Project Weber

Critical Design Review (CDR)

Purdue University 2023

500 Allison Road
West Lafayette, IN 47906
Purdue Space Program

1. Summary of CDR Report

1.1. Team Summary

Team Name	Purdue Space Program - NASA Student Launch
Mailing Address	500 Allison Road, West Lafayette, IN 47906
2023 Team Mentor	Christopher Nilsen; cnilsen@purdue.edu; (813) 442-0891 TRA 12041, Level 3 Certified
Final Launch Location and Date	Primary: 4/15/23; Backup: 4/16/22, Huntsville, Alabama
Total People-Hours	190 hours

Table 1.1: Team Summary

1.2. Launch Vehicle Summary

Target Altitude	4050' AGL

Motor Selection	CTI L1350-CS-P
Payload Section Size and Mass	30” 15.34 lb
Avionics and Recovery Section Size and Mass	40” 15.4 lb
Lower Airframe Section Size and Mass	28” 18.57 lb
Dry Mass without Ballast	38.43 lb
Dry Mass with Ballast	41.43 lb
Wet mass of Launch Vehicle	49.3lb
Burnout Mass of Launch Vehicle	44.84 lb
Landing Mass of Launch Vehicle	44.84 lb
Vehicle Recovery System	Dual Deployment, Apogee and 700 ft AGL
Rail Size/Length	15-15/12’

Table 1.2: Launch Vehicle Summary

1.3. Payload Summary

The payload system has been designed to extend an autonomous camera system out of the vehicle through an opening in the airframe that can only be deployed after completing the flight. Comprising four main mechanical subsystems and an autonomous software program, subsystems complete a unique task to accomplish the payload mission statement described in the 2022-2023 NASA USLI Handbook. When the payload electronics are turned on before flight, the system remains in a closed configuration. The closed configuration is defined when the two sections of the payload airframe are connected and there are no internal components outside the vehicle. During flight, software detects key flight events such as launch, apogee, and landing to determine a safe deployment time. Once on the ground, the first mechanical subsystem, the Internal Orientation System (IOS), uses planetary gears to spin a section of the payload bay to be aligned with the vertical axis. Next, the Retention and Deployment subsystem (R&D), moves a lead nut connected to the upper payload section to create a gap in the airframe. The Camera Deployment System (CDS), then uses a rack and pinion gear to raise the camera out of the vehicle. At this point, the payload system is now in an open configuration. To complete the payload mission requirements, an antenna receiver located in the payload coupler receives commands transmitted by NASA and controls the Two Axis Camera Orientation System (TACOS) through the Autonomous Payload Interface (API). The respective mechanical and software subsystems work together to capture images of the landing site and complete remaining mission objectives. Upon completing the payload mission, the system remains in an open configuration for team recovery.

2. Changes Made since PDR

2.1. Changes Made To Vehicle Criteria

The design of the launch vehicle has changed only slightly since PDR. The location of the main and drudge parachutes were swapped to avoid the main parachute affecting the performance of the payload after landing. The lower recovery airframe was lengthened by one inch to provide more room to pack the main parachute. An additional GPS tracker was placed within the booster coupler with an accompanying keyswitch. Ballast was added to the nose cone for stability and the avionics coupler to lower vehicle altitude. Also, the team decided to change the diameter of the drogue parachute. The team took this decision to minimize the descent time of the launch vehicle after ensuring the decision would not have a negative impact on safety.

2.2. Changes Made To Payload Criteria

The overall design intent for the payload system has remained unchanged. However, the Camera Deployment System (CDS) was the subsystem that has changed the most since PDR. While modeling CDS, it was found that the guide rod through the center of the payload heavily interfered with the original scissor lift mechanism. Moving the scissor lift to a different location with respect to the vertical axis resulted in subpar performance of the scissor lift due to the physical space limitations of the payload bay. The team had also received information from NASA that influenced the design decision as well. The team was clarified by NASA that the antennas that will be used to transmit the payload commands would be 200 feet high. This removes the necessity for the CDS to extend TACOS 12’’ above the ground. Therefore, the team has changed the criteria for CDS, in which CDS must lift TACOS out of the airframe. With these changes, the scissor lift has been replaced with a rack and pinion system, detailed in section 4.4.3.

2.3. Changes Made To Project Plan

The team decided not to implement significant changes to the project plan developed and presented at Preliminary Design Review. However, small adjustments were made to account for additional information the team has at the current stage of the project. For example, the Business Team made a more specific budget plan which accounts for the final launch vehicle design. Beyond that, project management updated the timelines in order to account for the manufacturing plan suited to the current vehicle design.

3. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

Flight Reliability and Confidence

3.1.1. Mission Statement

The mission of Project Weber is to design, manufacture, and fly a reusable launch vehicle capable of delivering a payload to 4050', descending from appogee within 80 seconds, and remaining under 65ft-lbf of landing energy per section. The project also will expose new members to real project engineering practices and continue to develop the technical skills of returning members. The payload is a camera system able to deploy to an elevated position after landing and perform commands received via radio-frequency. The team will accomplish this through educational and foundational experience developed from Purdue University's curriculum and previous competition years.

3.1.2. Chosen Alternatives

3.1.2.1. Vehicle Overview

The launch vehicle was designed using OpenRocket and modeled in Solidworks. It is 98" long, has an inner diameter of 6" and outer diameter of 6.17", and weighs 49.3lb. The airframe is G12 fiberglass tubing, and the launch vehicle averages 3.92cal of stability and maintains at least 2.1cal of stability in the worst conditions. It comprises three independent sections, payload, recovery, and booster, which remain connected in flight via a tether. The nose cone is an LV-HAACK, there are three airfoiled clipped delta resin cast fins, and the fins and motor are connected to the airframe through an internal aluminum structure. The selected motor is a 4280Ns impulse capable CTI L1350-CS-P, rated at 67% of a minimum L class.

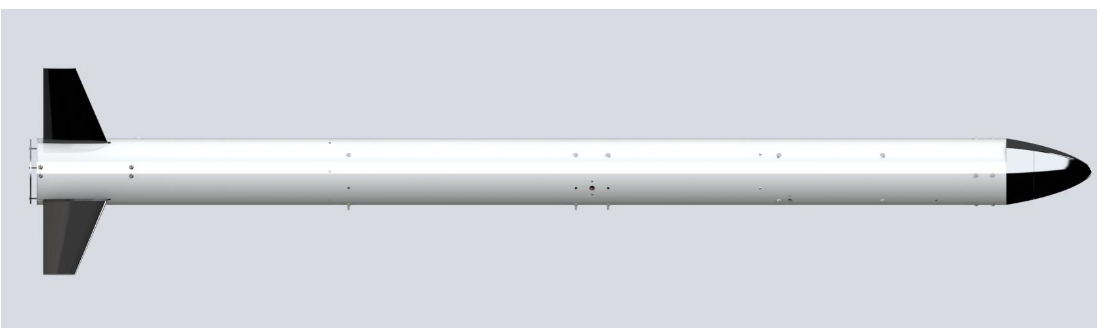


Figure 3.1.2.1.1: Model of Launch Vehicle

3.1.2.2. Airframe

Of the two design alternatives for the airframe, 5” and 6” diameter, the 6” diameter (Airframe Alternative Two) was chosen. Both alternatives use commercially available G12 fiberglass tubes, the only design difference being the diameter. After analyzing the feasibility tests of the two designs, a 6” airframe was found to be the most optimal for two main reasons. The first is the preservation of internal volume for the benefit of other project requirements and associated manufacturing concerns. The 6” airframe allows for a greater internal volume, allowing sufficient space for the avionics and payload components. Because the concern for space inside the launch vehicle affects multiple subsystems and components, this metric is highly valuable. Additionally, having sufficient space allows for a more streamlined manufacturing process, as this would negate the need to find new manufacturing solutions for previously used systems for a 6” airframe that are still included in this year’s design. The second reason for selecting the 6” diameter airframe was its performance in simulations in comparison to the 5” airframe. Both designs achieved a descent time of less than 90 seconds and a ground hit velocity of less than 15 ft/s in every simulation using OpenRocket. Though the 5” airframe performed better in these metrics on average and saved mass, these improvements were only marginally better than the 6” airframe. As such, the appealing internal space benefit of using a 6” airframe combined with the marginally different flight simulation metrics made the 6” airframe the optimal design choice. The full summary of OpenRocket Simulation Results for the selected 6” airframe is shown below.

Wind Speed (mph)	Launch Rail Angle (°)	Apogee (ft)	Time to Apogee (s)	Flight Time (s)	Descent Time (s)	Ground Hit Velocity (ft/s)
5	5	4491	17.4	106	88.6	13.2
7.5	5	4445	17.3	103	85.7	13.3
10	10	4159	16.7	99.7	83	14.9
15	10	4003	16.4	98.1	81.7	13.3
20	10	3836	16.1	95.4	79.3	14.9

Table 3.1.2.2.1: 6” Airframe OpenRocket Simulation Results

3.1.2.3. Motor Fin Support Structure

Two design alternatives were presented for the MFSS, and the second alternative was chosen as the final design. This design attaches the fin inserts directly to the centering and thrust plates through extrusions on both plates. This removes the need for fin spars, reducing weight and the time required for manufacturing and assembly. While this means that the stock used for both plates needs to be thicker and more material is shaved off, the tradeoff in cost and machining time was deemed advantageous. The first alternative employed rods that ran through the root chord of the fin, strengthening the fin and simplifying the attachment of the fins to the plates. This would also remove the need for a fin spar and instead utilize a single solid fin section. However, after consultation with BIDC and research of different manufacturing processes, it was determined that this would be impossible to manufacture with the equipment available to the team. As such, that alternative was rejected.

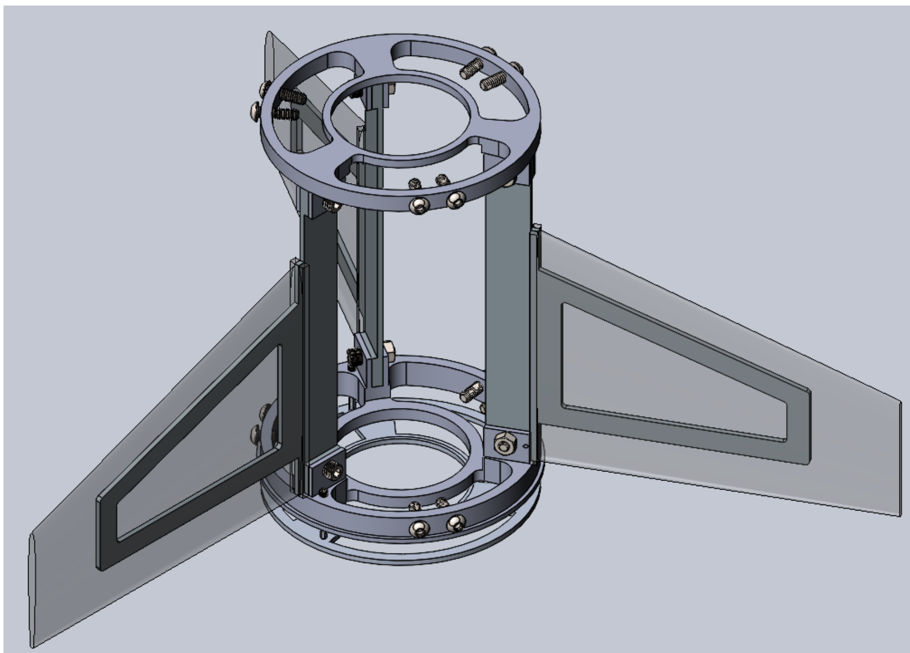


Figure 3.1.2.3.1: MFSS final design

3.1.2.4. Fins

Of the two design alternatives for the fins, Fin Alternative Two was chosen. This design utilizes a high-temperature epoxy resin with a G-10 fiberglass insert. The resin being used is EpoxAcast™ 670 HT epoxy, which was chosen for having high flexural strength and deflection temperature. On the other hand, Fin Alternative One utilized 3D printed Nylon 12 fins with a G-10 fiberglass insert. There were several reasons why Fin Alternative Two was the chosen final design. In the ANSYS simulation testing, this fin design was deemed to have sufficient rigidity and stiffness, ensuring improved survivability and sufficient resistance to fin flutter, which were both concerns with Fin Alternative One. Furthermore, this design maintains strength while reducing mass, as it uses less material than the alternative. The manufacturing process for the resin fins also lends itself to more uniformity between fins. The resin is cast in a mold, which is utilized for each fin. This method also encases the insert in the resin during the curing process, bonding the insert to the fin directly during manufacturing.

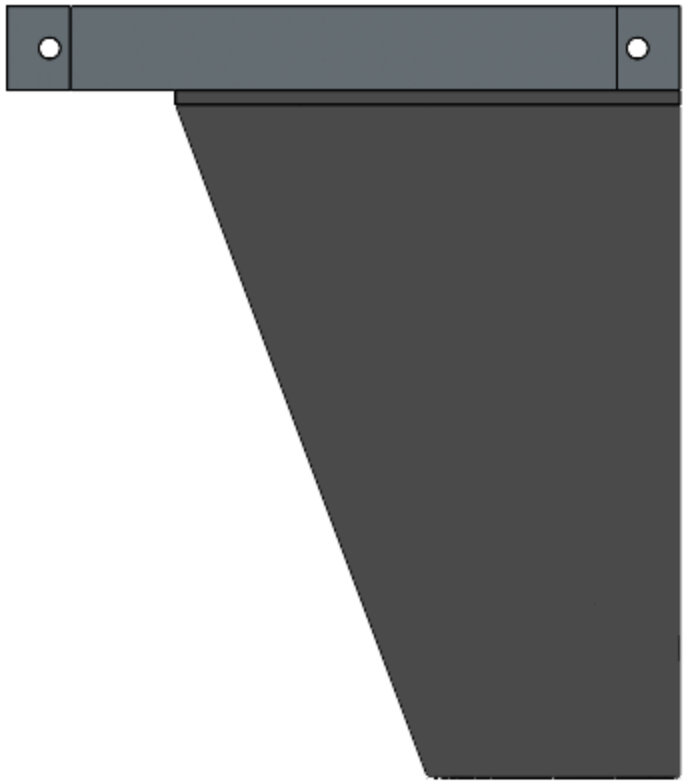


Figure 3.1.2.4.1: Fin final design

3.1.2.5. Nosecone

The chosen design for the nose cone is an 8” tall, 6.17” by 7.25” diameter parabolic-Von Karman blended body, which will be 3D printed using PETG. Many considerations led to this final design.

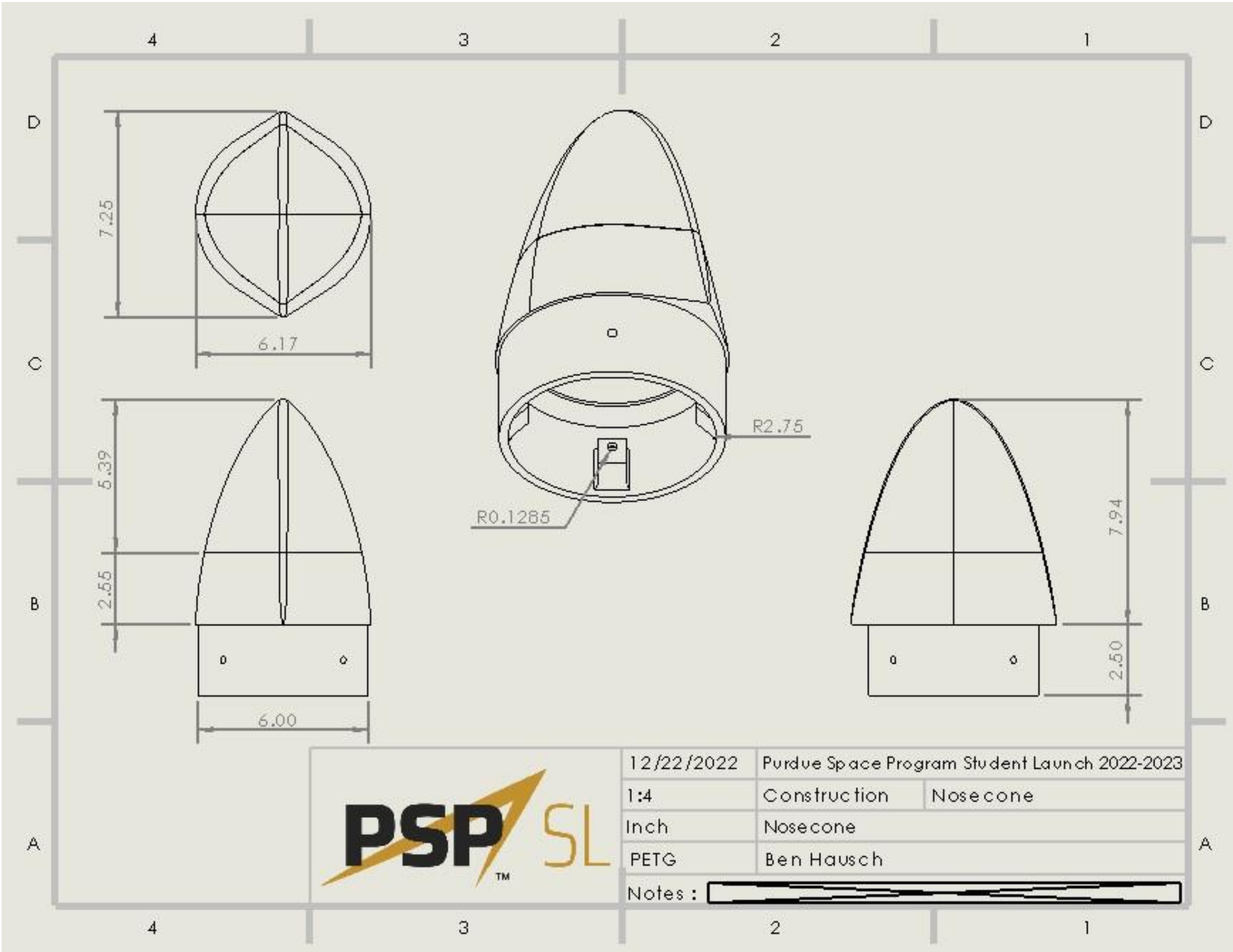


Figure 3.1.2.5.1: Nose cone technical drawing

In previous years, the cameras had been housed in aerodynamic strakes that protruded from the main body of the nose cone. This design was perfectly adequate until the incorporation of a fiberglass layup. Attempting to lay the sheets of fiberglass into sharp corners on complex curves was difficult. The fiberglass had trouble adhering completely to these corners and had to be fixed in many places. It was desirable to have these corners removed for the 2023 competition to better incorporate the fiberglass layup. This is why the blended body was chosen for this year's design.

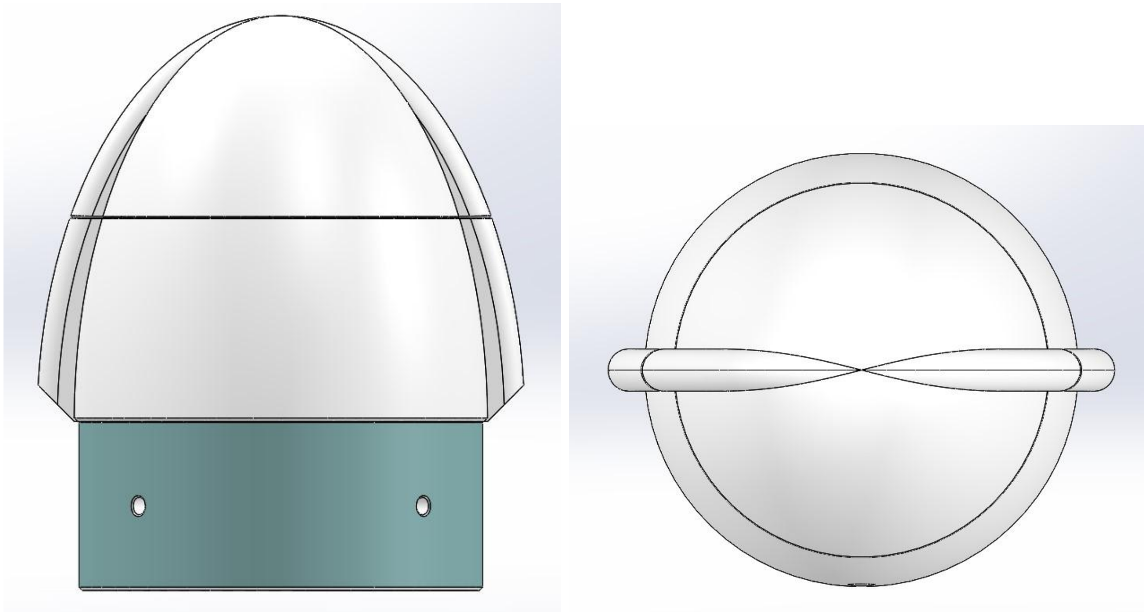


Figure 3.1.2.5.2: 2022 competition design showing protruding camera strakes

With respect to drag, the shape of the nose cone is largely negligible when traveling at the expected Mach numbers (~ 0.25). Because of this, the typical considerations were between a hemispheric shape, a parabolic shape, and a Von Karman shape. Not much data exists on the effects of nose cone shape on drag at such low Mach numbers, but the Von Karman shape is a well-known and proven shape for drag reduction. Because of this, the blended body consists of a parabolic and Von Karman shape.

The nose cone is 3D printed from PETG. Although PLA is more readily available, PETG has a higher glass transition temperature than PLA, making the nose cone more resistant to high temperatures that may be experienced during flight or storage.

3.1.3. Final Components

3.1.3.1. Booster Section

3.1.3.1.1. Motor Fin Support Structure

The Motor and Fin Support Structure (MFSS) is the modular assembly that holds the motor and attaches the fins to the launch vehicle. The MFSS is designed to slide in and out of the airframe easily. It aligns the motor, distributes the majority of the force into the airframe, and prevents any twisting that may be exerted on the fins.

Two minor changes were made to the MFSS since the Preliminary Design Review. First, new screws were sourced for attaching the booster standoffs, as suppliers for the old screws were difficult to find. Second, the fin insert gap on the centering and thrust plates was doubled to enhance manufacturability after Bechtel raised concerns in a consultation. All other widths and gaps were deemed manufacturable.

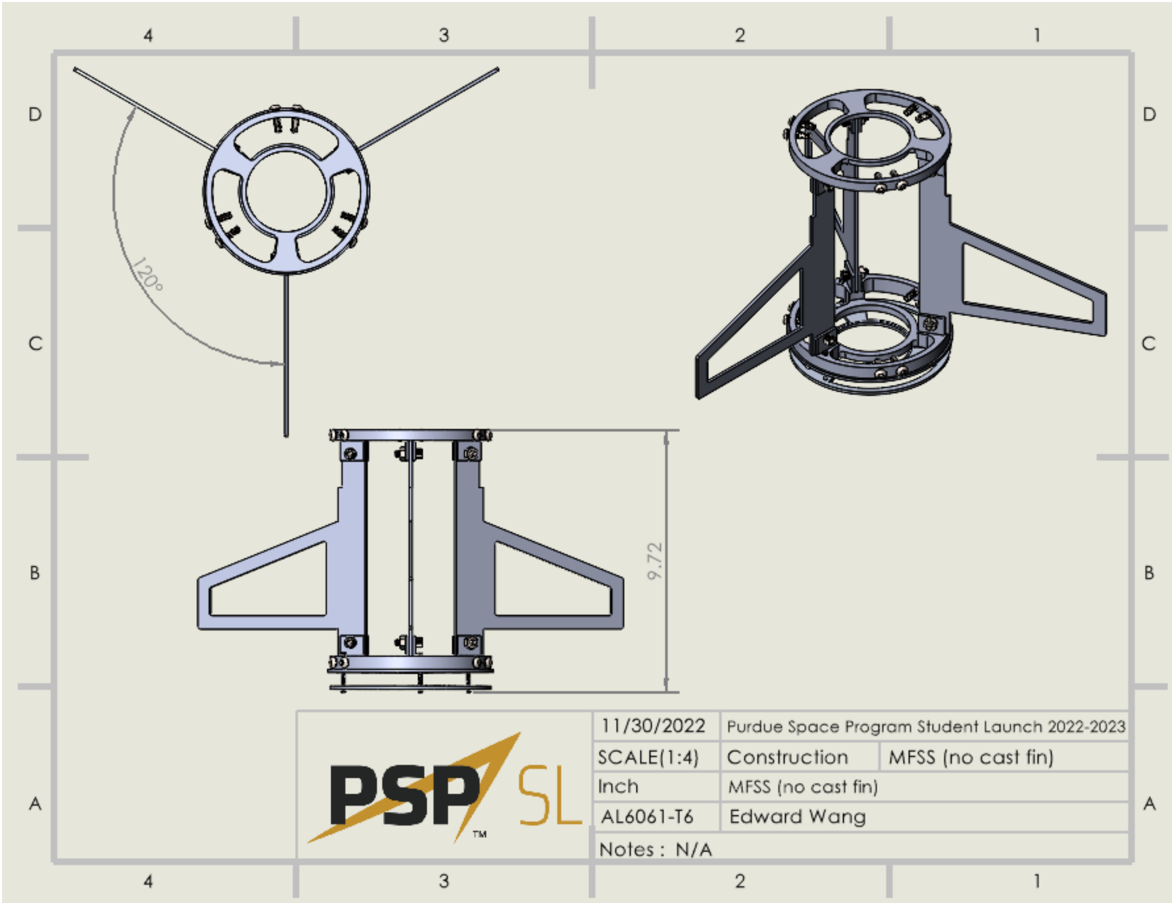


Figure 3.1.3.1.1.1: Technical Drawing for MFSS

Component	Quantity	Material	Mass per piece (lbm)	Total Mass (lbm)	Manufacturing
Thrust Plate	1	Aluminum 6061-T6	0.5223	0.5223	CNC Milled
Centering Plate	1	Aluminum 6061-T6	0.3465	0.3465	CNC Milled
Motor Retainer Plate	1	Aluminum 6061-T6	0.1101	0.1101	Laser Cut
Booster Standoff	3	Aluminum 6061-T6	0.0004	0.0012	Off-the-shelf
18-8 Stainless Steel Button Head Hex Drive Screw, 1/4"-20 Thread Size, 7/8" long	12	18-8 Stainless Steel	0.0132	0.1584	Off-the-shelf
18-8 Stainless Steel Socket Head Screw,	6	18-8 Stainless Steel	0.0144	0.0864	Off-the-shelf

1/4"-20 Thread Size, 3/4" Long					
18-8 Stainless Steel Hex Nut, 1/4"-20 Thread Size	6	18-8 Stainless Steel	0.0080	0.0480	Off-the-shelf
18-8 Stainless Steel Socket Head Screw, 4-40 Thread Size, 3/4" Long	3	18-8 Stainless Steel	0.0022	0.0066	Off-the-shelf
18-8 Stainless Steel Socket Head Screw, 4-40 Thread Size, 3/8" Long	3	18-8 Stainless Steel	0.0014	0.0042	Off-the-shelf
			Total Component Mass	0.9789	
			Total Fasteners Mass	0.3048	
			Total Assembly Mass	1.2837	

Table 3.1.3.1.1.1: MFSS Assembly List

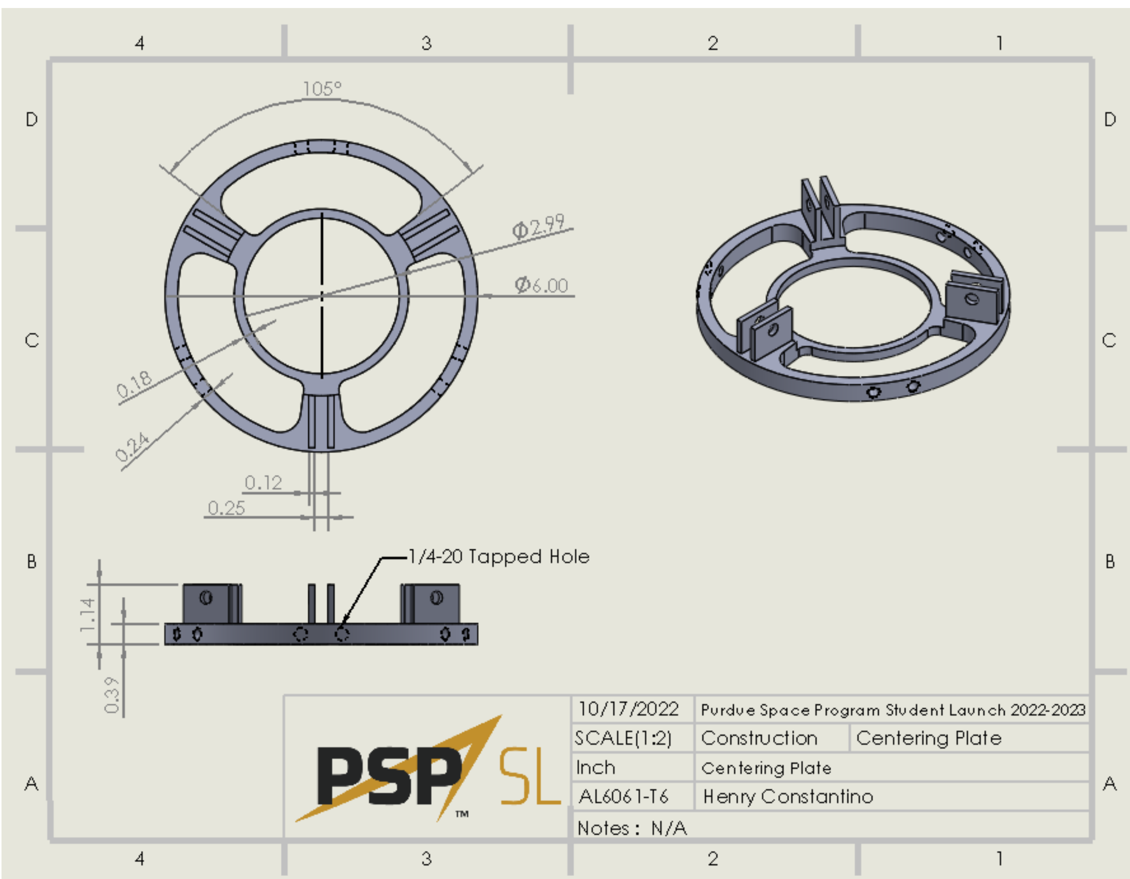


Figure 3.1.3.1.1.2: Technical Drawing for Centering Plate

Since PDR, the attachment slots for the fin inserts were widened from .125” to .25” as the tooling available to the team would not allow for the previous design.

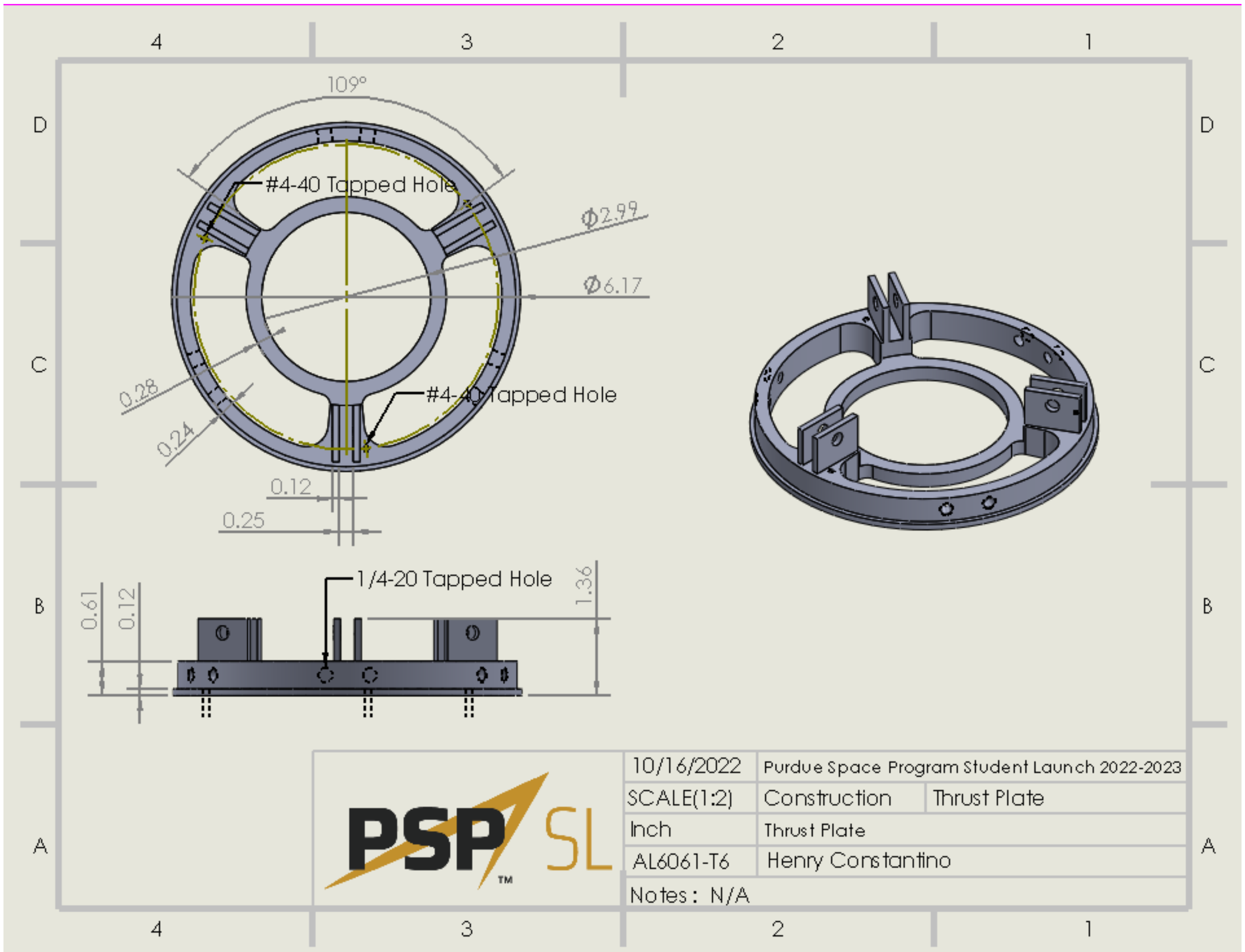


Figure 3.1.3.1.1.3: Technical Drawing for Thrust Plate

Since PDR, the attachment slots for the fin inserts were widened from .125” to .25” as the tooling available to the team would not allow for the previous design.

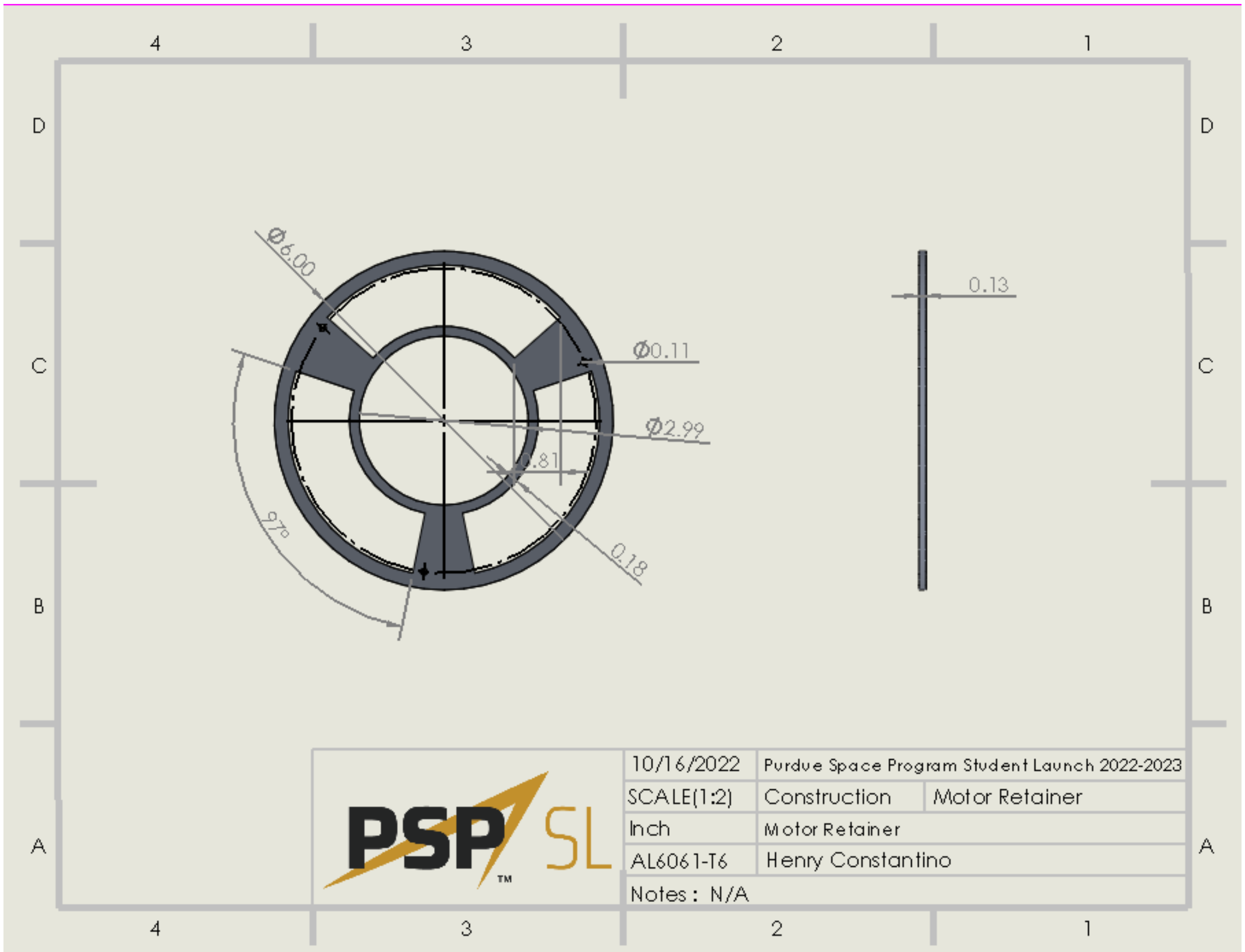


Figure 3.1.3.1.1.4: Technical Drawing for Motor Retainer Plate

3.1.3.1.2. Fins

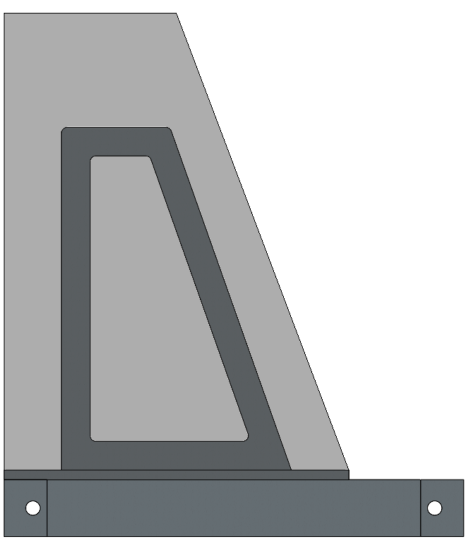


Figure 3.1.3.1.2.1: CAD for Fin

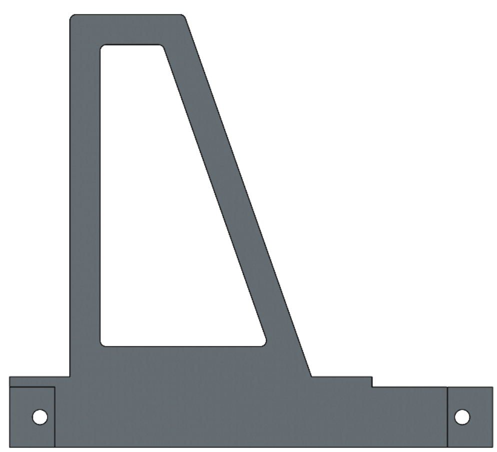


Figure 3.1.3.1.2.2: CAD for Fin Insert

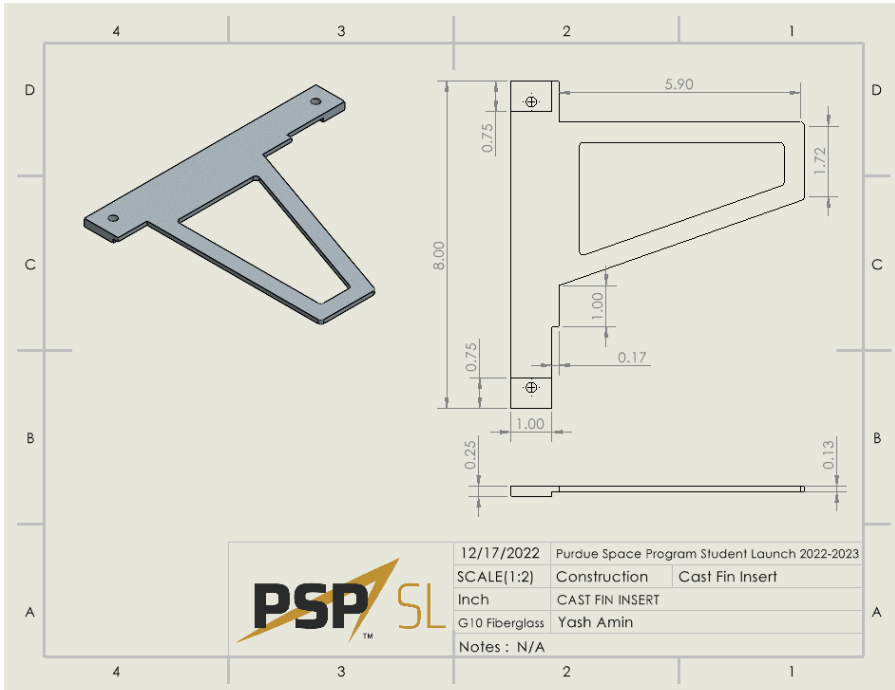


Figure 3.1.3.1.2.3: Technical Drawing for Fin Insert

The only changes made to the fin inserts are raised fiberglass sections around the attachment points to accommodate the larger slots on the centering and thrust plates. These will be manufactured separately and attached by the bolt connecting the insert to each plate.

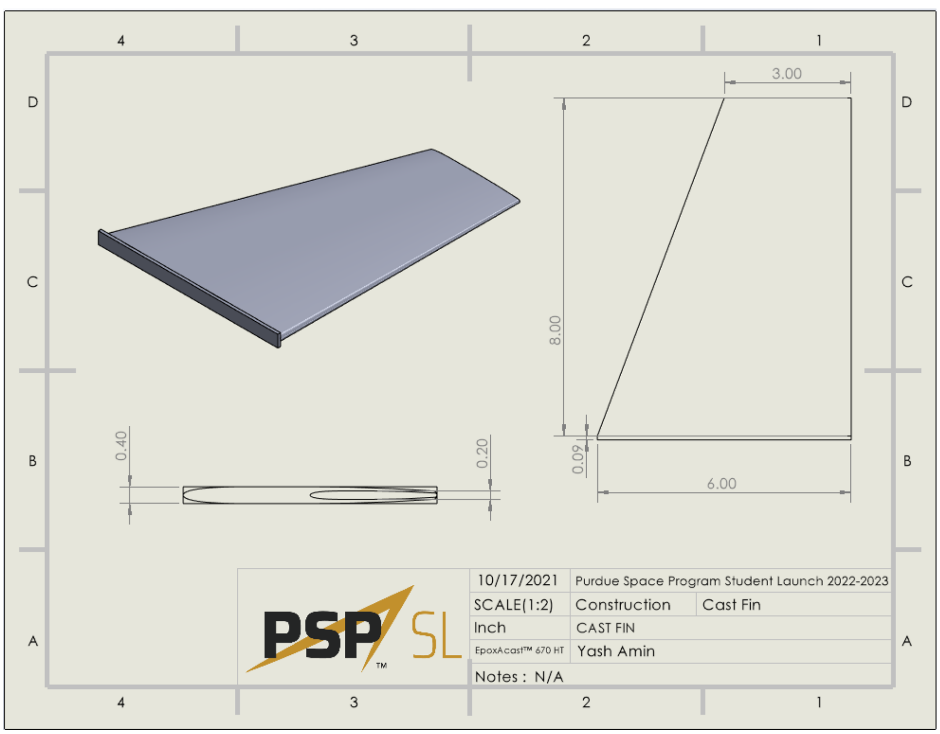


Figure 3.1.3.1.2.3: Technical Drawing for Fin

3.1.3.1.3. Booster Airframe

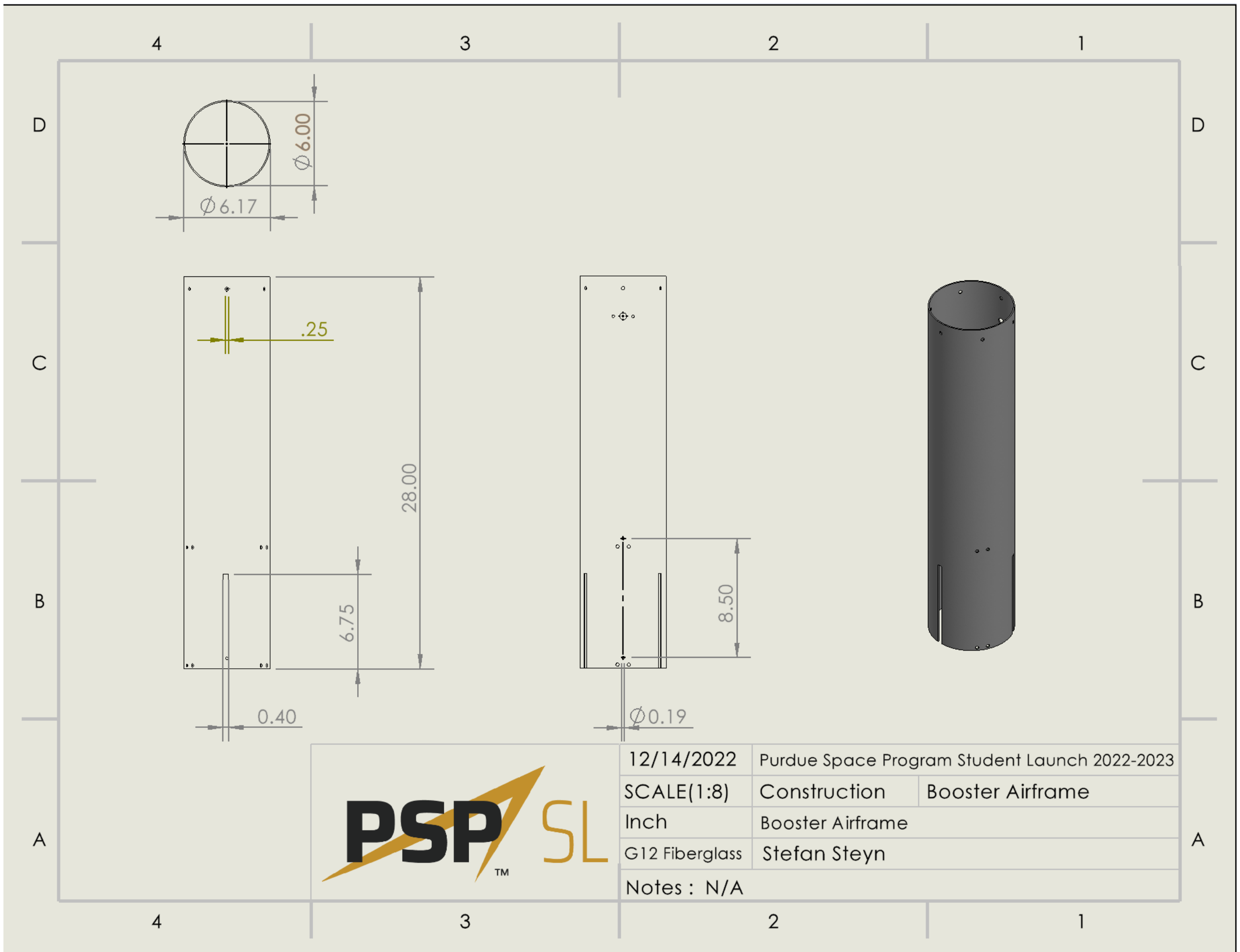


Figure 3.1.3.1.3.1: Technical Drawing for Booster Airframe

The only changes made to the booster airframe since the preliminary design report were an addition of a ½ inch hole for the key switch and two #6 radial holes to support it, as well as two ¼ inch holes for rail buttons. All other dimensions and materials remain the same.

3.1.3.1.4. Booster Coupler

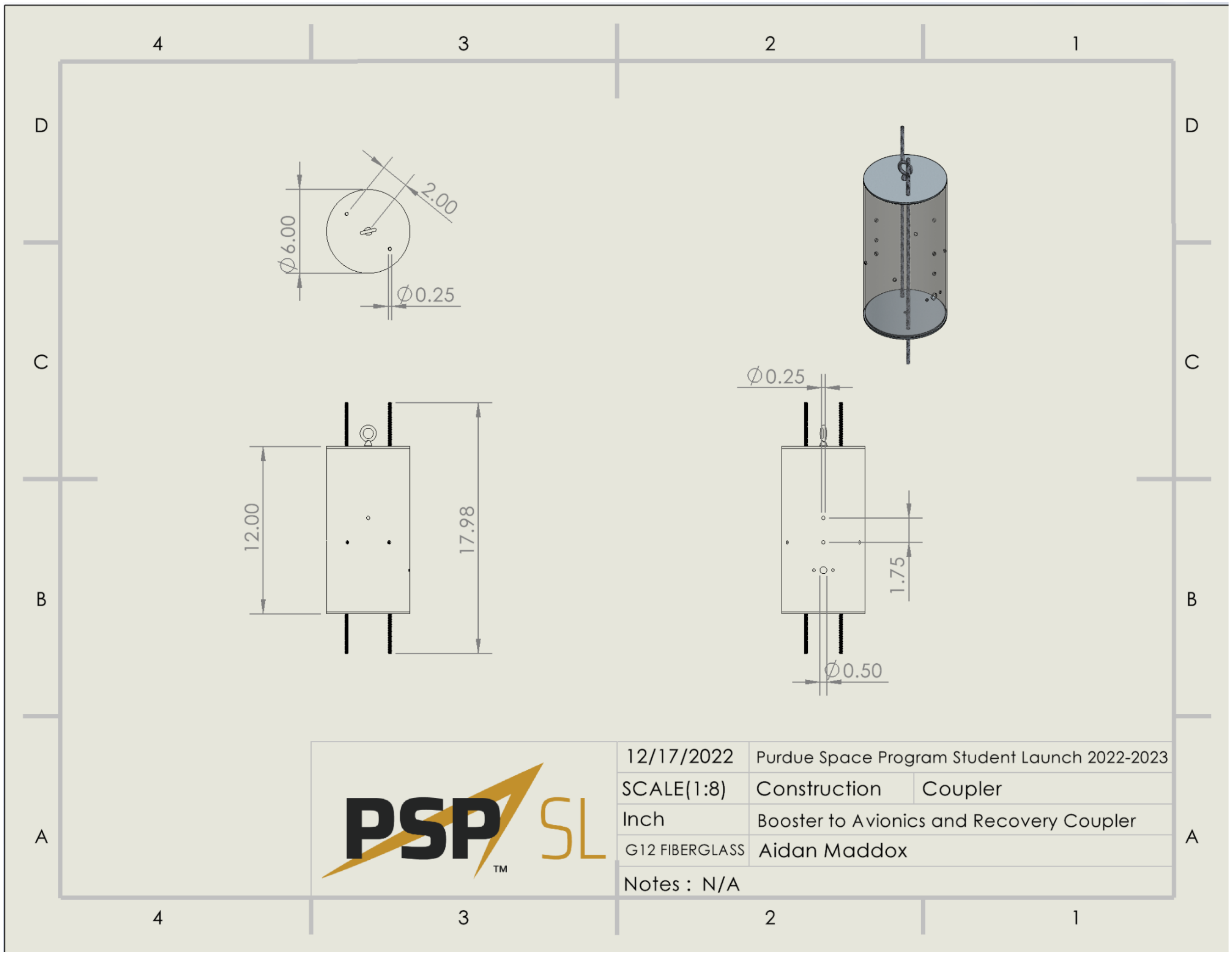


Figure 3.1.3.1.4.1: Technical Drawing for Coupler

The only change made to the booster coupler since the preliminary design report was adding a ½ inch hole for the key switch and two #6 radial holes to support it. All other dimensions and materials remain the same.

3.1.3.2. Recovery Section

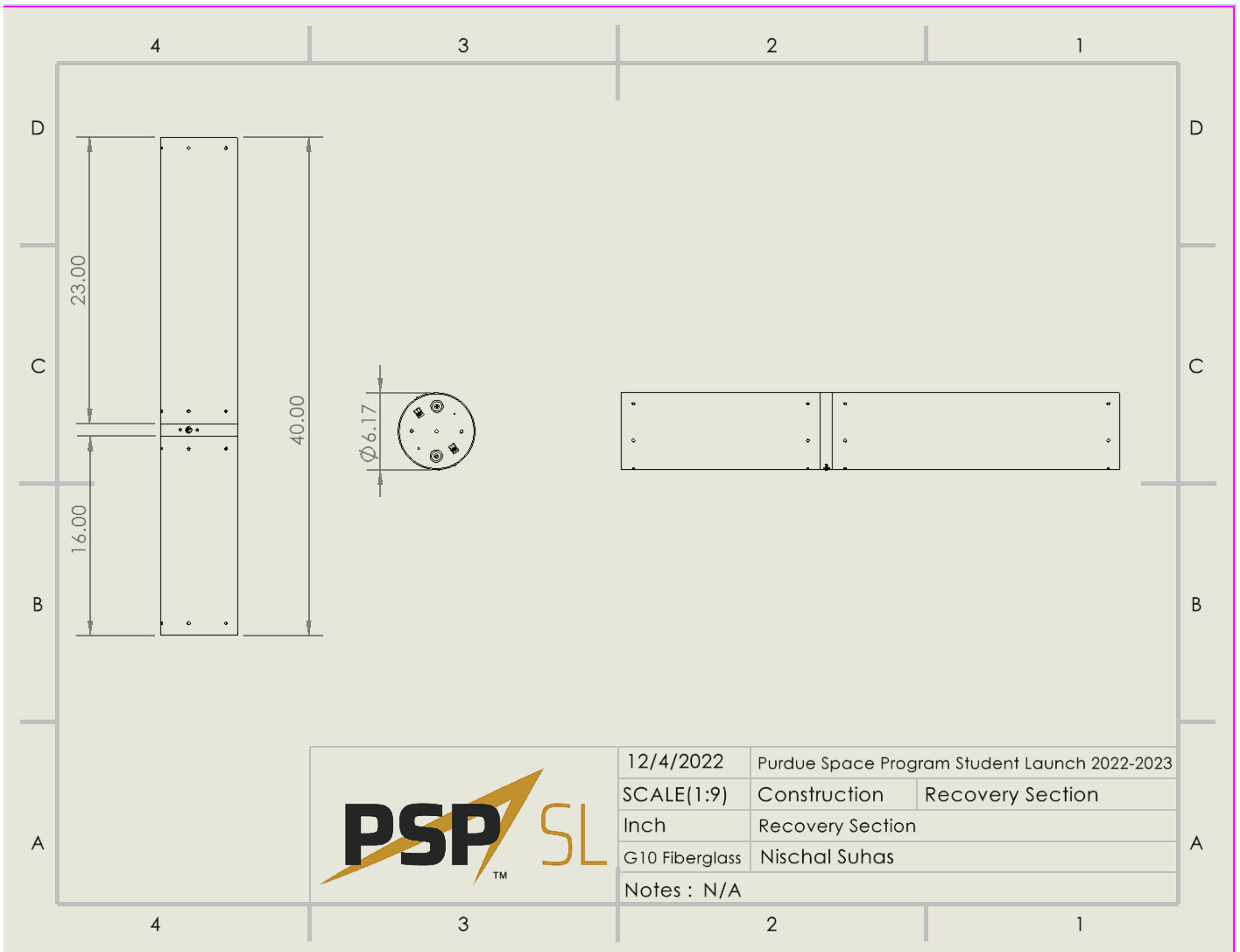


Figure 3.1.3.2.1: Recovery Section Assembly

The location of the main and drudge parachutes were swapped to avoid having the main parachute attached to the payload section and interfering while the cameras were performing. To accommodate this change, the dimensions of the lower and upper recovery tubes were also swapped to match the parachutes.

3.1.3.2.1. Lower recovery Airframe

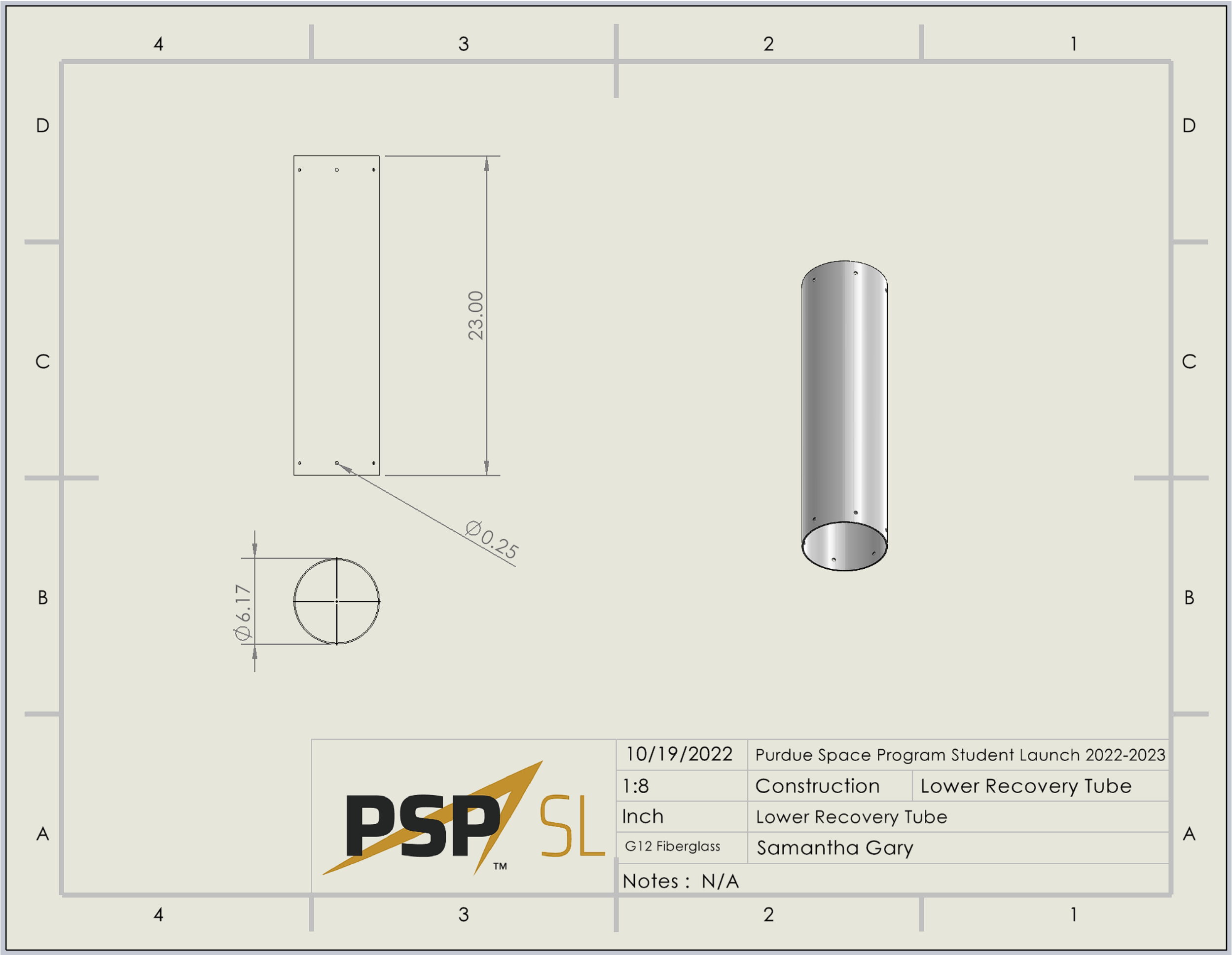


Figure 3.1.3.2.1.1: Technical Drawing for Lower Recovery Tube

Due to the location changes of the drogue and main parachutes, the lower recovery tube was increased to 23” in length, which was the previous length of the upper recovery tube. No material or diameter changes were made.

3.1.3.2.2. Avionics bay

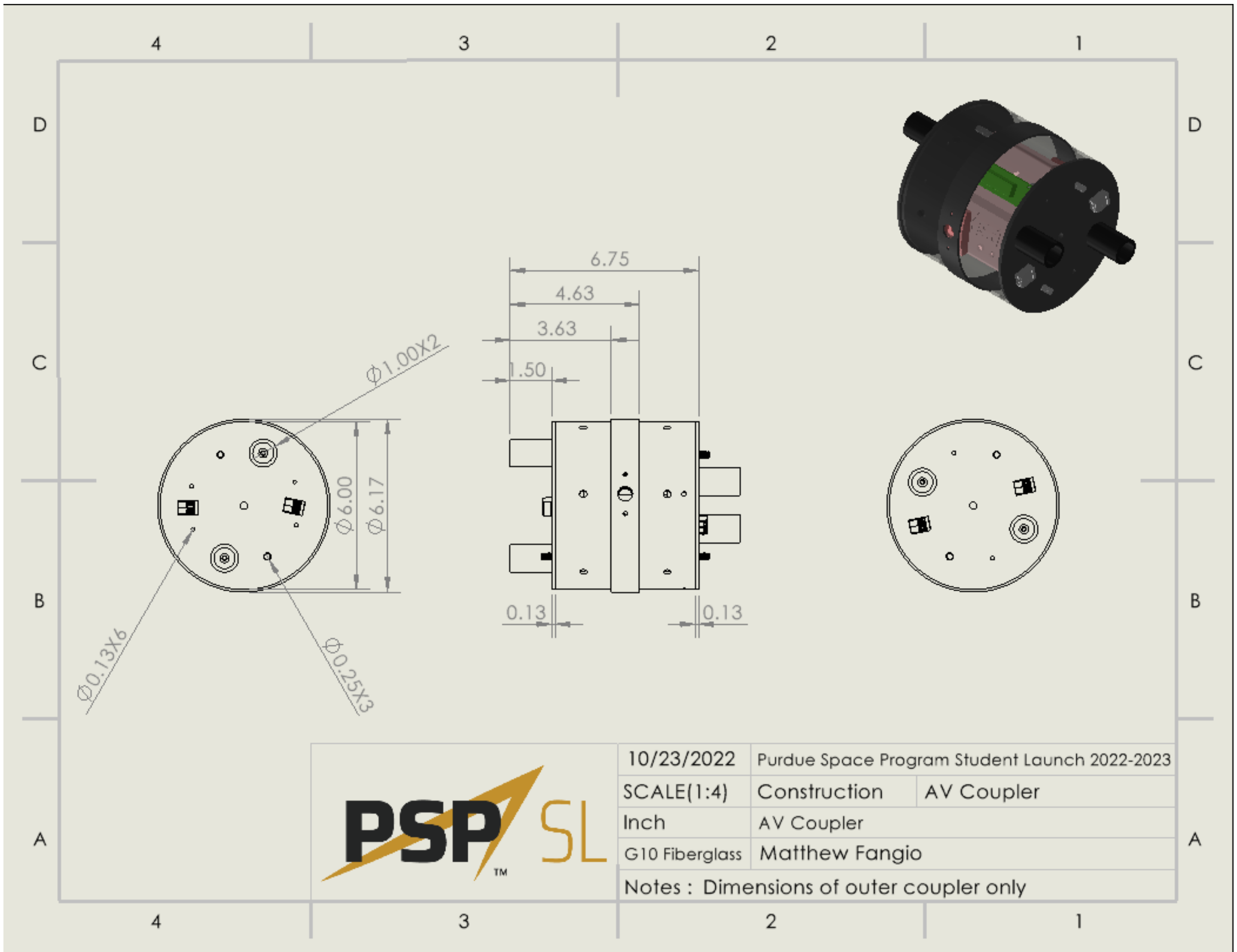


Figure 3.1.3.2.2.1: Technical Drawing for Avionics Bay

The avionics coupler is a non-in-flight separation point of the launch vehicle, and it houses the components for avionics. The coupler is designed to fit between the lower recovery airframe and the upper recovery airframe. No major changes were made to the coupler since the preliminary design review, so all components of the coupler remain the same.

3.1.3.2.3. Upper recovery airframe

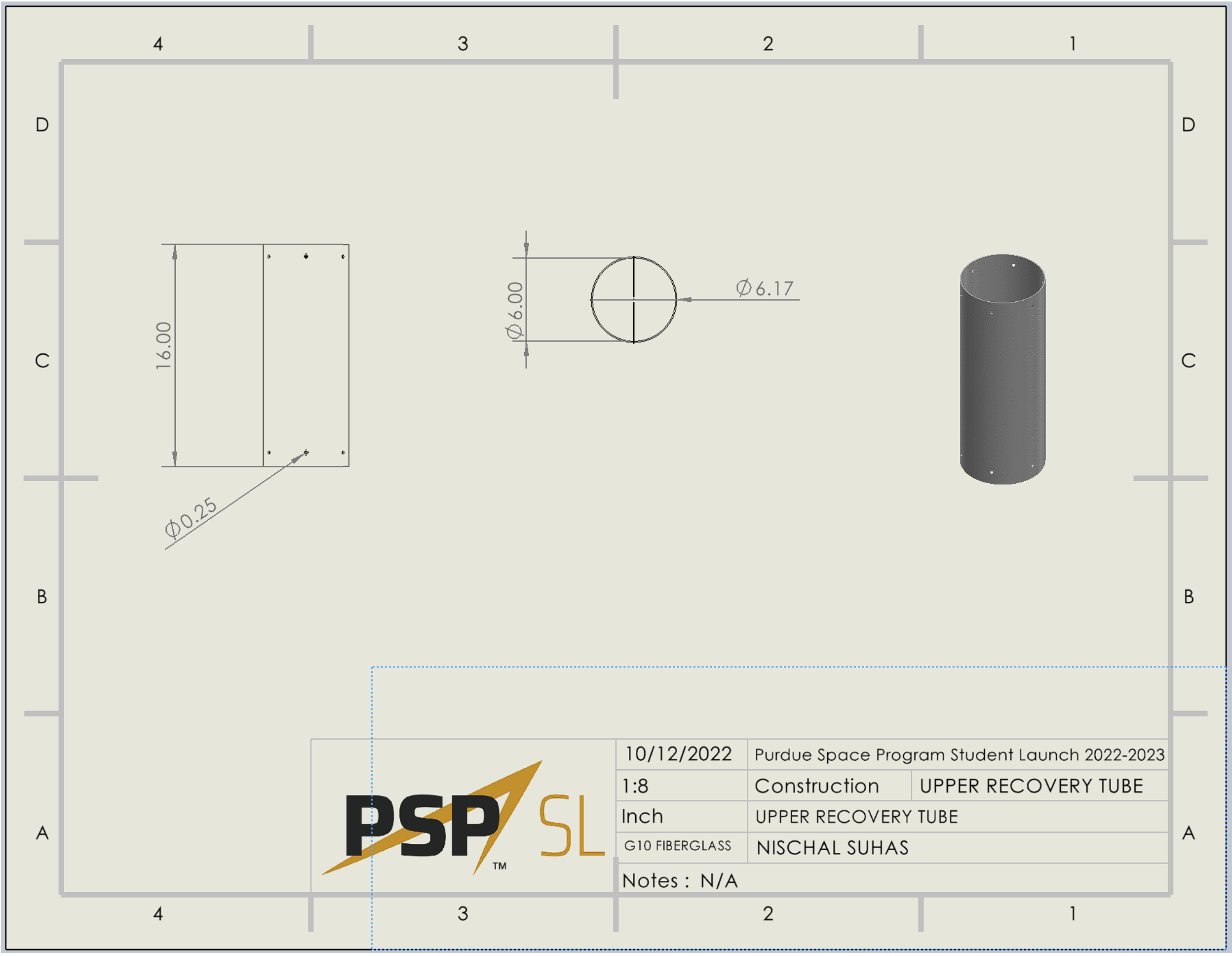


Figure 3.1.3.2.3.1: Technical Drawing for Upper Recovery Tube

Due to the location changes of the drogue and main parachutes, the upper recovery tube was shortened to 16" in length, the previous length of the lower recovery tube. No material or diameter changes were made.

3.1.3.3. Payload Section

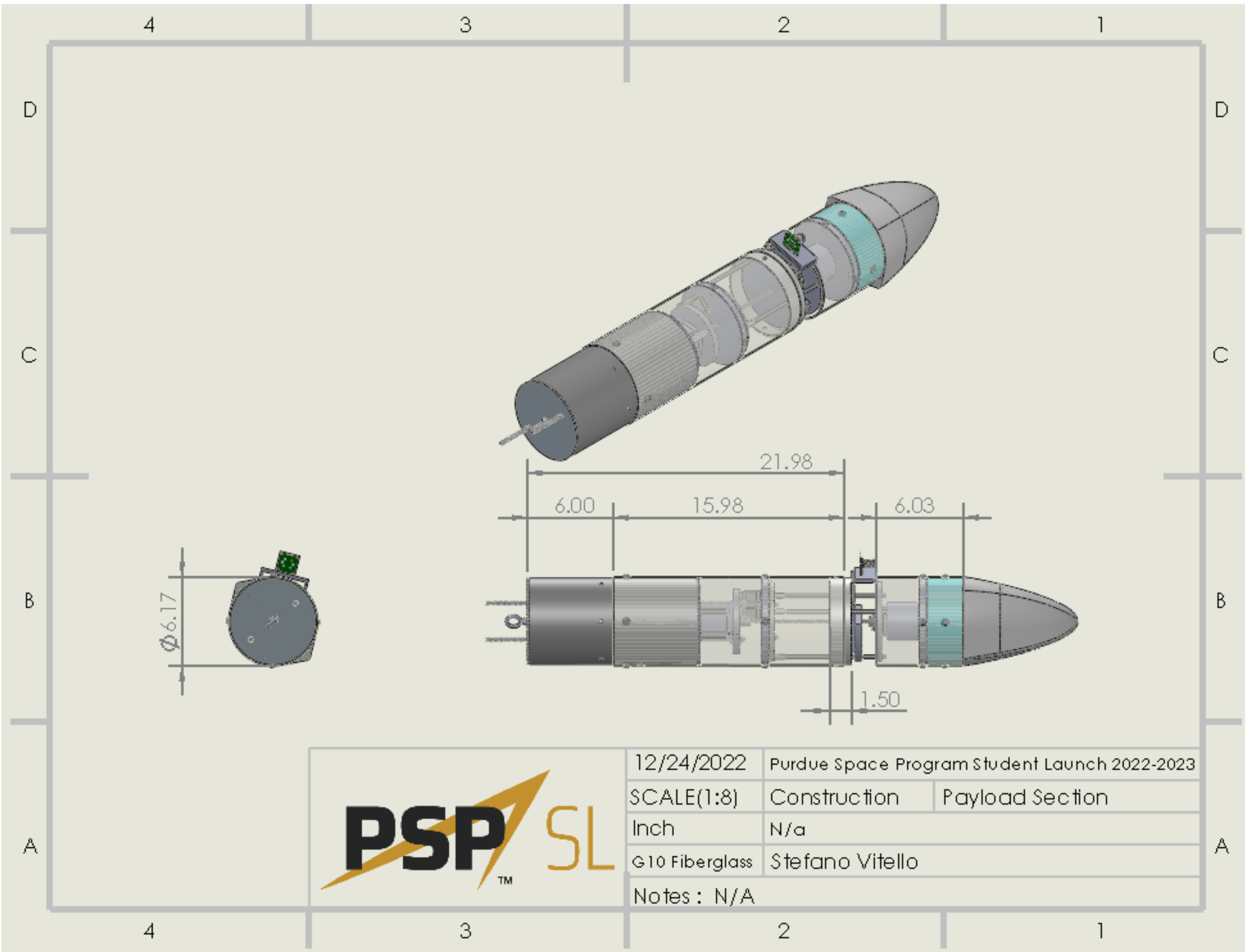


Figure 3.1.3.3.1: Technical Drawing for Payload Section

The payload section is mounted above the avionics and recovery section, joined via the payload-to-avionics coupler. The payload section contains the previously mentioned coupler, the payload airframe –both lower and upper–, the payload itself, a shoulder for the two airframes, and the nose cone. A key switch is placed within the coupler, while most of the payload remains within the airframe. A shoulder is mounted to the lower payload airframe to help orient the upper payload airframe such that it does not move horizontally while in flight. The nose cone has two cameras mounted to look towards the aft of the launch vehicle.

3.1.3.3.1. Payload Coupler

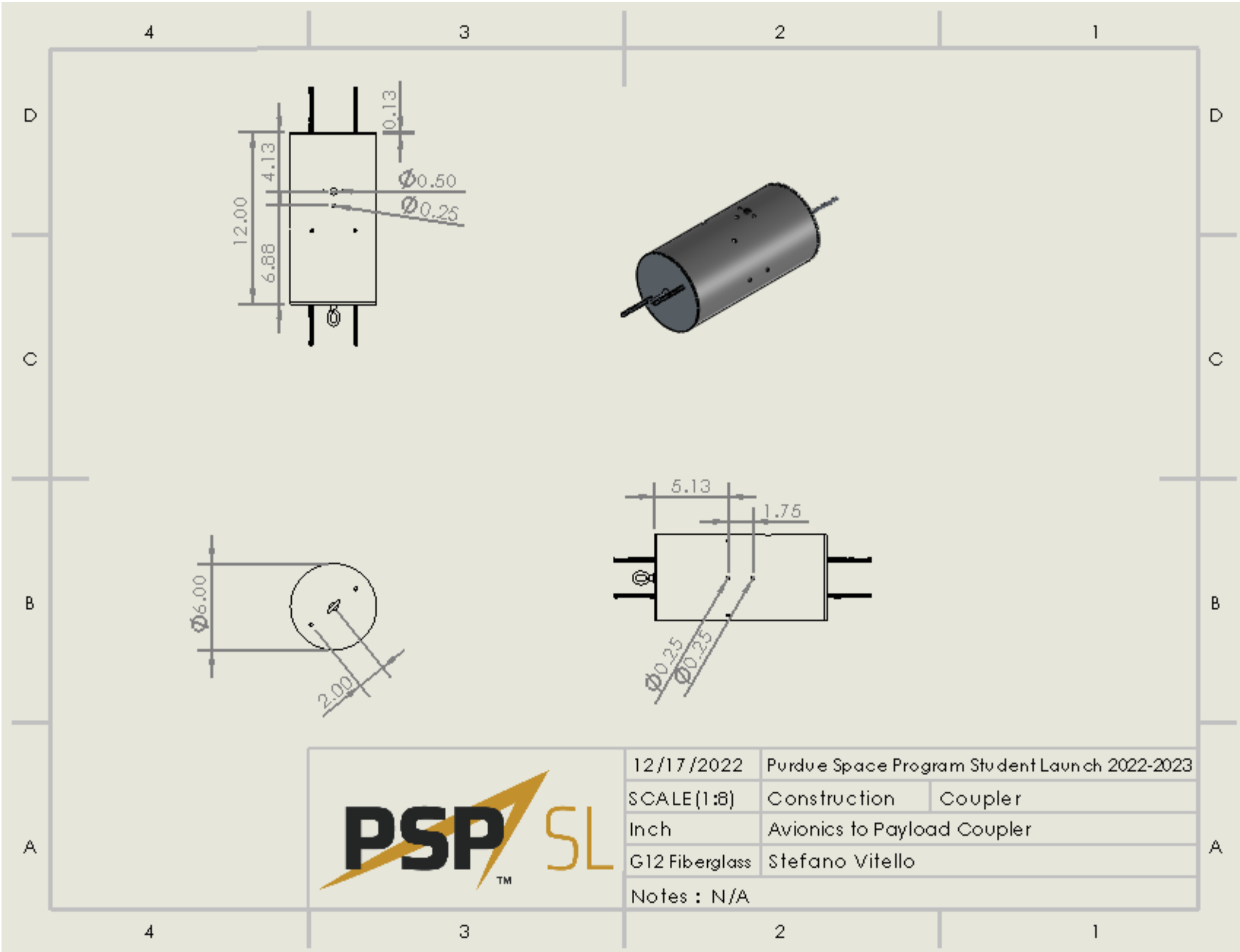


Figure 3.1.3.3.1.1: Technical Drawing for Avionics to Payload Coupler

The upper avionics to lower payload coupler joins and secures the two sections of the airframe for the duration of the flight. The coupler has several holes for mounting the two airframes, with the lowest ring of holes for the upper avionics airframe and the middle ring for the lower payload airframe. Since PDR, a .5" keyswitch hole and two #6 supporting radial holes were added to the coupler.

3.1.3.3.2. Payload Airframe

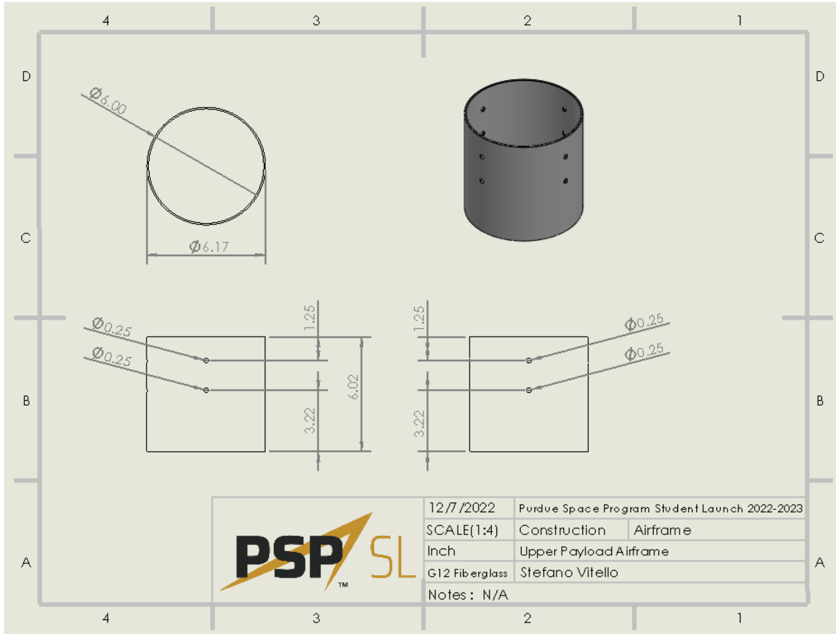


Figure 3.1.3.3.2.1: Technical Drawing for Upper Payload Airframe

The payload airframe has undergone numerous changes to reflect the changes in the payload design. The airframe is split into upper and lower sections to accommodate the actions of the payload. The upper section has two rings of four holes set ninety degrees from one another, the upper for mounting the nose cone and the lower ring for securing the payload. The upper payload airframe section is now just over 6” long.

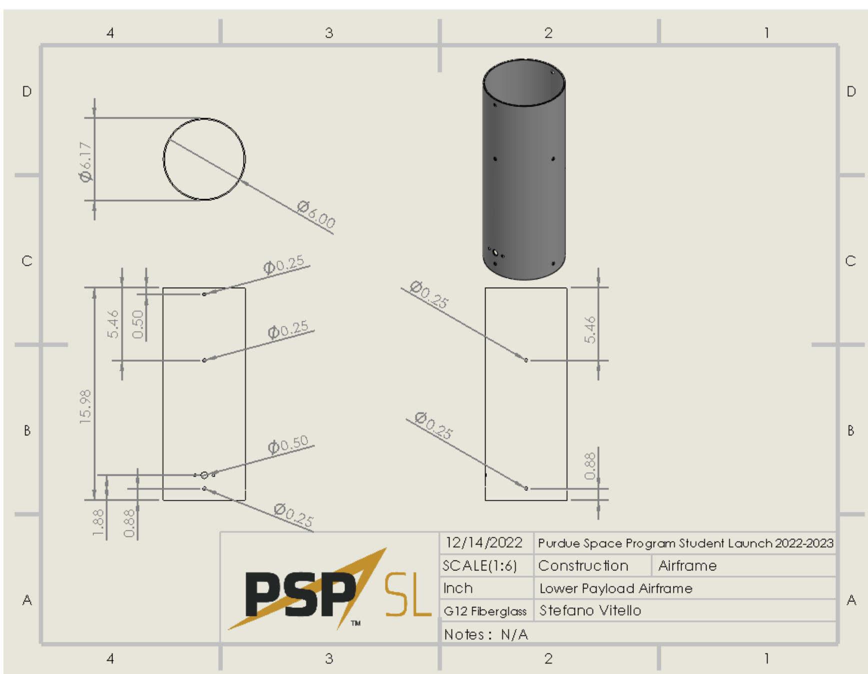


Figure 3.1.3.3.2.2: Technical Drawing for Lower Payload Airframe

As mentioned previously, the payload airframe is split into an upper and lower section. The lower section has two rings of four holes, a hole for a key switch, two holes beside that for mounting the keyswitch, and two holes closest to the top of the airframe. The holes closest to the top of the airframe are utilized for mounting the aforementioned shoulder. The lower ring of holes secures the payload coupler to the payload airframe, while the upper ring secures the payload to the airframe. The lower payload airframe section is now just under 16” long.

3.1.3.3.3. Nosecone

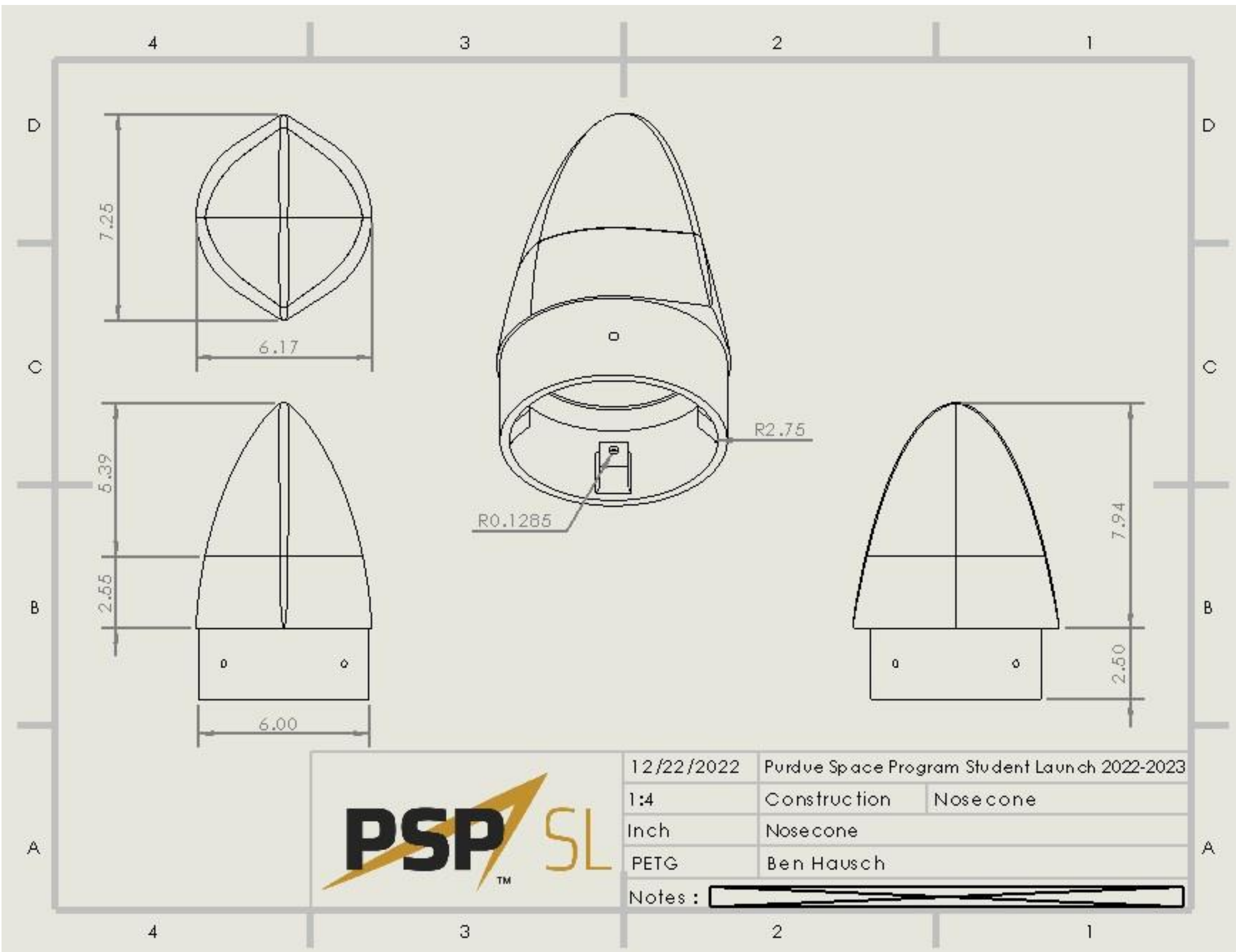


Figure 3.1.3.3.3.1: Technical Drawing for nose cone

The nose cone is an 8” tall, 6.17” by 6.25” by 7.25” Von Karman-paraboloid blend that will be 3D printed from PETG.

The main purpose of the nose cone is to capture launch footage. There will be two aft-facing cameras to capture footage. In the past, additional views like forward and outward cameras were used, but it was determined that the aft cameras were most useful. Furthermore, the nose cone is also expected to house ballast. There is more than 6” of space forward of the electronics plate which can be used to store ballast.

The electronics from previous years have proven to be lightweight, durable, effective and provide a long duration of recording, so the same makes/models will be used. A 18650 rechargeable lithium-ion battery is used to generate power. This battery runs to two Raspberry Pi Zeros, which each control one OV5647 Zero Cameras.

The electronics will all sit on a 3D printed plate, which can be loaded into the nose cone. This greatly eases assembly because the battery and electronics may all be connected and fastened to the plate outside of the nose cone, and then loaded into the nose cone with just four bolts. This process was used last year to great effect.

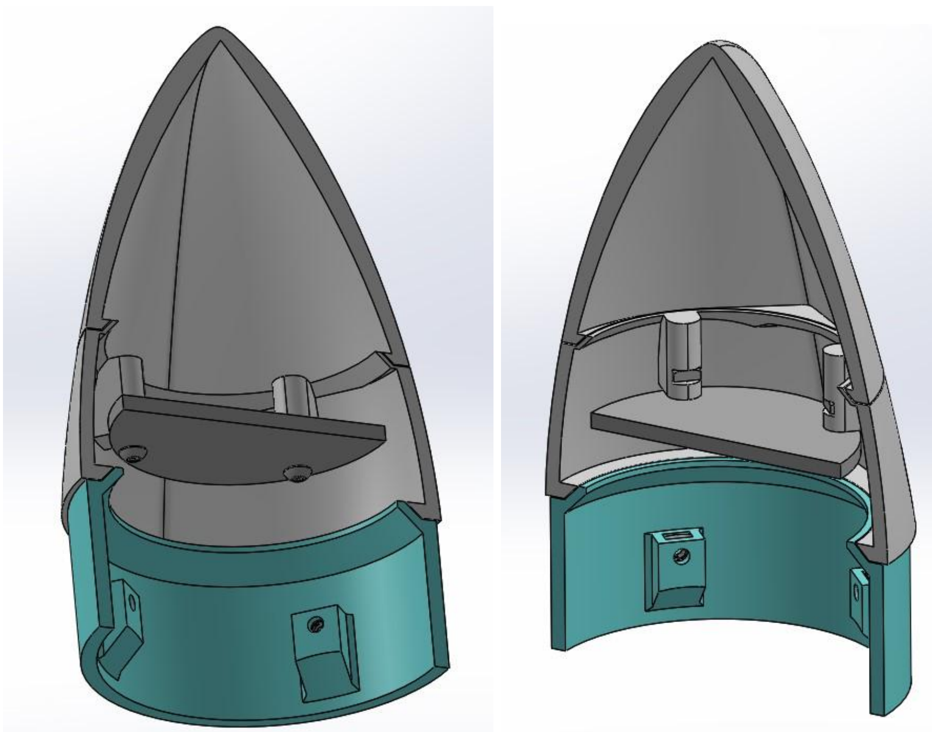


Figure 3.1.3.3.3.2: Nose cone section showing electronics plate

Captive nut configurations are used to secure fasteners in multiple locations within the nose cone. Permanently adhered square nuts inserted into slots allow bolts passing through them to hold. This configuration is used to hold the electronics plate up, and to secure the coupler to the payload airframe.

The nose cone is manufactured in 3 sections. This allows multiple 3D prints, which decrease both the severity and likelihood of print failure. These 3 sections will be adhered together using epoxy.

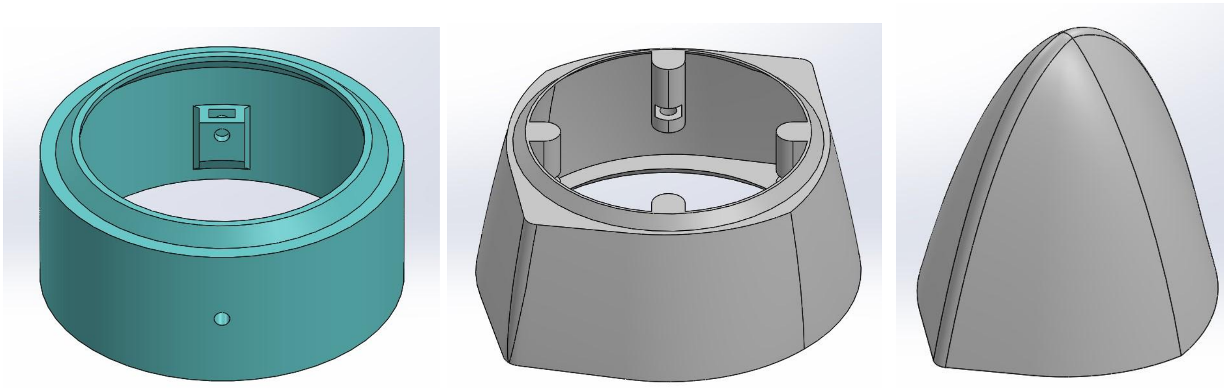


Figure 3.1.3.3.3.3: Three independent nose cone sections

These sections each have their own lips, which increase the surface area over which the epoxy will be acting. This will increase the strength of the bond between each section. In past years, a bolt has been used to mate the top and bottom sections of the nose cone. This year, with a fiberglass layup connecting the top and bottom sections, epoxy was determined to be sufficient to bond the two pieces permanently

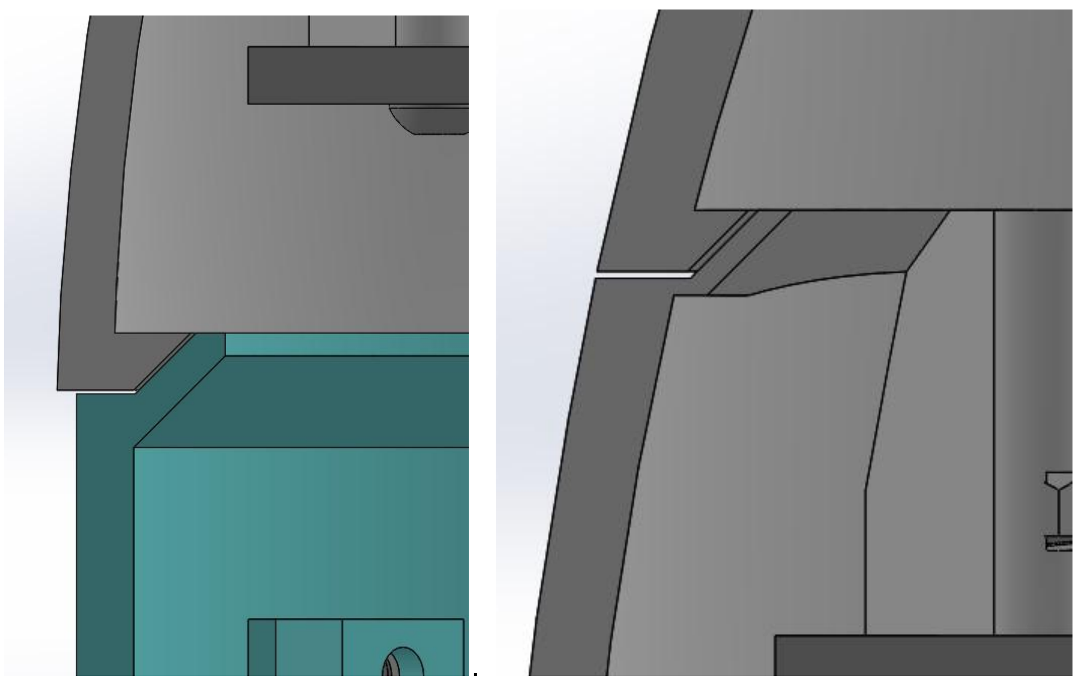


Figure 3.1.3.3.3.4: Coupler-bottom nose cone interface, and bottom-top nose cone interface sections, respectively

3.1.4. Points of Separation

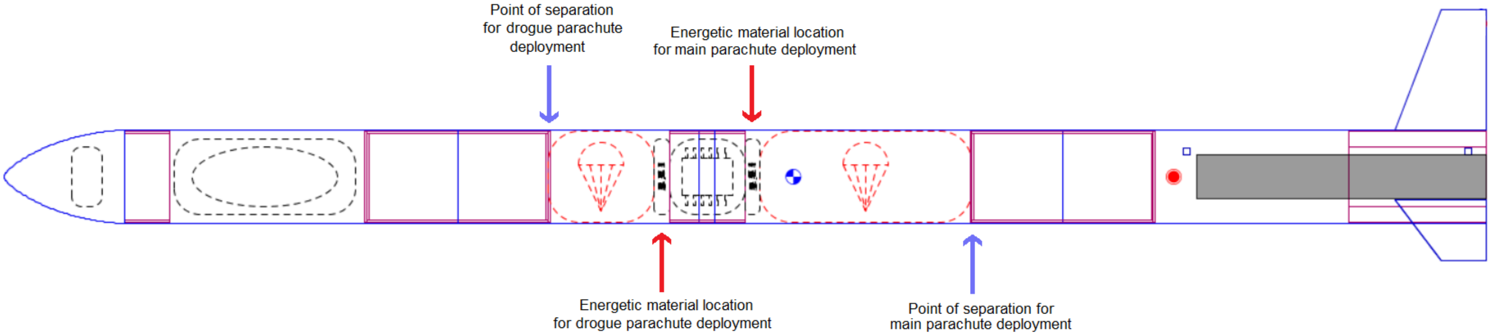


Figure 3.1.4.1: Locations of energetic material and points of separation

The launch vehicle design for 2023 follows a similar separation criteria to 2022, where separation occurs above and below the avionics bay. A diagram of the launch vehicle's separation process is outlined in Figure 3.1.4.1 above, where points of separation are indicated with blue arrows, and the locations of energetic material are indicated with red arrows. At the points of separation for the main and drogue parachutes, charges housed within the bulkheads of the avionics coupler ignite, forcing the two airframes apart and releasing their respective parachutes. A detailed analysis and discussion of the recovery system deployment is available in the Avionics and Recovery report in Section 6.

3.1.5. Manufacturability

3.1.5.1. Thrust and Centering Plates

Both plates are to be manufactured from aluminum 6061-T6 stock sourced from Midwest Steel Supply. For both plates, the stock dimensions are 8"x8"x2". There are a total of three operations, which were created in Fusion 360. The first operation is a 1.5" dovetail, machined onto the stock using the Haas VF2 vertical mill.

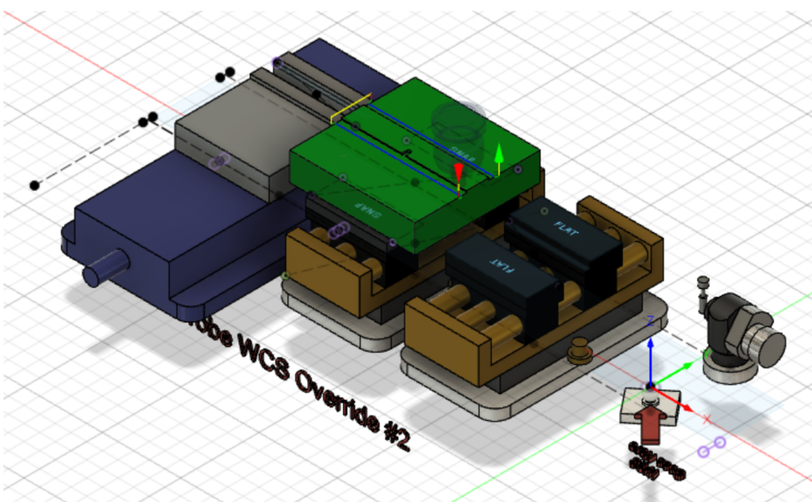


Figure 3.1.5.1.1: CAM simulation for dovetail stock preparation.

This 1.5” dovetail stock is then brought to the Haas VF4 5-axis CNC. Machining paths are then created for reducing the raw stock, clearing the inner spaces, final contouring, and screw holes.

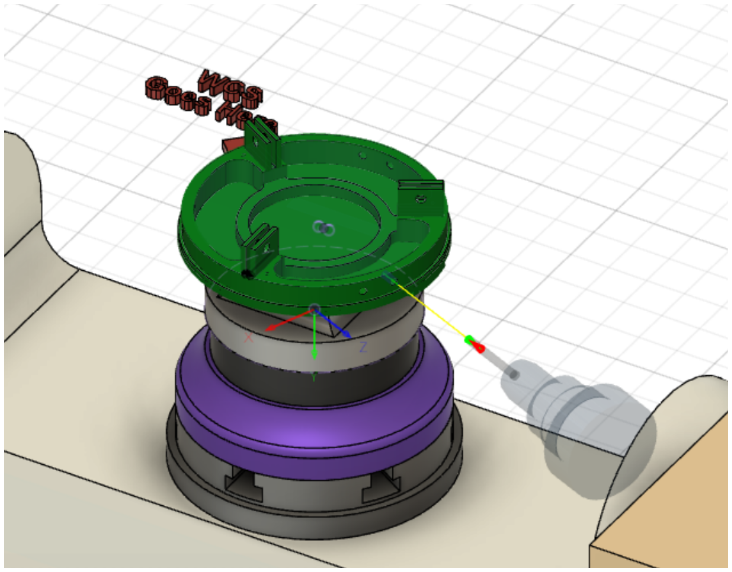


Figure 3.1.5.1.2: CAM simulation of the second operation for the thrust plate (before final contouring)

The completed stock is then brought back into the VF2 for removal of the dovetail and final clearing of the spaces around the center. In the case of the thrust plate, booster standoff screw holes previously unreachable with the VF4 are also machined. To clamp down on the plates during this final operation, custom soft jaws are machined with the VF2 to fit the contours of the plate.

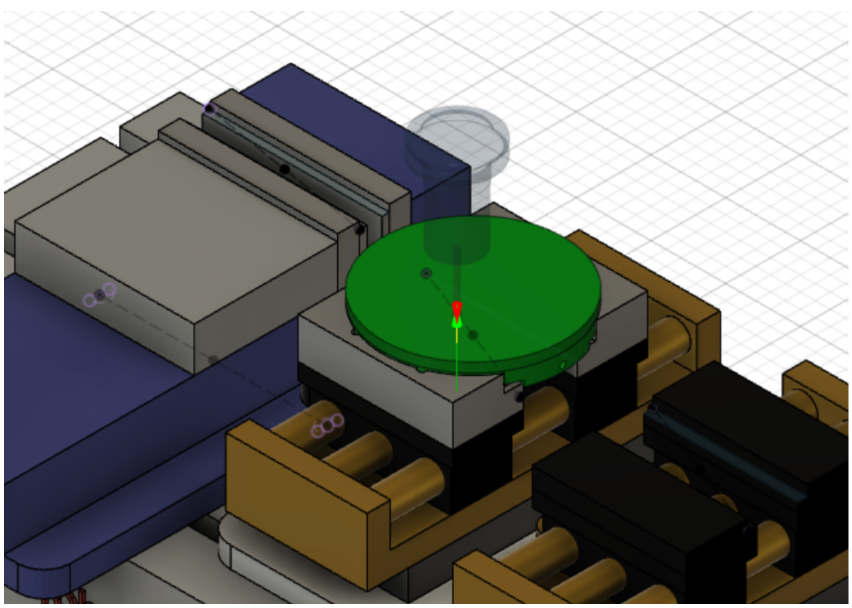


Figure 3.1.5.1.3: CAM simulation of the final operation for the thrust plate

3.1.5.2. Motor Retainer

The 0.125'' thickness and 2D geometry of the motor retainer permit simple and quick manufacturing using the laser cutter available at the BIDC. A Computer Aided Manufacturing (CAM) file is made by exporting the Solidworks part file to DWG format. The laser cutter is designed to cut along the lines at a certain depth. Colors were originally assigned to the outside borders and the internal holes of the motor retainer to attempt to aid the laser cutting process, but after having consulted with a peer mentor from the BIDC, this action was deemed unnecessary. A screenshot of the CAM file is attached below.

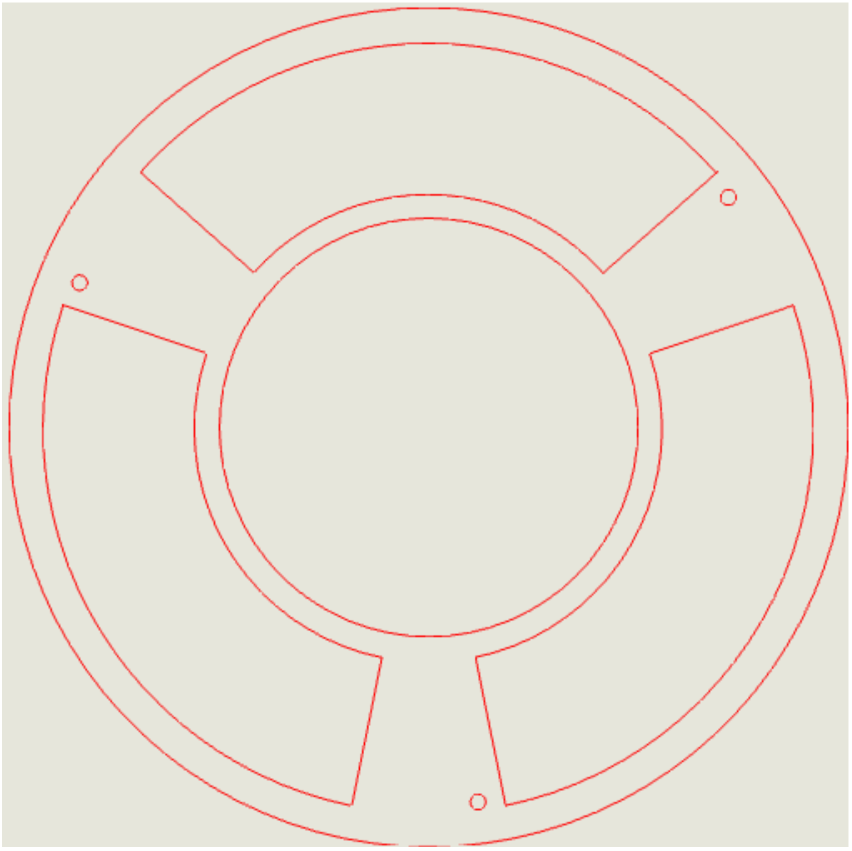


Figure 3.1.5.2.1: Screenshot of the CAM file of the motor retainer

3.1.5.3. Fin Inserts

Fin inserts will be made of G10 plate fiberglass. Although the physical dimensions of the insert are appropriate for the laser cutter, its material properties, toxicity and glass content, prohibit its use. For that reason, the team decided to use a waterjet FLOW MACH2 2020C.
For the test fin, the standard settings for waterjet were used. The result did not satisfy the team's expectations since the high pressure from the waterjet caused delamination in the fiberglass. However, this issue was not critical for the test fin.

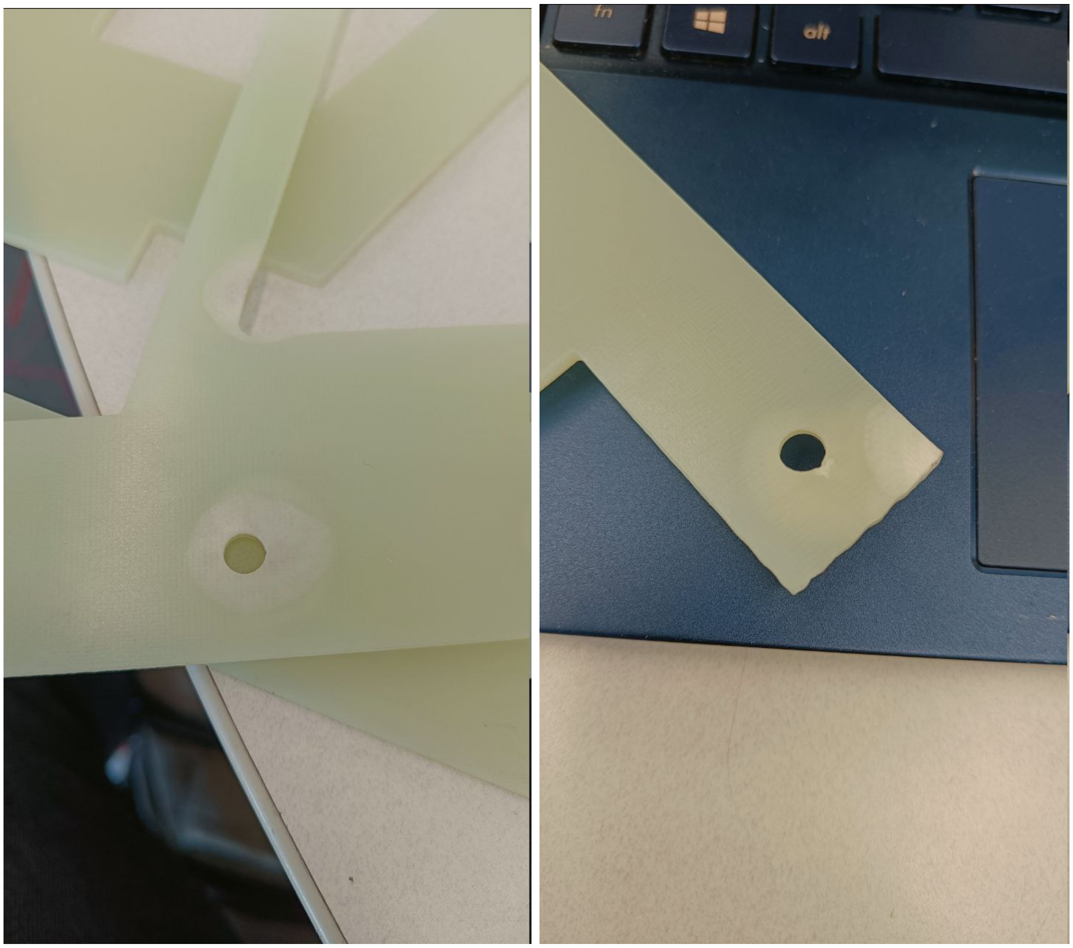


Figure 3.1.5.3.1: Delamination in fiberglass from waterjet

For the subscale launch, the team decided to use a low-pressure setting for the waterjet to reduce the amount of delamination. The configuration was tested by making a small hole in fiberglass, and the result was acceptable since the delamination was smaller than before.

Figure 3.1.5.3.2: Delamination in fiberglass from waterjet using the low-pressure setting.

Based on the result from the test cut, it was decided to cut fins using a low-pressure setting. However, the anomaly was found during the cutting process, so the machine was stopped and switched back to normal pressure.

Figure 3.1.5.3.3: Anomaly in the operation of waterjet cutting. The water jet reflects from the fiberglass sheet.

The low-pressure setting caused even more delamination than before, so the solution for this problem should not involve the pressure of the waterjet.

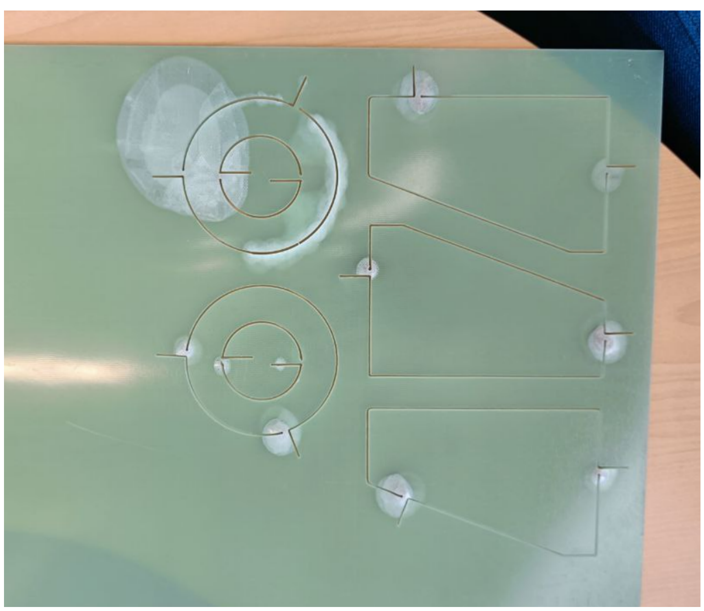


Figure 3.1.5.3.4: Delamination using low-pressure setting

After all tests with water jet cutting, the team noticed that the delamination occurs only at the point where the machine starts cutting. To resolve this, the waterjet will be programmed to start all cuts in scrap sections of fiberglass, then move toward the actual model. The radius of delamination at the starting point is approximately 0.75", so the offset from the model can be 1-1.5".

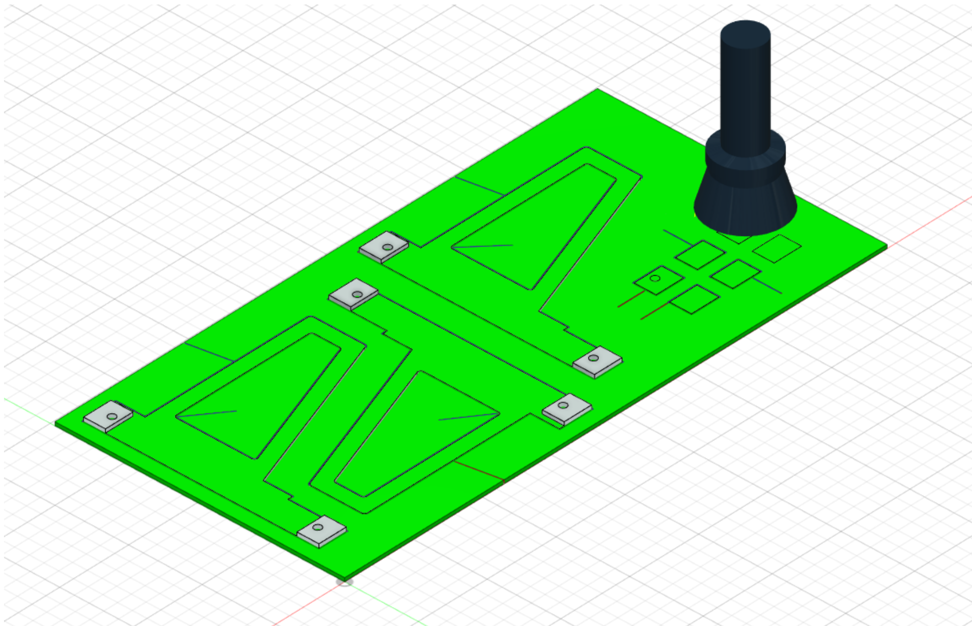


Figure 3.1.5.3.5: CAM for waterjet

Based on all results and experience, the team made a CAM model for the waterjet in FUSION 360. This CAM includes offsets that are required to avoid delamination. The .25" holes will be drilled separately on a manual mill as it is impossible to incorporate the offsets needed for the waterjet in that space.

3.1.5.4. Fin Shells

The fins will be made using EpoxAcast™ 670 HT resin. The resin will encase the fin inserts to ensure no separation between the two sections. The fins will be cast using a custom silicone mold. A positive of the fin will be printed using a stereolithography (SLA) 3D printer. The positive will then be used to create a negative in silicone. This type of printer was chosen because of its high layer resolution. The high resolution ensures the shape of the fin is not altered, and it will help prevent layer marks from appearing in the negative mold. Silicone was chosen because of its low tendency to bond with the molded model. A proof-of-concept fin was created weeks before PDR using an FDM 3D printed mold with polyethylene terephthalate glycol (PETG) filament. The biggest problem with the manufacturing process was separating the cured fin from the mold. The fin bonded to the mold, resulting in the destruction of the mold to free the fin. Additionally, the mold sections did not create a tight seal because of the low tolerances of FDM 3D printers. This resulted in resin leaking out of the mold cavity. Utilizing a silicone mold solves both of these problems. The silicone mold will be one-piece, eliminating any chance of resin leakage, and with the use of a release spray, the resin will not bond with the mold.

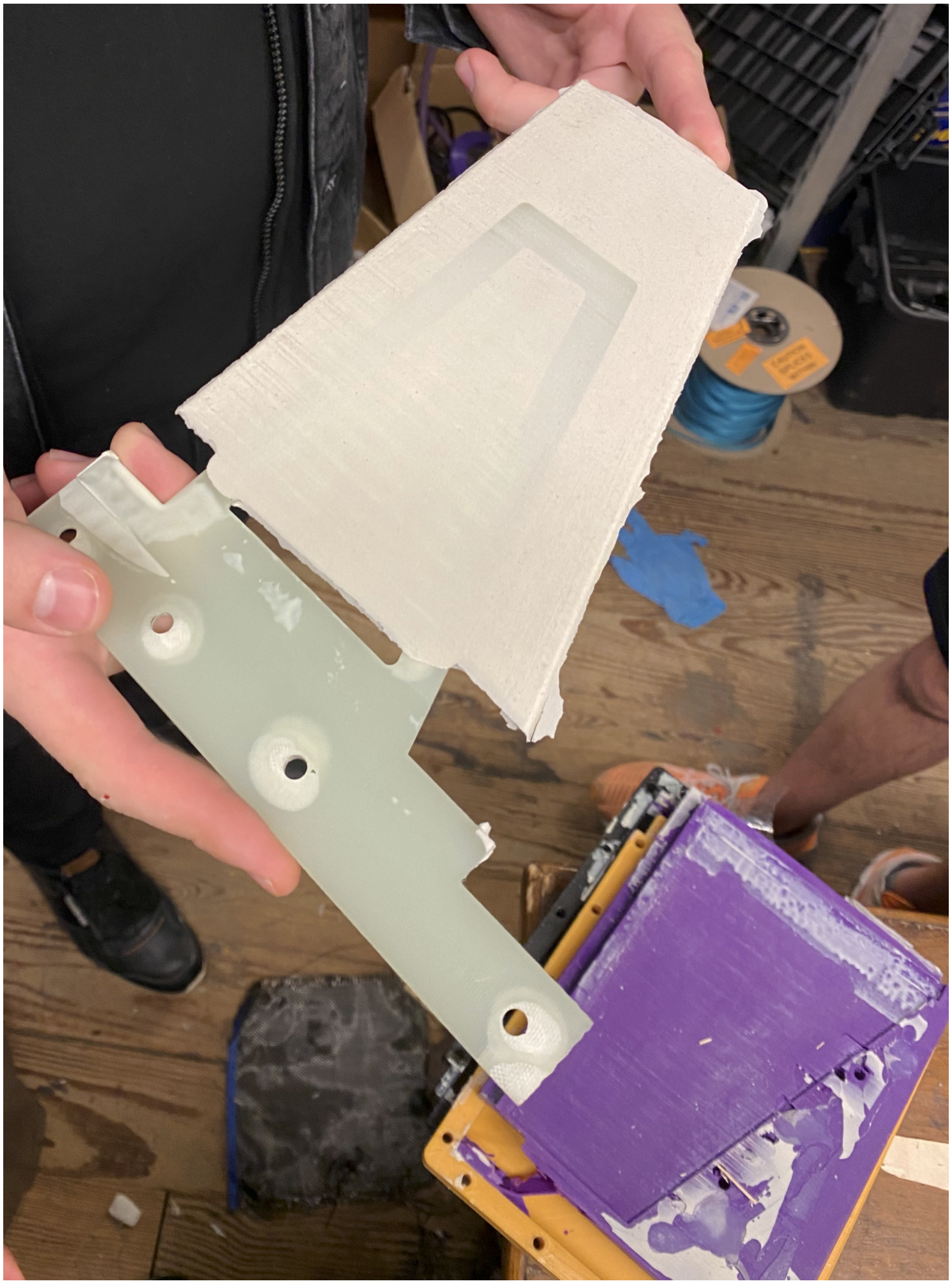


Figure 3.1.5.4.1: Unprocessed Proof-of-Concept Fin and Mold

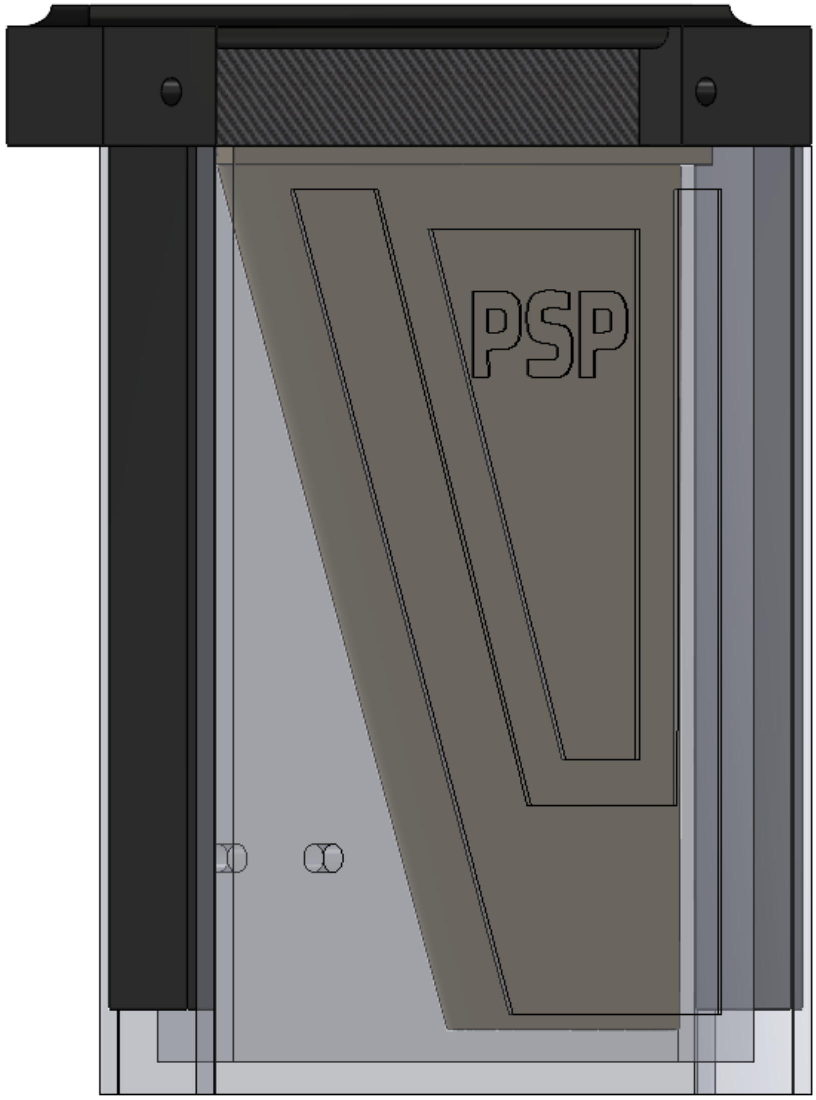


Figure 3.1.5.4.2: Silicone Mold Apparatus

A fiberglass wet layup will be added to increase the rigidity and strength of the fin. The proof-of-concept fin was overlaid with fiberglass. There were areas of separation and air pockets between the resin shell and the fiberglass. To eliminate this separation, the resin shell will be sprayed with adhesive before overlaying the fiberglass fabric. This will allow the fabric to remain stationary while the fiberglass is impregnated with resin. This results in fewer air pockets forming and, as a result, less separation.

Figure 3.1.5.4.3: Fiberglass Overlaid Fin

Figure 3.1.5.4.4: Fiberglass Overlay Separation

3.1.5.5. Nosecone

The nose cone is being 3D printed, which is the driving factor for most of the design considerations being made for manufacturing. However, some considerations are also made concerning the fiberglass layup.

The nose cone will be printed entirely on team-owned 3D printers. This will allow rapid printing, re-printing, and iteration should the need arise. Relying on personal printers allows for shorter lead times and allows for more focus on the design.

The nose cone is split into three independent sections. Although all three of these sections will be permanently adhered using epoxy, they are separated to ease manufacturing efforts. Each section can be independently printed. The full nose cone assembly would take well over three days to print as one piece. Splitting these sections up allows for modularity and makes printing failures less severe.

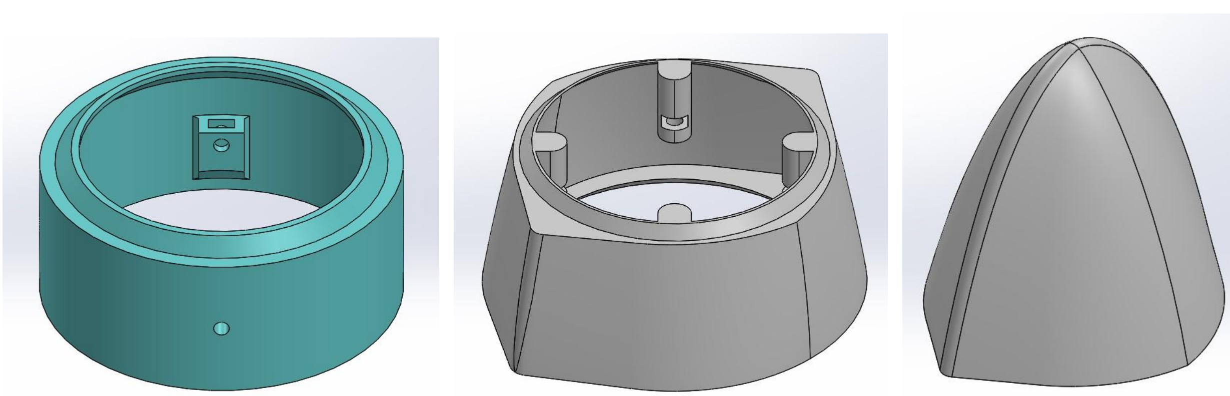


Figure 3.1.5.5.1: Independent nose cone sections: coupler, aft nose cone section, forward nose cone section, respectively.

Furthermore, the overall design of the nose cone heavily utilizes 45° angles. This decision is also made regarding 3D printing and decreasing manufacturing time. Support material, used to support overhangs in 3D prints, is required for angles larger than 45°. Support material adds tremendously to manufacturing time. By incorporating 45° angles in place of overhangs in as many locations as possible, print time for each of the three sections can be decreased significantly.

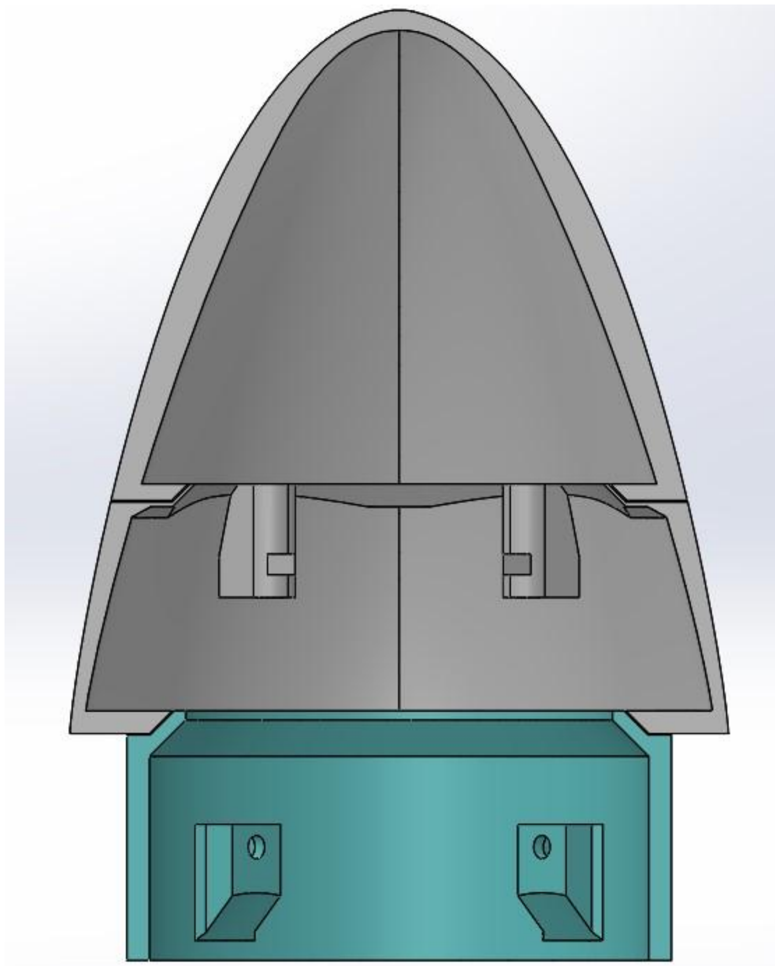


Figure 3.1.5.5.2: Cross section of nose cone demonstrating angles

The blended body was created to increase the manufacturability of the fiberglass layup. By removing any sharp corners from the design, the fiberglass sheets will be able to lay on the nose cone more easily, decreasing the likelihood of any detachments or roughness on the surface of the nose cone.

3.1.5.6. Airframe

Each part of the airframe is made out of G12 fiberglass which is easily manufactured using drills and rotary tools. In order to manufacture the airframe, the team modeled and 3D printed jigs to aid in the placement of the holes in the different components. For both the fins-to-airframe and the avionics bay-to-airframe connections, Solidworks was used to design a sleeve that would fit over the outside of the airframe to allow easy drilling of screw holes and cutting of the slots for the fins. Since the slots for the fins are cut using a dremel saw, the jig must be thicker so the saw wouldn't cut through the jig when trying to cut the slots. The holes in the jig to drill the screw holes were easily made and drilled through when manufacturing the airframe. To align the holes of the avionics bay to the upper recovery, a jig with a lip will be used to hold the upper recovery frame from moving. At the same time, holes will be drilled through the upper recovery and avionics bay, where the screws will hold them in place.

3.1.6. Integrity of Design

3.1.6.1. Fin Shape and Style

3.1.6.1.1. Fin Flutter

Since PDR, the fins have been in testing to verify their strength and flutter properties. The test fin is thinner than the full-scale design, adding to the safety factor for each test run. Using the principles of aeroelasticity, the fin flutter was modeled using a simple 2-degree-of-freedom dynamic model of the fin. The fin was assumed to be an idealized model of a straight cantilever fin. The bending stiffness of the fin was approximated as a bending spring, while the torsional stiffness of the fin was approximated as a torsion spring. There are typically two modes of motion, bending and twisting. This approximated method foregoes all other modes of motion and solely focuses on the main two. To gather data, the fin was mounted securely to a test bench. To test for the bending stiffness, the fin was tip-loaded with 7 lbs. Using cameras, the vertical displacement of the fin was measured to be 0.572". To test for the torsional stiffness, the fin was loaded with 7 lbs on an attached bar of length 11". Using cameras, the angular displacement was measured to be 9.2°. To test the yield bending load, the fin was tip-loaded with 65 lbs (the maximum weight available at the time of testing). The fin had a vertical displacement of 3.622"; however, there was no plastic deformation.

The data collected for the bending and torsional stiffness was used to model the two modes of motion as springs. The spring stiffnesses were found using the following equations:

$K_H = \frac{P_H}{\delta_t}$ *Equation 3.1.6.1.1.1: Bending Spring Stiffness*	$K_\alpha = \frac{P_\alpha d}{\theta}$ *Equation 3.1.6.1.1.2: TorsionSpring Stiffness*

The spring stiffnesses were applied to the following equation:

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

Equation 3.1.6.1.1.3: Determinant Equation

Where m is the mass of the fin, ω represents the harmonic motion of the fin, I_α is the polar inertia of the fin, $C_{L\alpha}$ is the lift curve slope, q is the dynamic pressure, x_{ac} is the distance from the center of lift to the elastic axis, S is the cross-sectional area, and S_α is the coupling inertia. To solve for the harmonic motion, ω, the equation can be rearranged as:

$A\omega^4 + B\omega^2 + C = 0$		
$A = mI_\alpha - S_\alpha^2$	$B = S_\alpha C_{L\alpha} qS + mC_{L\alpha} qSx_{ac} - mK_\alpha + I_\alpha K_h$	$C = K_h K_\alpha - K_h C_{L\alpha} qSx_{ac}$

Equation 3.1.6.1.1.4: Rearranged Determinant Equation

The motion becomes sinusoidal (unstable), when $B^2 < 4AC$. The only dynamic variable is the dynamic pressure, q. The dynamic pressure is defined as $q = \frac{1}{2}\rho V^2$ where ρ is the air density and V represents the air velocity. Assuming the air density to be constant leads to the air velocity determining the stability. The velocity at the flutter point (when q causes $B^2 = 4AC$) is the flutter speed. This is the speed where any increase will result in an unstable increasing amplitude motion. For the proof-of-concept fin, this flutter speed is much greater than the maximum speed the launch vehicle will achieve, leading to minimal threat of fin flutter.

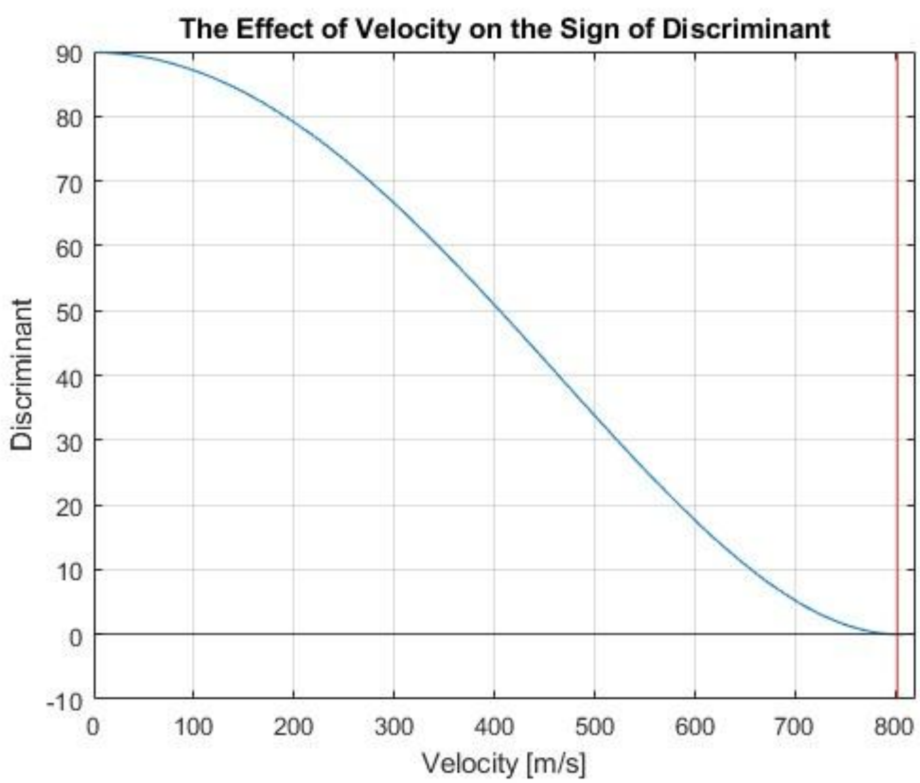


Figure 3.1.6.1.1.1: Plot of Discriminant versus Velocity

It is important to note that this analysis method is very primitive. This method is sensitive to the spring constants. The fiberglass insert, resin shell, and fiberglass overlay are all very stiff on their own. When combined, the fin is highly rigid, leading to large spring constant values (bending spring constant of 2143.16048 N/m and torsion spring constant of 54.1809 N-m/radian). These large values will impact the overall accuracy of the analysis. Ground vibration testing would provide a much better understanding of the flutter mechanics of the fins. However, the results of this analysis can be used to show that the flutter will not negatively affect the rocket's stability.

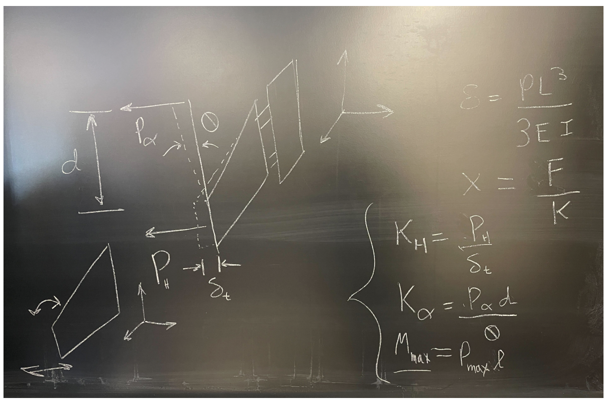


Figure 3.1.6.1.1.2: Modeling Diagram

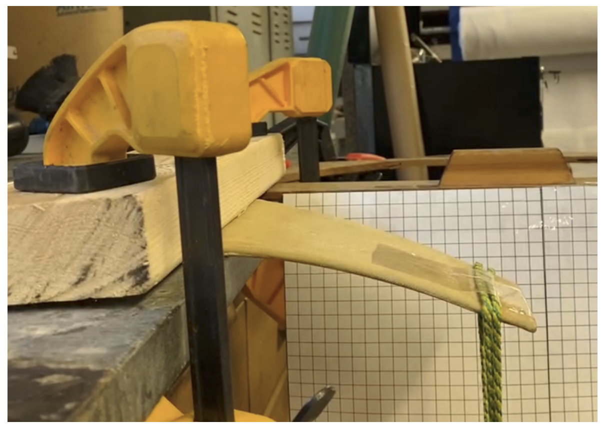


Figure 3.1.6.1.1.3: Yield Bending Load Test

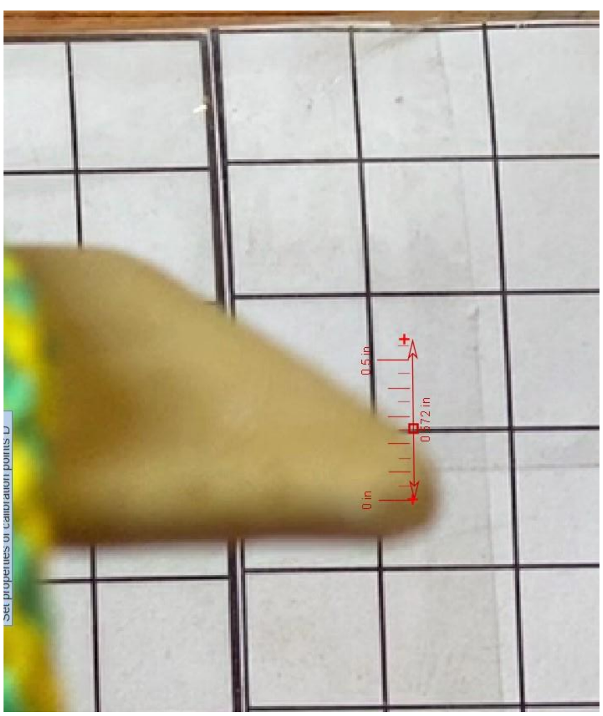


Figure 3.1.6.1.1.4: Bending Spring Displacement

Figure 3.1.6.1.1.5: Torsion Spring Displacement

3.1.6.1.2. Airfoil Design

As stated in PDR, the airfoil is based on the NACA 0006 design with modifications to improve manufacturability and survivability. This was done by blunting the trailing edge to maintain a reasonable minimum thickness of .1”, while also moving the first point of maximum thickness to 25% chord and extending it for 25% of the cord. These changes still allow the fins to take advantage of the aerodynamic properties of a NACA 0006 airfoil.

3.1.6.1.3. ANSYS Theory

To analyze a structure, ANSYS generates a mesh composed of very small elements to represent the structure's geometry. To determine failure, ANSYS utilizes the von Mises stress criterion. ANSYS first calculates the principal stresses for each element, and uses them to calculate the von Mises stress as follows:

$$\sigma_{VM} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]}$$

The von Mises stress criterion is then applied, which states that yielding of a ductile material occurs when the von Mises stress is greater than or equal to the yield stress under simple tension:

$$\sigma_{VM} \geq \sigma_Y$$

Permanent deformation occurs if the von Mises stress criterion is satisfied, indicating that the failure condition is also met.

3.1.6.1.4. Fin FEA

Before conducting Finite Element Analysis, the team needed to know the properties of the materials from which the fin is made (fiberglass and epoxy resin). The properties can be found online, but they vary from source to source. Data obtained in section 3.1.6.1.1 was used to prove the simulation's accuracy. The first model was created based on the experiment. The geometry consists of a fin insert and fin shell. In the simulations, the fin insert has the parameters of G10 fiberglass, and the shell has the parameters of epoxy resin. The force is applied at the same point as in the experiment.

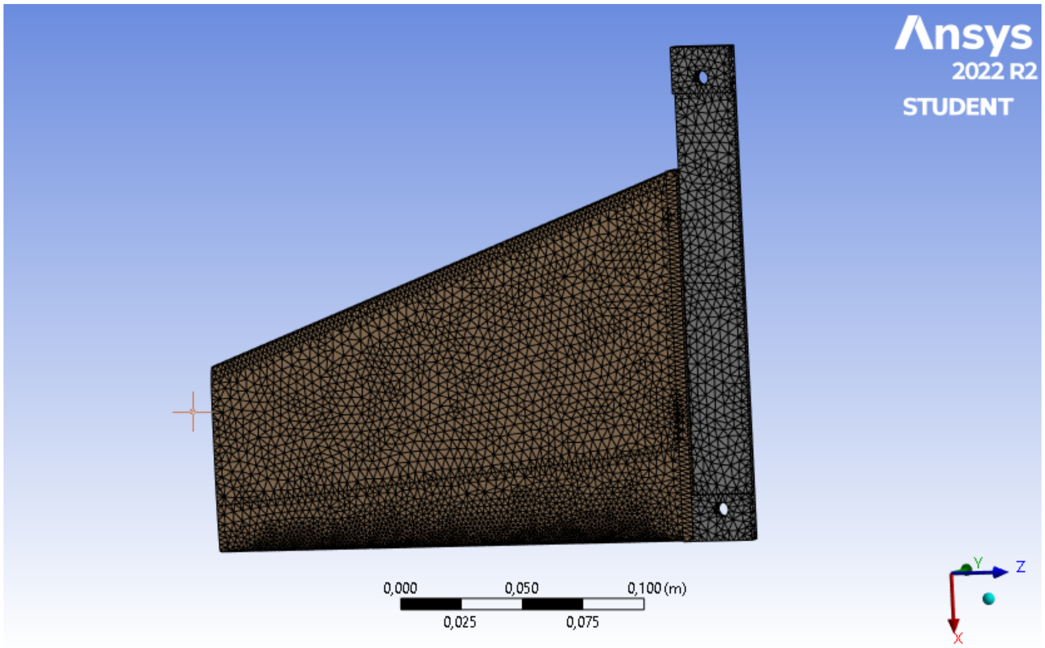


Figure 3.1.6.1.4.1: Mesh of the geometry

In the experiment, the fin bent by 3” under a load of 65lb. In the simulations, the fin bent by 1.7”, which is less than the value the team got from the experiment. However, the test fin used in the experiment is thinner by 33% compared to the fin model used in simulations. And because the deformation corresponds to the square of thickness, the predicted deformation for a thicker fin should be less in 1.69 time which is approximately 1.77”. This value is similar to what the team got from the simulations, supporting the materials' chosen parameters.

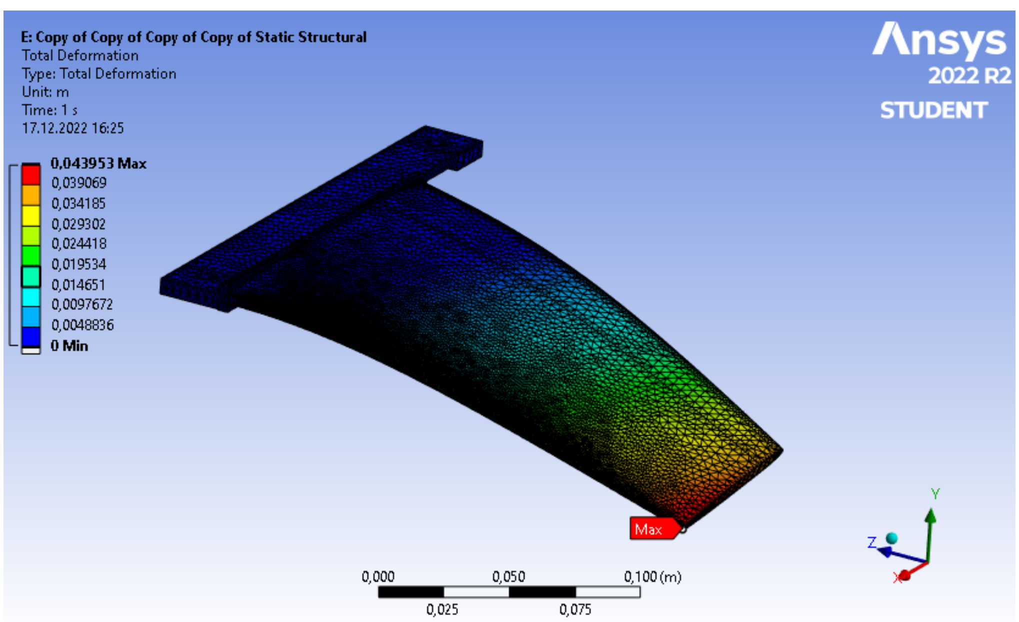


Figure 3.6.1.4.2: The results for simulation of conducted experiment

The next 3 simulations used the same geometry. Young’s modulus for the G10 fiberglass is 2e6 psi, and Young’s modulus for the epoxy resin is 1.5e6 psi. The first model simulates the pressure on the fin from the air during flight. The maximum pressure during the flight is 116.98 KPa, calculated using Bernoulli's equation at STP and v1 = 528.2ft/s.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$P_2 = P_1 + \frac{1}{2}\rho v_1^2$$

The configuration of the model is shown below.

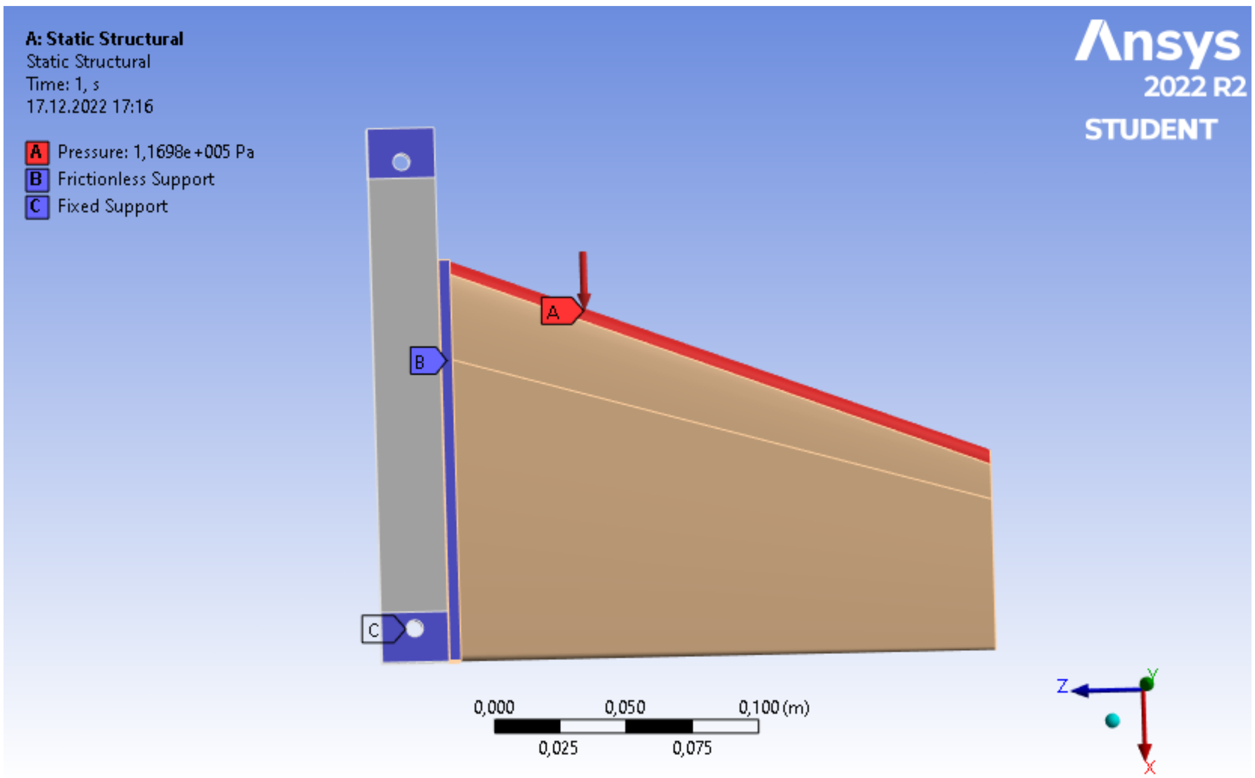


Figure 3.6.1.4.3: The configuration of the model

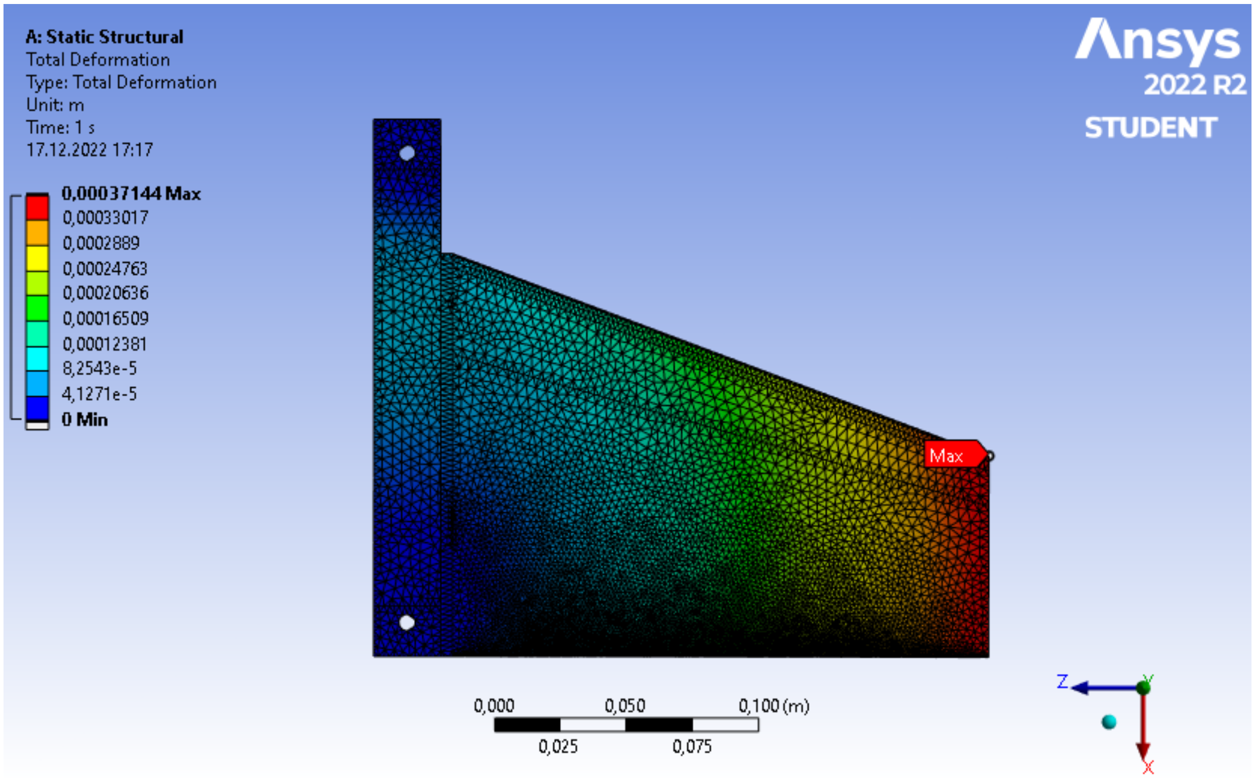


Figure 3.6.1.4.4: The deformation of the fin during the flight.

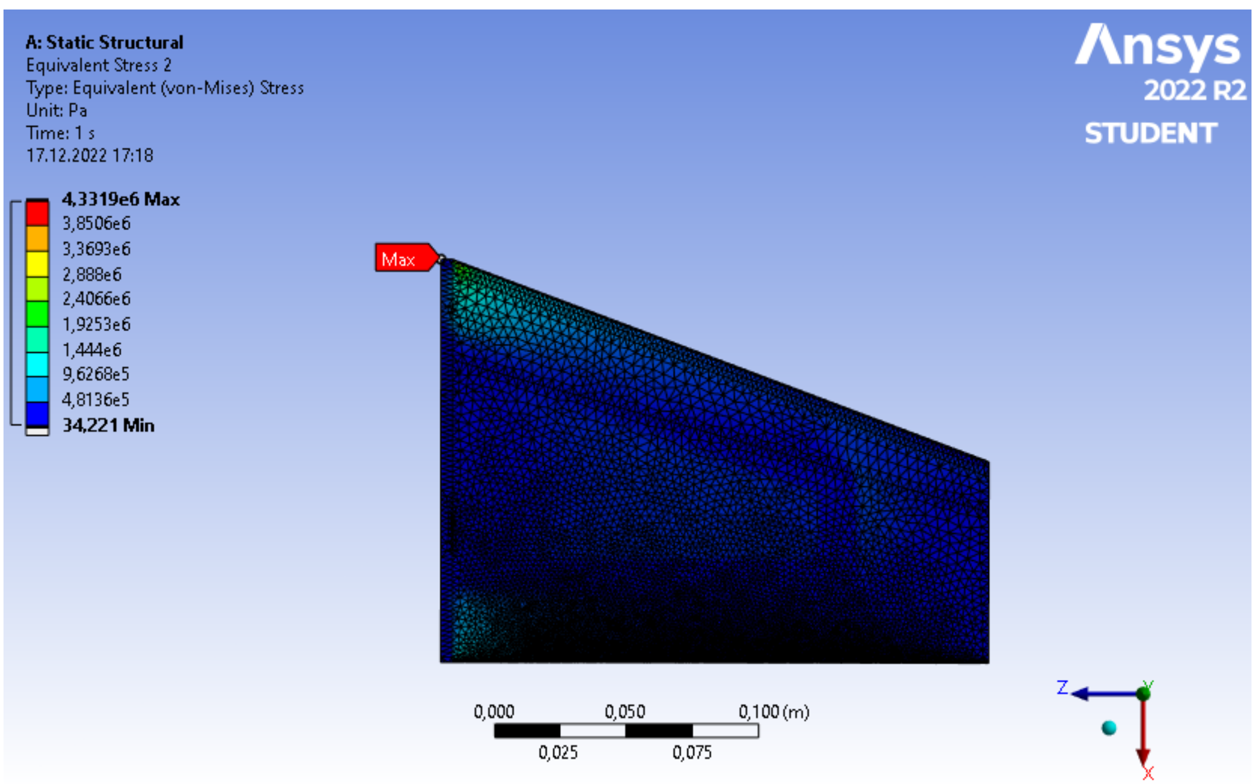


Figure 3.6.1.4.5: The stress of the fin shell during the flight.

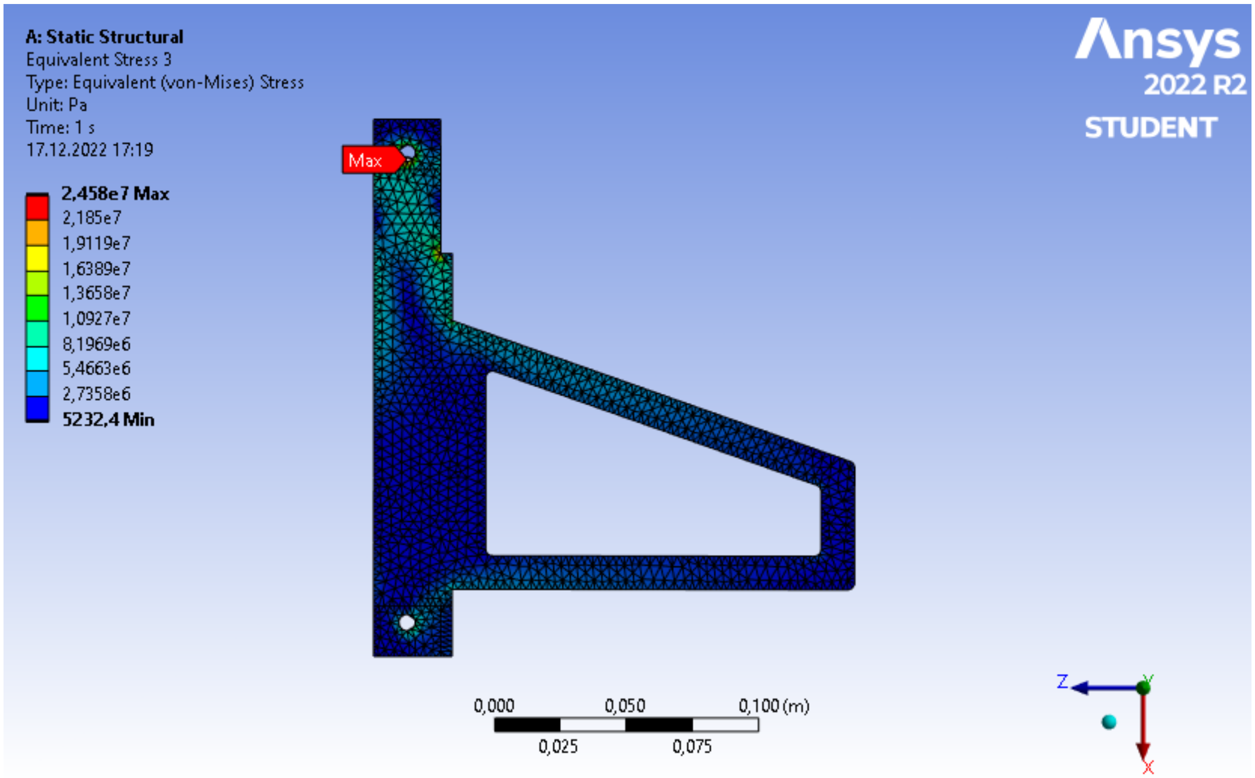


Figure 3.6.1.4.6: The stress of the fin insert during the flight.

The maximum stress in the simulations for the fin insert is 24.58 MPa which gives a safety factor of 16 with a Flexural strength of 392.5 MPa for G10 fiberglass. The Flexural strength for epoxy resin is 75.8 MPa, and the maximum stress is 4.33 MPa which gives the safety factor of 17.5. The Poisson's ratio for G10 fiberglass is 0.127 and for epoxy resin is 0.31.

The next model simulates landing directly on the fin. The landing velocity is 4.63 m/s, the landing mass is 6.576 kg, and the impact time is 0.1 s; using equation $F = \frac{mv}{t}$, the team calculated a landing force of 304 N. In this simulation, the force is applied to the side of the fin.

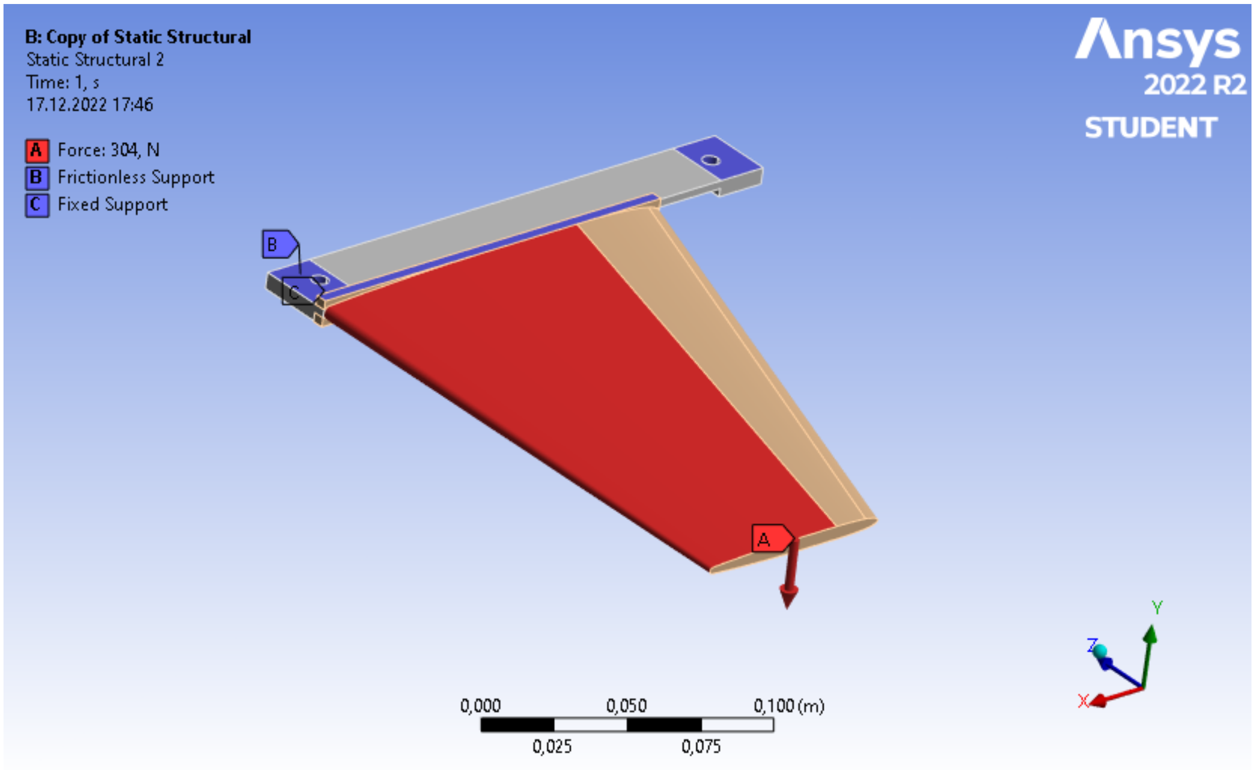


Figure 3.6.1.4.7: The configuration of the model.

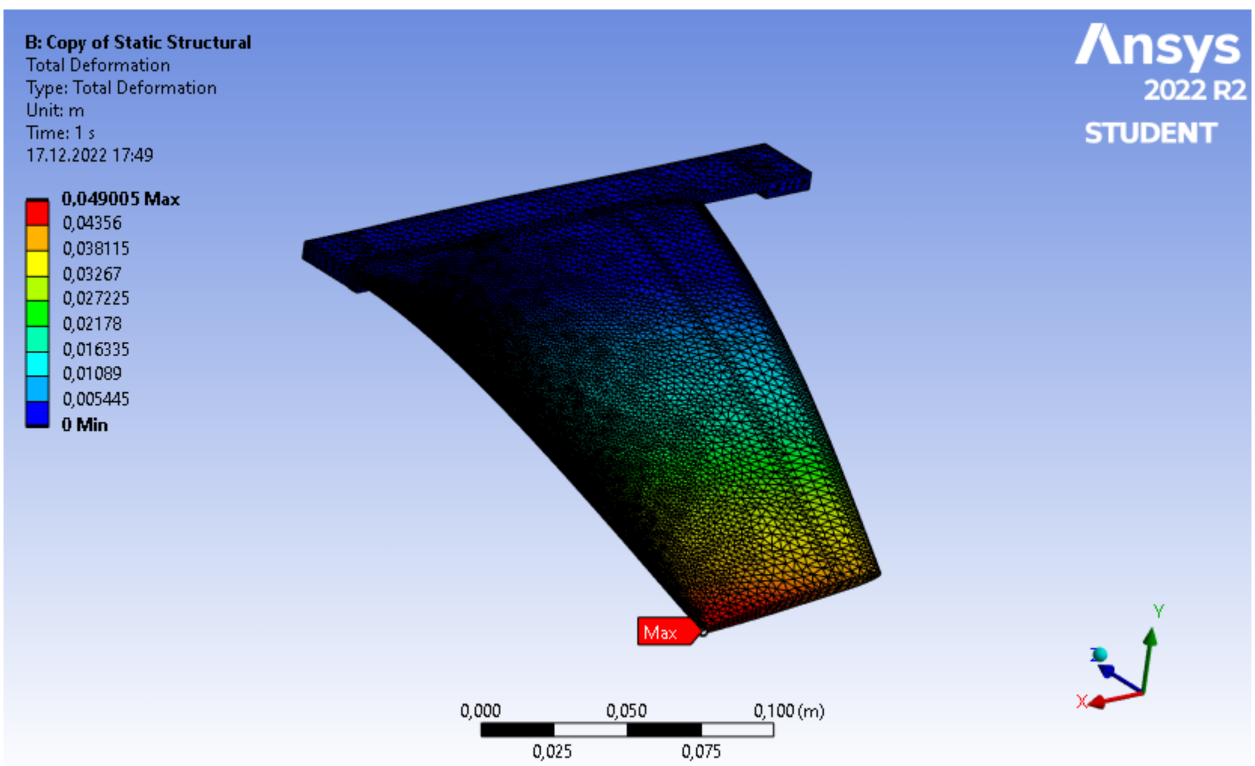


Figure 3.6.1.4.8: The deformation of the assembly from the force applied to the side.

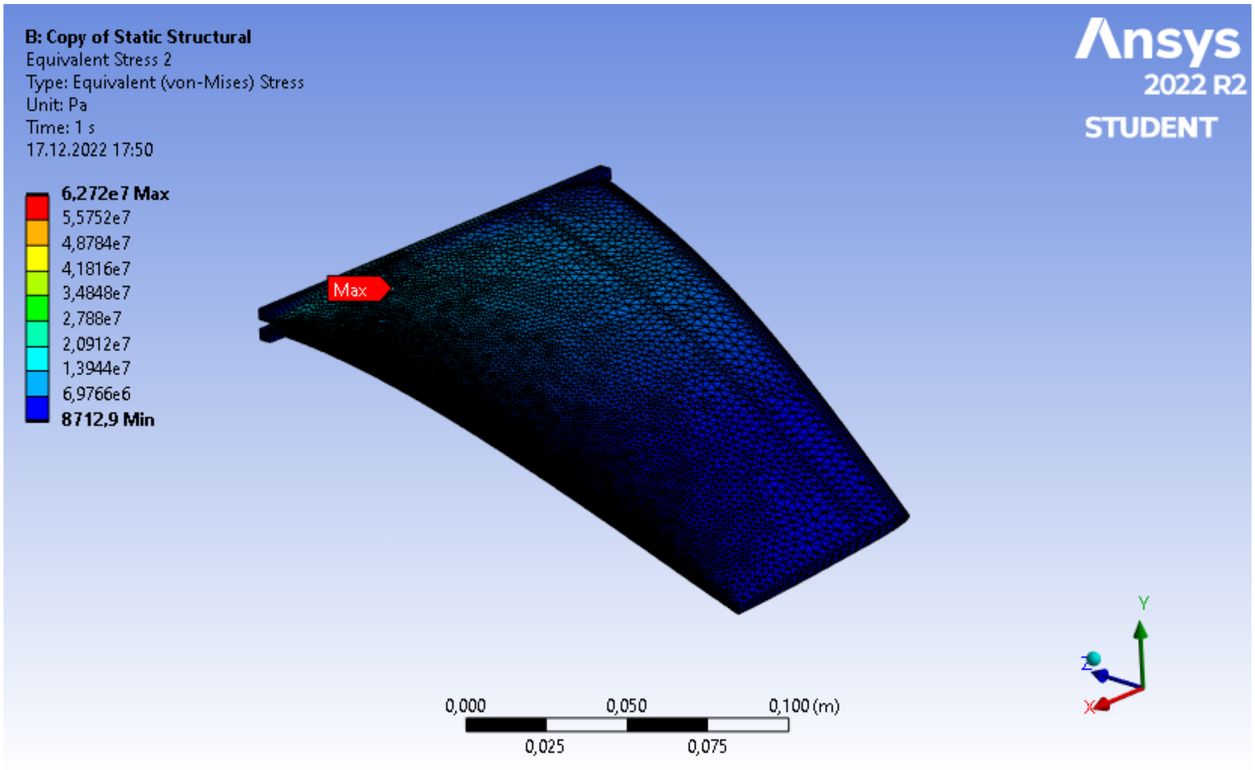


Figure 3.6.1.4.9: The stress of the fin shell.

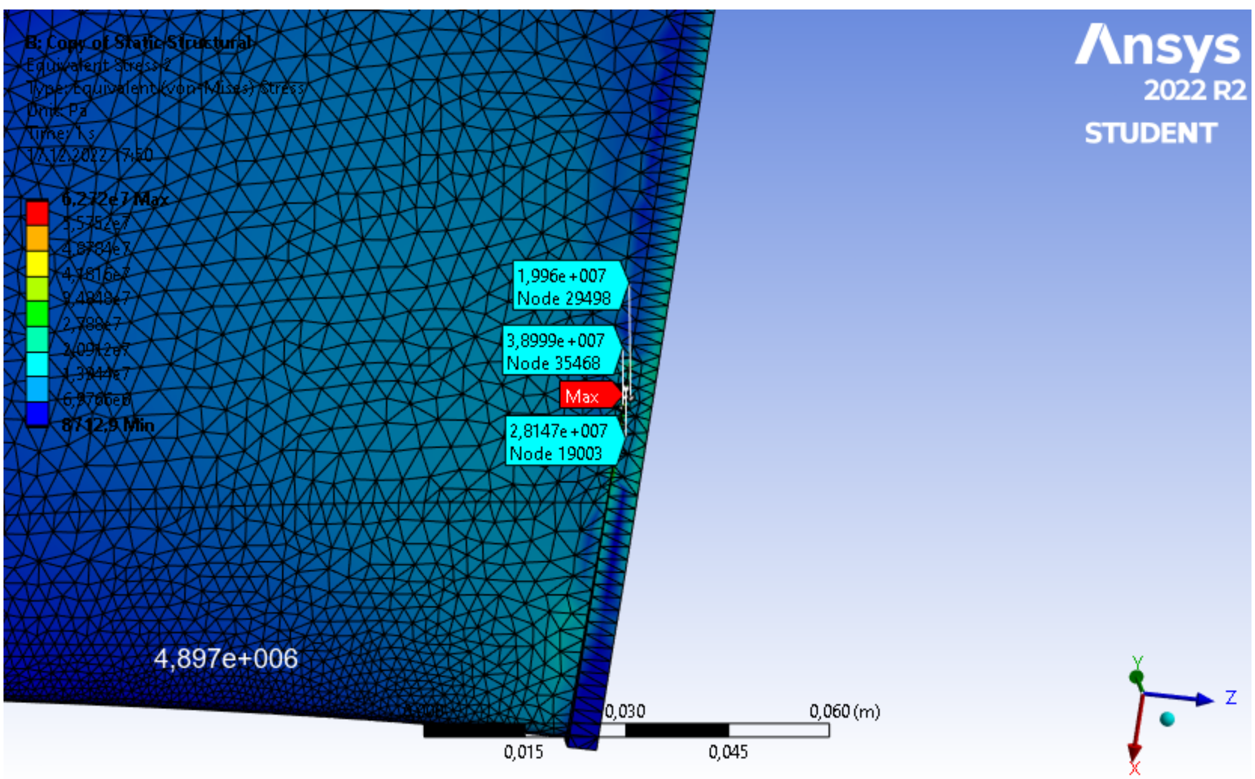


Figure 3.6.1.4.10: The stress of the fin shell closeup

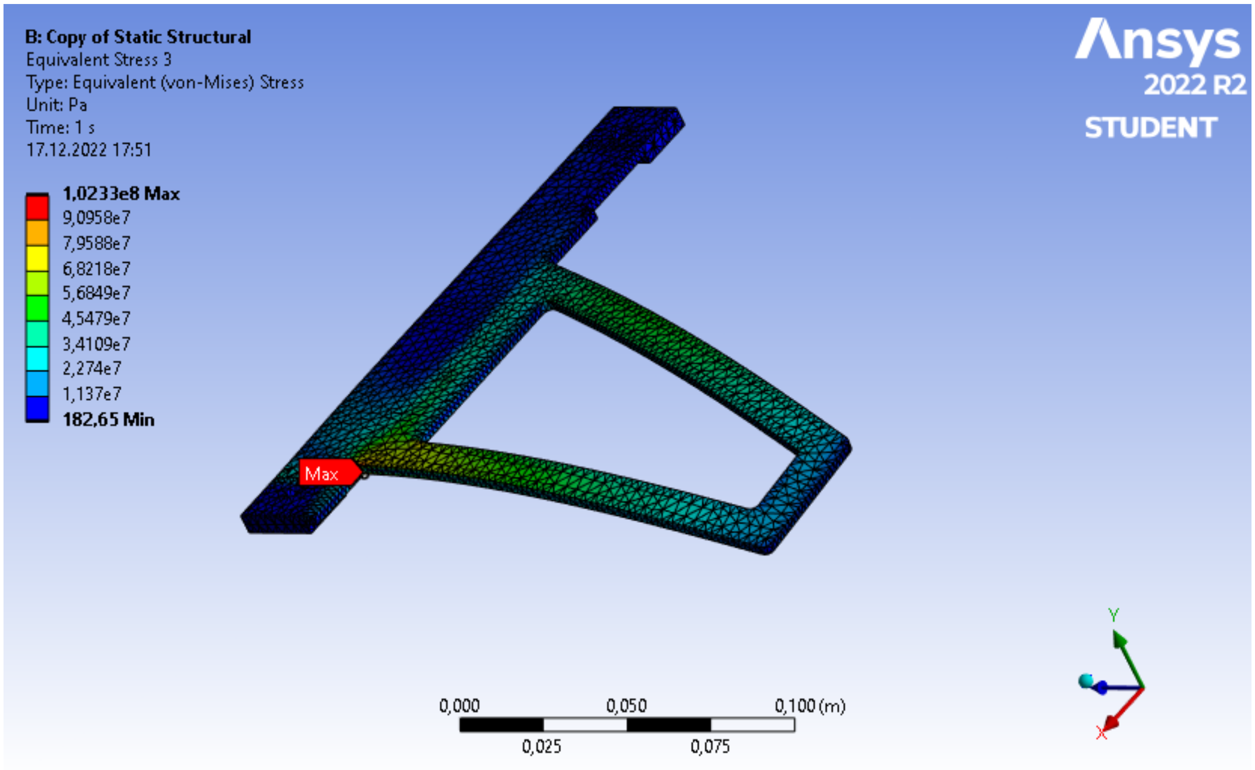


Figure 3.6.1.4.11: The stress of the fin insert.

The maximum stress for the fin insert is 102 MPa which gives a safety factor of 3.85. The maximum stress for the fin shell of 62.7 MPa gives a safety factor of 1.2. However, this small safety factor is only at one, non-critical, point on the fin, with all other points around it having a safety factor greater than 2. Moreover, this model simulates a very unlikely event in which all the force is applied to one fin in a short amount of time.

The final module simulates the force applied to the side of the fin. The magnitude of the force is the same as in the previous model.

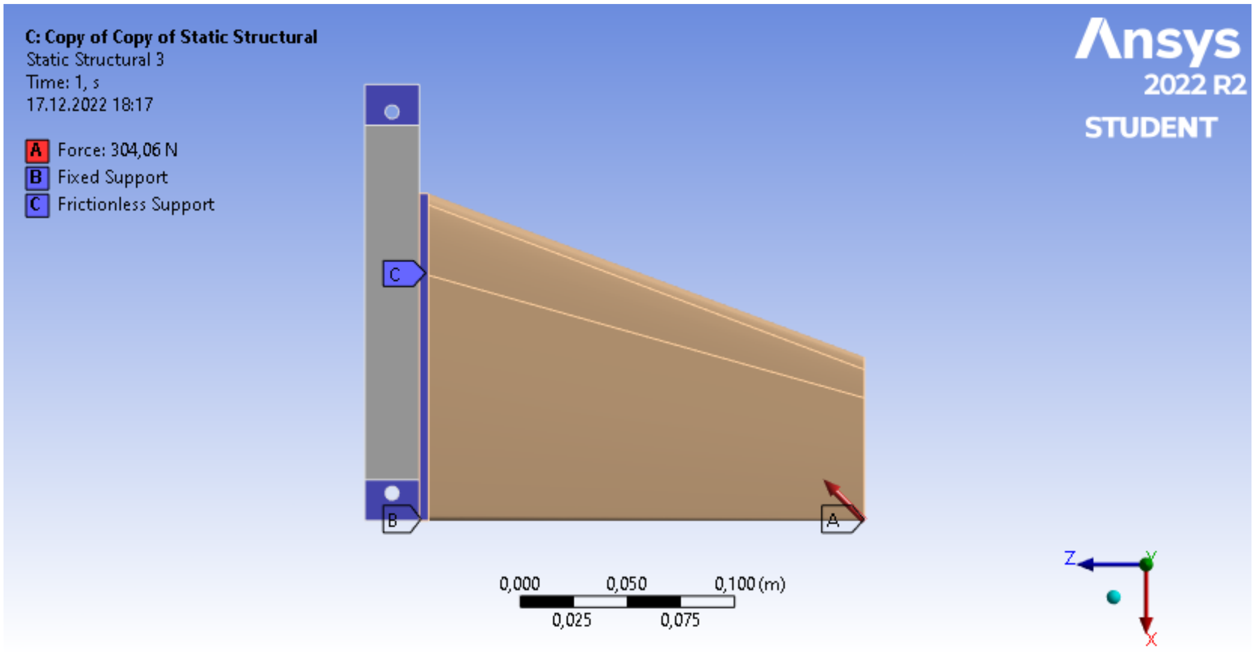


Figure 3.6.1.4.12: The configuration of the model.

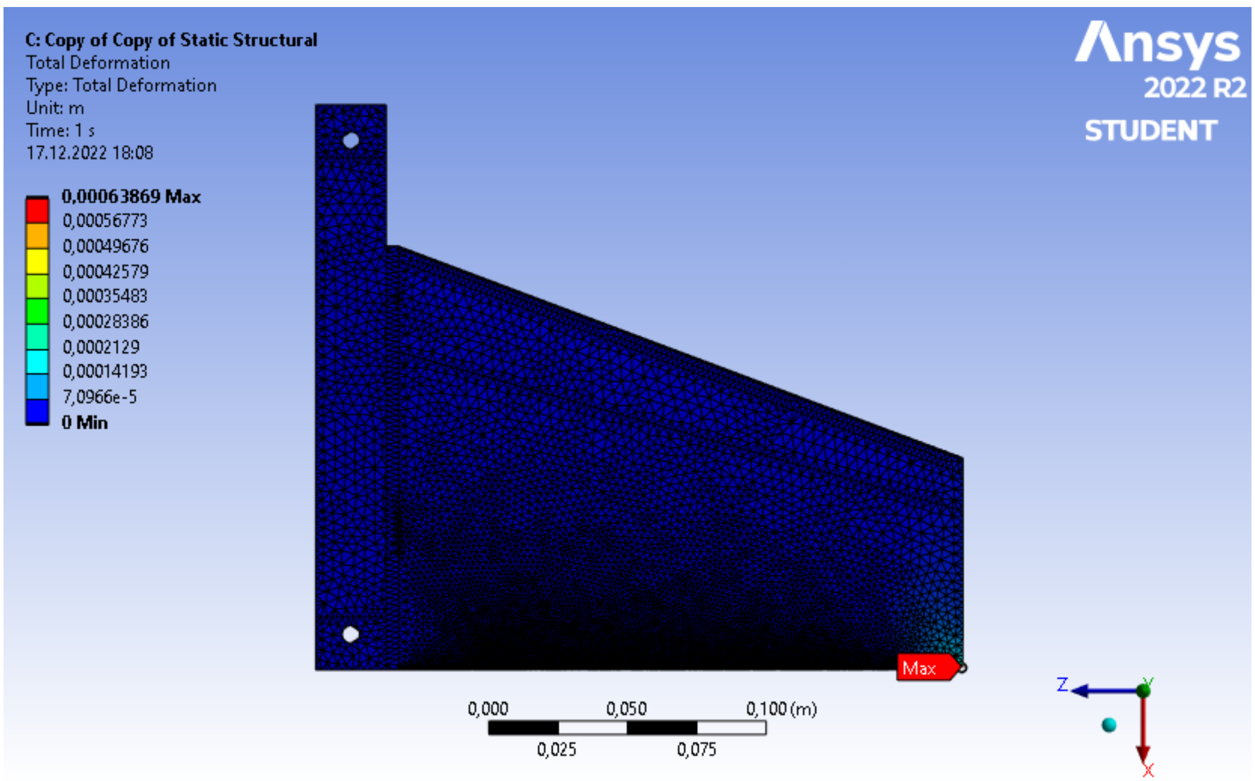


Figure 3.6.1.4.13: The deformation of the assembly from the force applied to the corner.

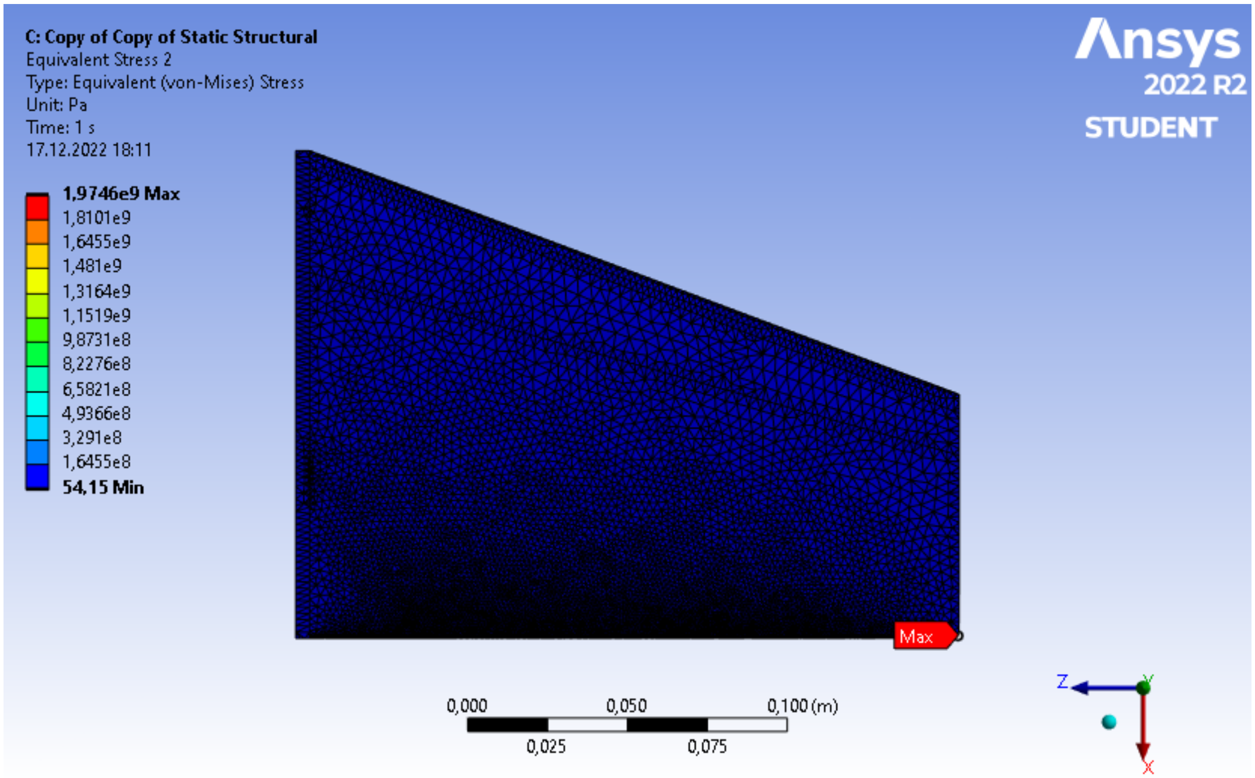


Figure 3.6.1.4.14: The stress of the fin shell.

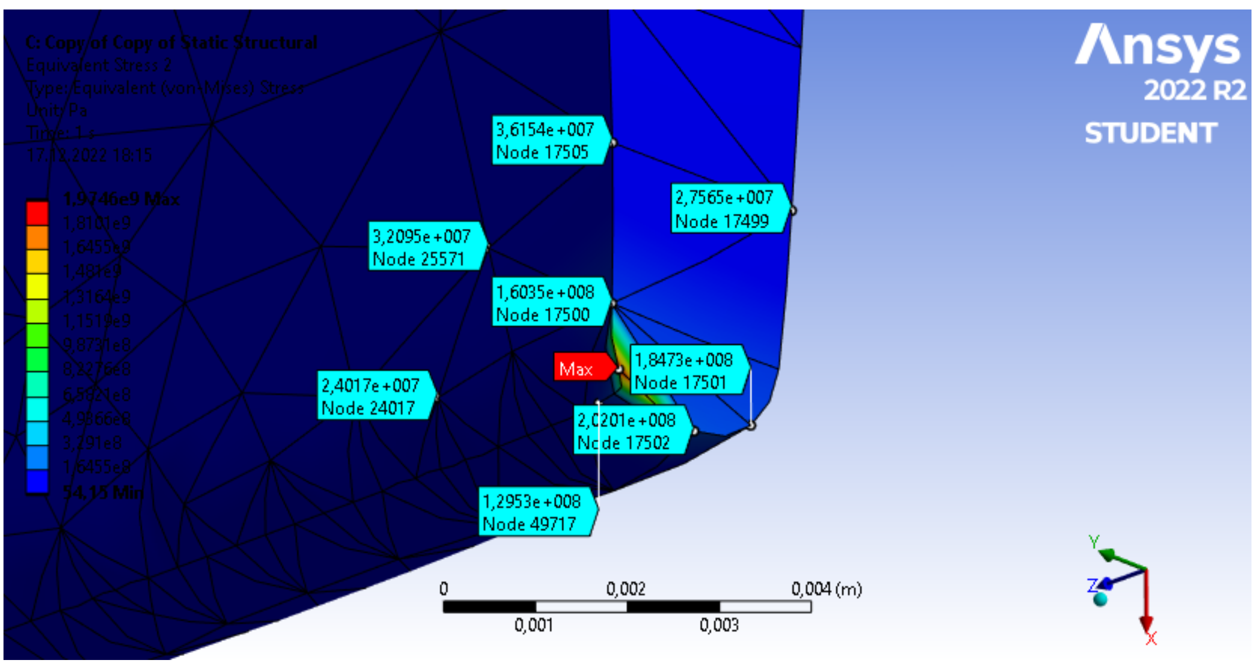


Figure 3.6.1.4.15: The stress of the fin shell closeup.

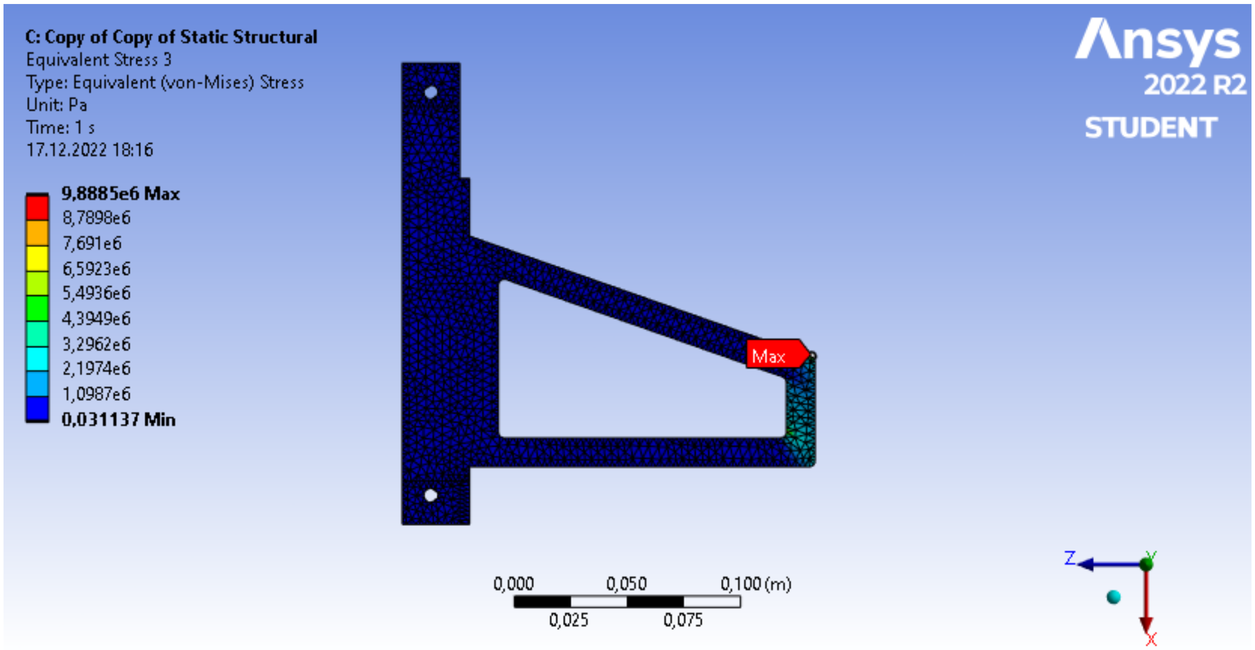


Figure 3.6.1.4.16: The stress of the fin insert.

The maximum stress in the simulation for the fin insert is 9.89 MPa which gives the safety factor of 39.7. The maximum stress for the fin shell is much higher than the Flexural strength of the epoxy resin. However, high stress occurs only at the point where the force is applied. The whole insert and other parts of the shell have a safety factor of more than 2 which means that the fin won't break completely during this impact, rather than will have small deformation or cracks at the corner.

The simulations proved that the fins the team designed can withstand expected loads during the flight and landing. Even though the fin shell has a small safety factor at some point, the fiberglass cover, which is not included in these simulations, should reinforce the fin and significantly improve the safety factor.

3.1.6.2. Material Selection

3.1.6.2.1. Motor Fin Support Structure

Subteam Needs	Technical Needs	Weight	304 STAINLESS STEEL	AL 6061-T6	AL 7075
High Strength	Yield Strength (psi)		30,000	35,000	73,000
		1	$(1)\frac{30,000}{100,000} = .3$	$(1)\frac{35,000}{100,000} = .35$	$(1)\frac{73,000}{100,000} = .73$
Low Weight	Mass Density		0.29	0.1	0.1

	(lb/in³)				
		2	$(2)\frac{0.29}{0.5} = 1.16$	$(2)\frac{0.1}{0.5} = .4$	$(2)\frac{0.1}{0.5} = .4$
Low Cost	Cost of 6"x6" plate, 1 ± 0.125" thick (USD)		$75.04	$40.36	$85.78
		6	$(6)(1 - \frac{75.04}{100}) = 1.50$	$(6)(1 - \frac{40.36}{100}) = 3.60$	$(6)(1 - \frac{85.78}{100}) = .85$
Yield Strength / Mass Density Ratio	Yield Strength / Mass Density Ratio (in)		103,960.62	358,813.57	715,686.27
		3	$(3)\frac{103,960.62}{500,000} = 1.89$	$(3)\frac{358,813.57}{500,000} = 2.16$	$(3)\frac{715,686.27}{500,000} = 4.3$
Manufacturability	–	0.5	Poor	Good	Excellent
			$(.1)(.5) = .05$	$(.75)(.5) = .38$	$(1)(.5) = .5$
Totals			**4.90**	**6.89**	**6.78**

Subteam Need	Weight
High Strength	1
Low Weight	2
Low Cost	6
Yield Strength / Mass Density Ratio	3
Manufacturability	0.5

Three common alloys were chosen as contenders for material of the MFSS–each of which are widely used for manufacturing structural components. To determine the optimal choice, the team created a decision matrix considering the material properties of each product. PSP sought alloys with high strength, low weight, and low cost. Each of these properties was assigned a weight so that the materials could be quantitatively evaluated by applying a normalizing function to each value and multiplying the resulting value by the property's assigned weight. Manufacturability was also a small consideration because an ideal material would minimize construction time. The greatest weight by far was given to the purchase cost because all the materials on the decision matrix provide the support required to ensure a structurally sound MFSS. Therefore, only a substantial increase in stability would justify a large increase in cost. The second greatest weight was given to the yield strength by mass density ratio because this metric assesses the amount of strength per unit of weight, with higher values displaying which material provides the optimal balance. And ideally, the team wanted the least weight and the most strength possible.

3.1.6.2.2. Fin

	Viscosity	**Specific Volume**	**Compressive Strength**	**Hardness**		**Scale**	
Weight	**5**	**1**	**2**	**2**	Scores	1-2	Poor
EPOXACAST 670 HT	**10**	**7**	**8**	**10**	**93**	3-4	Below Average
EPOXACAST 650 HT	7	4	10	6	71	5-6	Average
EpoxAmite 101	3	9	6	9	54	7-8	Above Average
Plasti-Paste EPOXY	1	10	2	8	35	9-10	Excellent

The design demands high levels of viscosity, specific volume, hardness, and compressive strength. The price points of the four chosen resin alternatives were similar, so this was not a factor in the decision-making process. In the decision matrix, EpoxAcast™ 670 HT won by a considerable margin based on the designed specifications.

3.1.6.2.3. Airframe/Bulkheads

Subteam Needs	**Technical Needs**	**Weight**	**G12/G10 Fiberglass**	**Carbon Fiber**	**304 Stainless Steel**
High Strength	Yield Strength (psi)		30,000	180,000	30,000
		1	$(1)\frac{30,000}{200,000} = .15$	$(1)\frac{180,000}{200,000} = .9$	$(1)\frac{30,000}{200,000} = .15$
Low Weight	Mass Density (lb/in^3)		.065	.069	.29
		2	$(2)(1 - \frac{.065}{.5}) = 1.74$	$(2)(1 - \frac{.069}{.5})$ =1.72	$(2)(1 - \frac{.29}{.5})$ =.84
Low Cost	Cost per pound (USD)		$10.58	$15.00	$2.12
		6	$(6)(1 - \frac{10.58}{100}) = 5.36$	$(6)(1 - \frac{15.00}{100}) = 5.10$	$(6)(1 - \frac{2.12}{100}) = 5.88$
Yield Strength / Mass Density Ratio	Yield Strength / Mass Density Ratio (in)		461,538.46	2,608,695.65	103,448.28
		2	$(2)\frac{461,538.46}{1,000,000} = .93$	$(2)\frac{2,608,695.65}{1,000,000} = 5.22$	$(2)\frac{103,448.28}{1,000,000} = .21$

Manufacturability	-		Good	Poor	Poor
		1	(1)(.75)=.75	(1)(.1)=.1	(1)(.1)=.1
Totals			8.78	13.04	7.18

Subteam Need	Weight
High Strength	1
Low Weight	2
Low Cost	6
Yield Strength / Mass Density Ratio	2
Manufacturability	1

To determine a suitable material for the airframe, the team created a decision matrix with the needs of the team: high strength, low weight, low cost, yield strength per mass density ratio, and manufacturability. The purpose of the airframe is to protect payload components by withstanding the forces of launch and descent while minimally limiting the ability of the launch vehicle to complete mission parameters by being low-weight. The team's needs were derived from achieving the purpose of the airframe. Weights given to each need were critical in determining the material for the airframe. All materials were sufficiently strong, so a low weighting was given to strength. Low weight and yield strength per mass density ratio were given moderate weights since, as stated, strength was already not an issue, so weight is more important. Manufacturability was also noted, as creating tube structures for the airframe would be necessary, and faster manufacturing is a better material quality. Price was given the greatest weight because all of the other requirements were met by each material in some capacity. Carbon fiber is by far the best choice for the airframe of the launch vehicle; however, the team has no experience working with carbon fiber and was advised against utilizing the material by the team mentor. The team is focusing on building a skillset to work with carbon fiber so that it can be considered for next year’s launch. G12/10 fiberglass is the remaining best option. The team has experience working with this material and is confident in its performance on the launch vehicle from previous launches.

3.1.6.3. Motor Mounting and Retention

3.1.6.3.1. Centering Plate FEA

For an explanation of how ANSYS works, see section 3.1.6.1.3 ANSYS THEORY.

The team decided to conduct Finite Element Analysis on the centering ring of the MFSS. This was to determine the max von Mises stress the centering ring would endure during the different flight portions. The team also decided to solve for the safety factor of the centering ring.

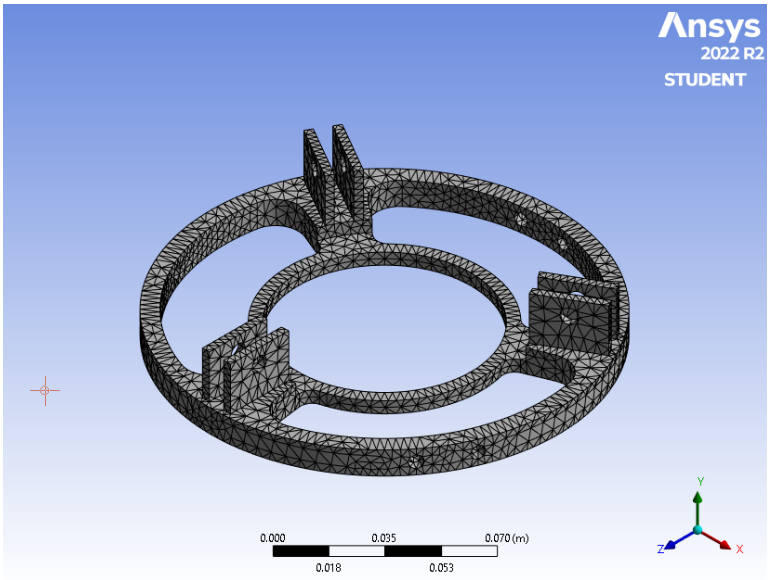


Figure 3.1.6.3.1.1 Centering Mesh

One boundary constraint was the fixed supports connecting the centering ring to the airframe. The other constraints were remote displacement supports on the inner ring and the outer ring of the centering ring. The remote displacement supports acted as roller supports, allowing the centering ring to rotate around its y-axis.

For the launch portion of the flight, a force of 1541 N was applied to the connection holes where the fins would be connected. This was because if the MFSS were not assembled correctly, the force experienced during launch would go up the fins and the fin connection points. As seen in figure Centering Plate Stress During Launch, the max von Mises stress was 3.68e7 Pa giving a safety factor of 7.46, which is high enough for the team.

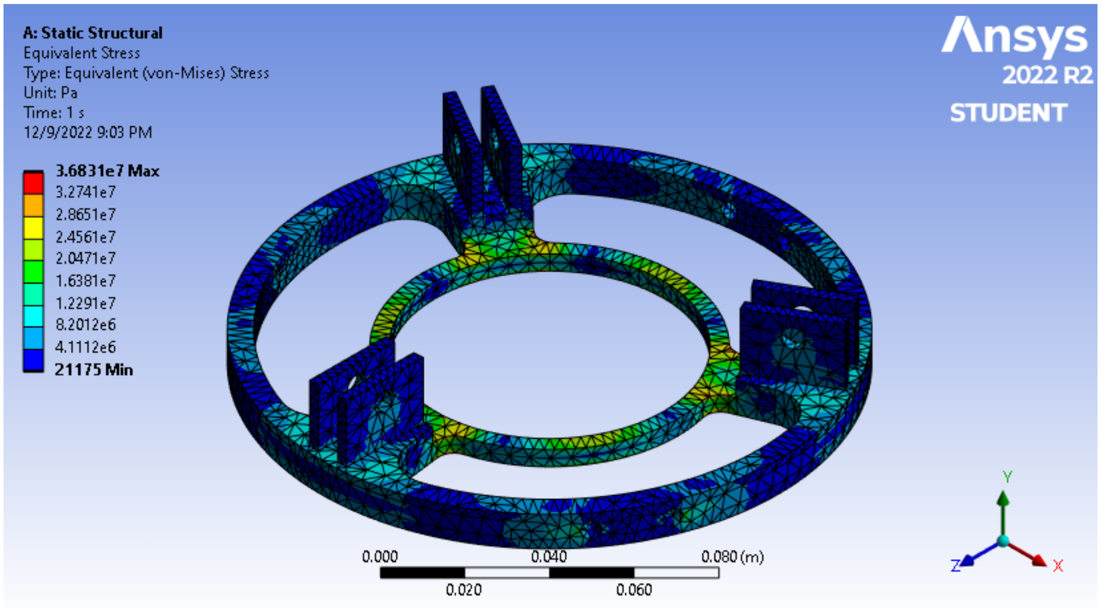
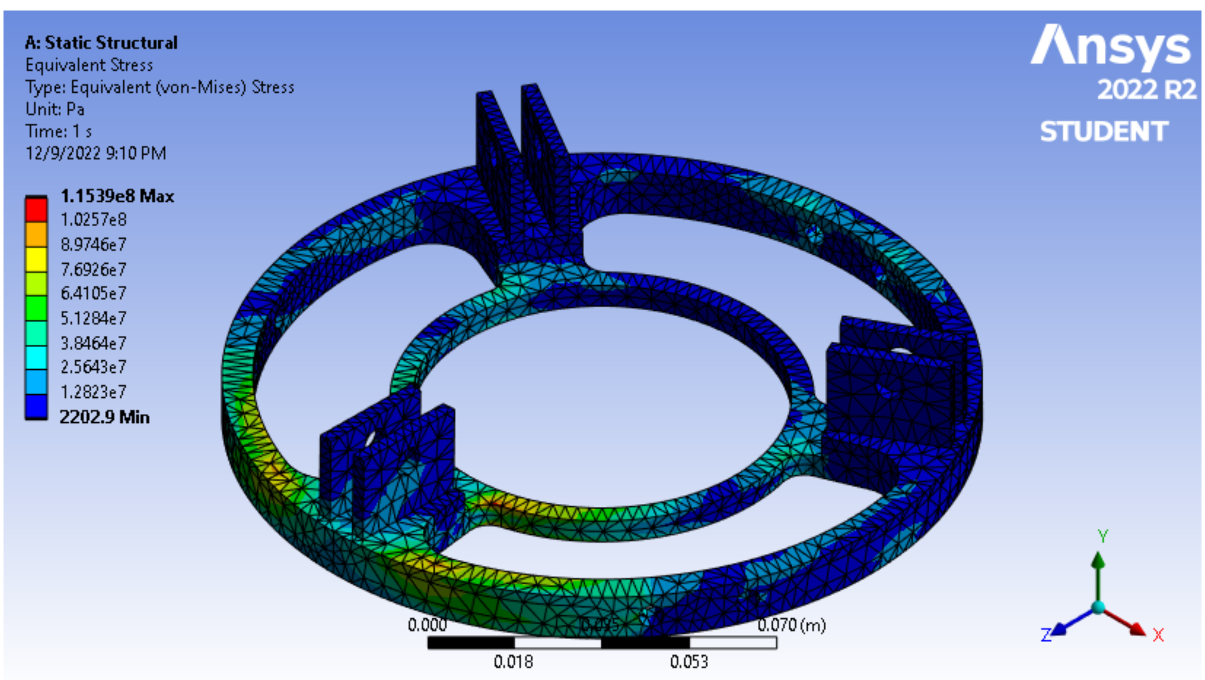


Figure 3.1.6.3.1.2 Centering Plate Stress During Launch

The team also wanted to measure the von Mises stress during landing. The team decided on two outcomes: an inward and outward torsion of the centering ring. A force of 983 N was applied on one of the fin connection points. The force was determined by using F = $\frac{mv}{t}$, where m was the mass of the booster section, v was the landing velocity, and t was the landing time. As seen in figure 3.1.6.3.1.2 Centering PlateInward and Outward Torsion Stress, the max von Mises stress for both the inward and outward torsion was 1.15e8 Pa, resulting in a safety factor of 2.388.



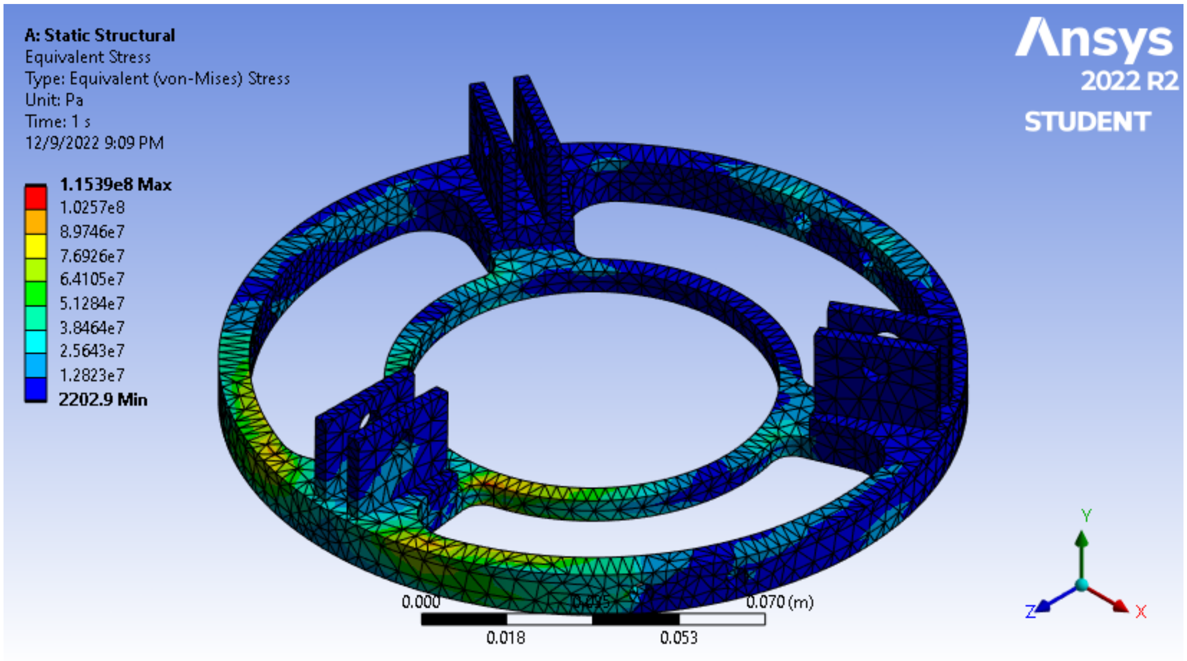


Figure 3.1.6.3.1.3 Mounting PlateInward and Outward Torsion Stress

3.1.6.3.2. Thrust Plate FEA

The team also decided to do finite element analysis on the thrust plate of the MFSS. The team wanted to determine the max von Mises stress the thrust plate would experience. The FEA was also conducted to determine the safety factor during different points in the flight.

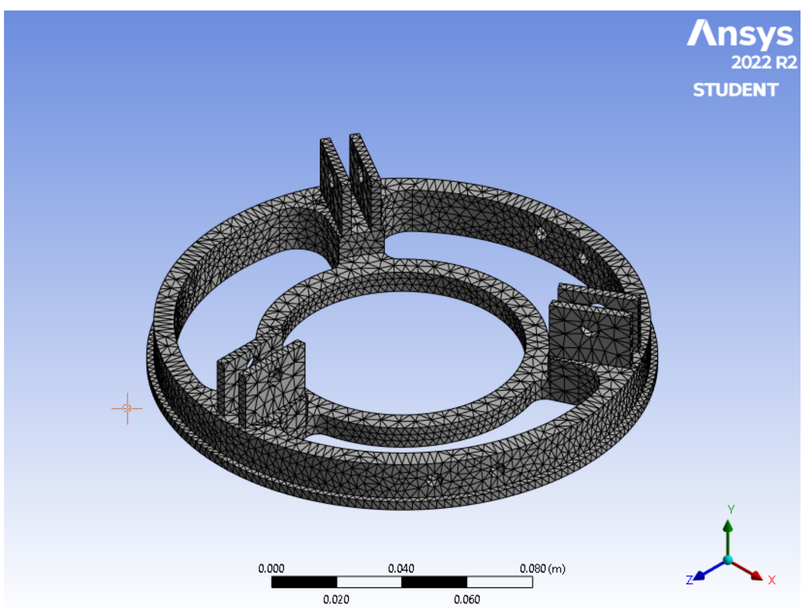


Figure 3.1.6.3.2.1 Thrust Plate Mesh

The boundary conditions of the thrust plate were similar to that of the centering ring. The six holes that would connect to the airframe were fixed supports. There we remote displacement supports on the inner diameter ring, the outer diameter ring, and the flange ring. The remote displacement supports acted as roller supports, allowing the thrust plate to rotate around the y-axis. A force of 1541 N was applied to the bottom of the thrust plate to act as the thrust force that would be experienced at launch. The max stress, as seen in Figure Thrust Plate Launch stress, is 6.127e7 Pa with a safety factor of 4.488, meeting the team's requirements.

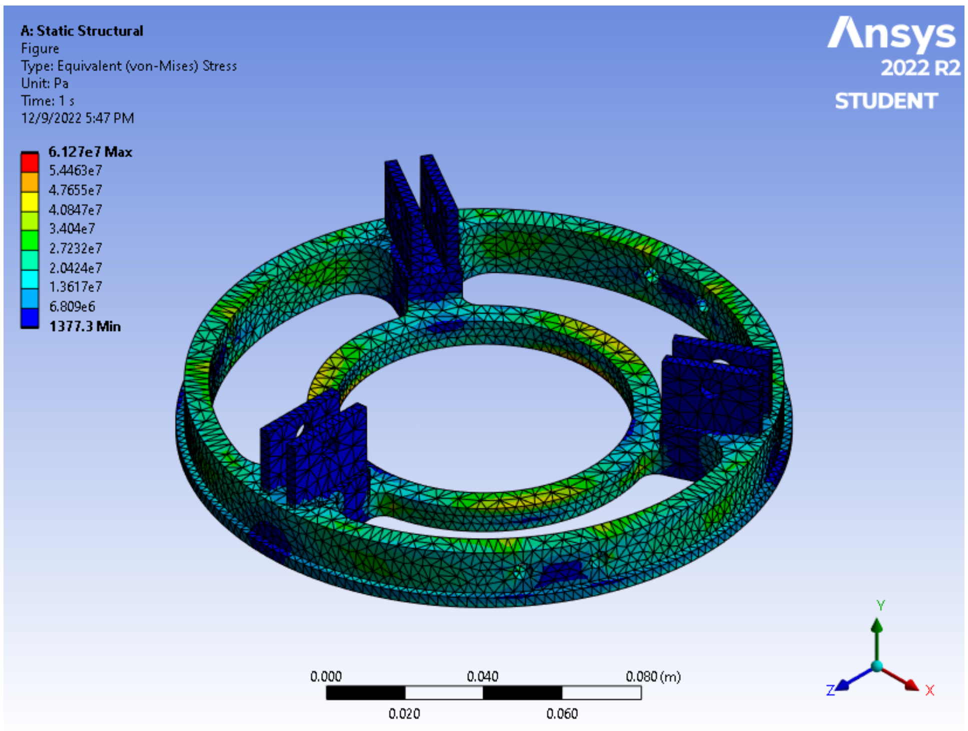
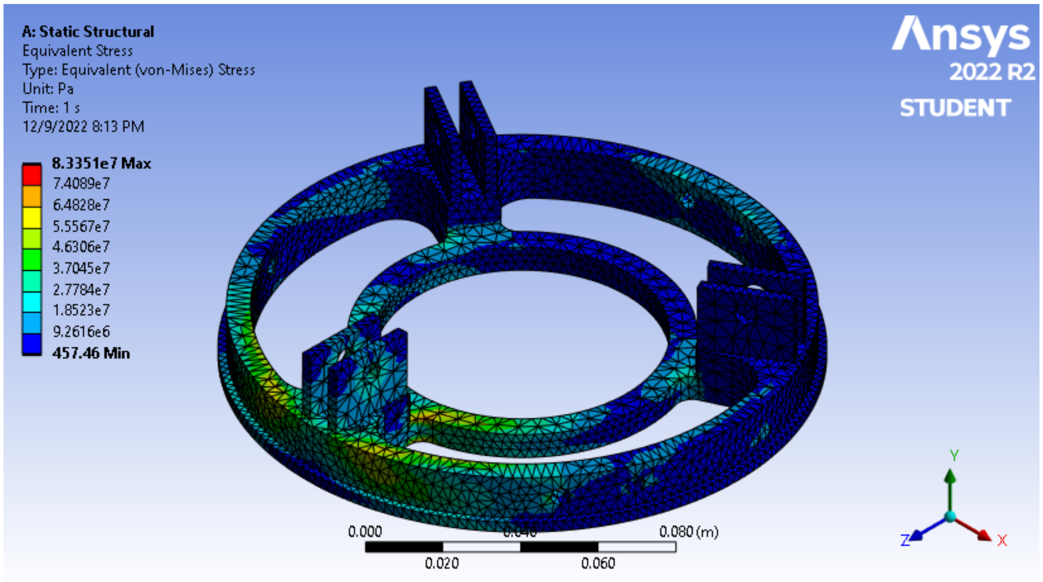


Figure 3.1.6.3.2.2 Thrust Plate Launch Stress

Similar to the centering ring, the team also wanted to look at the thrust plate at landing. The team decided to do FEA for inward and outward torsion if landing on one of the fins. The boundary constraints were kept from the launch FEA. A force of 983 N was applied from inside the connection points. The max von Mises stress that the thrust plate for both the inward and outward torsion would be 8.335e7 Pa as seen in figure Thrust Plate Inward and Outward Torsion Stress. This gives a safety factor of 3.299.



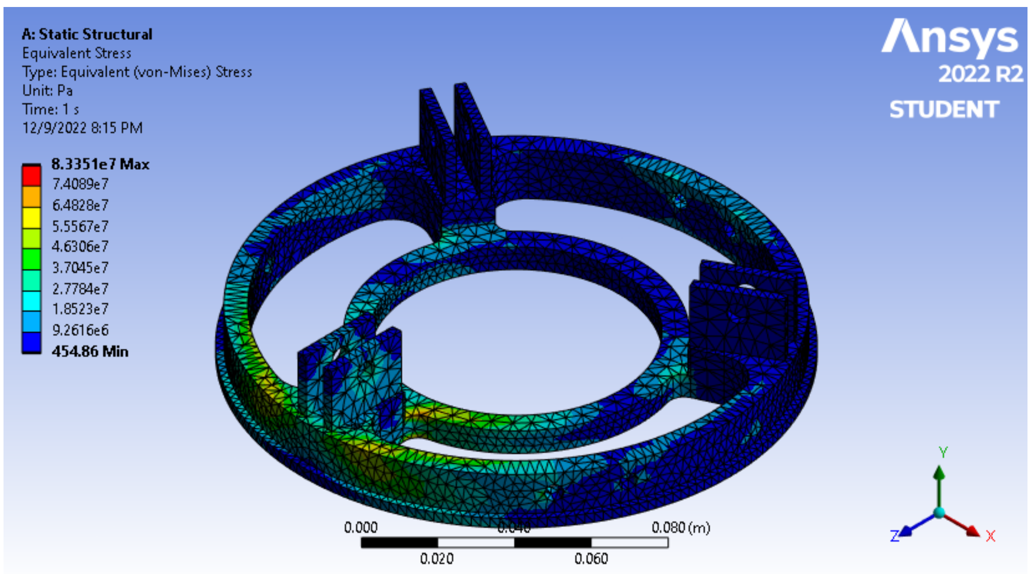


Figure 3.1.6.3.2.3 Thrust Plate Inward and Outward Torsion Stress

3.1.6.3.3. Retainer Plate FEA

The team also decided to conduct finite element analysis on the retainer plate part of the MFSS. The FEA was also conducted to determine the safety factor during different points in the flight.

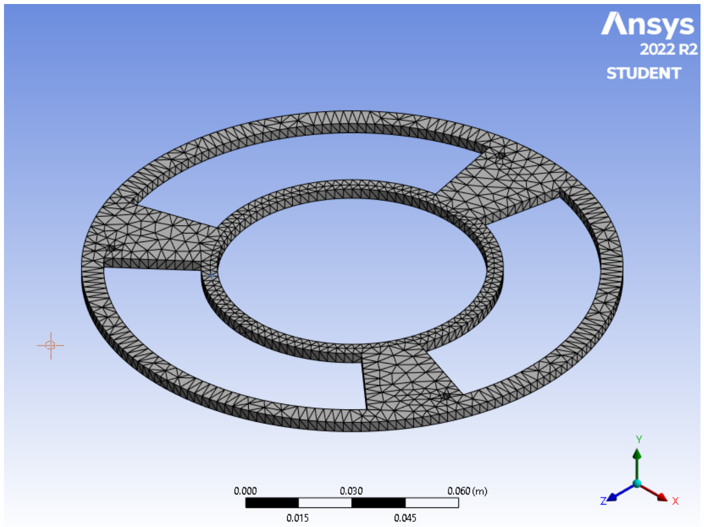


Figure 3.1.6.3.3.1 Retainer Plate Mesh

The boundary conditions included three fixed supports in the holes connecting the retainer plate to the rest of the MFSS. A force of 35.008 N was applied at the top of the inner diameter of the retainer to simulate the weight of the motor on the retainer plate. As seen in figure Retainer PlateStress of Motor Weight this leads to a max von Mises stress of 3.457e7 Pa and a safety factor of 7.953. This safety factor is high enough for the team.

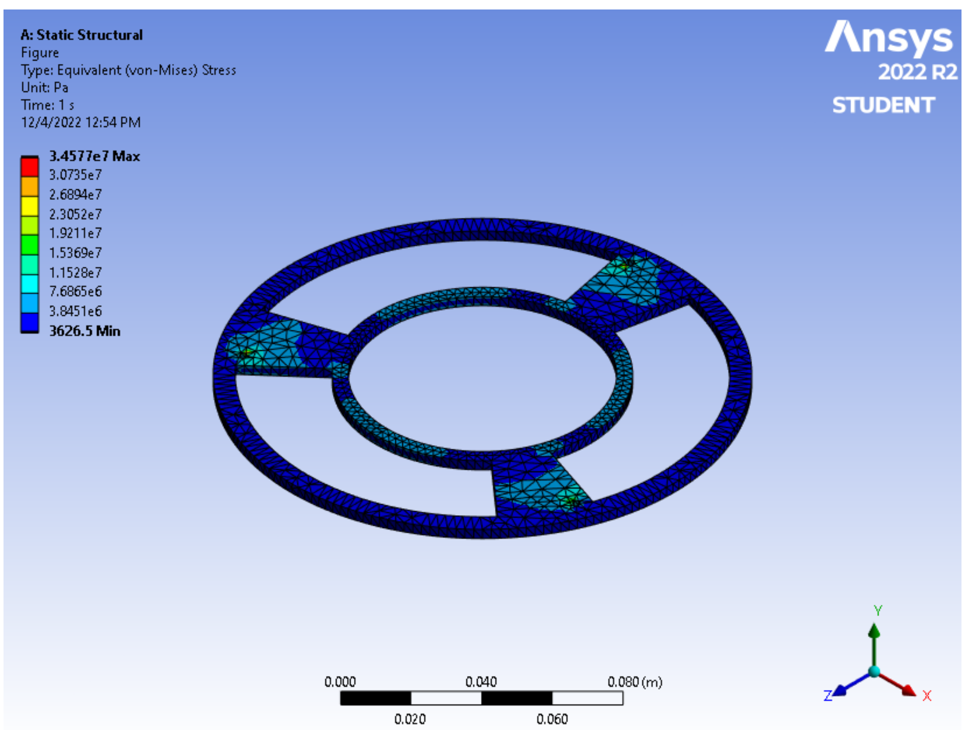


Figure 3.1.6.3.3.2 Retainer PlateStress of Motor Weight

The team also wanted to conduct FEA on the retainer plate if the booster section was to land directly on the retainer plate. A force of 983 N was applied to the bottom of the retainer. This led to a max von Mises stress of 1.728e8 Pa, as seen in figure Retainer Plate Landing Stress. This led to a safety factor of 1.605, which is high enough for the team. However, as seen in figure Retainer Plate Deformation there is slight plate deformation. This is expected during landing and will protect the rest of the booster section.

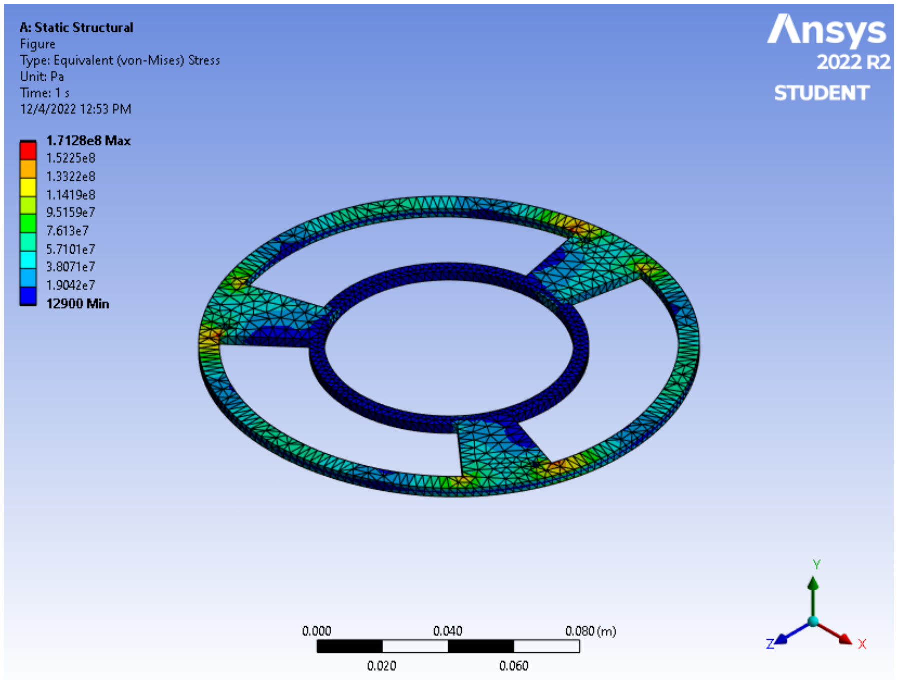


Figure 3.1.6.3.3.3 Retainer Plate Landing Stress

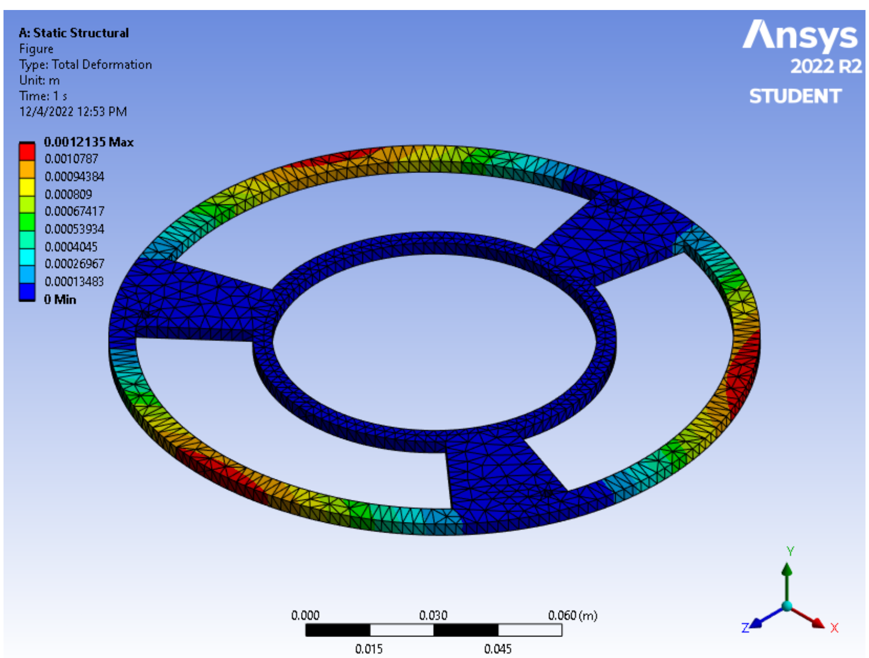


Figure 3.1.6.3.3.4 Retainer Plate Deformation

3.1.6.4. Mass of Vehicle and Sub-Sections

The vehicle's mass was determined through a combination of OpenRocket and physically weighing components in the team's possession. 3.25lb of metal ballast will be added to the launch vehicle to maintain the team's altitude goal of 4050'. 1.25lb will be placed in the nose cone to increase vehicle stability by moving the center of gravity up. The other 2lb will be placed in the avionics bay to keep the Payload section and Recovery section roughly the same weight and thus no one section has an abnormally high impact energy. The table below presents the weight of each major section, which individual components are in the parts list below.

Full Vehicle	**Payload**	**Recovery**	**Booster**
49.3lb	15.34lb	15.4lb	18.57lb (wet) 14.11lb (dry)

Table 3.1.6.4.1 Section Weight

Parts Detail

Sustainer

Nosecone	PETG (0.734 oz/in^3)	Haack series	Len: 8 in	Mass: 0.5 lb
Nosecone Shoulder	PETG (0.734 oz/in^3)	Dia_{in} 5.776 in Dia_{out} 6 in	Len: 3 in	Mass: 0.285 lb
Camera Bay		Dia_{out} 4 in		Mass: 1.2 lb
Ballast		Dia_{out} 0.984 in		Mass: 1.25 lb
Payload	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 22 in	Mass: 2.78 lb
Payload Coupler	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 5.776 in Dia_{out} 6 in	Len: 12 in	Mass: 2 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 6 in	Len: 0.125 in	Mass: 0.258 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 6 in	Len: 0.125 in	Mass: 0.258 lb
Payload		Dia_{out} 5 in		Mass: 6.3 lb
Upper Recovery	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 16 in	Mass: 2.02 lb
Drogue	Ripstop nylon (0.22 oz/ft^2)	Dia_{out} 18 in	Len: 7 in	Mass: 0.141 lb
Shroud Lines	Tubular nylon (11 mm, 7/16 in) (0.14 oz/ft)	Lines: 8	Len: 20 in	
Drogue Shock Cord	3/8in Tubular Kevlar (0.226 oz/ft)		Len: 360 in	Mass: 0.424 lb
Avionics Switchband	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 1 in	Mass: 0.127 lb
Avionics Equipment		Dia_{out} 5 in		Mass: 2.93 lb
Avionics Bay	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 5.776 in Dia_{out} 6 in	Len: 5 in	Mass: 0.807 lb
Ballast		Dia_{out} 0.984 in		Mass: 2 lb
Lower Recover	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 23 in	Mass: 2.91 lb
Main	Ripstop nylon (0.22 oz/ft^2)	Dia_{out} 144 in	Len: 14 in	Mass: 1.99 lb

Shroud Lines	Tubular nylon (11 mm, 7/16 in) (0.14 oz/ft)	Lines: 8	Len: 120 in	
Main Shock Cord	3/8in Tubular Kevlar (0.226 oz/ft)		Len: 720 in	Mass: 0.848 lb
Bolts		Dia$_{out}$ 1 in		Mass: 1.2 lb
Booster	G12 Fiberglass (1.25 oz/in³)	Dia$_{in}$ 6 in Dia$_{out}$ 6.17 in	Len: 28 in	Mass: 3.54 lb
Launch lug	Aluminum (1.56 oz/in³)	Dia$_{in}$ 0 in Dia$_{out}$ 0.5 in	Len: 0.4 in	Mass: 0.008 lb
Launch lug	Aluminum (1.56 oz/in³)	Dia$_{in}$ 0 in Dia$_{out}$ 0.5 in	Len: 0.4 in	Mass: 0.008 lb
MFSS	Aluminum (1.56 oz/in³)	Dia$_{in}$ 4 in Dia$_{out}$ 6 in	Len: 9.1 in	Mass: 1.1 lb
Fins and Inserts (3)	EpoxAcast™ 670 HT (0.665 oz/in³)	Thick: 0.4 in		Mass: 2.8 lb
Booster Coupler	G12 Fiberglass (1.25 oz/in³)	Dia$_{in}$ 5.776 in Dia$_{out}$ 6 in	Len: 12 in	Mass: 2 lb
Bulkhead	G10 Fiberglass (1.17 oz/in³)	Dia$_{out}$ 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in³)	Dia$_{out}$ 6 in	Len: 0.125 in	Mass: 0.258 lb
Bulkhead	G10 Fiberglass (1.17 oz/in³)	Dia$_{out}$ 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in³)	Dia$_{out}$ 6 in	Len: 0.125 in	Mass: 0.258 lb
Egg Finder		Dia$_{out}$ 2 in		Mass: 0.25 lb

Figure 3.1.6.4.1: OpenRocket Component List

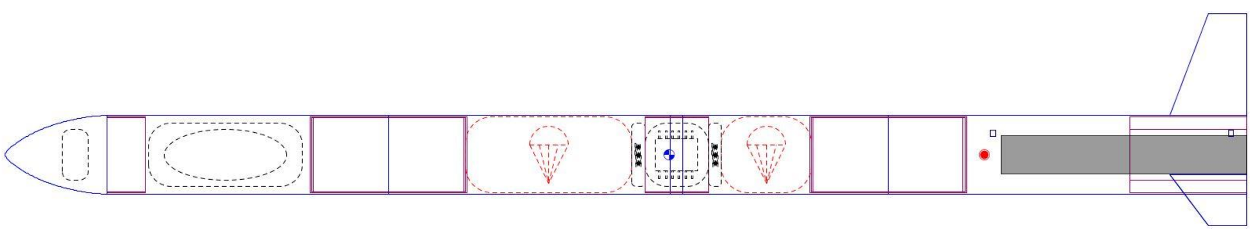


Figure 3.1.6.4.2: OpenRocket model of the launch vehicle.

3.2. Subscale Flight Results

3.2.1. Scaling of the Launch Vehicle

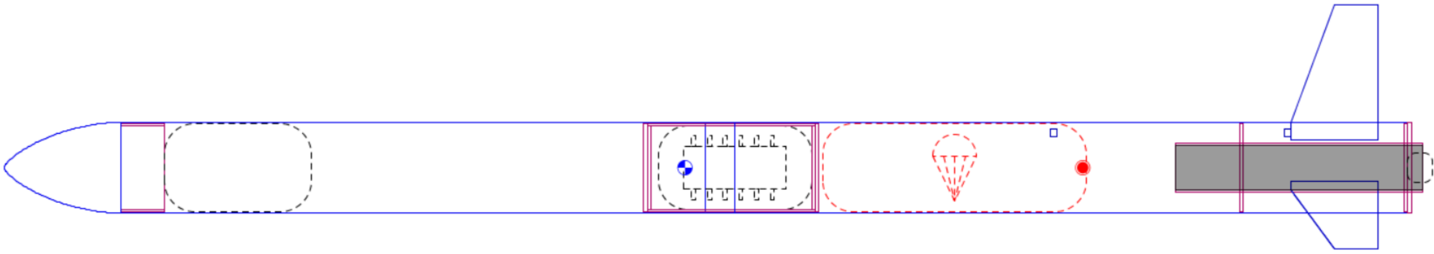


Figure 3.2.1: Subscale Launch Vehicle OpenRocket Model

The subscale flight aims to verify the feasibility of the final launch vehicle by remaining as geometrically similar as possible. To accomplish this, a 50% scaling factor was applied to the diameter and length of each section, as well as the individual parameters of the nose cone and fins. The results are a vehicle that is 48.85” long, 3” in diameter, and 5.75lb. The weight is not scaled 50% as volume does not scale linearly, and the payload is only a simple flight sensor, so the chosen motor, an Aerotech I175WS-5, has been appropriately scaled down. A single parachute is scaled to achieve an impact energy comparable to the full-scale vehicle. Ballast is also placed in the nose cone to increase the stability to that of full scale.

3.2.2. Recorded Flight Data

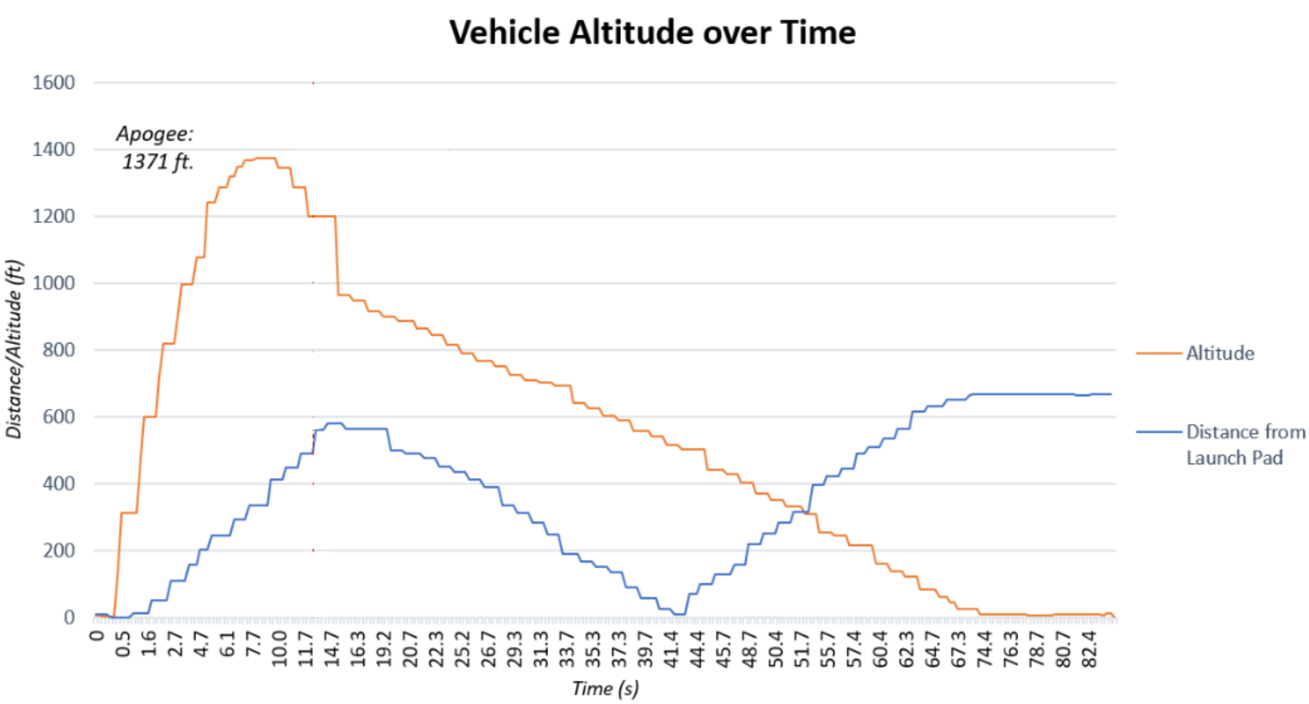


Figure 3.3.2a: Recorded Launch Vehicle Altitude and Distance from Launch Pad, Respective to Time

Note that the recorded distance from the launch pad decreases following parachute deployment as the wind carried the launch vehicle back within 10 feet of the launch pad, albeit 500 feet above the ground. The metrics below include drift distances relative to the launch pad and the total distance during the flight.

Subscale Flight Metrics	
Apogee	1371 ft
Maximum Velocity (ascent)	260.63 ft/s
Maximum Acceleration (ascent)	122.77 ft/s^2
Ascent Time	7.9 sec
Descent Time	66.4 sec
Landing Velocity	18.22 ft/sec
Drift Distance (relative)	656 ft
Drift Distance (total)	1236 ft

3.2.2.1. Photography

Figure 3.3.2.1b: Nose cone and upper stage. Image has been brightened to show deformation in the nose cone upon landing.

Figure 3.3.2.1a: Launch Vehicle Landing Configuration

3.2.3. Simulated Flight Data

3.2.3.1. Launch Day Conditions

The recorded temperature at launch was -6℃ with a wind speed of 12 kph from the east. The simulations for the subscale launch were computed using OpenRocket. These parameters were implemented into OpenRocket to simulate the subscale flight and produce the data below.

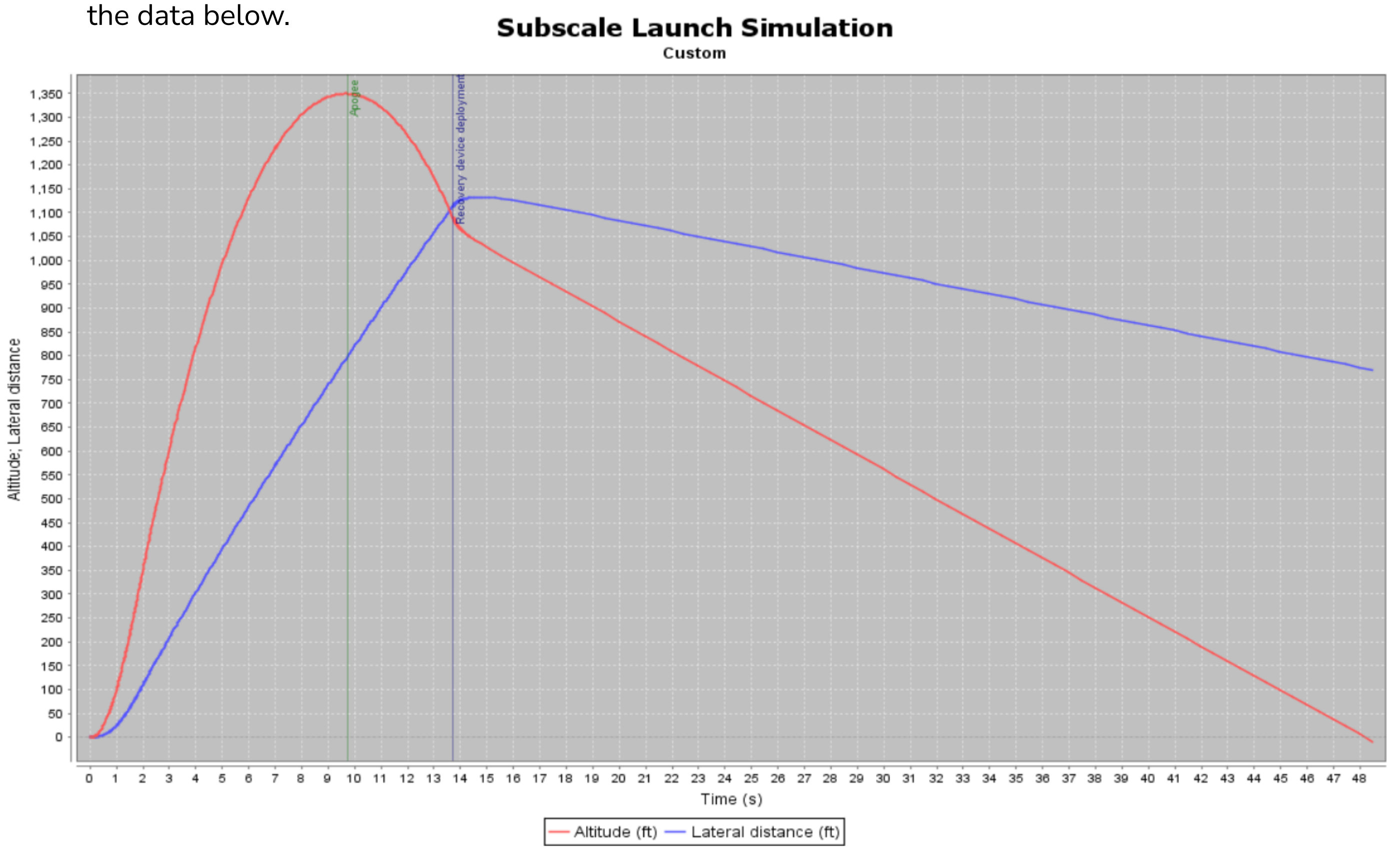


Figure 3.2.3.1.1: Simulated Launch Vehicle Altitude and Distance from Launch Pad, Respective to Time

Simulated Flight Metrics	
Apogee	1349 ft
Maximum Velocity (ascent)	297 ft/s
Maximum Acceleration (ascent)	240 ft/s^2
Ascent Time	9.8 sec
Descent Time	40 sec

Landing Velocity	30.75 ft/s
Drift Distance (relative)	775 ft
Drift Distance (total)	1475 ft

3.2.4. Recorded and Simulated Data Discussion

The recorded data and the simulated data are comparable; however, the team determined a few discrepancies upon analysis of both data sets. The OpenRocket simulations, when provided with launch day conditions, returned altimeter, distance, and flight time data that were deviant from the results of launch day. This was determined by the team to be attributed to OpenRocket failing to account for updrafts, or vertical wind speed, which affects the flight metrics of a launch.

Because it was below freezing at the time of launch, the low temperature likely affected both the burn rate of the 38mm White Lightning solid propellant and the overall performance of the Aerotech I175WS motor, given that the launch vehicle was exposed to these conditions for approximately two hours before launch. The extent to which this parameter affected the subscale launch and recorded data can be estimated by comparing it to the simulated flight data, which shows a lower performance overall.

Additionally, the maximum acceleration recorded during the launch was significantly lower than the OpenRocket simulated maximum acceleration. In addition to the discussion above regarding the low initial propellant temperature, this was also determined to be a fault of the data recording, specifically in that the on-board computer’s sample rate was not sufficient to accurately record the highest acceleration achieved, given that the events before engine burnout occur quickly.

The analysis performed did not conclusively determine that the Aerotech I175WS motor experienced significant failure. However, the team concluded that a combination of the above factors sufficiently explained the differences between the simulated flight and the recorded data.

3.2.5. Subscale Flight Impact on Full-Scale Design

During the landing of the subscale, the nose cone was damaged due to the vehicle landing on the paved road. To mitigate this risk, the nose cone for full-scale will be covered with a fiberglass wet layup to improve impact resistance and survivability. During the manufacturing of the subscale, it was determined that the space needed to pack the parachute had been slightly underestimated. To alleviate this, the recovery tube holding the main parachute was extended an inch in length to leave ample room for the deployment action. Besides those small adjustments, the subscale proved that the vehicle design is flight ready and will perform as expected during the full-scale launches.

3.3. Recovery Subsystem

3.3.1. Concept of Operations

The recovery subsystem Concept of Operations (CONOPTS) has four phases: preparation, initiation, flight, retrieval.

3.3.1.1. Phase 1: Preparation

During the preparation phase, occuring before the launch day, the following tasks will be completed. Both altimeters will be configured with the desired apogee and deployment altitudes/delays. A test will confirm data transfer from altimeters and tracking systems to the laptop that will be used on launch day. Next, the avionics bay will be assembled. This includes preparing the four ejection charges and connecting all the deployment system components. Then the deployment system and parachute systems will be interfaced with the rest of the launch vehicle.

3.3.1.2. Phase 2: Initiation

The initiation phase starts when the vehicle is on the launch pad. First, a key will turn on both deployment systems and both tracking systems. The altimeters will emit a series of beeps to indicate they are ready for flight. Next, altimeters and tracking systems will be connected to the laptop. The final action in the initiation phase is ignition of the motor.

3.3.1.3. Phase 3: Flight

The flight phase begins once the motor is ignited and the launch vehicle starts to ascend. Two actions occur during this phase: A) drogue parachute deployment and B) main parachute deployment. The primary drogue parachute charge will ignite at apogee followed by the redundant drogue charge 2 seconds later. The primary main parachute charge will ignite at 700’ AGL then redundant main charge at 500’ AGL.

3.3.1.4. Phase 4: Retrieval

The retrieval phase starts once the launch vehicle lands. The vehicle will be tracked by sight through the flight phase. If this is not possible, the on-board tracking system will be used to locate the launch vehicle upon landing. Data collected at the landing site will include photos from multiple angles, apogee from each altimeter, and maximum velocity from the main altimeter.

3.3.2. Updates from PDR

The dual deployment parachute method was chosen for the launch vehicle.The altimeter sled with holes for thumb screws was chosen. To avoid sizing error, the team will use smaller holes than anticipated and drill a larger hole if required. This design allows for team members to more easily assemble the altimeter sled without having to completely disassemble the avionics bay. Minor changes made throughout the design process caused for a higher decent time than preferred by team requirements for bonus points. Decreasing the diameter of the drogue parachute while maintaining an equivalent drag coefficient allowed for the expected descent time to be within nominal margins. The recovery team has also opted for an alternate configuration of the parachute with the main parachute not being attached to the payload section as there was concern from the Payloads Team for a potential malfunction to payload operations if the section was dragged after landing.

3.3.3. Systems

3.3.3.1. Parachute Systems

3.3.3.1.1. Parachutes

A 18” Fruity Chutes Classic Elliptical parachute was chosen for the drogue parachute and a 144” Rocketman High Performance CD 2.2 parachute was chosen for the main parachute. Both parachutes are made of 1.1 oz ripstop nylon and have been successfully tested and used in previous launches. After taking into consideration the new descent time requirements, the team conducted simulation testing to obtain the optimal parachute dimensions to be used. The optimal dimensions correlated with the dimensions from the past parachutes, allowing the team to use previously tested parachutes in the launch vehicle.

Figure 3.3.2.1.1.1 18’’ Drogue Parachute Model

Figure 3.3.2.1.1.2 144'' Main Parachute Model

3.3.3.1.2. Harnesses

The 24'' Drogue Parachute consists of zero-porosity 1.9 oz balloon cloth, 3 8'' mil-spec tubular shroud lines, and 1500 lb swivel. This parachute has a high drag coefficient of 1.16, is compact and lightweight, and offers a stronger material than other alternatives. This parachute has been used in previous years' flights and has been proven reliable. The 144" Main Parachute consists of 1.1oz rip-stop, 250lb nylon shroud lines, and 3000 lb swivel. As well as the drogue parachute, this parachute offers the advantages of a high drag coefficient of 2.2 and is compact and lightweight. This parachute is the same model as utilized in past launches and has been successful.

3.3.3.1.3. Heat Shields

The heat shielding utilized will be an 18 square inch single Nomex blanket for the drogue parachute and an 18" x 36" double Nomex blanket for the main parachute. This heat shielding will function to prevent parachute damage from hot ejection charges. Holes in the parachute have the potential to be formed by hotspots, so the Nomex blankets will completely surround each parachute to prevent this. In previous years' competition flights, this Nomex blanket configuration has been used and proven successful in warding off these holes.

3.3.3.1.4. Bulkheads and Attachment Hardware

The bulkheads are used to separate the front and aft sections of the vehicle while connecting the essential systems. The bulkheads contain the main and drogue parachutes as well as the black powder ejection charges used to deploy the parachutes. The bulkhead containing the drogue parachute will have a 30' long, ¾" wide tubular Kevlar shock cord with one end attached to the drogue parachute and the other end attached to a bulkhead eye bolt with ¼" quick links. The bulkhead containing the main parachute will have a 60' long, ⅜" wide tubular Kevlar shock cord with one end attached to the main parachute and the other end attached to a bulkhead eye bolt with ¼" quick links.

3.3.3.2. Tracking System

3.3.3.2.1. Primary GPS

The primary vehicle tracking system will be the Altus Metrum TeleMetrum altimeter positioned within the altimeter sled in the avionics bay. This altimeter provides GPS data by means of a GPS receiver. In previous years, this device has successfully maintained connection with the ground station during testing from a range of approximately one mile through the usage of a TeleDongle and Yagi Arrow 3 Element Antenna. The Altus Metrum TeleMetrum uses a frequency of 434.55 MHz comprising an RF transceiver with an output value of 40 mW. The ability to track the vehicle with this device will permit more easy and prompt recovery of the vehicle.

Figure 3.3.2.2.1 - Primary GPS - Telemetrum Altimeter

3.3.3.2.2. Secondary GPS

The secondary tracking system will be the EggTimer Rocketry EggFinder. The secondary GPS includes all of the supports of GPS tracking, just in another coupler, and is meant to ensure that the vehicle can be tracked in the case of problems with the primary GPS. The EggFinder is a GPS transmitter system that can track the launch vehicle while in flight and transmits live data back to the ground station. The EggFinder can connect with at least four satellites and track latitude and longitude and send the data to MapSphere so that an exact location of the vehicle can be tracked. The vehicle will contain only one EggFinder tracker this year, while in the past two had been used. The EggFinder tracker will be placed in the booster to recovery coupler. One EggFinder will be used so that it does not interfere with the GPS signal. In the past, the tracker was housed in a carbon fiber holder which was believed to be causing the interference problem, so PETG will be used instead. The tracker still had connectivity issues with the PETG material, but this is believed to be because there were multiple trackers that were interfering with each other. This year, one EggFinder tracker will be placed in the booster to recovery coupler to increase connectivity with the satellites and decrease interference. The EggFinder tracker will be housed in a 3D printed housing containing the tracker, its battery, and a key switch.

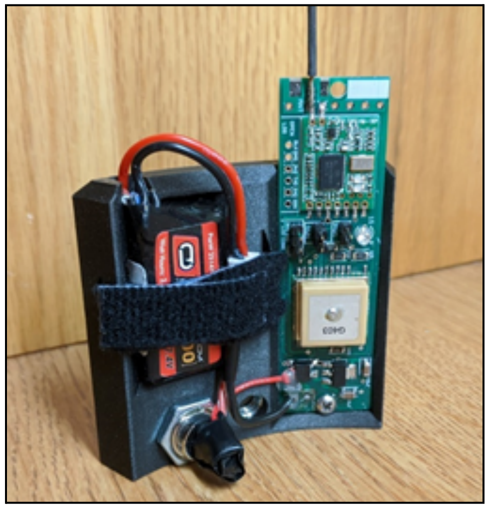


Figure 3.3.2.2.2.1- Failed EggFinder Tracker Setup From 2020 - 2021 Competition Year

3.3.3.3. Operational Environment

Due to competition flights being flown in Huntsville, Alabama and West Lafayette, Indiana the launch vehicle needs to be operational through a temperature range of 25 to 90 degrees fahrenheit. This is ensured via the varying temperatures of the ALtimeter Continuity and Battery Drain Test Altimeter Ejection Vacuum Test and the Black Powder Ejection Test (see section 6.2) The avionics and recovery system will operate in a large temperature range and under nominal launch conditions (0 - 20 mph winds).

3.3.3.4. Bay

The avionics bay connects the front section to the aft section of the launch vehicle and contains all avionics components. The bay consists of a body tube and a bulkhead on each end. The body tube will be 5" in length with an inner diameter of 5.776" and outer diameter of 6". These dimensions will allow for optimal usage of space while minimizing volume and weight added to the launch vehicle. Four ½" holes in the exterior of the bay will be used to attach the switch holders. Four #8 static port holes and twelve ¼" holes on each end of the avionics bay will connect the coupler with the upper and lower recovery sections to allow for deployment at the correct altitudes. The current design of the avionics bay utilizes 3D printing making it easy to modify as changes are made to the inner components and easily reusable across multiple launches.

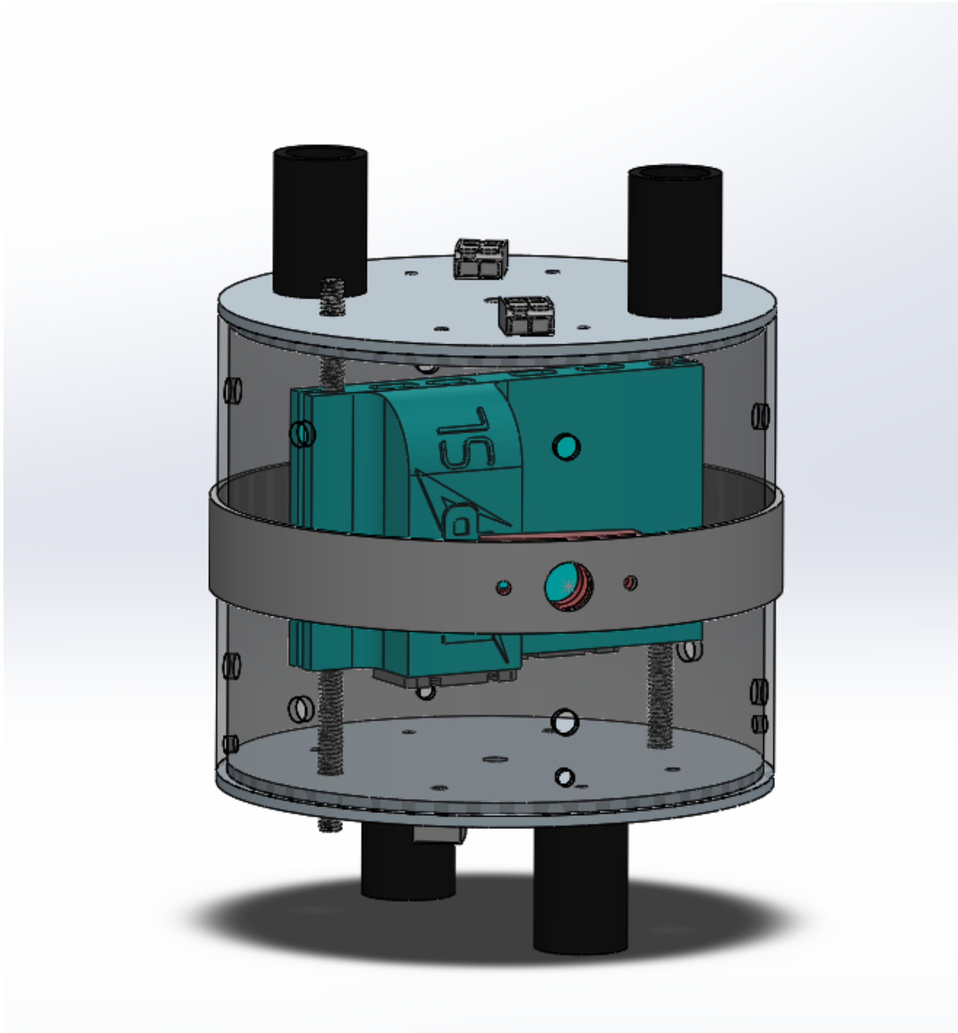


Figure 3.3.3.1.1: Avionics Bay

3.3.3.5. Switch Band

The switch band allows access to the key switches with two half inch diameter holes. The switch band will have four holes that surround the holes of the key switches. Also, the switch band will have a width of 1 inch that way it can completely cover the key switches. The inner diameter of 6 inches and outer diameter of 6.17 inches of the switch band will allow it to slide over the coupler. The current design of the switch band utilizes 3D printing making it easy to modify with the size of the coupler and easily reusable across multiple launches

3.3.3.6. Switches and Switch Holders

Deployment will be initiated by two key switches inside of the launch vehicle. The two key switches will be held in place on opposite sides of the avionics bay by cylindrical switch holders. The cylindrical switch holders will be attached to the avionics bay with two removable screws. The removable screws will make assembling and modifying the design easier. Key switches were chosen over key models for various reasons. The key switches will not be affected by vibrations caused during the launch or the collision with the ground while landing, while key models would. The switches are also good because they do not affect the aerodynamics of the launch vehicle. The current switch holder design utilizes 3D printing making it easy to modify in accordance with the size of the key switch and easily reusable across multiple launches.

3.3.3.7. Ejection Charges

The ejection charges will be FFFg black powder. FFFg black powder is both lightweight and has been used in the past, so it is known to be reliable. It also avoids using high-pressure gas in the ejection system, which increases reliability. To calculate the ejection charges, the interior volume of the airframe and the pressure needed to shear the four pins on the 6" diameter bulkhead are needed. Primary charges were calculated, and rounded up, for both the main and drogue parachutes. For the redundant charges, an additional gram of FFFg black powder will be used to ensure that the parachutes deploy at the correct time. It was determined that 4g of black powder will be used for the main parachute's primary ejection charge, and 5g will be used for the main parachute's redundant charge. For the drogue parachute, 2g will be used for the primary charge and 3g will be used for the redundant charge.

Ejection Charge Calculations:

To calculate the force needed to shear one shear pin, multiply the cross-sectional area of a 4-40 shear pin (radius 0.056 in) by the shear strength of nylon (τ_{Nylon}).

$$Area_{Pin} = \pi R^2$$

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

$$Force_{Pin,\,Failure} = Area_{Pin} * \tau_{Nylon}$$

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

Multiplying by 4 will give the force needed to shear four shear pins. This can be used to find how much pressure is needed to shear the four pins on a 6'' diameter bulkhead.

$$4 * Force_{Pin,Failure} = 394.1\,lbf$$

$$Area_{Bulkhead} = \pi R^2$$

$$Area_{Bulkhead} = 3.1415 * (3\,in)^2 = 28.27\,in^2$$

$$P_{Bulkhead} = \frac{4 * F_{Pin, Failure}}{Area_{Bulkhead}} = 13.94\ psi$$

$$G = Mass_{BP} = 0.0004 * P * D^2 * L * 1.2$$

The equation above gives G, or the number of grams of black powder needed in each canister. 0.0004 is the pressure coefficient (per 1 psi), P is the pressure required on the bulkhead (psi), D is the airframe section diameter (in), L is the length of the airframe section (in), and 1.2 is the safety factor. The values of G are then rounded up for safety.

Upper Recovery Section Side Primary Ejection Charge (Main Parachute):

$$G = Mass_{BP} = 0.0004 * 13.94\ psi * (6\ in)^2 * 13\ in * 1.2 = 3.131\ g \approx 4\ grams\ of\ black\ powder$$

Length of airframe section (for main parachute, up to shock cord) = 13 in

Upper Recovery Section Side Redundant Ejection Charge (Main Parachute):

$$G = 4\ g + 1\ g = 5\ grams\ of\ black\ powder$$

Lower Recovery Section Side Primary Ejection Charge (Drogue Parachute):

$$G = Mass_{BP} = 0.0004 * 13.94\ psi * (6\ in)^2 * 7\ in * 1.2 = 1.686\ g \approx 2\ grams\ of\ black\ powder$$

Length of airframe (for drogue parachute, up to shock cord) = 7 in

Lower Recovery Section Side Redundant Ejection Charge (Drogue Parachute):

$$G = 2\ g + 1\ g = 3\ grams\ of\ black\ powder$$

3.3.3.8. Ejection Charge Configurations

The avionics bay has two bulkheads, each holding two canisters of the FFFg black powder. One canister will hold the primary ejection charge and the other will hold the redundant charge. The upper bulkhead will contain the ejection charges for the drogue parachute, and the lower bulkhead will contain the ejection charges for the main parachute. In previous years, screw wire connectors were used to attach the e-matches to the recovery system. However, due to their difficulty to set up and the increased possibility of stripping wires between flights, lever nuts were considered instead. The lever nuts can be quickly assembled and reused. It was also confirmed that the Wagos 2 conductor of the Wagos brand would be able to withstand high power rocketry vibrations, or 0 - 2000 Hz, so it was selected to connect the e-match to the altimeter sled in this year’s design.

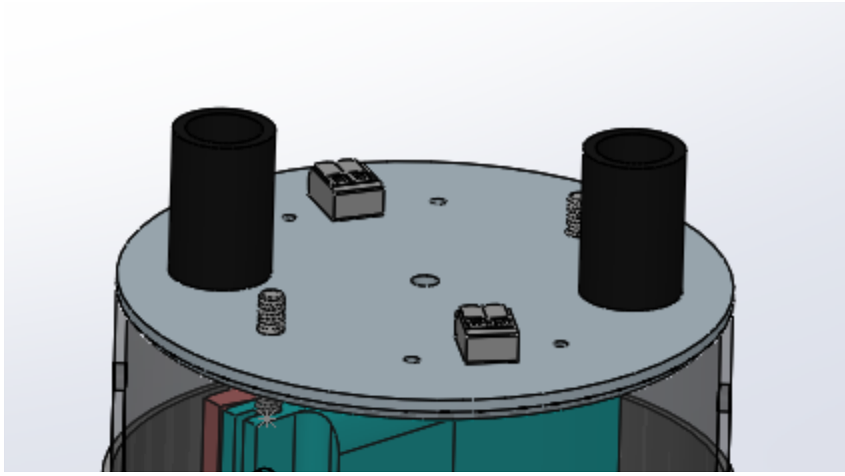


Figure 3.3.3.8.1 Charge canisters, Wire Connectors, Wire Holes and Threaded Rod Placement on Bulkhead

3.3.3.9. Altimeter Sled

The Altimeter sled is a 3D printed housing mounted inside the Avionics Bay. It is secured on two threaded rods that span the length of the bay. The sled contains two independent altimeter systems. The primary altimeter system consists of the Altus Metrum Telemetrum altimeter powered by a 3.7 volt lipo battery. The container for the lip battery will have a mark indicating the location of a fire hazard in addition to the team safety standards. The secondary system includes the PerfectFlite StratoLoggerCF altimeter powered by a 9 volt alkaline battery. Both systems are mounted inside the walls of the sled with battery and altimeter pair being opposite to each other across the span from bolt to bolt. These pairs themselves also alternate, meaning the altimeter of one pair will be next to the battery of the other. This helps keep the center of mass closer to the central axis of the rocket.

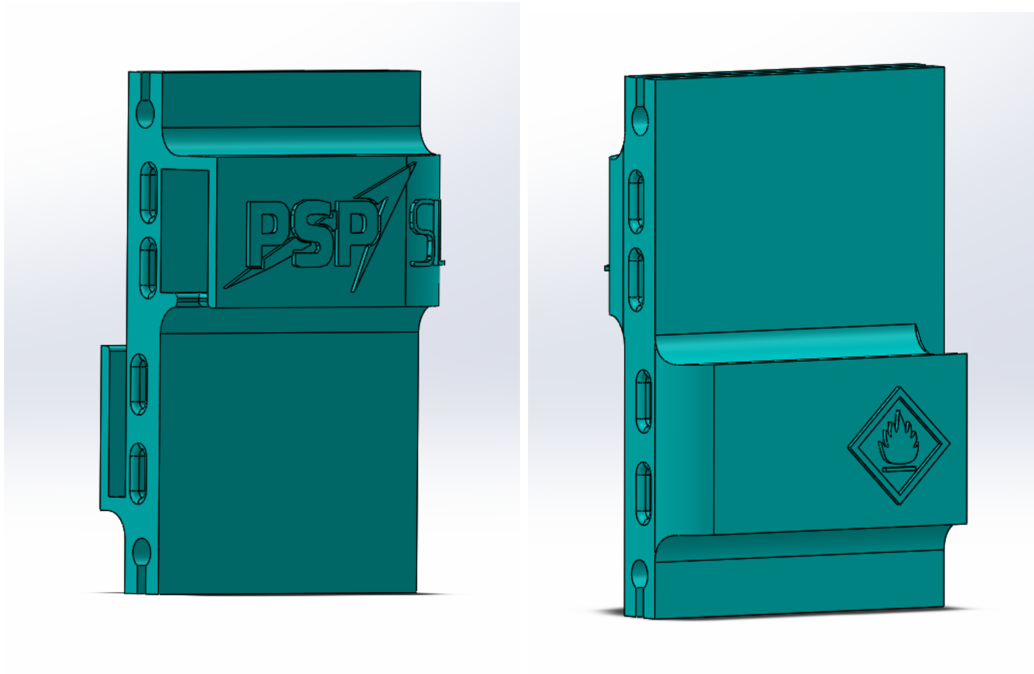


Figure 3.3.3.9.1- Altimeter Sled

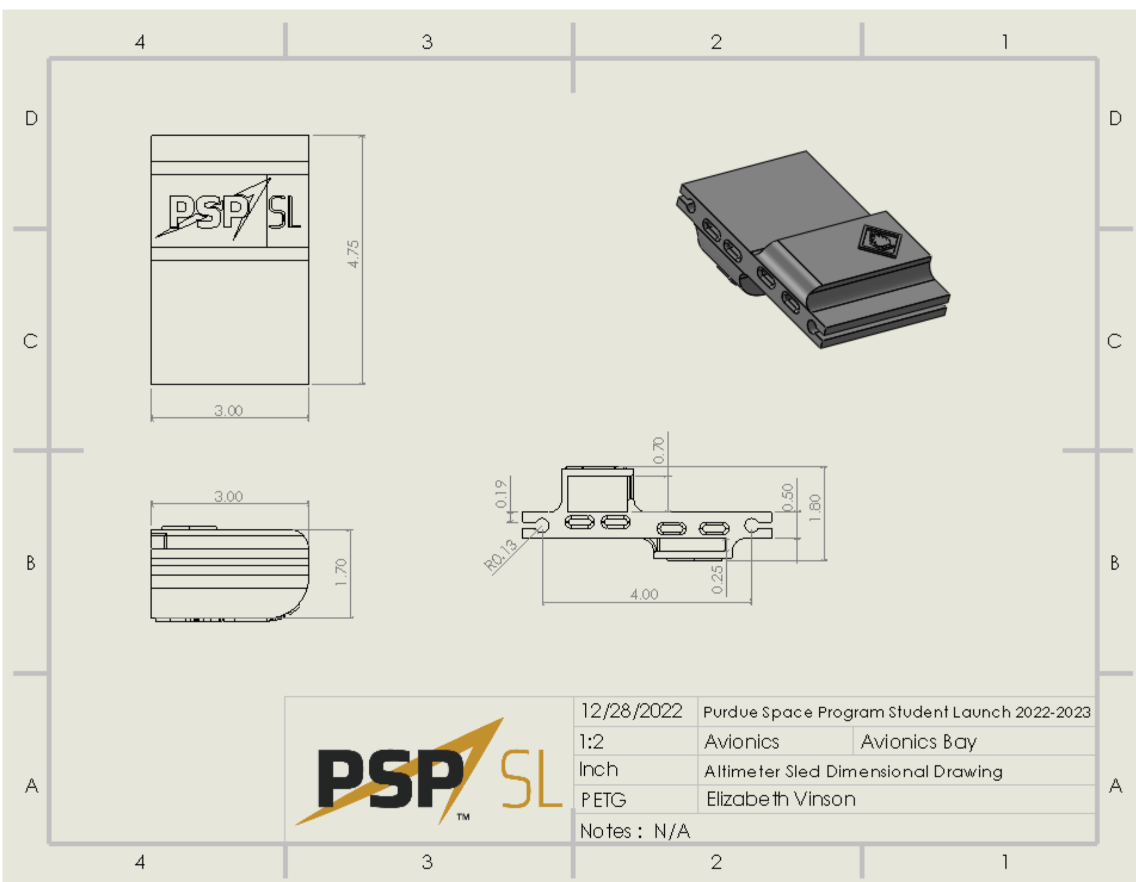


Figure 3.3.3.9.2: Altimeter Sled Technical Drawing

3.3.3.10. GPS Tracker Holder

The Egg Holder will be the 3D printed housing holding the EggFinder GPS tracker. It consists of housing for the EggFinder tracker, a key switch holder, and its battery. PETG has been chosen as the material to minimize interference and increase connectivity of the GPS. The Egg Holder will be secured with bolts and threaded rods and placed in the booster to recovery coupler, using the previous year's method of bolting the 3D printed Egg Holder on threaded rods. The EggFinder does not need to be as easy to access as the primary avionics bay, so a simplified version of past year's altimetier sled designs has been used. Therefore, the GPS sled will be secured on the threaded rods via four hex bolts. Two of the hex bolts will be tightened on the forward and aft ends of the GPS sled.

3.3.3.11. Battery Guard

The battery guard is designed to secure the batteries attached to the altimeter sled. The current design is easily accessible, contains a flat surface for better ease in 3D printing, and integrates well with the altimeter sled and threaded rods. In order to fulfill the reusability requirement, the current battery guard design utilizes 3D printing which eliminates the use of epoxy with this component and also promotes better integration among the other parts of the avionics bay.

3.4. Design Schematics

3.4.1. Electrical Components and Altimeters

The main electrical components used for the avionics bay in the launch vehicle are the two altimeters. These two altimeters are separated into two deployment systems: the primary deployment system and the redundant deployment system. The primary system uses the Altus Metrum TeleMetrum altimeter, powered by a 3.7V LiPo battery, along with a key switch, terminal block, and two e-matches for the drogue and main parachute ejection charges. The TeleMetrum was chosen as the primary altimeter because of its reliability in past launches. The redundant system is similar to the primary system, with the difference being the altimeter, battery, and associated e-matches. It instead uses the PerfectFlite StratoLoggerCF altimeter, powered by a standard 9V alkaline battery.

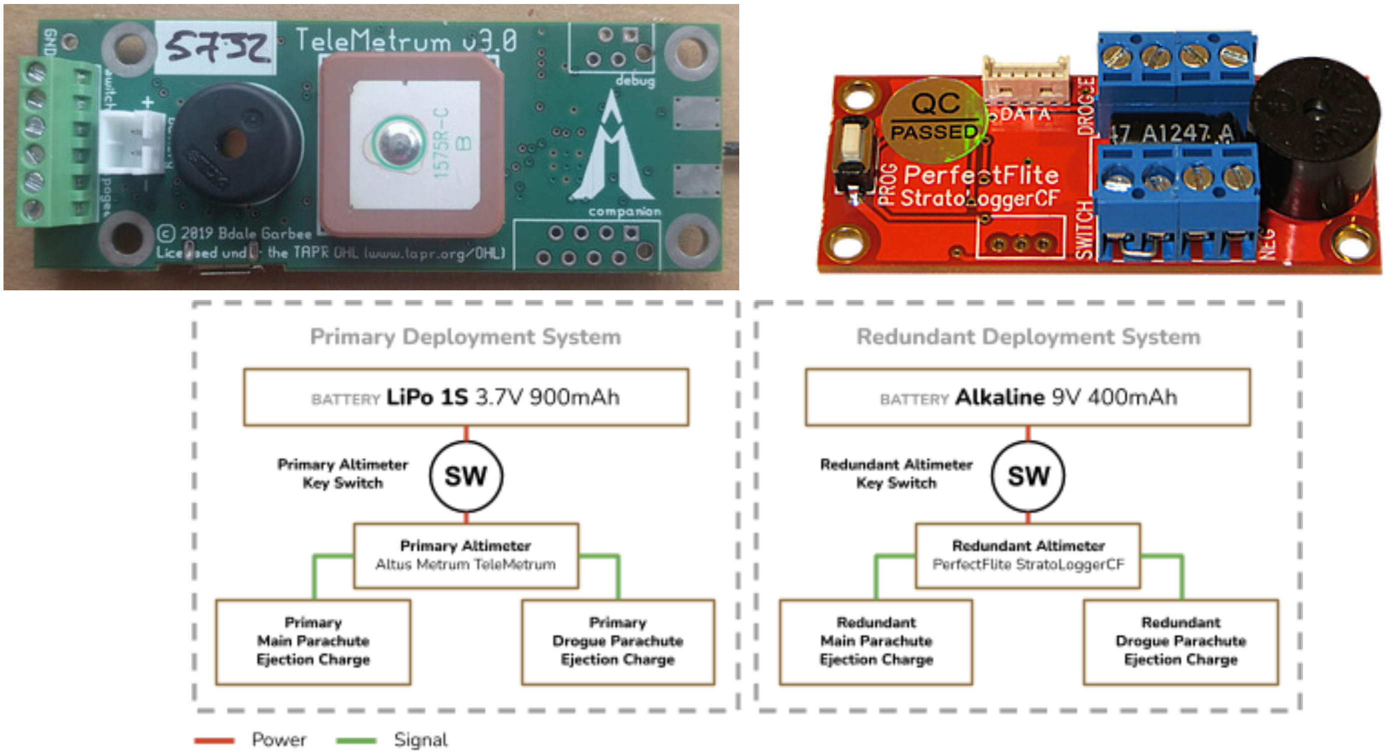


Figure 3.4.1.1: Deployment system wiring diagrams

This figure shows the two deployment systems in the avionics bay and how each component is connected. By keeping the two systems independent of each other, it allows for redundancy in the case that a failure occurs in the other system and stops it from working. The two altimeters being different models reduces the possibility the same error will occur in both altimeters.

3.4.2. Setting up the Primary GPS

The primary GPS is integrated within the primary altimeter. The primary altimeter must be in the outside and in the launch configuration in order to connect to GPS.

3.4.3. Setting up the EggFinder Tracker (Secondary GPS)

After downloading MapSphere and setting up an account, plug the EggFinder RX into the laptop. After a few seconds, a green LED light will blink, which indicates it is receiving data from the EggFinder TX. Once in MapSphere, select “choose GPS”.

3.5. Mission Performance Predictions

3.5.1. Vehicle Integrity

3.5.1.1. Airframe

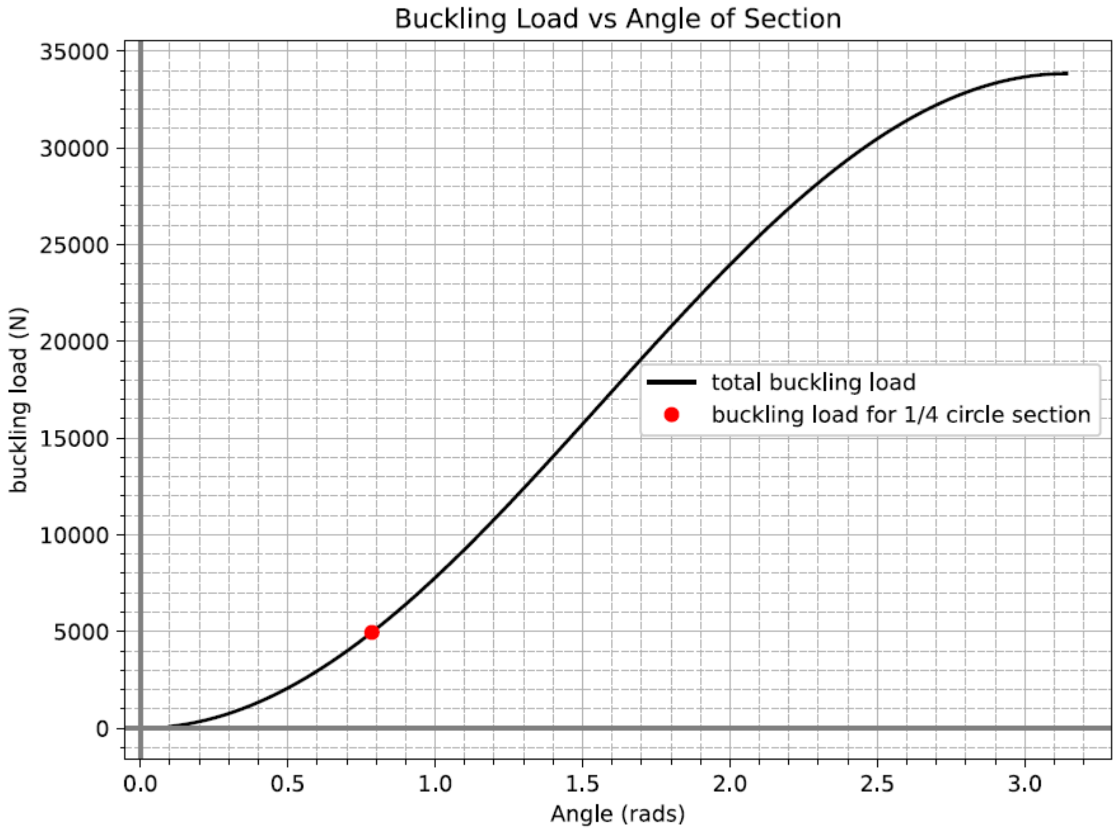
The material selected for the airframe of the launch vehicle is G12 class fiberglass. G12 was chosen due to a combination of material strength and its successful use in prior competition year launches. On the structural side, the force required to buckle the tube is much greater than the maximum forces expected in predicted flight conditions. This was determined using the shell buckling capacity of both +60/-60 and +45/-45 degree fiberglass layup as the supplier did not provide layup specifications. The following structural limits of G12 come from "Compressive Failure Analysis of Thin Walled Filament Wound Composite Cylinders", by Dimitrios Michalaros and Corey O'Brien.

Layup	$E_{xx}(GPa)$	$N_x(\frac{KN}{m})$	$\sigma_{uc}(MPa)$	$N_{uc}(KN)$
[60/-60]	8.127	-488.1	-266.1	-237
[45/-45]	10.79	-427.9	-198.2	-207.8

Table 3.5.1.1.1: Compressive Strength of each layup

Layup	Stress σ_{crit}(MPa)	Load $N'_{buck}(\frac{KN}{m})$	Load $N_{buck}(\frac{KN}{m})$
[60/-60]	-417.7	-902	-438
[45/-45]	-485	-1047.2	-508.5

Table 3.5.1.1.2: Shell buckling failure stress and loads of each layup



The forces of the launch and landing were then calculated to determine whether or not the airframe would maintain structure. The maximum acceleration at launch is expected to be 198 ft/s^2 with a maximum force of 1351.61N based on a launch vehicle mass of 790 oz. This value is well under the maximum buckling force. Likewise, the maximum force on landings is expected to be 304N, which is once again lower than the maximum airframe load capacities. Therefore, the airframe is expected to be structurally sound as maximum loads far exceed the maximum forces of the flight.

3.5.1.2. Nose cone

The nose cone is expected to easily sustain expected flight forces for two reasons: past success using only 3D printed plastic, and the addition of an improved fiberglass wet layup.

In the 2021 and 2022 (first vehicle demonstration flight) competitions, no additional reinforcements were added to the outside of the nose cone. The nose cone never failed in this configuration, demonstrating that PETG is strong enough to survive the expected flight forces. However, during the 2022 competition, the nose cone was dropped ~6ft onto concrete during construction which caused a large crack in the forwardmost surface of the nose cone, raising structural concerns outside of the flight envelope. To mitigate these concerns, a fiberglass wet layup was used to increase the strength of the nose cone even further. This increases the

material's tensile strength from ~7,700psi (PETG tensile strength) to 9,000-18,000psi (fiberglass tensile strength). This is a 14-148% increase in tensile strength upon a material that had already demonstrated the ability to survive multiple flights.
In the 2022 competition, a mold could not be constructed because the layup was conducted late in response to a material flaw. This negatively affected the fiberglass layup and, thus, the added strength of the material. With extra time to plan for this layup, the physical design of the nose cone has been altered to better incorporate a layup, and 3D printed mold will be used in the process of making the mold. Both of these changes will make the fiberglass layup even stronger than in previous years, which only adds to the confidence in the structure of the nose cone.

3.5.1.3. Computational Fluid Dynamics

Computational Fluid Dynamics were run on the launch vehicle to ensure that no areas of instability existed and that pressure-induced temperature remained below the limits of external materials. The figures below show ANSYS's pressure contour and temperature heat map results.

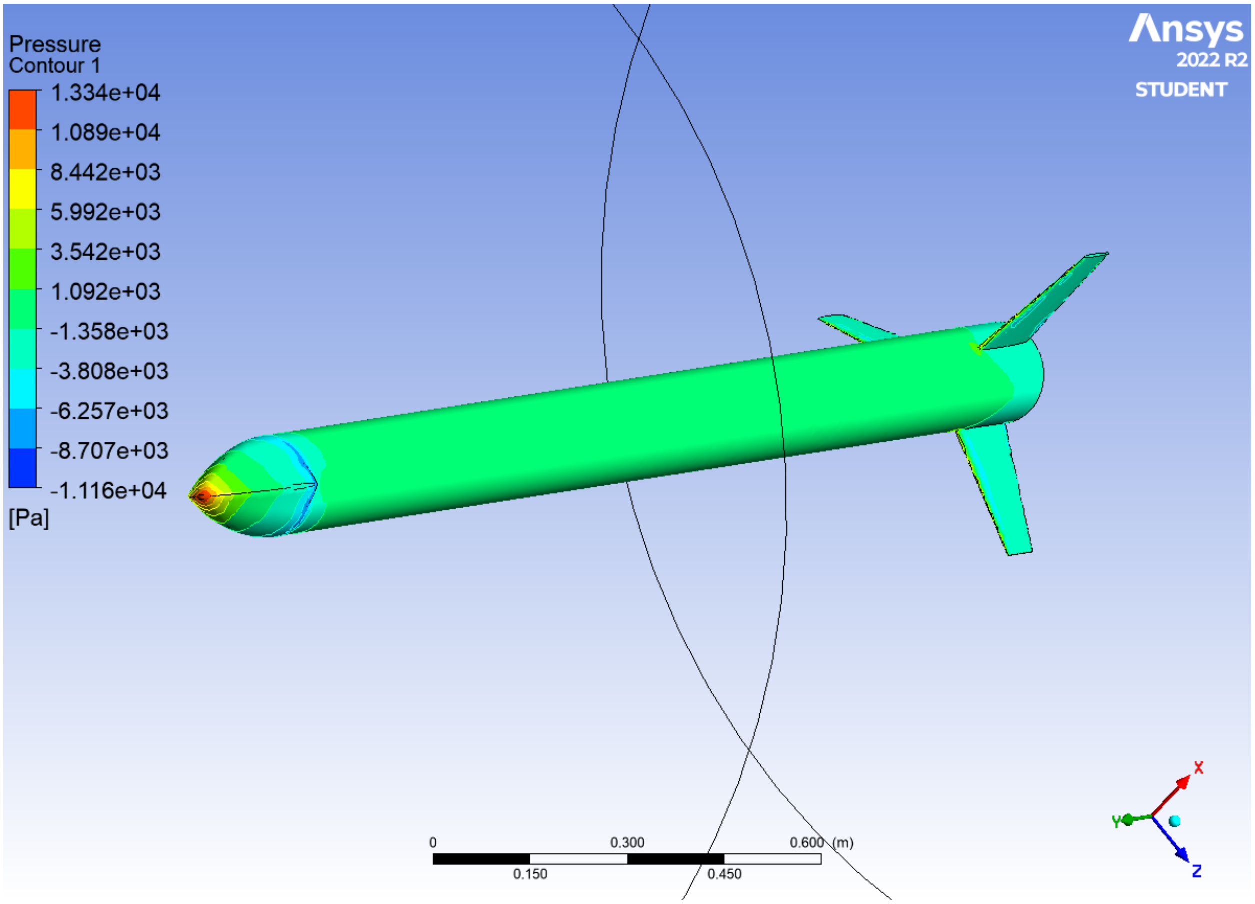


Figure 3.5.1.3.1: Pressure contour results from ANSYS

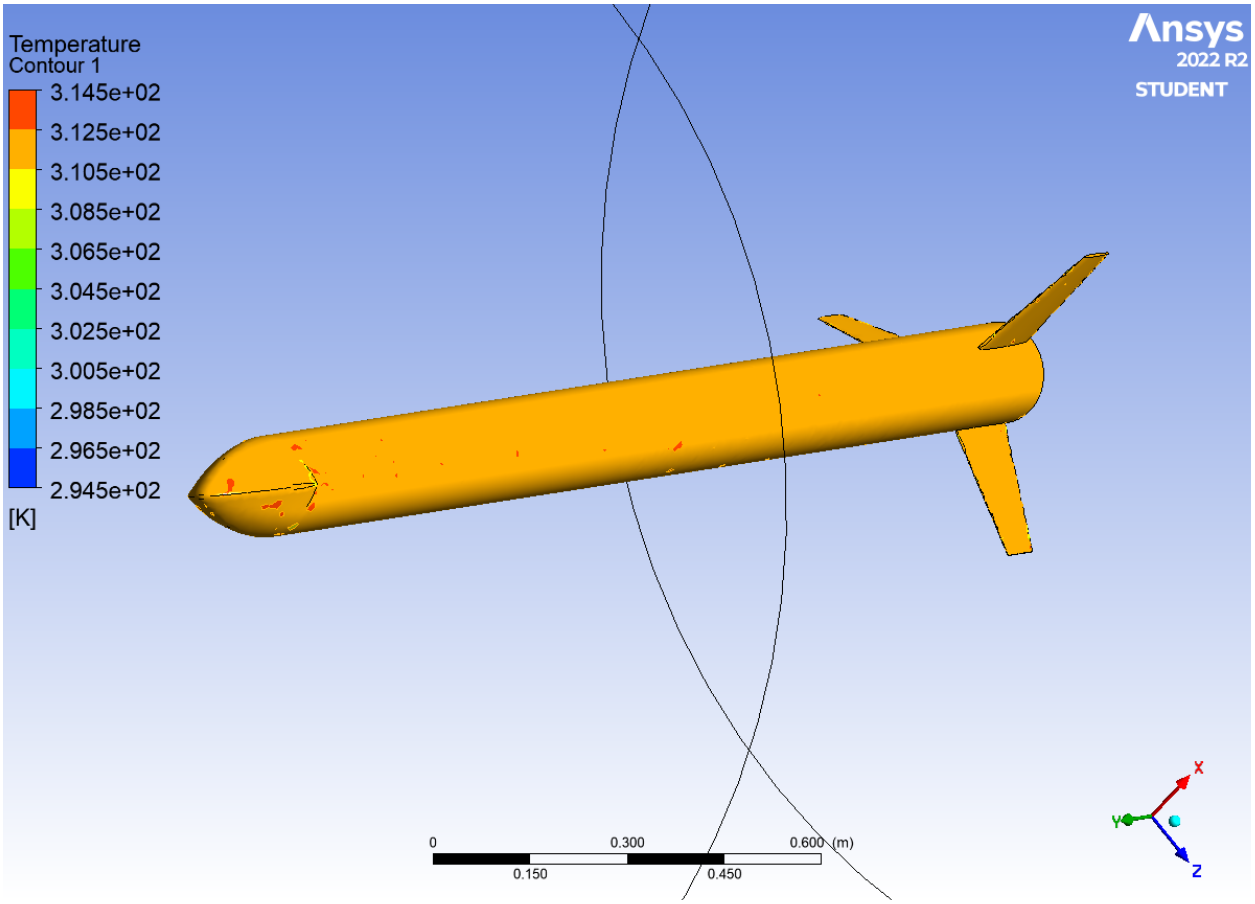


Figure 3.5.1.3.2: temperature contour results from ANSYS

As seen in figure 3.5.1.3.1 the pressure distribution is uniform and the low-pressure zone below the nosecone has no significant effect on the overall stability. As seen in figure 3.5.1.3.2 the maximum temperature of the launch vehicle during flight is 106.4F and only occurs in small isolated pockets. This temperature is well below 500F and 300F, the respective melting temperatures of PETG and fiberglass.

3.5.2. Component Weight

Parts Detail

Sustainer

Nosecone	PETG (0.734 oz/in^3)	Haack series	Len: 8 in	Mass: 0.5 lb
Nosecone Shoulder	PETG (0.734 oz/in^3)	Dia$_{in}$ 5.776 in Dia$_{out}$ 6 in	Len: 3 in	Mass: 0.285 lb
Camera Bay		Dia$_{out}$ 4 in		Mass: 1.2 lb
Ballast		Dia$_{out}$ 0.984 in		Mass: 1.25 lb
Payload	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 6 in Dia$_{out}$ 6.17 in	Len: 22 in	Mass: 2.78 lb
Payload Coupler	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 5.776 in Dia$_{out}$ 6 in	Len: 12 in	Mass: 2 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia$_{out}$ 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia$_{out}$ 6 in	Len: 0.125 in	Mass: 0.258 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia$_{out}$ 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia$_{out}$ 6 in	Len: 0.125 in	Mass: 0.258 lb
Payload		Dia$_{out}$ 5 in		Mass: 6.3 lb
Upper Recovery	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 6 in Dia$_{out}$ 6.17 in	Len: 16 in	Mass: 2.02 lb
Drogue	Ripstop nylon (0.22 oz/ft^2)	Dia$_{out}$ 18 in	Len: 7 in	Mass: 0.141 lb
Shroud Lines	Tubular nylon (11 mm, 7/16 in) (0.14 oz/ft)	Lines: 8	Len: 20 in	
Drogue Shock Cord	3/8in Tubular Kevlar (0.226 oz/ft)		Len: 360 in	Mass: 0.424 lb
Avionics Switchband	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 6 in Dia$_{out}$ 6.17 in	Len: 1 in	Mass: 0.127 lb
Avionics Equipment		Dia$_{out}$ 5 in		Mass: 2.93 lb
Avionics Bay	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 5.776 in Dia$_{out}$ 6 in	Len: 5 in	Mass: 0.807 lb
Ballast		Dia$_{out}$ 0.984 in		Mass: 2 lb
Lower Recover	G12 Fiberglass (1.25 oz/in^3)	Dia$_{in}$ 6 in Dia$_{out}$ 6.17 in	Len: 23 in	Mass: 2.91 lb
Main	Ripstop nylon (0.22 oz/ft^2)	Dia$_{out}$ 144 in	Len: 14 in	Mass: 1.99 lb

Shroud Lines	Tubular nylon (11 mm, 7/16 in) (0.14 oz/ft)	Lines: 8	Len: 120 in	
Main Shock Cord	3/8in Tubular Kevlar (0.226 oz/ft)		Len: 720 in	Mass: 0.848 lb
Bolts		Dia_{out} 1 in		Mass: 1.2 lb
Booster	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 28 in	Mass: 3.54 lb
Launch lug	Aluminum (1.56 oz/in^3)	Dia_{in} 0 in Dia_{out} 0.5 in	Len: 0.4 in	Mass: 0.008 lb
Launch lug	Aluminum (1.56 oz/in^3)	Dia_{in} 0 in Dia_{out} 0.5 in	Len: 0.4 in	Mass: 0.008 lb
MFSS	Aluminum (1.56 oz/in^3)	Dia_{in} 4 in Dia_{out} 6 in	Len: 9.1 in	Mass: 1.1 lb
Fins and Inserts (3)	EpoxAcast™ 670 HT (0.665 oz/in^3)	Thick: 0.4 in		Mass: 2.8 lb
Booster Coupler	G12 Fiberglass (1.25 oz/in^3)	Dia_{in} 5.776 in Dia_{out} 6 in	Len: 12 in	Mass: 2 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 6 in	Len: 0.125 in	Mass: 0.258 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 5.776 in	Len: 0.125 in	Mass: 0.24 lb
Bulkhead	G10 Fiberglass (1.17 oz/in^3)	Dia_{out} 6 in	Len: 0.125 in	Mass: 0.258 lb
Egg Finder		Dia_{out} 2 in		Mass: 0.25 lb

Figure 3.5.2.1: Launch Vehicle Component List

3.5.3. Motor Thrust Curve

The launch vehicle uses a Cesaroni 4263-L1350-CS-P motor, and the thrust curve, simulated on OpenRocket, is presented below.

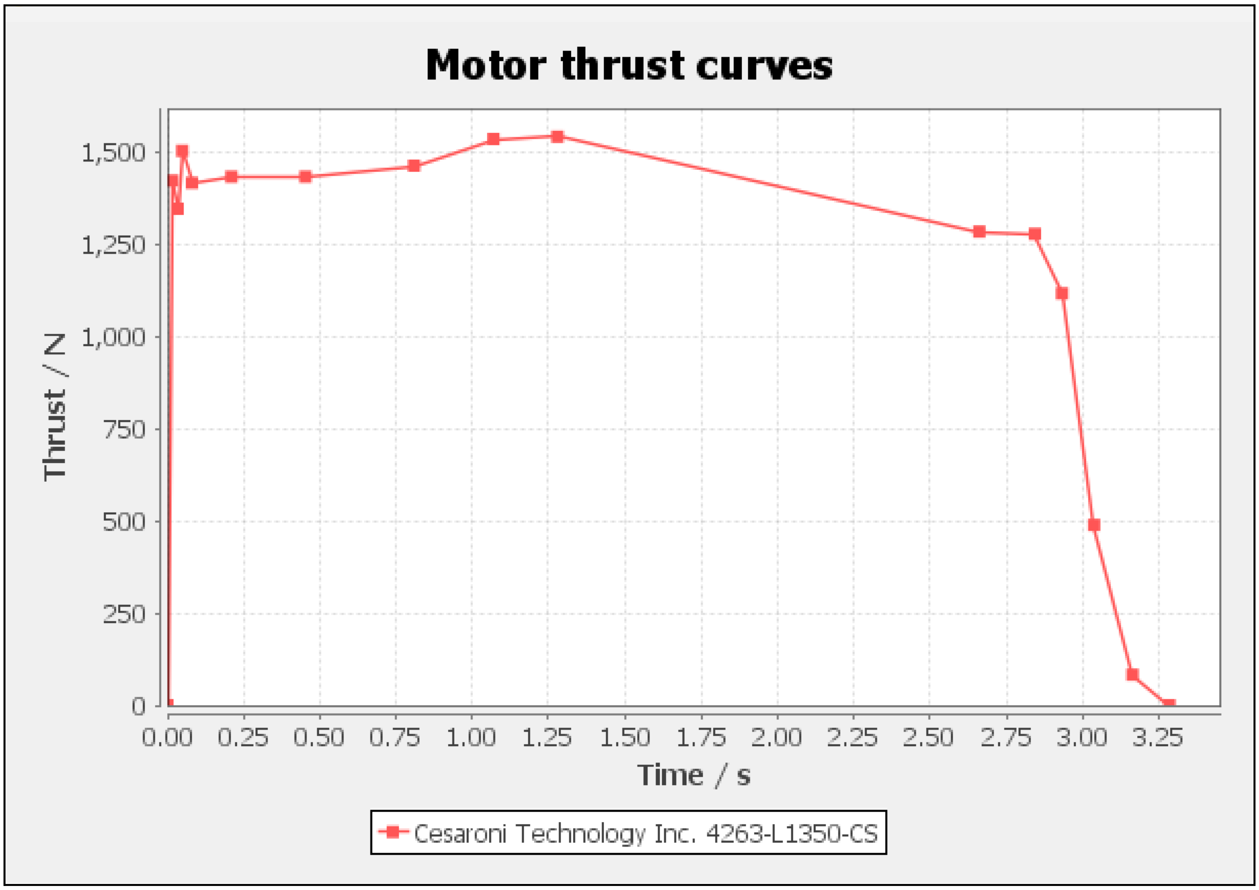


Figure 3.5.3.1: Thrust and propellant mass versus time

3.5.4. Official Competition Launch Target Altitude

The team's official competition launch target altitude is 4050' AGL. This target altitude was determined utilizing the methods shown in the flight profile simulations section. All altitudes for the remainder of this report will be reported as AGL.

3.5.5. Flight Profile Simulations

The primary simulator for the flight profile simulations is OpenRocket. OpenRocket simulation is the extended Barrowman equations with six degrees of freedom and a fourth-order Runge-Kutta differential equation numerical integration of the equations of motion.

The OpenRocket simulations were performed with a wind speed variation of 5 mph between 0 mph and 20 mph and a 2.5-degree launch angle variation between 5 and 10 degrees. The launch angles in the NASA competition handbook are between 5 and 10 degrees, and the wind speed is from 0 mph to 20 mph. Therefore the predicted apogee is calculated using values in between the NASA competition handbook values.

The calculations for apogee with varying wind speed and launch angle are presented in the table below, in addition to other important mission performance metrics.

Launch Angle (deg)	Wind Speed (mph)	Landing Kinetic Energy of heaviest section (ft-lbf)	Descent Time (sec)	Apogee (ft)	Min Stability	Drift Distance (ft)
5	0	56.02	74.8	4265	3.04	269
5	5	44.92	73.5	4193	3.15	133
5	10	44.92	71.7	4092	2.63	538
5	15	44.92	71.5	3965	2.29	986
5	20	56.02	69	3821	2.05	1358
7.5	0	56.02	71.6	4206	3.91	378
7.5	5	56.02	72.1	4110	3.16	36
7.5	10	56.02	72.6	3988	2.65	482
7.5	15	44.92	69.9	3844	2.31	883
7.5	20	56.02	69.1	3687	2.07	1313
10	0	44.92	72.2	4125	3.89	471
10	5	56.02	70.6	4007	3.16	49
10	10	44.92	71.3	3867	2.66	403
10	15	44.92	71	3709	2.33	856
10	20	56.02	66.8	3541	2.1	1205

Table 3.5.5.1 : Summary table of flight simulations

Weather data, particularly wind speed from Huntsville, Alabama on previous launch days, was used to determine the weights of the wind speeds found in the table below. In addition, since wind speed determines the launch angle, the corresponding launch angles for the given wind speeds are in the table below. These are the only wind speed and launch angle combinations used in determining average weighted apogee.

Weights of Target Apogee	**Variable**
Weight	Wind Speed (mph)
0.15	0
0.3	5
0.35	10
0.15	15
0.05	20

Table 3.5.5.2: A weighted average was calculated using the weights below

Wind Speeds of Target Apogee	**Corresponding Angle**
Wind Speed (mph)	Angle (deg)
0	5
5	5
10	7.5
15	7.5, 10
20	10

Table 3.5.5.3: The wind speed with the above launch angles were used for the weighted average

Target Apogee	**Weighted Final Average Apogee**
4050ft	4037ft

Table 3.5.5.4: The target apogee and weighted average apogee for specified simulations

The target apogee is 4050' and the predicted apogee is 4037' (13' smaller than the target average apogee) because the team is estimating launch conditions in Huntsville will be more ideal versus less ideal on launch day.

Vehicle Trajectory Simulations were performed with the finalized OpenRocket model. Altitude, Total Acceleration, and Total Velocity v.s. Time simulation plots were produced for each combination of launch angle and wind speed, as shown in the summary table of flight simulations. The plots are presented below.

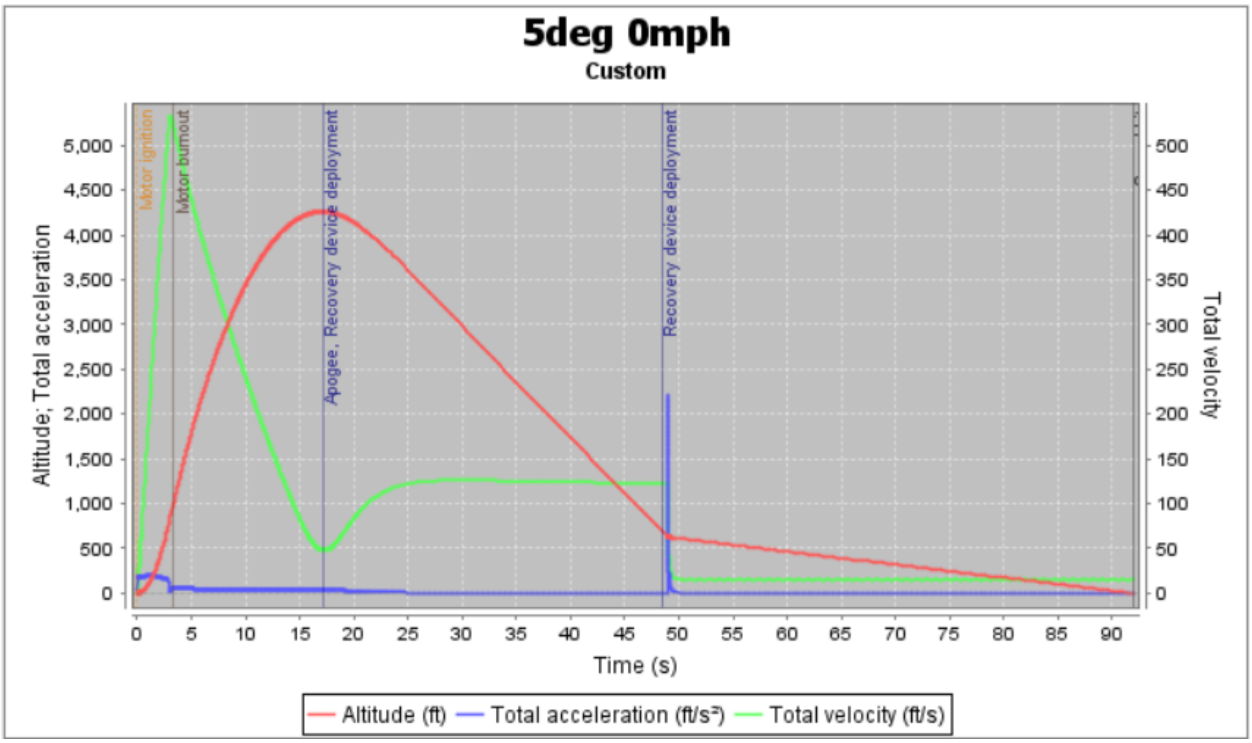


Figure 3.5.5.1 Altitude, Total Acceleration and Total Velocity v.s. Time for 5 degree launch angle and 0 wind speed

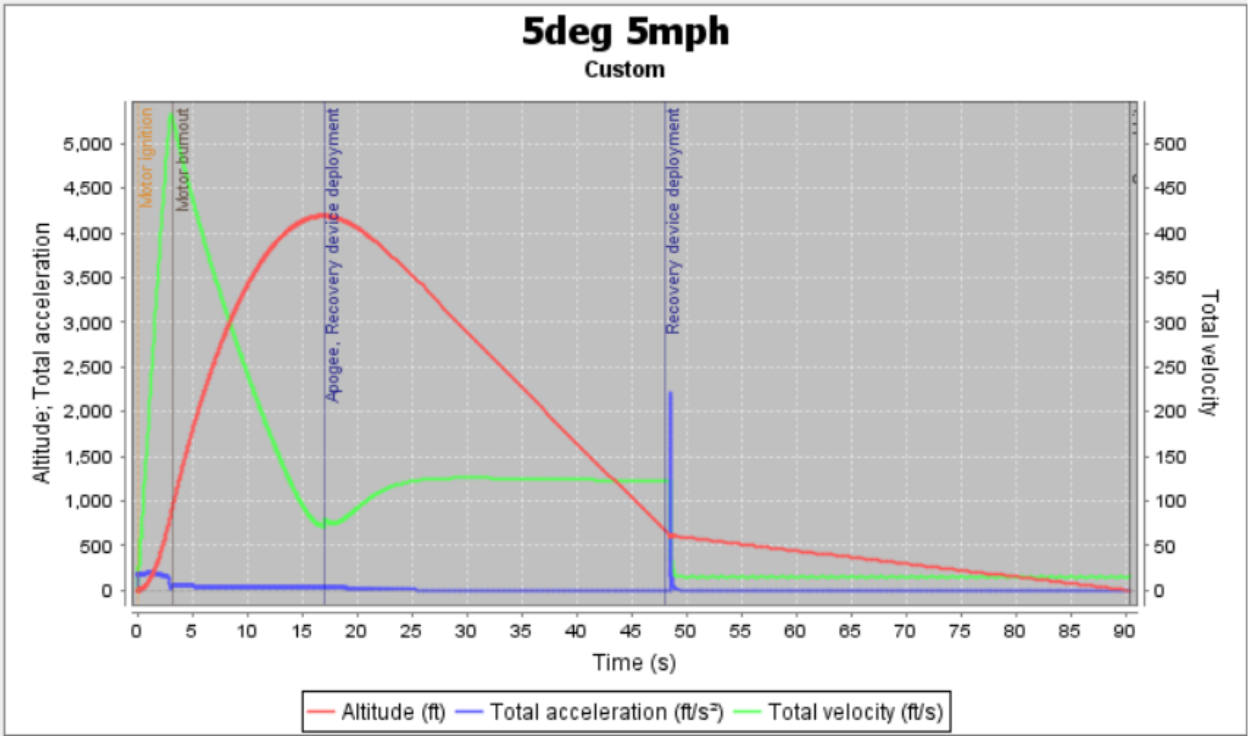


Figure 3.5.5.2 Altitude, Total Acceleration and Total Velocity v.s. Time for 5 degree launch angle and 5 mph wind speed

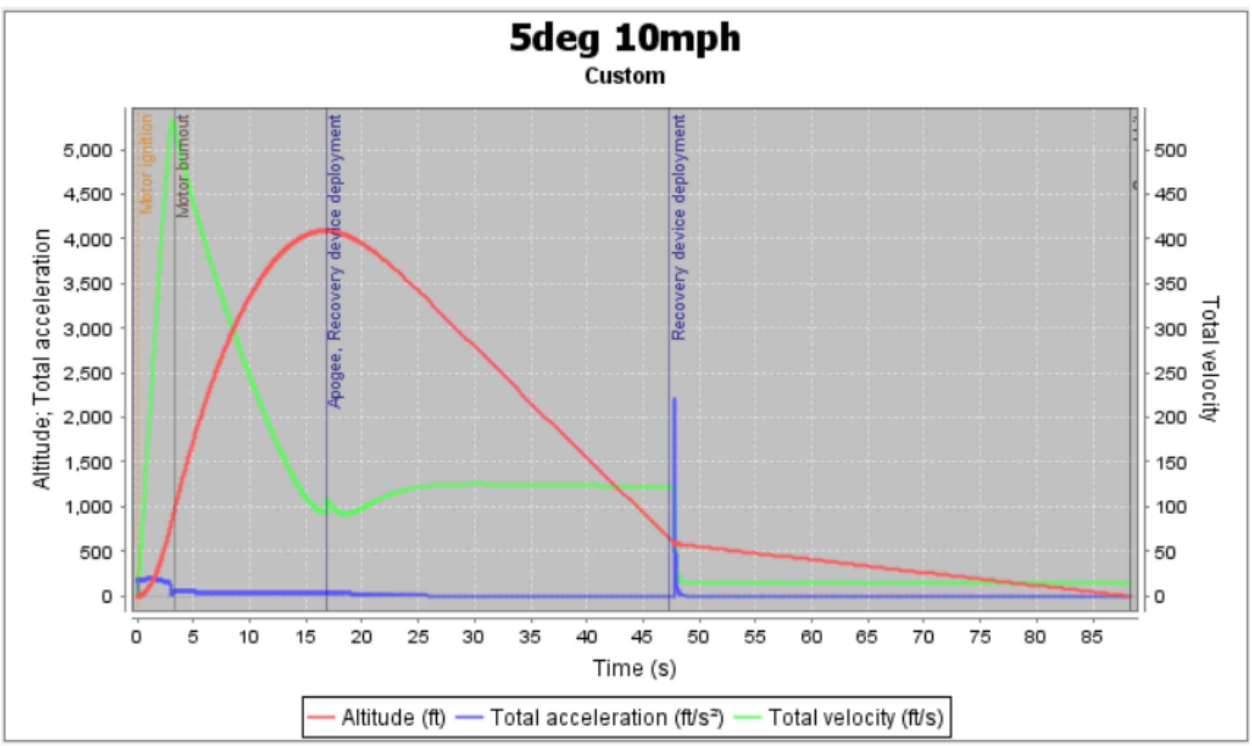


Figure 3.5.5.3 Altitude, Total Acceleration and Total Velocity v.s. Time for 5 degree launch angle and 10 mph wind speed

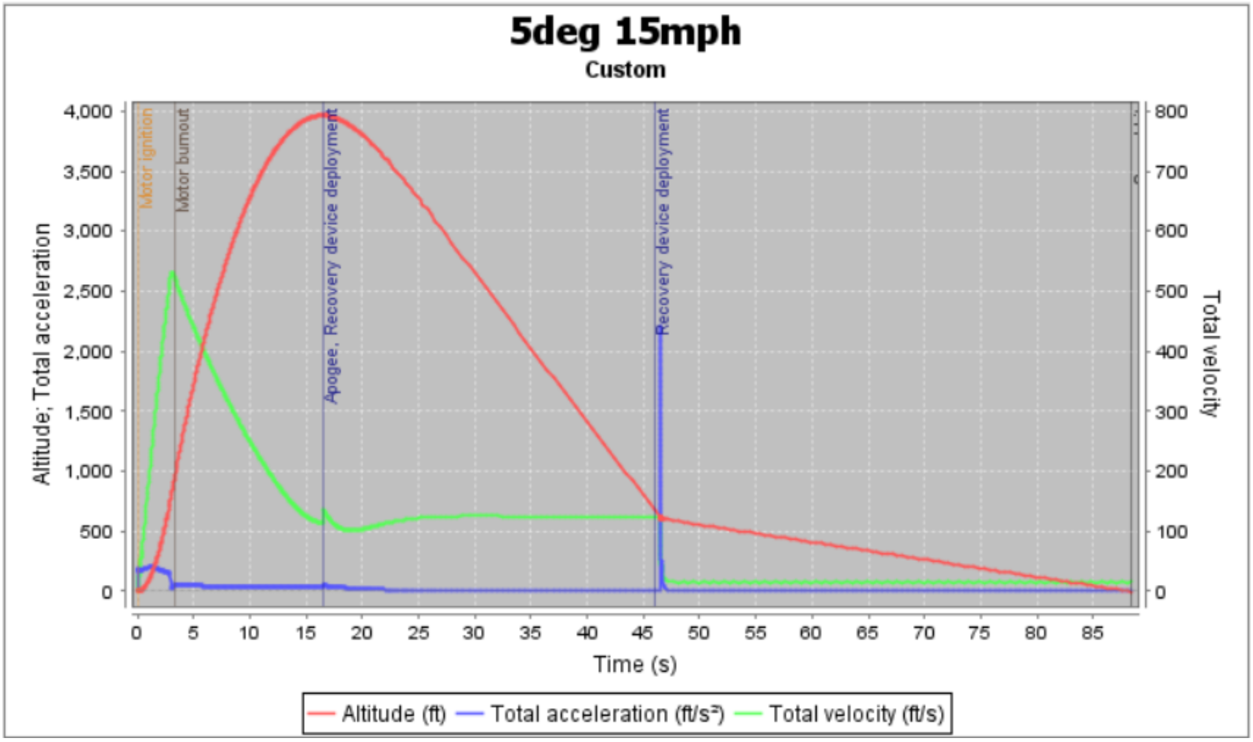


Figure 3.5.5.4 Altitude, Total Acceleration and Total Velocity v.s. Time for 5 degree launch angle and 15 mph wind speed

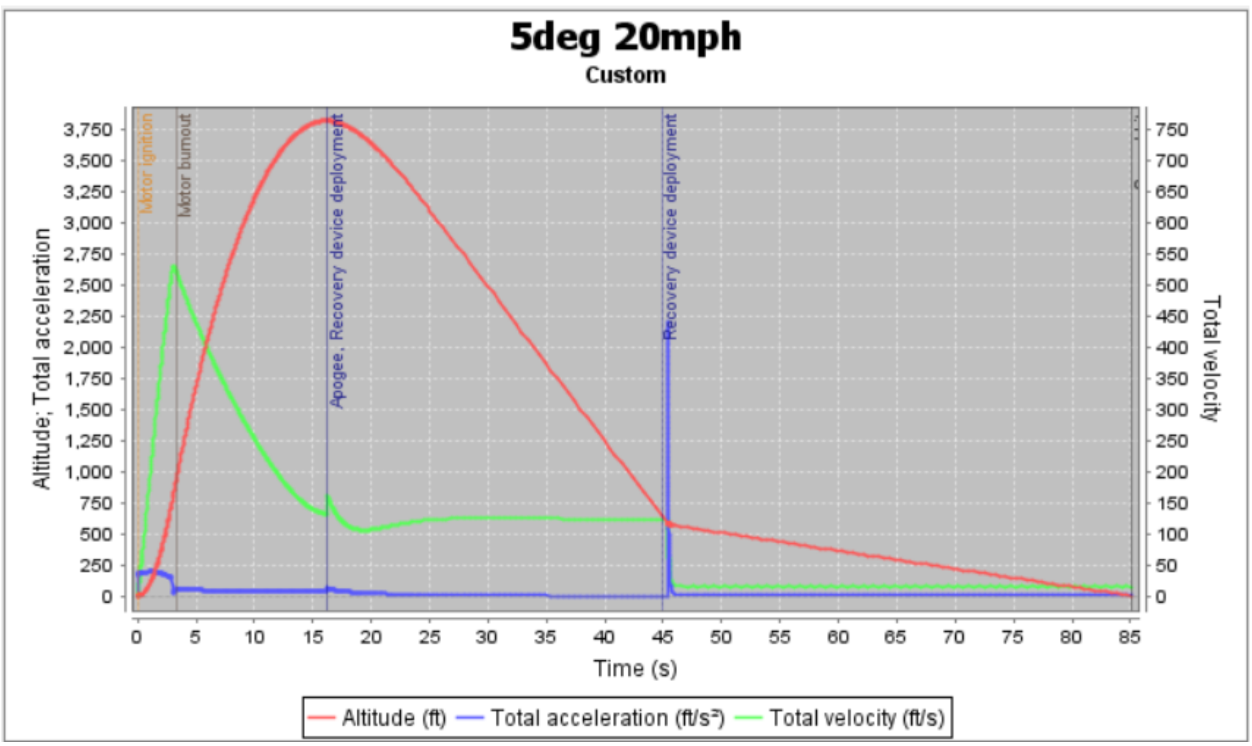


Figure 3.5.5.5 Altitude, Total Acceleration and Total Velocity v.s. Time for 5 degree launch angle and 20 mph wind speed

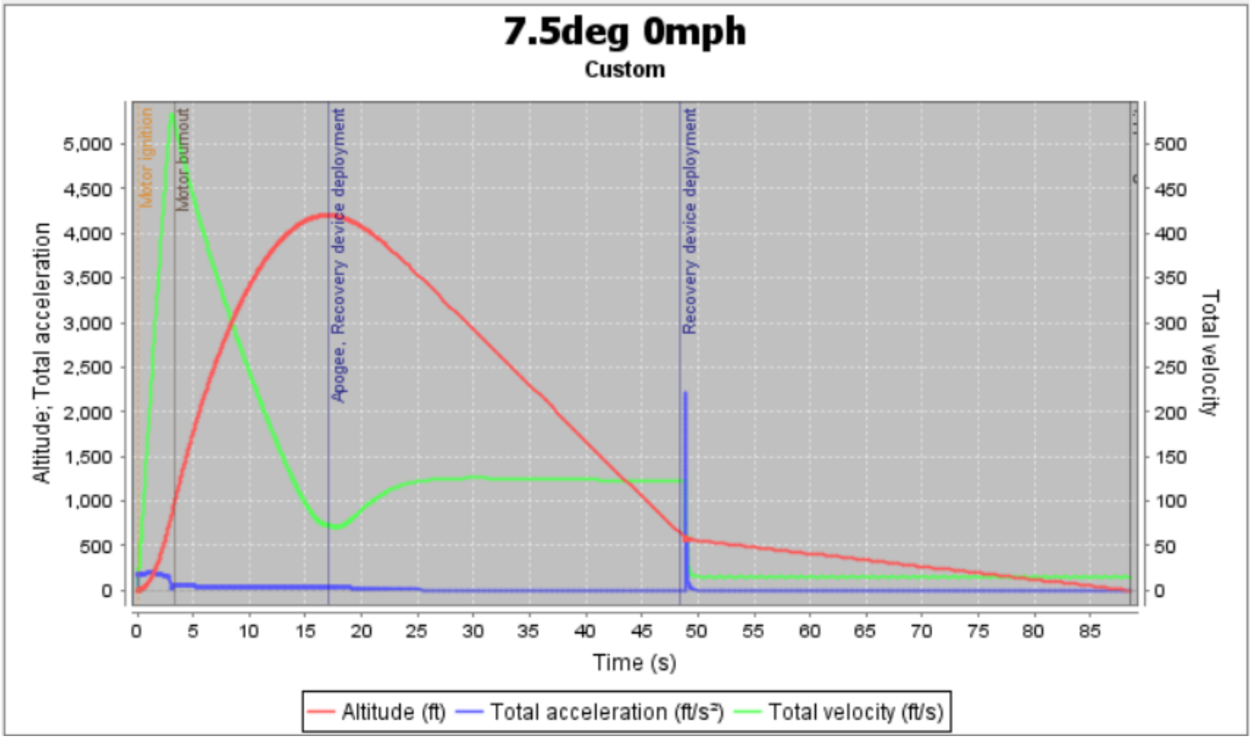


Figure 3.5.5.6 Altitude, Total Acceleration and Total Velocity v.s. Time for 7.5 degree launch angle and 0 wind speed

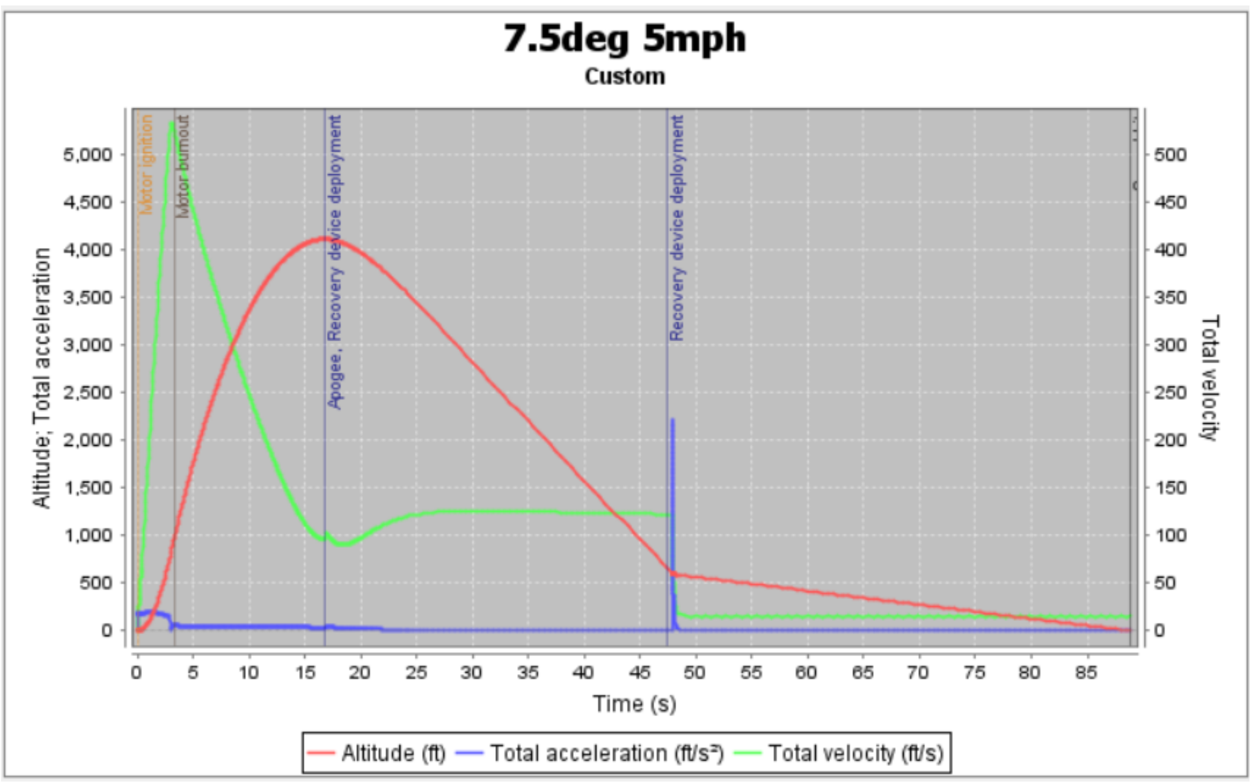


Figure 3.5.5.7 Altitude, Total Acceleration and Total Velocity v.s. Time for 7.5 degree launch angle and 5 mph wind speed

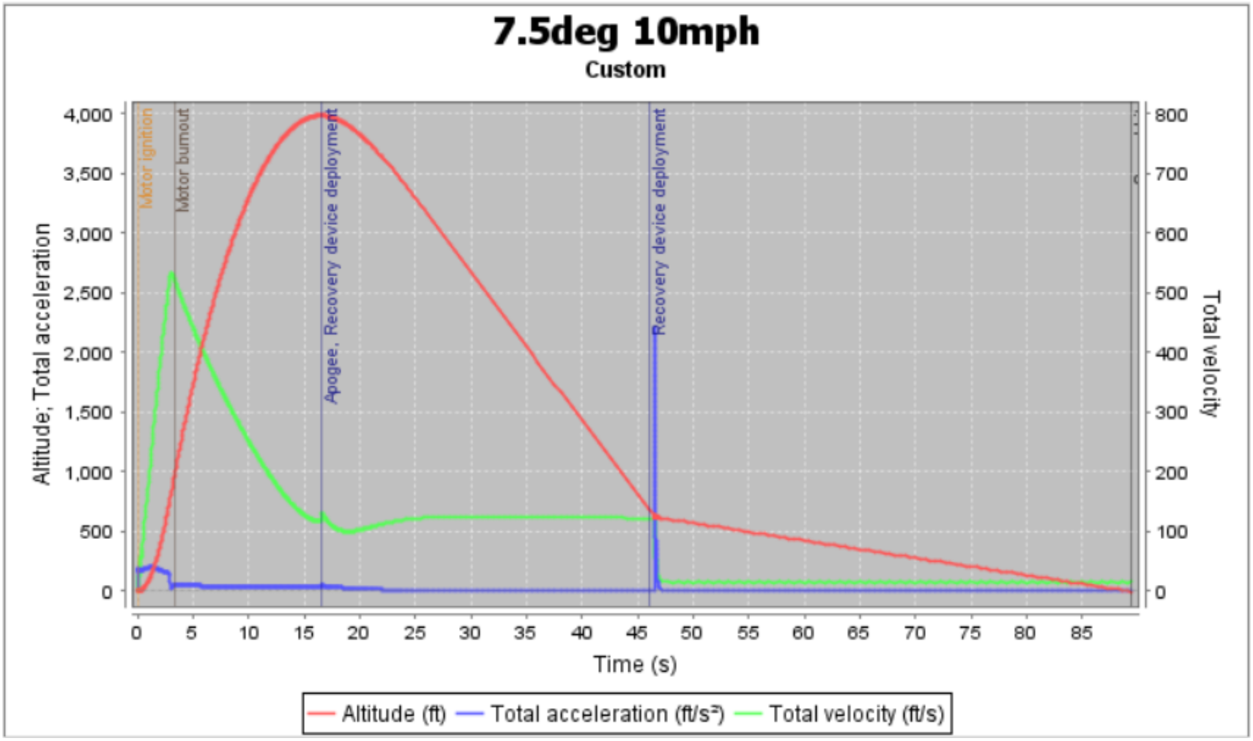


Figure 3.5.5.8 Altitude, Total Acceleration and Total Velocity v.s. Time for 7.5 degree launch angle and 10 mph wind speed

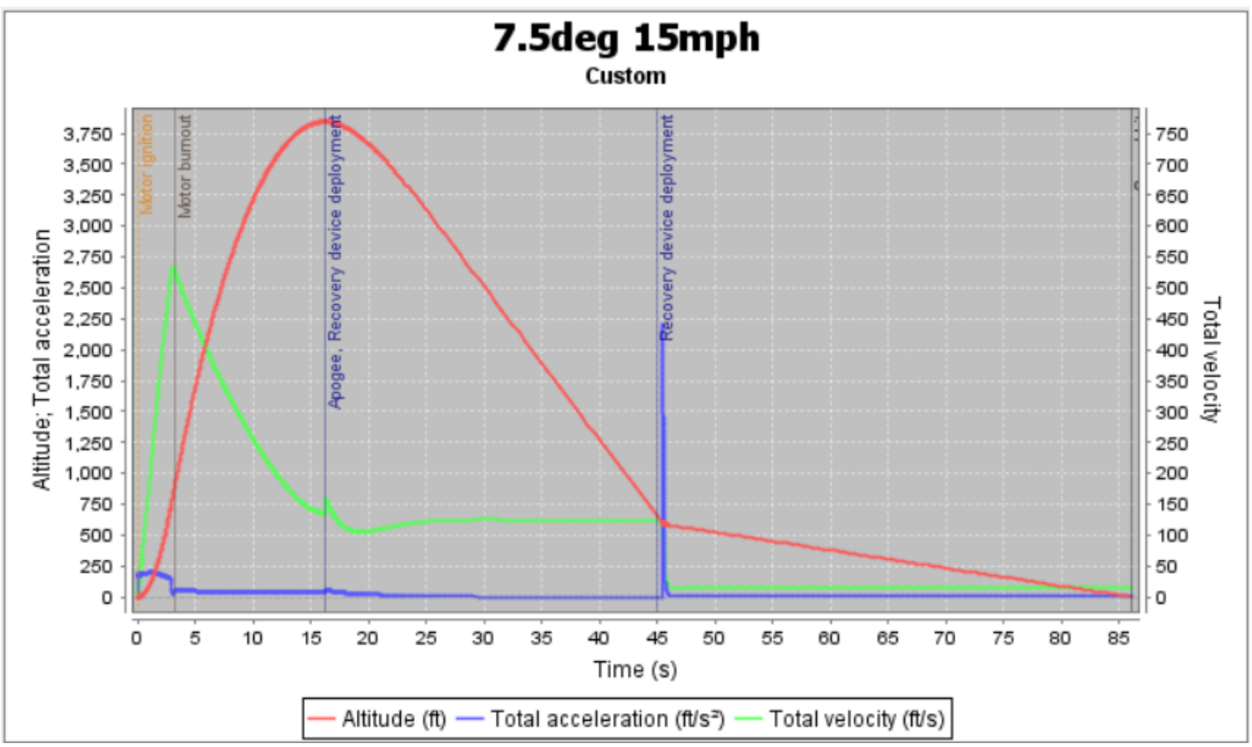


Figure 3.5.5.9 Altitude, Total Acceleration and Total Velocity v.s. Time for 7.5 degree launch angle and 15 mph wind speed

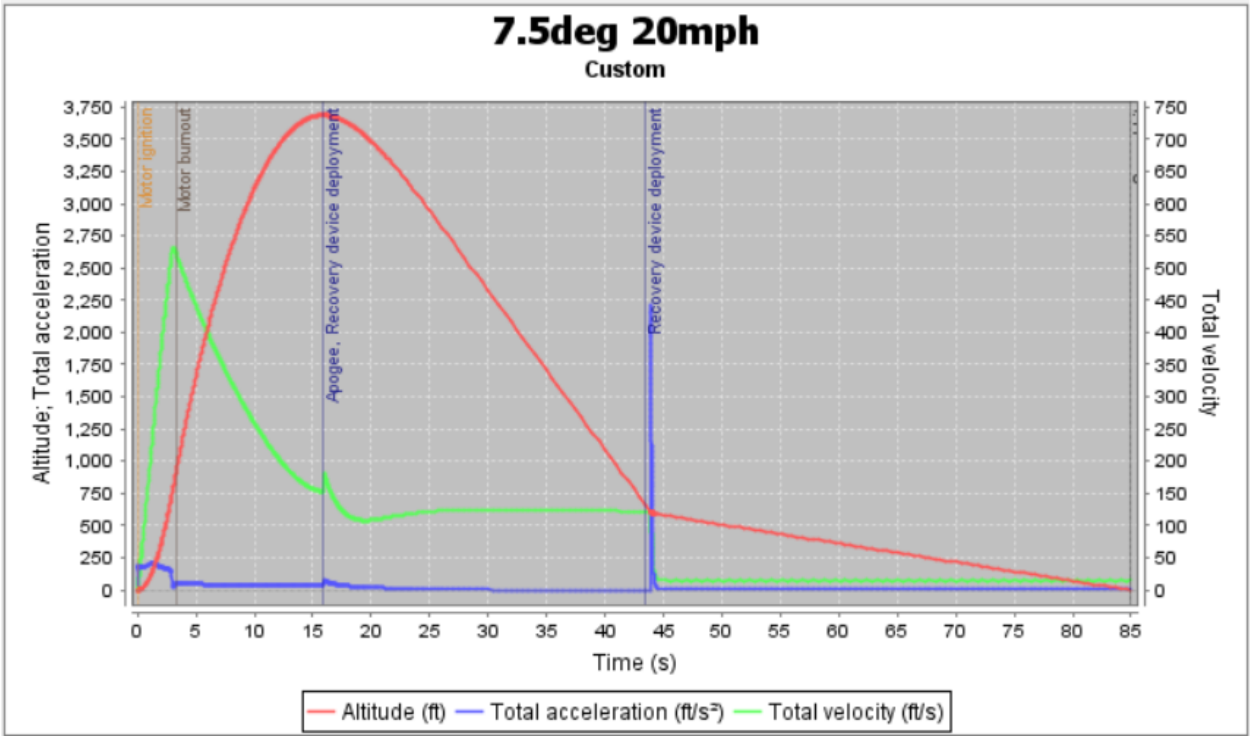


Figure 3.5.5.10 Altitude, Total Acceleration and Total Velocity v.s. Time for 7.5 degree launch angle and 20 mph wind speed

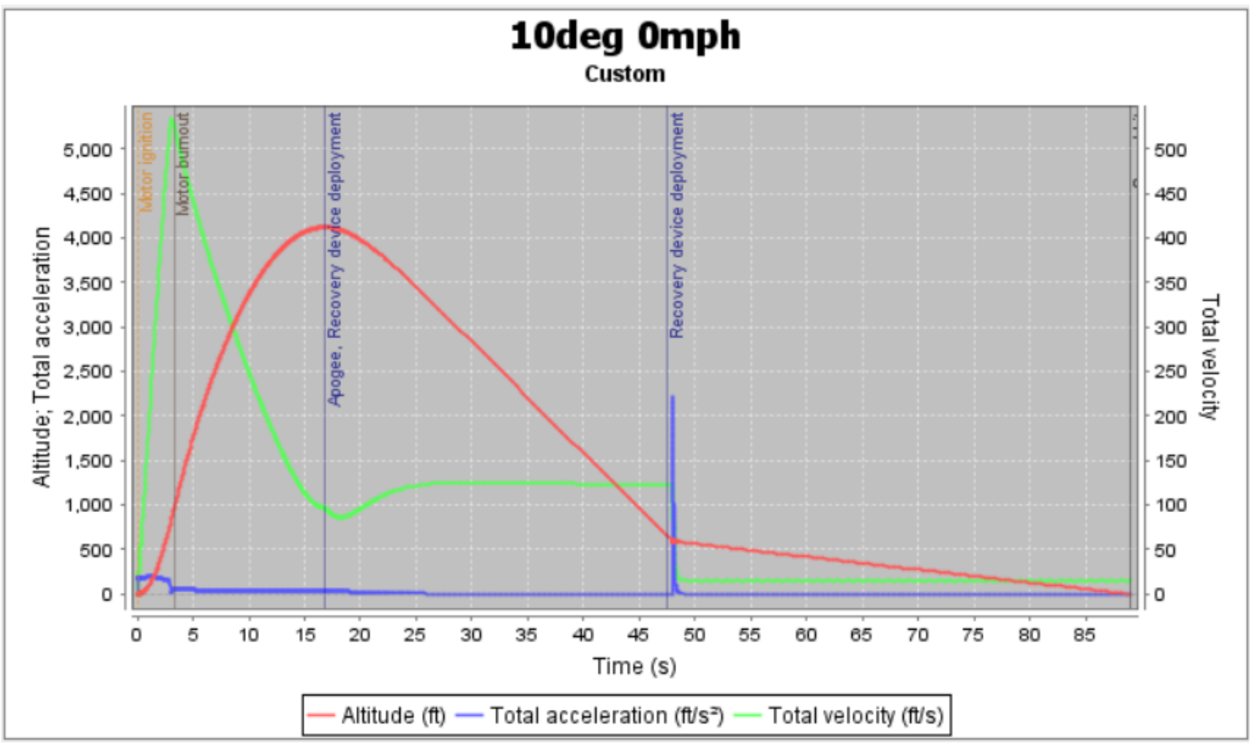


Figure 3.5.5.11 Altitude, Total Acceleration and Total Velocity v.s. Time for 10 degree launch angle and 0 wind speed

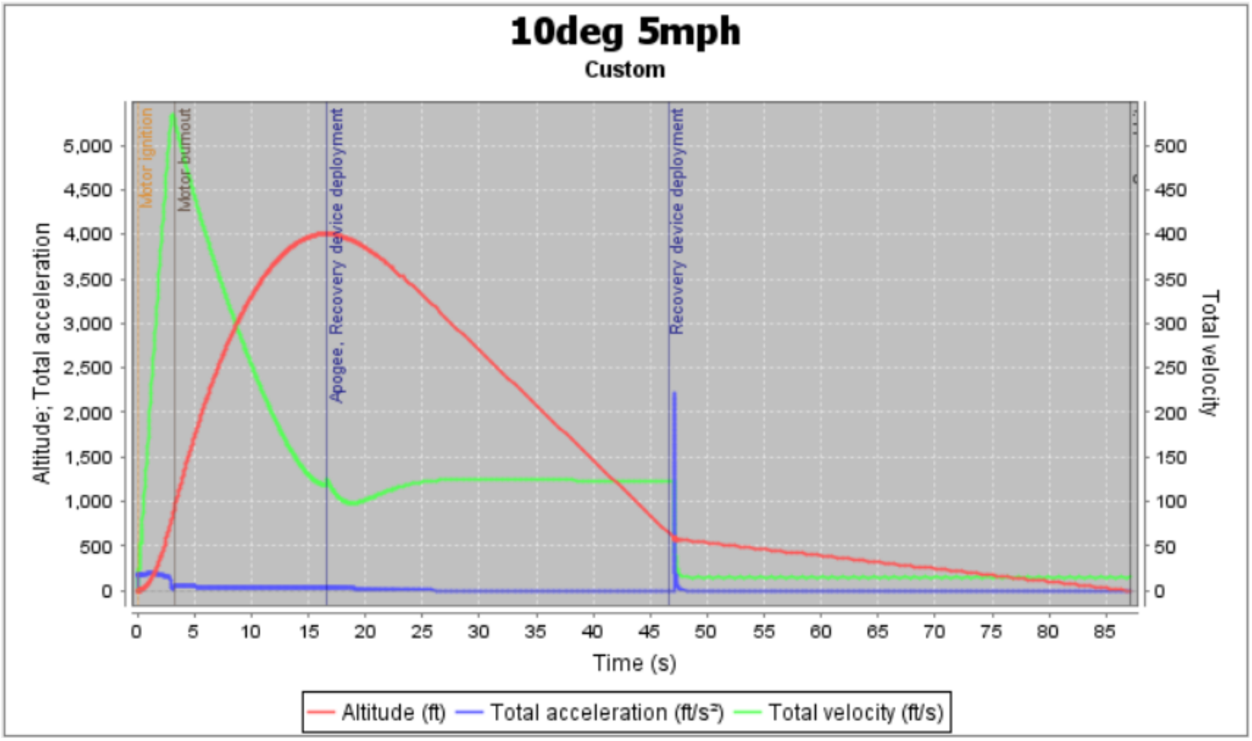


Figure 3.5.5.12 Altitude, Total Acceleration and Total Velocity v.s. Time for 10 degree launch angle and 5 mph wind speed

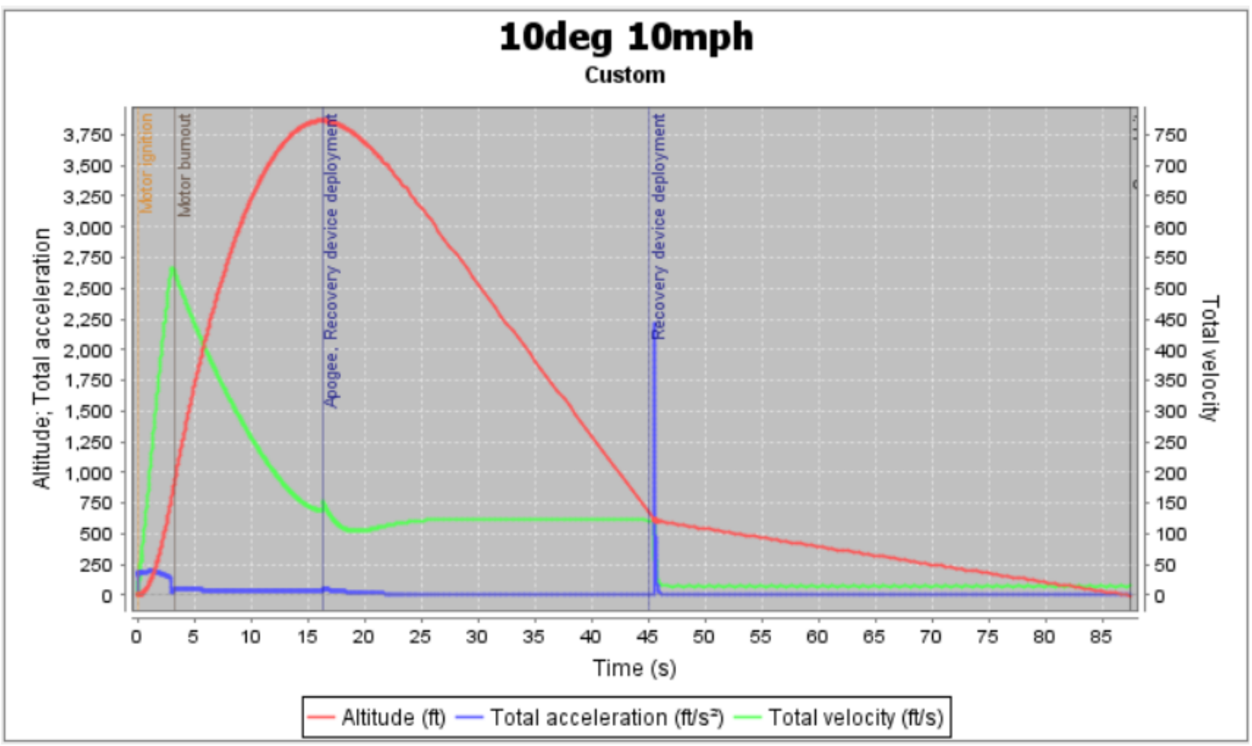


Figure 3.5.5.13 Altitude, Total Acceleration and Total Velocity v.s. Time for 10 degree launch angle and 10 mph wind speed

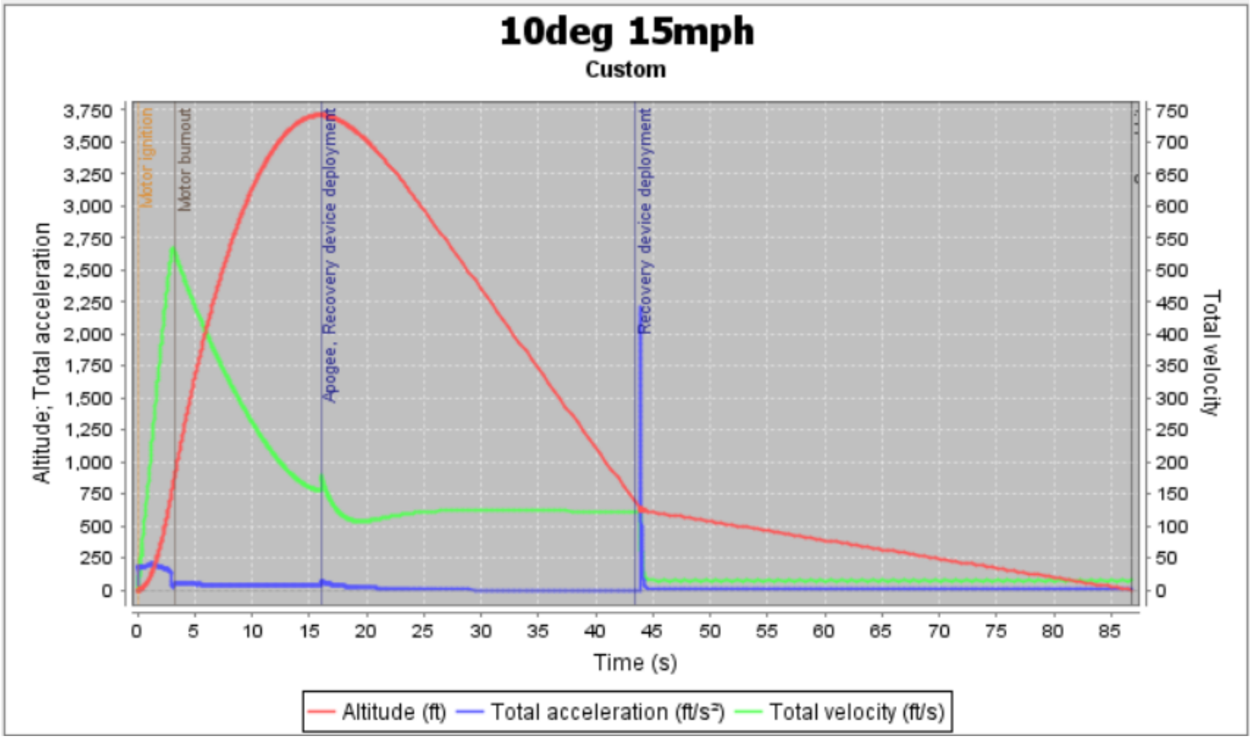


Figure 3.5.5.14 Altitude, Total Acceleration and Total Velocity v.s. Time for 10 degree launch angle and 15 mph wind speed

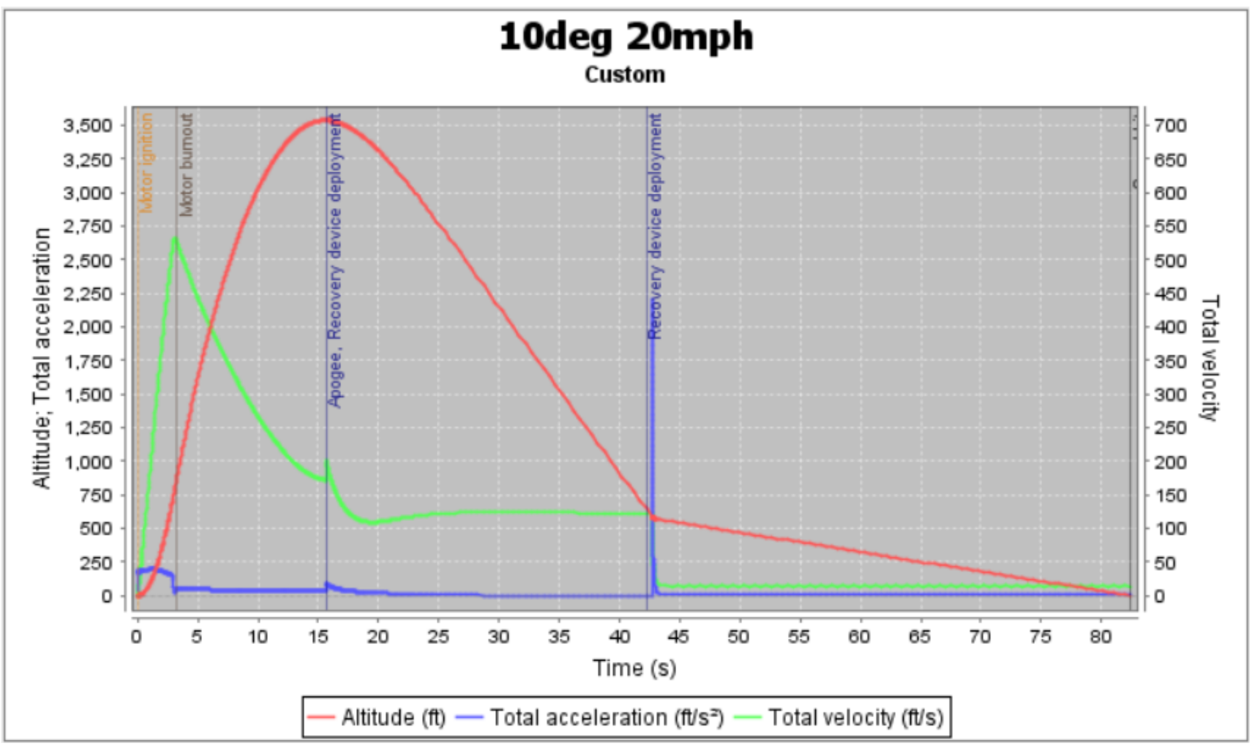


Figure 3.5.5.15 Altitude, Total Acceleration and Total Velocity v.s. Time for 10 degree launch angle and 20 mph wind speed

3.5.6. Stability margin, CP, CG

Minimum stability margin calibers were simulated for every combination of launch angle and wind speed explored for flight profiles. A few changes were made to the model since the Preliminary Design Review (PDR). OpenRocket simulations utilize the Barrowman Equations. The team's derived criteria (S.C.17) ensure that the simulated minimum stability margin calibers will be at least 2.1 cal at the rail exit. A table of minimum stability margin calibers with different launch angles and wind speeds is presented below.

Launch Angle (deg)	Wind Speed (mph)	Min Stability (calibers)
5	0	3.04
5	5	3.15
5	10	2.63
5	15	2.29
5	20	2.05
7.5	0	3.91
7.5	5	3.16
7.5	10	2.65
7.5	15	2.31
7.5	20	2.07
10	0	3.89
10	5	3.16
10	10	2.66
10	15	2.33
10	20	2.1

Table 3.5.6.1 : Stability of Launch Vehicle

All the simulated minimum stability margin calibers shown in the table above are above 2.1 stability at rail exit; therefore the launch vehicle design meets the team's and NASA's stability requirements.

OpenRocket Stability Verification

Center of Pressure (in. from nose) (red)	77.346
Center of Gravity (in. from nose) (blue)	53.186

Table 3.5.6.2 : Center of Pressure and Center of Gravity

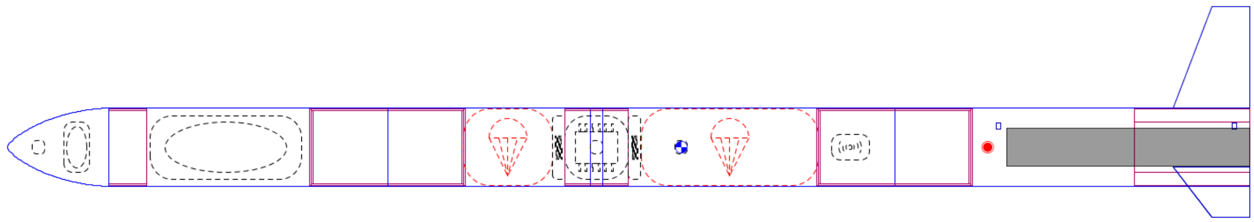


Figure 3.5.6.3 : Launch Vehicle with CP and CG displayed

The Center of Pressure for the finalized OpenRocket model is 77.35”. The Center of Gravity for the finalized OpenRocket model is 53.186”. Both numbers are measured from the nose cone tip of the rocket.

3.5.7. Landing Kinetic Energy

The team calculated Landing Kinetic Energy for each section of the final launch vehicle. The vehicle was divided into three sections: Payload, Recovery, and Booster. The Payload section comprises the Nose Cone and Payload. The recovery section comprises Upper & Lower Recovery and Avionics Switchband. The booster section comprises the booster and an empty motor. An empty motor weighs 3.41 lb after burnout. A table of each launch vehicle section is presented below for reference.

Payload (lb)	Recovery (lb)	Booster (lb)
15.34	15.4	14.11

Landing Kinetic Energy formula is as follow:

$$Ke = 0.5 * (m / 32.17) * v \wedge 2$$

Ke: kinetic energy, ft-lbf

m: weight of one section of the launch vehicle, lb

v: velocity at landing of the launch vehicle, ft/s

Landing velocities were simulated and obtained using an OpenRocket model of the launch vehicle. OpenRocket only returns one of two landing velocities for every scenario, either

15.3ft/s or 13.7ft/s. Landing kinetic energy was calculated with the higher velocity, 15.3ft/s, to account for the worst-case scenario.

Using the Landing Kinetic Energy formula, the team calculated landing kinetic energy for each section of the launch vehicle:

Payload Kinetic Energy (ft-lbs)	Recovery Kinetic Energy (ft-lbs)	Booster Kinetic Energy (ft-lbs)
55.81	56.02	51.33

The heaviest section of the launch vehicle, recovery, has landing kinetic energy lower than the 75ft-lbf competition maximum set by NASA and the 65ft-lbf maximum required for bonus points. This results in a sufficient margin to achieve both requirements.

3.5.8. Descent time

Descent Time formula:

Descent Time = Flight Time - Time to Apogee

The 18” drudge parachute deploys at apogee, and the 144” main parachute deploys at 700’. Under these two conditions, the time of flight and time to apogee were simulated in OpenRocket. By using the formula above, the team calculated the descent time. A table of vehicle descent time with different launch angles (deg) and wind speeds(mph) is presented below.

Launch Angle (deg)	Wind Speed (mph)	Descent Time (sec)
5	0	74.8
5	5	73.5
5	10	71.7
5	15	71.5
5	20	69
7.5	0	71.6
7.5	5	72.1

7.5	10	72.6
7.5	15	69.9
7.5	20	69.1
10	0	72.2
10	5	70.6
10	10	71.3
10	15	71
10	20	66.8
Weighted Average		**72.43**

Table 3.5.8.1 : Decent Time of Launch Vehicle

Every decent time above, including the weighted average, is below the 90sec competition maximum set by NASA and the 80sec maximum required for bonus points. This results in a sufficient margin to achieve both requirements.

3.5.9. Drift Distance

In order to calculate the accurate drift distance of the launch vehicle, it is important to establish correct launch site parameters. The latitude of the launch site is 34.7°N, the longitude is -86.6°E, the altitude is 600 ft, and the length of the launch rod is 144". The team simulated and calculated drift distance at every launch angle and wind speed combination explored in the flight profile section. It is reasonable and safe to assume that the drift distance applies to all parts of the launch vehicle because every part is tethered together during the entire flight. A table of drift distance under different launch angles and wind conditions is presented below.

Launch Angle (deg)	Wind Speed (mph)	Drift Distance(ft)
5	0	269
5	5	133
5	10	538
5	15	986
5	20	1358

7.5	0	378
7.5	5	36
7.5	10	482
7.5	15	883
7.5	20	1313
10	0	471
10	5	49
10	10	403
10	15	856
10	20	1205

Table 3.5.9.1 : Drift Distance from Apogee

Drift distance prediction plots for each of the wind speeds (0, 5, 10, 15, and 20 mph) were simulated and produced on OpenRocket, and they are presented below.

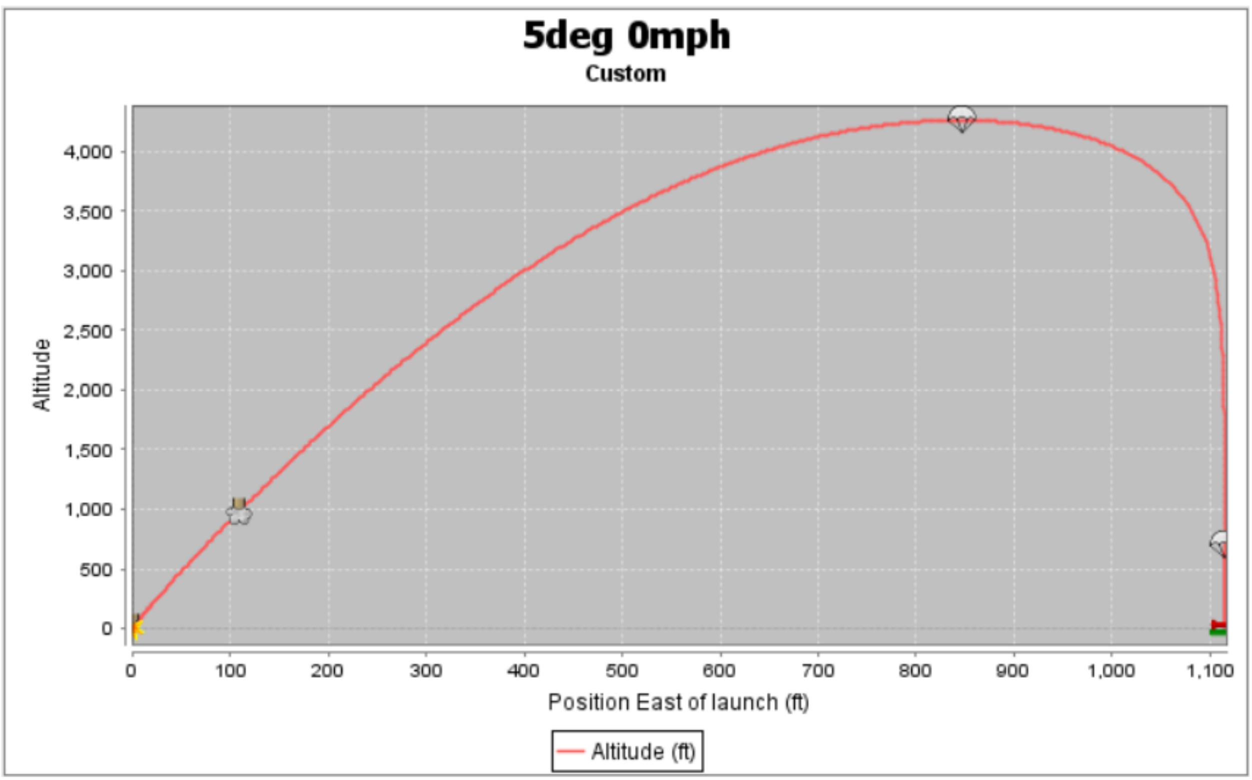


Figure 3.5.9.1 Altitude v.s. Position East of Launch for 5 degree launch angle and 0 mph wind speed

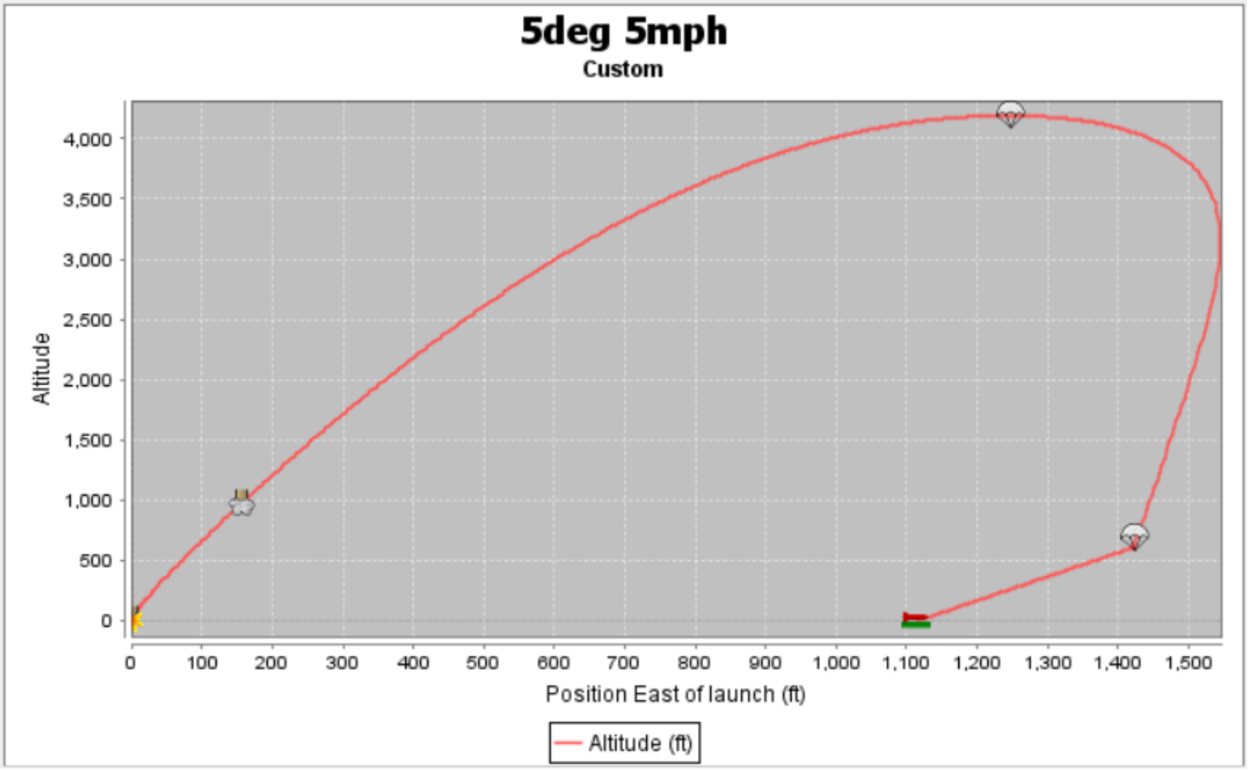


Figure 3.5.9.2 Altitude v.s. Position East of Launch for 5 degree launch angle and 5 mph wind speed

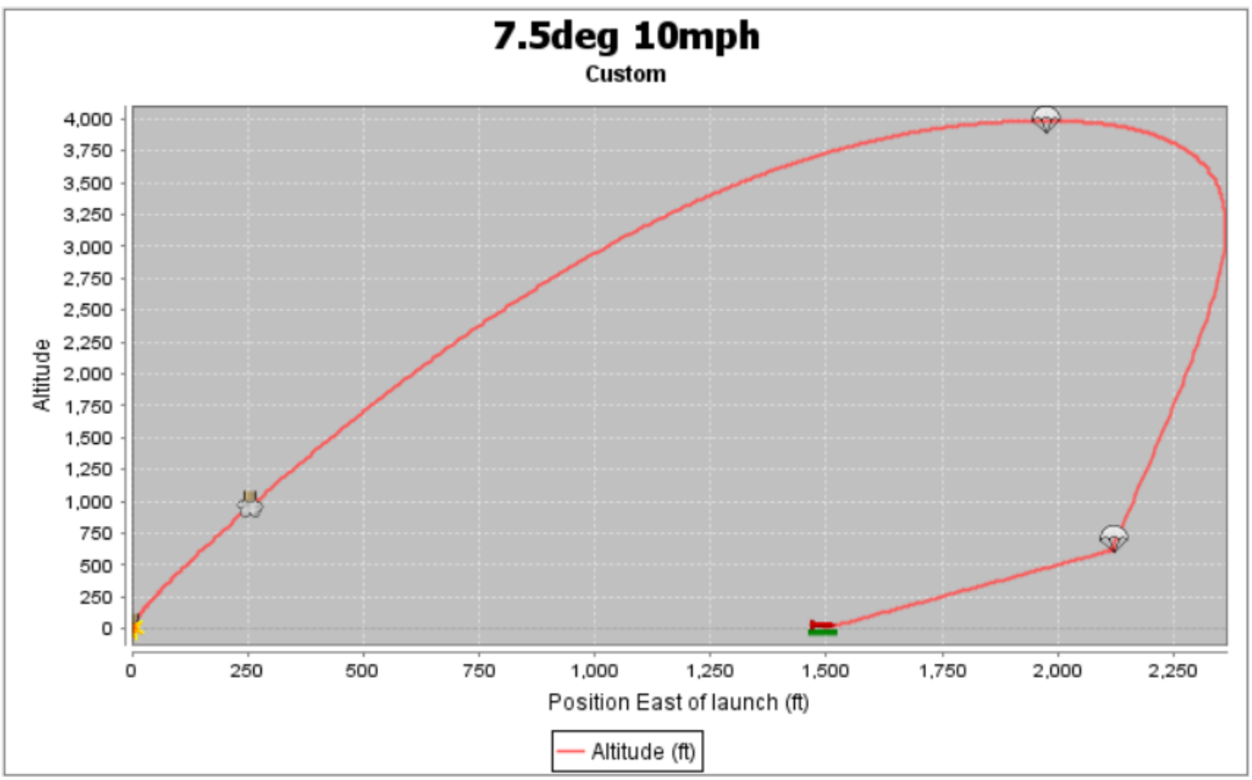


Figure 3.5.9.3 Altitude v.s. Position East of Launch for 7.5 degree launch angle and 10 mph wind speed

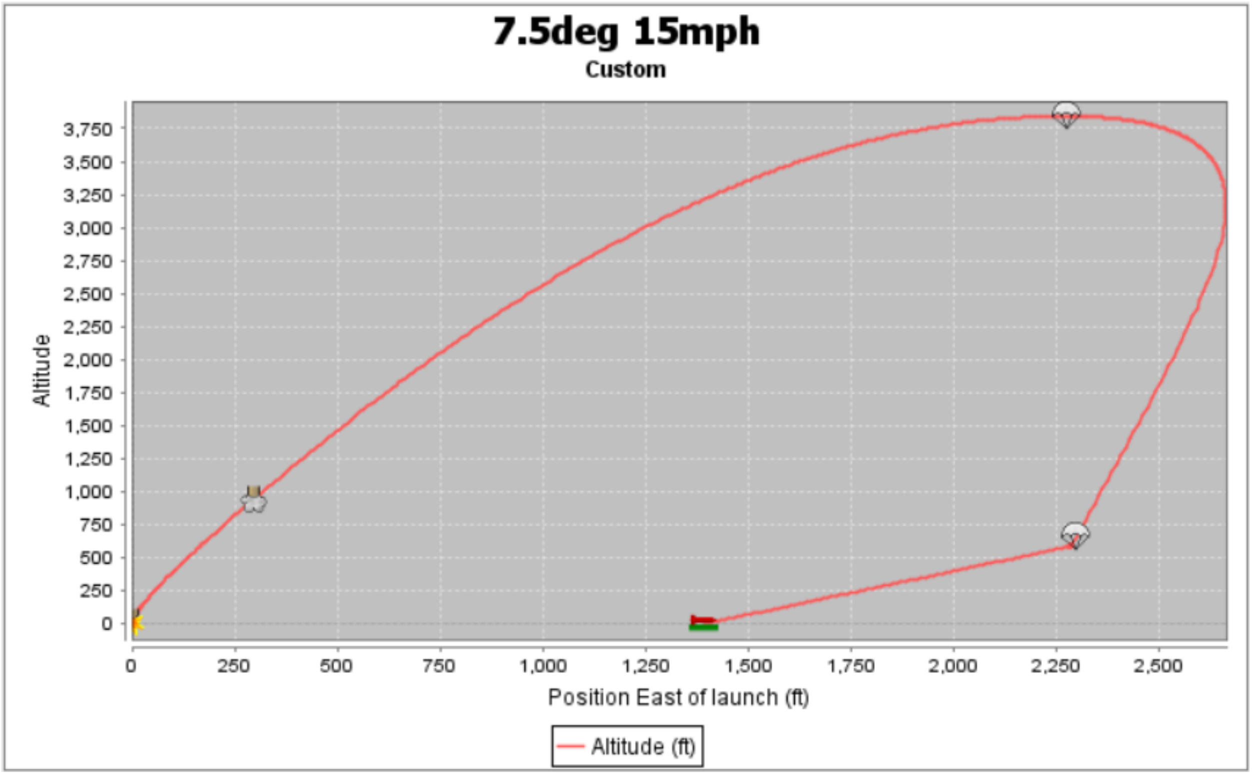


Figure 3.5.9.4 Altitude v.s. Position East of Launch for 7.5 degree launch angle and 15 mph wind speed

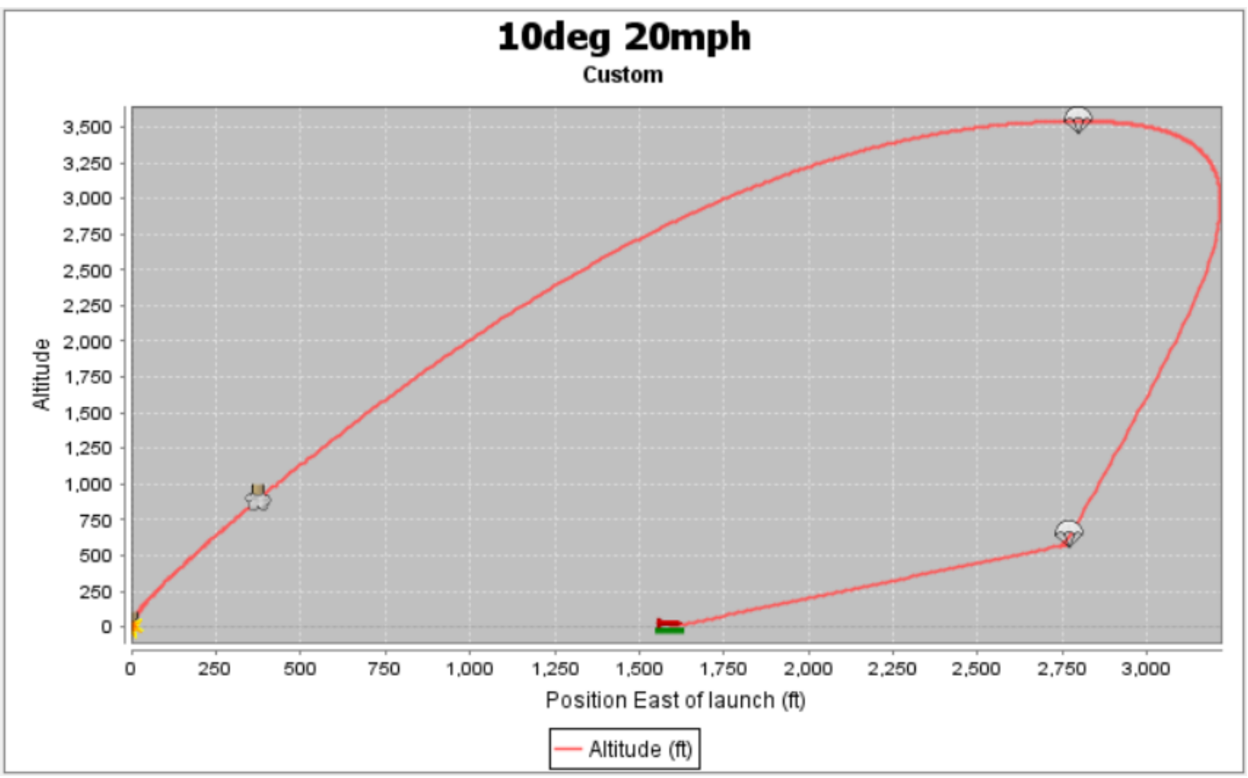


Figure 3.5.9.5 Altitude v.s. Position East of Launch for 10 degree launch angle and 20 mph wind speed

The plots above show reasonable simulated vehicle trajectories under different wind conditions. Without the presence of the wind, after reaching apogee, the vehicle would have a 90-degree downward momentum and would land straight down. With the presence of the wind, as the wind grows stronger, the vehicle's drift distance would increase as it drifts more to the west.

3.5.10. Simulink and OpenRocket differences

A Simulink model was developed to check the accuracy of the OpenRocket simulator and be the primary backup simulator. The Simulink model is a two-degrees-of-freedom custom vehicle trajectory simulation in Simulink that has been a reliable verification tool. The team has extensively and reliably utilized these simulations in previous years, and using Simulink in conjunction with OpenRocket has proven useful and accurate in the theoretical analysis of flight properties.

The Simulink model was performed for a worst case, moderate case, and best case scenario; which the team defined as 5deg 0mph, 7.5deg 10mph, and 10deg 20mph respectively. The launch angles in the NASA competition handbook are between 5 and 10 degrees, and the wind speed is from 0 mph to 20 mph. Therefore the predicted apogee is calculated using values in between the NASA competition handbook values.

The calculations for apogee with varying wind speed and launch angle in each scenario are presented in the table below, in addition to other important mission performance metrics.

Model	Launch Angle (deg)	Wind Speed (mph)	Landing Kinetic Energy of heaviest section (ft-lbf)	Descent Time (sec)	Apogee (ft)	Rail Exit Velocity (ft/sec)	Drift Distance (ft)
Simulink	5	0	57.7	71.3	4233	81.3	816
OpenRocket	5	0	56.02	74.8	4265	66.2	269
Simulink	7.5	10	57.7	70.2	4177	70.9	17
OpenRocket	7.5	10	56.02	72.6	3988	66.2	482
Simulink	10	20	57.7	69.5	4095	73.8	1311
OpenRocket	10	20	56.02	66.8	3541	66.3	1205

Table 3.5.10.1 : Summary table of Simulink flight simulations

The Simulink model also verified other important flight metrics such as apogee, landing kinetic energy of heaviest section, descent time, drift distance, and exit rail velocity. Apogee was closely simulated at low launch angles and wind speeds, however, started to become less accurate at more extreme launch conditions. This is due to the way Simulink models drag and is a known limitation the team has experience working around. For the landing kinetic energy of the heaviest section, each scenario predicted 57.7 ft-lbf, which is close to the 56.02 ft-lbf predictions for eight of the OpenRocket test cases. With descent time, Simulink predicts 71.3-69.5 seconds from the best to the worst case, as compared to 74.8-66.8 with the wider range of flight conditions tested in OpenRocket. This range predicted by Simulink fits into the range predicted by OpenRocket, so these results also agree. The Simulink model only predicts drift distance relative to launch point while the OpenRocket model can model drift relative to apogee. This is why the two models differ more at lower wind speeds where the difference in relative points is more pronounced. The two models start to converge at higher wind speeds and the Simulink model always remains within the NASA requirements. Finally, exit rail velocities for each simulation were used to compare relative stabilities. Simulink does not directly calculate stability like OpenRocket does, but stability is most closely related to exit rail velocity. The rail exit velocities are between 70.9 and 81.3 ft/sec for the Simulink model and 66ft/sec for the OpenRocket. As the Simulink model predicts higher rail exit velocity, its predicted stability could only be higher than OpenRocket, confirming the safety of the launch vehicle design. For each flight metric, the Simulink values were within the ranges of those calculated with OpenRocket or within a margin of error, accounting for the differing assumptions and numerical methods between the two platforms. Therefore, the Simulink results verify those completed previously in OpenRocket and demonstrate a full, accurate analysis of flight metrics for various flight conditions.

Vehicle Trajectory Simulations were performed in Simulink with each test scenario discussed–best, medium, and worst. Altitude v.s. Time simulation plots were produced for each scenario combination of launch angle and wind speed, as depicted in the summary table of flight simulations. The plots are presented below.

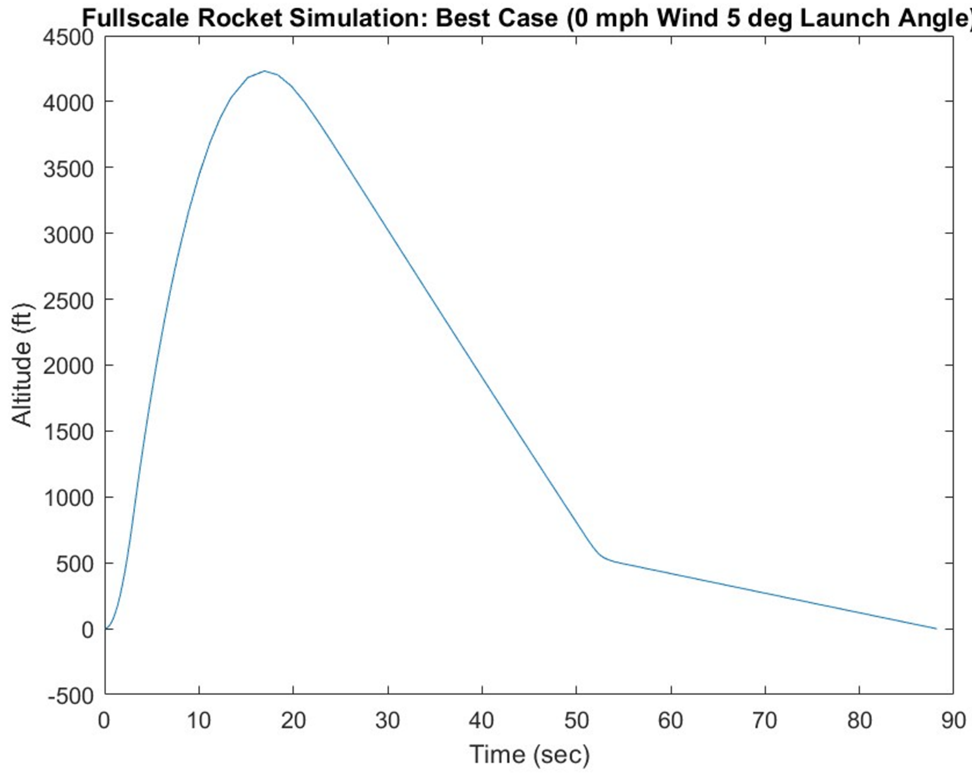


Figure 3.5.10.1 Altitude v.s. Time for 5 degree launch angle and 0 mph wind speed

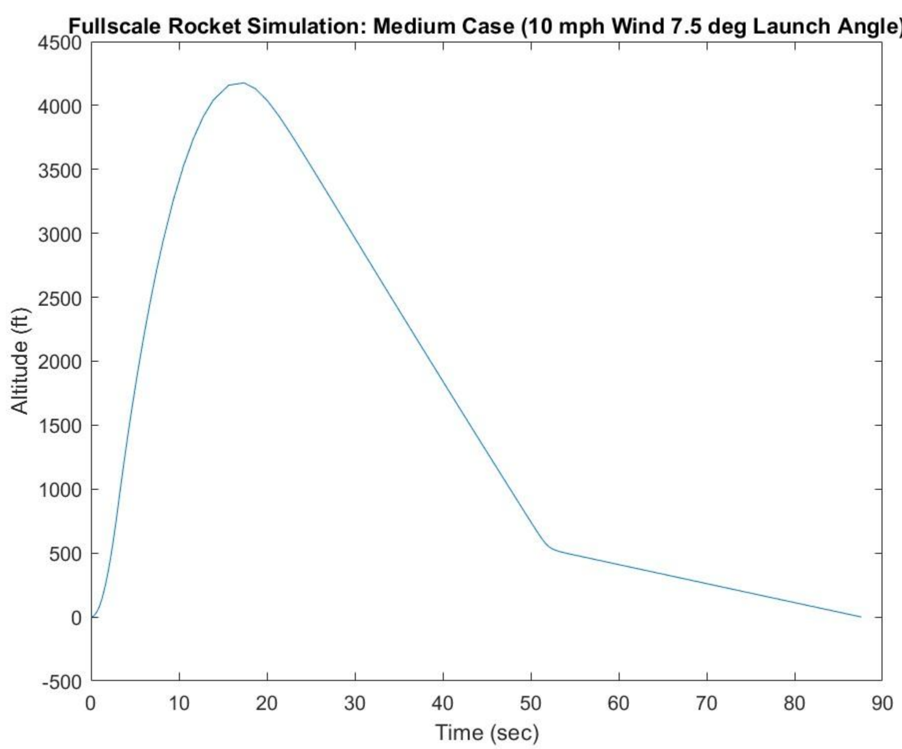


Figure 3.5.10.2 Altitude v.s. Time for 7.5 degree launch angle and 10 mph wind speed

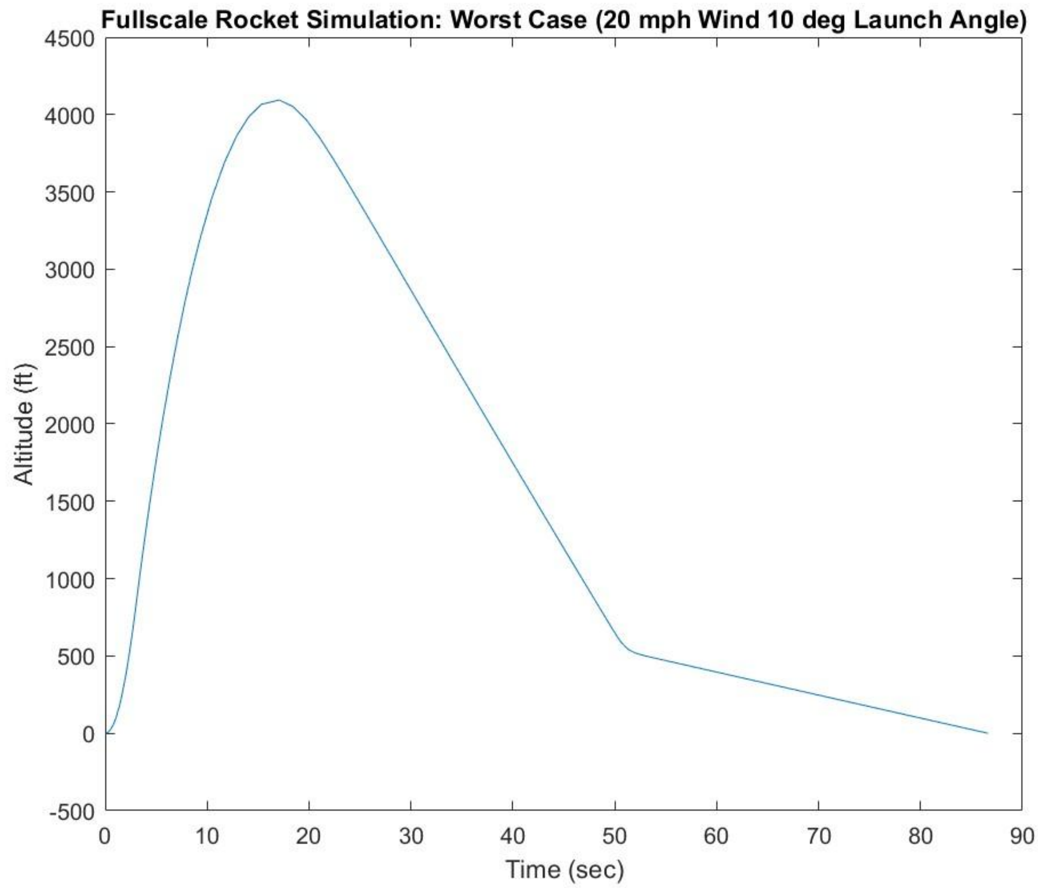


Figure 3.5.10.3 Altitude v.s. Time for 10 degree launch angle and 20 mph wind speed

4. Payload Criteria

4.1. Payload Mission Statement

The mission of the Payload System is to autonomously receive radio commands to control an internally rotating and vertically deployed onboard camera system. The Payload design consists of multiple subsystems designed to achieve the mission and is described in the following pages. The Retention and Deployment subsystem (R&D) will act to retain the system during flight and deploy the rest of the Payload Subsystems upon landing. The Internal Orientation System (IOS) is responsible for autonomously orienting the system so that the camera system will be deployed in the vertical direction. The Camera Deployment System (CDS) will be responsible for safely deploying the Two-Axis Camera Orientation System (TACOS) vertically from the launch vehicle. TACOS is the onboard camera system, capable of rotating 360 degrees horizontally to capture images of the launch vehicle landing site and complete all RF commands received from the NASA transmitter. The Autonomous Payload Interface software (API) will be designed to apply a range of filters to the captures, and transmit them via radio. All systems have been designed to meet all safety standards and fulfill requirements set forth by the 2022-2023 NASA Student Launch Handbook.

4.2. Payload Mission Success Criteria

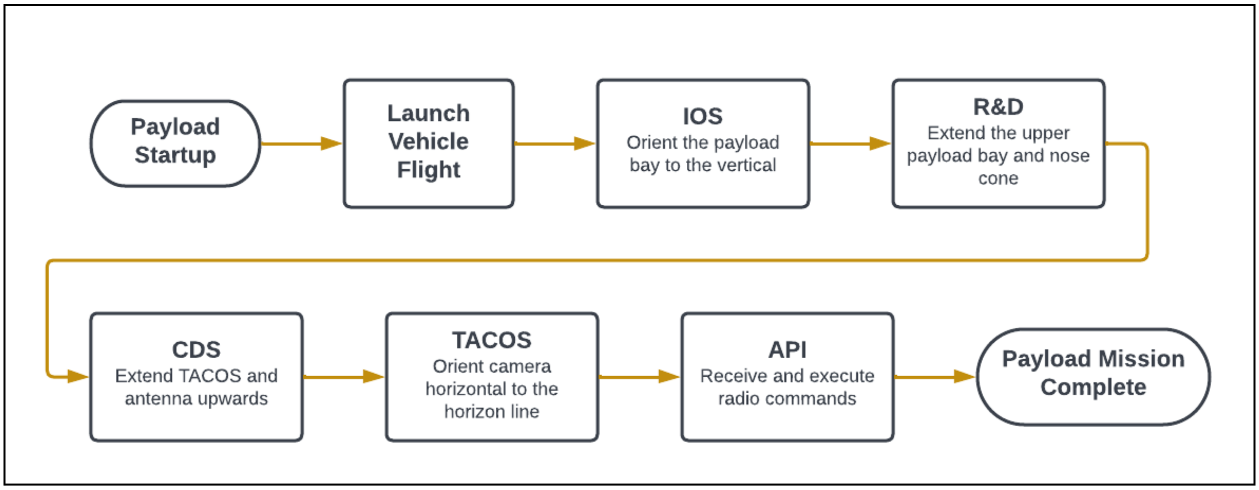


Figure 4.2.1: Payload System Order of Operations

Our selected payload design is a set of four divided subsystems so that the team may focus solely on a specific subsystem and how each interacts with others. The team can analyze each subsystem's performance and optimize processes that make up the subsystem. A brief description of each subsystem is described below.

Our selected payload subsystems include IOS, R&D, CDS, and TACOS. The R&D and IOS systems will work very closely together. These two subsystems are responsible for the airframe separation and internal orientation of the payload bay. Structural stability has been a primary focus in these subsystems because a well aligned and sturdy internal supports will minimize the challenges required to keep the cameras horizontal to the horizon line.

Following the order of operations specified in Figure 4.3.1, the IOS system is the first to actuate. This subsystem will rotate all other subsystems. The other subsystems will be mounted to IOS with linear rods and plates. This is spun with a stepper motor that will orient the CDS to be in-line with the vertical (the line perpendicular to the surface of the Earth).

Following the spinning of the IOS system, the R&D system will use a stepper motor to actuate the system linearly. This stepper motor will use a threaded rod run through the center of the payload bay to push the nose cone to separate the payload bay. This will extend the payload bay approximately 6” to allow the other subsystems to actuate and orient the camera. The nose cone assembly will still be attached to the upper payload bay, but the airframe separation is necessary to allow the CDS to deploy into the air properly. A centering ring will be mounted to the bottom of the separation gap to ensure proper alignment of the nose cone assembly. In order to ensure there is no separation of the nose cone assembly or upper payload bay mid-flight, the R&D system will apply a small amount of torque to the CDS, forcing the system to be locked in place.

After successfully activating the R&D system, the CDS will begin to actuate upwards through a scissor lift mechanism, extending the TACOS and the radio receiver’s antenna upward. The CDS will solely be responsible for getting the TACOS above the launch vehicle airframe and into the air high enough that it can take a picture of the surrounding area. The team has determined it needs to reach 8-12 inches above the ground to achieve an acceptable picture. This ensures that the camera will be above any terrain obstacles and will not be obstructed by the airframe of the launch vehicle.

Once the CDS has fully actuated, the TACOS will begin its part of the mission. TACOS will first orient the camera to be level with the horizon. The amount it will need to spin will be determined prior to TACOS actuation via an IMU placed inside the payload bay. Once the camera is level, TACOS will have completed its initialization phase.

Finally, the API can begin receiving and executing instructions after IOS, R&D, CDS, and TACOS have completed their initial deployments. These will be received with an antenna mounted on CDS, which is deployed alongside TACOS. API will determine which motions are necessary to perform based on each command and actuate the systems accordingly.

4.3. Payload System Overview

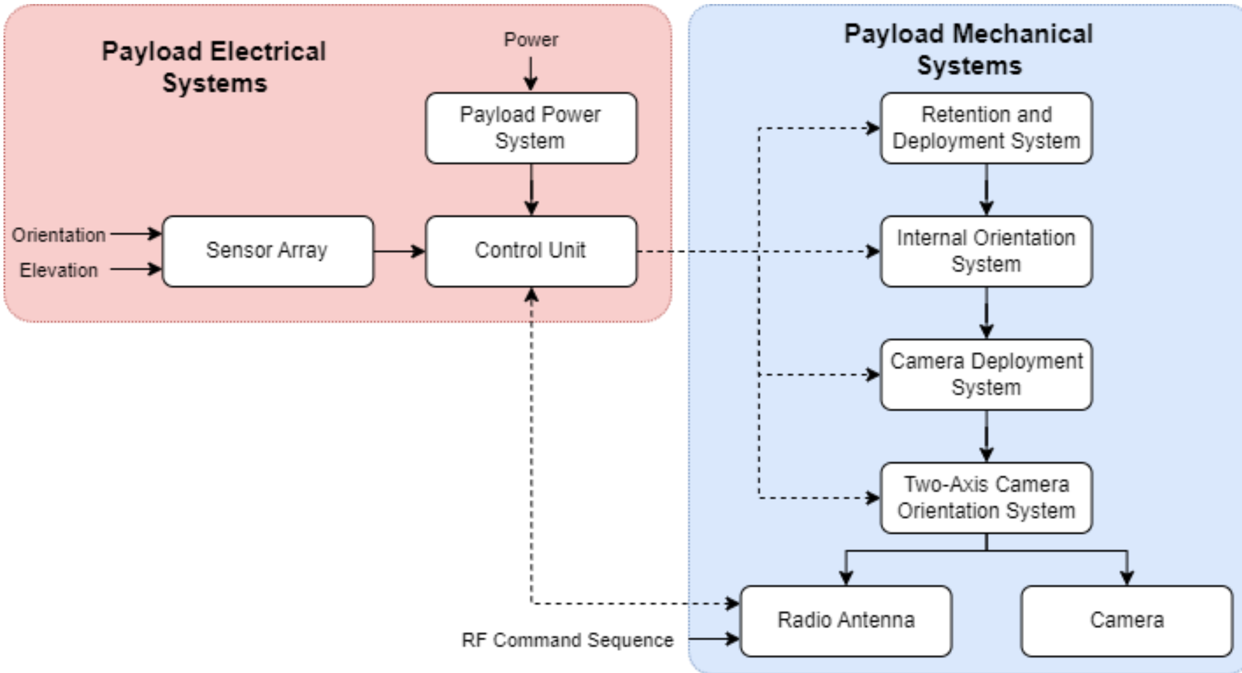


Figure 4.3.1: Payload System Flow Chart

The payload system is separated into two main areas, electrical and mechanical systems. Each subsystem has its respective contributions to the amount of mechanical and electrical design they need. The sensor array in the payload system will detect orientation and elevation telemetry from the launch vehicle to estimate the current status of the flight. Once landing has been detected, signaled by an elevation at ground level, the sensor array, data will drive the control unit. The control unit is powered by the Payload Power System (PPS). The primary objective of the control unit is to send signals to the four primary payload subsystems at the appropriate times for proper payload deployment. During the flight, the control unit will be responsible for securing the upper payload bay and nose cone assembly to the top of the launch vehicle. This data will be continuously fed from the onboard sensor array. Upon successful deployment of the TACOS, the radio antenna will establish a connection between NASA's ground transmitter and receive the radio frequency commands to complete the payload mission. While the radio antenna is connected to the ground transmitter, it will also be connected to the control unit. The control unit will also be responsible for actuating the TACOS when needed. All images will be processed through the API and stored in the payload system for team review.

4.4. Detailed Design Review

The following are descriptions of the main mechanical Payload sub-systems in their physical form. Descriptions will include design justification and team verification of the functionality for each subsystem. After further review of all design options from PDR, the team has refined and optimized all Payload subsystems to ensure a safe and proper autonomous deployment once on the ground.

Figure 4.4.1: Top Level Assembly Render (Closed Configuration)

The primary state of the payload is in the Closed Configuration. Here, the upper and lower sections of the payload airframe are closed. To verify the system is active, a buzzer in the electrical system will sound when the Payload system is activated with a key switch. Once in an active state, the R&D motor will apply a small amount of torque to the upper airframe along the center lead screw to ensure the upper airframe will not open during flight. Payload will remain in the closed configuration until the electrical system detects the launch has occurred and landed on the ground.

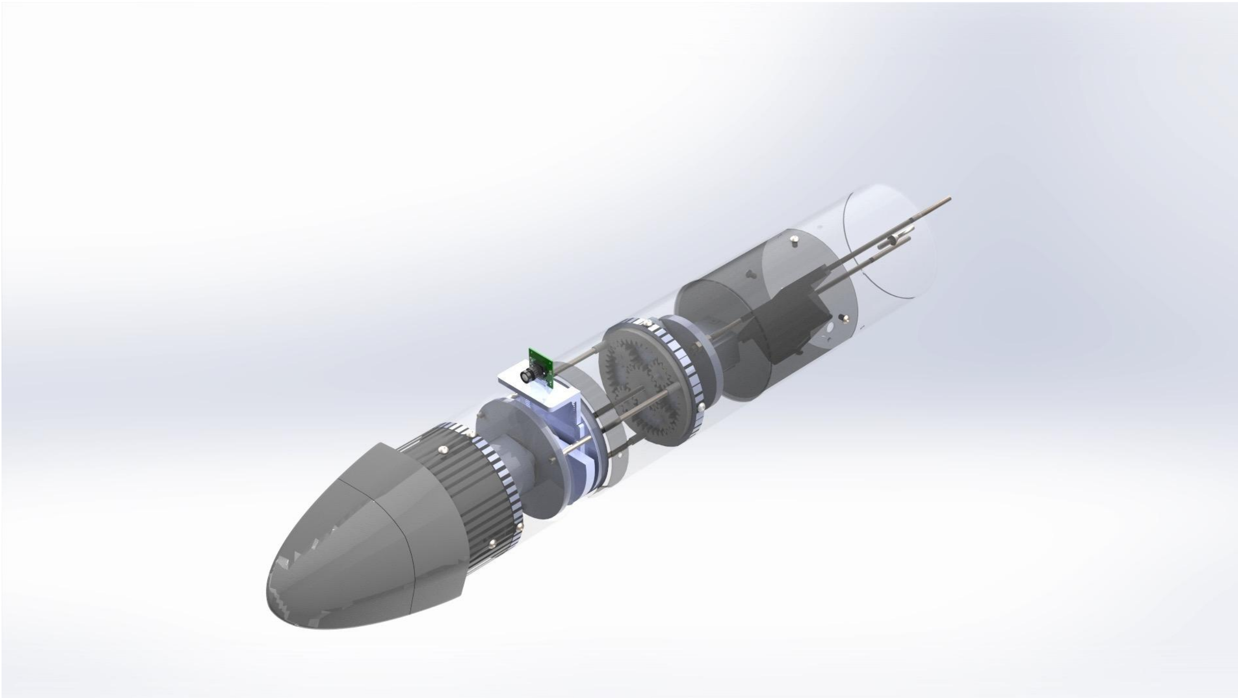


Figure 4.4.2: Top Level Assembly Render (Open Configuration)

After the Payload has determined that the flight has concluded, the deployment sequence will begin. During the sequence, a maneuver is required to extend the upper payload airframe and nose cone assembly 1.75” above the lower payload airframe. This separation distance is enough to allow for the extension of the Camera Deployment System. A support ring that is mounted on the upper side ensures the upper assembly will not be misaligned to the axis through the center of the vehicle. The payload system is able to transition back and forth between open and closed configurations. However, during the deployment sequence, the payload will not transition from open to closed until the payload has completed the mission and has been successfully recovered by the payload team.

4.4.1. Internal Orientation Subsystem (IOS)

The IOS has remained unchanged from the preliminary design. It is responsible for rotating the internal payload bay within the airframe. It is driven by a Nema 17 stepper motor. There is a planetary gear system spanning the entirety of the inner airframe, which allows the rotation. The stepper motor drives the sun gear to spin the internals and provide sufficient torque. It uses the onboard IMU to determine the current rotation. It rotates until the CDS system is positioned so that when extended, it will be perpendicular to the plane of the ground. When the IOS system is rotating, the payload system will be in closed configuration.

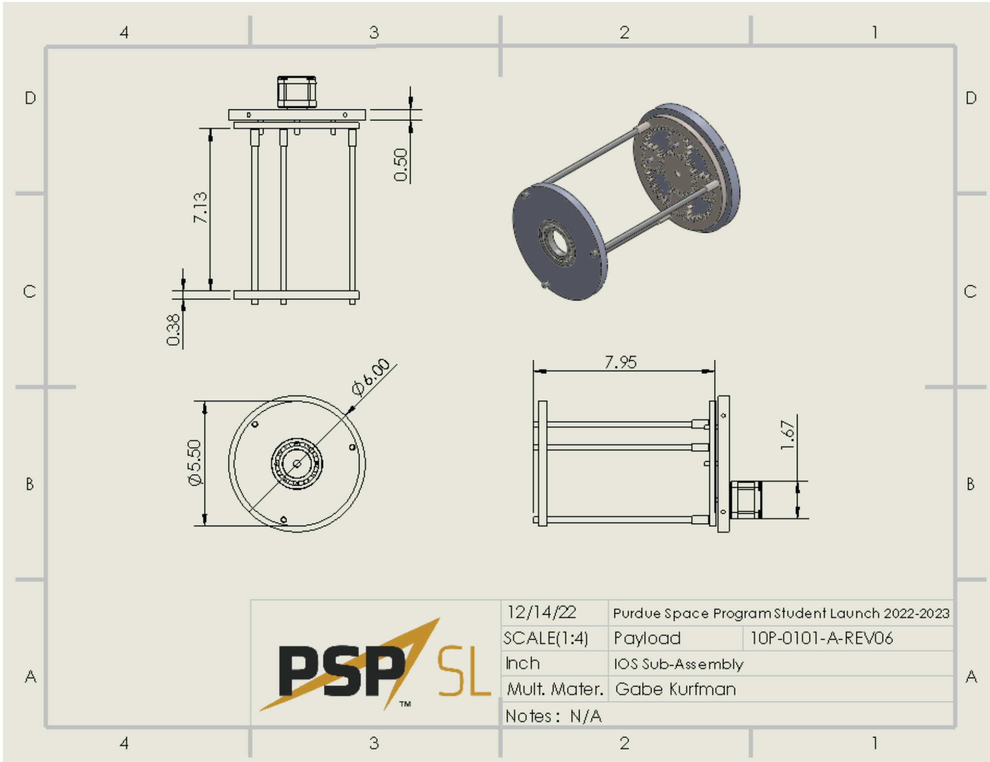


Figure 4.4.1.1: IOS Sub-Assembly Technical Drawing

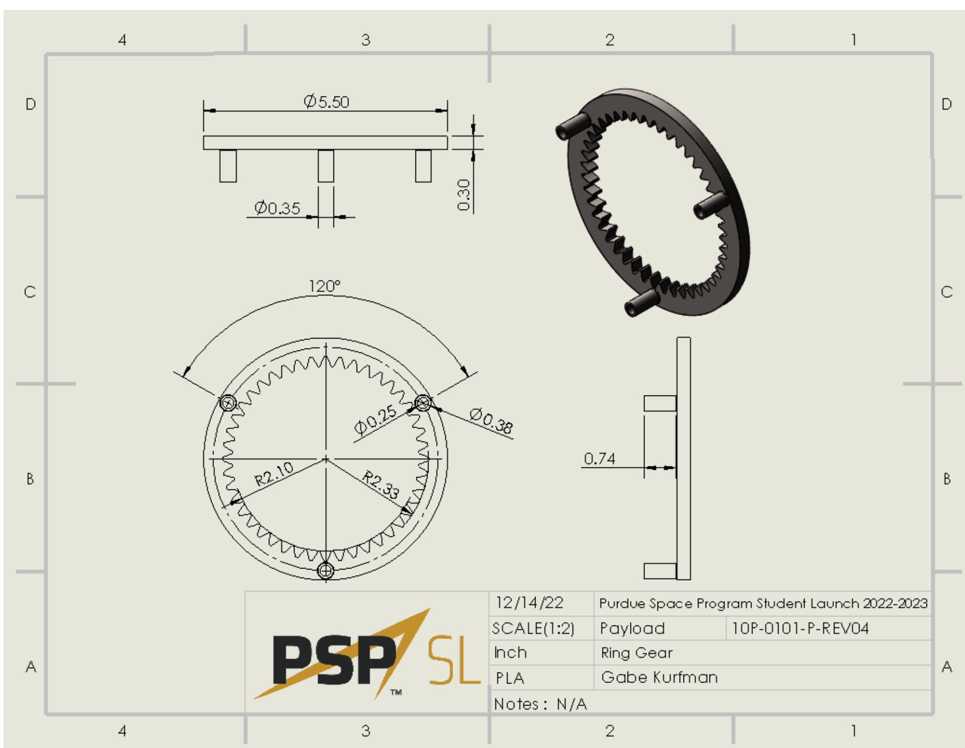


Figure 4.4.1.2: IOS Ring Gear Technical Drawing

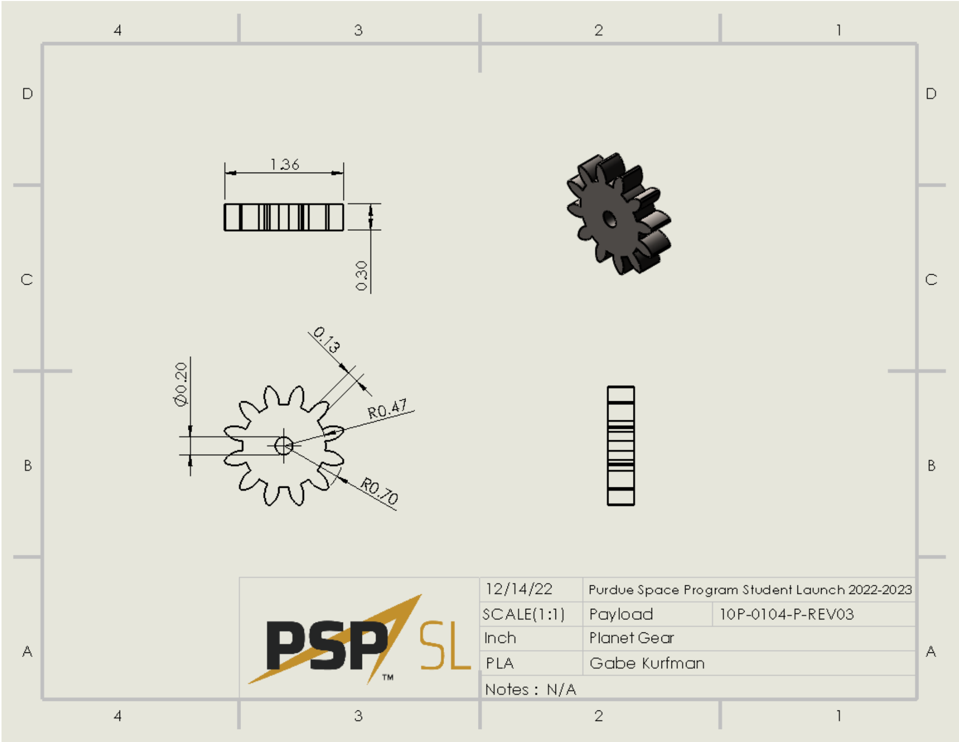


Figure 4.4.1.3: IOS Planet Gear Technical Drawing

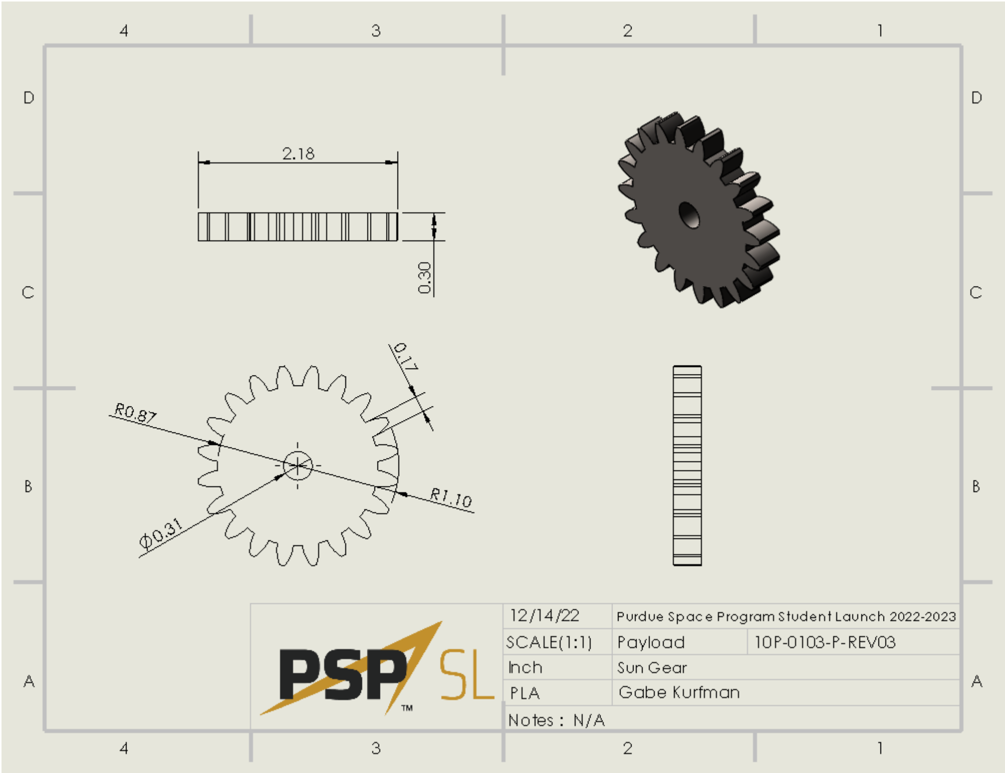


Figure 4.4.1.4: IOS Sun Gear Technical Drawing

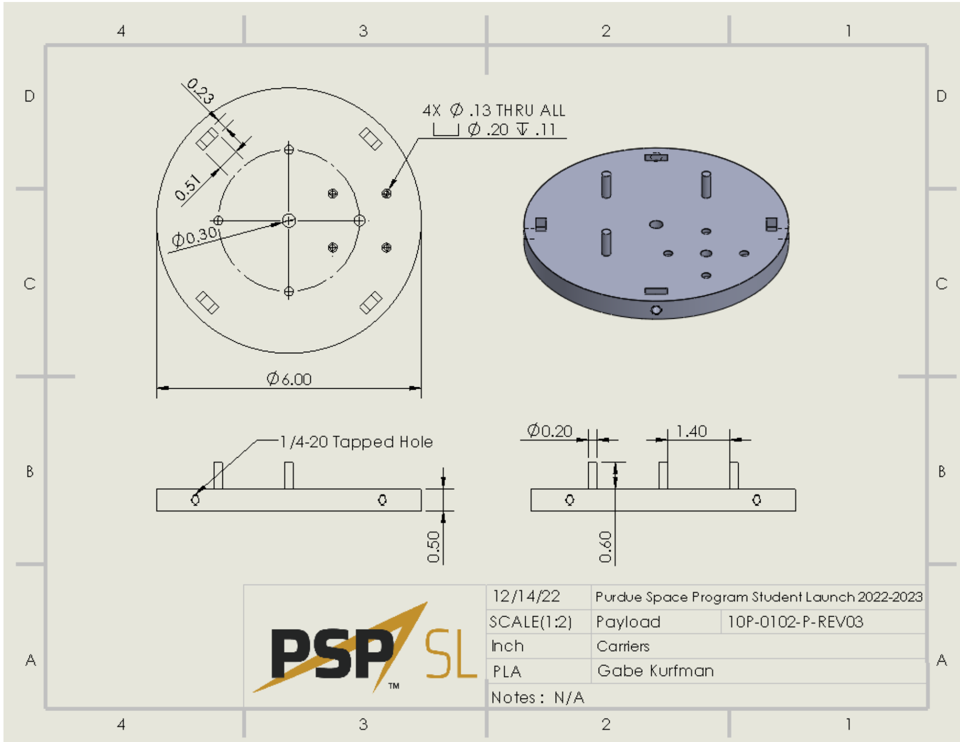


Figure 4.4.1.5: IOS Carriers Technical Drawing

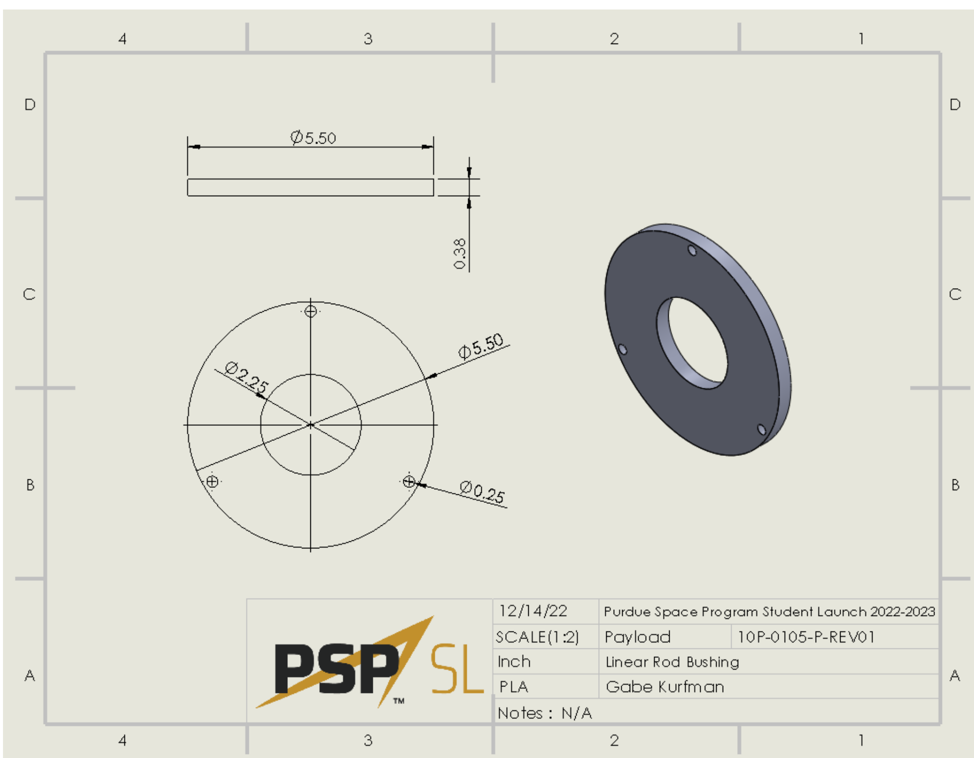


Figure 4.4.1.6: IOS Linear Rod Bushing Technical Drawing

4.4.2. Retention and Deployment Subsystem (R&D)

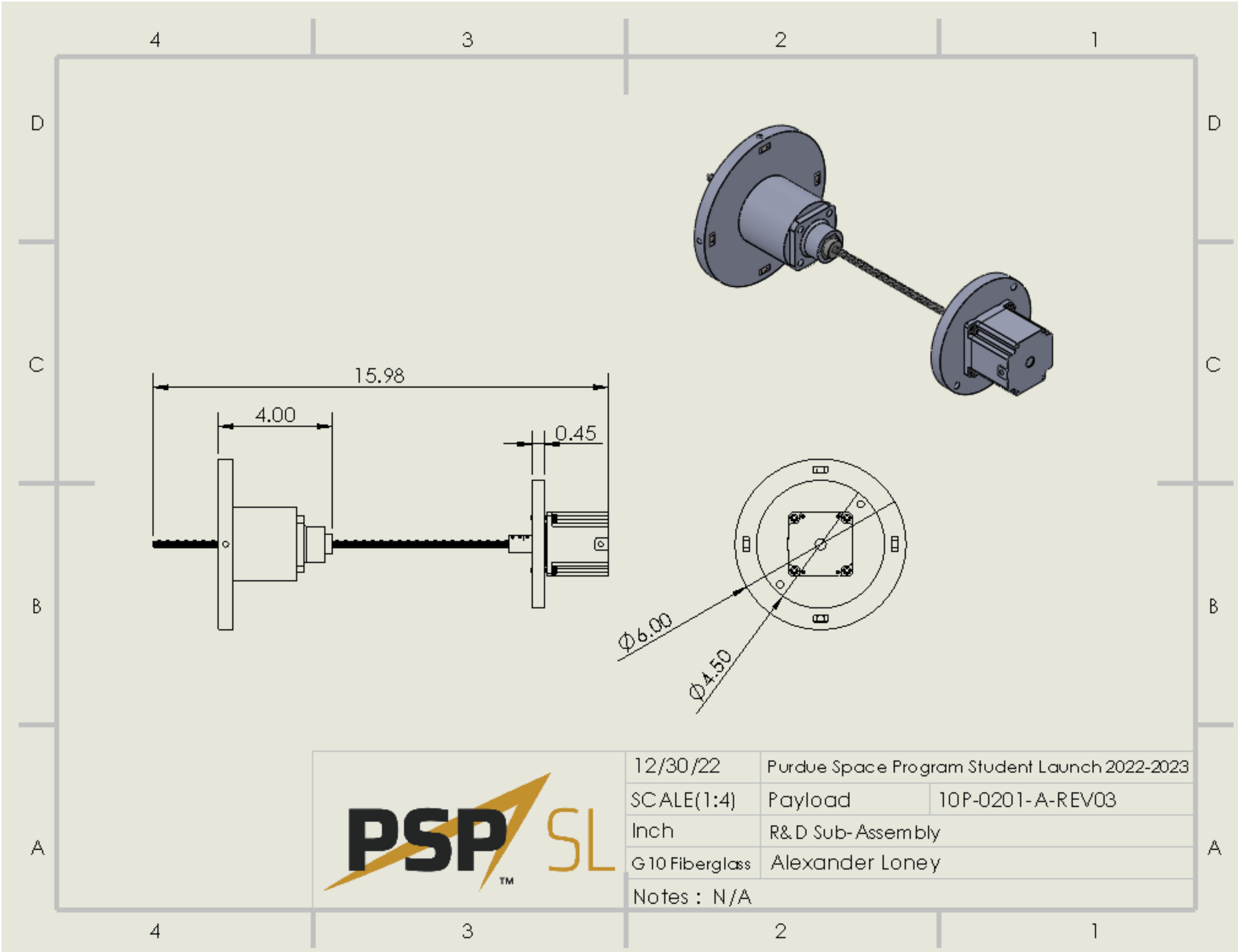


Figure 4.4.2.1: R&D Sub-Assembly Technical Drawing

The R&D subsystem is firstly responsible for retaining the payload bay before and during flight. It uses the holding torque of a Nema 23 stepper motor to achieve it. When the system is in the pre-launch phase, it keeps the stepper motor off, but once the IMU detects launch, it provides power to the stepper motor, which enables the holding torque. The team is confident that the holding torque will be sufficient to retain the entire payload bay throughout the duration of the flight because in last year's competition, the team used the exact same concept with a lower torque Nema 17 motor. That worked perfectly, so by using a Nema 23 that has a higher holding torque of 1.5 Nm, the team is confident in the approach.

The second major responsibility of R&D is to linearly deploy the entire payload bay after IOS has finished orienting the internal payload bay vertically. Instead of using the Nema 23 for its holding torque, it rotates the lead screw that runs down the middle of the payload bay. The selection of the Nema 23 was due to its greater amount of torque to make sure that the upper payload airframe and nose cone assemblies overcome the unknown amount of static friction caused by the ground. The Nema 23 transitions the payload system from closed to open to reveal the CDS that has been oriented vertically by the IOS beforehand.

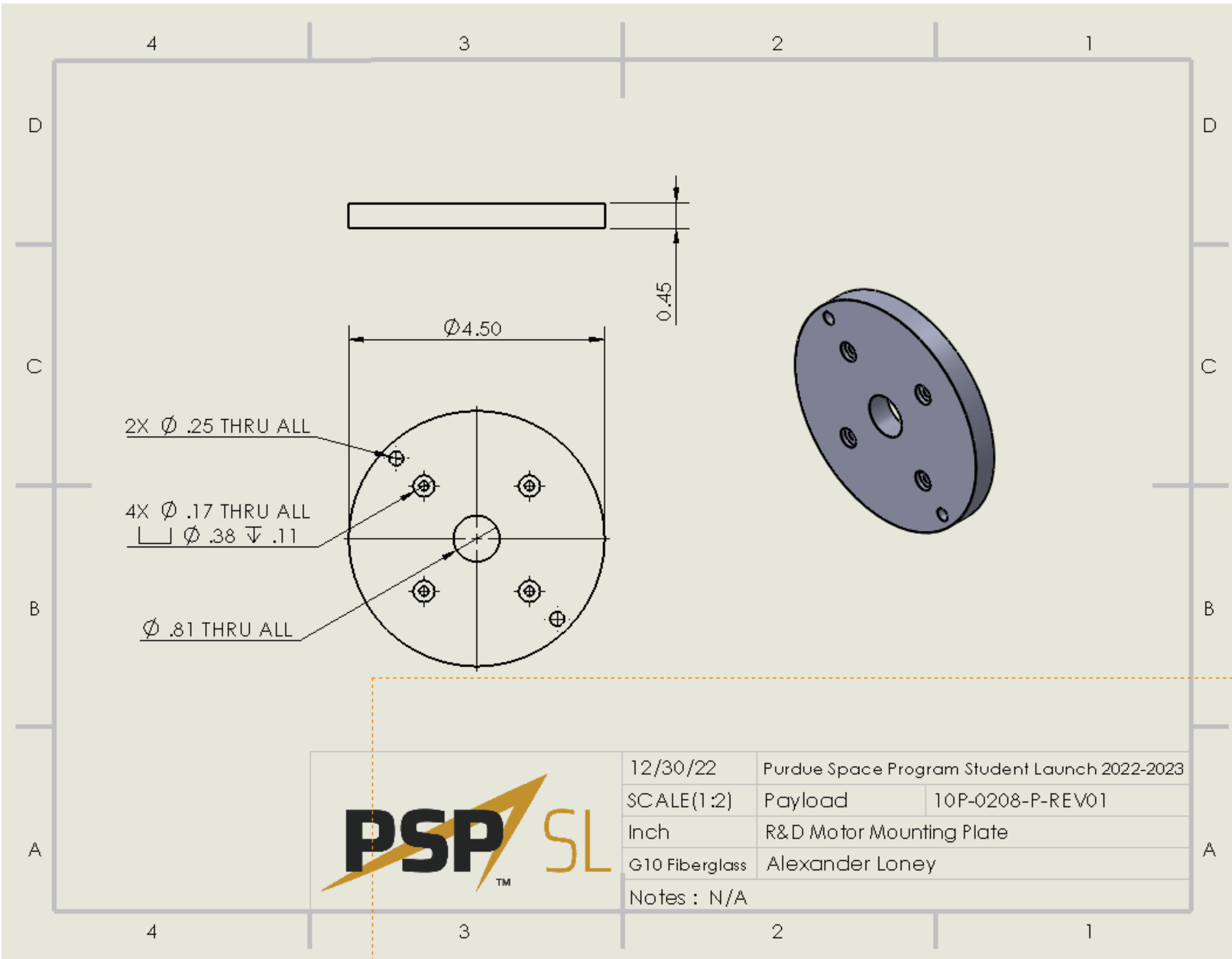


Figure 4.4.2.1.1: R&D Motor Mounting Plate Technical Drawing

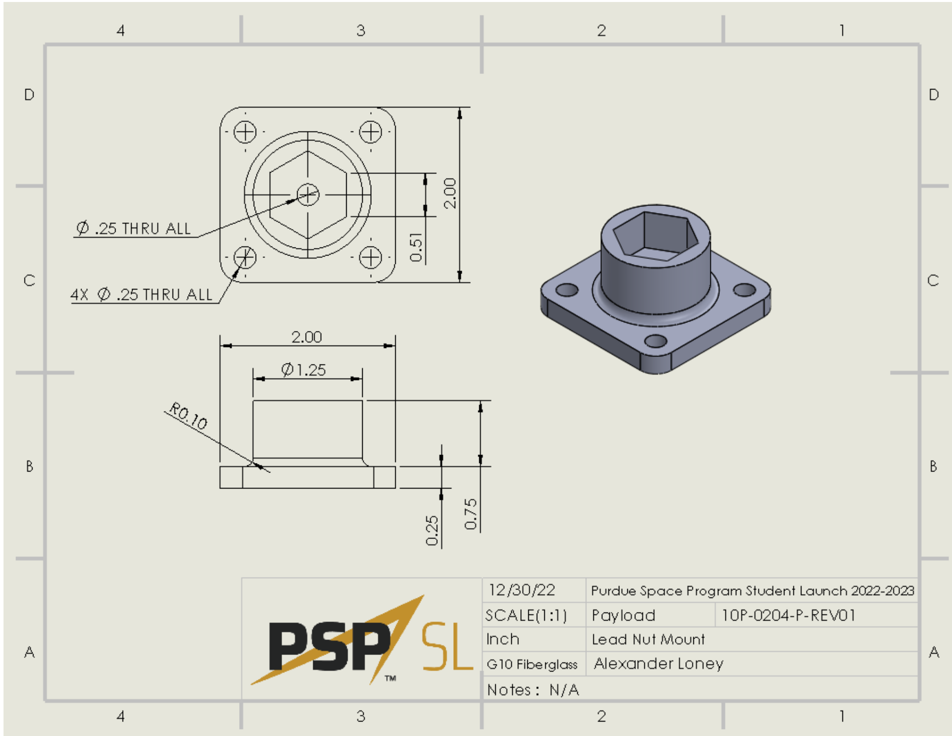


Figure 4.4.2.2: R&D Lead Nut Mount Technical Drawing

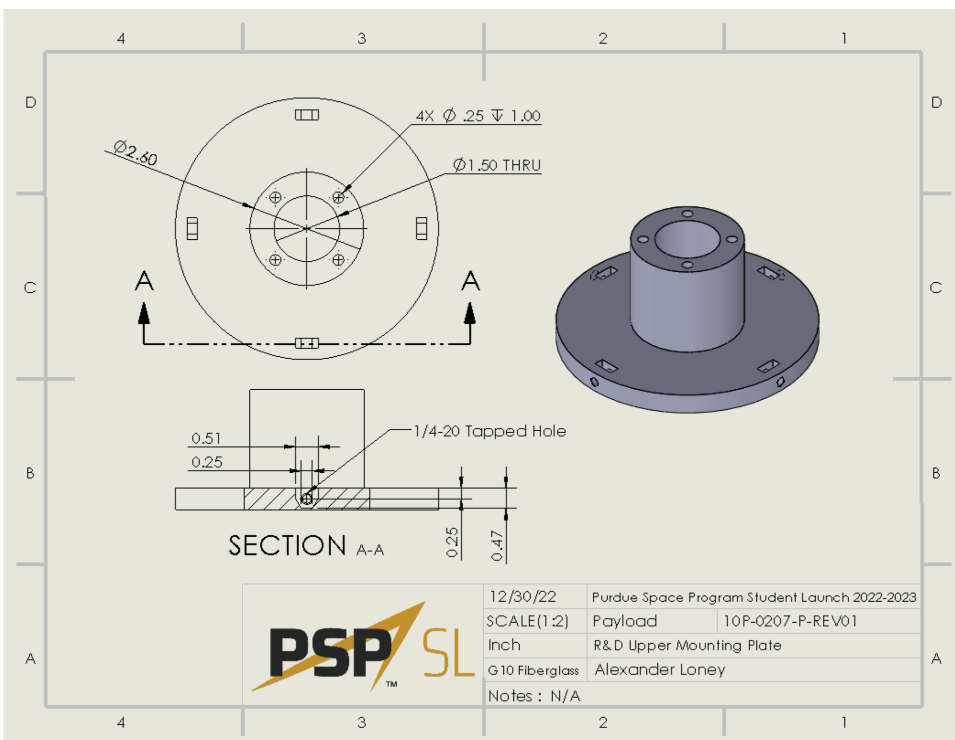


Figure 4.4.2.3: R&D Upper Mounting Plate Technical Drawing

4.4.3. Camera Deployment Subsystem (CDS)

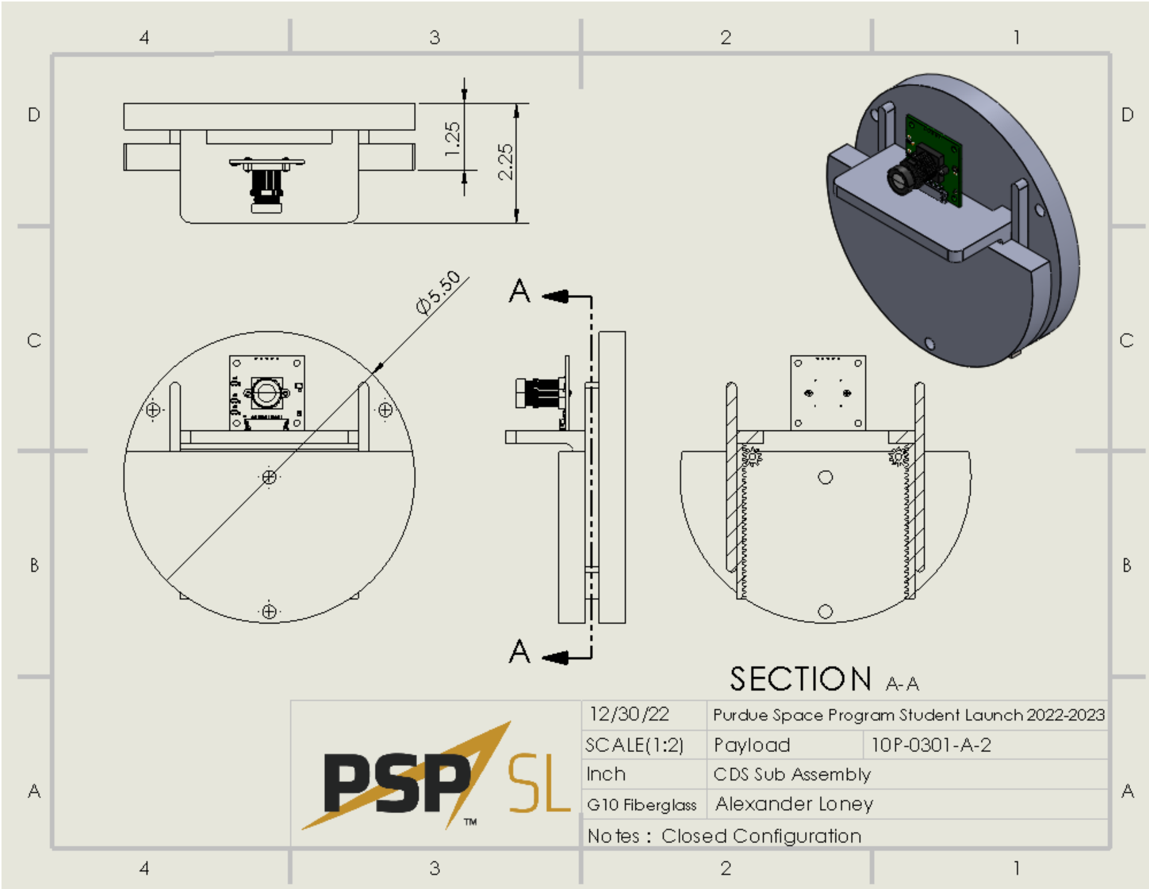


Figure 4.4.3.1: CDS Sub Assembly Technical Drawing

The Camera Deployment System (CDS) is responsible for vertically deploying the camera out of the landed launch vehicle. For this, a rack and pinion design was chosen. With this design the subsystem will have two motors to run the two pinions on either side of the CDS. This helps reduce the mechanical complexity of the CDS, as the pinion gears are not mechanically joined. The rack and pinion system allows the CDS to extend TACOS outside of the airframe, with an extension length of 3.85”. The rack and pinion design allows the CDS to fit in the extension space requirements as well. The payload bay, once landed, will open 1.75” and orient with the IOS and R&D subsystems. This 1.75” is enough to fit a rack and pinion design, with two racks extending out of the payload bay, with a platform holding TACOS. Using two racks allows the CDS to maintain structural stability when extending, as opposed to one. This is further increased with the racks being sandwiched between two bulk plates. This prevents the racks from torquing out of place when extending.

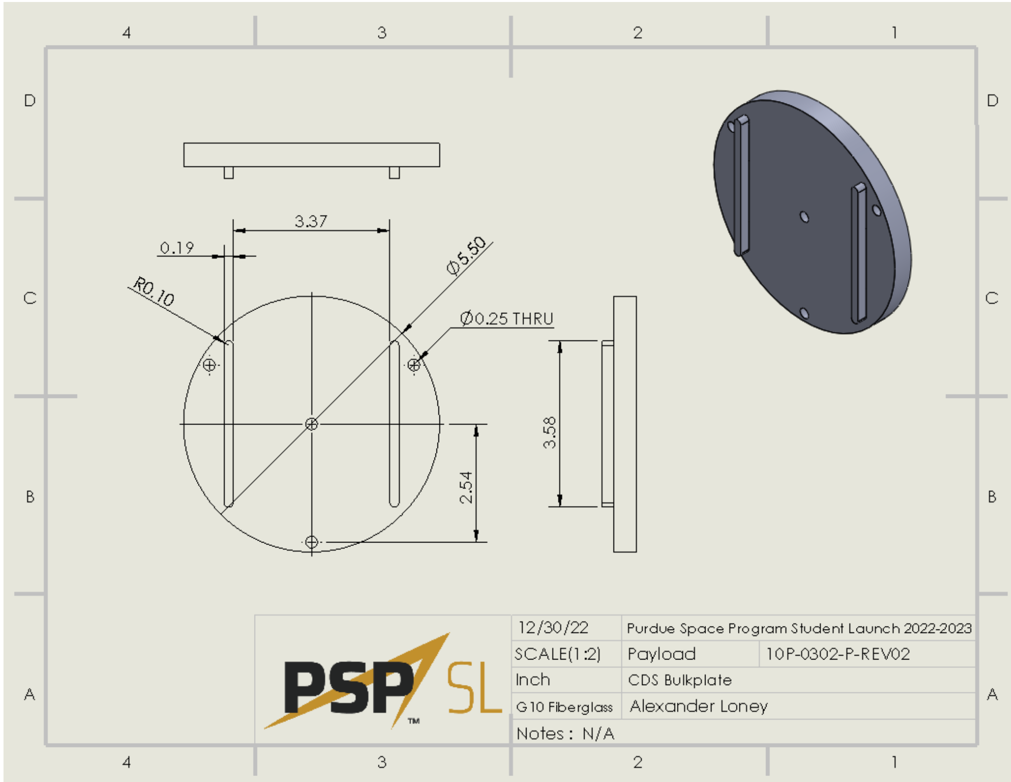


Figure 4.4.3.4: CDS Bulk Plate Technical Drawing

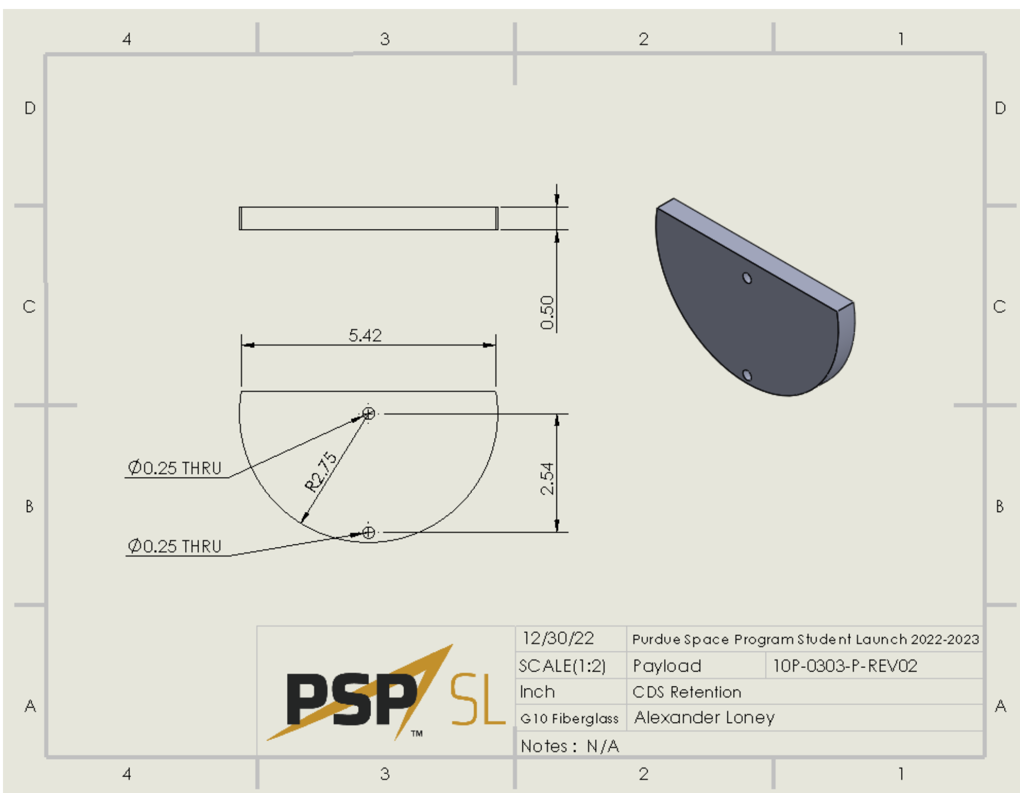


Figure 4.4.3.5: CDS Retention Technical Drawing

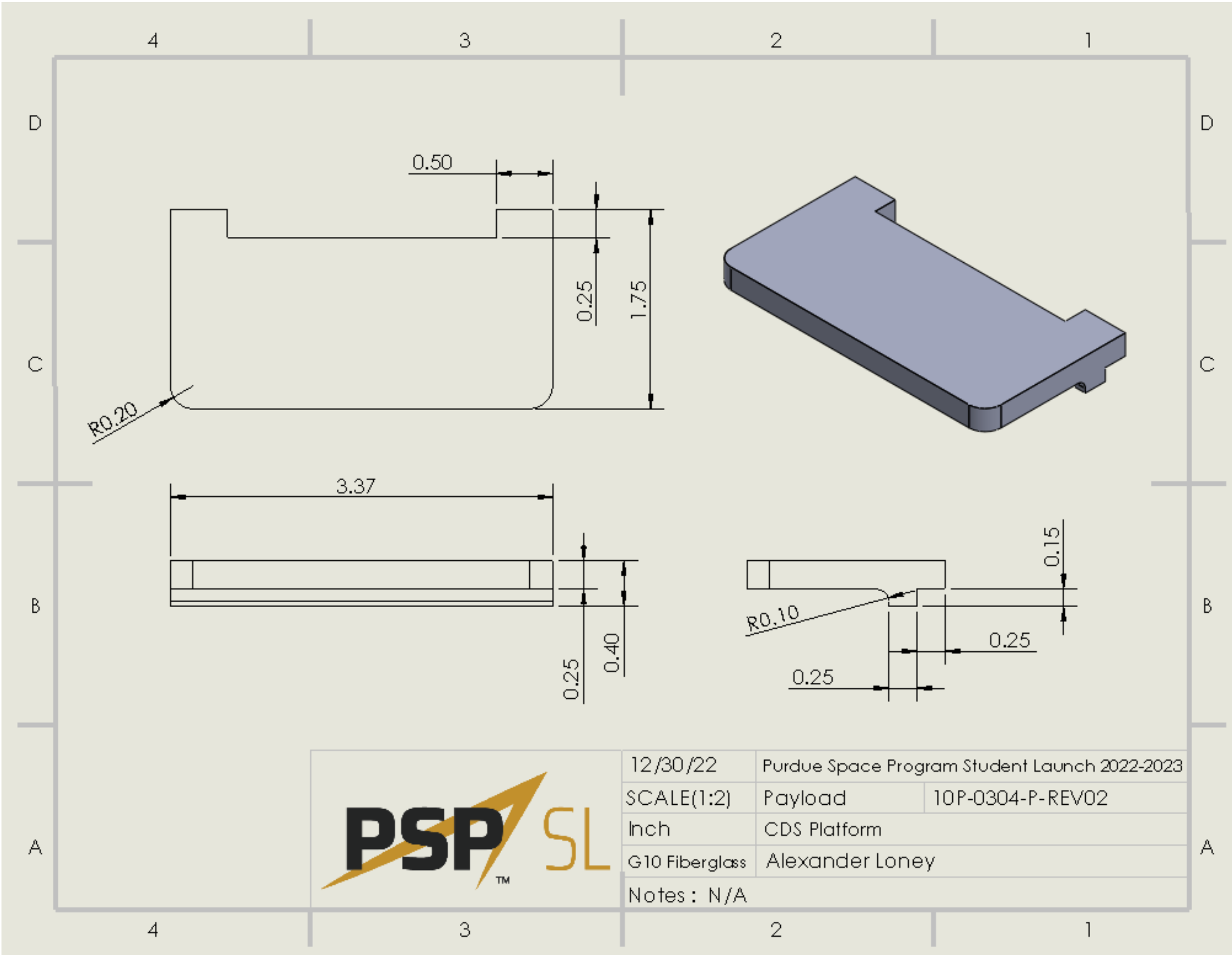


Figure 4.4.3.5: CDS Platform Technical Drawing

4.4.4. Two-Axis Camera Orientation Subsystem (TACOS)

TACOS is used to correctly orient the camera to take the proper pictures. Specifically, the subsystem orients the camera along the y and z axes. The y axis in this system is defined as the axis perpendicular to the axis through the center of the vehicle called x. The z axis is perpendicular to the x and y axes pointing upwards. In TACOS, the camera will be attached to a stepper motor which is attached to a positional servo motor to allow rotation along two axes. After the gimble is lifted into the air, a servo motor is used to orient the stepper motor and camera parallel to the ground, which is about the y-axis. This is so the images can be taken correctly oriented with respect to the horizon line. Then, a stepper motor will turn the camera about the vertical axis to the angle required for that image, which is about the z-axis.

4.4.5. Autonomous Payload Interface (API)

The API is an entirely software based subsystem. It handles the software side of receiving APRS packets, parsing them, image processing, and image storage. Firstly, the APRS packets are received on a Raspberry Pi Zero 2. That uses a Python script to parse the packets and extract the sequence of commands sent by the NASA Student Launch Management Time. The API then sends the received commands to the Arduino (ATSAMD21G18) microcontroller, which will handle executing each command in order. The Arduino will tell the Raspberry Pi when to take a picture and what filter to apply. These images are stored on the Raspberry Pi Zero 2's file system, so the team can obtain the images after landing.

4.5. Mechanical Deployment Sequence

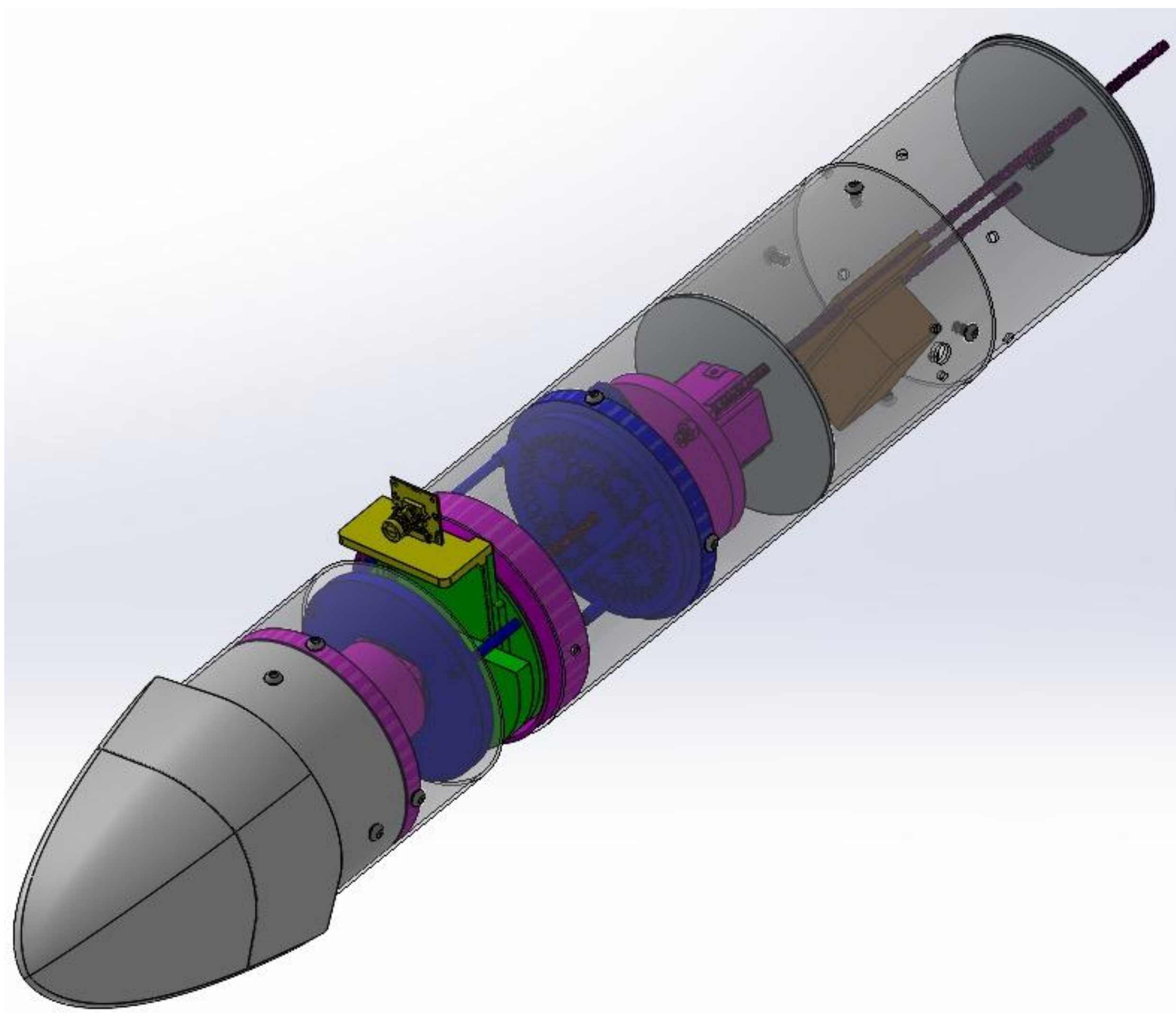


Figure 4.5.1: Color Coded Deployment Sequence Render (Open Configuration in Isometric View)

The figures shown in this section are color coded to display the appropriate subsystem for a better visualization. IOS shown in **blue**, R&D shown in **magenta**, CDS shown in **green**, TACOS shown in **yellow**, and the electronics sled shown in **orange**.

Startup: When the vehicle is on the pad, a key switch will be used to turn on the payload system. The key switch is located in the payload to avionics and recovery coupler airframe segment. A buzzer will sound indicating a successful activation of the system. The rest of the payload subsystems are entirely autonomous. The payload will be in closed configuration on the launch pad.

Flight: During flight, the R&D motor will retain the upper payload airframe and nose cone assembly. Sensors will detect launch, apogee, and landing to know when to continue applying torque. The payload remains in closed configuration.

Post-Landing Deployment: Once the sensors have determined the payload system is successfully on the ground, the IOS system will align CDS to the axis perpendicular to the horizon. During rotation, the payload system remains closed. R&D then activates to push the upper section to make a small gap in the airframe. CDS then activates the linear actuator and the camera platform raises out of the vehicle. TACOS then aligns the camera to the horizon. API receives the RF commands from NASA transmitters and completes the commands by controlling TACOS. After a successful mission, the payload remains in the fully deployed, open configuration, state for a safe and proper recovery by the payload team.

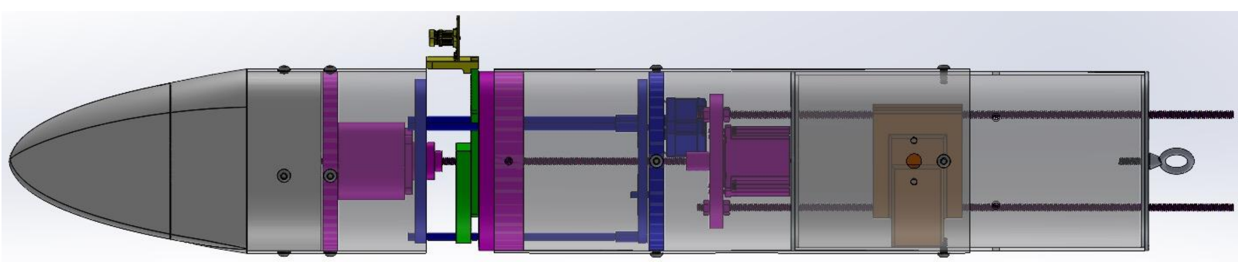


Figure 4.5.2: Color Coded Deployment Sequence Render (Open Configuration in Side View)

4.6. Payload Electronics

4.6.1. Electronics Overview

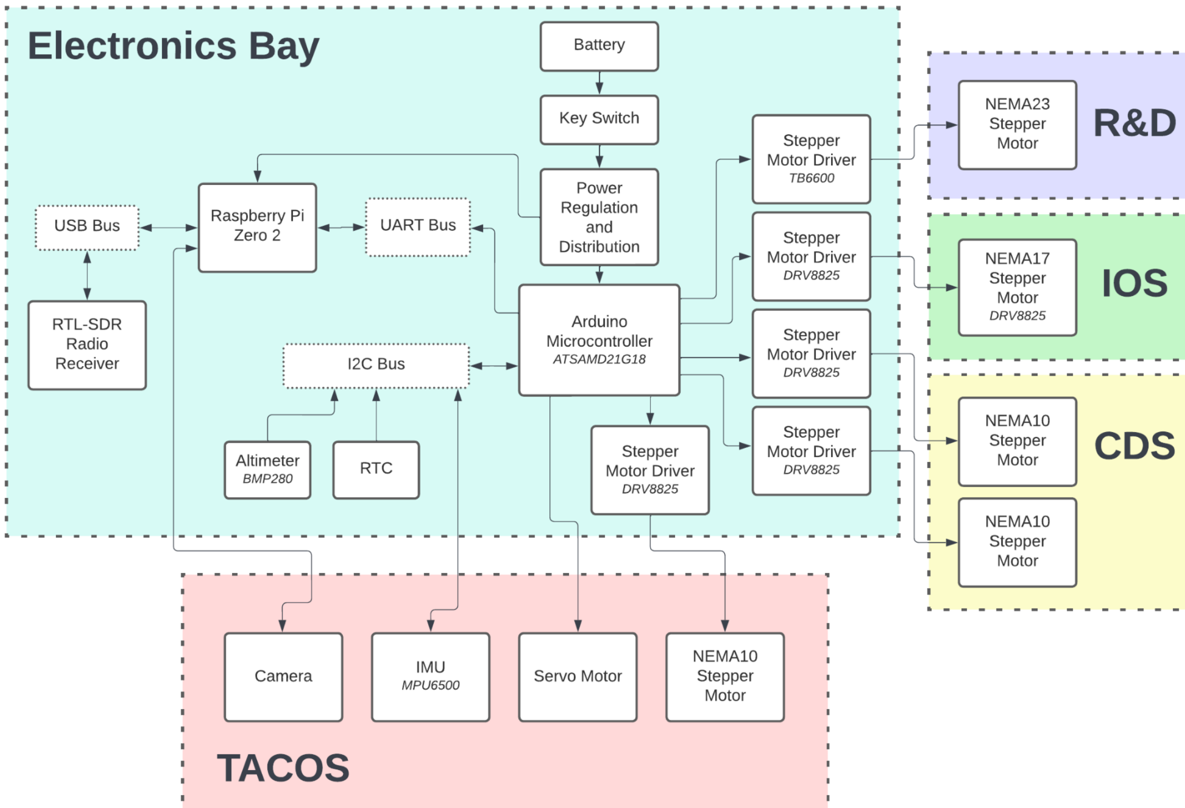


Figure 4.6.1.1: *Payload Electrical System Block Diagram*

The payload system has components driving every major section. The 5 primary areas where electrical components are present are in the electronics bay, R&D, IOS, CDS, and TACOS. The electronics bay holds the PCB and all the electronics to perform computations and instructions. The PCB will hold the microcontroller, motor drivers, Real Time Clock (RTC), and altimeter. Additionally, there will be a Raspberry Pi Zero 2 mounted on top of the PCB. The purpose of this extra microprocessor is to handle radio APRS decoding and image capturing and processing. The Raspberry Pi will be driven by the Arduino microcontroller, which is where the program control loop will be running.

In the sections of the payload outside of the electronics bay there are several electrical components. There is a NEMA23 stepper motor that drives the lead screw for R&D. Additionally, there is a NEMA17 stepper motor driving the rotation for IOS. A linear actuator is used to actuate CDS. The TACOS system has a plethora of components. Firstly, it has a camera for capturing images. TACOS has a servo motor and NEMA10 stepper motor for orienting and moving the camera. Its last component is an IMU for detecting the orientation of the system to ensure the camera is level.

The ATSAMD21G18 microcontroller will tell the Raspberry Pi when to start receiving, when to take a picture, etc. Upon receiving the command to start receiving radio packets, the Raspberry Pi will receive the APRS messages, and send the received commands to the ATSAMD21G18. Then, the ATSAMD21G18 will begin following the sequence of commands received by NASA.

4.6.2. Key Switch Configuration

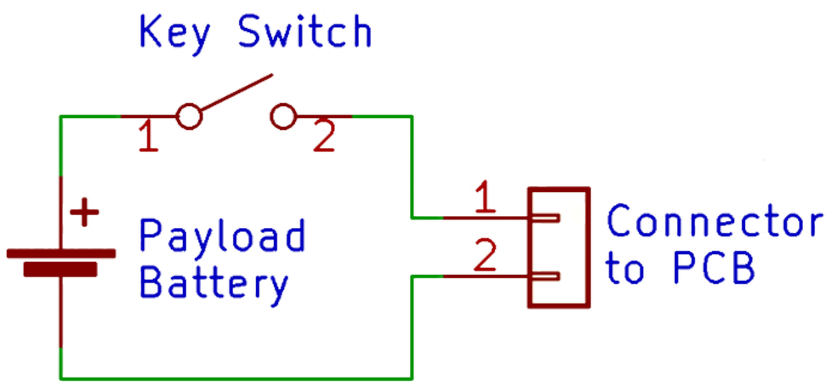


Figure 4.6.2.1: Key Switch Power Connection

To ensure safety and ease of powering the system, the team will use a key switch to turn the electronics on and off. The key switch will create an open or closed circuit between the positive lead of the battery and the PCB. This allows the battery to be completely disconnected and isolated from the electronics.

4.6.3. R&D Stepper Motor

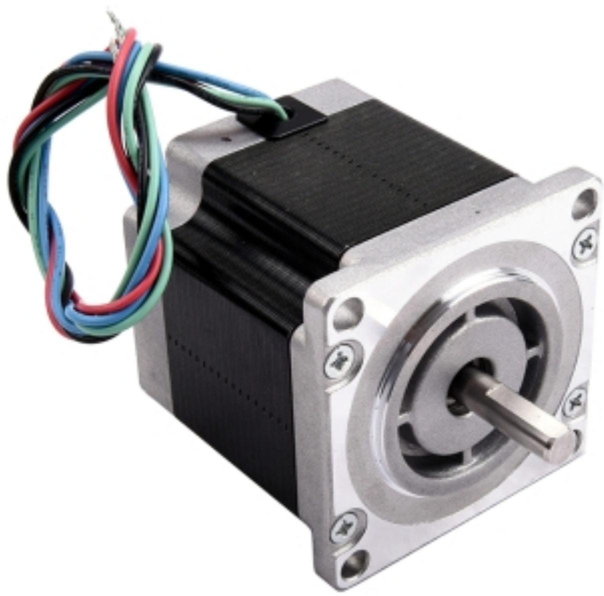


Figure 4.6.3.1: NEMA23 Stepper Motor

The motor the team has chosen for the R&D system is the LS23HS8L4550 motor. This is a NEMA23 motor with a holding torque of 1.5 Nm, which is larger than the motors used in the past by the team. The increase in size is due to last year's team's tests with R&D. The system worked last year with a NEMA17 under most conditions, but to further improve reliability the team has elected to increase the motor size.

4.6.4. IOS Stepper Motor

Figure 4.6.4.1: NEMA17 Stepper Motor

The motor chosen for IOS is the MS17HD6P4050. This is a smaller size than the R&D stepper motor due to it being the input to a planetary gear system. The gear system will increase the torque that the motor generates in order for it to be able to rotate the whole system.

4.6.5. CDS & TACOS Stepper Motor

Figure 4.6.5.1: NEMA10 Stepper Motor

The motor chosen for both CDS & TACOS is the MS10HY0F4025. This motor is much smaller than the other two. Its purpose is to raise the camera and rotate the camera 360 degrees horizontally. This ensures the camera will be able to rotate in each direction. Two motors will be in place behind the CDS bulk plate to drive the spur gears in the rack and pinion design. Both subsystems require low torque and have sizing restraints for this motor.

4.6.6. Microcontroller

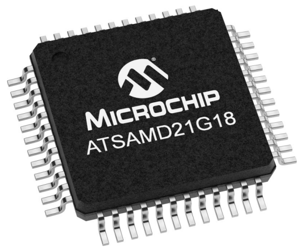


Figure 4.6.6.1: ATSAMD21G18 Microcontroller

The ATSAMD21G18 microcontroller was chosen as the primary processor for the payload system. It will be flashed with an Arduino bootloader to make software development easier. This will run the control loop and interface with all other components. The largest reason why this was chosen was due to the team's past experience with it. Additionally, it has enough flash memory to store all the libraries and code that the system requires to operate. It also has the necessary I/O pins to interface with all other components.

4.6.7. Raspberry Pi Zero 2

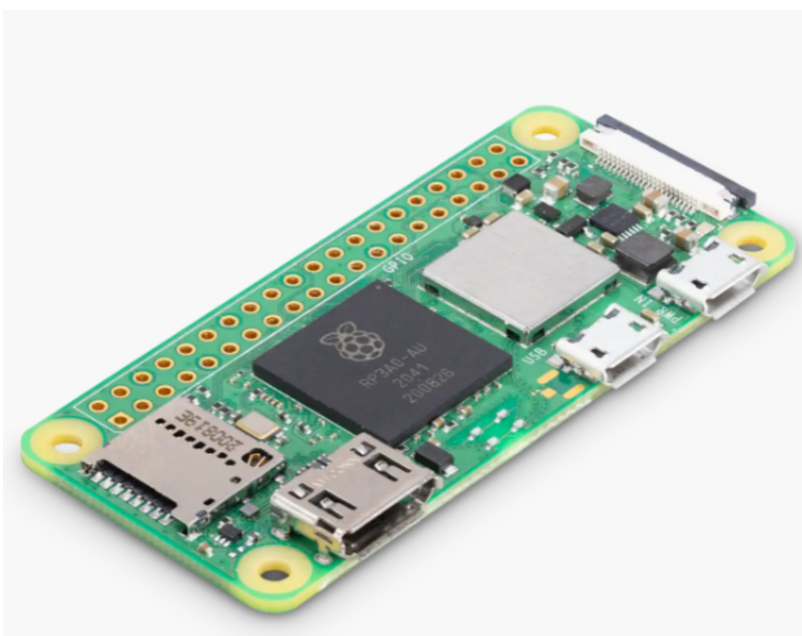


Figure 4.6.7.1: Raspberry Pi Zero 2

In addition to the ATSAMD21G18 microcontroller, the team will interface a Raspberry Pi Zero 2 with it via a UART bus. The Raspberry Pi will drive the radio receiver as well as the camera.

The reason the team chose to do this is to make software development easier. There are easy to use libraries for APRS decoding as well as camera and image processing that will be run on the Raspberry Pi.

4.6.8. Camera

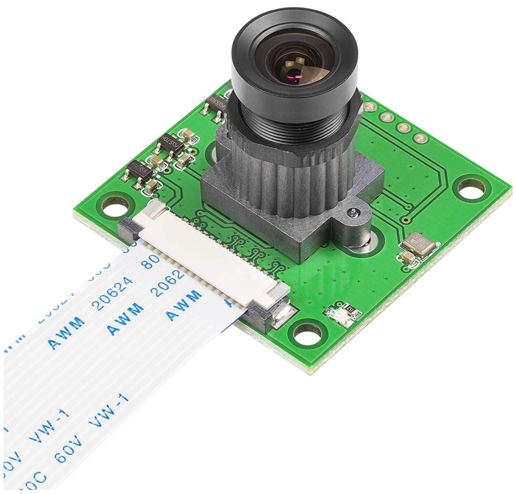


Figure 4.6.8.1: ArduCAM OV5647

The ArduCAM OV5647 is the camera chosen by the team. This camera was chosen due to the interface and compatibility with the Raspberry Pi. This will help ease development and image processing. This camera also has the same lens mounting mechanism as the previous ArduCAM OV2640, so the same lenses can be used. This means the team can fulfill the field of view (FOV) requirements of the camera by switching the lens.

4.6.9. Inertial Measurement Unit (IMU)

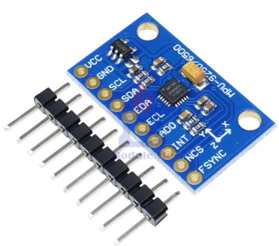


Figure 4.6.9.1: MPU6500 IMU

The IMU that was chosen was the MPU6500. This was chosen due to its high sampling rate and 6 degrees of freedom. This will allow the team to acquire the necessary inertial data to detect launch, landing, and the orientation of the payload bay. The orientation of the payload bay is necessary so that API can determine the appropriate number of rotations to spin the IOS stepper motor.

4.6.10. Altimeter

Figure 4.6.10.1: BMP280 Altimeter

The BMP280 is the altimeter the team has chosen. The primary reason is the team's past success with it. The BMP280 has been used by the team for several years and no issues have been found with it. Its reliability and ease of interface made it the ideal candidate for this year's challenge. The purpose of this component is to be used to assist in landing and launch detection.

4.6.11. Real Time Clock (RTC)

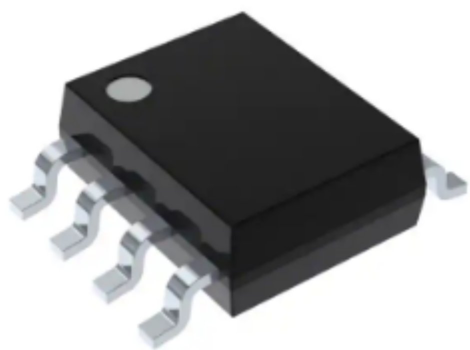


Figure 4.6.11.1: DS1307 RTC Chip

The DS1307 was selected as the RTC to use for payload. This was chosen due to its availability, ease of implementation, and ability to keep time in accordance with payload requirements. The RTC will keep track of the date and time in order to timestamp each image the payload system takes.

4.6.12. NEMA17 and NEMA10 Stepper Drivers

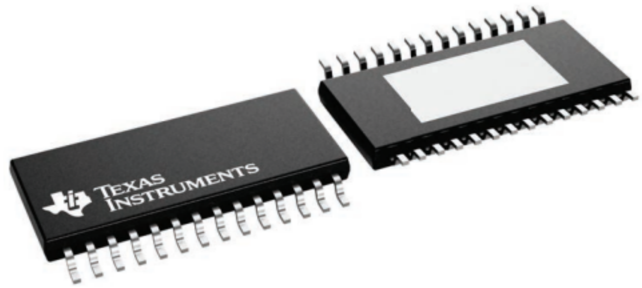


Figure 4.6.13.1: DRV8825 Stepper Motor Driver

The NEMA17 stepper motor used for IOS and the NEMA10 stepper motors used in TACOS and CDS will each be driven by DRV8825s. This driver was chosen for three primary reasons: it is easily interfaceable, is readily available, and the team has had prior success using it. While this driver is appropriately sized for the NEMA17, it has a bit of unused capability when driving the NEMA10. The team elected to drive both motors with these drivers to reduce the number of unique major components used in the design to reduce the possibility of errors.

4.6.13. NEMA23 Stepper Driver

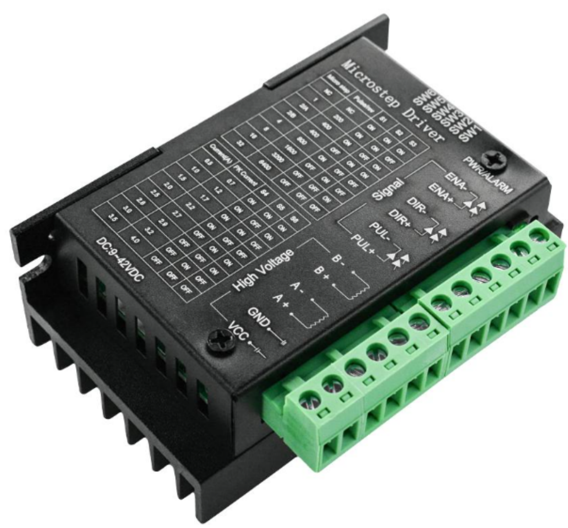


Figure 4.6.14.1: TB6600 Stepper Motor Driver

The TB6600 is the motor driver that was chosen to control the NEMA23 motor that R&D uses. This is significantly larger than the other motor drivers due to the power consumed by the NEMA23 motor. This will notably not be present on the PCB, but will be mounted separately inside the payload bay. It will then be wired to the PCB to be interfaced with.

4.6.14. Radio Selections

4.6.14.1. Radio Receiver Selection

Figure 4.6.15.1.1: RTL-SDR Radio Receiver

The RTL-SDR has been chosen to receive the APRS messages transmitted by NASA. Originally, the team was attempting to use a raw DRA818V chip and demodulate the radio signals manually. This proved too complex and too unreliable to be completed in a time sensitive project. Thus, the team elected to switch to the RTL-SDR which demodulates the radio signals automatically. This will be plugged into the Raspberry Pi via the USB which will drive this receiver. The SMA end will be plugged in the antenna.

4.6.14.2. Antenna Selection

Figure 4.6.15.2.1: 8" Whip Antenna

The team is currently researching and will be testing two different antennas. The first is a whip antenna. This antenna would be mounted horizontally along the airframe of the payload electronics bay. The omnidirectional properties of a whip antenna coupled with the transmitter being mounted over 300 feet in the air will allow the team to receive radio messages when the launch vehicle has landed.

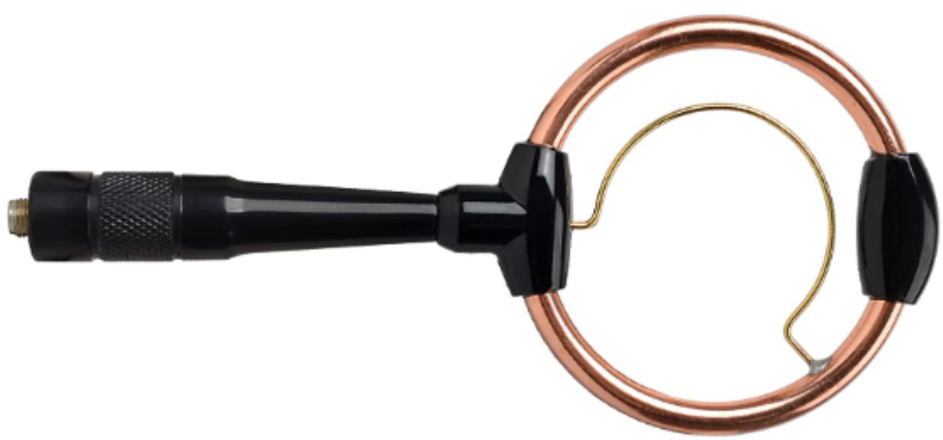


Figure 4.6.15.2.2: Loop Antenna

The second antenna the team will be testing is a loop antenna. This antenna can be much shorter than the whip antenna because it utilizes a loop instead of increasing the length of the antenna. Due to this, the team will be able to experiment with orienting the antenna vertically or horizontally inside the payload electronics bay.

4.6.14.3. Transmitter Selection

Figure 4.6.15.3.1: E32-433T30D Radio Transceiver

If the team completes the challenge early in the competition, the team has decided that attempting to transmit the images back to a Ground Control Station (GCS) would be a good reach goal. To accomplish this, the team would use the E32-433T30D radio transceiver. This allows the team to transmit using 433 MHz (UHF band). The captured and processed images would be transmitted back to GCS using this module after every image has been taken. This ensures the images can be captured quickly as well as giving the transmission time to ensure reliability. Again, this goal will only be attempted if the rest of the payload challenge has already been completed.

4.6.15. Electronics Subscale Testing

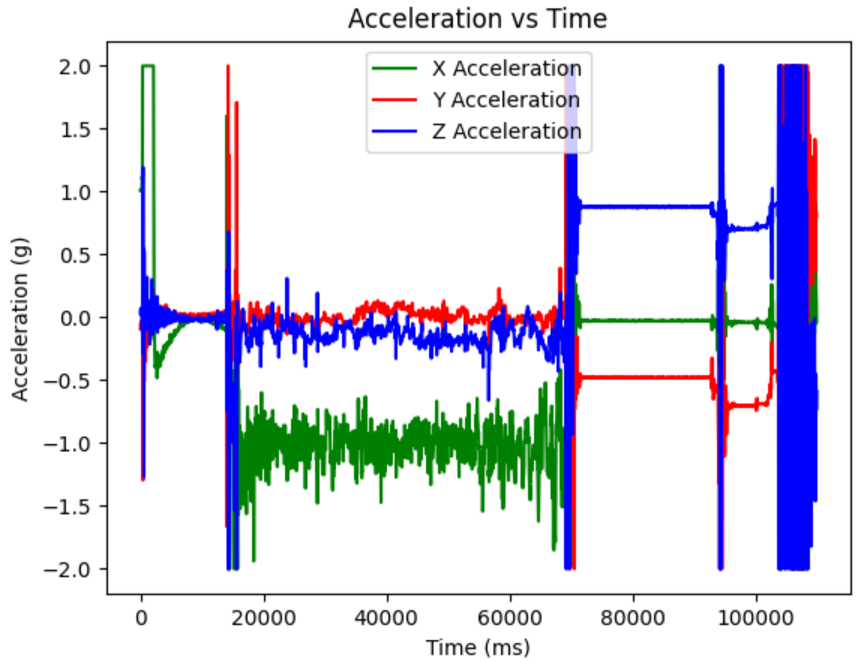


Figure 4.6.16.1: Subscale Acceleration vs Time Graph

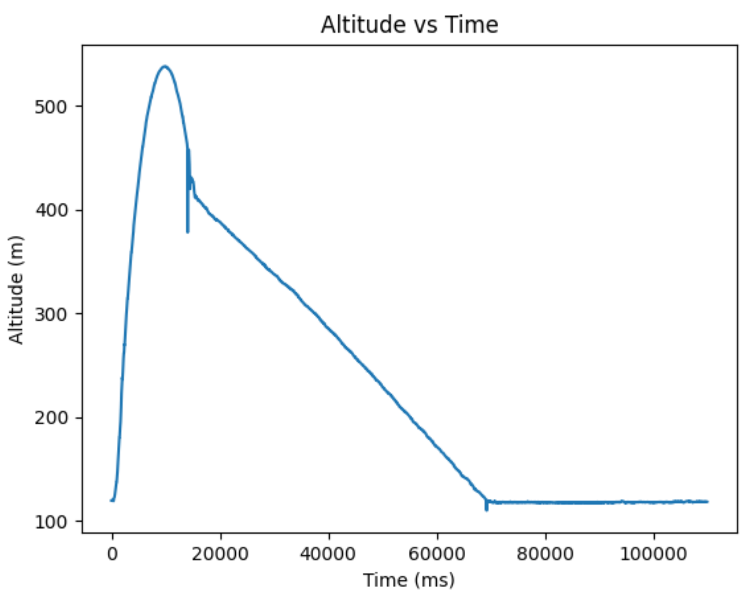


Figure 4.6.16.2: Subscale Altitude vs Time Graph

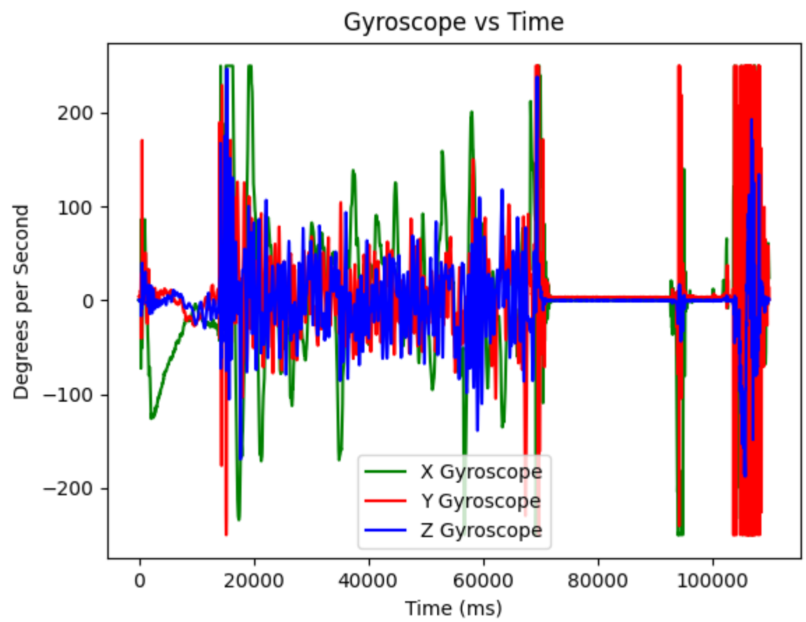


Figure 4.6.16.3: Subscale Gyroscope vs Time Graph

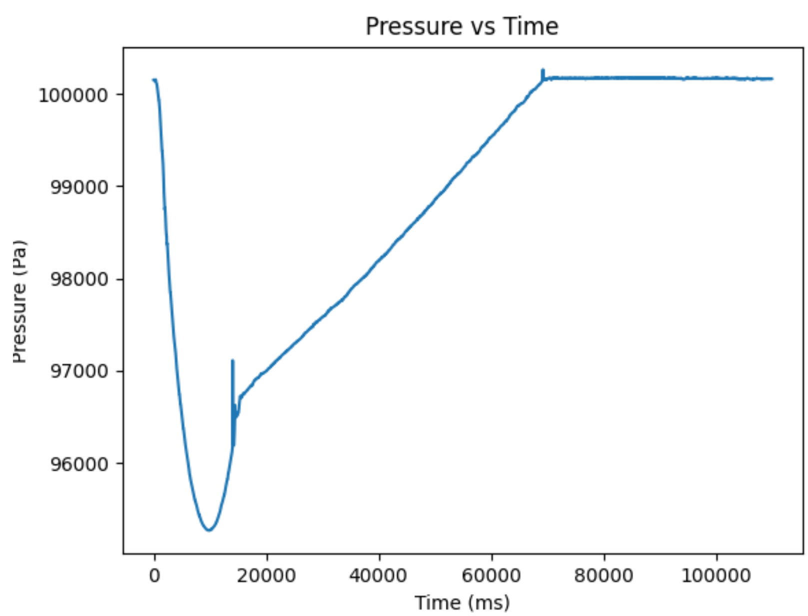


Figure 4.6.16.4: Subscale Pressure vs Time Graph

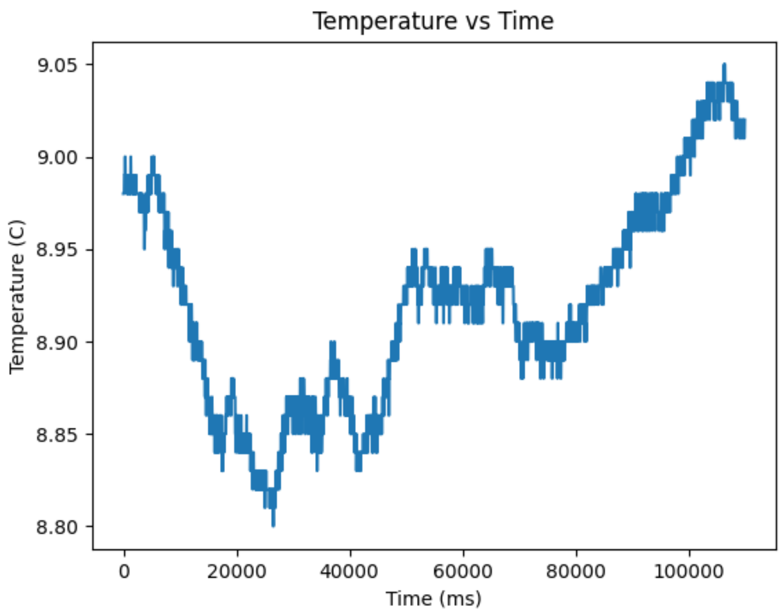


Figure 4.6.16.5: Subscale Temperature vs Time Graph

During the subscale launch, the payload team was able to successfully demonstrate use of the DS3231 Real TIme CLock, the BMP280 Altimeter, MPU6500 6-DOF IMU, and the ATSAMD21G18 microcontroller. A perfboard was used to solder breakout boards of the previously listed electronics, and payload software libraries were utilized to collect data during the subscale flight.

4.6.16. Electronics Power

4.6.16.1. Power Constraints

Component	Power Consumption (Launch Ready)	Power Consumption (During Flight)	Power Consumption (After Landing and Orienting)
R&D Stepper Motor	0 mA	1000 mA	0 mA
IOS Stepper Motor	0 mA	400 mA	0 mA
CDS Linear Actuator	0 mA	70 mA	70 mA
TACOS Stepper Motor	0 mA	0 mA	100 mA
TACOS Servo Motor	0 mA	0 mA	30 mA
Raspberry Pi Zero 2	100 mA	100 mA	400 mA
All Other Components	30 mA	30 mA	30 mA
Total	**130 mA**	**1600 mA**	**630 mA**
Worst Case Time in Stage	**120 minutes**	**5 minutes**	**20 minutes**
Battery Power Consumed	**260 mAh**	**133.33 mAh**	**210 mAh**

Total Battery Power Used	**603.33 mAh**

Figure 4.6.17.1.1: Power Consumption Breakdown per Component

The largest power consumers of the electronics systems are the Raspberry Pi and the stepper motors. The stepper motors have the advantage of only requiring power during flight or executing commands received via the radio. This means that they take a lot of instantaneous power but will not drain the battery much. In total, under the worst case scenario, the total power consumption will be 603 mAh.

4.6.16.2. Battery Selection

Figure 4.6.17.2.1: 4S 1550 mAh LiPo Battery

Due to the total power consumption, the battery chosen needs to have at least that much power. Additionally, the stepper motors will need a high voltage to operate. Thus, the team has chosen a 4S LiPo battery. The battery has a 1550 mAh capacity in order to maintain enough charge to complete the mission and to have extra in case the motors need more current after initial tests.

4.7. Payload Software States

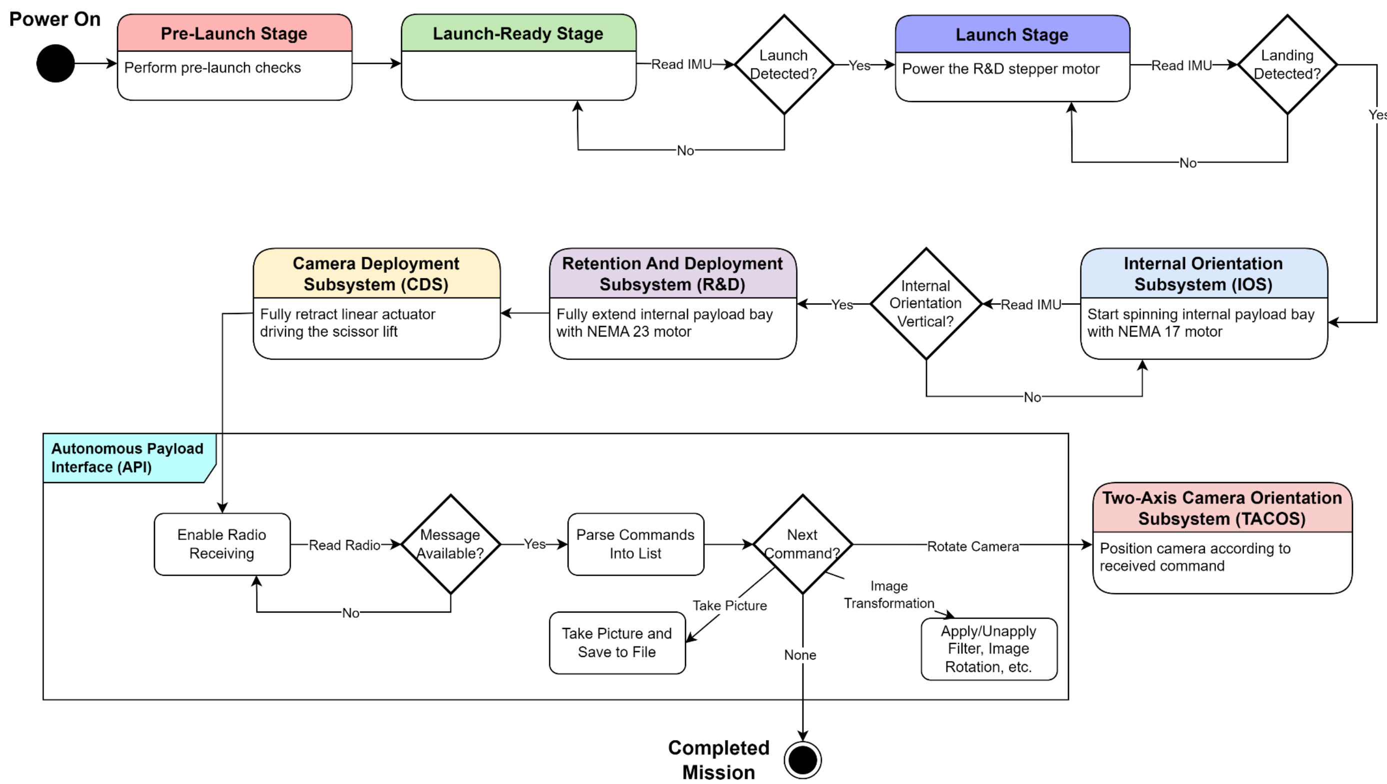


Figure 4.7.1: Payload Software State Diagram

The payload software can be broken down into a serializable set of states. The first stages, Pre-Launch Stage and Launch-Ready Stage, are both performed while on the launch pad. Once the system detects launch, it enters the Launch Stage and powers the R&D stepper motor. That enables the holding torque of the motor to retain the payload bay during flight. During the whole flight, the system is reading the IMU to determine if the launch vehicle has landed. Once landed, it triggers the IOS to begin orienting the internal payload bay. Once it has oriented the CDS into a position where the CDS will be able to deploy vertically in the air, it moves to the R&D state. The R&D motor begins separating the payload bay linearly. Once fully separated, the linear actuator within CDS begins to retract the bottom of the scissor lift, which extends the lift upwards.

After fully extended, the API begins its main loop. It continuously waits for the NASA RAFCO message to be received. The Arduino microcontroller will act as the master device. It will block and wait for the Raspberry Pi Zero to receive the RAFCO message and send the message to the Arduino microcontroller. After the Arduino receives them, it parses and iterates over them. For each RAFCO command, it is broken down into 3 major categories: Take Picture, Image Transformation, and Rotate Camera. If the command is C3 it is categorized as a Take Picture command. That is forwarded back to the Raspberry Pi Zero to take the picture and save it to a file. If the command is D4, E5, F6, G7, or H8, it is categorized as an Image Transformation command, and is also sent to the Raspberry Pi. If the command is A1 or B2, it is categorized as a Rotate Camera command and is forwarded to TACOS to properly orient the camera. If it reaches the end of the command sequence, it has completed the mission and ends the loop.

5. Safety

5.1. Operation Procedures

In preparation for actual launch operations, the following checklists have been created to maintain a clear and exhaustive flow of launch operations and ensure maximum personnel and vehicle safety. In addition, the creation of these checklists allows the team to develop contingencies against worst case scenarios, namely misfires or unintended ballistic trajectories. While there is no way to truly lessen the danger associated with the latter, the creation of a contingency is the best method for prevention.

5.1.1. Final Assembly Personnel

Only team members designated as necessary for full-scale assembly and preparation will be allowed access to the launch workstation. All other members will be required to stand a minimum safe distance of 15ft from assembly. This will prevent overcrowding of the workstation area and allow for procedures to be more easily executed with increased safety.

Team Mentor: Christopher Nilson

Project Management	**Project Manager**: Mateusz Jaszczuk
	Safety Officer: Alex Edwards
Parachute Packing & Avionics	**Lead Operator(s)**: Ellie Vinson
	Support: Nick Morales, Camille DeMange, Julia Spihlman
Vehicle Assembly	**Lead Operator(s):** Matt Fangio
	Support: N/A
Payload Assembly	**Lead Operator(s)**: Alexander Loney
	Support: Jaylen Young, Sean Boltjes

Lead Operators will be responsible for double checking a completed part with which they were involved in its assembly or construction. Support members will provide assistance with procedures and inspections. Upon final assembly prior to launch, Lead Operators will be responsible for answering if their step has been completed and witnessed. As procedures are completed, Lead Operators will be responsible for initialing crucial steps as physical proof of completion and checking.

5.2. Subteam Procedures

Each subteam has prepared assembly and launch day procedures for their system detailing steps in sequential order. These procedures will be printed out and delivered to Lead Operators as needed. These steps have been categorized as:

- **In Advance**
    - Concurrent: Avionics & Recovery, Payload
- **The Day Before**
    1. Avionics & Recovery, Construction
    2. Avionics & Recovery, Construction
    - Concurrent: Payload
- **The Day Of - Launch Prep**
    1. Safety Team
    2. Payload, Construction
    3. Avionics & Recovery
    4. Propulsion Prep
- **The Day Of - Countdown to Launch**
    1. Safety Team
- **The Day Of - Post Launch**
    1. Safety Team
    2. Avionics & Recovery
- **The Day After**
    - Avionics & Recovery
- **Troubleshooting**

Each category name is in reference to full-scale launch. The chronological order of procedures is outlined for each subteam within each category. An asterix (*) at the top of each procedure's checklist indicates the following subteam procedures will be carried out concurrently with other subteam procedures. A numbered listing (ex: 1.) notes the specific order subteams will carry out procedures, indicating when a subteam requires another subteam to complete a task before starting their own. A combination of both (ex: 1*.) notes when multiple subteams will perform operations concurrently within the same step of the procedures.

5.2.1. In Advance

*AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

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Programming TeleMetrum:

NOTE

The LiPo battery can be charged by plugging it into the TeleMetrum and then plugging the TeleMetrum into a laptop with a micro-USB cable. The red light will turn green when the battery is fully charged. A switch does not need to be connected.

- ☐ Connect the TeleMetrum to its LiPo battery and switch. Make sure AltOS (https://altusmetrum.org/AltOS/) is installed, then plug the Telemetrum into the laptop using a micro-USB cable.
- ☐ After choosing Configure Altimeter, while the TeleMetrum is lying flat, turn on the TeleMetrum with the switch. Select the TeleMetrum device from the devices to select, then continue to the settings window. The TeleMetrum should stop beeping, indicating it is connected.
- ☐ Configure with the desired settings. Set the main deploy altitude to 800' and the apogee delay to 0 seconds. Ensure these settings:
    a. Frequency: 434.550 MHz Channel 0
    b. Telemetry/RDF/APRS Enable: Enabled
    c. Telemetry Baud Rate: 9600 baud
    d. APRS Interval(s): 5
    e. Callsign: KD2IKO
    f. Maximum Flight Log Size (kB): 8192 (1 flight)
    g. Igniter Firing Mode: Dual Deploy
    h. Pad Orientation: Antenna Up
- ☐ Save these settings to the TeleMetrum. The accelerometer can be calibrated by selecting Calibrate Accelerometer, and the TeleMetrum can be rebooted by selecting Reboot, if desired.
- ☐ Choose Save Flight Data before any flight and make sure all previous flights are deleted so that no flight logs are lost.

Programming Stratologger CF:

- ☐ Connect the DT4Ux cable to the USB-B to USB-A cable. Next, connect the DT4Ux cable to the StratoLogger CF altimeter's data port, and connect the USB-B to USB-A cable to a laptop that has PerfectFlite DataCap installed (http://www.perfectflite.com/Download.html). Make sure to connect the 9V battery and switch to the StratoLoggerCF.
- ☐ Open DataCap and turn on the switch. The StratoLogger will go through its initialization beeps, so while that is occurring, make sure the correct comm port (COM6) is selected by choosing Altimeter, then CommPort. Then choose Altimeter, then Setup to make sure there was a

successful connection with the altimeter. If successful, the serial number and current settings will appear and the altimeter will stop the initialization beeps. To indicate that it is connected, it will beep every few seconds.

- [ ] If that does not work to connect the altimeter, try choosing Data, then Acquire.
- [ ] To configure the settings, choose Preset 4, setting the main deploy altitude at 600' with a 2 second apogee delay. Set Siren Delay to 0 seconds. To save these settings, select Update Alt.
- [ ] By selecting Altimeter, then Test, one could do self-tests if needed.
- [ ] Past flights cannot be deleted from the StratoLoggerCF, but after 16 flights the oldest will be deleted automatically.

Programming Eggfinder:

- [ ] Turn on the keylock switch of the EggFinder TX by using a key.
- [ ] Plug the EggFinder RX into a laptop. At first, a red LED light will turn on, indicating it has power, and then one or two seconds later the green LED should start blinking. This means it is now receiving data from the EggFinder TX.
- [ ] Download "Windows Driver Installer Setup Program" which can be found on the Prolific serial driver webpage at the bottom of the list (https://prolificusa.com/product/pl2303hx-rev-d-usb-serial-uart-bridge-controller/). After downloading, extract the zip file and run the application "PL2303-WHQLDriver_Setup_v1230_20190815.exe", then follow the instructions on how to install the driver.
- [ ] If not already done, download MapSphere, create an account, and then run it. (http://www.mapsphere.com/download/mapsphere)

Preliminary Avionics Assembly:

- [ ] As specified in the CAD model, cut the two threaded rods to length using a Dremel.
- [ ] On the altimeter sled, drill out the mounting post holes so that they have a slightly larger diameter (if the mounting posts do not already fit). Screw one mounting post into each of the eight holes and secure them into place with some hot glue around the edges.
- [ ] Epoxy the switch band around the center of the avionics coupler, and drill out all holes in the coupler/switch band assembly using the hole jig (static port holes, airframe interface screw holes, switch holes, and switch holder interface screw holes).
- [ ] On each key switch, solder a length (4") of 22 AWG stranded wire onto each lead, twist them together, and add a wire sleeve at the top for support. Also solder each wire onto the metal contacts of the male JST connector and add a wire sleeve at the bottom for support.
- [ ] Insert the key switches into each switch holder and secure with the included nuts. Hot glue the switch holder interface hex nuts into place on the underside of the switch holder using appropriately sized screws as guides.
- [ ] Attach the switch holders with the key switches inside to the interior of the coupler using appropriately sized screws. Also glue the press-in nuts to the appropriate places on the interior face of the coupler with E6000.

- [ ] As specified in the CAD model, drill out all holes on each bulkhead (threaded rod holes, eye bolt holes, black powder canister holes, terminal block holes, and wire through-holes).
- [ ] On each bulkhead, attach an eyebolt using an appropriately sized hex nut, washer, and thread-locking fluid. Also, as specified in the CAD model, attach the black powder canisters using screws, washers, and hex nuts, and attach the terminal blocks using screws and hex nuts.
- [ ] Cut four more pieces of 22 AWG stranded wire to length (2”) and twist together into two sets. On each set, crimp the female metal JST contacts onto one end of each wire and slide them into the female JST connector. Add a wire sleeve at the interface for support. These will be the switch connection wires for each altimeter.
- [ ] Cut eight more pieces of 22 AWG stranded wire to length (10”) and twist together into four sets. These will be the drogue and main lighter connection wires for each altimeter.

*PAYLOAD

Lead Operator(s): Alexander Loney **Required PPE**: Safety Glasses

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Preliminary Payload Assembly:

- [ ] Before assembly of the TACOS, the R&D and IOS subassemblies must be completed.
    a. The R&D bay separation apparatus should be assembled as designed in CAD. This involves attachment of the following components.
        i. The battery should be charged before installing into its holder. The battery must be marked with brightly visible tape to ensure visibility.
        ii. Keyswitch
        iii. R&D Stepper, Wiring Slip-ring, and Lead Screw
        iv. R&D Forward Bulkhead and Upper Payload bay airframe
        v. R&D Moment Rollers
    b. The TACOS subassembly should be assembled in parts as designed in CAD.
        i. The electronics board should be assembled separately.
        ii. The TACOS chassis should be integrated and tested to ensure proper extension operation.
- [ ] To assemble the TACOS, the following components should be integrated in order:
    a. The Payload coupler bay and internal components should be assembled and closed.
    b. The R&D dual-plate, threaded rod frame should be integrated with the IOS and its associated plates and electronics boards.
    c. The R&D dual-plate, threaded rod frame should be fastened to the R&D lead screw.
    d. The R&D plate guide rail should be installed along with the Lower Payload bay airframe and Payload bay coupler.
    e. The R&D forward bulkhead and Upper Payload bay airframe should be installed to the end of the R&D dual-plate, threaded rod frame.

- [ ] To retract the TACOS, ensure the following is done:
    a. The TACOS retraction routine is activated.
    b. The R&D retraction routine is activated.
        i. The R&D rotational guide bolt must be aligned before the bay is allowed to close entirely.
        ii. The R&D should cause the Lower and Upper Payload bay airframes to meet and mesh across the Payload bay coupler.

NOTE

Ensure fingers and other tools and objects are clear from the R&D separation point before and during the closing sequence.

    c. The system must be turned off via the Payload key switch before handling.

*CONSTRUCTION

Lead Operator(s): Matt Fangio **Required PPE**: Safety Glasses, Safety Gloves, N95 Masks

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MFSS Assembly:

- [ ] Attach the top of the fin assembly to the centering plate with a .25” bolt
    - Repeat for remind 2 fins
- [ ] Attach the bottom of the fin assembly to the thrust plate with a .25” bolt
    - Repeat for remind 2 fins
- [ ] Connect motor retainer plate to the bottom of the thrust plate with three standoffs
- [ ] Insert MFSS into the aft of the launch vehicle airframe, ensuring a snug fit

NOTE

Insertion of the MFSS must be done with care, as it will affect motor alignment on the final launch vehicle

- [ ] Screw in 6 screws in centering plate after motor installation (Note: motor installation occurs later (see launch procedures))
    - Repeat for thrust plate

INSPECTION

Inspect MFSS assembly for the following. If any are missing, damaged, or otherwise incorrect, halt launch procedures and direct attention to the Lead Operator(s), who will appropriately respond to the irregularity.

- Inspect for the presence of:
    - ➢ Securement of all fins inside spars
    - ➢ MFSS secured into the aft of launch vehicle

5.2.2. The Day Before

1. AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

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Assembling the Avionics Bay:

NOTE

See the INSPECTION step for Vehicle Assembly below. The inspection for orange tape covering all quick link fasteners and LiPo batteries, along with the proper technique of parachute folding must be done simultaneously with those steps. The inspection for the correct location of screws and shear pins must occur once the vehicle is fully assembled.

****WARNING****

Black powder is a dangerous energetic material and must be handled carefully using proper safety precautions. The Safety Officer will provide supervision during the procedure.

- ☐ Taking a nitrile glove, cut the finger tips off four of the fingers. Using two small zip ties, seal each fingertip closed. Measure out 2g, 3g, 4g, and 5g quantities of FFFFG black powder using a gram scale and funnel each quantity into a separate glove fingertip. Insert a lighter cut to size into each fingertip.
- ☐ Insert the 2g and 3g black powder charges into their respective black powder canisters on the drogue bulkhead and the 4g and 5g black powder charges into their respective black powder canisters on the main bulkhead. Use fireproof cellulose insulation to pack tightly and then seal with masking tape. Screw the lighters into their respective terminal blocks.
- ☐ Screw each set of switch connection wires into the switch terminals of each altimeter. Also, screw a set of both drogue and main lighter connection wires into their respective terminals of each altimeter.
- ☐ Using nylon altimeter mounting screws, attach the TeleMetrum and StratoLoggerCF altimeters to their respective sets of mounting posts on the altimeter sled.
- ☐ Ensure that the 3.7V LiPo and 9V batteries are fully charged and insert them into their respective compartments in the altimeter sled. Connect the 3.7V LiPo battery to the TeleMetrum. Attach a 9V battery connector to the 9V battery and screw the connector into the battery terminals on the StratoLoggerCF.

INSPECTION

Inspect the avionics bay components for the following. If any of the criteria is missing, damaged, or otherwise incorrect, halt launch procedures and direct attention to the Lead Operator(s), who will conduct the appropriate response to the abnormality.

- ➢ Inspect that the following are present:
  - ☐ 1 washer on each of the 2 threaded rods on the drogue bulkhead side
  - ☐ 2 nuts on each of the 2 threaded rods on the drogue bulkhead side

- [ ] 1 washer on each of the 2 threaded rods on the main bulkhead side
    - [ ] 2 nuts on each of the 2 threaded rods on the main bulkhead side
    - [ ] Altimeter sled
    - [ ] Battery guard
    - [ ] 4 nuts on each of the 2 threaded rods securing the avionics sleds
    - [ ] TeleMetrum altimeter
    - [ ] StratoLoggerCF altimeter
    - [ ] 4 wires connecting the TeleMetrum to the main and drogue terminals
    - [ ] 4 wires connecting the StratoLoggerCF to the main and drogue terminals
- [ ] Conduct a pull test on each wire connecting the altimeters to the ejection charges
- [ ] Check that the batteries are connected to their respective altimeters
- [ ] Check that the 3.7V LiPo battery connects to the TeleMetrum
- [ ] Check that the 9V battery connects to the StratoLoggerCF

- [ ] Screw two hex nuts onto each threaded rod so there is about 0.8” between the top of the second hex nut and the bottom of the threaded rod. Place a washer on each threaded rod.
- [ ] Face the drogue bulkhead downward and slide it onto the threaded rods.
- [ ] Screw two more hex nuts onto each threaded rod so there is about 0.5” between the bottom of the first hex nut and the bulkhead.
- [ ] Slide the altimeter sled on with the battery compartment facing upward so that it touches the recently placed hex nuts on the threaded rods. Feed the drogue lighter connection wires from each altimeter though their respective holes in the drogue bulkhead.
- [ ] Slide the battery guard on, then add two more hex nuts onto each threaded rod so that they touch the battery guard.
- [ ] Slide the coupler over the components until it touches the bulkhead.
- [ ] Connect the two sets of switch-to-altimeter JST connections together. Screw the drogue lighter connection wires into the other ends of their respective terminal blocks on the bulkhead exterior. Confirm that the switches are OFF.
- [ ] Feed the main lighter connection wires of each altimeter though their respective holes in the main bulkhead, then slide the bulkhead onto the threaded rods, sealing the coupler.
- [ ] Screw the main lighter connection wires into the other ends of their respective terminal blocks on the bulkhead exterior. Secure everything together by adding a washer and two hex nuts to each threaded rod.

2. CONSTRUCTION

Lead Operator(s): Matt Fangio **Required PPE**: Safety Glasses, Safety Gloves

Pre-Recovery Vehicle Integration:

A. Launch vehicle is currently made up of 3 individual sections.
   a. Payload
      i. Nosecone, payload bay, coupler
   b. Avionics & Recovery
      i. Upper recovery tube, avionics bay, lower recovery tube
   c. Lower Airframe
      i. MMFS, lower airframe tube

INSPECTION

Inspect vehicle sections for the following. If any are missing, damaged, or otherwise incorrect, halt launch procedures and direct attention to the Lead Operator(s), who will appropriately respond to the irregularity.

- ➢ Ensure that all fasteners are tightened into place and are properly secured
- ➢ Ensure all airframe and coupler sections are properly aligned
- ➢ Inspect outer airframe for protruding or loose objects

WARNING

Failure to inspect and ensure these aspects of the flight vehicle can potentially result in the endangerment of all team members and loss of flight vehicle

B. Once proper inspection and repairs have taken place, Avionics & Recovery will conduct full vehicle integration.

3. AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

Full Vehicle Integration:

- ☐ Attach one EggFinder tracker module to the interior of the booster coupler
- ☐ Make three loops in each shock cord (one on each end and one 1/3 of the shock cord length from one end). For every 10’ of shock cord, make one bundle of z-folds and tape the bundle together using masking tape. Attach large quick links to every loop.
- ☐ Fold the main parachute on a tarp so that when finished, it is long and thin. Attach the drogue parachute and a Nomex blanket to the middle quick link of the 30’ shock cord and the main parachute and another Nomex blanket to the middle quick link of the 60’ shock cord. Indicate that each quick link has been closed by flagging them with orange tape.
- ☐ Attach the shorter end of the drogue shock cord to the eyebolt on the bulkhead of the drogue side of the avionics bay and the longer end to the eyebolt on the bulkhead of the booster section

through the lower recovery section. Flag each quick link with orange tape to indicate that it has been closed. Using shear pins, reconnect the lower recovery section to the booster section. A rubber mallet may be required to do as such.

- [ ] Insert the drogue parachute followed by the shock cord into the lower recovery section. Check that on top they are adequately covered with the Nomex blanket as safeguard from ejection charge gasses. Reconnect the lower recovery section to the avionics bay with screws.
- [ ] Attach the longer end of the main shock cord to the eyebolt on the bulkhead of the main side of the avionics bay and the shorter end to the eyebolt on the bulkhead of the payload section through the upper recovery section. Flag each quick link with orange tape to signify it has been closed. Reconnect the upper recovery section to the payload section using shear pins. A rubber mallet may be required to do as such.
- [ ] Insert the folded main parachute followed by the shock cord into the upper recovery section. Check that on top they are adequately covered with the Nomex blanket as safeguard from ejection charge gasses. The main parachute should be as loose as possible while still having its length fit into the upper recovery section. Reconnect the upper recovery section to the avionics bay with screws.
- [ ] Use a key to shortly turn on and off each keylock switch through the switch band. Listen for the initialization beeps from each altimeter to verify that all wiring is still secure.

INSPECTION

Inspect the final vehicle assembly for the following. If any of the criteria is missing, damaged, or otherwise incorrect, halt launch procedures and direct attention to Project Management, who will conduct the appropriate response to the abnormality.

➢ Inspect that the following are present:
  - [ ] Proper packing of both the drogue and main parachutes
  - [ ] Orange tape around the closed connections at the following points:
    - Shock cord to main parachute
    - Shock cord to drogue parachute
    - Drogue shock cord to booster section
    - Drogue shock cord to drogue bulkhead
    - Main parachute shock cord to payload bay
    - Main parachute shock cord to main bulkhead
  - [ ] Shear pins at the following points:
    - Upper recovery section to payload bay
    - Lower recovery section to the booster section
  - [ ] Screws at the following points points:
    - Upper recovery section to avionics bay
    - Lower recovery section to avionics bay

*PAYLOAD

Lead Operator(s): Alexander Loney **Required PPE**: Safety Gloves, Safety Glasses

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Preparing Electronics:

- ☐ Charge the LiPo battery
- ☐ Open CAD assembly to access the electronics bay. This may require removal of airframe bolts or safe activation of electronics systems via their respective system key switch
- ☐ Remove and clear the memory storage drives (SD cards) of all data logging devices
- ☐ Final software needs to be uploaded to Payload components
- ☐ Reinsert all memory storage drives into their respective logging devices
- ☐ Calibrate the inertial measurement units on Payload components
- ☐ Calibrate the altimeters on Payload components
- ☐ Load charged LiPo batteries into their respective holders
- ☐ Close respective assemblies to prepare them for final calibration on launch day

NOTE

Ensure electronics are turned off via their respective system key switch before departure.

5.2.3. The Day Of - Launch Prep

1. SAFETY TEAM

Lead Operator(s): Alexander Edwards

Upon Arriving:

- Briefing to team members by Safety or Systems Team Lead:
  - ☐ Timeline of events prior to, during, and after launch
  - ☐ Launch field etiquette
  - ☐ NAR minimum safe distance from launch vehicle
  - ☐ "Scatter" callout in case of ballistic trajectory
  - ☐ Identification of fire suppression and first aid equipment
  - ☐ Designate a "rapid response" person or persons to be the one(s) to perform duties such as administering first aid in the case of an emergency.
  - ☐ Designate spotters to keep track of the launch vehicle's descent and to point out its location as it falls.

Events below may occur at the same time:

- ☐ Selecting a launch area:

- Student Mentor, Project Management, Construction Team Lead, and Safety Team Lead select a launch area that is free from wildlife intrusion and general obstructions.
- Ensure a fire blanket has been placed under the pad if conditions at launch are dry enough to require it.
- Safety Team Lead marks off NAR minimum safe distance for personnel and communicates it to the team.

- [ ] Ensure two-way radios are functioning properly

INSPECTION

- ➢ Inspect all vehicle components for damage from travel.
  - If damage has occurred, Project Management must be notified to determine whether the launch may proceed.
- ➢ Inspect motor, motor casing, and motor retainment system for damage.
  - If damage has occurred, Project Management must be notified to determine whether the launch may proceed.

*2. PAYLOAD

Lead Operator(s): Alexander Loney **Required PPE**: Safety Glasses

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<u>Electronics Startup</u>

- [ ] Turn on the Payload key switch in the team's prep area.
- [ ] Ensure that the payload buzzer sounds signaling system is active.

****WARNING****

In the event of a faulty R&D activation sequence, the launch vehicle should be set down immediately. The Lead Operating personnel should act to safely turn off the system key switch before team members may inspect and attempt to reset the system. Return to step 1 in this scenario.

Payload is now in a launch ready state.

*2. AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

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Altimeter Continuity:

- [ ] Turn on both altimeter keylock switches through the switch band with a key.
- [ ] Below is a set of beeps that should come from the StratoLoggerCF. A lower-pitched beep will come before each set of beeps. Make sure that the **bold** events happen.
    - 4 beeps (indicates **Preset 4** was set).
    - 8 beeps, then 10 beeps, then 10 beeps (indicates main deploy altitude of **700'** was set).
    - One very long beep (indicates an apogee delay of **2 seconds** was set).
    - The number of beeps that give the apogee from the previous flight in feet
    - Beeps that give the battery voltage in volts (ones place first, then tenths place). Make sure the voltage is **above 8.0V**.
    - **3 continuity beeps** every 0.8s.

      INSPECTION

        - ➢ If only 2 continuity beeps – Indicates continuity on only main lighter
        - ➢ If only 1 continuity beep – Indicates continuity on only drogue lighter
        - ➢ If 0 continuity beeps: Indicates continuity on neither drogue nor main lighters

- [ ] Below are the sets of beeps that should come from the TeleMetrum. Specific beeps, including *dits* and *dahs* are specified. Make sure that the **bold** events happen.
    - Beeps that give the battery voltage in volts (ones place first, then tenths place). Make sure it is above **3.3V**.
    - *Dit*, *dah*, *dah*, *dit* (this means TeleMetrum is in **Pad Mode** and is waiting for launch).

      INSPECTION

        - ➢ If the beeps are only *dit, dit* – this means the TeleMetrum is in Idle Mode; make sure it is in the correct orientation (pointing up)

    - **3 continuity *dits*** every 5s.

      INSPECTION

        - ➢ If only 2 continuity *dits* – Indicates continuity on only main lighter
        - ➢ If only 1 continuity *dit* – Indicates continuity on only drogue lighter
        - ➢ If *brap* – Indicates continuity on neither drogue nor main lighters
        - ➢ If *warble* – Indicates storage is full; extraneous flights need to be deleted

- [ ] Turn on both trackers' keylock switches with a key.
- [ ] Make sure that any static port holes are free from debris.

Setting Up the TeleDongle at the Launch Viewing Area:

- ☐ Set up the TeleMetrum antenna with the long prongs on the bottom and the short prongs on top.
- ☐ Next, plug the antenna into the TeleDongle, then take the TeleDongle and plug it into a laptop that has AltOS downloaded on it.
- ☐ Open AltOS, then choose Monitor Flight. Under options to select, the TeleDongle should show up. Select the TeleDongle and then go to the telemetry window.
- ☐ Make sure the frequency is set to 434.550 MHz Channel 0 and the baud rate is set to 9600 baud. Live telemetry from the TeleMetrum should now show up on the screen.

NOTE

*Make sure all lights are **green**.*

a) Check that the battery, apogee igniter, and main igniter voltages are all **above 3.3V**.
b) Make sure On-Board Data Logging is **Ready to record**.
c) Ensure **at least 4** GPS satellites are in solution, which could take a few minutes.
d) Make sure GPS Ready is **Ready**.

- ☐ On the Site Map tab, make sure the launch area fills it.

Setting Up the EggFinder Tracker at the Launch Viewing Area:

- ☐ Follow the second step in the “Setting Up the EggFinder Tracker” section above.
- ☐ Open MapSphere, then select GPS, then Configure. Next, select the COM port that the GPS is connected to, then click OK.
- ☐ In the lower right is the GPS Status tab. Check there to see if the GPS satellites are coming into view.

NOTE

*****Need to have at least 4 GPS satellites in solution. This could take a few minutes.*

- ☐ The main map should now **show the current location** as an orange triangle, and should have real time tracking.
- ☐ Motor installation can now take place on the vehicle.

3. CONSTRUCTION

Lead Operator(s): Matt Fangio, Christopher Nilsen **Required PPE**: Safety Glasses, Safety Gloves

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Motor Assembly

Instructions for the specified motor are attached in the page below.

****WARNING****

Assembly of the CTI L1350-CS-P will be conducted only by the Team Mentor.

- [ ] Grease motor tube forward and aft closure threads.
- [ ] Bolt on forward closure (with eye bolt attached).
- [ ] Place one grain in the motor tube.
- [ ] Insert RUBBER washer.
- [ ] Repeat the last two steps for all motor grains.
- [ ] Apply lubricant as necessary to O-rings.
- [ ] Bolt the aft closure / nozzle onto the motor tube.

NOTE

Igniter and nozzle cap will be added once the launch vehicle is on the launch pad. Under no circumstances are they to be inserted prior to being on launch pad.

Motor Installation

- [ ] Insert assembled motor into the MFSS
- [ ] Secure retainer into place by screwing it onto the aft side of the MFSS, thus securing the motor in place.

4. SAFETY TEAM

Lead Operator(s): Alexander Edwards

Safety Checks

- [ ] Safety Team Lead will call out team members responsible for all Lead Operators steps to ensure that the launch vehicle is ready for flight. These are:
    - Avionics Bay Assembly
    - Thrust Structure Assembly
    - Payload Bay Assembly
    - Final Vehicle Assembly
- [ ] If any Lead Operator step cannot be verified, halt launch proceedings and investigate any source of uncertainty. Launch operations may continue ONLY when all Lead Operator steps can be accounted for.
- [ ] If all Lead Operator steps are accounted for, the vehicle is ready for installation onto the launch pad.

Installing the Vehicle on the Launch Rail:

- [ ] Check that the weather conditions remain favorable for launch.
- [ ] Move the launch vehicle to the launch rail.

NOTE

Only launch essential personnel and those carrying the launch vehicle are allowed to accompany the launch vehicle to the launch pad

INSPECTION

- ➢ Ensure launch rail is at least the minimum safe distance from spectators based upon the NAR minimum distance table
- ➢ Ensure the launch controller is disarmed prior to installing the launch vehicle onto the pad
- ➢ Ensure the launch pad is stable and is an adequate size for the launch vehicle being used

- [ ] Tilt launch rail and slide launch vehicle onto rail along rail buttons.
- [ ] Ensure the launch vehicle slides smoothly along the launch rail.
    - If this is not the case, halt launch proceedings to lubricate the launch rail and check the rail buttons for proper alignment.

5. PROPULSION PREP

Lead Operator(s): Christopher Nilsen

Required PPE: Safety Gloves, Safety Glasses

Installing Ignitor On the Pad

NOTE

ONLY the Student Mentor may install the ignitor.

1. Ensure ignitor clips are clean and undamaged.
2. Ground ignitor clips to ensure excess static charge has been dissipated.
3. Install the ignitor into the motor.
4. Return to the viewing area.
5. Ensure the ignition system has continuity.

THE VEHICLE IS NOW READY FOR LAUNCH

5.2.4. The Day Of - Countdown to Launch

SAFETY TEAM

Lead Operator(s): Alexander Edwards

****WARNING****

The launch and the flight should not be angled towards any spectators or buildings. If any obstructions become present, halt launch procedures and adjust the positioning of the vehicle on the launch rail or wait until obstruction passes.

- ☐ Check cloud ceiling and winds and make sure the skies around the launch area are clear.
- ☐ Ensure there are no obstructions or hazards in the launch area.
- ☐ Designate at least 2 rapid response persons to administer first aid and call for help, respectively.
- ☐ Designate at least 2 spotters to track launch vehicle's flight path.
    a. Spotters must point to the launch vehicle at all times.
- ☐ Remind spectators of the appropriate reaction to a ballistic trajectory and "scatter" call
    a. If a "scatter" is called, all personnel must turn away from the launch vehicle and run for at least 10 seconds.

<u>Go / No Go Poll</u>

- ☐ The Project Manager will now conduct a "Go / No Go" Poll for each of the Lead Operators.
- ☐ If any system is "No Go" for launch, halt all proceedings until that system is "Go." If the "Go / No Go" Poll is halted at any time, restart the Poll once all personnel are ready.
- ☐ **If all systems are "Go," the vehicle is confirmed for launch.**

<u>Launching</u>

- ☐ Shortly before the countdown, give a loud announcement that the launch vehicle will be launched; if applicable to the situation, use a PA system.
- ☐ **When launching, give a loud countdown of "5, 4, 3, 2, 1, LAUNCH!"**
- ☐ Spotters are to follow the path of the launch vehicle and call any deviation or unusual behavior in the vehicle's flight (unsteady flight, sudden course deviation, etc.).
- ☐ Ensure deployment of drogue parachute is evident at most 4 seconds after apogee.
- ☐ If no sign of drogue deployment is apparent, see Troubleshooting below.
- ☐ **Call a loud "Heads up!" (If needed, sound an air horn) in the case of any launch vehicles approaching the prep area or spectators; all who see the incoming launch vehicle should point at it as it descends.**
- ☐ Make sure whoever is responsible for recovery is kept fully aware of the status of the launch vehicle (failed to launch, nominal in-flight, midair failure, returning for recovery, etc.).
- ☐ Communicate launch progress effectively to NASA officials, if needed.

5.2.5. The Day Of - Post Launch

1. SAFETY TEAM

Lead Operator(s): Alexander Edwards

- [ ] Assign teams to approach the main vehicle and payload.

NOTE

Ensure these teams are only as large as needed to prevent unnecessary personnel from coming into contact with the vehicle and payload systems. It is recommended for Lead Operators to be the sole members of the retrieval team.

- [ ] Give each team and the group of team members not approaching the vehicle or lander a two-way radio for communication.

2. AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

At the Landed Vehicle

- [ ] Check that the main parachute is secure and does not drag the vehicle along the ground.
- [ ] Take numerous pictures of the landed vehicle at varying angles.
- [ ] The StratoLoggerCF should produce the following sets of beeps, with one lower-pitched beep preceding each set:
    - Beeps corresponding to the apogee in feet.
    - Beeps corresponding to the maximum velocity in miles per hour.
- [ ] The TeleMetrum should produce the following sets of beeps:
    - Beeps corresponding to the apogee in meters.
- [ ] Record these values as failure to record the altimeter data before turning them off could result in disqualification from the competition. Once this is done, use a key to turn off both keylock switches for the altimeters through the switch band.
- [ ] Collect each section of the vehicle and transport it back to the launch viewing area.

Downloading GPS Data from the EggFinder Tracker at the Launch Viewing Area

- [ ] On one laptop, go into the MapSphere program. Select GPS, then Save GPS-log to save the GPS log as a raw GPS data file.
- [ ] Use a key to turn off both keylock switches for the tracker.

3. SAFETY TEAM

Lead Operator(s): Alexander Edwards

Post-Flight Tasks

- [ ] Notify NASA officials to verify the results of the launch, if necessary.
- [ ] Disarm the launch controller.
- [ ] Place cap on launch rods, if necessary.
- [ ] Take down the launch pad, if necessary.
- [ ] Perform sweep of the launch field to ensure no materials are unintentionally left behind.

5.2.6. The Day After

*PAYLOAD

Lead Operator(s): Alexander Loney **Required PPE**: Safety Glasses

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Payload Mission Aftermath:

- [ ] The R&D system will be set into the open position to allow for internal access
- [ ] The SD card will be read to acquire photos taken and any logged mission data that the team deems useful for analysis.
- [ ] Any batteries used on launch day will be charged.

*AVIONICS & RECOVERY

Lead Operator(s): Ellie Vinson **Required PPE**: Safety Gloves, Safety Glasses

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Downloading Flight Data from the TeleMetrum Altimeter:

- [ ] From the "Programming the TeleMetrum Altimeter" section, follow step 1.
- [ ] Now, select Save Flight Data and switch on the TeleMetrum, which should now show up as a device to select. Choose the TeleMetrum device, then go to the following window. To indicate connection, the TeleMetrum will stop beeping.
- [ ] Choose the newest flight and then save a data file with the raw TeleMetrum data to the laptop.
- [ ] To see a plot, statistics, and map of the flight, select Graph data, then choose the TeleMetrum file that was just saved. Select Configure Graph to configure the plot.
- [ ] Next, convert the raw TeleMetrum file to a CSV file by selecting Export Data, then clicking the raw TeleMetrum file that was just saved. Save the CSV file to the laptop. By changing the Export File Type to Google Earth Data (a .KML file), coordinate location data can be saved, then analyzed just as the raw GPS data files are in the EggFinder tracker section below.

- [ ] Similarly, when the TeleDongle is plugged into the laptop, the raw TeleDongle file can be saved and analyzed.

Downloading Flight Data from the StratoLoggerCF Altimeter:

- [ ] From the “Programming the StratoLoggerCF Altimeter” section, follow steps 1 and 2.
- [ ] Choose Data, then Acquire, then select the most recent flight. Next, select start.
- [ ] Now, the flight’s plot and statistics should appear. By choosing different options under Displayed, different plots can be seen.
- [ ] Select Data, then Inspect to retrieve the numerical data.
- [ ] Copy and paste the data into an Excel file by choosing Select All, then copy. In the Excel file, the data can be plotted and analyzed.
- [ ] Save the raw StratoLoggerCF file by selecting File, then Save As. Later, to open with having the point of StratoLoggerCF plugged in to the laptop, select File, Open, and then chose the raw data file.

Converting Raw GPS Data Files from the EggFinder Tracker:

- [ ] With a laptop, click Choose File in GPSVisualizer (https://www.gpsvisualizer.com/), then select the raw GPS data file from launch day.
- [ ] For the output format, select JPEG map, then Map it. Now, on the next page, download the image to save the map.
- [ ] On the first page, select the output format as plain text table. Choose Convert It, then download the text file on the next page. This will save the coordination location information. Then, copy and paste the coordinates to an Excel document and convert to a CSV file if desired for more analysis.

5.2.7. Troubleshooting

SAFETY TEAM

Lead Operator(s): Alexander Edwards

In the case of a misfire:

- [ ] Wait a minimum of one minute before approaching the launch pad.
- [ ] Disarm launch controller and avionics.
- [ ] Remove failed igniter and motor if needed.
- [ ] Determine if another attempt at launch is feasible.

In the case of unintended ballistic trajectory:

- [ ] If the launch vehicle is in freefall for longer than four seconds without any indication of parachute ejection (smoke from ejection charge, parachute deploying), those tasked with observing the trajectory will loudly announce “Scatter.”
- [ ] All spectators of the launch are to immediately turn away from the direction of the launch vehicle and run for a minimum of 10 seconds.

In case of missing section of launch vehicle during descent:

- [ ] If any sections of the launch vehicle are present, inspect for signs indicating point of separation.
    - If failure mode can be determined, keep in mind any dangers that may be associated with the missing sections of the launch vehicle.
- [ ] Taking into account last known launch trajectory and wind, on a map or map-analogue identify the most likely location of missing part.
- [ ] Assemble team at the edge of the nearest road or other linear landmark.
    - Spread the team out with between 30 and 50 feet between adjacent team members.
    - Instruct team members to keep their gaze between 40 and 50 feet in front of them, scanning the ground in 180-degree arcs, walking in a straight line.
        - If applicable, follow ruts in the dirt from plowing devices or planting
- [ ] Once the far end of the search area has been reached, move the search party such that the last person in the line now stands where the first person was before the move
    - Move back in the direction of the initial linear landmark, and repeat search

5.3. Hazard Analysis Methods

The seriousness of a risk is evaluated by two criteria: the likelihood of an event to occur and the severity of the event should it happen or fail to be prevented. The breakdown of the methods used in the team's risk analysis and the assessment of personnel, vehicle failure mode, environmental, and project risks are discussed in the following sections:

5.3.1. Likelihood of Event

Category	**Value**	**Gauge**
Remote	1	Extremely unlikely to occur
Unlikely	2	Unlikely to occur
Possible	3	Average odds to occur
Likely	4	Above-average likelihood to occur
Very Likely	5	Very likely to occur/has occurred previously

Table 5.3.1: Event Likelihood Scale

5.3.2. Severity of Event

Category	Value	Health and Personal Safety	Equipment	Environment	Flight Readiness
Negligible	A	Negligible injury. No first aid required. No recovery time needed.	Minimal and negligible damage to equipment or facility. No required correction.	Negligible damage. No repair or recovery needed.	No flight readiness disruption.
Minor	B	Minor injury. Requires band-aid or less to treat. 5-10 minutes of recovery time required.	Minor damage. Consumable equipment element requires repair.	Minor environmental impact. Damage is focused on a small area. Little to no repair or recovery needed. Outside assistance not required.	Flight proceeds with caution.
Moderate	C	Moderate injury. Gauze or wrapping required. Recovery time up to one day.	Reversible equipment failure. Non-consumable element requires repair. Outside assistance not required.	Reversible environmental damage. Personal injuries unlikely. Outside assistance recommended. Able to be contained within team.	Flight delayed until effects are reversed.
Major	D	Serious injury. Hospital visit required. No permanent loss of function to any body part.	Total machine failure. Outside assistance required to repair.	Serious but reversible environmental damage. Outside assistance required. Personal injuries possible.	Flight on hold until system is removed.

Disastrous	E	Life-threatening or debilitating injury. Immediate hospital visit required. Permanent deformation or loss of bodily function.	Irreversible failure. Total machine loss. New equipment required.	Serious irreversible environmental damage. Personal injuries likely. Immediate outside assistance required. Area must be vacated. Needs to be reported to a relevant environmental agency.	Flight scrubbed or completely destroyed.

Table 5.2: Event Likelihood Scale

5.3.3. Risk Analysis

By cross examining the likelihood of an event with the impact it would have if it occurred, a total risk can be determined, and is detailed in the table below. The color code displayed is as follows:

- Green: Minimal risk
- Yellow: Low risk
- Orange: Medium risk
- Light red: High risk
- Dark red: Very high risk

		Severity				
		Negligible (A)	**Minor (B)**	**Moderate (C)**	**Major (D)**	**Disastrous (F)**
Likelihood	**Remote (1)**	A1	B1	C1	D1	E1
	Unlikely (2)	A2	B2	C2	D2	E2
	Possible (3)	A3	B3	C3	D3	E3
	Likely (4)	A4	B4	C4	D4	E4
	Very Likely (5)	A5	B5	C5	D5	E5

Table 5.3: Total Risk Scale

Prior to a plan for risk mitigation, many of the events listed in the following sections fall outside of the acceptable tolerance of Medium risk. Listed alongside these events are the team's risk mitigation plans, as well as verification metrics to ensure team compliance. Post-mitigation risk is also listed, ensuring all project risks are acceptable after mitigation.

5.4. Personnel Hazard Analysis

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Post Mitigation Risk
Propulsion/Motor System & Energetic Materials						
Unintended Black Powder Ignition	3 (Accidental black powder exposure to flame or enough electric charge near black powder)	E (Possible severe hearing damage or other personal injury)	E3, High	Label containers storing black powder, ensure black powder is only handled by those with relevant safety training.	Project Management and the Team Leads must verify that the handling of black powder is only done and supervised by team members qualified to handle it.	E1, Moderate
Hearing Damage	4 (Close proximity to loud noises or prolonged exposure to sounds over 70 dbs)	D (short to long term hearing loss)	D4, High	Seek alternative machines / methods to fabricate the desired part if possible. Always wear appropriate PPE such as earplugs when using power tools and larger machines.	Team Leads and Safety Officers must brief team members on the dangers of the workplace prior to its use. Team Leads must ensure all engineering controls available have been implemented and that proper PPE is always worn during team operations.	D1, Low
Burns from Motor	2 (Improper proximity to launch pad, touching motor casing too soon after landing)	C (Mild to moderate burns)	C2, Low	Strictly maintain minimum safe launch distance from vehicle according to NAR standards. Wait an appropriate amount of time after launch to retrieve the vehicle.	The Safety Team lead will ensure the minimum safe distance region is marked and communicated to team members at the launch.[1] Safety Officer will ensure the motor is sufficiently cool before handling.	C1, Low
Launch Pad Fire	1 (Premature completion of fire triangle on launch pad)	D (Moderate to severe burns)	D1, Low	Prevent excess heat from occurring on the launch pad, as the fuel (vehicle motor) and oxygen (air) cannot be removed from the system. Have fire suppression systems nearby and use a protective ground tarp.	The Safety Team Lead is responsible for maintaining proper fire suppression equipment and for bringing it to all launch activities.[3]	C1, Low

Premature Ignition	2 (Short circuit, improper installation of motor and / or ignitors)	C (Mild burns)	C2, Low	Prepare energetic devices only immediately prior to flight. Ensure ignitor leads are shorted before attachment to the motor.	The Safety and Systems Lead must ensure that the proper personnel prepare the ignition system for flight.[4]	C1, Low
Injury from Projectiles Launched by Vehicle Jet blast	2 (Debris striking team members because of a failure to properly clear launchpad, or failure to stand an appropriate distance from the launch vehicle during launch)	C (Moderate injury to personnel)	C2, Low	Clean and clear the launchpad before use. Ensure all members are wearing proper PPE for launch. Ensure all team members are an appropriate distance from the launch vehicle when launching. Use a tarp to hold down loose debris under the launchpad.	The Construction and Safety Team Leads will verify that the launchpad is clean and clear of debris before launch occurs.[1]	C1, Low
			Hardware/Electronic Construction & Assembly			
Entanglement with Construction Machines	3 (Unintended contact of loose hair, clothing, or jewelry with machines utilizing spinning or binding parts)	E (Severe injury, death)	E3, High	Secure loose hair, clothing and remove jewelry before operating machinery. Always wear appropriate PPE for the machine being worked with.	All use of construction machines will be done under the supervision of a person / people also trained on that specific machine. This is fulfilled by student supervisors at the locations where construction machines are found.	E1, Moderate
Workplace Fire	2 (Unplanned ignition of flammable substance, overheated workplace, improper use or supervision of heating elements, or improper wiring)	E (Severe burns, loss of workspace, irreversible damage to project)	E2, High	Have fire suppression systems nearby, prohibit open flames, and store energetic devices in Type 4 magazines as stated in the CFR, Title 27.	Team Leads must brief team members on the dangers of the current workplace prior to its use and ensure all materials are being properly stored. The Safety Team Lead must ensure that fire suppression systems are available and acknowledged by the team members when the team is in the workplace.	E1, Moderate
Power Tool Cuts, Lacerations,	3 (Carelessness or improper use of power tools, power tool	D (Possible hospitalization from damages)	D3, Moderate	Ensure loose hair and clothing is tied back and jewelry is removed before operating	Team Leads must brief team members on the dangers of the current workplace prior to its use.	D1, Low

and Injuries	malfunction or failure)			power tools.		
Physical Contact with Falling Construction Tools or Materials	3 (Materials which were not returned to a safe location after use striking a team member)	D (Bruising, cuts, lacerations, possible severe physical injury)	D3, Moderate	Brief personnel on proper clean-up procedures for working with tools and materials. Wear appropriate clothing and shoes for machine work.	Team Leads and / or relevant supervisors must ensure team members are aware of proper procedures for cleaning up the current workplace.	D1, Low
Electrocution	2 (Unintended contact with electrical systems that are faulty or improperly used or stored, improper use of electrical system)	D (Potentially dangerous levels of electricity being passed through a team member, potential hospitalization)	D2, Moderate	Give labels to all high voltage equipment warning of their danger and ground oneself when working with high-voltage equipment.	Members working with high voltage equipment must guarantee no open electrical components by inspection. Team Leads must allow only one member to work on electrical components at a time with proper PPE and student supervising.	D1, Low
Tripping Hazards	3 (Improper storage of materials and equipment, unsecured cables overhead and along the ground)	C (Bruising, abrasions, possible severe harm if tripping into construction equipment)	C3, Moderate	Brief personnel on proper clean-up procedures for working with tools and materials. Wear appropriate clothing and shoes for machine work. Tape loose cords or wires to the ground if they must cross a path which is used by personnel.	Team Leads must brief team members on the dangers of the current workplace prior to its use.	C1, Low
Physical Contact with Hot Sources	3 (Contact with launch vehicle parts which were recently machined, improper use of soldering iron or other construction equipment)	C (Moderate to severe burns)	C3, Moderate	Turn off all construction tools when not in use. Team members must be aware of potential hot surfaces created during machining. Always wear appropriate PPE, such as gloves, when handling materials.	Team Leads must brief team members on the dangers of the materials prior to their use. Team members are told to be aware of their surroundings to avoid accidental burns.	C1, Low
Hazardous Materials						

Direct Contact with Hazardous Chemicals	3 (Improper use or storage of chemicals leading to unintended contact with the body)	C (Moderate burns, abrasions)	C3, Moderate	Minimize the need for hazardous chemicals. Always wear appropriate PPE, such as gloves or lab coats, when working with chemicals.[2]	Safety Team or relevant Team Lead will verify that each participating member is wearing appropriate PPE during construction and testing operations.	C1, Low
Dust or Chemical Inhalation	2 (Breathing in airborne particulate debris from construction or testing operations)	D (Short to long-term oral or respiratory damage, possible hospitalization)	D3, Moderate	Work in a well-ventilated area if possible. Always wear appropriate PPE for materials being worked with, such as a respirator.	Safety Team or relevant Team Lead will verify that each participating member is wearing appropriate PPE during construction and testing operations. Team members will not be allowed to work with hazardous materials without proper PPE.	D1, Low
Epoxy Contact	3 (Bodily contact with resin spill through improper use or storage of resin)	C (Mild skin irritation, possible allergic reaction, redness and rashes on skin)	C3, Moderate	Minimize the need for hazardous chemicals. Always wear appropriate PPE, such as gloves or lab coats when working with resin.	Team Leads must ensure all members working with hazardous chemicals are wearing proper PPE and are working in a safe environment.	C1, Low
Contact with Airborne Chemical Debris	3 (Airborne particulate debris generated from construction or testing operations making direct contact with the body)	B (Minor burns, abrasions)	B3, Low	Install / use proper guard on machinery to prevent contact with debris if possible. Always wear appropriate PPE such as gloves, lab coats and breath masks.	Safety Team or relevant Team Lead will verify that each participating member is wearing appropriate PPE during construction and testing operations.	B1, Minimal
Eye Irritation	3 (Airborne particulate debris entering unprotected eye, dry air / low humidity)	B (Temporary eye irritation)	B3, Low	Install / use proper guard on machinery to prevent contact with debris if possible. Always wear appropriate PPE such as face shields and safety glasses.	Team Leads must ensure all engineering controls available have been implemented and that proper PPE is always worn during team operations.	B1, Minimal
Full-Scale Launch Day						

Injury from Falling Vehicle	3 (Vehicle striking team members due to a recovery system failure (ballistic trajectory) or a lack of awareness of vehicle descent under parachutes)	E (Severe injury, death)	E3, High	Keep all eyes on the launch vehicle during flight. Call "heads up" if vehicle is approaching team members under parachutes. Call "scatter" if vehicle is under ballistic descent.	Team will be briefed on launch day procedures before the launch occurs by the Safety or Systems Team Lead., emphasizing the importance of keeping eyes on the launch vehicle during flight.[3]	E1, Moderate
Injury from Falling Components	3 (Failure to keep all components securely attached to the launch vehicle, result of improper staging constraints, part failure, or excessive vibration during flight)	E (Severe injury, death)	E3, High	Keep eyes on the launch vehicle during flight. Call "heads up" if unintended components separate from the vehicle during flight.	Team will be briefed on launch day procedures before the launch occurs by the Safety or Systems Team Lead., emphasizing the importance of keeping eyes on the launch vehicle during flight.[3]	E1, Moderate
Injury from Navigating Terrain	2 (Tripping over uneven ground, contact with poisonous plants, falling into fast-moving water)	E (Broken bones, infections, drowning)	E2, High	Do not attempt to recover the launch vehicle from dangerous areas. Seek professional aid to recover vehicle if it cannot be done by team members.	The Safety Team Lead will set boundaries to not cross at the launch location before the launch occurs and communicate that to the rest of the team.[1]	E1, Moderate
Downed Power Lines	2 (Launch vehicle becomes entangled in power lines, knocking them within range of personnel)	E (Fatal electrocution)	E2, High	Attempt to launch away from power lines. If vehicle entanglement occurs, call the power company and stand clear until proper personnel arrive.	Any team member must alert all team members of the hazard if spotted. The Safety Team Lead must ensure all members are stood clear of the area until certified personnel clean up the area and verify it is safe.	E1, Moderate
Dehydration	3 (Failure to drink adequate amounts of water)	D (Exhaustion and possible hospitalization)	D3, Moderate	Ensure all members have access to water at all team activities, including launch, testing, and construction operations.	Team members will be instructed to bring water to team activities, and team leads will ensure all members are properly hydrated by encouraging members to drink water when not working.	D1, Moderate
Heatstroke	3 (Extended exposure to high temperatures during team operations)	D (Exhaustion and possible hospitalization)	D3, Moderate	Wear clothing appropriate to the weather, and ensure all members have access to water at team operations.	Safety Team or relevant Team Lead will ensure that team members are appropriately dressed and have enough water. If this is not the case,	D1, Moderate

					the team member will be sent to remedy their situation in whatever way the relevant Team Lead deems fit.	
Hypothermia	3 (Extended exposure to cold temperatures during team operations)	D (Sickness and possible hospitalization)	D3, Moderate	Wear clothing appropriate to the weather, and ensure all members have access to a warm area to rest at launch, such as a heated car or inside of a building.	Safety Team or relevant Team Lead will ensure that team members are appropriately dressed for team operations. If this is not the case, the team member will be sent to remedy their situation in whatever way the relevant Team Lead deems fit.	D1, Low
Kinetic Damage to Personnel	2 (Forceful detonation of combustible or explosive materials near team members due to reckless actions or improper storage of materials)	D (Possible severe kinetic damage to personnel)	D2, Moderate	Eliminate need for excitable materials if possible. Ensure team members are aware of excitable materials in the workspace and how to properly store and use them.	Team Leads must brief team members on the dangers of the current workplace prior to its use.	D1, Low

Table 6.4: Personnel Hazard Analysis

For verification of certain mitigation plans, see the following footnotes:

1. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Selecting a Launch Area”*
2. *3.1.6.2 Motor & Fin Support Structure Analysis*
3. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Briefing to team members by Safety or Systems Team Lead”*
4. *6.2.3 The Day Of - Launch Prep, PROPULSION PREP: “Installing Ignitor”*

5.5. Failure Modes and Effects Analysis

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**	**Post Mitigation Risk**
			Project Management			

Flight Path Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	E (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	E2, High	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area. Hold launch until flight path is clear.	Visually inspect the surrounding launch area to make sure no incoming wildlife or loose objects appear.	E1, Moderate
Damage to or Loss of Parts	2 (Failure during testing, improper part care during construction, transportation, or launch)	E (Cannot construct or fly vehicle without spare parts)	E2, High	Have extra parts on hand in case parts need to be replaced, follow all safety procedures for transportation, launch, and construction.	Confirm a minimum number of parts needed so the team is able to obtain duplicates for certain parts. Assign responsibility for more important and expensive parts.	E1, Moderate
Damage During Transit	2 (Mishandling during transportation)	E (Inability to fly launch vehicle)	E2, High	Protect all launch vehicle components during transit.	Ensure launch vehicle safety secured with padding and bracing.	E1, Moderate
Damage by Non-Team Members	1 (Accidental damage caused by other workspace users)	E (Extensive repairs necessary, delay in construction)	E1, Moderate	Separate all components from other areas of the workspace as necessary.	Ensure only team members can have access to vehicle components.	E1, Moderate
Forgotten or Lost Components	3 (Carelessness with launch vehicle components, failure to take note of inventory before attempting to launch)	D (Launch vehicle does not launch at the desired launch time)	D3, Moderate	Ensure all launch vehicle components are accounted for prior to departure to the launch field. Bring backup parts to the launch field as necessary.	Team Leads are responsible for assigning the transportation of their section of the vehicle to the launch field.	D1, Low
Construction Subteam						
Premature Stage Separation	3 (Premature ejection, shear pin or fastener failure)	E (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	E3, High	Check altimeter settings prior to flight, use appropriate vent holes, choose shear pins and fasteners suitable for flight.	Redundant altimeter will be used by design. Inspect shear pins and fasteners for proper installation.	E1, Moderate
Motor Expulsion	2 (Improper retention methods)	E (Risk of recovery failure, low apogee, falling debris)	E2, High	Use a positive retention method to secure the motor.	Motor retainment inspection shall be performed by Student Mentor prior to launch.[6]	E1, Moderate

Premature Ejection	2 (Altimeter programming, poor venting)	E (Zippering, potential loss of vehicle components)	E2, High	Check altimeter settings prior to flight and use appropriate vent holes. Test altimeter in similar conditions to those to be experienced at launch.	Altimeter settings shall be checked prior to launch.[8]	E1, Moderate
Loss or Damage of Fins	2 (Poor construction or improper materials used)	E (Partial or total destruction of vehicle)	E2, High	Ensure proper analysis has been completed on the thrust structure.	Fin slots in the thrust structure must be designed to properly contain the fins.[9]	E1, Moderate
Damaged / Destroyed Nose Cone	2 (Poor construction or improper materials used, damage from previous flights, poor storage, or transportation)	E (Partial or total destruction of vehicle)	F2, High	Use materials and building techniques appropriate to high-power rocketry.	Check for nose cone damage prior to flight and ensure that nose cone is secured to vehicle for test flights.[10]	E1, Moderate
Motor and Fin Support Structure Failure	2 (Excessive force from motor, poor construction)	E (Partial or total destruction of vehicle, ballistic trajectory)	E2, High	Design thrust structure according to analysis of material strength and performance under stress, make use of reliable building techniques, confirm analyses with test launches.	Thrust structure design will be subject to testing and analysis before launch.[9]	E1, Moderate
Destruction of Bulkheads	2 (Poor construction or improper bulkheads chosen which cannot withstand launch forces)	E (Partial or total destruction of vehicle, ballistic trajectory)	E2, High	Use appropriate materials according to analysis of materials and previous flight data, make use of reliable building techniques, confirm analyses with test launches.	Bulkheads will be visually inspected for damage prior to launch.[9][10]	E1, Moderate
Launch Vehicle Disconnects from Launch Rail	2 (High wind speeds, failure to properly use the rail buttons, faulty rail buttons)	E (Partial or total destruction of vehicle, ballistic trajectory which endangers personnel, onlookers, and property on the ground)	E2, High	Use physical analysis to ensure the rail buttons are properly aligned and working as planned, double check the rail buttons are properly attaching the launch vehicle to the launch pad before launch, test rail buttons with subscale flights.	Rail buttons will be inspected prior to launch for cracks, misalignment, or other inaccuracies.[10]	E1, Moderate

Airframe Zippering	2 (Excessive deployment deceleration)	E (Partial or complete destruction of vehicle)	E2, High	Properly time ejection charges and use an appropriately long tether.	Ensure design of vehicle and thrust structure are sound, test and observe vehicle at full scale launch prior to Huntsville.	E1, Moderate
Failure to Ignite Propellant	2 (Faulty motor preparation, poor quality of propellant, faulty igniter, faulty igniter power source, damage to motor)	E (Launch vehicle does not immediately launch and is a considerable hazard until it is confirmed that it will not launch, changes to igniters or launch vehicle required)	E2, High	Purchase motor and ignitors only from reliable sources, Team Mentor must install motor and ignitors, determine if the igniters chosen work well during subscale testing.	Team Mentor is the only one allowed to install motor and ignitors.[5] [15]	E1, Moderate
Broken Fastener	2 (Excessive force from launch or descent)	E (Ballistic trajectory)	E2, High	Ensure proper fasteners are purchased and used based on the seller's reputation and the products past use in flight.	Inspect fasteners before launch to ensure they are not damaged.[7]	E1, Moderate
Propellant Explosion	2 (Faulty motor preparation, poor quality of propellant, damage to motor)	E (Ballistic trajectory, catastrophic destruction of vehicle, possible harm to bystanders)	E2, High	Purchase motor and ignitors only from reliable sources, check the motor for damage prior to launching, Team Mentor must install motor and ignitors.	Team Mentor is the only one allowed to install motor and ignitors.[5] [15] Inspect motor prior to launch to ensure proper installation.[6]	E1, Moderate
Airframe Failure	2 (Buckling or shearing of the airframe from poor construction or use of improper materials, faulty stress modeling)	E (Partial or total destruction of vehicle, ballistic trajectory)	E2, High	Use appropriate materials according to industry standards and previous flight experiences of the airframe, bulkheads, fasteners, and shear pins. Make use of reliable building techniques, confirm analyses with test launches.	The Construction Team will ensure proper materials are being used. If the airframe does not perform well in test launches, perform another test launch with a new airframe design before confirming flight readiness.	E1, Moderate
Motor Detonation	2 (Motor defect, assembly error)	E (Partial or total destruction of vehicle)	E2, High	Inspect the motor prior to assembly and closely follow assembly instructions.	Motor inspection shall be performed by Student Mentor prior to launch.[6]	F1, Medium
Instability	2 (Stability margin of less than 2.00)	E (Potentially dangerous flight path, loss of vehicle)	E2, High	Measure the physical center of gravity and compare it to the calculated center of pressure.	Have measured physical center of gravity documented and marked prior to arriving at the launch site.[7]	F1, Medium

Motor Angled Incorrectly	2 (Poor construction, damage from previous flights, poor storage or transportation)	D (Lower launch vehicle stability, launch vehicle does not follow desired flight path)	D2, Moderate	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube. Implement checklists to ensure proper constraint and alignment of the motor within the thrust structure	Inspect motor and motor retainer prior to launch to ensure proper installation.	D1, Low
Propellant Fails to Burn for Desired Duration	2 (Faulty motor preparation, poor quality of propellant, damage to motor)	C (Launch vehicle does not follow the designated flight path well, lower maximum height, if drastic change in maximum height the ejection charges for recovery may not deploy)	C2, Low	Purchase motor and ignitors only from reliable sources, check the motor for damage prior to launching, Team Mentor must install motor and ignitors.	Team Mentor is the only one allowed to install motor and ignitors.[5 15] Inspect motor prior to launch to ensure proper installation.[6]	C1, Low
High Launch Rail Friction	3 (Faulty installation of rail buttons, faulty setup of launch rail, faulty installation of launch vehicle on launch rail, failure to properly lubricate launch rail as needed, weather conditions cause excess friction)	B (Launch vehicle does not follow the designated flight path well, lower maximum height, failure to leave pad)	B3, Low	Set up the rail using instructions which come with the product, use lubrication on the rail as needed according to weather and rail type, ensure the launch vehicle is properly installed on the launch rail.	Launch rails will be tested by tactile inspection to insure proper lubrication.[14]	B1, Minimal
Failure to Ignite Motor	2 (Lack of ignitor continuity)	A (Recycle launch pad)	A2, Minimal	Check for continuity prior to attempted launch.	Ignitor continuity shall be checked prior to launch.[5]	A1, Minimal
			Avionics & Recovery Subteam			
Ejection Charge Failure	3 (Not enough power from improper charge	E (Ballistic trajectory, destruction of vehicle)	E3, High	Perform ground test to ensure ejection charges sufficiently separate vehicle sections.	Construction of the full scale rocket has not occurred yet, so ground test of ejection charges will occur	E1, Moderate

	sizing, electrical failure)				after the CDR deadline. Ejection charge testing of the subscale assembly will occur after the PDR deadline.	
Altimeter Failure	3 (Loss of connection or improper programming)	E (Ballistic trajectory, destruction of vehicle)	E3, High	Perform altimeter settings and continuity check prior to launch.	Detailed procedures will be determined to ensure altimeter continuity prior to launch.[11]	E1, Moderate
Battery Overcharge / Leakage/ Ignition	3 (Unsupervised/undocumented charge, battery puncture)	E (Destruction of battery, potential ballistic trajectory of vehicle)	E3, High	Ensure batteries are documented and supervised if charging. Properly house and place batteries in launch vehicle.	Reminders will be set by testing personnel to track battery charging tests.	E1, Moderate
Battery Overcharge / Leakage/ Ignition	3 (Unsupervised/undocumented charge, battery puncture)	E (Destruction of battery, potential ballistic trajectory of vehicle)	E3, High	Ensure batteries are documented and supervised if charging. Properly house and place batteries in launch vehicle.	Reminders will be set by testing personnel to track battery charging tests.	E1, Moderate
Arming System Failure	3 (Faulty arming system, faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	E (Disqualified, objectives not met, failure to correctly trigger ejection charges)	E3, High	Ensure the avionics bay is successfully communicating with the team prior to flight, test arming system through test launches.	Ensure communication between avionics bay and the team is established and reliable right before launch.[16]	E1, Moderate
Premature Stage Separation	3 (Premature ejection, shear pin or fastener failure)	E (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	E3, High	Check altimeter settings prior to flight, use appropriate vent holes, choose shear pins and fasteners suitable for flight.	Redundant altimeter will be used by design. Inspect shear pins and fasteners for proper installation.	E1, Moderate
Excessive Landing Speed	3 (Parachute damage or entanglement, improper load, improperly sized parachute)	E (Partial or total destruction of vehicle)	E3, High	Properly size, pack, and protect parachute.	Avionics Lead must ensure the proper parachute is purchased and used. Parachute packing must be observed by at least one other team member with knowledge of the recovery system.[12]	E1, Moderate

Power Loss to Avionics Bay	3 (Faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	E (Disqualified, objectives not met, failure to correctly trigger ejection charges)	E3, High	Test the reliability of the wiring and batteries through subscale flights, check batteries and connections before flight.	Perform continuity checks for altimeters prior to launch, visible wires will be inspected for nicks or damage prior to launch.[11]	E1, Moderate
Stages Fail to Separate	3 (Faulty ejection charge, excessive strength is used to hold stages together, altimeter failure)	E (Launch vehicle does not follow desired flight path, possible ballistic trajectory, lower maximum height, damage to the launch vehicle)	E3, High	Examine ejection charges for damage before launch, ensure proper functionality of the altimeters, ejection charges, and interstage joints, have a secondary ejection charge for each stage separation.	Ejection charge testing will be performed to ensure charges can separate stages, and dual altimeters will be employed to enable redundancy.	E1, Moderate
Heat Damaged Recovery System	2 (Insufficient protection from ejection charges)	E (Parachute damage, excessive landing velocity, potentially ballistic trajectory)	E2, High	Use appropriate protection methods, such as Nomex blankets.	Check that proper recovery system protection methods are installed before launch.[12]	E1, Moderate
Premature Black Powder Ignition	2 (Accidental exposure to flame or sufficient electric charge)	E (Partial destruction of vehicle, premature stage separation)	E2, High	Ensure design has sufficient distance/ protection from outside, and motor, charges, and batteries.	Ensure by design and testing that black powder wells secure from other systems. Ground test of ejection charges for subscale will occur after the PDR deadline.	E1, Moderate
Flight Path Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	E (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	E2, High	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area. Hold launch until the flight path is clear.	Visually inspect the surrounding launch area to make sure no incoming wildlife or loose objects appear.[13]	E1, Moderate
GPS Lock Failure	2 (Interference or dead battery)	E (Loss of vehicle)	E2, High	Ensure proper GPS lock and battery charge before flight.	Ensure GPS signal is established before flight.[16]	E1, Moderate

Tangled Parachute or Shock Cord	2 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or parachutes, poor sizing of parachutes or shock cord, unstable or ballistic flight)	E (Shock cord or parachutes may not fully extend or inflate, possible ballistic trajectory, possible failed recovery)	E2, High	Only buy parachutes and shock cords from reliable sources, any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachutes and shock cord for damage before launch, check performance of parachutes and shock cord in test flights, appropriately follow recommended sizing for shock cord and parachutes.	Ensure parachute packing is observed by at least one other team member with knowledge of the recovery system.[12]	E1, Moderate
Parachute Comes Loose from Launch Vehicle	2 (Failure of recovery system mount on the launch vehicle body, poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	E (Recovery failure, ballistic trajectory)	E2, High	Only buy parachutes from reliable sources, check the recovery system for damage before launch, double check that the recovery system is properly mounted before launch.	Ensure parachute packing is observed by at least one other team member with knowledge of the recovery system.[12]	E1, Moderate
Parachute or Shock Cord Catch Fire	2 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	E (Shock cord or parachutes do not fully achieve their goal, possible ballistic trajectory, possible failed recovery, damage to internal launch vehicle components)	E2, High	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights.	Ensure parachute packing is observed by at least one other team member with knowledge of the recovery system.[12]	E1, Moderate
Drogue Parachute Fails to Deploy	2 (Poor design of where parachute is in launch vehicle, poor sealing of	E (Drogue parachute does not slow down the launch vehicle,	E2, High	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute	Ejection charge testing will be done to ensure charge effectively deploys the parachute.	E1, Moderate

	parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	recovery failure, ballistic trajectory)		and ejection charges for damage before launch, have a secondary ejection charge in case of emergency which is larger than the first.		
Main Parachute Fails to Deploy	2 (Poor design of where parachute is in launch vehicle, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	E (Main parachute does not slow down the launch vehicle, recovery failure, ballistic trajectory)	E2, High	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, have a secondary ejection charge in case of emergency which is larger than the first.	Ejection charge testing will be done to ensure charge effectively deploys parachute.	E1, Moderate
Parachute Shroud Lines Break	1 (Poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	E (Possible recovery failure, ballistic trajectory)	E1, Moderate	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, check the recovery system for damage before launch.	Examination of the shroud lines and parachutes must occur before packing into the main vehicle.[7]	E1, Moderate
Shock Cord Breaks or Disconnects	1 (Faulty shock cord, damage to shock cord, poor connection to the launch vehicle)	E (Parachute disconnect from the launch vehicle, recovery failure, ballistic trajectory)	E1, Moderate	Any team member who connects the shock cord to the launch vehicle must be supervised by at least one other team member, check the shock cord for damage before and after flight, only buy shock cords from reliable sources, analyze the shock cord with test flights.	Orange tape must be placed over the fasteners connecting different vehicle components together.[12]	E1, Moderate
Insufficient Landing Speed	3 (Improper load, higher coefficient of drag for the parachutes than	B (Unexpected changes in flightpath and landing area, increased potential for drift)	B3, Low	Use subscale flights to determine if the subscale parachutes were accurately sized, use recommended and proven-to-work parachute	Avionics Lead must ensure the proper parachute is purchased and used.	B1, Minimal

	needed, higher surface area of the parachutes than needed)			sizing techniques for full scale vehicle.		
Payload Subteam						
Payload Early R&D Release	3 (IMU or Barometric Sensor error leads to premature activation of R&D separation and orientation, followed by IOS activation)	D (Disqualified, objectives not met, loss of electronic control, improper payload deployment)	D3, Moderate	Proper testing and calibration of the Payload sensor array. Full system in the loop deployments prior to launch.	Perform deployment test VT.P.5	D2, Moderate
Payload Computer Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	D (Disqualified, objectives not met, loss of electronic control, improper payload deployment)	D3, Moderate	Test payload prior to flight, check batteries and connections before flight.	Ground test payload in flight like conditions, inspect software before use, monitor payload during VDF. Testing will occur after the CDR deadline.	D1, Low
Payload Electrical Failure	3 (Electrical failure, program errors, dead battery)	C (Disqualified, objectives not met, loss of electronic control)	C3, Moderate	Test payload prior to flight, check batteries and connections. Assemble payload with care to prevent errors.	Full payload testing will occur after the CDR deadline.	C2, Low

Table 6.5: Vehicle Failure Modes and Effects Analysis

For verification of certain mitigation plans, see the following footnotes:

5. *6.2.3 The Day Of - Launch Prep, PROPULSION PREP: “Installing Ignitor”*
6. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Inspect motor, motor casing, and motor retainment system for damage”*
7. *6.2.2 The Day Before, AVIONICS & RECOVERY:* Full Vehicle Integration
8. *6.2.1 In Advance, AVIONICS & RECOVERY: “Programming the TeleMetrum Altimeter” and “Programming the StratoLoggerCF Altimeter”*
9. *3.1.6.2 Motor & Fin Support Structure Analysis*

10. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Inspect all vehicle components for damage from travel”*
11. *6.2.3 The Day Of - Launch Prep, AVIONICS & RECOVERY: “Altimeter Continuity”*
12. *6.2.2 The Day Before, AVIONICS & RECOVERY: INSPECTION*
13. 6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Selecting a Launch Area”
14. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Installing the Vehicle on the Launch Rail”*
15. *6.2.2 The Day Before, CONSTRUCTION: “Motor Assembly”*
16. *6.2.3 The Day Of - Launch Prep, AVIONICS & RECOVERY: “Setting Up the EggFinder Trackers at the Launch Viewing Area”*

5.6. Environmental Hazards

Hazards to Environment						
Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**	**Post Mitigation Risk**
Fire to Surroundings	3 (Exhaust caused by launch vehicle engine)	E (Possible spread of wildfire, damage to wildlife or landscape)	E3, High	Ground will be cleared per NAR standard, fire extinguishers will be on hand.	Safety Team Lead will ensure compliance with NAR safety standard on minimum clear area. Safety Team Lead is responsible for bringing fire suppression equipment to the launch field.	E1, Moderate

Vehicle collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area)	E (Damage to public property or private property not owned by the team, damage to team equipment, serious damage to team personnel or passerby)	E2, High	Do not launch under adverse conditions which may affect the course of the launch vehicle, run simulations which analyze the launch vehicle's trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch procedures closely.	Simulate results for vehicle trajectory.[19] Project Management and the Avionics Team Lead must ensure that the actual launch is ran in a similar way to that which was simulated. Safety Team Lead will monitor weather conditions prior to launch.[20]	E1, Moderate
Pollution from Team Members	2 (Failed disposal of litter, improper cleanup procedures, members walk through important plant life, farming fields, sod, etc.)	D (Litter may degrade extremely slowly, wildlife may consume harmful litter, destruction of crops)	D2, Moderate	Brief team members on proper cleanup procedures, foster a mindset of leaving no trace at launch sites, only the minimum number of required team members should retrieve the launch vehicle.	Follow societal standards and leave site cleaner than was found, make sure disposable equipment is kept track of and guaranteed to remain at designated locations. This will occur in the Safety briefing upon team arrival to the launch field.[18]	D1, Low
Kinetic Damage to Buildings	2 (Launch vehicle veers off trajectory causing landing in occupied area)	D (Repairable destruction to building)	D2, Moderate	Choose launch site that is remote enough to make this risk negligible.	Safety Team Lead must ensure minimum distance from building exceeds minimum building distance as established by NAR safety standard.[24]	D1, Low
Rocket Mid-Air Separation	3 (Airframe structural failure, shock cords rip)	D (Ballistic trajectory of multiple rocket sections/components, failed recovery)	D2, Moderate	Construction subteam must ensure airframe materials are structurally sound, and Recovery subteam must ensure all individually sections of the launch vehicle are properly secured together.	Prior to launch day procedures, Construction and Avionics subteams will assemble the full launch vehicle and ensure all connection points are fastened. Safety team will verify.	C1, Low
Pollution from Vehicle Itself	3 (Loss of components from vehicle in surroundings)	C (Materials degrade extremely slowly, possible harm to wildlife or water contamination)	C3, Moderate	Ensure all parts are attached to each component of the vehicle and that the components of the vehicle are properly attached. Scavenge for fallen parts after launch is	Quality Witness checks shall be performed as part of the assembly of each vehicle component and the integration of the components into the larger vehicle.[17]	C1, Low

				completed.		
Battery Leakage	3 (Absence of or damage to battery casing causing puncture to battery)	C (Possible toxic acid leak, heavy metal contamination, degradation and harm to plant and animal life)	C3, Moderate	Batteries will be individually enclosed in plastic casing, parachutes will be selected to reduce landing kinetic energy below levels that will damage the casing.	Examine the battery casing for damages prior to launch. It is assumed that if the kinetic energy of the vehicle landing is less than the maximum outlined in the Handbook[22], the battery casing will not be damaged to the point of battery puncture. Fulfillment of the kinetic energy upon landing requirement is calculated.[23]	C1, Low
Pollution from Exhaust	5 (Combustion of APCP motors)	A (Small amounts of greenhouse gasses emitted)	A5, Moderate	Use only launch vehicle motors approved for use by the National Association of Rocketry, Canadian Association of Rocketry, or Tripoli Rocketry Association.	Launch vehicle motors in consideration will be purchased and installed by the team's Student Mentor to ensure compliance.	A4, Moderate
Kinetic Damage to Terrain	4 (Launch vehicle has excessive landing speed)	A (Creation of small ground divots, mild inconvenience to wildlife and flora)	A4, Moderate	Parachute selection must ensure that vehicle does not land with an excess of kinetic energy.	Avionics Team has verified proper vehicle landing kinetic energy.	A1, Minimal

Table 6.6: Hazards to Environment

For verification of certain mitigation plans, see the following footnotes:

17. *6.2.2 The Day Before, AVIONICS & RECOVERY: INSPECTION*
18. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: "Briefing to team members by Safety or Systems Team Lead"*
19. *3.4.1.1 Vehicle Trajectory Simulations*
20. *6.2.4 The Day Of - Countdown to Launch, as well as various other points in launch procedures*
21. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: "Inspect all vehicle components for damage from travel"*
22. *2021 NASA Student Launch Handbook and RFP, Proposal / Statement of Work, Section 3.3*
23. *3.4.3 Kinetic Energy Calculations*
24. 6.2.3 The Day Of - Launch Prep, SAFETY TEAM: "Selecting a Launch Area"
25. *6.2.3 The Day Of - Launch Prep, SAFETY TEAM: "Briefing to team members by Safety or Systems Team Lead"*

Hazards From Environment						
Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**	**Post Mitigation Risk**
Landscape	3 (Vehicle contact with trees, brush, water, power lines, wildlife)	E (Inability to recover launch vehicle, damage or destruction of vehicle or vehicle components)	E3, High	Angle launch vehicle into wind as necessary to reduce drift. Choose a launch area that is flat and clear of large flora.	Safety Team Lead, Project Management and the Student Mentor shall pick a launch area that is free from obstructions.[27]	E1, Moderate
Rain	3 (Poor forecast)	E (Inability to launch or recover vehicle, damage to vehicle components)	E3, High	Ensure team is wearing appropriate clothing for extended periods of time in rain. Keep launch vehicle covered and dry before launch. Ensure weather forecast for launch day predicts favorable conditions.	Safety Team Lead will monitor weather conditions prior to launch.	E1, Moderate
Winds	3 (Poor forecast)	D (Inability to launch, excessive drift)	D3, Moderate	Angle into wind as necessary, abort launch if wind exceeds 20 mph (NAR High Power Rocketry Code, point 9)	Safety Team Lead will monitor weather conditions prior to launch.[26]	C1, Low
Extreme weather-cocking of launch vehicle	2 (Center of pressure too far from center of mass, high winds)	C (excessive drift, unintentional launch trajectory)	C2, Moderate	Angle into wind, design launch vehicle to be within an acceptable caliber range for high wind speeds to ensure flight stability	Safety Team Lead will monitor weather conditions and provide oversight into construction of launch vehicle.	C1, Low
Wildlife Contact with Launch Vehicle	1 (Failure to accurately predict trajectory, unexpected appearance of wildlife, poor choice	D (Damage to vehicle components, damage to wildlife, unexpected trajectory close to the ground)	D2, Moderate	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching.	Safety Team Lead, Project Management and the Student Mentor shall pick a launch area that is free from obstructions and places where wildlife could be found.[27]	C1, Low

	of launch area)					
Wildlife Contact with Launch Pad	1 (Failure to monitor the launch pad, poor choice of launch area)	D (Possible inability to launch the launch vehicle, unpredictable launch behavior or trajectory)	C2, Moderate	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching, if animals tamper with the launchpad, do not launch.	Safety Team Lead, Project Management and the Student Mentor shall pick a launch area that is free from obstructions and places where wildlife could be found.	C1, Low
Snow	3 (Poor forecast)	D (Difficulty in preparing launch procedures, obstruction in constructing launch rail, difficulty recovering vehicle)	D4, High	Ensure the team is wearing appropriate clothing for extended periods of time in cold environments. Keep the launch vehicle at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the launch vehicle, do not launch and return it to a warm location. Ensure weather forecasts predict favorable conditions for launch day.	Safety Team Lead will monitor weather conditions in the days prior to launch.	C2, Low
Low Cloud Coverage or Visibility	2 (Poor forecast)	E (Inability to launch or recover vehicle)	E2, High	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching. Ensure weather forecasts predict favorable conditions for launch day.	Safety Team Lead will monitor weather conditions in the days prior to launch.	C1, Low
High Temperature	3 (Poor forecast)	C (Heat related injury or damage to vehicle components)	C3, Moderate	Ensure the team is wearing appropriate clothing for extended periods of time in hot environments. Keep the launch vehicle in a shaded area until	Safety Team Lead or Project Management must notify the team of weather on the day of launch or manufacturing to wear proper clothing, Safety	C1, Low

				before launch.	Team Lead must ensure mitigation is strictly followed due to weather conditions.	
Low Temperatures	3 (Poor forecast)	C (Cold-related personnel injuries, frost on ground, ice on vehicle, clogging of vehicle ventilation, change in launch vehicle rigidity and mass, higher drag force on launch vehicle)	C3, Moderate	Ensure team is wearing appropriate clothing for extended periods of time in cold environments. Keep the launch vehicle at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the launch vehicle, do not launch and return it to a warm location.	Safety Team Lead or Project Management must notify the team of weather on day of launch or manufacturing to wear proper clothing, Safety Team Lead must ensure mitigation is strictly followed due to weather conditions.	C1, Low
Humidity	2 (Climate, poor forecast, improper storage of launch vehicle when not in use)	C (Rust on metallic components, failure of electronics components)	C2, Low	Use as little ferrous metal as possible in vehicle design, store vehicle indoors when not in use.	Team Leads should be aware of this hazard throughout the design process of the vehicle and its components.	C1, Low
Uneven Ground	4 (Mounts of dirt, wet ground areas, general uneven terrain)	C (Launch rail placed on uneven and unstable ground, vehicle won't be visible upon landing)	C2, Low	Ensure the base of the launch rail is placed on terrain that is as flat as possible, and ensure the launch rail is angled appropriately. Spotters will be assigned to watch the launch vehicle for recovery.	Safety Team Lead and Team Mentor shall pick out a location to place the launch rod and facilitate in setting up. Spotters will be assigned by the Safety Team Lead.	C1, Low
Wet Launch Field Conditions	3 (Rain shortly before launch)	B (Difficulty in preparing launch procedures, obstruction in constructing launch rail, inconvenience in recovering vehicle)	B3, Low	Ensure the team is wearing appropriate clothing for extended periods of time in wet environments. Keep the launch vehicle covered and dry. Should electronics become wet, do not	Safety Team Lead will monitor weather conditions prior to launch.[26]	B1, Low

				launch and return the launch vehicle to a dry location. Ensure weather forecasts predict favorable conditions for launch day.		

Table 6.7: Hazards from Environment

For verification of certain mitigation plans, see the following footnotes:

26. *6.2.4 The Day Of - Countdown to Launch, as well as various other points in launch procedures*
27. 6.2.3 The Day Of - Launch Prep, SAFETY TEAM: “Selecting a Launch Area”

6. Project Plan

6.1. Testing

6.1.1. Avionics and Recovery

<table>
<tr><th colspan="3">Verification Plan ID</th><th>Status</th><th>Verification Plan Title</th><th>Requirements Satisfied</th></tr>
<tr><td>VT</td><td>A</td><td>1</td><td>Complete</td><td>Altimeter Continuity and Battery Drain Test</td><td>S.A.14, S.A.13.1, S.A.13.2 S.A.14.1, S.A.14.3</td></tr>
<tr><th colspan="6">Verification Plan Objective</th></tr>
<tr><td colspan="6">This test verifies that the primary and secondary altimeters including their batteries will function in all potential launch temperatures. In addition, the altimeters will maintain continuity throughout flight and the batteries will supply usable voltage for the maximum expected duration of pad time and flight.</td></tr>
<tr><th colspan="4">Success Criteria</th><th colspan="2">Dependent Variables</th></tr>
<tr><td colspan="4">Both altimeters must maintain continuity and receive adequate power from their respective batteries for 3 hours powered on in both cold and warm 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 75°F.
- Cold-weather test: Must be below 35°F.
- Each 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 remain at 8V or higher.
- In the powered-on test, the voltage of the 3.7V LiPo battery must remain at 3.3V or higher.</td><td colspan="2">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.</td></tr>
<tr><th colspan="4">Why is this necessary?</th><th colspan="2">Test Articles</th></tr>
<tr><td colspan="4">This test verifies that both altimeters will be able to maintain continuity and receive adequate power from their respective batteries for 3 hours powered on in both temperature extremes (1 hour longer than the given pad time of 2 hours), and the voltages of both batteries will be able to remain the same after 18 hours powered off in warm weather. This anticipates the timeline of charging the batteries, assembly, and launch/recovery of the vehicle. This is all done in order to ensure the successful recovery of the vehicle.</td><td colspan="2">StratoLoggerCF Altimeter, Telemetrum Altimeter, 9V Battery, 3.7V LiPo Battery</td></tr>
<tr><th colspan="6">Test Equipment and Methodology</th></tr>
</table>

Test Equipment
StratoLoggerCF altimeter, TeleMetrum altimeter, 9V battery, 9V battery connector, 3.7V LiPo battery, two switches, four e-matches, multimeter, screwdriver set

Methodology
Powered-On Test (Warm and Cold Weather)
1. The current temperature was noted.
2. A 9V battery was connected to the StratoLoggerCF altimeter using a 9V battery connector, and a key switch was also connected. An e-match was connected to each of the drogue and main outputs as well.
3. The altimeter was powered on using the switch and allowed to complete its initialization routine. Then, the system was left for 3 hours.
4. Every 0.5 hours (including at 0 hours and 3 hours), the voltage of the battery was recorded using a multimeter, and the number of continuity beeps that were being emitted was also recorded.
5. The procedure was repeated with the 3.7V LiPo battery and the TeleMetrum altimeter. However, since a multimeter cannot be used to measure the voltage of a 3.7V LiPo battery, the voltage was measured by briefly flipping the switch off and then on again, restarting the TeleMetrum. The number of initialization beeps (which represent the current voltage level detected by the TeleMetrum) was then recorded as the voltage measured for that interval of time.
Note: The entire test was conducted in both the early fall and in the winter 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 was 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, no action will be required to correct the continuity and power delivery performance, and it can be expected that the altimeters will have enough charge to eject the parachutes with no issues during launch. The selection of components will be verified in this case. If one or both altimeters or batteries fail this test, a complete retest will need to be conducted on the altimeters or batteries that failed in order to determine and correct the issue, and new altimeters and/or batteries may be considered.

Test Data

Warm Weather Trial: 75.2°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	3 3.8V	3 3.8V	3 3.8V	3 3.7V

StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage	3 9.35V	3 9.20V	3 9.12V	3 9.04V
	Reading 5 (2 hours)	**Reading 6 (2.5 hours)**	**Reading 7 (3 hours)**	
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3 3.7V	3 3.7V	3 3.6V	
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage	3 8.90V	3 8.85V	3 8.82V	
Cold Weather Trial: 33.0°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	3 3.8V	3 3.8V	3 3.7V	3 3.7V
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage	3 9.75V	3 9.60V	3 9.53V	3 9.39V
	Reading 5 (2 hours)	**Reading 6 (2.5 hours)**	**Reading 7 (3 hours)**	
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3 3.8V	3 3.7V	3 3.7V	
StratoLoggerCF/9V Number of Continuity	3 9.25V	3 9.19V	3 9.15V	

Beeps/Battery Voltage				
Powered Off Test: 75.2°F Altimeter/Battery	**Reading 1 (Before 18 hours)**		**Reading 2 (After 18 hours)**	
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3 3.8V		3 3.8V	
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage	3 9.12V		3 9.12V	
Test Results				
Altimeter/Battery		**Early Fall Test Warm Weather: 76.0°F**	**Winter Test Cold Weather: 30.0°F**	**Powered-Off Test: 76.0°F**
TeleMetrum/3.7V LiPo		Pass	Pass	Pass
StratoLoggerCF/9V		Pass	Pass	Pass
Conclusions				
This test was conducted on both September 18, 2022 and November 16, 2022 to test the components in both warm and cold weather outdoor conditions. Each altimeter maintained continuity over the 3 hour test period. Both altimeters consistently demonstrated continuity over the entire 3-hour period in both temperature extremes with no issues. Therefore, it can be said that both altimeter systems pass the continuity test for warm and cold weather. Both batteries also remained well above the safety margins for voltage in both temperature extremes when powered on and both altimeter systems pass the battery drain test as well. No design changes need to be made. There is no need to retest, and the project requirements have been verified.				

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	A	2	Incomplete	**Altimeter Ejection**	S.A.13, S.A.13.3

				Vacuum Test	
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 800 ± 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 will verify 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, twelve e-matches, screwdriver set, glass bowl, sheet of plexiglass, wine stopper, wine bottle air remover pump, plumber's putty, AltimeterOne altimeter

Methodology

1. One large hole is drilled into the sheet of plexiglass. The wine stopper is placed into this hole and a small ring of plumber's putty is placed around it in order to prevent air from escaping.
2. A smaller hole is drilled to the side of the larger one (this acts as a pressure release hole to simulate descent).
3. To test each altimeter, an e-match is connected to each the drogue and main outputs, and a battery and switch are also connected. This system (along with the AltimeterOne turned on and set to Real Time mode) is placed in the glass bowl, with the switch and the e-matches hanging over the rim of the bowl to allow easy access to turn the altimeter on and off as well as to allow the e-matches to ignite in a non-constrained environment. Both altimeter systems (as described above) are placed in the bowl at the same time, with the TeleMetrum pointing up.
4. A larger ring of plumbers' putty is placed around the rim of the bowl, over the e-matches and switch wires. The prepared sheet of plexiglass is then placed over the bowl and pressed down until there is a uniform seal around the entire perimeter. Extra plumbers' putty is placed around the exposed wires as needed.
5. A small piece of plumbers' putty is used to seal the pressure release hole, then the altimeters are switched on and allowed to complete their initialization routines. It is important that these steps are completed in this order because if the chamber is sealed after the altimeters are switched on, they might detect the small drop in pressure and start the launch.
6. The wine bottle air remover pump is then used to remove air through the stopper. Once the process of removing air is halted at the expected apogee altitude (the digital display of the AltimeterOne indicates when this is), the drogue e-match is expected to ignite (or 2 seconds after apogee for the StratoLoggerCF altimeter).
7. Finally, the small piece of plumbers' putty is very slightly lifted away from the plexiglass to slowly allow air back inside it, causing the altitude to decrease according to the AltimeterOne. The main e-match is expected to ignite at pressures corresponding to an altitude of 800' (or 600' for the StratoLoggerCF altimeter).
8. The flight data is downloaded onto a laptop for analysis.
9. The procedure is repeated two more times for a total of three trials.

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			
2			
3			
StratoLoggerCF Trial	Time at TeleMetrum Drogue Ignition Altitude (s)	Time of StratoLoggerCF Drogue Ignition (s)	Main Ignition Altitude (ft)
1			
2			
3			
Data Analysis			
Telemetrum Trial		Distance Between Apogee and Drogue Ignition (ft)	Distance Between Main Ignition and Expected Main Ignition (ft)
1			
2			
3			
StratoLoggerCF Trial		Time Between TeleMetrum and StratoLoggerCF Drogue Ignition (s)	Distance Between Main Ignition and Expected Main Ignition (ft)
1			
2			
3			
Test Results			
Altimeter	Trial 1	Trial 2	Trial 3
TeleMetrum			
StratoLoggerCF			
Results and Conclusions			
This test has not yet been conducted. It is planned to be executed in February 2023.			

<table>
<tr><th colspan="3">Verification Plan ID</th><th>Status</th><th>Verification Plan Title</th><th>Requirements Satisfied</th></tr>
<tr><td>VT</td><td>A</td><td>3</td><td>Incomplete</td><td>Black Powder Ejection Test</td><td>S.A.6, S.A.7, S.A.8</td></tr>
<tr><th colspan="6">Verification Plan Objective</th></tr>
<tr><td colspan="6">This test verifies that the black powder canisters will create appropriate separation between the airframe sections, and that the parachutes will be completely protected on all sides and slide out easily during ejection.</td></tr>
<tr><th colspan="4">Success Criteria</th><th colspan="2">Dependent Variables</th></tr>
<tr><td colspan="4">Both black powder canisters must separate the 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 recovery section side of the avionics bay: ignition must result in at least 6’ of separation between the upper recovery section and the payload section for at least one amount of black powder equal to or greater than 4g.
-- Black powder canister on the lower recovery section side of the avionics bay: 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 2g.</td><td colspan="2">The dependent variables are the amount of separation on the ground between the correct airframe sections both the drogue and main side black powder canisters result in, whether or not any vehicle components are damaged, and whether or not the parachutes are fully ejected.</td></tr>
<tr><th colspan="4">Why is this necessary?</th><th colspan="2">Test Articles</th></tr>
<tr><td colspan="4">This test will verify that both black powder canisters are able to separate the correct airframe sections the appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes. This will ensure the successful recovery of the vehicle and validate the choices of all of these components.</td><td colspan="2">Drogue and Main Ejection Systems</td></tr>
<tr><th colspan="6">Test Equipment and Methodology</th></tr>
</table>

Test Equipment Avionics bay, upper recovery section, payload section, lower recovery section, booster section, screws, shear pins, screwdriver set, hex wrench set, black powder, gram scale, disposable latex gloves, small zip ties, e-matches, fireproof cellulose insulation, masking tape, 10’ wires, main parachute, drogue parachute, Nomex blankets, 60’ shock cord, 30’ shock cord, quick links, rubber mallet, remote detonator, measuring tape **Methodology** 1. The black powder canister on the upper recovery section side of the avionics bay is filled with 4g of black powder. Specifically, the black powder is measured out using the gram scale and poured into the cut tip of a finger of a disposable latex glove, which is then zip-tied shut with the end of an e-match also placed in there. This is then placed into the black powder canister, which is packed with fireproof cellulose insulation and covered with masking tape to prevent anything from falling out. 2. The other end of the e-match is connected to the terminal block on the avionics bay, and the 10’ extension wire is also connected to the other end of the terminal block. 3. The main parachute and its double Nomex blanket are attached off-center to the 60’ shock cord via a loop and quick link. The longer end is attached to the eyebolt on the bulkhead of the upper recovery section side of the avionics bay, and the shorter end is attached to the eyebolt on the bulkhead of the payload section through the upper recovery section. The main parachute and Nomex blanket are packed in flight configuration in the upper recovery section, which is then reconnected to the avionics bay using screws. The upper recovery section is also reconnected to the payload section using shear pins (using a rubber mallet if necessary). 4. The extension wire has already been threaded through one of the switch holes so it can be accessed from the outside of the vehicle. The remote detonator is connected to the extension wire. 5. The person conducting the test stands 40’ away from the system and sets off the remote detonator. The ejection charges are then expected to ignite and result in the separation of the two sections connected by shear pins. If they do indeed separate, the distance between them is measured in feet using the tape measure. 6. If the above success criteria are not met, the procedure is repeated using increasing amounts of black powder (in 1g increments) until 6’ of separation is achieved. This last amount of black powder is then recorded as the ideal amount of black powder. 7. The procedure is also repeated for the black powder canister on the lower recovery section side of the avionics bay (with the drogue parachute and single Nomex blanket inserted and attached on the other side to the booster section with the 30’ shock cord), with 2g of black powder.
Potential Impact of Results
If both black powder canisters pass this test, no action will be required to correct the performance of airframe separation, and it can be expected that the black powder canisters will successfully separate the correct airframe sections and eject the parachutes with no issues during launch. If one or both black powder canisters fail this test, the following responses will be taken: if the upper recovery section and payload section separation is less than 6', black powder will be added in 1g increments from the initial

4g until 6' of separation is achieved. If the lower recovery section and booster section separation is less than 6', black powder will be added in 1g increments from the initial 2g until 6' of separation is achieved. These retests will be conducted until 6' of separation of the two airframe sections is achieved by both the drogue and main side black powder canisters. Then, these ideal amounts of black powder will be used in the new vehicle design.

Test Data				
Black Powder Canister Side	**Amount of Black Powder Used**	**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 has not yet been conducted. It is planned to be executed in February 2023.

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	4	Incomplete	**Independent Section Tracker GPS Test**	S.A.17

Verification Plan Objective
This test verifies that the GPS trackers will maintain connection to field computers throughout the duration of the flight.

Success Criteria	Dependent Variables
All GPS trackers must maintain connection to the Avionics Ground Control Station (AGCS) for the duration of each trial.	The dependent variable is the connection status of the trackers to the AGCS.
Why is this necessary?	**Test Articles**

This test will verify that the TeleMetrum and EggFinder GPS trackers are able to maintain connection to the AGCS throughout the duration of the launch activities. This is critical to fulfilling the team-derived requirement of having a functional tracker located within each independent section of the vehicle. This test will also verify that the trackers are able to connect without RF interference from the primary and secondary payload electrical systems.	TeleMetrum Altimeter GPS and EggFinder Trackers

Test Equipment and Methodology

Test Equipment

TeleMetrum altimeter, 3.7V LiPo battery, switch, TeleMetrum antenna, TeleDongle, EggFinder TX modules, EggFinder RXs, keylock switch keys, laptop, complete launch vehicle

Methodology

Part 1: Establishing Connectivity Without Potential Interference

TeleMetrum Altimeter GPS

1. Use a key to turn on the keylock switch of the TeleMetrum altimeter (in launch configuration with battery and switch).
2. Assemble the TeleMetrum antenna. The longest prongs go at the bottom and the shortest go at the top. Plug the antenna into the TeleDongle, then plug the TeleDongle into a laptop with AltOS installed.
3. Open AltOS and choose Monitor Flight. The TeleDongle should appear as a device to select. Select the TeleDongle device and continue to the telemetry window. Set the frequency to 434.550 MHz Channel 0 and baud rate to 9600 baud. Live telemetry from the TeleMetrum should now be appearing on the screen.
4. Ensure all lights are green.

-- At least 4 GPS satellites are in solution. This may take a few minutes.

-- GPS Ready is Ready.

5. Verify that this connection is maintained as the altimeter is moved around a local area.

EggFinder Trackers

1. Use a key to turn on the keylock switch of one EggFinder TX.
2. Plug the corresponding EggFinder RX into a laptop. The red LED should immediately come on, indicating the board has power. After one or two seconds, the green LED should then begin blinking, indicating that it is receiving data from the EggFinder TX.
3. In MapSphere, choose GPS, then Configure. Choose the COM port the GPS is connected to, then OK. In the GPS Status tab to the lower right, GPS satellites should begin coming into view. At least 4 GPS satellites must be in solution. This may take a few minutes.
4. In the main map, the current location should now be shown as an orange triangle and be tracked in real time.

5. Verify that this connection is maintained as the tracker is moved around a local area. 6. Repeat this process with the other EggFinder TX. Part 2: Establishing Connectivity With Potential Interference 1. Repeat the same procedure as in Part 1, but with the trackers in their respective places in the vehicle and all vehicle electronics activated.			
Potential Impact of Results			
If all of the GPS trackers pass this test, no action will be required to correct the performance of the GPS tracking of the independent sections of the vehicle, and it can be expected that these systems will function successfully for the duration of the flight. If one or more trackers fail this test, a complete retest will need to be conducted on the tracker(s) that failed in order to determine and correct the issue, and new trackers may be considered.			
Test Results			
Part 1: Trackers Outside of Vehicle Trial	**TeleMetrum Altimeter GPS**	**EggFinder Tracker 1**	**EggFinder Tracker 2**
1			
2			
3			
Part 2: Trackers in Vehicle Trial	**TeleMetrum Altimeter GPS**	**EggFinder Tracker 1**	**EggFinder Tracker 2**
1			
2			
3			
Conclusions			
This test has not yet been conducted. It is planned to be executed in February 2022.			

<table>
<tr><th colspan="3">Verification Plan ID</th><th>Status</th><th>Verification Plan Title</th><th>Requirements Satisfied</th></tr>
<tr><td>VT</td><td>A</td><td>5</td><td>In Progress</td><td>Parachute Drop Test</td><td>S.A.5</td></tr>
<tr><th colspan="6">Verification Plan Objective</th></tr>
<tr><td colspan="6">This test verifies that the parachutes will open consistently within an appropriate distance range or time frame to allow for full deployment after ejection.</td></tr>
<tr><th colspan="4">Success Criteria</th><th colspan="2">Dependent Variables</th></tr>
<tr><td colspan="4">Both parachutes must fully deploy within their respective maximum diameters.
-- The elapsed time between the weight being dropped and the drogue parachute fully opening must be below 1.5s for each trial.
-- The final estimate for the total drop distance required for the main parachute to open fully, including shock cord extension, must be below 150’.</td><td colspan="2">The dependent variables are the elapsed time between the weight being dropped and the drogue parachute fully opening and the final estimate for the total drop distance required for the main parachute to open fully, including shock cord extension.</td></tr>
<tr><th colspan="4">Why is this necessary?</th><th colspan="2">Test Articles</th></tr>
<tr><td colspan="4">This test verifies that both parachutes are able to fully deploy within their respective maximum parameter in order to ensure the successful recovery of the vehicle and validate the choices of parachutes.</td><td colspan="2">Drogue and Main Parachutes</td></tr>
<tr><th colspan="6">Test Equipment and Methodology</th></tr>
</table>

Test Equipment Drogue parachute, subscale parachute, main parachute, Nomex blankets, 30’ shock cord, 60’ shock cord, green painters, tape, two quick links, 50lbm weight, old upper airframe, two smartphones with video recording/timing capabilities **Methodology** 1. The walls on the parking garage facing the camera were marked with green tape in 5’ increments horizontally along each floor. A note was made of the distance between each floor and the 2. The drogue parachute was attached to the center of the 30’ shock cord via a loop and quick link, and the ends of the shock cord were tied a few times around the 50lbm weight (simulating the weight of the launch vehicle) and secured with another quick link. 3. The drogue parachute was packed in the old upper airframe with the single Nomex blanket wrapped around it (in flight configuration), which was then held over the top edge of the parking garage. With a running timer on one smartphone in view of another smartphone also video recording the drop, the weight was tossed over the top edge of the parking garage. 4. This procedure was repeated three times for a total of three drops of the drogue parachute. 5. This procedure was also repeated three times for a total of three drops of both the subscale and main (with double Nomex blanket) parachutes. However, these were not timed. 6. When later analyzing the video recordings, the elapsed time between the weight being dropped and the drogue parachute fully opening was recorded for each trial. For the subscale parachute, the distance between the parachute leaving the airframe and fully opening was recorded for each trial. For the main parachute, the distance between the parachute leaving the airframe and hitting the ground was recorded for each trial, as well as the approximate percentage the parachute was open to just before hitting the ground. 7. The distance to open values (these not including the extension of the shock cord) of the drogue and subscale parachutes were plotted against parachute surface areas (hemispherical model). Linear and exponential models were then created from this data. 8. The percentage opened values of the main parachute were plotted against precise drop distance, and an exponential model was then created from this data. This model was used to estimate the total drop distance required for the main parachute to open fully (100%). 9. The surface area of the main parachute was input into both the linear and exponential distance to open models created from the drogue and subscale data to output two more estimates of the total drop distance required for the main parachute to open fully. The one that is closer to the estimate from the main parachute percentage data was then averaged with that estimate. Finally, 30’ (the extension of the 60’ shock cord that will be used with the main parachute in flight, when doubled up) was added to that number to produce the final estimate.			
Potential Impact of Results			
If both parachutes pass 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 one or both parachutes fail 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**

Drogue (18" diameter) **Distance to open (not including extension of shock cord)** **Time to open (including extension of shock cord)**			
Subscale (48" diameter) **Distance to open (not including extension of shock cord)**	34.10'	34.23'	41.21'
Main (144" diameter) **Percentage opened in precise drop distance (not including extension of shock cord)**			
Test Results (Data Analysis Not Shown)			
Parachute	**Trial 1**	**Trial 2**	**Trial 3**
Drogue			
Main			
Conclusions			
This test has not been conducted. The subscale parachute was tested and passed this test. However, due to required changes in mission performance the team opted for a smaller drogue parachute and new version of the main parachute. Therefore, the new 18'' drogue parachute drop test will be conducted at a later date. There was a purchase of a new main parachute, so testing will resume once all new parachutes have been acquired.			

6.1.2. Construction

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	C	1	In Progress	Fin Flutter Test	S.C.10
Verification Plan Objective					

<table>
<tr><td colspan="2">Satisfies requirement S.C.10: The torsional and bending material property data collected from this test will confirm that the speed required for fin flutter is above the maximum predicted flight speed with a sufficient factor of safety.</td></tr>
<tr><th>Success Criteria</th><th>Dependent Variables</th></tr>
<tr><td>Data collected from the test fin is sufficient to prove that fin flutter will not be a risk.</td><td>Vertical and angular displacement</td></tr>
<tr><th>Why is this necessary?</th><th>Test Articles</th></tr>
<tr><td>Fin flutter is a dangerous phenomenon that needs to be accounted for in high-powered rocketry. On top of that, the aspect ratio of the fins leaves them more susceptible to fin flutter.</td><td>Epoxacast 670 Proof of concept fin with a G10 fiberglass insert.</td></tr>
<tr><th colspan="2">Methodology</th></tr>
<tr><td colspan="2">- Secure the fin by the root chord over the edge of a table
- Apply 7lb to the tip and measure deflection
- Attach a 10” rod starting a the leading edge of the tip and running through the trailing edge and overhanging the fin
- Apply 7lb to the overhung end of the rod and measure angular displacement</td></tr>
<tr><th colspan="2">Potential Impact of Results</th></tr>
<tr><td colspan="2">If the calculated fin flutter speed is not a sufficient factor of safety away from the maximum expected flight speed the dimensions of the fin will be modified to increase its resistance to flutter. This would include increasing the thickness and reducing the height.</td></tr>
<tr><th colspan="2">Test Data</th></tr>
<tr><td>Vertical Displacement</td><td>.572”</td></tr>
<tr><td>Angular Displacement</td><td>9.2°</td></tr>
<tr><th colspan="2">Test Results (Data Analysis Not Shown)</th></tr>
<tr><td colspan="2">Fin Flutter Speed: 800 m/s
(Analysis not shown)</td></tr>
<tr><th colspan="2">Conclusions</th></tr>
</table>

The fin flutter speed determined from the material properties is sufficiently higher than the expected maximum flight speed and thus the design of the fins do not have to be altered.

6.1.3. Payload

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	P	1	In Progress	APRS Decoding Test	S.P.14
Verification Plan Objective					
To verify requirement S.P.14. The requirement states that the system must be able to receive NASA transmitted APRS signals between 144.90 and 145.10 MHz.					
Success Criteria				**Dependent Variables**	
The system can both receive and decode encoded APRS information with a radio receiver.				Frequency of the radio signals.	
Why is this necessary?				**Test Articles**	
The Payload system must be able to receive APRS signals across a small spectrum of frequencies in order to receive commands from NASA's transmitter.				Handheld radio, laptop, Payload electronics	
Methodology					
This test will take place in an outdoor environment, with a small distance between transmitter and receiver. The test will be performed with two groups, a transmitting group that uses the handheld radio connected to a laptop, and a receiving group that has the payload electronics. 1. Appropriate test software should be uploaded onto the payload electronics and the laptop. This software will replicate the software used on launch day, but optimized for testing. 2. The payload electronics will be placed on a small box approximately 6 inches off the ground to replicate the conditions of the launch. 3. The radio will be connected to the laptop via an aux cord and placed a short distance from the receiver. 4. Both receiver and transmitter stations will be turned on and will be waiting in the ready state. 5. The transmitter will begin sending APRS messages on 144.90 MHz. 6. Upon successfully receiving the message, the transmitter will increment its frequency by 0.05 MHz. 7. The receiver's code is then updated to receive 0.05 MHz higher than it was before (same as the transmitter's frequency now). 8. Steps 5-7 are repeated until the frequency reaches 145.10 MHz.					
Potential Impact of Results					

The results of this test will determine if the system can receive APRS signals. This is integral to the software and electronics design of the system. If the system does not pass this test, the payload mission will not be able to succeed with its mission.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	2	Incomplete	R&D Loading Test	S.P.13, S.P.24
Verification Plan Objective					
To verify that the R&D system is compliant with Subteam Requirements S.P.13 and S.P.24. These requirements dictate that the R&D system be capable of handling accelerations that will occur during launch until the point of deployment while maintaining a minimum failure point factor of safety of 1.33.					
Success Criteria				**Dependent Variables**	
The R&D system is able to retain the CDS under a Payload Section deceleration force equivalent of 2.66g.				R&D loading in pound-force	
Why is this necessary?				**Test Articles**	
The R&D system must be tested in order to ensure that it will operate as intended, even under worst-case flight loads as it is possible for the R&D system to fail in retaining the CDS before the desired time and position. Although the deployment of the main parachute generates a deceleration of up to 2g on the payload section, the stepper motor located in the aft payload coupler is holding it in place to prevent the payload bay from opening at the separation point prematurely.				R&D Bay (CDS Assembly not required), Payload Suspension Apparatus, Pull Scale, Testing Weights	
Methodology					

1. The Payload Bay and nose cone should be weighed together. 2. The Payload Bay must be assembled to its completed state. For the purposes of this testing rig, the vehicle's nose cone will be removed. 3. The R&D electronics' stepper motor is powered and its motor driver activated to produce a holding torque. 4. The Payload Bay will be suspended from the Payload Suspension Apparatus by its eyebolt. This can be accomplished by hanging it from a properly supported ceiling. 5. A weight equal to 2.66 times the Payload System weight should be secured beyond the forward bulkhead. This will statically simulate 2.66g of deceleration (2g of load with a 1.33 FoS). 6. The team should wait until oscillation of the Payload Bay has ceased or until the R&D is back-driven (stepper motor spins without commanding it to). If the latter occurs, the R&D has failed the test. 7. Remove the applied load. 8. Repeat steps 5-8 two more times to ensure loading integrity. 9. The team should inspect the R&D for internal damage. If the R&D visibly back-drives at all during this test, the team should reconsider the safety of the design.
Potential Impact of Results
The results of this test will determine if the R&D system has enough strength and resistance to complete its descent task under the most strenuous conditions. If the R&D system fails under the aforementioned loading conditions, then the R&D system must be redesigned to handle more load. If the R&D system is capable of withstanding this level of loading without detectable damage, then the system is ready for flight.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	3	Incomplete	Payload Battery Drain Test	S.P.4, S.P.5
Verification Plan Objective					
Confirm compliance with S.P.4 and S.P.5, ensuring that all Payload subsystems have sufficient battery life to sustain their pre-flight state for 24 hours, and their launch-ready state for an additional 3 hours.					
Success Criteria				**Dependent Variables**	
The payload system will maintain enough battery power to successfully perform its mission after staying in a pre-launch state for 24 hours and a				Battery voltage in volts, Time in pre-flight state in hours	

launch-ready state for 3 hours.	
Why is this necessary?	**Test Articles**
The payload must not drain too much battery before launch. If the battery is drained too much, the electronics would not be able to be powered and the mission would result in failure.	Payload LiPo battery, LiPo battery charger, multimeter, Stopwatch, fully assembled payload electronics, keyswitch
Methodology	
Pre-flight drain test: 1. The battery is charged until it is full. 2. The battery is disconnected from its charger and the starting voltage is measured using a digital multimeter. 3. The battery is then connected to the payload system. The electronics will remain off. This is controlled via a keyswitch. 4. The system will remain in that configuration for 24 hours. After which the battery voltage is measured again. Launch-Ready test: 1. The battery is charged until it is full. 2. The battery will be disconnected from the charger and connected to the payload system. 3. The control system will be turned on and put into its launch-ready configuration. 4. The system will be left on for at 3 hours. This is controlled via a keyswitch. 5. The voltage of the battery will be measured every 30 minutes (including the start and end times).	
Potential Impact of Results	
After the tests have been completed the test data will be analyzed to determine if the battery still contains sufficient power to complete the mission. The power consumption of the system will be graphed so that the team can estimate how long the system can wait in this state in a worst-case-scenerio. If the selected battery cannot sustain the GOAT subsystems for the required time, then the team will need to make modifications and conduct more tests. These modifications could include changes to the electronics or software to reduce power consumption or changing to a higher capacity battery.	
Results and Conclusions	

This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	P	4	Incomplete	Payload Weight Test	S.P.21
Verification Plan Objective					
Fulfill requirements S.P.21: The overall mass of the launch vehicle payload system should not exceed 10 lbm					
Success Criteria				**Dependent Variables**	
Mass of the Payload systems including IOS, R&D, CDS, TACOS, coupler rods, and all electrical hardware.				Mass of each system of the Payload in pound-mass, determined through measuring pound-force.	
Why is this necessary?				**Test Articles**	
A smaller total weight is necessary to obtain the required minimum thrust-to-weight ratio of 5:1, as defined by G.2.15. Additionally, properly coordinated weight is essential to achieving the desired apogee.				Payload Bay, Weighing Scale	
Methodology					
1. Assemble individual components in flight configuration. 2. Measure the mass of each system with a scale. a. Measure the combined mass of the Payload system. b. Measure the individual mass of the R&D system. c. Measure the individual mass of the ADS system. Since this system is not deployed, this measurement is only for reference.					
Potential Impact of Results					
Should any system exceed weight requirements, further work would be required to optimize the materials used in construction of components, whether that be design changes or other relevant compromises. Should each system meet weight requirements, no further modifications would be					

necessary.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	5	Incomplete	R&D and IOS Deployment Test	S.P.2, S.P.3
Verification Plan Objective					
Satisfy requirement S.P.2 and S.P.3. These requirements ensure that the payload system will rotate the camera deployment system to the correct orientation in respect to the normal direction of the ground. Additionally, it ensures the system will be linearly actuated enough to allow the camera deployment system to deploy.					
Success Criteria				**Dependent Variables**	
Following activation of R&D, the system shall be rotated appropriately and the air frame will be open.				Time of deployment, angle of the camera deployment system in respect to the normal of the ground.	
Why is this necessary?				**Test Articles**	
The objective of R&D and IOS is to orient and open the payload bay to allow the camera deployment system to be appropriately positioned to orient the camera.				Payload system, keyswitch, protractor, stopwatch	
Methodology					
1. Fully assemble the Payload system. 2. Close payload bay and switch the payload electronics from pre-flight status to flight ready status. 3. Position the system in a random orientation on a dirt field. 4. Signal the electronics to perform IOS orientation maneuver. 5. Signal the electronics to activate the R&D separation maneuver. 6. Measure the final angle of the camera deployment system with respect to the local vertical. This may be found by dangling a weighted string. 7. Measure the deployment time from start to finish to ensure it can be completed in a reasonable time. 8. Repeat steps 2–7 two more times after relocating or choosing a surface with a different local grade. This will simulate possible landing configurations.					
Potential Impact of Results					

If the payload system performs as expected, no action is necessary. If the camera deployment system is shown to extend at an insufficient angle, then modification to IOS will be necessary. Deployment angles directly toward the ground will suggest improper orientation by IOS. If CDS is only partially exposed or if there is no separation of the air frame, that indicates a modification to R&D is necessary. Additionally, the times recorded will be used to determine when and how fast deployment shall be anticipated to occur.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	6	Incomplete	CDS Deployment Test	S.P.25

Verification Plan Objective	
Satisfy requirement S.P.25. This ensures the camera's images are not blocked by the airframe of the launch vehicle.	
Success Criteria	**Dependent Variables**
Following activation of CDS, the camera will be above the airframe and will have an unobstructed view of the launch field.	Time of deployment, height of camera system above ground.
Why is this necessary?	**Test Articles**
The objective of CDS is to lift the camera out of the airframe. This is necessary to ensure the camera can take acceptable images of the surrounding terrain.	Payload system, keyswitch, ruler, stopwatch

Methodology
1. Fully assemble the Payload system. 2. Open payload bay manually and switch the payload electronics from pre-flight status to flight ready status. 3. Position the system such that CDS is pointed upward in respect to the normal of the ground. 4. Signal the electronics to perform CDS deployment maneuver 5. Measure the final distance that the camera was raised with respect to the ground. This may be found by measuring with a ruler. 6. Measure the deployment time from start to finish to ensure it can be completed in a reasonable time.
Potential Impact of Results

If CDS performs as expected, no action is necessary. If the camera is not extended sufficiently, it will require a modification to the mechanics of CDS to obtain acceptable pictures. Additionally, the time recorded will be used to determine when and how fast deployment shall be anticipated to occur.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	7	Incomplete	TACOS Rotation Test	S.P.8, S.P.10
Verification Plan Objective					
Satisfy requirement S.P.25. This ensures the camera's images are not blocked by the airframe of the launch vehicle.					
Success Criteria				**Dependent Variables**	
Given any angle within 20 degrees of the horizon, TACOS will be able to level itself and spin to any point within 360 degrees.				Camera vertical angle from horizontal, camera horizontal angle from its starting position, time of movement in seconds	
Why is this necessary?				**Test Articles**	
The objective of CDS is to orient and rotate the camera in accordance with commands sent by NASA. Thus, if the payload system is to complete these commands, TACOS must be able to rotate the camera.				Payload TACOS, keyswitch, protractor, stopwatch	
Methodology					
1. Fully assemble the Payload TACOS. 2. Position TACOS in any position within 20 degrees of the horizon. 3. Signal the electronics to orient the camera. 4. Signal the electronics to perform all rotation related commands that NASA could send, measuring the angles moved after each motion. 5. Measure the time during each motion for reference. 6. Perform steps 2-5 several more times to ensure it is functional on different angles.					
Potential Impact of Results					

If the TACOS performs as expected, no action is necessary. If the camera is moved to an angle that is unexpected or wrong, then a modification to TACOS must be made. Depending on the error, it may entail a hardware, electronic, or software change. Additionally, the times recorded will be used to determine when and how fast rotations shall be anticipated to occur.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	8	In Progress	Camera Imaging Test	S.P.18, S.P.19, S.P.23
Verification Plan Objective					
Satisfy requirement S.P.18 and S.P.19, S.P.23. These requirements dictate that the camera will be able to capture images, perform post-processing on them, and store the finished product on an SD Card for analysis later.					
Success Criteria				**Dependent Variables**	
The captured images have the necessary actions done to them and are saved to an SD Card. Each image needs a time stamp and whatever post-processing is required for that specific image.				Image processing commands used on a specific image.	
Why is this necessary?				**Test Articles**	
NASA sends commands to perform processing on images. The camera must be able to capture images and the microcontroller must perform post-processing on it according to the commands sent.				Payload camera, keyswitch, stopwatch	
Methodology					
1. Fully assemble the Payload electronics. 2. Position the camera in a stationary position. 3. Signal the electronics to capture an image. 4. Signal the electronics to perform various commands that NASA can send. 5. Measure the time during each capture and image processing for reference. 6. After the electronics have signaled the image is done via an LED igniting, remove the SD Card and verify the image is correct. 7. Perform steps 3-6 several more times to ensure it is functional with all commands.					
Potential Impact of Results					

If the camera imaging works as expected, no change is necessary. If the images are too blurry or do not have the correct FOV, a new camera may be required. If the image processing is incorrect, such as an incorrect flip, grayscale, etc, then the software will need to be modified. Time will be kept to ensure all this processing can complete in a reasonable time.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	P	9	Incomplete	Command Execution Test	S.P.10, S.P.12, S.P.15
Verification Plan Objective					
Satisfy requirements S.P.10, S.P.12, and S.P.15. These requirements dictate the payload will execute incoming APRS commands properly, assuring the camera is able to rotate to the the desired position without exceeding 30 seconds					
Success Criteria				**Dependent Variables**	
The string of commands is executed in an orderly and timely manner according to the necessary margins				Order of command execution, time taken to rotate to position	
Why is this necessary?				**Test Articles**	
The payload must be able to receive and execute commands at any moment after landing, and the connection between receiver and TACOS must be demonstrated				Payload electronics, Handheld Radio, Command APRS Messages, TACOS, Stopwatch, Protractor	
Methodology					
1. Link Receiver and TACOS electronics. 2. Initialize Receiver electronics and software. 3. Fully assemble and initialize the Payload TACOS. 4. First of three APRS messages is sent with commands testing two full revolutions clockwise. 5. Time between each command and total time is recorded. 6. Second of three APRS messages is sent with commands testing two full revolutions counter-clockwise. 7. Time between each command and total time is recorded. 8. Third of three APRS messages is sent with commands testing changing directions and halting of camera for taking pictures. 9. Time between each command and total time is recorded.					
Potential Impact of Results					

If the Command Execution test works as expected, no change is needed. If commands are not communicated between the receiver and TACOS, the software for each subsystem must be revised and checked for. Missexecution of commands will result in checking TACOS software to confirm the defect. Delayed or non-timely execution of commands will yield inspection of TACOS motors and motor drivers.
Results and Conclusions
This test has not been conducted and will be done when the system is complete in 2023.

6.2. Requirements and Verifications Plan

Critical analysis of the requirements listed in the Handbook ensures that the PSP-SL team designs of the launch vehicle and payload are safe and effective. The Requirements and Verification Planning (R&VP) system emphasizes the value of R&VP in guiding the team throughout the year, rather than simply satisfying NASA requests.

The current list of requirements are included on the following pages. This, however, is not to say that these are the only requirements the team will follow. As the scope of the project and the solution to the problem presented is developed further, more requirements derived by the PSP-SL team will arise.

Subsystem	Letter	Mnemonic
Social, Business, Outreach, Documentation	N	Non-technical
Construction	C	Construction
Payload	P	Payload
Avionics and Recovery	A	Avionics
Standards, Guidelines	G	Guidelines
Systems, Project Management	M	Management
Safety	H	Health

Table 7.1: Designations for R&VP tables

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.*

PROJECT REQUIREMENTS (NASA Requirements, Team Requirements)							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). Teams will submit new work. Excessive use of past work will merit penalties.		☐	☐	☑	☐	☐		The team will record hourly work performed by members of the team.
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 will maintain a record of all leadership positions and responsibilities required for the project. Documentation of progress will be provided in reports and presentations to the NASA team.
G	1.3	☑	Complete	NASA	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.		☐	☐	☑	☐	☐		A list of FN's will be provided to NASA before the PDR deadline.
G	1.4	☑	Complete	NASA	The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include:		☑	☐	☐	☐	☐	G.1.4.1, G.1.4.2, G.1.4.3	The team will utilize the provided NASA RSVP system to ensure all attending members are accounted for.
G	1.4.1	☑	In Progress	NASA	Students actively engaged in the project throughout the entire year.	G.1.4	☐	☐	☑	☐	☐		A roster of team contacts and accountability will be held by the team.
G	1.4.2	☑	Complete	NASA	One mentor (see requirement 1.13).	G.1.4	☐	☐	☑	☐	☐		One mentor will be utilized and their contact provided to NASA.
G	1.4.3	☑	Complete	NASA	No more than two adult educators.	G.1.4	☐	☐	☑	☐	☐		Up to two educators will be utilized and their contact provided to NASA.
G	1.5	☑	In Progress	NASA	The team will engage a minimum of 250 participants in direct educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. A template of the STEM Engagement Activity Report can be found on pages 40-43.		☐	☐	☑	☐	☐		The team will record participation of members in all event activities and the final count will be submitted to NASA before FRR.
G	1.6	☑	Complete	NASA	The team will establish and maintain a social media presence to inform the public about team activities.		☐	☐	☑	☐	☐		The team will establish a team social media account and will submit the identification of any accounts to NASA.
G	1.7	☑	Complete	NASA	Teams will 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 milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.		☐	☐	☑	☐	☐		The team will work with NASA to ensure deliverables are complete and submitted on time through the appropriate channels
N	1.8	☑	Complete	NASA	All deliverables must be in PDF format.		☐	☐	☐	☑	☐		The team will convert all deliverables to PDF format.
N	1.9	☑	Complete	NASA	In every report, teams will provide a table of contents including major sections and their respective sub-sections.		☐	☐	☐	☑	☐		The team will add a table of contents to all deliverable reports.
N	1.10	☑	Complete	NASA	In every report, the team will include the page number at the bottom of the page.		☐	☐	☐	☑	☐		A page number will be included on all pages of report deliverables.
G	1.11	☑	Complete	NASA	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.		☐	☐	☑	☐	☐		The team will work with NASA to ensure professional communication procols are followed. Equipment and rooms will be arranged ahead of time.

PROJECT REQUIREMENTS (NASA Requirements, Team Requirements)							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	1.12	☑	In Progress	NASA	All teams attending Launch Week will 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 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.		☐	☐	☑	☑	☐		Verify launch rail length and angle by inspection, appropriate rail buttons (15-15) were demonstrated during VDF.
G	1.13	☑	Complete	NASA	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team mem- ber, 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 mentor must maintain a current certifi- cation, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend 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.		☐	☐	☑	☐	☐		One mentor will be utilized and their contact provided to NASA. This mentor will satisfy the certification requirements outlined by NASA. Any violation of these requirements will result in the removal and replacement of the mentor with NASA's permission.
G	1.14	☑	In Progress	NASA	Teams will track and report the number of hours spent working on each milestone.		☐	☐	☑	☐	☐		The team will record hourly work performed by members of the team.
C	2.1	☑	In Progress	NASA	The vehicle will 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.		☐	☑	☑	☐	☐	S.C.14	Simulation with OpenRocket and simulink, demonstration with altimeter data.
G	2.2	☑	Complete	NASA	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.		☐	☑	☑	☐	☐	S.C.14	Simulation with OpenRocket and simulink and analysis with weighted average, declared 4050', demonstration with altimeter data.
A	2.3	☑	Complete	NASA	The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4). An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.		☐	☐	☐	☑	☐		The team will utilize altimeters that satisfy the requirements as outlined. These altimeters will be reported in both reports and flysheets.
A	2.4	☑	In Progress	NASA	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.		☐	☑	☑	☐	☐		Structural integrity simulations with FEA, recovery testing, demonstation during VDF.
C	2.5	☑	In Progress	NASA	The launch vehicle will 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.	S.P.13, S.P.14	☑	☐	☑	☑	☐	C.2.5.1, C.2.5.2	Verified by inspection and demonstration during VDF. 3 independent sections.
C	2.5.1	☑	In Progress	NASA	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	C.2.5	☑	☐	☑	☑	☐	S.C.15	Please see S.C.15
C	2.5.2	☑	In Progress	NASA	Nosecone shoulders which are located at in-flight separation points will be at least 1⁄2 body diameter in length.	C.2.5	☐	☐	☑	☑	☐		Inspected prior to and demonstrated during VDF.
G	2.6	☑	In Progress	NASA	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.		☑	☐	☑	☐	☐	S.C.8	Demonstrated during VDF.

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P	2.7	☑	In Progress	NASA	The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.		☑	☐	☐	☐	☐	S.C.8, S.P.4, S.A.14.1	The team will comply with the launch-ready configuration power requirement by applying a more internal and stringent power requirement capability as defined in the Payload subteam requirements. This set of subteam requirements increases the required launch-ready time and includes pre-flight power capability.
G	2.8	☑	In Progress	NASA	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.		☐	☐	☑	☐	☐		Verified during VDF.
G	2.9	☑	In Progress	NASA	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).		☐	☐	☑	☐	☐		Verified during VDF.
G	2.10	☑	In Progress	NASA	The launch vehicle will 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).		☐	☐	☑	☑	☐		Verified by inspection and demonstration during VDF.
G	2.10.1	☑	Complete	NASA	Final motor choices will be declared by the Critical Design Review (CDR) milestone.		☐	☐	☑	☐	☐		Motor chosen at CDR was used during VDF.
G	2.10.2	☑	Incomplete	NASA	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.		☐	☐	☑	☑	☐		If the motor is changed after CDR, the appropriate approvals will be made. Currently no change is planned.
G	2.11	☑	Complete	NASA	The launch vehicle will be limited to a single stage.		☐	☐	☑	☐	☐		The design of the launch vehicle will include a single propulsive stage.
G	2.12	☑	Complete	NASA	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).		☐	☐	☑	☐	☐		The design of the launch vehicle will not exceed total impulse classification requirements.
G	2.13	☑	Discontinued	NASA	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:		☑	☐	☐	☐	☐	G.2.13.1, G.2.13.2, G.2.13.3	If pressure vessels are utilized, the following requirememts will be met:
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.	G.2.13	☐	☑	☐	☐	☐		The team will verify through mathematical analysis that the design FoS to meet or exceed the 4:1 requirement.
G	2.13.2	☑	Discontinued	NASA	Each pressure vessel will 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.	G.2.13	☐	☐	☑	☐	☐		The design of any pressure vessel system will include the required valves and will be reported in documentation to NASA.
G	2.13.3	☑	Discontinued	NASA	The full pedigree of the tank will 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.	G.2.13	☐	☐	☑	☐	☐		The design of any pressure vessel will be reported in documentation to NASA.
G	2.14	☑	Complete	NASA	The launch vehicle will 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.		☑	☑	☑	☐	☐	S.C.16	Verified by simulation in OpenRocket and ANSYS Fluent, demonstration during VDF.
G	2.15	☑	Complete	NASA	The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.		☐	☑	☑	☑	☐		Verified by simulation in OpenRocket and ANSYS Fluent, demonstration during VDF, T/W: 9.55:1. Inspection of mass.
G	2.16	☑	In Progress	NASA	Any structural protuberance on the rocket will 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.		☑	☑	☑	☐	☐	S.C.11	Verified by simulation in OpenRocket and ANSYS Fluent, demonstration during VDF.
G	2.17	☑	In Progress	NASA	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.		☐	☑	☑	☐	☐		Verified by simulation in OpenRocket and ANSYS Fluent, demonstration during VDF with Telemetrum data, measured 60ft/s.

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G	2.18	☑	Complete	NASA	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The sub-scale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).		☐	☑	☑	☐	☐		Verified by simulation in OpenRocket, demonstration during subscale flight with altimeter data.
G	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 will not be used as the subscale model.		☑	☑	☑	☐	☐	S.C.12	Verified by simulation in OpenRocket, demonstration during subscale flight with altimeter data.
A	2.18.2	☑	Complete	NASA	The subscale model will carry an altimeter capable of recording the model's apogee altitude.		☑	☐	☑	☐	☐	S.A.13.2	Demonstration during subscale flight with altimeter 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.		☐	☐	☑	☐	☐		Demonstration during subscale flight with altimeter data and pictures.
A	2.18.4	☑	Complete	NASA	Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.		☑	☐	☑	☐	☐	S.A.13.2	Demonstration during subscale flight with altimeter data and pictures.
C	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.		☐	☑	☑	☐	☐		Analysis with OpenRocket, demonstration during subscale flight with altimeter data and pictures.
G	2.19	☑	Incomplete	NASA	All teams will complete demonstration flights as outlined below.		☑	☐	☐	☐	☐	G.2.19.1, G.2.19.2	The team will complete the following requirements:
G	2.19.1	☑	Incomplete	NASA	Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight:	G.2.19	☑	☐	☑	☐	☐	A.2.19.1.1, C.2.19.1.2, P.2.19.1.3, B.2.19.1.4, G.2.19.1.5, G.2.19.1.6, A.2.19.1.8, G.2.19.1.9	The team will conduct a vehicle demonstration flight. The results of this flight will be recorded and documented in the FRR report as Flight Performance.
A	2.19.1.1	☑	In Progress	NASA	The vehicle and recovery system will have functioned as designed.	G.2.19.1	☐	☐	☑	☐	☐		The correct separation events will be recorded to have occured. The altitudes of events will be recorded and the flight profile will be recorded, analyzed, and provided to NASA in FRR.
C	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	☐	☐	☑	☐	☐		Demonstration during VDF with altimeter data and pictures.
P	2.19.1.3	☑	In Progress	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 following requirements will be satisfied:
P	2.19.1.3.1	☑	In Progress	NASA	If the payload is not flown, mass simulators will be used to simulate the payload mass.	P.2.19.1.3	☐	☐	☑	☐	☐		The payload system will be flown with close approximations to final hardware. When hardware is omitted, the mass will be replaced with appropriate mass simulators.
P	2.19.1.3.2	☑	In Progress	NASA	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	P.2.19.1.3	☐	☐	☑	☐	☐		The payload system will be flown with close approximations to final hardware. When hardware is omitted, the mass will be replaced with appropriate mass simulators.
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 nose cone separation system will be tested during VDF to ensure it remains closed during flight.
G	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	☐	☐	☑	☐	☐		Motors have been purchased.

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G	2.19.1.6	☑	In Progress	NASA	The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re- flight of the full-scale launch vehicle.	G.2.19.1	☐	☐	☑	☐	☐		Ballast is planned to be added in the VDF re-flight, which will serve as PDF too.
G	2.19.1.7	☑	Incomplete	NASA	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).		☐	☐	☑	☐	☐		Any changes made to the launch vehicle design will be recorded and provided to the NASA RSO for confirmation. Qualification of the VDF is not preconditioned upon this requirement.
A	2.19.1.8	☑	Incomplete	NASA	Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement.	G.2.19.1	☑	☐	☑	☐	☐	S.A.13.2	Vehicle Demonstration Flight performance will be recorded and sumbitted in the FRR report.
G	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	☐	☐	☑	☐	☐		Vehicle Demonstration Flight performance will be recorded and sumbitted in the FRR report.
G	2.19.2	☑	Incomplete	NASA	Payload Demonstration Flight - All teams will 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 pur- pose 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, G.	The team will conduct a Payload Demonstration Flight. The results of this flight will be recorded and documented in the FRR report as Flight Performance. If the FRR deadline is not met, then the FRR Addendum will be used instead.
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.	G.2.19.2, G.2.19.2.3	☐	☐	☑	☐	☐		The progress of the payload system will be documented and submitted to NASA for inspection of compliance. The system will be designed to meet these requirements.
P	2.19.2.2	☑	Incomplete	NASA	The payload flown shall be the final, active version.	G.2.19.2, G.2.19.2.3	☐	☐	☑	☐	☐		The payload system will attempt to complete its mission during PDF, meaning that all related tests and software will be shown to be operational during ground testing.
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.	G.2.19.2	☑	☐	☑	☐	☐	P.2.19.2.1, P.2.19.2.2	Contingent upon VDF performance, the requirement will be assesed.
G	2.19.2.4	☑	Incomplete	NASA	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	G.2.19.2	☐	☐	☑	☐	☐		The team will conduct a Payload Demonstration Flight and the results of this flight will be recorded and documented by or before the FRR Addendum.
G	2.20	☑	Incomplete	NASA	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA- required Vehicle Demonstration Re-flight after the submission of the FRR Report.		☐	☐	☑	☐	☐		The team will conduct a Payload Demonstration Flight. The results of this flight will be recorded and documented in the FRR report as Flight Performance. If the FRR deadline is not met, then the FRR Addendum will be used instead.
G	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.		☐	☐	☑	☐	☐		The team will conduct a vehicle demonstration flight, an additional payload demo flight, or both. The results of this flight will be recorded and documented in the FRR report as Flight Performance. If the FRR report deadline is not met, the FRR Addendum will be used instead.

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G	2.20.2	☑	Incomplete	NASA	Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.		☐	☐	☑	☐	☐		The team will conduct a Payload Demonstration Flight. The results of this flight will be recorded and documented in the FRR report as Flight Performance. If the FRR deadline is not met, then the FRR Addendum will be used instead.
G	2.20.3	☑	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 at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.		☐	☐	☑	☐	☐		The team will conduct a Payload Demonstration Flight. The results of this flight will be recorded and documented in the FRR report as Flight Performance. If the FRR deadline is not met, then the FRR Addendum will be used instead. Contingent upon the possible incomplete mission status during PDF, the team will conduct the necessary inspections with the NASA RSO prior to the final launch.
G	2.21	☑	Incomplete	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 design of the launch vehicle shall include the required identification methods.
H	2.22	☑	Incomplete	NASA	All Lithium Polymer batteries will 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.		☐	☐	☐	☑	☐		The team will ensure all LiPo batteries are properly marked with bright orange tape and are sufficently protected to lower the risk of fire hazards.
C	2.23	☑	Incomplete	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, C.2.23.8, C.2.23.9, C.2.23.10	The launch vehcile shall comply with the following prohibitions:
C	2.23.1	☑	Complete	NASA	The launch vehicle will not utilize forward firing motors.	C.2.23	☐	☐	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.2	☑	Complete	NASA	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	C.2.23	☐	☐	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.3	☑	Complete	NASA	The launch vehicle will not utilize hybrid motors.	C.2.23	☐	☐	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.4	☑	Complete	NASA	The launch vehicle will not utilize a cluster of motors.	C.2.23	☐	☐	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.5	☑	Complete	NASA	The launch vehicle will not utilize friction fitting for motors.	C.2.23	☐	☐	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.6	☑	In Progress	NASA	The launch vehicle will not exceed Mach 1 at any point during flight.	C.2.23	☐	☑	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
C	2.23.7	☑	In Progress	NASA	Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	C.2.23	☐	☑	☑	☑	☐		The design of the launch vehicle will demonstrably and clearly comply with this requirement in all documentation and during flights.
G	2.23.8	☑	Incomplete	NASA	Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	C.2.23	☐	☐	☑	☐	☐		Any transmitters active prior to landing will meet the power requirements set by NASA.
G	2.23.9	☑	Incomplete	NASA	Transmitters will not create excessive interference. Teams will utilize unique frequencies, hand- shake/passcode systems, or other means to mitigate interference caused to or received from other teams.	C.2.23	☑	☐	☑	☐	☐		The team will properly and legally utilize frequencies operable by the team as well as provide relevant frequency information to NASA through the flysheet.

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C	2.23.10	☑	Incomplete	NASA	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	C.2.23	☑	☑	☑	☑	☐	S.C.7	The strength to weight ratio of selected structural materials will be such that parts contain the minimum allowable weight to satisfy factor of safety requirements.
C	2.24	☑	In Progress	NASA	All structural components will be designed with a minimum Factor of Safety of 1.2		☑	☑	☑	☐	☐	S.C.17, S.P.24	All teams will abide by the FoS requirement as defined by the Construction team. Relevant analysis and demonstration will be required to ensure FoS's are adhered to in all relevant component designs.
A	3.1	☑	In Progress	NASA	The full scale launch vehicle will 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 full scale vehicle launch will demonstrate recovery with a drogue and main parachute.
A	3.1.1	☑	In Progress	NASA	The main parachute shall be deployed no lower than 500 feet.	A.3.1	☐	☐	☑	☐	☑		The full scale vehicle launch will demonstrate the deployment of the main parachute. Additionally, the **Parachute Drop Test** will verify the main parachute deploys at the correct point in flight.
A	3.1.2	☑	In Progress	NASA	The apogee event may contain a delay of no more than 2 seconds.	A.3.1	☐	☐	☑	☐	☑		The full scale vehicle launch will demonstrate the deployment of the drogue parachute. Additionally, the **Parachute Drop Test** will verify the drogue parachute deploys at the correct point in flight.
A	3.1.3	☑	In Progress	NASA	Motor ejection is not a permissible form of primary or secondary deployment.	A.3.1	☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate that motor ejection is not used in the vehicle.
A	3.2	☑	In Progress	NASA	Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	S.A.5	☐	☐	☐	☐	☑		The **Black Powder Ejection Test** will verify the black powder canisters are able to create 6' of separation between vehicle sections on the ground and the parachutes are able to be fully ejected without sustaining any damage.
A	3.3	☑	In Progress	NASA	Each independent section of the launch vehicle will 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.		☐	☑	☑	☐	☐		Analysis will be performed to ensure the largest section of the vehicle will have a landing kinetic energy of less than 75 ft-lbf. Then, the full scale vehicle launch will verify this.
A	3.4	☑	Complete	NASA	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.		☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the usage of redundant, commercially available altimeters.
A	3.5	☑	Complete	NASA	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.		☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the usage of dedicated altimeter power supplies that are commercially available batteries.
A	3.6	☑	In Progress	NASA	Each altimeter will 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.		☑	☐	☑	☐	☐	S.A.15	The full scale vehicle launch will demonstrate the usage of accessible, dedicated mechanical arming switches.
A	3.7	☑	In Progress	NASA	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).		☑	☐	☑	☐	☐	S.A.15	The full scale vehicle launch will demonstrate that the arming switches cannot be disarmed due to flight forces.
A	3.8	☑	Complete	NASA	The recovery system electrical circuits will be completely independent of any payload electrical circuits.		☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the usage of recovery system electrical circuits that are completely independent of any payload electrical circuits.
A	3.9	☑	In Progress	NASA	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.		☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the usage of removable shear pins for the parachute compartments.
A	3.10	☑	In Progress	NASA	The recovery area will be limited to a 2,500 ft. radius from the launch pads.		☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate that the recovery area will be limited to a 2,500 ft. radius from the launch pads.

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A	3.11	☑	In Progress	NASA	Descent time of the launch vehicle will 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.		☐	☑	☑	☐	☐		Analysis will be performed to ensure the descent time of the launch vehicle will be limited to 90 seconds. Then, the full scale vehicle launch will verify this.
A	3.12	☑	In Progress	NASA	An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.		☑	☐	☑	☐	☐	A.3.12.1, A.3.12.2	The full scale vehicle launch will demonstrate the usage of an electronic GPS tracking device.
A	3.12.1	☑	In Progress	NASA	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.	A.3.12	☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the usage of an electronic GPS tracking device for all untethered sections of the launch vehicle.
A	3.12.2	☑	In Progress	NASA	The electronic GPS tracking device(s) will be fully functional during the official competition launch.	A.3.12	☐	☐	☑	☐	☐		The full scale vehicle launch will demonstrate the functionality of the electronic GPS tracking devices.
A	3.13	☑	In Progress	NASA	The recovery system electronics will 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 full scale vehicle launch, as well as inspection, will demonstrate that recovery system electronics will not be adversely affected by any other on-board electronic devices during flight.
A	3.13.1	☑	In Progress	NASA	The recovery system altimeters will 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 full scale vehicle launch will demonstrate that the recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
A	3.13.2	☑	In Progress	NASA	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	A.3.13	☐	☐	☐	☑	☐		The team will inspect the shielding of the recovery system electronics to ensure inadvertent excitation from all onboard transmitting devices will be avoided.
A	3.13.3	☑	In Progress	NASA	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	A.3.13	☐	☐	☐	☑	☐		The team will inspect the shielding of the recovery system electronics to ensure inadvertent excitation from all onboard devices which may generate magnetic waves will be avoided.
A	3.13.4	☑	In Progress	NASA	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	A.3.13	☐	☐	☐	☑	☐		The team will inspect the shielding of the recovery system electronics to ensure inadvertent excitation from any other onboard devices will be avoided.
P	4.1.a	☑	In Progress	NASA	—Teams shall design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and shall be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.		☐	☐	☑	☐	☐		The system will autonomously react to RF commands given by the command tent. The success rate will be analyzed to fall within team-defined and NASA-defined bounds of success.
M	4.1.b	☑	Discontinued	NASA	An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.		☐	☐	☐	☐	☐		
P	4.2.1	☐	Incomplete	NASA	Launch Vehicle shall contain an automated camera system capable of swiveling 360° to take images of the entire surrounding area of the launch vehicle.	S.P.10	☑	☐	☑	☐	☐	P.4.2.1.1, P.4.2.1.2, P.4.2.1.3, P. 4.2.1.4, S.P.10	The camera will be able to rotate 360°
P	4.2.1.1	☑	Incomplete	NASA	The camera shall have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane with the sky oriented up and the planetary surface oriented down.	P.4.2.1	☑	☐	☑	☐	☐	SP.2	The system will be designed to operate with the z-axis perpendicular to the planetary surface.
P	4.2.1.2	☑	Incomplete	NASA	The camera shall have a FOV of at least 100° and a maximum FOV of 180°.	P.4.2.1	☑	☐	☑	☐	☑	S.P.3	The camera FOV will be between 100° and 180°
P	4.2.1.3	☑	Incomplete	NASA	The camera shall time stamp each photo taken. The time stamp shall be visible on all photos submitted to NASA in the PLAR	P.4.2.1	☐	☐	☑	☐	☑		The camera will timestamp each picture.

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P	4.2.1.4	☑	Incomplete	NASA	The camera system shall execute the string of transmitted commands quickly, with a maximum of 30 seconds between photos taken	P.4.2.1	☐	☐	☑	☐	☑		The system will perform its task in a quick manner with a maximum of 30 seconds between photos.
P	4.2.2	☑	Incomplete	NASA	NASA Student Launch Management Team shall transmit a RF sequence that shall contain a radio call sign followed by a sequence of tasks to be completed. The list of potential commands to be given on launch day along with their radio transcriptions which shall be sent in a RF message using APRS transmission in no particular order are: A1—Turn camera 60º to the right B2—Turn camera 60º to the left C3—Take picture D4—Change camera mode from color to grayscale E5—Change camera mode back from grayscale to color F6—Rotate image 180º (upside down). G7—Special effects filter (Apply any filter or image distortion you want and state what filter or distortion was used). H8—Remove all filters.		☑	☐	☑	☐	☑	S.P.18, P.2.2.1	The system will react to the commands as outlined in the guideline.
P	4.2.2.1	☑	Incomplete	NASA	An example transmission sequence could look something like, "XX4XXX C3 A1 D4 C3 F6 C3 F6 B2 B2 C3." Note the call sign that NASA will use shall be distributed to teams at a later time.		☐	☐	☑	☐	☑		The system will be designed to accept the given sequence as an input format
P	4.2.3	☑	Incomplete	NASA	The NASA Student Launch Management Panel shall transmit the RAFCO using APRS.	P.4.2.2	☐	☐	☑	☐	☐		The system will be designed to accept APRS data.
P	4.2.3.1	☑	Incomplete	NASA	NASA will use dedicated frequencies to transmit the message. NASA will operate on the 2-Meter amateur radio band between the frequencies of 144.90 MHz and 145.10 MHz. No team shall be permitted to transmit on any frequency in this range. The specific frequency used will be shared with teams during Launch Week. NASA reserves the right to modify the transmission frequency as deemed necessary.	P.4.2.2	☑	☑	☐	☐	☐	S.P.12	The system will operate on the given frequency range.
P	4.2.3.2	☑	Incomplete	NASA	The NASA Management Team shall transmit the RAFCO every 2 minutes.	P.4.2.2	☑	☐	☐	☐	☐		
P	4.2.3.3	☑	Incomplete	NASA	The payload system shall not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface	S.P.16	☑	☐	☑	☐	☐	P.4.2.3.1, P.4.2.3.2	The system will be designed to and demonstrate cabability to not activate until the launch vehicle has landed.
P	4.2.4	☑	Discontinued	NASA	The payload shall not be jettisoned.		☐	☐	☑	☐	☐		The system will be designed to and demonstrate cabability to operate while remaining in the launch vehicle.
P	4.2.5	☑	Incomplete	NASA	The sequence of time-stamped photos taken need not be transmitted back to ground station and shall be presented in the correct order in your PLAR.		☐	☐	☑	☐	☐		The system will not transmit its data back to any station, instead conataining it for download upon retrieval.
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	The system will adhere to the following requirements.
P	4.3.1	☑	Discontinued	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 system will be explicitly designed without the use of energetic materials. The team will indicate this fact on reports and to all NASA personnel.
P	4.3.2	☑	In Progress	NASA	Teams shall abide by all FAA and NAR rules and regulations.	P.4.3	☑	☐	☑	☐	☐	S.P.6	The team will continually check for related regulations and update procedures to comply with FAA and NAR rules and regulations.
P	4.3.3	☑	Discontinued	NASA	Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.	P.4.3	☐	☐	☑	☐	☐		The team has determined through discussion with the NASA team that mechanically separating events while the launch vehicle is grounded does not constitute a "recovery phase jettison event".
P	4.3.4	☑	Discontinued	NASA	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will 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 team will explicitly pursue a design which does not include a UAS.

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P	4.3.5	☑	Discontinued	NASA	Teams flying UASs will 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	☐	☐	☑	☐	☐		If applicable, the team will follow FAA UAS regulations, including registration and legal flight of the UAS.
P	4.3.6	☑	Discontinued	NASA	Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	P.4.3	☐	☐	☐	☑	☐		If applicable, the team will follow FAA UAS regulations, including registration and legal flight of the UAS.
H	5.1	☑	Incomplete	NASA	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.		☐	☐	☑	☐	☐		Launch preparation and launch day procedures for each launch are prepared by each subtem in conjunction with the safety officer.
H	5.2	☑	Complete	NASA	Each team shall identify a student safety officer who will be responsible for all items in section 5.3.		☐	☐	☑	☐	☐		The student safety officer has been identified as Alex Suppiah.
H	5.3	☑	In Progress	NASA	The role and responsibilities of the safety officer will include, but are not limited to:		☑	☐	☐	☐	☐	H.5.3.1, H.5.3.2, H.5.3.3, H.5.3.4	The safety officer will abide by the following:
H	5.3.1	☑	In Progress	NASA	Monitor team activities with an emphasis on safety during: Design of vehicle and payload Construction of vehicle and payload components Assembly of vehicle and payload Ground testing of vehicle and payload Subscale launch test(s) Full-scale launch test(s) Competition Launch Recovery activities STEM Engagement Activities	H.5.3	☐	☐	☑	☐	☐		The safety officer, or a trained, designated acting safety officer, will be present at all team activities, including general team meetings, team build days, subteam meetings, STEM engagement activites, and all team launches and associated activities.
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 officer will work with the individual subteams, as well as Project Management, to develop procedures for both pre-launch and launch day activities.
H	5.3.3	☑	In Progress	NASA	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	H.5.3	☐	☐	☑	☐	☐		Updated hazard analyses, failure mode analyses, procedures, and MSDS/chemical inventory data will be provided with the submission of each milestone.
H	5.3.4	☑	In Progress	NASA	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	H.5.3	☐	☐	☑	☐	☐		The safety officer is solely responsible for the writing and development of each milestone's safety section.
H	5.4	☑	In Progress	NASA	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		☐	☐	☑	☐	☐		The team will clearly communicate launch intentions with the appropriate personnel, including FAA representatives, and will abide by the guidance of the RSO.
H	5.5	☑	In Progress	NASA	Teams will abide by all rules set forth by the FAA.	S.P.6	☐	☐	☑	☐	☐		All FAA rules will be observed and followed by the team.

CONSTRUCTION SUBTEAM REQUIREMENTS							Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Project Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
S.C	1	☐	In Progress	Matthew Fangio	All componets can be manufactured in house		☐	☐	☑	☑	☐		Manufacturability of all componets will be evaluated during design phase
S.C	2	☑	Complete	Matthew Fangio	Selected motor will use the minimum impulse required to sucessfully meet all other criteria		☑	☑	☐	☐	☐	S.C.14	OpenRocket and Simulink simulations and inspection of motor parameters
S.C	3	☑	In Progress	Matthew Fangio	Kinetic impact energy of heaviest section will be below 65 ft-lbf	G.3.3	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations and mass distrubition between independent sections during design
S.C	4	☑	In Progress	Matthew Fangio	Decent time will be below 80 seconds	G.3.11	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations and low target altitude
S.C	5	☐	Complete	Matthew Fangio	Launch vehicle assembly will not require additonal onsite componet modification		☐	☐	☐	☑	☐		Tolerances of each componet will be individually verified after each manufacturing process
S.C	6	☑	Complete	Matthew Fangio	Nosecone camera bay does not significantly disturb launch vehicle profile		☐	☑	☐	☐	☐		Vehicle FEA and CFD analysis
S.C	7	☑	Complete	Matthew Fangio	All booster section components will be designed with the best mass saving design practices.	C.2.23.10	☐	☑	☐	☐	☐		Design consultation with specialists at BIDC and FEA to remove mass from overstrengthen componets
S.C	8	☐	In Progress	Matthew Fangio	Fins, MFSS, and motor can be easily inserted and removed from the launch vehicle during integration	G.2.6	☐	☐	☐	☑	☐		Each design will be modular in nature and the use of adhesives, like epoxy, to secure componets will be avoided
S.C	9	☐	In Progress	Matthew Fangio	Airframe modifications (screw holes and fin slits) are made with use of custom alignment aids		☐	☐	☑	☐	☐		Custom alignment aids will be created for each section of airframe
S.C	10	☑	Complete	Matthew Fangio	Fin design is strengthened to resist fin flutter and improve reusability		☐	☑	☐	☐	☐		FEA and physical strength tests conducted on proof of concept fins. Theoritcal analysis done to suplement results.
S.C	11	☐	In Progress	Matthew Fangio	All fins are consistant in casting process and launch vehicle alignment		☐	☐	☐	☑	☐		Percise mesuring equipment and consistancy focused manufacturing methods choosen
S.C	12	☐	Complete	Matthew Fangio	Subscale mimics the geometry of fullscale	G.2.18.5, G. 2.18.1	☐	☐	☐	☑	☐		OpenRocket modeling and visual inspection to verify geometirc simularitys
S.C	13	☑	Complete	Matthew Fangio	Ballast will be applied to keep altitude as close to target as possible, up to the maximum allowable mass	G.2.23.7	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations and confirming estimated weights after manufacturing
S.C	14	☑	Complete	Matthew Fangio	Target altitude will be as low as possible to facilitate decent time and landing kinetic energy requirements	G.2.1, S.C.2	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations
S.C	15	☑	Complete	Alex Edwards	Couplers will be designed in accordance with NASA guidelines		☐	☑	☐	☐	☐		OpenRocket and SolidWorks modelling
S.C	16	☑	Complete	Alex Edwards	The launch vehicle will have a minimum stability for the worst case simulation will be at least 2.1	G.2.14	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations

S.C	17	☑	Complete	Alex Edwards	The factor of safety will be at least 1.33	C.2.24	☐	☑	☐	☐	☐		OpenRocket and Simulink simulations
AVIONICS SUBTEAM REQUIREMENTS							Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Project Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
S.A	1	☑	In Progress	Lily Kenna	Adequate length of shock cord for both parachutes.		☐	☐	☑	☐	☐		Full scale vehicle shock cords will be 60' and 30' for main and drogue parachutes respectively, and the shock cord length will be scaled appropriately for the subscale vehicle launch.
S.A	2	☑	In Progress	Lily Kenna	Shock cords connecting parachutes will be tied unaligned to prevent in-air collisons of airframe sections.		☐	☐	☑	☑	☐		The team will verify that the parachutes and shock cord are not directly aligned. The launch of the subscale vehicle will allow the team to demonstrate that vehicle sections do not collide in-air with this method.
S.A	3	☑	In Progress	Lily Kenna	Shock cords will be stored in a folded configuration to remain untangled and deploy with less shock.		☐	☐	☐	☑	☐		The team will ensure the shock cord is in a z-fold while stored in the vehicle.
S.A	4	☑	In Progress	Lily Kenna	Parachutes will be the proper size for safe deployment and landing of vehicle.	A.2.4	☐	☑	☑	☐	☐		With simulation tools like Simulink and OpenRocket the team will find the appropriate size of the parachute to safely recover the vehicle. The subscale launch will, on a smaller scale, test the sizing.
S.A	5	☑	In Progress	Lily Kenna	Ejection, then full deployment of parachute will happen at appropriate time and distance range.	A.3.1, A.3.1.1,A.3.1.2	☑	☐	☐	☐	☑	A.3.2	To make sure the drogue parachute opens no more than 1.5s after release and the main parachute opens no more than 150' after release, the team will conduct the **Parachute Drop Test**.
S.A	6	☑	In Progress	Ellie Vinson	Nomex blanket will protect parachute on all sides.		☐	☐	☐	☑	☑		The **Black Powder Ejection Test** will verify that the Nomex blanket protects the parachutes from ejection charges. The team will verify that the parachutes are properly packed in the vehhicle with the Nomex blankets on all sides.
S.A	7	☑	In Progress	Ellie Vinson	Parachutes will be packed neatly and loosely to ensure easy and smooth ejection.		☐	☐	☐	☑	☑		The **Black Powder Ejection Test** will ensure that the parachutes will be ejected fully during the vehicle seperation. The team will also observe the parachutes in the vehicle to make sure they are packed loosely
S.A	8	☑	In Progress	Ellie Vinson	Airframe sections will separate as a result of the black powder canisters.		☐	☑	☐	☐	☑		Analysis will be done in order to calculate the sizes of the charges needed to ensure vehicle section seperation. The **Black Powder Ejection Test** will ensure that the black powder canisters will create 6' of seperation between the vehicle sections.
S.A	9	☑	In Progress	Ellie Vinson	Avionics coupler will be easily accessible for repair regardless of vehicle assembly status.		☐	☐	☐	☑	☐		The avionics coupler will be inspected by the team to verify that the components are accessible
S.A	10	☑	In Progress	Ellie Vinson	During flight and landing all components of avionics coupler will be secured in place		☐	☐	☐	☑	☐		The avionics coupler will be inspected by the team to verify that the components are secure

S.A	11	☑	In Progress	Ellie Vinson	Avionics components will be stored neatly to avoid tangles or breaks, with any cords/wires folded in groups		☐	☐	☐	☑	☐		The avionics coupler will be inspected to ensure that the components grouped together to prevent entangelent. The avionics coupler will also be checked to make sure they are organized.
S.A	12	☑	In Progress	Ellie Vinson	Avionics coupler components must be strong enough to tolerate shock loads from launch, deployment, and landing		☐	☐	☑	☐	☐		The subscale vehicle launch will show that all the components of the avionics coupler will stay in the correct place during the duration of the flight
S.A	13	☑	In Progress	Ellie Vinson	Altimeters must be able to accurately read values and perform through all phases of flight	A.2.18.2	☐	☐	☑	☐	☑		The subscale vehicle launch will show that the altimeter completes some of its functions. Also, the **Altimeter Ejection Vacuum Test** will ensure the altimeters' ejection capabilities.
S.A	13.1	☑	In Progress	Ellie Vinson	Altimeter function will not be affected by any temperature it could face inflight		☐	☐	☐	☐	☑		35°F to 75°F is the minimum and maximum of the likely temperature extremes for flight scenarios.The **Altimeter Continuity and Battery Drain Test** will ensure that the altimeters can record readings and achieve continuity at these temperature extremes of 35°F to 75°F.
S.A	13.2	☑	In Progress	Ellie Vinson	Altimeter continuity will be reached throughout all phases of the flight	A.2.18.4,A.2.19.1.8	☐	☐	☐	☐	☑		The **Altimeter Continuity and Battery Drain Test** will show that the altimeters can establish and maintain continuity on both the pad and the flight. The continuity will be shown in the test by continuity beeps in sets of 3 for 3 hours.
S.A	13.3	☑	In Progress	Ellie Vinson	Ejection charges will ignite according to altimeter readings at specific times. Drogue and main charges will be ignited by primary altimeter with comfortable margins, with comfortable margins before redudant altimeter ignites.		☐	☐	☐	☐	☑		The ascent and descent of the launch vehicle will be simulated by the **Altimeter Ejection Vacuum Test**. The test will also ensure that each eltimeter ignites at the correct time. The primary altimeters will light the drogue charge at apogee and the main charge of an altitude of 800 feet. The redundant altimeter will light the drough charge 2 seconds after the apogee and the main charge at an altitude of 600 feet.
S.A	14	☑	In Progress	Ellie Vinson	The altimeter batteries will function properly for the entire duration of the flight. They will also gurantee successful altimeter function.	A.3.5	☐	☐	☑	☐	☑		The **Altimeter Continuity and Battery Drain Test** will ensure the ability of the batteries to function on both the pad and in flight. Also, the subscale vehicle launch will show certain altimeter battery functions.
S.A	14.1	☑	In Progress	Ellie Vinson	Altimeter batteries will supply usable voltage for 3 hours. This is one hour longer than the necessary amount of time.	A.3.5, P.2.7	☐	☐	☐	☐	☑		The **Altimeter Continuity and Batter Drain Test** will ensure that the altimeter batteries have the capability to power the altimeters for a duration of 3 hours. The voltage will be measured every 30 minutes to verify that the altimeters can function continously.
S.A	14.2	☑	In Progress	Ellie Vinson	The avionics coupler will have battery shielding or casing in order to prevent battery damage in the event of a ballistic impact. Other coupler component will not compromise the casing.	A.3.13.4	☐	☐	☑	☑	☐		The integrity of the casings will be shown in the subscale vehicle launch. Also, for the full scale vehicle, the avionics couplers will be looked at by the team to verify that the batteries are located correctly in the casings.

S.A	14.3	☑	In Progress	Lily Kenna	Altimeter batteries will be tested in extreme temperautres to ensure that they will not fail at various launch temperatures	A.3.5, P.2.7	☐	☐	☐	☐	☑		The **Altimeter Continuity and Battery Drain Test** will show that the altimeter batteries function in a range of tempertures from 75°F to 35°F. 75°F to 35°F represents the temperature extremes for flight scenarios.
S.A	15	☑	In Progress	Lily Kenna	Disaramant of the altimeter and ejection systems during the flight will be prevented by key switches. Nothing will be able to engage or disengage these systems but the keys	A.3.7, A.3.6	☐	☐	☑	☑	☐		The subscale vehicle will show that flight forces are unable to disengage the altimeter system. Also, the team will inspect the avionics couplers in the full scale vehicle. The teamm will also ensure that the batteries are located in the correct space within the casings.
S.A	16	☐	In Progress	Mikie Kilbourne	Descent time of the launch vehicle will be less than 80 seconds	A.3.11	☐	☑	☐	☐	☑		The descent of the launch vehicle from apogee to landing will be simulated in Simulink and OpenRocket. The descent time on our various launch days will also be measured.
S.A	17	☐	In Progress	Mikie Kilbourne	Landing energy of the heaviest section of the launch vehicle will be less than 65ft-lb	A.3.3	☐	☑	☐	☐	☑		The kinetic sections of these launch vehicles will be verified through OpenRocket and Simulink simulations. The kinetic energies will also be measured during the launches.
PAYLOAD SUBTEAM REQUIREMENTS							Verification Type(s)						
Label	ID	Mission Critical	Status	Originator	Requirement Summary	Project Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
S.P	1	☑	Incomplete	Jaylen Young	The payload system must be able to withstand the force experienced during recovery. The payload bulkplate and the payload system must withstand a pressure of 13.94 psi and a force of 394.1 lbs.		☐	☑	☐	☐	☑		All force from the payload bulkplate will translate into the airframe and not into any payload components. No major modifications to the coupler or bulkplate.
S.P	2	☐	Incomplete	Jacob Daniel	Payload must be able to rotate the camera deployment system to within 15 degrees of the normal direction of the ground	P.4.2.1.1	☐	☑	☐	☐	☑		Sensor data after the launch vehicle lands will indicate initial orientation. The IOS will continue to rotate until this requirement is met.
S.P	3	☐	Incomplete	Jacob Daniel	Payload must be able to linearly actuate the camera deployment system 8-12 inches after landing		☐	☑	☐	☐	☑		Properly designed scissor lift mechanism
S.P	4	☑	Incomplete	Sean Boltjes	Payload will be able to maintain a 'pre-launch' state for 24 hours prior to launch and still maintain adequate battery power to complete the mission	P.2.7	☑	☑	☐	☐	☑	S.P.5	All components and their respective subsystems will be installed and tested for continuity.
S.P	5	☑	Incomplete	Sean Boltjes	Payload will be able to maintain a 'launch-ready' state for 3 hours prior to launch and still maintain adequate battery power to complete the mission	P.2.7	☐	☑	☐	☐	☑		Adequate battery amperage to sustain power on the pad, during flight, and payload deployment/payload mission.
S.P	6	☑	Incomplete	Nicholas William	All payload design must be deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	P.4.3.2, H.5.5	☐	☑	☐	☐	☐		The payload design will meet all safety regulations set forth by the FAA.

S.P	7	☐	Incomplete	Kade Boltjes	All software will undergo code reviews and pull requests to ensure code quality.		☐	☐	☑	☐	☐		During software development and testing, the team will ensure that all code is working as intended.
S.P	8	☐	Incomplete	Gabe Kurfman	Camera arm will be able to level from an angle of up to 20° from the horizon to account for rough landing terrain		☐	☐	☐	☐	☑		Sensor data will determine camera adjustments
S.P	9	☐	Incomplete	Felipe Sandoval	Onboard transmissions must not exceed 250mW		☐	☐	☑	☐	☐		Team will select a transmitter that will not output power over 250mW.
S.P	10	☐	Incomplete	Nicholas William	The payload camera system must be capable of rotating 360 degrees to capture a full images of the launch vehicles surroundings.	P.4.2.1	☑	☐	☐	☐	☑	P.4.2.1.1, P.4.2.1.2, P.4.2.1.3, P.4.2.1.4	The TACOS will be able to freely rotate the camera about the *z* axis.
S.P	11	☐	Incomplete	Nicholas William	Stepper motor used to extend the payload has adequate torque to do so, but less torque than that of the orientation stepper motor.		☐	☐	☐	☐	☑		The selected motor torque will be larger and its corresponding motor driver will be larger as well.
S.P	12	☑	Incomplete	Felipe Sandoval	Payload must be able to recieve transmission between the frequencies of 144.90 MHz and 145.10 MHz	P.4.2.3.1	☐	☑	☑	☑	☐		Team will select a receiever that will recieve the range of frequencies.
S.P	13	☑	Incomplete	Jaylen Young	Payload must be able to retain the sections together securely during flight and recovery.	C.2.5	☐	☐	☑	☐	☑		Properly installed exterior screws and necessary shear pins.
S.P	14	☐	Incomplete	Jaylen Young	The payload battery must not become damaged during flight and/or recovery of the vehicle.	C.2.5	☐	☐	☐	☐	☑		All payload batteries will have a mounted battery holder such that the batteries do not become disconnected during flight or become damaged.
S.P	15	☐	Incomplete	Sean Boltjes	The payload camera system shall be able to rotate within 360 degrees of its current position and take an image in less than 30 seconds.		☐	☐	☑	☐	☑		The servo motors on the TACOS will be selected to ensure these precise movements.
S.P	16	☐	Incomplete	Sean Boltjes	The payload system must not accept radio transmissions until it has landed.	P.4.2.3.3	☐	☐	☐	☐	☑		The receiver will only be online after sensor data has determined the launch vehicle has landed.
S.P	17	☐	Incomplete	Sean Boltjes	The payload system will not actuate any motors until the launch vehicle has landed and is stationary.		☐	☐	☑	☐	☑		Only from sensor data that determines that the launch vehicle is on the ground after flight will the payload system begin to deploy.
S.P	18	☐	Incomplete	Sean Boltjes	The payload system shall be capable of performing post-processing on images to convert them to greyscale, flip upside down, and filter them.	P.4.2.2	☐	☐	☐	☐	☑		The API subsystem will be specialized in processing the images.
S.P	19	☐	Incomplete	Sean Boltjes	The payload system will store the captured images in an onboard SD card to be recovered after the launch.		☐	☐	☐	☑	☐		An SD card or other similar type of digital image storage device will be installed into the payload bay.

S.P	20	☐	Incomplete	Sean Boltjes	The payload system will track the current date and time using a Real Time Clock that has been synchronized at the launch pad.		☐	☑	☐	☐	☑		Accurate sensor data between the RTC and the payload bay clock.
S.P	21	☐	Incomplete	Sean Boltjes	The payload system shall not exceed 10 pounds in total mass.		☐	☐	☐	☐	☑		Mass will be accounted for during the CAD development stage and materials will be weighed before launch vehicle integration.
S.P	22	☐	Incomplete	Sean Boltjes	The payload system will retain and keep the payload bay sealed during the entire flight of the vehicle		☐	☐	☐	☐	☑		R&D motor will turn in the opposite direction slightly to hold down the upper payload bay and nose cone assembly.
S.P	23	☐	Incomplete	Sean Boltjes	The payload camera system will have an FOV of 120 degrees.	P.4.2.1.2	☐	☐	☐	☐	☑		Team will select a camera that meets this requirement.
S.P	24	☐	Incomplete	Alex Edwards	The factor of safety will be 1.33	C.2.24	☐	☑	☐	☐	☐		Team will use CAD and component selection to determine the factor of safety.
S.P	25	☐	Incomplete	Sean Boltjes	The Camera Deployment System will be able to lift the camera above the airframe of the launch vehicle		☐	☐	☑	☑	☐		Team will use CAD and testing to confirm this.

6.3. Budget

6.3.1. Updated Line Item Budget

This line item budget has been updated to reflect purchases made as the team completed the subscale flight test and has moved toward building the main launch vehicle. The following tables break down purchases by subteam, with each category giving estimations in place of expected purchases that are yet to be made. Anticipating the exact components that will need reworking between now and the end of the season is complicated, and these figures accordingly give conservative estimates. The updated budget has been broken down between an overview of incomes, expenses, and an overall summary, as shown in the following tables.

SUMMARY		
SUBTEAM	ESTIMATED COSTS	COSTS TO DATE
Avionics and Recovery	$ (813.46)	$ (385.00)
Construction	$ (3,385.64)	$ (3,104.71)
Payload	$ (1,138.99)	$ (803.92)
Project Management	$ (3,745.19)	$ (245.19)
	TOTAL ESTIMATED COSTS	$ (9,083.28)
	TOTAL COSTS TO DATE	$ (4,538.82)
	TOTAL ESTIMATED BUDGET	$ 12,093.04
	BUDGET TO DATE	$ 8,043.04
	ESTIMATED REMAINING BALANCE	$ 3,009.77
	CURRENT REMAINING BALANCE	$ 3,504.23

Table 6.3.1.1: Line Item Budget Summary

INCOME		
Category	Projected Amount	Current Amount
SOGA Grant	3,050.00	3,050.00
BOSO Account	1,741.14	1,741.14
Relativity Award for Vehicle Reusability (2022)	1,000.00	1,000.00
General PSP Funding	751.90	751.90

PESC Grant (Fall Cycle)	1,500.00	1,500.00
AAE Department	650.00	0.00
ME Department	650.00	0.00
ECE Department	750.00	0.00
PESC Grant (Spring Cycle)	500.00	0.00
Local Funding	1,500.00	0.00
	PROJECTED TOTAL	$ 12,093.04
	CURRENT TOTAL	$ 8,043.04

Table 6.3.1.2: Updated Income Summary

EXPENSES					
Subteam	**Vendor**	**Item Cost**	**Added Fees**	**Estimated Item Total**	**Actual Item Total**
AVIONICS AND RECOVERY					
Main Parachute	Rocketman Parachutes	385.00	0.00	385.00	385.00
Required 3D Printing	Purdue University BIDC	20.00	0.00	20.00	0.00
Drogue Parachute	Fruity Chutes	60.00	2.89	62.89	
General Fasteners	McMaster-Carr	50.00	2.58	52.58	0.00
General Coupler Internal Hardware	McMaster-Carr	150.00	3.94	153.94	0.00
Test Hardware	McMaster-Carr	25.00	1.53	26.53	0.00
Altimeter Connectors	Apogee Components	50.00	2.17	52.17	0.00
Deployment Hardware	MJG Technologies	48.00	12.35	60.35	0.00
				ESTIMATED TOTAL	813.46
				CURRENT TOTAL	385.00
CONSTRUCTION					
Silicone Mold Release Spray	Benasse	15.99	1.12	17.11	17.11
Resin for Casting	Reynolds Advanced Materials	52.57	18.44	71.01	71.01

Fiberglass Plates	Amazon Services	32.86	2.30	35.16	35.16
Full Scale Airframe Tubes	Composite Wearhouse	540.00	0.00	540.00	540.00
Full Scale Couplers	Composite Wearhouse	270.00	0.00	270.00	270.00
Full Scale Coupler Lids	Composite Wearhouse	126.00	0.00	126.00	126.00
Full Scale Fiberglass Sheets	Composite Wearhouse	140.00	9.99	149.99	149.99
Proof of Concept Airframe	Composite Wearhouse	136.00	0.00	136.00	136.00
Proof of Concept Couplers	Composite Wearhouse	45.00	0.00	45.00	45.00
Proof of Concept Coupler Lids	Composite Wearhouse	15.00	9.99	24.99	24.99
Retainer	Apogee Components	29.17	17.75	46.92	46.92
Body Tube	Apogee Components	8.66	3.89	12.55	12.55
3" Fiberglass Tube, 5'	Composite Wearhouse	98.00	2.00	100.00	100.00
3" Fiberglass Tube, 2'	Composite Wearhouse	38.00	2.00	40.00	40.00
3" Fiberglass Coupler, 1'	Composite Wearhouse	30.00	2.00	32.00	32.00
3" Fiberglass Coupler, 0.75'	Composite Wearhouse	15.00	2.00	17.00	17.00
3" Av-Bay Lid	Composite Wearhouse	50.00	1.99	51.99	51.99
75-3 Grain Hardware Set	Cesaroni Technology Incorporated	360.27	13.87	374.14	374.14
L1350-CTI C Star	Cesaroni Technology Incorporated	236.02	60.85	296.87	296.87
L1350-CTI C Star (x2)	Cesaroni Technology Incorporated	472.04	57.48	529.52	529.52

Aerotech 38mm HP SU DMS Motor	Apogee Components	62.05	71.29	133.34	133.34
Fiberglass Mat	Everbilt (via Home Depot)	8.28	1.21	9.49	9.49
Stencil Brush Set	Everbilt (via Home Depot)	3.47	1.20	4.67	4.67
Liquid Hardener	Everbilt (via Home Depot)	7.98	0.57	8.55	8.55
Fiberglass Resin	Everbilt (via Home Depot)	31.78	0.63	32.41	32.41
Hex Bolts	Everbilt (via Home Depot)	15.30	1.12	16.42	0.00
Hex Nuts	Everbilt (via Home Depot)	2.42	1.05	3.47	0.00
Disposable Masks	3M (via Home Depot)	22.98	0.52	23.50	0.00
Duct Tape	3M (via Home Depot)	6.89	0.65	7.54	0.00
General Manufacturing Stock	Purdue University BIDC	30.00	0.00	30.00	0.00
General Fasteners	McMaster-Carr	150.00	50.00	200.00	0.00
				ESTIMATED TOTAL	3,385.64
				CURRENT TOTAL	3,104.71
PAYLOAD					
Teensy 4.1 ARM Processor	PJRC (via Amazon)	33.10	1.99	35.09	35.09
Wire Clamps and Holders	Rustark (via Amazon)	11.96	0.69	12.65	12.65
Cable Wrap	Amazon	7.59	0.68	8.27	8.27
Flat Ribbon IDC Wire Cable	Glarks (via Amazon)	14.69	1.17	15.86	15.86
Cable Connector Adapter Sockets	Glarks (via Amazon)	16.99	1.16	18.15	18.15
Hex Lock Nuts	Swpeet (via Amazon)	6.99	0.52	7.51	7.51

SX1276 SX1278 LoRa Module (x2)	CDEByte (via Amazon)	24.18	5.00	29.18	29.18
Omnidirectional Antenna Connector (x2)	Noyito (via Amazon)	13.98	1.04	15.02	15.02
3 Axis Gyro Module (x2)	AITrip (via Amazon)	12.99	0.91	13.90	13.90
IMU Accelerator/Gyro (x5)	Digi-Key Electronics	39.96	8.14	48.10	48.10
Mini Electric Linear Actuator	Amazon	29.99	1.89	31.88	31.88
Mini Digital Servo	Stemedu (via Amazon)	23.99	1.89	25.88	25.88
USB Cable for Ham Radio (x2)	Baofeng (via Amazon)	15.98	2.31	18.29	18.29
Ham Radio Walkie Talkie	Baofeng (via Amazon)	50.00	2.31	52.31	52.31
DC Motor Driver Carrier (x3)	FeeTech	20.85	4.95	25.80	25.80
Sub-Micro Servo (x2)	FeeTech	13.00	2.72	15.72	15.72
Raspberry Pi Zero	RasTech (via Amazon)	152.95	10.71	163.66	163.66
Audio Interface Cable	Baofeng (via Amazon)	22.49	1.66	24.15	24.15
USB Adapter	UGreen (via Amazon)	7.99	0.73	8.72	8.72
Raspberry Pi Camera Cable	Aokin (via Amazon)	5.79	0.13	5.92	5.92
Lens Board Sensor for Raspberry Pi	UCTronics (via Amazon)	18.99	2.14	21.13	21.13
Radio with Dipole Antenna Kit	RTL-SDR Blog (via Amazon)	42.95	2.31	45.26	45.26
Wire Harness	MOONS	4.00	0.00	4.00	4.00
Servo Stepper Motor (MS10HY0F4060)	MOONS	38.50	0.00	38.50	38.50
Servo Stepper Motor (ML23HS8L4550)	MOONS	52.70	0.00	52.70	52.70
Servo Stepper Motor (MS10HY0F4025)	MOONS	38.50	0.00	38.50	38.50

Mini USB RTL-SDR Receptor	NooElec (via Amazon)	25.95	1.82	27.77	27.77
Stepper Motor for IOS	MOONS	40.00	2.10	42.10	0.00
Loop Antenna for Testing	Amazon	21.00	2.99	23.99	0.00
Whip Antenna For Testing	Amazon	17.50	1.48	18.98	0.00
Test Hardware	McMaster-Carr	200.00	50.00	250.00	0.00
				ESTIMATED TOTAL	1,138.99
				CURRENT TOTAL	803.92
PROJECT MANAGEMENT					
Team 3D Printer	Creality	99.95	10.24	110.19	110.19
Team Bonding Bowling Night	Purdue University Memorial Union	135.00	0.00	135.00	135.00
Huntsville Travel Expenses	N/A	2,500.00	0.00	2,500.00	0.00
Team Events	N/A	500.00	0.00	500.00	0.00
Outreach Events	N/A	500.00	0.00	500.00	0.00
				ESTIMATED TOTAL	3745.19
				CURRENT TOTAL	245.19

Table 6.3.1.3: Updated Expenses Summary

6.3.2. Updated Funding Plan

The funding plan has been altered slightly in response to slower than expected working conditions with University-based funding sources. Accordingly, a focused effort will be made in the early part of spring 2023 to work with Purdue Engineering departments to come to a more desirable funding arrangement. Understanding these conversations may continue to prolong, more time will be spent exploring grant-based funding. There are several grants available to Purdue student organizations on a semester basis. These programs, similar to the PESC merit fund awarded in the fall, will become available in January 2023.

The allocation of these funds and plan to coordinate material acquisition has not changed. A table giving the overall budget allocation has been provided below. This is still based on an overall budget of $12,000.00, with the distribution between each area of the project remaining constant. Likewise, the list of material vendors has not changed significantly, as seen in the expense table above.

BUDGET ALLOCATION	
SUBTEAM	Budgeted Amount
Avionics and Recovery	1,500.00
Construction	3,500.00
Payload	2,000.00
Project Management	2,000.00
Project Management (Travel)	2,500.00
Outreach	500.00
TOTAL BUDGET	$ 12,000.00

Table 6.3.2.1: Projected Budget Allocation

6.4. STEM Engagement Events

So far, PSP-SL has participated in one large outreach event with several sub-components. These activities reached over 700 students from across the state of Indiana and surrounding areas as well. Each of these activities completed so far are education/direct engagements. Breakdowns of the events can be found in the table below.

Event	**Date**	**In person Engagements**
Purdue Space Day	**10/29/2022**	**718 Student Participants**
Activity 1: Mars Rovers	10/29/2022	104
Activity 2: Straw Rockets	10/29/2022	153
Activity 3: Momentum and Force	10/29/2022	114
Activity 4: Reentry Vehicles	10/29/2022	102
Activity 5: Mars Rovers	10/29/2022	124
Activity 6: Powered Descent	10/29/2022	121
	Total	718 Engagements

Table 6.4: STEM Engagement Events

The team participated in its largest and most popular outreach event, Purdue Space Day (PSD), on October 29, 2022. This event brings in local 3rd-8th graders to do space-related STEM activities, hear a presentation from an astronaut, and overall foster a love of learning about space. The students are split into three groups to better focus the activities in accordance with age and knowledge: 3rd and 4th, 5th and 6th, and 7th and 8th. This year's event was fully in-person again, so the previously online events were combined with in person events to make for a comprehensive, hands-on experience for the children. Team members served as either activity heads or group leaders. Activity heads gave presentations and coordinated activities 2-5 for the corresponding age groups of students. These activities allowed students to learn concepts ranging from Newton's Laws to gravitation to basic engineering design. Group leaders each brought groups of approximately 20-30 students around campus to each of the activities, answering questions and helping support activity heads during activity time.

6.5. Timeline

The PSP-SL team developed a three-level timeline organization within the team, which was before discussed in the Preliminary Design Review. This allows project management to keep track of workflow within the team, while enabling team leads to assign specific tasks to their sections. Besides that, the team decided to use Slack to maintain communication among team members and enable quick and efficient information flow among different subteams. The team decided to maintain the current organization pattern, as it establishes efficient workflow.

Team General Schedule is the top-level organizational timeline that the team follows. The table reflects the general team's needs and includes major project events, like milestones, videoconferences, and launch dates. There were no significant changes made to this timeline since PDR.

Date	Event	Date	Event
8/17/2022	Student Launch Handbook Released	2/5/2023	PSP-SL General Meeting
9/3/2022	PSP-SL General Meeting	2/9/2023	FRR Q&A
9/3/2022	Team Social Media Presence Established	2/12/2023	PSP-SL General Meeting
9/11/2022	PSP-SL General Meeting	2/19/2023	PSP-SL General Meeting
9/18/2022	PSP-SL General Meeting	2/26/2023	PSP-SL General Meeting

9/19/2022	Proposal Due	3/5/2023	PSP-SL General Meeting
9/25/2022	PSP-SL General Meeting	3/6/2023	Vehicle Demonstration Flight Due
10/2/2022	PSP-SL General Meeting	3/6/2023	FRR Due
10/6/2022	PDR Q&A	3/12/2023	PSP-SL General Meeting
10/19/2022	PSP-SL General Meeting	3/13/2023 - 3/31/2023	FRR Video Teleconferences
10/16/2022	PSP-SL General Meeting	3/19/2023	PSP-SL General Meeting
10/23/2022	PSP-SL General Meeting	3/26/2023	PSP-SL General Meeting
10/26/2022	PDR Due	4/1/2023	Launch window opens for teams not traveling to Launch Week
11/1/2022 - 11/21/2022	PDR Video Teleconferences	4/2/2023	PSP-SL General Meeting
11/6/2022	PSP-SL General Meeting	4/3/2023	Payload Demonstration Flight and Vehicle Demonstration Re-flight Due
11/13/2022	PSP-SL General Meeting	4/6/2023	Launch Week Q&A
11/27/2022	PSP-SL General Meeting	4/3/2023	FRR Addendum Due
12/1/2022	CDR Q&A	4/9/2023	PSP-SL General Meeting
12/4/2022	PSP-SL General Meeting	4/12/2023	Travel to Huntsville
12/11/2022	PSP-SL General Meeting	4/12/2023	LRR for Teams Arriving Early
12/18/2022	PSP-SL General Meeting	4/13/2023	Launch Week Kickoff, LRR
1/9/2023	Subscale Flight Due	4/14/2023	Launch Week Activities
1/9/2023	CDR Due	4/15/2023	Launch Day
1/15/2023	PSP-SL General Meeting	4/16/2023	Backup Launch Day

1/17/2023 - 2/7/2023	CDR Video Teleconferences	4/23/2023	PSP-SL General Meeting
1/22/2023	PSP-SL General Meeting	4/30/2023	Launch window closes for teams not traveling to Launch Week
1/29/2023	PSP-SL General Meeting	5/1/2023	PLAR Due for Teams Traveling to Huntsville

Table 6.2.1 - Team General Timeline

For management and project planning purposes, the team decided to implement a secondary timeline, which would enable leads to control the work flow among the team. For this, the team decided to establish Gantt's Chart, whose purpose is to transfer major events presented in General Timeline into subteams specific tasks and guidelines. The Gantt's Chart reflects the tasks which are necessary for achieving project objectives, like launch dates, manufacturing slots, and design periods. The purpose of the secondary timeline is to project management to efficiently track work progress of the team with respect to the General Timeline. The secondary timeline reflects the entire project length. Although its structure remains unchanged since PDR, the team decided to implement more specific manufacturing dates to the timeline. The Gannt's chart has been updated since PDR to reflect more accurate manufacturing planning.

Finally, the team decided to establish a third-level timeline system to enable team leads to assign specific tasks to the team. To accomplish this task efficiently, the team decided to implement Jira, a project management software that team leads can create Sprints and Issues, which they further assign to particular members. The main objective of creating a third-level timeline is to enable efficient task management within the team that reflects guidelines presented in the secondary timeline. The third-level timeline system turned out to be the effective and efficient way of distributing taste among team members so far in the project. For this reason, the team decided to keep it as a leading communication tool within the team.

Gantt Chart

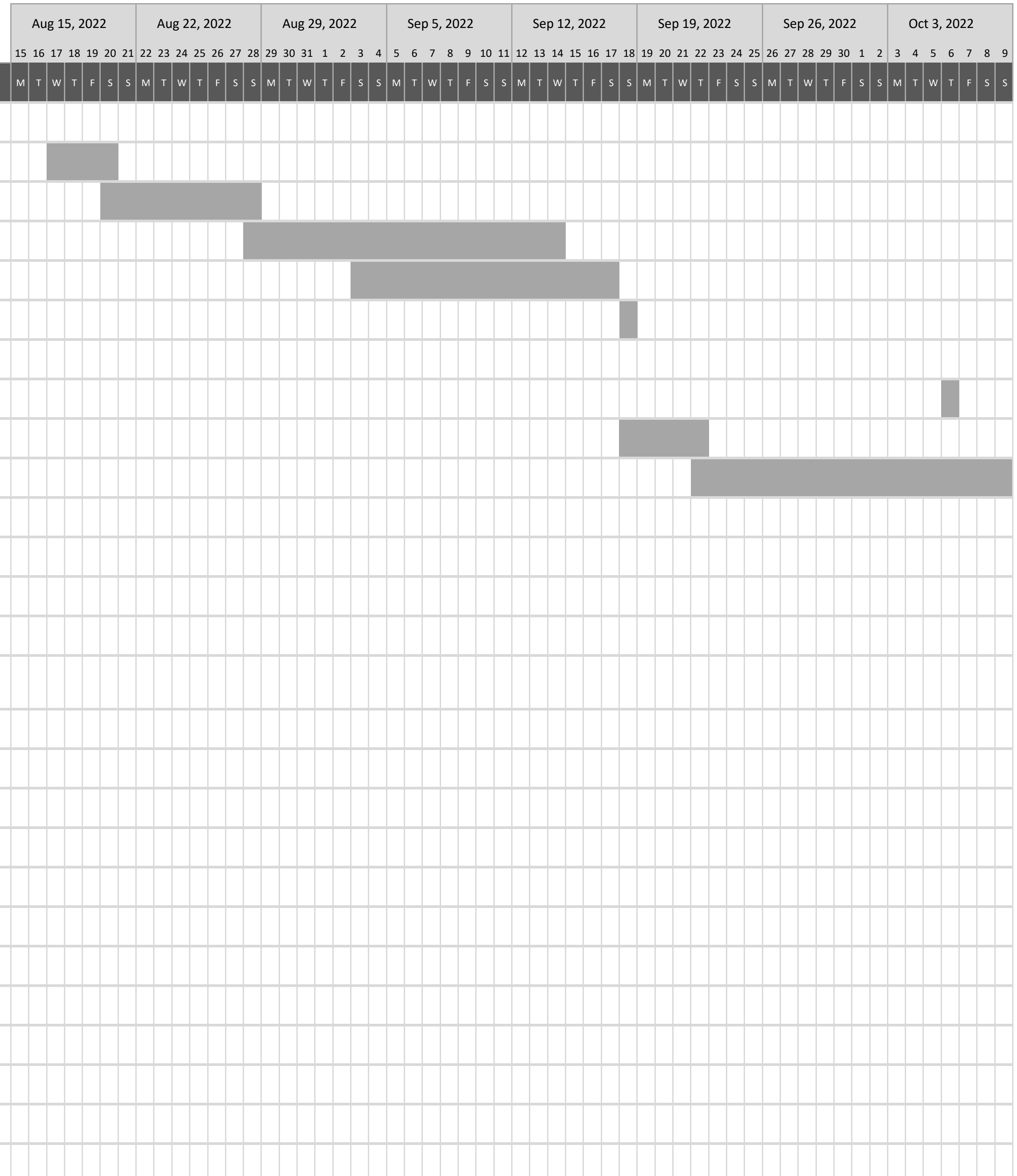
PROJECT WEBER

Purdue Space Program - NASA Student Launch

Project Start: Wed, 8/17/2022

Display Week: 1

TASK	PROGRESS	START	END
1 - Introduction			
Read and Analyze the Handbook	100%	8/17/22	8/20/22
Pepare Launch Vechicle Concept	100%	8/20/22	8/28/22
Completing Proposal	100%	8/28/22	9/14/22
Organize Onboarding of New Members	100%	9/3/22	9/17/22
Submit Proposal	100%	9/18/22	9/18/22
2 - Preliminary Design Review			
PDR Video Conference	100%	10/6/22	10/6/22
Subteams Specify Vechicle Criteria	100%	9/18/22	9/22/22
Subteams Work on Vechicle Design	100%	9/22/22	10/16/22
Team pre-PDR Presentation	100%	10/17/22	10/17/22
Team Rewiev of PDR, PDR Presentation, and Flysheet	100%	10/16/22	10/23/22
PDR Documentation Submittion	100%	10/26/22	10/26/22
3 - Subscale Flight			
Generate the Concept of the Subscale Based on the Full Scale Design	100%	10/16/22	10/19/22
Run Rocket Sizing Code to Determine the Subscale Design	100%	10/19/22	10/21/22
Desing all components of the Subscale Rocket	100%	10/21/22	10/24/22
Perform Subscale Flight Simulation	100%	10/24/22	10/26/22
Order Materials for Subscale Construction	100%	10/26/22	10/26/22
Build Major Componets (Epoxy, 3D Printing, etc)	100%	10/26/22	11/1/22
Assemble Subscale Vechicle	100%	11/1/22	11/4/22
Pre-Launch Inspection (Project Leads with Certified Advisor)	100%	11/4/22	11/5/22
Subscale Launch Event	100%	11/4/22	11/8/22
Post-Launch Vechicle Inspection	100%	11/8/22	11/10/22
3 - Critical Design Review			
PDR Presentation	100%	10/27/22	10/27/22
Prototype and Test of Vechicle Systems (fins, payload elements, parachu	100%	11/5/22	11/19/22



Display Week: 1

Aug 15, 2022 | Aug 22, 2022 | Aug 29, 2022 | Sep 5, 2022 | Sep 12, 2022 | Sep 19, 2022 | Sep 26, 2022 | Oct 3, 2022

TASK	PROGRESS	START	END
Perform Vechicle Simulations (FEA, CFD, Flight Profile Simulations)	100%	11/12/22	11/19/22
Evaluate Rocket Design Based on Test Results	100%	11/19/22	11/26/22
Purdue Space Day	100%	10/29/22	10/29/22
Choose Final Vechicle Design Based on all Evaluation	100%	11/27/22	11/30/22
Perfom Final Flight Profile Simulations	100%	11/30/22	12/3/22
Prepare Critical Design Review Documentation	100%	12/3/22	12/17/22
Check and Submit CDR Documentaion	100%	12/17/22	1/8/23
4 - Vehicle Demonstration Flight			
CDR Videoconference		TBD	TBD
Evaluate Payload Design for VDF		1/9/23	1/14/23
Order Materials for Vechicle Construction		1/9/23	1/19/23
Manufacture Major Vechicle Components (Epoxy, 3D Printing, CNC etc.)		1/14/23	1/28/23
Assemble Major Vechicle Components (fins, MFSS, payload elements)		1/28/23	2/3/23
Perfrom Element Analysis (compare experimental values to FEA results)		2/3/23	2/8/23
Complete Vechicle and Payload Assembly		1/28/23	2/3/23
Verify Vechicle Integrity (compare with predicted outcome)		2/3/23	2/8/23
Pre-Launch Inspection (Project Leads with Certified Advisor)		2/8/23	2/15/23
Vechicle Demostration Flight - Launch Event		2/15/23	2/22/23
Post-Launch Vechicle Inspection		2/22/23	2/22/23
5- Flight Readiness Review			
Subteams Evaluate Vechicle Demonstration Flight Data		2/22/23	2/27/23
Analyze Eventual Minor Design Changes to Launch Vechicle		2/27/23	3/2/23
Subteam Working on Flight Readiness Review Documentation		2/27/23	3/3/23
Prepare and Submit Flight Readiness Review Report		3/3/23	3/6/23
4 - Payload Demonstration Flight			
Subteams Analyze Any Construction Changes Reqiuired for Vechicle Launch		3/6/23	3/11/23
Order Materials for Vechicle Reconstruction		3/6/23	3/16/23
FRR Videoconference		TBD	TBD
Analyze Payload Elements Performance from VDF		3/11/23	3/15/23
Manufacture Major Payload Components (Epoxy, 3D Printing, CNC etc.)		3/15/23	3/19/23

Display Week: 1

Aug 15, 2022 | Aug 22, 2022 | Aug 29, 2022 | Sep 5, 2022 | Sep 12, 2022 | Sep 19, 2022 | Sep 26, 2022 | Oct 3, 2022

TASK	PROGRESS	START	END
Assemble Major Payload Components (CDS, TACOS, etc)		3/19/23	3/23/23
Perfrom Element Analysis (compare experimental values to FEA results)		3/19/23	3/22/23
Complete Vechicle and Payload Assembly		3/22/23	3/26/23
Verify Vechicle Payload Integrity (compare with predicted outcome)		3/26/23	3/27/23
Pre-Launch Inspection (Project Leads with Certified Advisor)		3/27/23	3/27/23
Vechicle Demostration Flight - Launch Event		3/27/23	3/30/23
Post-Launch Vechicle Inspection		3/27/23	3/30/23
Subteams Evaluate Payload Demonstration Flight Data		3/6/23	3/20/23
Subteam Working on Flight Readiness Review Amendum Documentation		3/20/23	3/21/23
Prepare and Submit Flight Readiness Amendum Review Report		3/21/23	3/28/23
5 - Launch Week			
Research and Book Hotels in Huntsville	100%	11/19/22	12/4/22
Organize Transportation to Huntsville		3/20/23	3/26/23
Launch Week Q&A		4/6/23	4/6/23
All Team Travel to Huntsville		4/12/23	4/12/23
Launch Week Activities		4/14/23	4/14/23
Launch Readiness Review		4/13/23	4/13/23
Launch Day		4/15/23	4/16/23
All Team Travel to West Lafayette		4/16/23	4/16/23
6 - Post-Launch Assessment Review			
All Subteams Analyze Competition Flight Data		4/17/23	4/24/23
Preparation and Review of PLAR Report		4/24/23	4/29/23
Post-Launch Assessment Review Submition		4/29/23	4/30/23