NASA	Students actively engaged in the project throughout the entire year;	G.1.3	☑	☐	☑	☐	☐		The team is ensuring that all student members have a part in the project and do not feel left out or unengaged
G	1.3.2	☑	Complete	NASA	One mentor (see Requirement 1.13);	G.1.3	☑	☐	☑	☐	☐		Christopher Nilson is acting as the PSP Student Launch mentor
G	1.3.2	☑	Complete	NASA	No more than two adult educators.	G.1.3	☑	☐	☑	☐	☐		The team has no more than two adult educators are helping the team
N	1.4	☑	Complete	NASA	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 40 – 43.		☐	☐	☑	☐	☐		Purdue Space Day on October 26, 2024 had 612 participants which is well over the minimum of 250. More STEM engagement activities are planned for the future
N	1.5	☑	Complete	NASA	The team shall establish and maintain a social media presence to inform the public about team activities.		☐	☐	☑	☐	☐		The team has created multiple social media accounts across various platforms such as X (formally Twitter), Instagram, and Facebook

							Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
M	1.6	☑	In Progress	NASA	Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will NOT be accepted. Teams that fail to submit the PDR, CDR, or FRR milestone documents will be eliminated from the project.		☐	☐	☑	☐	☐		Project management is ensuring that all requirements for each project milestone are met before the PDR, CDR, and FRR submission dates and the reports are completed on time
M	1.7	☑	In Progress	NASA	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) will be provided action items to be completed following their review and will be required to address action items in a delta review session. After the delta session, the NASA management panel will meet to determine the teams' status in the program, and the teams will be notified shortly thereafter.		☐	☐	☑	☐	☐		Project management is ensuring that each milestone is satisfactorily completed so this situation does not arise
N	1.8	☑	In Progress	NASA	All deliverables shall be in PDF format.		☐	☐	☐	☑	☐		Project management will turn in all deliverables in PDF format
N	1.9	☑	In Progress	NASA	In every report, teams will provide a table of contents, including major sections and their respective subsections.		☐	☐	☐	☑	☐		Project management will create a table of contents for each milestone report
N	1.10	☑	In Progress	NASA	In every report, the team shall include the page number at the bottom of the page.		☐	☐	☐	☑	☐		Project management will include the page number for each milestone report
G	1.11	☑	Complete	NASA	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.		☐	☐	☑	☐	☐		Purdue University allows students to get access to many of these pieces of computer equipment. Anything not provided by Purdue University will be provided by project management
G	1.12	☑	Incomplete	NASA	All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 – 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.		☐	☐	☑	☑	☐		The team is designing the launch vehicle with these launch rail requirements in mind to ensure that this requirement is met during the Huntsville launch

							Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
G	1.13	☑	Complete	NASA	Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The team mentor shall not be a student team member. 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 two flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.		☐	☐	☑	☐	☐		As stated in Requirement 1.3.2, Christopher Nilson is acting as the PSP Student Launch mentor
G	1.14	☑	In Progress	NASA	Teams will track and report the number of hours spent working on each milestone.		☐	☑	☑	☐	☐		Project management is currently keeping track of the number of manhours through self-reports of how much each member spent on each milestone
C	2.1	☑	In Progress	NASA	The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.		☐	☑	☑	☐	☐		The construction team designed the launch vehicle and selected the motor to meet an apogee of 4772 ft
G	2.2	☑	Complete	NASA	Teams shall declare their target altitude goal at the CDR milestone. The declared target altitude shall be used to determine the team's altitude score.		☐	☑	☐	☐	☐		The team declared an apogee of 4772 ft
A	2.3	☑	In Progress	NASA	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 avionics team is designing a double-parachute system to safely recover the launch vehicle without major damage done during landing. The subscale launch demonstrated that the system is recoverable and reusable on a smaller scale

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C	2.4	☑	Complete	NASA	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.		☐	☐	☑	☐	☐	C.2.4.1, C.2.4.2, C.2.4.3	The four independent sections for the launch vehicle are the booster, upper recovery, lower recovery, and payload sections
C	2.4.1	☑	Complete	NASA	Coupler/airframe shoulders which are located at in-flight separation points shall be at least two airframe diameters in length. (One body diameter of surface contact with each airframe section).	C.2.4	☑	☐	☑	☐	☐		The smallest coupler (payload coupler) has a length of 10.63 in which is around 2.13 times greater than the airframe diameter of 5 in
C	2.4.2	☑	Complete	NASA	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.)	C.2.4	☑	☐	☑	☐	☐		All couplers are at in-flight separation points so this requirement is automatically met
C	2.4.3	☑	Complete	NASA	Nosecone shoulders which are located at in-flight separation points shall be at least ½ body diameter in length.	C.2.4	☑	☐	☑	☐	☐		The nosecone shoulder is 2.76 in in length which is 0.55 times the diameter of the launch vehicle
G	2.5	☑	In Progress	NASA	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.		☐	☐	☑	☐	☐		All subteams are designing their subsystems to ensure that the entire launch vehicle can be prepared within 2 hours
G	2.6	☑	In Progress	NASA	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.		☐	☐	☑	☑	☑		All subteams are designing their subsystems to ensure that the entire launch vehicle can be launch-ready for at least 3 hours. This is mainly acccomplished by ensuring that all electronics have enough battery life to function during this time
C	2.7	☑	In Progress	NASA	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 construction team is ensuring that the selected motor can be fired by a standard 12-volt direct current firing system
G	2.8	☑	In Progress	NASA	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).		☐	☐	☑	☐	☐		All subteams are designing their subsystems to be self-contained and not require and external circutry of ground support equipment
G	2.9	☑	Complete	NASA	Each team shall use commercially available ematches or igniters. Hand-dipped igniters shall not be permitted.		☐	☐	☑	☐	☐		The selected motors will use commercially available igniters

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C	2.10	☑	Complete	NASA	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).		☐	☐	☑	☐	☐	C.2.10.1, C.2.10.2	Both the Loki L930 and L1482 use APCP and are NAR/TRA approved
C	2.10.1	☑	Complete	NASA	Final motor choice shall be declared by the Preliminary Design Review (PDR) milestone.	C.2.10	☑	☐	☑	☐	☐		The Loki L930 is the selected primary motor and the Loki L1482 is the selected secondary motor
C	2.10.2	☑	Complete	NASA	Any motor change after PDR shall be approved by the NASA management team or NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment shall not be approved. A scoring adjustment against the team's overall score shall be incurred when a motor change is made after the PDR milestone. The only exception is teams switching to their secondary motor choice provided the primary motor choice is unavailable due to a motor shortage.	C.2.10	☑	☐	☑	☐	☐		The construction team is not changing the motor selected in PDR
C	2.11	☑	Complete	NASA	The launch vehicle shall be limited to a single motor propulsion system.		☐	☐	☑	☐	☐		The booster section only uses one motor for launch
C	2.12	☑	Complete	NASA	The total impulse provided by a College or University launch vehicle shall not exceed 5,120 Newtonseconds (L-class).		☐	☑	☑	☐	☐		Both the Loki L930 and L1482 are below 5,120 Newtonseconds of total impulse
G	2.13	☑	Discontinued	NASA	Pressure vessels on the vehicle must be approved by the RSO and shall meet the following criteria:		☐	☐	☑	☐	☐		No subteam will be using a pressure vessel
G	2.13.1	☑	Discontinued	NASA	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	C.2.13	☑	☑	☐	☐	☐		See 2.13
G	2.13.2	☑	Discontinued	NASA	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.	C.2.13	☑	☐	☑	☐	☐		See 2.13
G	2.13.3	☑	Discontinued	NASA	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.	C.2.13	☑	☐	☐	☑	☐		See 2.13

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Label	ID	Mission Critical	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
C	2.14	☑	Complete	NASA	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 static stability will be 3.7 at the point of rail exit
C	2.15	☑	Complete	NASA	The launch vehicle shall have a minimum thrust to weight ratio of 5.0:1.0.		☐	☑	☑	☐	☐		The primary motor gives the launch vehicle a thrust to weight ratio of around 6.98:1
C	2.16	☑	Complete	NASA	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.		☐	☑	☑	☐	☐		The construction team will ensure all structural protuberances is located aft of the burnout center of gravity. Camera housing are present on the nosecone and the constrcution team performed CFD analysis.
C	2.17	☑	Complete	NASA	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.		☐	☐	☑	☐	☐		The launch vehicle will accelerate to a minimum of 62.1 fps at rail exit
G	2.18	☑	Complete	NASA	All teams shall successfully launch and recover a subscale model of their rocket. 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).		☐	☑	☑	☑	☑	C.2.18.1, A.2.18.2, G.2.18.3, N.2.18.4, G.2.18.5	The subscale flight was launched and recovered safely on November 17, 2024
C	2.18.1	☑	Complete	NASA	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.	G.2.18	☑	☐	☑	☐	☑		The subscale model is a near perfect 60% scale of the fullscale launch vehicle which will allow it to perform as similarly as possible to the full-scale
A	2.18.2	☑	Complete	NASA	The subscale model shall carry an altimeter capable of recording the model's apogee altitude.	G.2.18	☑	☐	☑	☐	☐		The avionics team included a Telemetrum altimeter on the subscale launch to record flight data
G	2.18.3	☑	Complete	NASA	The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	G.2.18	☑	☐	☑	☐	☐		The team is built a new subscale rocket specific to this year's project
N	2.18.4	☑	Complete	NASA	Proof of a successful flight shall be supplied in the CDR report.	G.2.18	☑	☐	☐	☑	☐	N.2.18.4.1, N.2.18.4.2	The CDR report includes various pieces of documentation such as flight data and photographs to prove that the subscale launch was successful

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N	2.18.4.1	☑	Complete	NASA	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) will not be accepted.	N.2.18.4	☑	☑	☐	☐	☐		The data from the altimeter is provided to prove that the launch was successful
N	2.18.4.2	☑	Complete	NASA	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: nosecone, recovery system, airframe, and booster.	N.2.18.4	☑	☐	☐	☑	☐		Pictures of the as-landed sections are provided in the CDR report
G	2.18.5	☑	Complete	NASA	The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter, 100" length rocket, your subscale shall not exceed 3" diameter and 75" in length.	G.2.18	☑	☐	☑	☑	☐		All dimensions for the subscale model are approximately 60% that of the fullscale launch vehicle
G	2.19	☑	Incomplete	NASA	All teams shall complete demonstration flights as outlined below.		☐	☐	☑	☐	☐	G.2.19.1, G.2.19.2	See below
G	2.19.1	☑	Incomplete	NASA	Vehicle Demonstration Flight— All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight:	G.2.19	☑	☑	☑	☑	☑	G.2.19.1.1, G.2.19.1.2, P.2.19.1.3, P.2.19.1.4, C.2.19.1.5, C.2.19.1.5, C.2.19.1.6, G.2.19.1.7, N.2.19.1.8, M.2.19.1.9	The team will launch the full scale rocket prior to the FRR deadline as a Vehicle Demonstration Flight to validate all systems onboard (exluding payload) are working as intended
G	2.19.1.1	☑	Incomplete	NASA	The vehicle and recovery system shall have functioned as designed.	G.2.19.1	☑	☐	☑	☐	☑		The team will collect data and provide pictures of the landing site to prove the vehicle and recovery systems work as designed
G	2.19.1.2	☑	In Progress	NASA	The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	G.2.19.1	☑	☐	☑	☐	☐		All subteams will not be permitted to use any sections from previous year's launch vehicles
P	2.19.1.3	☑	Incomplete	NASA	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:	G.2.19.1	☑	☐	☑	☐	☐	P.2.19.1.3.1,P.2.19.1.3.2	The payload subteam will ensure the following requirements are met

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P	2.19.1.3.1	☑	Incomplete	NASA	If the payload is not flown, mass simulators shall be used to simulate the payload mass.	P.2.19.1.3	☑	☐	☑	☐	☐		The payload subteam will include mass simulators to approximate the payload mass
P	2.19.1.3.2	☑	Incomplete	NASA	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	P.2.19.1.3	☑	☐	☐	☑	☐		The payload subteam will distribute these mass simulators approximately where the payload will be located on the launch vehicle during subsequent launches
P	2.19.1.4	☑	Incomplete	NASA	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	G.2.19.1	☑	☐	☑	☐	☐		The payload subteam will ensure that all external disturbances (if designed) are present for the Vehicle Demonstration Flight
C	2.19.1.5	☑	In Progress	NASA	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.	G.2.19.1	☑	☐	☑	☐	☐		The construction team will acquire multiple instances of the same competition launch motor and use it for the Vehicle Demonstration Flight as well as the launch in Huntsville
C	2.19.1.6	☑	In Progress	NASA	The vehicle will be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast shall not be added without a re-flight of the full-scale launch vehicle.	G.2.19.1	☑	☐	☑	☐	☐		The construction team will ensure that all available ballast is added during the Vehicle Demonstration Flight
G	2.19.1.7	☑	In Progress	NASA	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA management team or Range Safety Officer (RSO).	G.2.19.1	☑	☐	☑	☑	☐		All subteams will not modify their respective systems after successfully completing the full scale demonstraion flight without permission of NASA management or the RSO
N	2.19.1.8	☑	Incomplete	NASA	Proof of a successful flight shall be supplied in the FRR report.	G.2.19.1	☑	☐	☐	☑	☐	A.2.19.1.8.1, N.2.19.1.8.2, N.2.18.1.8.3	Both data and pictures of the flight will be provided as proof of a successful launch
A	2.19.1.8.1	☑	Incomplete	NASA	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted.	N.2.19.1.8	☑	☑	☐	☐	☐		The avionics subteam will provide complete altimeter data as proof of a successful launch
N	2.19.1.8.2	☑	Incomplete	NASA	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: nosecone, recovery system, airframe, and booster.	N.2.19.1.8	☑	☐	☐	☑	☐		Quality pictures of all sections of the launch vehicle as-landed will be provided for the FRR report

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N	2.19.1.8.3	☑	Incomplete	NASA	Raw altimeter data shall be submitted in .csv or .xlsx format.	N.2.19.1.8	☑	☐	☐	☑	☐		Project management will ensure raw altimeter data is provided to NASA in .csv or .xlsx format
M	2.19.1.9	☑	Incomplete	NASA	Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum deadline.	G.2.19.1	☑	☐	☑	☐	☐		Project management will ensure the Vehicle Demonstration flights are completed well before the FRR deadline to give the team ample time to write the report
G	2.19.2	☑	Incomplete	NASA	Payload Demonstration Flight— All teams shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:	G.2.19	☑	☑	☑	☑	☑	P.2.19.2.1, P.2.19.2.2, G.2.19.2.3, M.2.19.2.4	The team will launch the full scale rocket again (if needed) with the complete payload onboard to prove that all systems (including payload) work as intended
P	2.19.2.1	☑	Incomplete	NASA	The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.		☑	☐	☑	☐	☐		The payload team will ensure that the payload is securely retained until its intended point of release
P	2.19.2.2	☑	Incomplete	NASA	The payload flown shall be the final, active version.		☑	☐	☑	☐	☐		The payload team will fly the final version of the system onboard the Payload Demonstration Flight
G	2.19.2.3	☑	Incomplete	NASA	If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.		☑	☐	☑	☐	☐		If the team is ahead of schedule, the team will attempt to include the final payload design during the Vehicle Demonstration Flight

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M	2.19.2.4	☑	Incomplete	NASA	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.		☑	☐	☑	☐	☐		Project management will ensure tha Payload Demonstration Flight is completed well before the FRR Addendum deadline to give the team a reasonable amount of time to write the report
G	2.20	☑	Incomplete	NASA	An FRR Addendum shall be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.		☐	☐	☑	☐	☐	M.2.20.1, M.2.20.2	If a Payload Demonstration Flight or Vehicle Demonstration Re-Flight is needed, then the team will write and submit a FRR Addendum report to NASA
M	2.20.1	☑	Incomplete	NASA	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.	G.2.20	☑	☐	☑	☐	☐		The team will submit the FRR Addendum by the deadline if a Vehicle Demonstration Re-Flight is ndded
M	2.20.2	☑	Incomplete	NASA	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload during launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	G.2.20	☑	☐	☑	☐	☐		If the Payload Demonstration Flight is not successful, then the team will ask for permission to fly the payload if the team is confident in the safety of the payload design
G	2.21	☑	In Progress	NASA	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.		☐	☐	☐	☑	☐		The team will ensure that the team's name and contact information is provided in an intuitive way without needing to open the vehicle
G	2.22	☑	In Progress	NASA	All Lithium Polymer batteries shall be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.		☐	☐	☐	☑	☐		All subteams using Lithium Polymer batteries will ensure that they are protected from impact during landing and distinguish it as a fire hazard
G	2.23	☑	In Progress	NASA	Vehicle Prohibitions:		☐	☑	☑	☐	☐	C.2.23.1, C.2.23.2, C.2.23.3, C.2.23.4, C.2.23.5, C.2.23.6, C.2.23.7, G.2.23.8, G.2.23.9, C.2.23.10	See below
C	2.23.1	☑	Complete	NASA	The launch vehicle shall not utilize forward firing motors.	G.2.23	☑	☐	☑	☐	☐		The launch vehicle only uses downward firing motors
C	2.23.2	☑	Complete	NASA	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	G.2.23	☑	☐	☑	☐	☐		The Loki L930 and L1482 do not expel titanium sponges
C	2.23.3	☑	Complete	NASA	The launch vehicle shall not utilize hybrid motors.	G.2.23	☑	☐	☑	☐	☐		The Loki L930 and L1482 are both solid rocket motors

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C	2.23.4	☑	Complete	NASA	The launch vehicle shall not utilize a cluster of motors.	G.2.23	☑	☐	☑	☐	☐		The booster section only uses one motor for launch
C	2.23.5	☑	Complete	NASA	The launch vehicle shall not utilize friction fitting for motors.	G.2.23	☑	☐	☑	☐	☐		The MFSS will use a retainer plate to secure the motor
C	2.23.6	☑	Complete	NASA	The launch vehicle shall not exceed Mach 1 at any point during flight.	G.2.23	☑	☑	☑	☐	☐		The maximum velocity in all simulated conditions is 179 m/s or Mach 0.52
C	2.23.7	☑	Complete	NASA	Vehicle ballast shall not exceed 10% of the total un-ballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	G.2.23	☑	☑	☐	☐	☐		The current launch vehicle does not use any ballast
G	2.23.8	☑	In Progress	NASA	Transmissions from on-board transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter).	G.2.23	☑	☐	☑	☐	☐		The avionics and payload subteams will use transmitters that do not exceed 250 mW
G	2.23.9	☑	In Progress	NASA	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.	G.2.23	☑	☐	☑	☐	☐		The avionics and payload subteams will use transmitters that do not create excessuve interfernce for other transmissions
C	2.23.10	☑	In Progress	NASA	Excessive and/or dense metal shall not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	G.2.23	☑	☐	☑	☐	☐		The construction subteam will use lightweight metals such as aluminum if needed in the launch vehicle's design
A	3..1	☑	Complete	NASA	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.		☐	☐	☑	☐	☐	A.3.1.1, A.3.1.2, A.3.1.3	The launch vehicle uses a two-stage parachute system where a drogue deploys at apogee and a main deploys at a lower altitue
A	3.1.1	☑	Complete	NASA	The main parachute shall be deployed no lower than 500 feet.	A.3.1	☑	☑	☑	☐	☐		The main parachute is designed to deploy at 700 ft
A	3.1.2	☑	In Progress	NASA	The apogee event shall contain a delay of no more than 2 seconds.	A.3.1	☑	☑	☑	☐	☐		The avionics subteam will use altimeter data to detect apogee and deploy the drogue parachute during apogee
A	3.1.3	☑	Complete	NASA	Motor ejection is not a permissible form of primary or secondary deployment.	A.3.1	☑	☐	☑	☐	☐		Black powder charges are being used for both the drogue and main parachutes

							Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
A	3.2	☑	In Progress	NASA	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.		☐	☑	☑	☐	☑		The avionics subteam will perform a ground ejection test and document its success before all subscale and full scale flights. A successful ground ejection test was performed for subscale
A	3.3	☑	Complete	NASA	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 maximum kinetic energy is currently estimated at 45.7 ft-lbf
A	3.4	☑	Complete	NASA	The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.		☐	☐	☑	☐	☐		A Telemetrum is selected at the primary altimeter and a Stratologger is selected as the secondary altimeter. Both of these are barometric
A	3.5	☑	Complete	NASA	Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.		☐	☐	☑	☐	☐		The avionics subteam ensured that each altimeter has its own power supply and is separate from each other
A	3.6	☑	Complete	NASA	Each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.		☐	☐	☑	☐	☐		An arming keyhole is designed to be accessible from the exterior of the rocket airframe
A	3.7	☑	Complete	NASA	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 arming keyhole is able to be locked in the ON position for launch
A	3.8	☑	Complete	NASA	The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.		☐	☐	☑	☐	☐		The avionics and payload subsystems are located in different independent sections of the launch vehicle to ensure that they are independent of each other
A	3.9	☑	Complete	NASA	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.		☐	☐	☑	☐	☐		The avionics sections will use shear pins for both the main and drogue parachute compartments
A	3.10	☑	In Progress	NASA	Bent eyebolts shall not be permitted in the recovery subsystem.		☐	☐	☐	☑	☐		The avionics subteam will ensure that all eyebolts used are not bent
A	3.11	☑	Complete	NASA	The recovery area shall be limited to a 2,500 ft. radius from the launch pads.		☐	☑	☑	☐	☐		In the worst case situation (20 mph winds at a 20 degree launch angle), the max landing distance is around 2162 ft

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Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
A	3.12	☑	Complete	NASA	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 will be awarded bonus points.		☐	☑	☐	☐	☐		In the worst case situation (no wind and 0 degree launch angle), the descent time is around 69.4 seconds
A	3.13	☑	Complete	NASA	An electronic GPS tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.		☐	☐	☑	☐	☐	A.3.13.1, A.3.13.2	The Telemetrum altimeter has an on-board GPS
G	3.13.1	☑	Discontinued	NASA	Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic GPS tracking device.	A.3.13	☑	☐	☑	☐	☐		No rocket section or payload component will be untethered to the launch vehicle
A	3.13.2	☑	In Progress	NASA	The electronic GPS tracking device(s) shall be fully functional during the official competition launch.	A.3.13	☑	☐	☑	☐	☐		The avionics subteam will ensure that the GPS tracking device is fully active during the entire launch period
A	3.14	☑	In Progress	NASA	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).		☐	☐	☐	☑	☐	A.3.13.1, A.3.13.2, A.3.13.3, A.3.13.4	The avionics subteam will work with other subteams to ensure that its onboard electronic devices is not affected by any other subsystems
A	3.14.1	☑	Complete	NASA	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.	A.3.13	☑	☐	☑	☐	☐		The avionics subteam is locating its design in a separate section than that of payload's section
A	3.14.2	☑	In Progress	NASA	The recovery system electronics shall be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	A.3.13	☑	☐	☑	☐	☐		The avionics subteam will ensure that all the recovery system electronics are shielded from all on-board transmissions
A	3.14.3	☑	In Progress	NASA	The recovery system electronics shall be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	A.3.13	☑	☐	☑	☐	☐		The avionics subteam will ensure that all the recovery system electronics are shielded from all on-board magnetic waves
A	3.14.4	☑	In Progress	NASA	The recovery system electronics shall be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	A.3.13	☑	☐	☑	☐	☐		The avionics subteam will ensure that all the recovery system electronics are shielded from all on-board devices which may produce interference

							Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
P	4.1	☑	In Progress	NASA	USLI Payload Mission objective: College/University Division — Teams are tasked with designing, building, and flying a STEMnaut flight capsule capable of safely retaining four STEMnauts and transmitting, via radio frequency, relevant rocket and STEMnaut landing site data to a NASA-owned receiver located at the launch site. STEMnauts are physical representations of the crew on-board the rocket. 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 subteam will design a payload with this overarching requirement as its key design principle
P	4.2	☑	In Progress	NASA	STEMCRaFT Mission Requirements:		☐	☐	☑	☐	☑	P.4.2.1, P.4.2.2, P.4.2.3, P.4.2.4, P.4.2.5, P.4.2.6	See below
P	4.2.1	☑	In Progress	NASA	Teams shall choose a minimum of 3 pieces of data from the below list to a maximum of 8 to transmit to the NASA receiver. • Temperature of landing site • Time of landing • Apogee reached • Maximum velocity • Battery check/power status • Landing velocity, G-forces sustained • Orientation of on-board STEMnauts • Calculated STEMnaut crew survivability probability • Maximum altitude	P.4.2	☑	☐	☑	☐	☐		The payload subteam currently selected the temperature of landing site, time of landing, and apogee reached
P	4.2.2	☑	In Progress	NASA	The payload shall not have any protrusions from the vehicle prior to apogee that extend beyond a quarter inch exterior to the airframe.	P.4.2	☑	☐	☑	☐	☐		The payload subteam will ensure that its design does not protrude from the vehicle prior to apogee
P	4.2.3	☑	In Progress	NASA	Payload shall transmit on the 2-M band. A specific frequency shall be given to the teams later. NASA shall use the FTM-300DR transceiver.	P.4.2	☑	☐	☑	☐	☐		The payload subteam will transmit on the 2-M band
P	4.2.4	☑	Complete	NASA	All transmissions shall start and stop with team member call sign.	P.4.2	☑	☐	☑	☐	☐		The payload subteam will start and stop all transmissions with the team call sign
P	4.2.5	☑	In Progress	NASA	Teams shall submit a list of what data they will attempt to transmit by NASA receiver by March 17.	P.4.2	☑	☐	☑	☐	☐		The payload subteam will select at least three pieces of data before March 17. Currently the list is the temperature of landing site, time of landing, and apogee reached
P	4.2.6	☑	In Progress	NASA	Teams shall transmit with a maximum of 5W and transmissions shall not occur prior to landing.	P.4.2	☑	☐	☑	☐	☐	P.4.2.6.1	The payload subteam will transmit at a maximum of 5W and will not transmit prior to landing

							Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
P	4.2.6.1	☑	Incomplete	NASA	Teams shall not transmit on the specified NASA frequency on launch day prior to landing.	P.4.2.6	☑	☐	☑	☐	☐		The payload subteam will not transmit on the specified NASA frequency prior to landing
P	4.3	☑	In Progress	NASA	General Payload Requirements:		☐	☐	☑	☐	☐	P.4.3.1, P.4.3.2, P.4.3.3, P.4.3.4, P.4.3.5, P.4.3.6	See below
P	4.3.1	☑	Complete	NASA	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.	P.4.3	☑	☐	☑	☐	☐		The payload subteam will not use energetics in its design. Energetics is only reserved for the motor and the ejection systems
G	4.3.2	☑	Complete	NASA	Teams shall abide by all FAA and NAR rules and regulations.	P.4.3	☑	☐	☑	☐	☐		The entire team shall abide by all FAA and NAR rules and regulations
P	4.3.3	☑	Discontinued	NASA	Any payload experiment element that is jettisoned during the recovery phase shall receive realtime RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	P.4.3	☑	☐	☑	☐	☐		The payload subteam is not jettisoning any subsystem
P	4.3.4	☑	Discontinued	NASA	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.	P.4.3	☑	☐	☑	☐	☐		The payload subteam is not designing a UAS
P	4.3.5	☑	Discontinued	NASA	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).	P.4.3	☑	☐	☑	☐	☐		The payload subteam is not designing a UAS
P	4.3.6	☑	Discontinued	NASA	Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.	P.4.3	☑	☐	☑	☐	☐		The payload subteam is not designing a UAS
H	5.1	☑	In Progress	NASA	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.		☐	☐	☑	☑	☐		The team will create a launch and safety checklist before any flight and the final checklist will be included in FRR
H	5.2	☑	Complete	NASA	Each team shall identify a student safety officer who will be responsible for all items in Section 5.3.		☐	☐	☐	☐	☐		Julia Spihlman is the team's safety lead
H	5.3	☑	In Progress	NASA	The role and responsibilities of the safety officer shall include, but are not limited to:		☐	☑	☑	☑	☐	H.5.3.1, H.5.3.2, H.5.3.3, H.5.3.4	See below
H	5.3.1	☑	Complete	NASA	Monitor team activities with an emphasis on safety during:	H.5.3	☑	☐	☐	☑	☐	H.5.3.1.1, H.5.3.1.2, H.5.3.1.3, H.5.3.1.4, H.5.3.1.5, H.5.3.1.6, H.5.3.1.7, H.5.3.1.8, H.5.3.1.9	The safety lead will ensure that safe design practices are enforced in the following items listed below
H	5.3.1.1	☑	Complete	NASA	Design of vehicle and payload	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.2	☑	Complete	NASA	Construction of vehicle and payload components	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.3	☑	Complete	NASA	Assembly of vehicle and payload	H.5.3.1	☑	☐	☐	☑	☐		See above

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H	5.3.1.4	☑	Complete	NASA	Ground testing of vehicle and payload	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.5	☑	Complete	NASA	Subscale launch test(s)	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.6	☑	Complete	NASA	Full-scale launch test(s)	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.7	☑	Complete	NASA	Competition Launch	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.8	☑	Complete	NASA	Recovery activities	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.1.9	☑	Complete	NASA	STEM Engagement Activities	H.5.3.1	☑	☐	☐	☑	☐		See above
H	5.3.2	☑	In Progress	NASA	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	H.5.3	☑	☐	☐	☑	☐		The safety lead will develop implementation procedures for this year's construction, assembly, launch, and recovery activities
H	5.3.3	☑	Complete	NASA	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data.	H.5.3	☑	☑	☑	☐	☐		The safety lead has created current revisions for the team's hazard analyses, FMEA tables, prodecures, and SDS/chemical inventory data
H	5.3.4	☑	Complete	NASA	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	H.5.3	☑	☐	☑	☐	☐		The safety lead has created hazard analsyses, FMEA tables, and procedures
G	5.4	☑	In Progress	NASA	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 team will communicate all intent with the local rocketry President and RSO. The team will ensure that it follows all guidance set by the local RSO
G	5.5	☑	Complete	NASA	Teams shall abide by all rules set forth by the FAA.		☐	☐	☑	☐	☐		The team will follow all FAA rules
G	6.1	☑	Incomplete	NASA	NASA Launch Complex		☐	☐	☑	☐	☐	G.6.1.1, G.6.1.2, G.6.1.3, G.6.1.4, G.6.1.5	See below
G	6.1.1	☑	Incomplete	NASA	Teams are not permitted to show up at the NASA Launch Complex outside of launch day without permission from the NASA management team.	G.6.1	☑	☐	☑	☐	☐		The team will arrive on the specified launch day of May 3 or May 4
G	6.1.2	☑	Incomplete	NASA	Teams shall complete and pass the Launch Readiness Review conducted during Launch Week.	G.6.1	☑	☐	☑	☐	☐		The team will complete and pass the Launch Rediness Review before launching
G	6.1.3	☑	Incomplete	NASA	The team mentor shall be present and oversee rocket preparation and launch activities	G.6.1	☑	☐	☑	☐	☐		The team mentor will be present during Launch Week to oversee launch vehicle activies and procedures
A	6.1.4	☑	Incomplete	NASA	The scoring altimeter shall be presented to the NASA scoring official upon recovery. The scoring altimeter shall be one of the altimeters used for recovery events.	G.6.1	☑	☐	☑	☐	☐		The avionics subteam will present the scoring altimeter to NASA upon recovery

							Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
G	6.1.5	☑	Incomplete	NASA	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch, will not be scored and will not be considered for awards.	G.6.1	☑	☐	☑	☐	☐		The team will only launch once during Launch Week
G	6.2	☑	Incomplete	NASA	Commercial Spaceport Launch Site		☐	☐	☑	☐	☐	G.6.2.1, G.6.2.2, G.6.2.3, G.6.2.4, G.6.2.5, G.6.2.6, G.6.2.7, G.6.2.8	If the team does not attend Launch Week, then the following items below will apply
G	6.2.1	☑	Incomplete	NASA	The launch shall occur at a NAR or TRA sanctioned and insured club launch. Exceptions may be approved for launch clubs who are not affiliated with NAR or TRA but provide their own insurance, such as the Friends of Amateur Rocketry. Approval for such exceptions shall be granted by NASA prior to the launch.	G.6.2	☑	☐	☑	☐	☐		The team will launch at a NAR or TRA sanctioned and insured launch club
G	6.2.2	☑	Incomplete	NASA	Teams shall submit their rocket and payload to the launch site Range Safety Officer (RSO) prior to flying the rocket. The RSO shall inspect the rocket and payload for flight worthiness and determine if the project is approved for flight. The local RSO shall have final authority on whether the team's rocket and payload may be flown.	G.6.2	☑	☐	☑	☐	☐		The team will hand the launch vehicle and payload to the RSO and wait for RSO permission before flight
G	6.2.3	☑	Incomplete	NASA	The team mentor shall be present and oversee rocket preparation and launch activities.	G.6.2	☑	☐	☑	☐	☐		The team mentor will be present to oversee launch vehicle activies and procedures
G	6.2.4	☑	Incomplete	NASA	BOTH the team mentor and the Launch Control Officer shall observe the flight and report any offnominal events during ascent or recovery on the Launch Certification and Observations Report.	G.6.2	☑	☐	☑	☐	☐		The team mentor and the Launch Control Officer will observe the flight and report any offnominal events
A	6.2.5	☑	Incomplete	NASA	The scoring altimeter shall be presented to BOTH the team's mentor and the Range Safety Officer. The scoring altimeter shall be one of the altimeters used for recovery events.	G.6.2	☑	☐	☑	☐	☐		The avionics subteam will present the scoring altimeter to both the team mentor and the RSO
G	6.2.6	☑	Incomplete	NASA	The mentor, the Range Safety Officer, and the Launch Control Officer must be three separate individuals who must ALL complete the applicable sections of the Launch Certification and Observations Report. The Launch Certification and Observations Report document will be provided by NASA upon completion of the FRR milestone and shall be returned to NASA by the team mentor upon completion of the launch.	G.6.2	☑	☐	☑	☐	☐		The mentor, RSO, and Launch Control Officer will be three separate individuals during the launch

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G	6.2.7	☑	Incomplete	NASA	The Range Safety Officer and Launch Control Officer certifying the team's flight shall be impartial observers and shall not be affiliated with the team, individual team members, or the team's academic institution.	G.6.2	☑	☐	☑	☐	☐		The RSO and Launch Control Officer will be third parties not affiliated with the team
G	6.2.8	☑	Incomplete	NASA	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch will not be scored and will not be considered for awards.	G.6.2	☑	☐	☑	☐	☐		The team will only launch once during this time

Table 6.2.3 Construction R&VP Table

CONSTRUCTION SUBTEAM REQUIREMENTS								Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Requirement Jus fica on	Project Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
S.C	1	☑	Complete	Ryan Do	Motor Fin Support Structure shall have at least a structural factor (stress load) of safety of 1.5	Having an adequately high stress factor of safety reduces the probability of MFSS failure which would render the launch vehicle inoperable		☐	☑	☐	☐	☐		Individual parts have a factor of safety greater than 1.5 with the lowest of all parts being 10.63 but no analysis of the entire assembly has been performed yet
S.C	2	☑	Complete	Anthony Mansour	MFSS stock plates shall be precision milled/ground according to the technical drawing	MFSS being precision milled/ground ensures a secure fit into the launch vehicle as this is a mission critical component		☐	☐	☐	☑	☐		MFSS design is completed but not manufactured yet
S.C	3	☑	Complete	Anthony Mansour	The material used for MFSS shall have ultimate tensile strength of above 200MPa, density below 5g/cc, and cost per volume below $3.00/in^3.	The MFSS material must be light and strong in order to meet overall launch vehicle requirements and expectations		☐	☑	☐	☐	☐		The MFSS material chosen is Aluminum 6061-T6 which has an ultimate tensile strength of 310 MPa, density of 2.7 g/cc, and a cost of $0.42 / in^3
S.C	4	☑	In Progress	Ryan Do	Airframe shall be manufactured with fiberglass	Fiberglass is a good material known for its light weight and durable properties allowing airframe to be light and strong without compromise		☐	☐	☐	☑	☐		Airframe design has been completed but not manufactured yet
S.C	5	☐	In Progress	Kendall Allen	Airframe shall provide easy access to avionics bay, payload bay, and parachute compartments	Having easy access to launch vehicle components represents fundamentally good launch vehicle design. It also allows easy assembly and diassembly		☐	☐	☑	☑	☐		Launch vehicle design has been created but not manufactured yet so test assembly can't be performed
S.C	6	☑	In Progress	Kendall Allen	Airframe components shall be adhered with epoxy if screws aren't used	Static parts of the launch vehicle that don't require ocasional diassembly and use screws need alternate methods of being held together		☐	☐	☐	☑	☐		Airframe design has been completed but not manufactured or assembled yet
S.C	7	☐	Complete	Stefano Vitello	Fins shall utilize an airfoil shape	Minimal drag needs to be achieved which can be done through the usage of airfoils		☐	☑	☐	☑	☐		Fin design has been completed (Utilizes NACA 0012)
S.C	8	☑	Complete	Ryan Do	MFSS shall fit inside airframe	MFSS is a mission critical component that must fit inside the airframe, otherwise the launch vehicle design will fail		☐	☐	☑	☑	☐		MFSS design is completed but not manufactured yet
S.C	9	☑	In Progress	Stefano Vitello	Fins shall be able to mount onto the MFSS	Fins are mission critical components that allows safe and stable trajectory of the launch vehicle which will be housed on the MFSS		☐	☐	☑	☑	☐		Fin and MFSS design is completed but not manufactured or undergo test assembly
S.C	10	☑	Complete	Ryan Do	Retainer plate of MFSS shall have a maximum strain of 0.01 after every launch for reusability	The retainer plate having minimal deformation allows reusability meaning that only a few plates need to be manufactured instead of many saving costs		☐	☑	☐	☐	☑		No test launch has been completed yet, ANSYS FEA indicates minimum deformation is less than 0.01
S.C	11	☑	Complete	Ryan Do	Airframe inner diameter shall be 5 inches	Airframe inner diameter being 5 inches allow adequate volume to fit both payload, avionics, and other mission critical components while also not being excessively heavy		☐	☐	☐	☑	☐		Airframe design has been completed and uses a 5 in inner diameter airframe
S.C	12	☑	Complete	Ryan Do	Overall launch vehicle static stability shall be no less than 2.5	Having a static stability above 2.5 ensures a stable flight trajectory		☐	☑	☐	☐	☐		Launch vehicle design has been completed (Has static stability of 3.56
S.C	13	☑	Complete	Anthony Mansour	Retainer plate shall be less than or equal to 1/8" in thickness so that it can be laser-cut	1/8" is the maximum thickness the laser cutter at the BIDC can handle.		☐	☐	☐	☑	☐		Retainer plate of MFSS design has been completed (thickness of plate is 1/8")
S.C	14	☑	Complete	Ryan Do	Members shall complete BIDC's safety training to operate equipment	Completion of safety training is mandatory by BIDC in order to operate their equipment		☐	☐	☑	☑	☐		Members have completed safety training to operate equipment at BIDC and are ready to begin manufacturing

CONSTRUCTION SUBTEAM REQUIREMENTS								Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Requirement Justification	Project Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
S.C	15	☐	Complete	Stefano Vitello	Fin size shall be contained within a 9 in cube to be manufactured using 3D SLA printers accessible by the team	Fin size being contained in a 9 in. cube allows 3D printing using SLA method rather than the traditional FDM method		☐	☐	☐	☑	☐		Fin design is complete and falls within the dimensions allowed for manufacturing by the accessible 3D printers
S.C	16	☑	In Progress	Kendall Allen	All composite materials shall be manufactured in the properly ventilated environment	Composite materials need to be manufactued in separate ventilated rooms to prevent contamination and a potential compromise of the materials properties. This also ensures the safety of everyone inside of the room due to the hazards of breathing in composite materials		☐	☐	☑	☑	☐		All composite components will be manufactured in a special composites room located in the PTC
S.C	17	☐	In Progress	Kendall Allen	All non-separable airframe holes shall use 1/4 inch 20" thread	Standardized hole size allows the team to easily track usage of screws and how many is needed		☐	☐	☐	☑	☐		Airframe design has been completed but holes must be reverified after completion of manufacturing
S.C	18	☐	In Progress	Ryan Do	Nosecone shall be 3D printed	Nosecone being 3D printed makes manufacturing of complex nosecone shapes easier. Also manufacutring inhouse reduces costs		☐	☐	☐	☑	☐		Nosecone design has been completed but not manufactured yet
S.C	19	☐	In Progress	Kendall Allen	The construction subteam shall utilize circular jigs for manufacturing of any circular components	Using circular jigs when drilling holes into circular components ensures high quality during manufacturing		☐	☐	☑	☑	☐		Creation of circular jigs has not been completed yet
S.C	20	☑	Complete	Anthony Mansour	The construction subteam shall utilize softjaws in MFSS CNC manufacturing	Using softjaws during CNC manufacturing ensures the CNC machine manufactures with high quality and prevents the machine from potentially failing		☐	☐	☑	☑	☐		Creation of softjaws has been completed
S.C	21	☑	In Progress	Ryan Do	The nosecone should be designed and utilize materials to prevent fracture upon landing	The nosecone not fracturing upon landing allows it to be reused and thus fewer nosecones need to be manufactured		☐	☑	☐	☐	☑		No full-scale test launch has been completed yet. ANSYS FEA indicates the nosecone doesn't fracture and can withstand predicted flight conditions
S.C	22	☑	In Progress	Ryan Do	The fin tip can withstand up to 50 lbf of force without extreme permanent deformation	The fin tip must be able to withstand 50 lbf of force such that it will not deform during flight or on landing		☐	☑	☐	☐	☑		A previous fin design was tested and failed the test so a new fin was designed without changing the launch vehicle's center of pressure. A test is yet to be conducted for this new fin

Table 6.2.4 Avionics R&VP Table

AVIONICS SUBTEAM REQUIREMENTS								Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Requirement Jus fica on	Project Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
S.A	1	☑	In Progress	Payton Gross	Altimeter batteries shall be testing within a range of the maximum temperature of 90F and a minimum to 0F to ensure functionality for all possible launch conditions.	In order to verify our batteries will be able to launch in the expected temperatures for when the team will be launching in the team's home state plus the expected weather for Huntsville, the batteries will be tested across the extreme ranges of possible temperatures to ensure there will be no failure.	G.2.6	☐	☐	☐	☐	☑		Altimeter batteries' voltage drain shall be tested within a range of the maximum temperature of 90F and a minimum to 0F ensure functionality for all possible launch conditions.
S.A	2	☑	In Progress	Payton Gross	Altimeter batteries shall function for the entirety of flight and will support successful altimeter performance.	In order for the launch vehicle to have a successful recovery system, the altimeters must have power and continuity for the entire flights.	A.3.1, A.3.5	☐	☐	☐	☐	☑		Altimeter batteries' continuity shall be tested for a minimum of three hours. Every 30 minutes, the altimeters' continuity shall be checked using the continuity beeps.
S.A	3	☑	In Progress	Payton Gross	Altimeter batteries shall supply minimum usable voltage to maintain altimeter continuity for a minimum of 3 hours.	In order to ensure our batteries will be able to supply voltage for the recommended possible time the team's launch vehicle will be on the launch pad, the batteries will undergo a battery drain test to ensure they can supply voltage for at least 3 hours.	G.2.6	☐	☐	☐	☐	☑		Altimeter batteries' voltages shall be tested for a minimum of three hours. Every 30 minutes, battery voltage will be checked to ensure it remains about the minimum usable voltage.
S.A	4	☑	Complete	Payton Gross	Altimeter batteries shall be covered and labeled with neon colors within the avionics sled to protect them in case of impact.	In order to prevent a safety hazard with potential fires in the rocket due to damage from any sort of impact against a battery, the team has required there will be methods of protecting and labeling the battery built into the avionics sled designs.	G.2.22	☐	☐	☑	☐	☐		Avionics sled shall be 3D printed with a battery guard that has proper labeling and neon coloring to protect from ground impact. All current designs have multiple proposed methods of covering and protecting both altimeter batteries.
S.A	5	☑	Complete	Payton Gross	The altimeter batteries and ejection system shall only be armed and disarmed by the switch.	The ejection system will be run off altimeter that must be turned on and off by a dedicated switch for each altimeter.	A.3.7	☐	☐	☐	☑	☐		The team will verify switches are properly connected prior to any and all launches and that the altimeter power activation is only controlled by the switches.
S.A	6	☑	Complete	Payton Gross	Flight forces shall not be able to disengage the system switches. Landing kinetic force is expected to be below 65 ft/lbs and deployment forces are expected to be a maximum of 98.52 lbf.	In order for the parachutes to safely deploy for a successful recovery, both the switches and avionics must remain connected for the entire flight.	A.3.7	☐	☐	☐	☑	☑		The subscale flight will verify that the switches cannot be disengaed by flight forces.
S.A	7	☑	In Progress	Payton Gross	Altimeter continuity shall be tested and confirmed established at the launch pad and will be maintained throughout flight.	The altimeters must have power and continuity to facilitate successful recoveries which will be checked before every single flight at the launch pad. Additionally, continuity must remain for the entire possible time the rocket will be at the launch pad.	A.3.1	☐	☐	☐	☑	☐		The three hour altimeter coninuity testing will demonstrate that altimeter continutiy will be established and remain connected through the expected launch wait time and all of flight. The security of the altimeter connections will be tested and verified before the avionics bay is integrated into the rocket and at the launch pad by reading the altimeter beeps after being turned on.
S.A	8	☐	In Progress	Payton Gross	Descent time of the launch vehicle shall be less than 90s.	The team has decided to target a maximum descent time of 90 seconds instead of trying to achieve the 80 second bonus points.	A.3.12	☐	☑	☑	☐	☐		Descent time will be simulated both in OpenRocket and RocketPy and will be recorded and verified during launches.
S.A	9	☑	Complete	Payton Gross	Primary and redundant altimeters shall be in two independent circuits.	This fulfills the requirements that the recovery systems are completely independent from payload circuits and that the altimeters each have their own batteries. This also ensures that the system is completely redundant as there are no points of connection between the primary and redundant system that could affect the other.	A.3.5, A.3.8	☐	☐	☐	☑	☐		In order to ensure that the recovery systems are completely independent from the Payload circuits and that the altimeters each have their own batteries, the primary and redundant recovery systems will be designed as completely independant of each other.
S.A	10	☑	In Progress	Payton Gross	The descent velocity for the drogue parachute shall remain below 150 ft/s for a safe deployment and opening of the main parachute.	In order for the main parachute to deploy safely without the chance of it ripping, the descent velocity under drogue must remain below 150 ft/s.		☐	☑	☑	☐	☐		The drogue descent velocity should be simulated to be less than 150 ft/s in OpenRocket and RocketPy. This will be verified during launches. The decent time has been verified in both OpenRocket and RocketPy as being below 150 ft/s, generally being close to 130 ft/s.

AVIONICS SUBTEAM REQUIREMENTS								Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Requirement Jus fica on	Project Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
S.A	11	☑	In Progress	Payton Gross	All avionics components shall be verified as secured before launch and inspected after landing.	In order to have a successful recovery, all components of the avionics and recovery systems must be within the coupler and secured to verify they cannot come lose.		☐	☐	☐	☐	☑		The team shall verify before launch that the avionics sled is fully assembled and all components are completely secure from flight forces with various tests. Following all launches, the team will inspect the avionics coupler to ensure all components remained secure.
S.A	12	☑	Complete	Payton Gross	All recovery system components shall be strong enough to withstand the expected shockloads during launch, deployment, and landing. Landing kinetic force is expected to be below 65 ft/lbs and deployment forces are expected to be a maximum of 98.52 lbf.	In order to have a successful recovery, all components of the avionics and recovery systems must remain undamaged and secure. Shocks from ejection, launch, and landing cannot loosen any compotent as this could result in serious safety hazards with the use of black powder.		☐	☐	☑	☐	☐		Following all launches, the team will inspect the avionics coupler to ensure all components remained secure. The subscale flight will be used to demonstrate that the strength of all components.
S.A	13	☑	In Progress	Payton Gross	Parachutes shall be shielded from the heat of the black powder charges, expected around 600F, using nomex blankets.	Since the recovery system parachutes are nylon, in order to ensure they are not damaged during deployment, they must be wrapped in protective material.		☐	☐	☑	☑	☑		Prior to launch, the parachutes will be packed and folded into a nomex blanket with the thickest layering facing toward the ejection charges. This will be observed and verified by an additional team member before the parachutes are packed into the rocket. This blanket will also be tested during the Black Powder Ejection Test to verify that it is strong enough to withstand the heat from the charges deploying.
S.A	14	☑	In Progress	Payton Gross	Parachutes shall be packed using methods that have been tested and verified to ensure full parachute deployment.	In order to successful deploy the full recovery system and meet the descent challenges, the parachutes cannot have any risk of tangling.		☐	☐	☐	☑	☑		The Black Powder Ejection test will be used to verify parachutes can be fully ejected when the sections of the launch vehicle separate. Prior to launch, the team will pack and attach the parachutes with an additional team member observing to verify the correct methods were used.
S.A	15	☑	In Progress	Payton Gross	Shock cords shall be attach to both independent sections at the parachute separation points.	Since every independent section must remain tethered to the rocket and the only expected separation points are for parachute deployment, the team has decided to use the rcovery system shock cords as the tethers between independent sections.	C.2.4	☐	☐	☑	☑	☐		The shock cords will be tied before launch to an eye-bolt on each independent section. This will be verified by another team member observing the shock cord attachment process.
S.A	16	☑	In Progress	Payton Gross	Shock cords shall be folded using z-folds to prevent mid-air colisions between launch vehicle sections and to ensure safe packing and full parachute deployment.	For a proper full parachute deployment to slow down the rocket, the shock cords must fully unravel for the proper descent. Additionally, because the shock cords are acting as the tethers between independent sections, to prevent damage, the sections cannot crash into each other.		☐	☐	☑	☑	☐		Shock cords will be tied unaligned using Z-folds in order to prevent mid-air collisions. Prior to launch, the shock cords will be inspected to confirm this packing. The subscale launch will be used to verify this method prevents collisions.
S.A	17	☑	Complete	Payton Gross	The recovery system shall have two parachutes.	Per the requirement there must be a main and drogue event, we will have two parachutes. Additionally, the team has chosen to not use alternative recovery systems such as streamers.	A.3.1	☑	☐	☐	☐	☐		The recovery system design shall consist of a main and drogue parachute.
S.A	18	☑	Complete	Payton Gross	The recovery system shall have two shockcords.	There are three separate sections. Per requirement C.2.4, all independent sections must be tethered and these will be used a separation points for the parachutes therefore, the shockcords for the parachute deployment will act as the tether.	C.2.4	☐	☐	☑	☐	☐		The shock cords will be at least 50' and 30' feet for the main and drogue parachutes respectively. This length will be tested using OpenRocket and RocketPy and will be verified during subscale launch.
S.A	19	☑	Complete	Payton Gross	Altimeters shall have at least two pyro outputs.	Requirement 17 and A.3.1, because there are two parachutes that will be deployed using black powder, the altimeters must have two pyro outputs.	A.3.1	☐	☐	☐	☑	☐		When considering altimeters, it was a requirement for there to be at least two pyro outputs.

AVIONICS SUBTEAM REQUIREMENTS								Verifica on Type(s)						
Label	ID	Mission Cri cal	Status	Originator	Requirement Summary	Requirement Jus fica on	Project Req's Subordinate To	PR	A	D	I	T	Verifica on ID's or Prerequisites	Verifica on or Prerequisite Summary
S.A	20	☑	In Progress	Payton Gross	Parachute shall be deployed used black powder charges.	The team has decided to use a cannon method of deploying the parachutes which requires the use of black powder.		☐	☐	☐	☑	☐		To calculate the sizes of the ejection charges, analysis will be done to gather the section weights to calculate the pressure necessary to achieve vehicle section separation. The Black Powder Ejection Test will verify that the airframe separates at least 6' between independent sections.
S.A	21	☐	Complete	Payton Gross	Altimeters shall be able to store at least two flights in memory.	Based on requirement N.2.18.4, the team decided to make a requirement that multiple flights must be able to be stored in case flight data cannot be accessed between flights in order to be used as proof of a successful flight.	N.2.18.4	☐	☐	☑	☐	☐		When chosing altimeters, it was a requirement for the altimeters to be able to store multiple flights in memory.
S.A	22	☐	Complete	Payton Gross	Altimeter data shall be accessible on a computer after flight.	Based on requirement N.2.18.4, our team estrablished a reuirement that altimeter data must be accessible by a computer after flight in order to make flight profile graphs as proof for a successful flight.	N.2.18.4	☐	☐	☑	☑	☐		When chosing altimeters, it was a requirement for the altimeter memory data to be accessible on a computer.
S.A	23	☑	Complete	Payton Gross	Altimeters shall be dual deploy.	Since the team's recovery system consists of two parachutes, it is a requirement that the altimeter must be dual deploy.		☐	☐	☑	☐	☐		When considering altimeters, it was a requirement they had dual-deploy capabilities.
S.A	24	☐	In Progress	Payton Gross	The landing kinetic energy of the heaviest section shall be less than 65 ft-lbf.	The team has decided to target the landing kinetic energy bonus points.	A.3.3	☐	☑	☑	☐	☐		Impact velocity will be simulated both in OpenRocket and RocketPy and used to calculate landing KE. Impact velocity will also be recorded following every launch to calculate landing KE in order to verify this.
S.A	25	☑	Complete	Payton Gross	The altimeters will read correct altitudes to sense and deploy the parachutes at the correct times.	Since the main parachute cannot deploy below 500' and the drogue parachute must deploy at apogee, the altimeter must have accurate altitude sensing.	A.3.1.1, A.3.1.2	☐	☐	☑	☐	☑		The Altimeter Ejection Vacuum Test will simulate the ascent of the launch vehicle. It will test that the altimeters can deploy the parachutes at the correct times by igniting the ematches at the detected apogee for the primary altimeter with a 2s delay for redundant altimeter and 700' AGL (primary) +600' AGL (redundant).
S.A	26	☑	In Progress	Payton Gross	All parachutes will be sized for a safe deployment and landing of the launch vehicle within mission requirements.	In order to stay within the descent time, drift distance, and landing kinetic energy requirements, parachute sizes must be calculated to the requirements the team has determined.	A.3.11, A.3.12, A.3.3	☐	☑	☑	☐	☐		Preliminary analysis and calculations will be verified by simulations run in OpenRocket and RocketPy to allow the team to find the correct size for the drogue and main parachutes for safe descent and landing with drift distance, landing kinetic energy, and descent time requirements. Following simulations, it has been determined the main parachute will be 10' and the drogue parachute will be 24".The subscale launch will provide a smaller scale verification of this.
S.A	27	☐	Complete	Payton Gross	The primary altimeter shall have GPS capability.	In order to fulfill the requirement that there must be a GPS within the launch vehicle, the team decided to require that the primary altimeter have a GPS to fulfill this requirement.		☐	☐	☐	☐	☐		The chosen primary altimeter (Altus Metrum Telemetrum) has GPS capability

Table 6.2.5 Payload R&VP Table

PAYLOAD SUBTEAM REQUIREMENTS								Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Requirement Justification	Project Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
S.P	1	☑	Complete	Heather Wallace	The chosen payload design must be deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	This is a requirement that is a prerequisite to all our other requirements. The mission is a failure if this requirement is not complete.		☐	☐	☑	☐	☐		Regular design reviews of the payload system will be held to confirm safety and legal compliance.
S.P	2	☑	In Progress	Heather Wallace	The payload shall be 3 lbs (+- 0.1lbs) in weight.	This requirement is vital to ensuring the launch vehicle has the correct stability metrics.		☐	☐	☑	☑	☐		Regular weight testing as well as planning ahead will ensure that we are not exceeding this limit.
S.P	3	☑	Complete	Heather Wallace	The payload shall fit into a cylinder that is 5" in diameter and 15.748" in length.	This requirement is based on the space allotted for the payload according to our launch vehicle models.		☐	☐	☑	☑	☐		Measuring and sizing our components to fit within these parameters will ensure this requirement is completed.
S.P	4	☑	In Progress	Heather Wallace	The radio transmission with the landing site data shall clearly transmit to the receiver without an obstruction that blocks the transmission from being received.	This requirement is derived from requirement P.4.1, and it emphasizes that the transmission should have a clear path to the NASA receiver and will not be blocked by a physical obstruction	P.4.1	☐	☐	☑	☐	☑		A transmitter and receiver similar/the same as the ones used on launch day shall be tested up to a range of one mile and through any materials used in the integration system and structure of the launch vehicle (fiberglass)
S.P	5	☑	In Progress	Heather Wallace	The STEMcRAFT and the sensors within it shall remain in operating condition throughout the flight, descent, and landing.	Our sensor package is useless unless the sensors remain undamaged throughout flight and can collect valid data once the launch vehicle has landed.	P.4.1, P.4.2	☐	☐	☑	☑	☑		The STEMcRAFT will undergo a drop test with a landing velocity similar/the same to the landing velocity experienced during the flight, and the sensors will be made to collect data. This data will then be checked for accuracy.
S.P	6	☑	Complete	Zander Unger	The STEMcRAFT shall include a method of ingress/egress for the STEMnaut passengers.	In an emergency situation, the STEMnauts need to "able" to exit the capsule and make it to safety.		☐	☐	☑	☑	☐		Incorporating this feature into all drafts of the STEMnaut capsule design will ensure this requirement is completed.
S.P	7	☑	Complete	Heather Wallace	The STEMcRAFT shall not expose the STEMnauts to excessive rotational velocities in the yaw, pitch, and roll axes, as outlined in Appendix D.	This requirement acts as the team's definition of "safety" for the STEMnauts, as the team needs to ensure that the STEMnauts remain safe throughout flight.		☐	☑	☐	☐	☐		The STEMcRAFT will undergo a drop test with a landing velocity similar/the same to the landing velocity experienced during the flight, and the team will be able to verify onboard rotational velocities using onboard telemetry sensors.
S.P	8	☐	In Progress	Heather Wallace	The STEMcRAFT and deployment system shall be able to operate within temperatures up to 115 degrees Farenheit	During flight and on the launch pad, the payload could be subjected to high temperatures, and therefore needs to be able to withstand such temperatures without significant changes to operability.		☐	☐	☑	☐	☑		The STEMcRAFT and integration system will be tested in a heat-controlled environment to ensure both systems can fully operate in the heat of Huntsville
S.P	9	☑	In Progress	Heather Wallace	The STEMcRAFT's battery must have the capacity of three hours of runtime.	Due to the scheduling on launch day, we need to ensure that our battery and therefore electronics system can last throughout any time we are on the pad waiting to launch.	G.2.6, S.P.4	☐	☑	☑	☐	☑		The team will run the sensor package prior to launch for three hours time and ensure that it remains operational for that amount of time.

6.3 Finance

6.3.1 Budget

The budget for the 2024-2025 competition year has been updated to reflect purchasing made since PDR. The raw material and parts purchases for each subteam are listed and are split between subscale and full-scale in Tables 6.3.1.1-5. Most subteams had few changes in their budget from PDR, but some prices were adjusted to reflect the cost of purchases made as the team made specific selections and quantities of items. However, the construction subteam had an increase of $1,150 as not all parts were accounted for in the PDR budget. This was not a concern as the team had budgeted a healthy amount for incidentals. Another notable change in the budget is that the team has sourced 3D printing out of an internal parent organization printer this year thus the relevant costs are set to $0. Additionally, fundraising had exceeded estimated costs by well over $1000 including the incidental forecast worst case scenario. Each part to be purchased is listed with an estimated cost including shipping. Once an item is purchased, the realized cost is updated from $0 to the item cost, and for items already owned the realized cost will remain $0. The incidental forecast percentage is a safety factor created to account for consumables as well as incidentals like reworking parts. These percentages are based on historical averages. Compared to PDR, this percentage has been halved for construction since there is less uncertainty about the final design and the majority of purchasing has been done. Finally, the overall budget is shown in Table 6.3.1.6. The cost to date is around $3,503.60 and the estimated total cost is $14,950.00. This tracks with the 2023-2024 final budget which was $15,541. The estimated remaining balance of $2,910.40 will either roll into the next competition cycle or be invested into new equipment or R&D.

Table 6.3.1.1: Construction Budget

Construction			
Name	Vendor	Estimated Cost (USD)	Realized Cost (USD)
Subscale			
CR-3.0-1.5: Centering ring	Wildman Rocketry	6.18	6.18
G10-1/8: Fiberglass sheet stock	Wildman Rocketry	39.60	39.60
AeroTech Aluminum Motor Case	Aerotech Rocketry	96.99	96.99
AeroTech I305FJ-14A RMS-38/600 Reload Kit	Aerotech Rocketry	165.98	165.98
RA38P Motor Retainer	Wildman Rocketry	25.00	25.00
MMT-1.52 x 11 in. Fiberglass tubing	Wildman Rocketry	4.28	4.28
G12CT-3.0 Fiberglass Coupler Stock	Wildman Rocketry	167.40	167.40
G12CT-3.0 Main	Wildman Rocketry	124.05	124.05

Airframe Stock			
AV-bay lid 75mm	Wildman Rocketry	105.60	105.60
Various Fasteners	N/A	50.00	50.00
SUBTOTAL		785.08	785.08
Full-scale			
L-930 LW Reload	Loki Research	1,140.00	1223.67
Centering Plate Stock 5" diameter	Coremark Materials	87.81	87.81
Thrust Plate Stock 5.25" diameter	Coremark Materials	97.86	97.86
Retainer Plate Stock 12x12" 1/8" thick	Online Metals	73.89	73.89
76mm 2 turn Internal Spiral Retaining ring	Loki Research	22.00	22.00
2 76mm Snap Ring	Loki Research	9.00	9.00
G12-5.0 (30 in) 5" airframe	Wildman Rocketry	150.88	150.88
G12-5.0 (60 in) 5" airframe	Wildman Rocketry	280.56	280.56
3 G12CT-5.0 (12 in) Coupler	Wildman Rocketry	208.92	208.92
3 G10-1/8 Fiberglass Sheet	Wildman Rocketry	80.61	80.61
5 Av-Bay Lid 5in	Wildman Rocketry	121.00	121.00
Various Fasteners	N/A	100.00	54.68
Consumables	N/A	300.00	0.00
Subtotal		2,672.52	2,410.88
(approx. 15% Incidental Forecast)		542.39	
TOTAL		4000.00	3195.96

Table 6.3.1.2: Avionics and Recovery Budget

Avionics and Recovery			
Name	Vendor	Estimated Cost (USD)	Realized Cost (USD)
Subscale			
Altimeter	Already Own	0.00	0.00
Quick Links	Already Own	0.00	0.00
Black Powder	Already Own	0.00	0.00
Subscale parachute	Already Own	0.00	0.00
3D Printing Components	Purdue PSP Printer	0.00	0.00
SUBTOTAL		0.00	0.00
Full-scale			
Keyswitches	Digikey	63.60	0.00
Telemetrum Altimeter	Altus Metrum	345.00	0.00
Shock Cords	One Bad Hawk	86.25	0.00
24 in. Drogue Parachute	Fruity Chutes	80.00	0.00
120 in. Main Parachute	Fruity Chutes	345.00	0.00
10 in. Nomex Blanket	Already Own	0.00	0.00
Black Powder	Already Own	0.00	0.00
Quick Links	Already Own	0.00	0.00
Fasteners	N/A	25.00	0.00
Consumables	N/A	25.00	0.00
3D Printing Components	Purdue PSP Printer	25.00	0.00
SUBTOTAL		969.85	0.00
(approx. 40%		380.15	

Incidental Forecast)			
TOTAL		1,350.00	0.00

Table 6.3.1.3: Payload Budget

Payload			
Name	Vendor	Estimated Cost (USD)	Realized Cost (USD)
Subscale			
7.4V Li-ion Battery	Adafruit	29.80	29.80
Adafruit ADXL345 Triple-Axis Accelerometer	Adafruit	17.99	17.99
Arduino Uno REV3 [A000066]	Adafruit	27.60	27.60
Adafruit BMP388 - Precision Barometric Pressure and Altimeter	Adafruit	15.99	15.99
Tungsten Ballast	Already Own	0.00	0.00
High-Speed 4K Ultra HD HDMI 2.0 Cable 3ft	Amazon	5.79	5.79
2 Layer Bare Rigid Circuit Board	Amazon	6.90	6.90
Batter Adapter - DC Supply Connector	TME US	16.13	16.13
3D Printing Components	Purdue PSP Printer	0.00	0.00
Subtotal		120.20	120.20
Full-scale			
Sensors from Subscale	N/A	0.00	0.00
Voice Intercom Module/Data	Alibaba	13.06	13.06

Transmission Module			
Walkie-talkie Module Wireless Voice Intercom Data Transmission 4W Pwr	High Cost Performance Tool Store	29.99	29.99
Threaded Rods	McMaster-Carr	30.00	0.00
3D Printing Components	Purdue PSP Printer	0.00	0.00
Consumables	N/A	250.00	0.00
SUBTOTAL		323.05	43.05
(approx. 20% Incidentals Forecast)		106.75	
TOTAL		550.00	163.25

Table 6.3.1.4: Research and Development Budget

Research & Development			
Name	Vendor	Estimated Cost (USD)	Realized Cost (USD)
Airbrakes			
Subscale servo motor	Horizon Hobby	20.00	00.00
Full-scale servo	Horizon Hobby	50.00	0.00
Subscale rocket motor x5	Chris Rocket Supplies	200.00	0.00
Altimeter	Adafruit	10.00	15.95
Accelerometer	Adafruit	10.00	34.95
Arduino	Adafruit	30.00	0.00
5-pin to 4-pin Qwiic Cable (100mm)	Adafruit	5.00	4.39
STEMMA QT/Qwiic JST SH 4-pin cable	Adafruit	5.00	4.79

(50mm)			
Wind tunnel stands	In-house 3D printed	50.00	0.00
Improved Fiberglass Layups			
Vacuum (single stage)	Robinair	190.00	0.00
Release Peel Ply	Composite Envisions	28.00	0.00
Bleeder & breather sheets	Composite Envisions	10.00	0.00
Release film	Composite Envisions	7.00	0.00
Hose	Harbor Freight	18.00	0.00
Hose Fittings	Harbor Freight	13.00	0.00
Polyethylene bagging film	Harbor Freight	7.00	0.00
Stretchlon 200 bagging film	Harbor Freight	10.00	0.00
Nosecone Cameras			
Raspberry Pi	Adafruit	35.00	0.00
USB-Connected Cameras x2	Adafruit	30.00	0.00
Camera interfacing board	Adafruit	35.00	0.00
Parachute Deployment			
Full-scale motor	Chris Rocket Supplies	285.00	0.00
Launch day fees	-	75.00	0.00
Drogue parachute	Chris Rocket Supplies	75.00	0.00
SUBTOTAL		1268.90	0.00

(approx. 10% Incidentals Forecast)		131.10	
TOTAL		1,400.00	60.08

Table 6.3.1.5: Project Management/Branding Budget

Project Management/Branding			
Name	Vendor	Estimated Cost (USD)	Realized Cost (USD)
PPE (N95 Respirators)	Amazon	10.15	10.15
PPE (Work/Nitrile Gloves)	Harbor Freights	42.72	42.72
PPE (Safety Glasses/Work Gloves)	Home Depot	31.44	31.44
Huntsville Travel Expenses (Hotel & Gas Reimbursements)	N/A	5,500.00	0.00
Team Uniforms (Shirts)	TBD	300.00	0.00
SUBTOTAL		5,884.31	84.31
(approx. 30% Incidentals Forecast)		1,765.69	
TOTAL		7,650.00	84.31

Table 6.3.1.6: Overall Budget

Overall Budget		
Subteam	Estimated Costs (USD)	Costs to Date (USD)
Construction	4,000.00	3,195.95
Avionics and Recovery	1,350.00	0.00
Payload	550.00	163.25

Research and Development	1,400.00	60.08
Project Management	7,650.00	84.31
Total Estimated Costs	14,950.00	
Total Costs to Date		3,503.60
Estimated Remaining Balance	2,910.40	
Current Remaining Balance		13,356.80

6.3.2 Funding Plan

In Table 6.3.2.1 are listed the funding sources and amounts donated for the 2024-2025 competition year. The current total represents the amount of money raised so far during this competition year and the projected total includes grants that will be applied for as well as estimations of those amounts based on previous allocations. The team is funded by both internal grants such as Purdue Engineering Presidents' Council, Purdue Engineering Student Council, and general Purdue Space Program disbursements as well as external grants. The amount fundraised is greater than the estimated costs for this year, however, fundraising continues to provide a margin of safety and allow for investments into tools and for rollover into the next competition year. All grants received continue to be without restriction on spending, and required reporting has been and will continue to be done throughout the year.

Table 6.3.2.1 : Funding Sources

Funding Sources		
Organization	Projected Amount (USD)	Current Amount (USD)
PEPC Competition Support Pilot	7,900.00	7,900.00
L3Harris	5,000.00	5,000.00
General PSP Funding	3,735.00	3,735.00
PESC Grant	500.00	500.00
Blue Origin	500.00	0.00
Rollover	(294.60)	(294.60)
Local Funding	20.00	20.00
PEPC Grant	500.00	0.00

PROJECTED TOTAL	$17,860.40	
CURRENT TOTAL		$16,860.40

6.4 Timeline

Table 6.4.1: Color Code Legend

Color	Meaning	Color Representation
Green	NASA Q&A	
Red	Milestone Deadlines	
Blue	Competition Specific	
Orange	School Specific	

Table 6.4.2: Timeline

Date	Event	Date	Event
~~8/4/2024~~	~~Leads Meeting~~	~~8/25/2024~~	~~Leads Meeting~~
~~9/3/2024~~	~~Team Callout~~	~~9/7/2024~~	~~New Member Orientation~~
~~9/8/2024~~	~~General Meeting~~	~~9/11/2024~~	~~Proposal Due to NASA~~
~~9/15/2024~~	~~General Meeting~~	~~9/22/2024~~	~~General Meeting~~
~~9/29/2024~~	~~General Meeting~~	~~10/6/2024~~	~~General Meeting~~
~~10/7/2024~~	~~PDR Q&A~~	~~10/13/2024~~	~~General Meeting~~
~~10/18/2024~~	~~PDR Due to PM~~	~~10/20/2024~~	~~General Meeting~~
~~10/26/2024~~	~~Purdue Space Day~~	~~10/27/2024~~	~~General Meeting~~
~~10/28/2024~~	~~PDR Due to NASA~~	~~11/3/2024~~	~~General Meeting~~
~~11/16/2024~~	~~Potential Subscale Launch~~	~~11/17/2024~~	~~Subscale Launch~~
~~11/24/2024~~	~~General Meeting~~	~~11/27/2024 - 12/1/2024~~	~~Thanksgiving break~~

12/3/2024	CDR Q&A	12/15/2024 - 1/13/2025	Purdue Winter Break
1/8/2025	CDR Due to NASA	1/13/2025	First Day of Spring Semester
1/19/2025	General Meeting	1/26/2025	General Meeting
2/1/2025	Possible VDF Launch Date	2/8/2025	FRR Q&A
2/9/2025	General Meeting	2/16/2025	General Meeting
2/23/2025	General Meeting	3/2/2025	General Meeting
3/9/2025	General Meeting	3/16/2025	General Meeting
3/17/2025	FRR due to NASA	3/23/2025	General Meeting
3/30/2025	General Meeting	4/6/2025	General Meeting
4/13/2025	General Meeting	4/14/2025	FRR Addendum Due to NASA
4/17/2025	Launch Week Q&A	4/20/2025	General Meeting
4/30/2025 - 5/4/2025	Launch Week Activities in Huntsville	5/19/2025	PLAR Due to NASA

6.4.1 Gantt Chart

This section contains the updated Gantt chart. This includes the changes described in Section 2. Completed tasks and milestones are marked in green. The tasks and milestones in the blue are considered in progress. The tasks and milestones in red are considered not started.

Purdue Space Program Student Launch Proposal and PDR

ID	Task Name	Start	End	Duration
1	Proporsal	14 Aug 2024	11 Sep 2024	21 days
2	Write Proposal	14 Aug 2024	06 Sep 2024	18 days
3	Proofread Proposal	02 Sep 2024	06 Sep 2024	5 days
4	Submit Proposal to PM	06 Sep 2024	11 Sep 2024	4 days
5	Submit Proposal to NASA	11 Sep 2024	11 Sep 2024	0 days
6	Preliminary Design Review	11 Sep 2024	30 Oct 2024	36 days
7	Write PDR	11 Sep 2024	22 Oct 2024	30 days
8	Proofread PDR	14 Oct 2024	21 Oct 2024	6 days
9	Submit PDR To PM	18 Oct 2024	30 Oct 2024	9 days
10	Submit PDR TO NASA	28 Oct 2024	28 Oct 2024	0 days

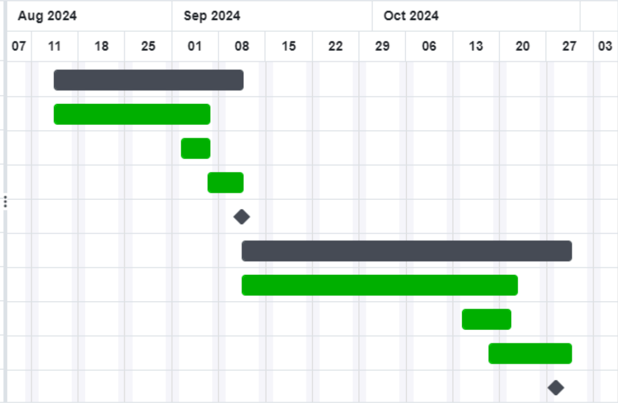


Figure 6.4.1.1: Proposal and PDR Gantt Chart

ID	Task Name	Start	End	Duration
1	Critical Design Review	2024-10-24	2025-01-14	59 days
2	Member Gateway Application	2024-10-29	2024-10-29	0 days
3	Purchase Subscale Materials	2024-10-24	2024-10-24	0 days
4	Reserve Huntsville	2024-10-28	2024-10-28	0 days
5	Write CDR	2024-10-24	2025-01-14	59 days
6	Proofread CDR	2024-12-23	2024-12-23	1 day
7	CDR Q&A	2024-12-03	2024-12-03	0 days
8	Submit CDR To Leads	2024-12-23	2024-12-23	1 day
9	Submit CDR To PM	2024-12-30	2024-12-30	0 days
10	Submit CDR To NAS	2025-01-08	2025-01-08	0 days

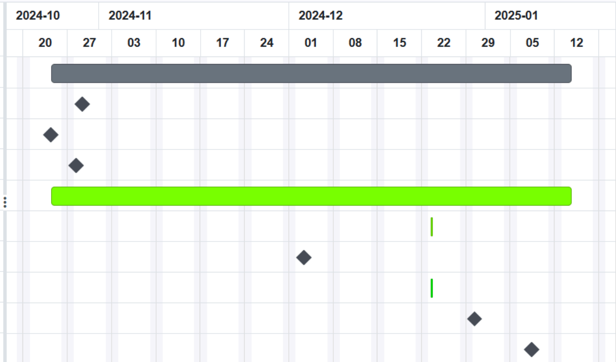


Figure 6.4.1.2: CDR Gantt Chart

ID	Task Name	Start	End	Duration
1	Subscale	2024-10-01	2024-11-18	34 days
2	Subscale Manufacturing	2024-10-01	2024-11-12	31 days
3	Order Subscale Airframe	2024-10-01	2024-10-01	0 days
4	Cut Airframe Lengths	2024-10-28	2024-11-05	7 days
5	Drill Airframe Holes	2024-11-04	2024-11-12	7 days
6	Order Fin Materials	2024-10-01	2024-10-01	0 days
7	Cut Fin Materials	2024-11-04	2024-11-04	0 days
8	Avionics Subscale sled Design	2024-10-24	2024-11-06	10 days
9	Avionics Subscale Sled Manufacture	2024-11-04	2024-11-12	7 days
10	Subscale Testing	2024-11-04	2024-11-14	8 days
11	Subscale Sled Verification	2024-11-04	2024-11-04	0 days
12	Drogue Parachute Testing	2024-11-04	2024-11-04	0 days
13	Altimeter Vaccum Testing	2024-11-04	2024-11-04	0 days
14	Altimeter Hot Battery Drain	2024-11-11	2024-11-11	0 days
15	Subscale Black Powder Ejection Test	2024-11-14	2024-11-14	0 days
16	Subscale Launch	2024-11-15	2024-11-18	1 day
17	Subscale Vehicle Integration	2024-11-15	2024-11-15	1 day
18	Subscale launch	2024-11-18	2024-11-18	0 days

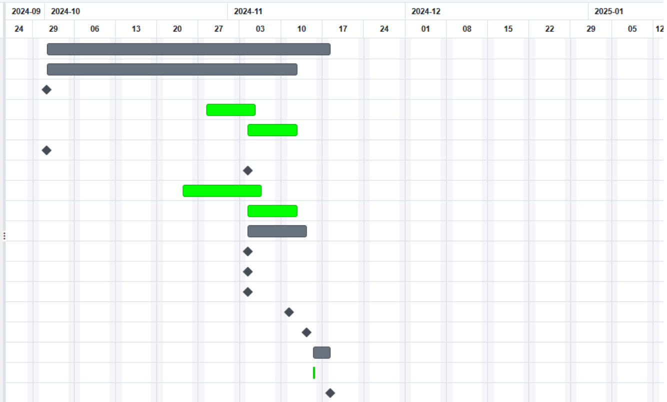


Figure 6.4.1.3: Subscale Gantt Chart

ID	Task Name	Start	End	Duration
1	Flight Readiness Review	2025-01-13	2025-03-04	36 days
2	Write FRR	2025-01-13	2025-02-27	34 days
3	Proofread FRR	2025-02-17	2025-02-25	7 days
4	FRR Q&A	2025-02-10	2025-02-10	0 days
5	Submit FRR To Leads	2025-02-24	2025-02-24	0 days
6	Submit FRR To PM	2025-03-03	2025-03-03	0 days
7	Submit FRR To NASA	2025-03-04	2025-03-04	0 days

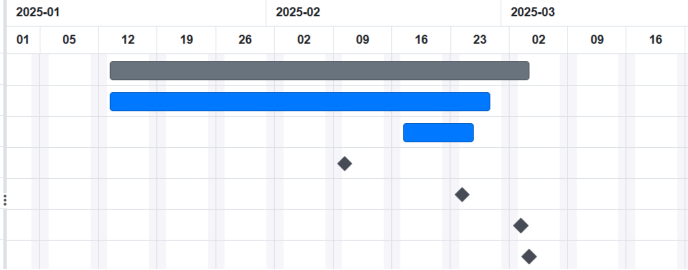


Figure 6.4.1.4 FRR Gantt Chart

ID	Task Name	Start	End	Duration
1	Fullscale	2024-10-10	2025-03-03	103 days
2	Fullscale Manufacture	2024-10-10	2025-03-03	103 days
3	Order Fullscale Airfram	2024-10-10	2024-10-10	0 days
4	Cut Airframe Lengths	2025-01-13	2025-01-21	7 days
5	Drill Airframe Holes	2025-01-13	2025-01-21	7 days
6	Order Fin Materials	2024-10-10	2024-10-10	0 days
7	Manufacture Fin Molds	2024-12-02	2024-12-10	7 days
8	Manufacture Fins	2024-12-02	2024-12-10	7 days
9	Order MFSS Materials	2024-10-10	2024-10-10	0 days
10	Manufacture MFSS	2025-01-13	2025-01-16	4 days
11	Fulscale Altimeter Sled	2024-12-16	2025-03-03	56 days
12	Fullscale Testing	2024-12-02	2025-02-28	65 days
13	Fin Testing	2024-12-09	2024-12-09	1 day
14	Vacuum Testing Altimeter	2025-01-13	2025-01-31	15 days
15	Black Powder Ejection Test	2025-01-13	2025-02-12	23 days
16	Parachute Test	2024-12-02	2025-02-28	65 days
17	Fullscale Launch	2025-02-05	2025-02-17	8 days
18	Fullscale Integration	2025-02-05	2025-02-07	3 days
19	Possible Fullscale Launch	2025-02-10	2025-02-10	0 days
20	Possible Fullscale Launch	2025-02-17	2025-02-17	0 days
21	Fullscale Launch Analysis	2025-02-17	2025-03-03	11 days

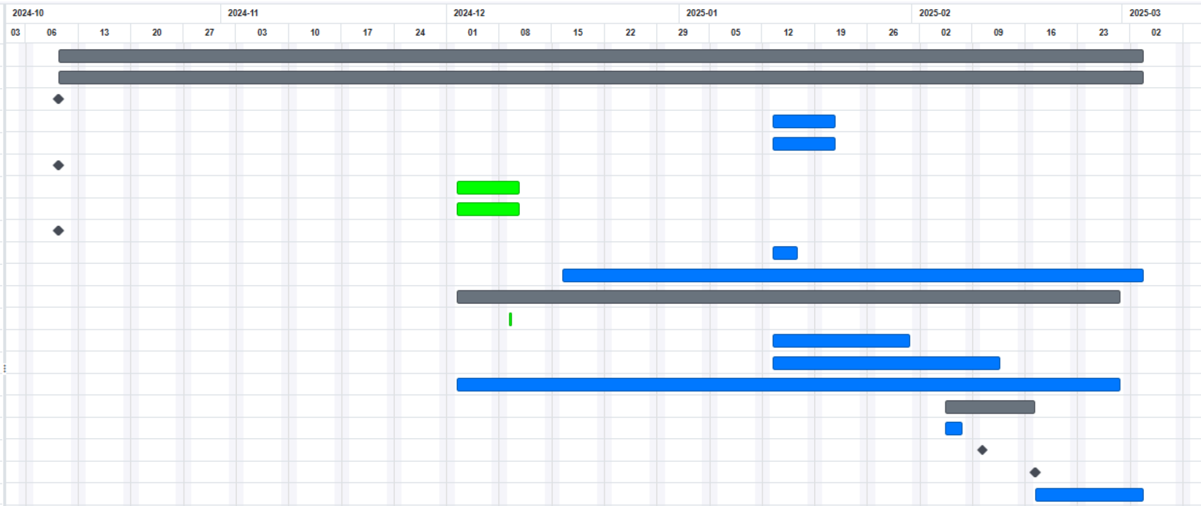


Figure 6.4.1.5: Full-scale Gantt Chart

ID	Task Name	Start	End	Duration
1	Payload	2024-09-02	2025-01-03	90 days
2	Individual Brainstor...	2024-09-02	2024-10-10	29 days
3	Team Brainstorming	2024-09-09	2024-10-08	22 days
4	Preliminary Selection	2024-09-30	2024-10-24	19 days
5	Initial Design	2024-10-21	2024-12-17	42 days
6	Complete Prototype	2024-12-02	2025-01-03	25 days

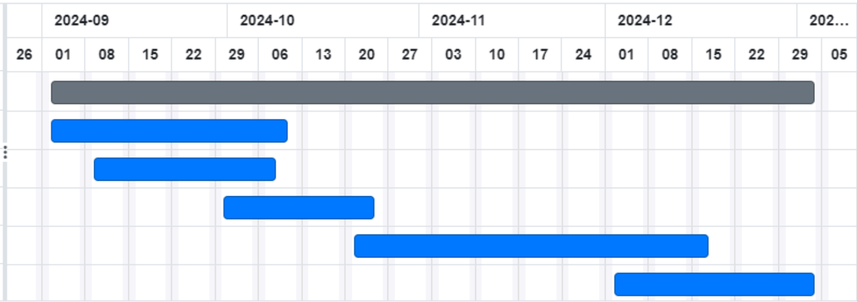


Figure 6.4.1.6 Payload Gantt Chart

ID	Task Name	Start	End	Duration
1	Launch Week	2025-04-17	2025-05-05	13 days
2	Launch Week Q&A	2025-04-17	2025-04-17	0 days
3	Pack Launch Vehicle	2025-04-18	2025-05-02	11 days
4	Pack Tools	2025-04-18	2025-05-02	11 days
5	Drive to Huntsville	2025-04-30	2025-04-30	0 days
6	Competition Launch	2025-05-05	2025-05-05	1 day
7	Leave Huntsville	2025-05-05	2025-05-05	0 days
8	PLAR	2025-05-05	2025-05-20	12 days
9	Write PLAR	2025-05-05	2025-05-12	6 days
10	Proofread PLAR	2025-05-12	2025-05-13	2 days
11	Submit to PM	2025-05-12	2025-05-20	7 days
12	Submit to NASA	2025-05-19	2025-05-19	0 days

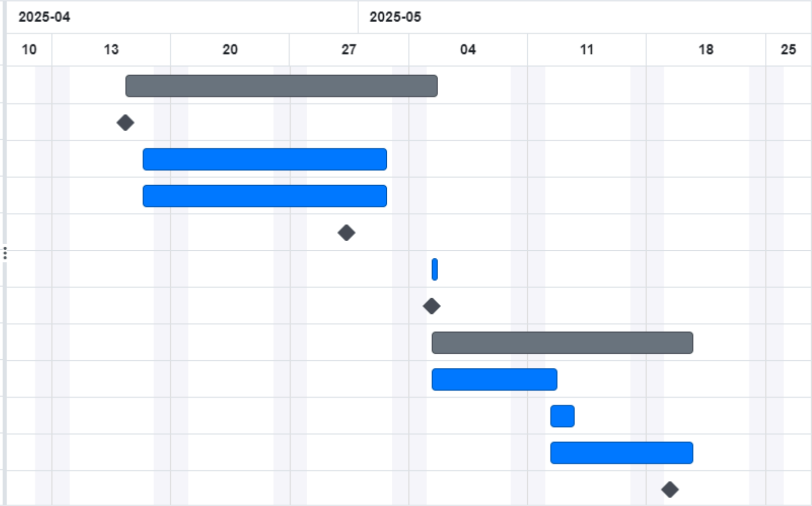


Figure 6.4.1.7: Launch Week and PLAR Gantt Chart

Appendix A: NAR High Power Rocket Safety Code

As written in the National Association of Rocketry (NAR) website, the High Power Rocket Safety Code contains the following:

1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 ft. of these motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is 2at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor’s exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 ft., whichever is greater, or 1000 ft. for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 ft.).
11. **Launcher Location.** My launcher will be 1500 ft. from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

Appendix B: NAR Minimum Distance Table

As written in the NAR website, the Minimum Distance Table contains the following:

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

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors.

Appendix C: Risk Assessment Code

Likelihood	
Rating	**Description**
5 Nearly Certain	Event is nearly certain to occur in normal circumstances.
4 Likely	Event will probably occur in most circumstances.
3 Possible	Event could occur in some circumstances.
2 Unlikely	Event may occur in select circumstances.
1 Remote	Event only possible in extraordinary circumstances.

Likelihood					
5	6	16	20	23	25
4	5	13	18	22	24
3	4	10	15	19	21
2	2	8	11	14	17
1	1	3	7	9	12
	1	2	3	4	5
	Consequence				

Consequence			
	Personnel	**Resources**	**Environment**
5 Serious	Immediate medical treatment required as defined by OSHA. Severe, life-threatening, or debilitating injury. Lasting consequences.	Damage to irreplaceable items(s) beyond repair.	Repeated or irreversible violation of OSHA/EPA standards. Immediate action required. Termination of work.
4 Major	Medical treatment required as defined by OSHA. Anything resulting in loss of consciousness. No permanent consequences.	Damage to item(s) that cannot be repaired without the help of external services.	Reversible significant violation of OSHA/EPA with help of external services. Temporary halt of work.
3 Moderate	All other forms of first aid care as defined by OSHA. No more than one day of recovery time.	Irreparable damage to consumables. Repairable damage to non-consumable.	Reversible violation of OSHA/EPA regulations. Remedial action required.
2 Minor	Care at most requires use of a bandage. 5-10 minutes of recovery time.	Surface-level damage. Repairable damage to consumables.	Violation of OSHA/EPA regulations. Minimal remedial action required.
1 Negligible	Inconvenience or annoyance. Requires no care or recovery time.	No visible damage. Repair unnecessary.	No OSHA/EPA violations. No corrective action required.

Appendix D: Selections from NASA-STD-3001 Volume 2

Sustained Translational Acceleration Limits (Non-deconditioned, Seated)

Ax	**Upper limit**	**Duration [s]**	0.5	5	300	
		Acceleration [m/s^2]	186	157	73.5	
	Lower limit	**Duration [s]**	0.5	5	120	400
		Acceleration [m/s^2]	-216	-147	-58.8	-39.2

Ay	**Upper limit**	**Duration [s]**	0.5	1000
		Acceleration [m/s^2]	29.4	19.6
	Lower limit	**Duration [s]**	0.5	1000
		Acceleration [m/s^2]	-29.4	-19.6

Az	**Upper limit**	**Duration [s]**	0.5	5	1200	
		Acceleration [m/s^2]	81.4	62.8	39.2	
	Lower limit	**Duration [s]**	0.5	5	60	1200
		Acceleration [m/s^2]	-58	-37.3	-21.6	-9.81

Source: Space Medicine in the Era of Civilian Spaceflight

Sustained Rotational Velocity Limits (Non-deconditioned, Seated)

Limit	**Duration [s]**	0.5	1	700
	Acceleration [rad/s]	6.6	5.2	0.63

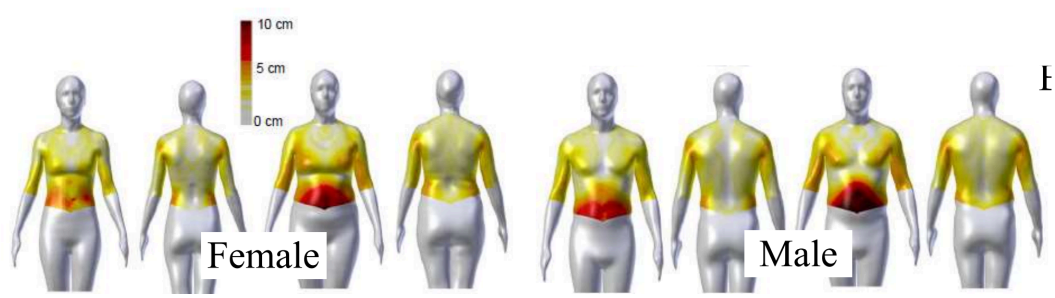
Sustained Rotational Acceleration Due to Cross-Coupled Rotation

Limit	**Duration [s]**	0.5
	Acceleration [rad/s^2]	2

Hang Time Limit: 7 min duration

Launch Position Limit: 3hr, 15 min duration

Blunt Force Max. Allowable Compression Depth Limits



Vibration Limits during Dynamic Phases of Flight

Max. Exposure Duration per 24-hr Period	10 min	0.4 g RMS
Max. Frequency-Weighted Acceleration	1 min	0.6 g RMS