Project Moses

Critical Design Review

Purdue University 2024
500 Allison Road
West Lafayette, IN 47906

Purdue Space Program

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Abbreviations and Acronyms

Table 1: Abbreviations and Acronyms

Abbreviation/Acronym	Definition
AGCS	Avionics Ground Control Station
AGL	Above Ground Level
ASL	Aerospace Sciences Laboratory
BIDC	Bechtel Innovation Design Center
CFD	Computational Fluid Dynamics
ESC	Electronic Speed Controller
FEA	Finite Element Analysis
FDM	Fused Deposition Modeling
FMEA	Failure Modes and Effects Analysis
GCS	Ground Control Station
MFSS	Motor Fin Support Structure
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
PSP	Purdue Space Program
R&D	Retention and Deployment
R&VP	Requirements and Verification Plans
RSO	Range Safety Officer
SAIL	STEMnauts Atmosphere Independent Lander
SL	Student Launch
SLA	Stereolithography
UAV	Unmanned Aerial Vehicle

1 Summary of CDR Report

1.1 Team Summary

Table 1.1 Team Summary

Team Name	Purdue Space Program - NASA Student Launch
Mailing Address	500 Allison Road, West Lafayette, IN 47906
2024 Team Mentor	Christopher Nilsen; cnilsen@purdue.edu; (813) 442-0891 TRA 12041, Level 3 Certified
Final Launch Location and Date	Primary: 4/13/24; Backup: 4/14/24, Huntsville, Alabama
Total People-Hours	260

1.2 Launch Vehicle Summary

Table 1.2: Launch Vehicle Summary

Target Altitude	4768’ AGL
Motor Selection	Loki Research L1482-LB
Payload Section Size and Mass	32” 14.7 lb
Avionics and Recovery Section Size and Mass	25.5” 10.3 lb
Booster Section Size and Mass	35” 16.7 lb
Dry Mass	33.9 lb
Wet mass of Launch Vehicle	41.7lb
Burnout Mass of Launch Vehicle	37.7 lb
Maximum Landing Mass of Launch Vehicle	37.7 lb
Minimum Landing Mass of Launch Vehicle	32.7 lb
Vehicle Recovery System	Dual Deployment, Apogee and 700 ft AGL
Rail Size/Length	15-15/144”

1.3 Payload Summary

The Project Moses Payload Mission features a quadcopter with a three-blade propeller on each arm linked to four UAV motors. Both the arms and legs are initially housed within the payload bay, which extend to their operational configuration upon deployment. The SAIL deploys via a system with a latch for tether release, a tether threaded through the payload bay, and strategically angled eye bolts on the nose cone. When authorized by the RSO command, the controlled release mechanism allows the tether to descend, securely catching onto a hole in the nose cone bulk plate. This allows the nose cone to fall away, facilitating the quadcopter's exit from the launch vehicle.

2 Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

The design of the launch vehicle has had some changes since PDR, with adjustments to mass to account for new predictions of the mass of novel sub-systems and incorporate new payload vehicle criteria. First, the launch vehicle will now have three separation points and four independent sections to allow for the ejection of the SAIL. The nose cone will now be ejected to allow the SAIL to be released at its intended altitude, independent of other launch vehicle subsystems. The nose cone will still be tethered to the rest of the launch vehicle, and it will not be ejected through the use of energetics, but rather through the use of a mechanical system. Next, in scaling the motor/fin support structure (MFSS), further design improvements were made from last year's design to increase design efficiency by reducing unnecessary material without sacrificing its structural integrity. As such, its mass has decreased from a previously predicted 1.2lb to 0.755lb. In previous years, the team encountered issues with the launch rail bending slightly with the launch vehicle on the rail. Further research into this issue led to the conclusion that the rail button placement should be changed such that the top button is near the vehicle CG. Anecdotal evidence and experience from other PSP teams indicated that this placement is more ideal for the stability of the launch vehicle on the pad, and as it exits the rail. This placement is also intended to avoid bending the launch rail. The bottom rail button was also incorporated as a fastener on the MFSS, increasing design efficiency by reducing the total number of fasteners needed as well as reducing the number of holes drilled into the airframe. Another design change came after discussion during the PDR presentation, during which concern about pressurization of the booster airframe during the black powder ejection would be difficult given the open design of the MFSS. As such, a 1/8" bulkplate was added directly above the motor, through which the parachute eye bolt will be connected to the upper closure in the motor casing. This bulkplate is machined out of bulk 6061 aluminum because of its strength, low weight, and its ability to withstand high temperatures. This is the material used to manufacture the MFSS, so it was determined to be appropriate for this bulkplate as well. Another adjustment was to shorten the payload airframe by 1" and to increase the booster section by 3" to accommodate for this bulkplate and allowing more room above the motor without necessitating further compacting the drogue parachute. The thickness of the parachute shock cords was also increased to ⅜" to minimize the risk of it being too thin and potentially ripping. The recovery system will now use key switches rather than screw switches due to their increased security during flight. The final design change was to shorten the nose cone by 1" to save mass while still reducing drag with an elongated LV-HAACK profile. This allows the launch vehicle to still remain close to the target apogee set in PDR despite the other design changes included which alter the mass of the launch vehicle.

2.2 Changes Made to Payload Criteria

While the majority of the payload competition design has remained unchanged since PDR, several minor adjustments and clarifications have been made. The first of these clarifications establishes compliance with the FAA's 14 CFR 107.51. Due to the 400' altitude restriction for UAS, the team's payload criteria have been adjusted to initiate the SAIL jettison event at exactly 400' AGL. This adjustment ensures that all sections landing untethered to the launch vehicle will remain attached until the specified maximum altitude is reached, while also remaining in the spirit of the Student Launch competition. In addition to this procedural update, an alternative design for jettisoning the SAIL has been proposed and developed to replace the electronic pull pin method proposed in PDR. The design consists of a pulley-like tether fixed at one end to the central payload coupler. The tether is threaded through the nose cone and back to the coupler where it is locked to an electronic latch. When a signal is sent to the latch, it releases one end of the tether and allows the nose cone to fall away from the vehicle. The nose cone is then caught by the released end of the tether, effectively opening the payload bay and releasing the SAIL. While this adds an additional independent section to the vehicle (bringing the total to four), the revised design offers several major advantages. The first is that the SAIL can now be contained entirely inside the launch vehicle and does not need to be integrated into the nose cone, which reduces weight. The second is that the design utilizes the tether itself for retention, reducing unnecessary complexity. Finally, this design ensures passive retention, meaning that the SAIL will remain tethered until triggered to release even in the case of total power failure.

2.3 Changes Made to Project Plan

The Project Plan has undergone minimal changes since reaching the PDR milestone. However, certain dates within the plan have been slightly adjusted to accommodate new information and incorporate valuable input from the team. The adjustments primarily reflect a commitment to maintaining accuracy and adaptability in response to evolving project requirements.

3 Vehicle Criteria

3.1 Mission Statement

Project Moses is a student-run mission to construct a fully reusable launch vehicle capable of ascending to a target apogee of 4,768' AGL, using an accumulation of engineering techniques acquired by team members throughout their educational careers at Purdue University, individual technical experiences gained from PSP participation, and external research and industry experience. This launch vehicle aims to carry an in-air deployable payload capable of safely recovering four "STEMnauts" in a predetermined orientation without the use of a parachute or chemical propulsion. Project Moses also seeks to improve the overall efficiency, strength, and reusability of the launch vehicle, progressing the lessons learned from the previous year's Project Weber launch vehicle and to equip new members with the experience necessary to continue the success of PSP-SL in future projects and challenges.

3.2 Design and Verification of Launch Vehicle

3.2.1 Vehicle Overview

The launch vehicle was designed using OpenRocket and modeled in NX and Solidworks to compare analysis between the two CAD platforms, as well as to introduce members to multiple CAD software. The launch vehicle is 92.5" long, with an outer diameter of 5.15" and an inner diameter of 5". It weighs 41.7 lb with a loaded Loki Research L1482-LB motor, which is capable of 3882Ns of total impulse, 51% of the maximum L class designation. The launch vehicle averages 4.2 cal of stability while maintaining at least 2.1 cal of stability in the worst predicted weather conditions. The airframe consists of G12 fiberglass tubing. The launch vehicle comprises four independent sections: nose cone, payload, recovery, and booster. These sections remain connected in flight via a tether, with the exception of the SAIL payload. The nose cone is an LV-HAACK design, there are three airfoiled trapezoidal fiberglass-resin-cast composite fins, and the fins and motor are connected to the airframe through an internal aluminum structure (MFSS). The full vehicle cross-sectional assembly is shown below, with each independent section shown in a different color (nose cone is orange, payload is green, recovery is red, and booster is blue).

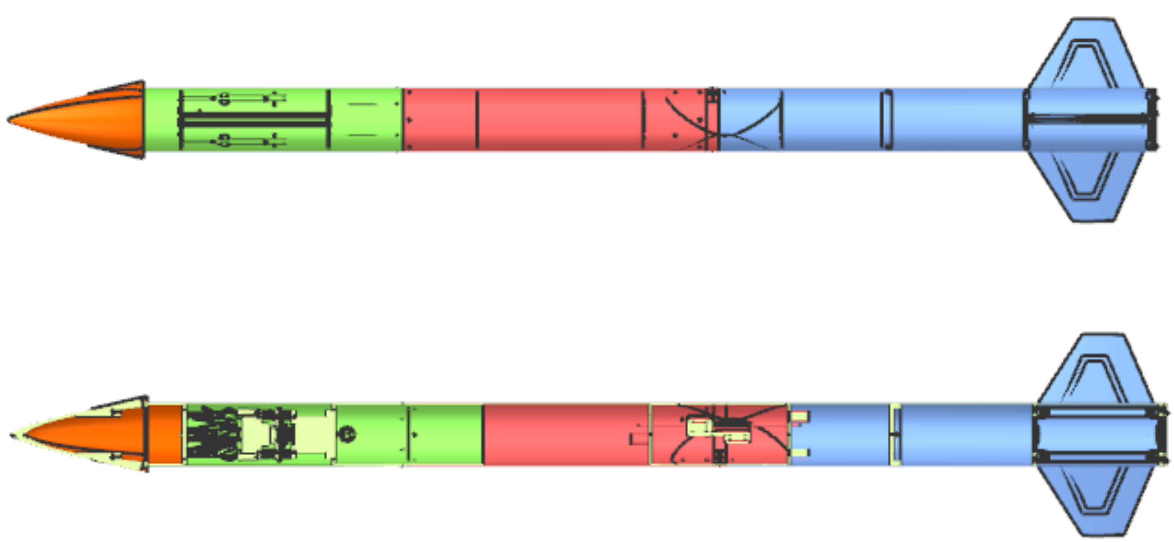
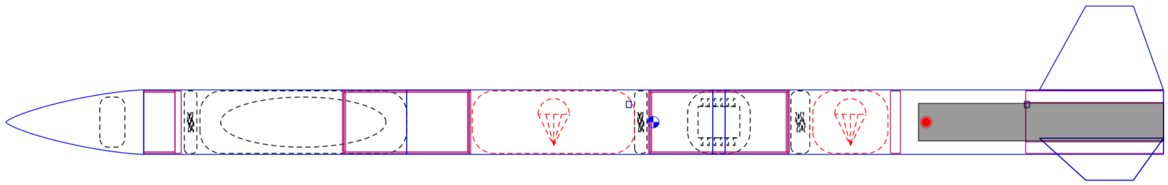


Figure 3.2.1: Color-Coordinated Full Vehicle Cross-Sectional Assembly

3.2.2 Chosen Alternatives

3.2.2.1 Top-Level Design



Rocket
Stages: 1
Mass (with motor): 41.7 lb
Stability: 4.23 cal
CG: 51.761 in
CP: 73.559 in

L1482-0

Altitude	4792 ft
Flight Time	87 s
Time to Apogee	17.7 s
Optimum Delay	15.1 s
Velocity off Pad	72.1 ft/s
Max Velocity	603 ft/s
Velocity at Deployment	134 ft/s
Landing Velocity	16 ft/s

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Motor Wt	Size
L1482-LB	344 lbf	2.52 s	395 lbf	868 lbf·s	8.26:1	4 lb	2.99/19.6 in

Figure 3.2.2: Selected Top-Level Design

Of the two design alternatives for the overall top-level design, one including swept delta fins and a third coupler, and another including trapezoidal fins and only two couplers, the second design was chosen (Top-Level Alternative 2). This design features a 5” interior diameter airframe, selected to reduce overall vehicle mass and allow for achievement of competition requirements with a greater margin of error. Because this vehicle is smaller and lighter, a higher apogee is selected to ensure all apogee predictions are safely above the competition-designated 3500’ minimum across all weather conditions. This simultaneously allows for a descent time and landing kinetic energy that are also within both competition requirements and bonus point thresholds. This design also eliminates one coupler that was utilized in previous years’ designs, which was previously located between the recovery section and booster section. Placing the drogue parachute directly above the motor and eliminating this coupler further increases the overall efficiency of the design and reduces mass. The separation point for the booster section is thus located at the avionics bay. The team concluded that anecdotal evidence from other competition teams, as well as other PSP teams, indicates that a Nomex blanket around the drogue parachute is sufficient to ensure the functionality of all components in the design and protect the parachute from hot combustion products, given proper functionality of the motor. This vehicle design also features an airfoiled trapezoidal fin set. The root chord is 9.9”, the tip chord is 3.8”, the height is 6.7”, and the sweep length is 3.7”. This fin geometry, along with a shorter launch vehicle created by eliminating a coupler, allows for a higher minimum stability and lower maximum stability, ensuring vehicle safety by meeting competition requirements without greatly inflating the risk of overstabilization and weathercocking. The minimum stability achieved is 2.4cal (off the rail in the worst weather conditions), and the maximum stability achieved is 4.9cal (at maximum velocity in the most tranquil weather conditions). Overall, the vehicle is 92.5” long and weighs 41.7lb.

3.2.2.2 Airframe

Of the two airframe design alternatives, one with four couplers at a 104” total length and the other with three couplers at a total length of 92.5”, the 92.5” design (Airframe Alternative 2) was chosen. Both designs consisted of a 5” inner diameter and a 5.15” outer diameter, and both designs used G12 Fiberglass. After conducting a feasibility analysis, the team chose this design alternative because it more accurately fulfilled mission criteria S.C. 3 and S.C. 5. The main benefit of this design was the decreased mass of the launch vehicle. Due to this decrease in mass, the simulated apogee increased, and the simulated ground hit velocity and descent times decreased. Another benefit of this design alternative was its feasibility in cost for this year’s budget and ease of manufacturing compared to Design Alternative 1. As such, Airframe Alternative 2 was the most desirable design choice. The summary of simulation results for the selected airframe under different conditions is summarized below in Table 3.1.2.2.1.

Table 3.2.1 - Airframe OpenRocket Simulation Results

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	4778	17.7	86.1	68.4	15.9
7.5	5	4733	17.6	87.6	70.0	15.9
10	10	4455	17.0	84.8	67.8	15.9
15	10	4305	16.8	83.5	66.7	15.9
20	10	4143	16.4	83.4	67.0	15.9

3.2.2.3 Motor Fin Support Structure

Several changes were made to the MFSS to improve the manufacturability, weight, and requirements of this year’s competitions. The first was a change from 6 airframe holes to 3. The purpose of these holes is to secure the centering plate and thrust plate in place. Previously, the

6 holes were there for redundancy due to expected inaccuracies caused by errors in the jigs which caused some screw holes to be out of alignment. The team determined that 6 holes added more complexity to the design that was not justified by the marginal security and layer of redundancy provided by the extra 3 screws. Instead, methods of improving jig accuracy were investigated to negate alignment issues. The second change was to remove the standoffs, which were designed with the expectation that the motor casing would be identical to last year's. Instead of a thick lip on the motor casing, the lip is much thinner and wirelike, so it was determined that standoffs would not be necessary. Instead, the retainer plate is screwed directly to the thrust plate. The CDR assembly had a factor of safety greater than 6,, which is far larger than the minimum requirement of 1.5: as such, the thickness of various features was decreased in order to reduce weight. The final factor of safety after mass reducing modifications for the MFSS assembly for CDR is 5.98.

3.2.2.4 Fins

Of the two final fin alternatives considered the fin material, the composite of fiberglass and resin was chosen. This is due to the fact that when factors like reusability, cost, weight, survivability, and airfoil precision were considered, the composite material performed as well, if not better, than the 3D printed nylon alternative. Further, considerations into soft factors like experience and learning opportunities gained from manufacturing a composite in house led to reinforcement of this decision. The worries of undesirable performance were quelled when a finite element analysis produced a factor of safety of 15, the maximum able to be recorded with FEA software. This decision has historically led to reduced costs, improved performance, higher survivability, and more gained experience for team members. In regard to the fin shape choice, it similarly has remained the same since PDR. The two main choices that were considered was the larger and smaller design. The larger design was chosen primarily due to concerns of the strength of the smaller design due to a lack of sufficient resin around the fiberglass. Further, the smaller design had a higher stability at top speed which resulted in concerns of overstability. Since FEA has been performed, the larger alternative appears to be sufficient given a factor of safety of 15.

3.2.2.5 Nose Cone

The design of the nose cone is a LV-Haack series with a height of 11'', a base radius of 2.58'', and a wall thickness of 0.25''. There are two flanges on the nose cone separated by 180 degrees that house the camera bay. The inside of the nose cone contains an electronics plate with a radius of 2.13'' that mounts the battery, two Zero Raspberry Pis, one 3B+ Raspberry Pi, and a key switch. The nose cone will be mounted to the rocket by two 0.25'' rods that screw into the inside of the nose cone and a base plate with a radius of 2.58''.

The cameras used in the nose cone will consist of two aft-facing OV5647 Zero cameras configured based on the success of the aft camera orientation used in the 2021, 2022, and 2023 competition years. Footage from the nose cone cameras has been invaluable, specifically in use for project outreach and flight diagnostics. Before the team switched to the aft-facing camera orientation in 2021, the cameras were either oriented forward or outward facing. The resulting footage was found to be ineffective as it provided minimal flight data and was visually less interesting for outreach. As well, the shape of the nose cone is designed to be symmetrical, and the two-camera system coincides with its symmetry and aids in redundancy and mass balance.

The electronics controlling the two cameras will consist of two Raspberry Pi Zeroes and a Raspberry Pi 3 Model B+. Each Raspberry Pi Zero will be connected to and control one of the two cameras. The Raspberry Pi 3 Model B+ would serve as a bridge between the two Raspberry Pi Zeros to synchronize them and combine the camera footage into one file to be exported. The Raspberry Pi 3 Model 3+ also has bluetooth capabilities which could be harnessed to wireless export the camera footage. The three-Raspberry Pi board design will increase the efficiency and convenience of exporting and analyzing the camera footage.

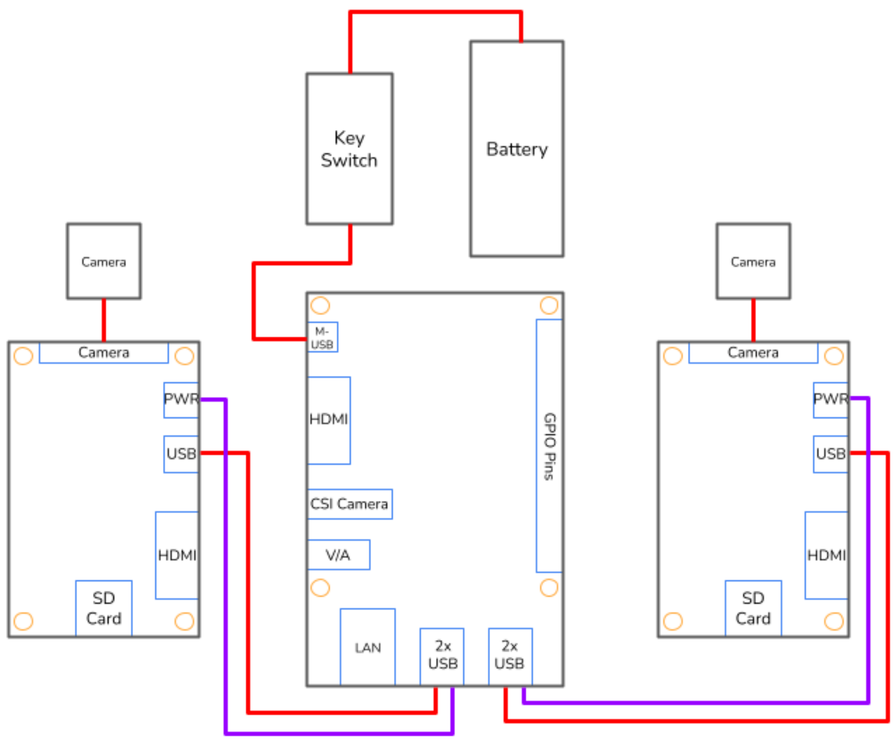


Figure 3.2.3: Nose Cone Camera Electronics Schematic

3.3 Final Components

3.3.1 Booster Section

The booster section is the aftmost section of the launch vehicle. It consists of the booster airframe, MFSS, fins, motor, internal pressurization bulkplate, and drogue parachute. This section is tethered to the rest of the launch vehicle, and separates at the avionics bay coupler to deploy the drogue parachute just after apogee. The booster section is intended to safely contain the motor and fins, transfer the forces of powered flight to the airframe, and house the drogue parachute. A cross sectional view of the booster section assembly is shown below.

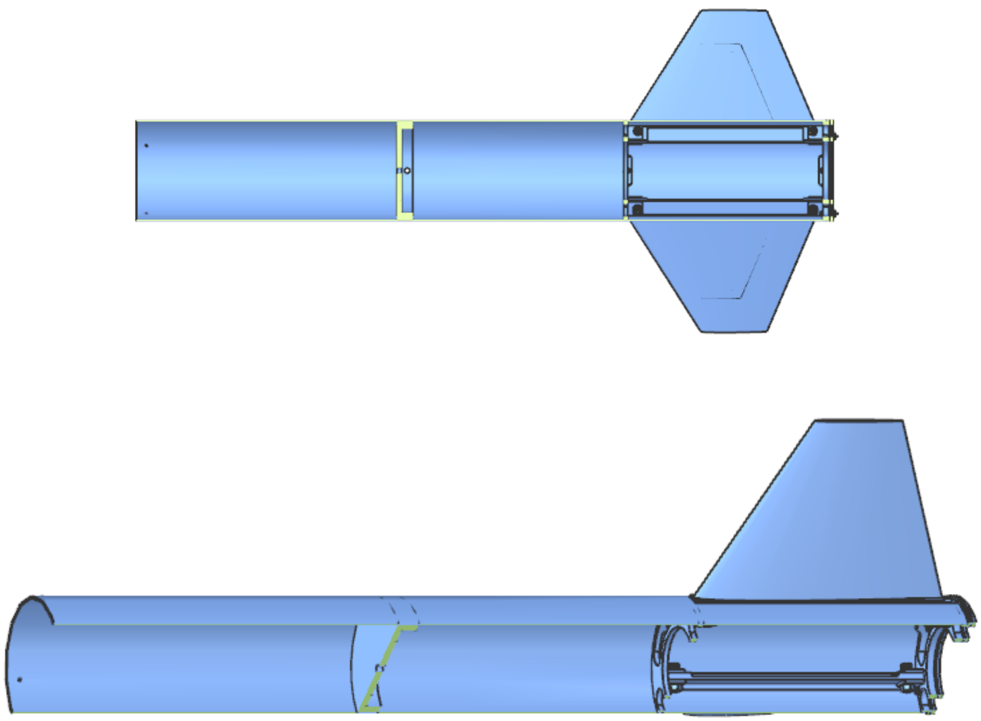
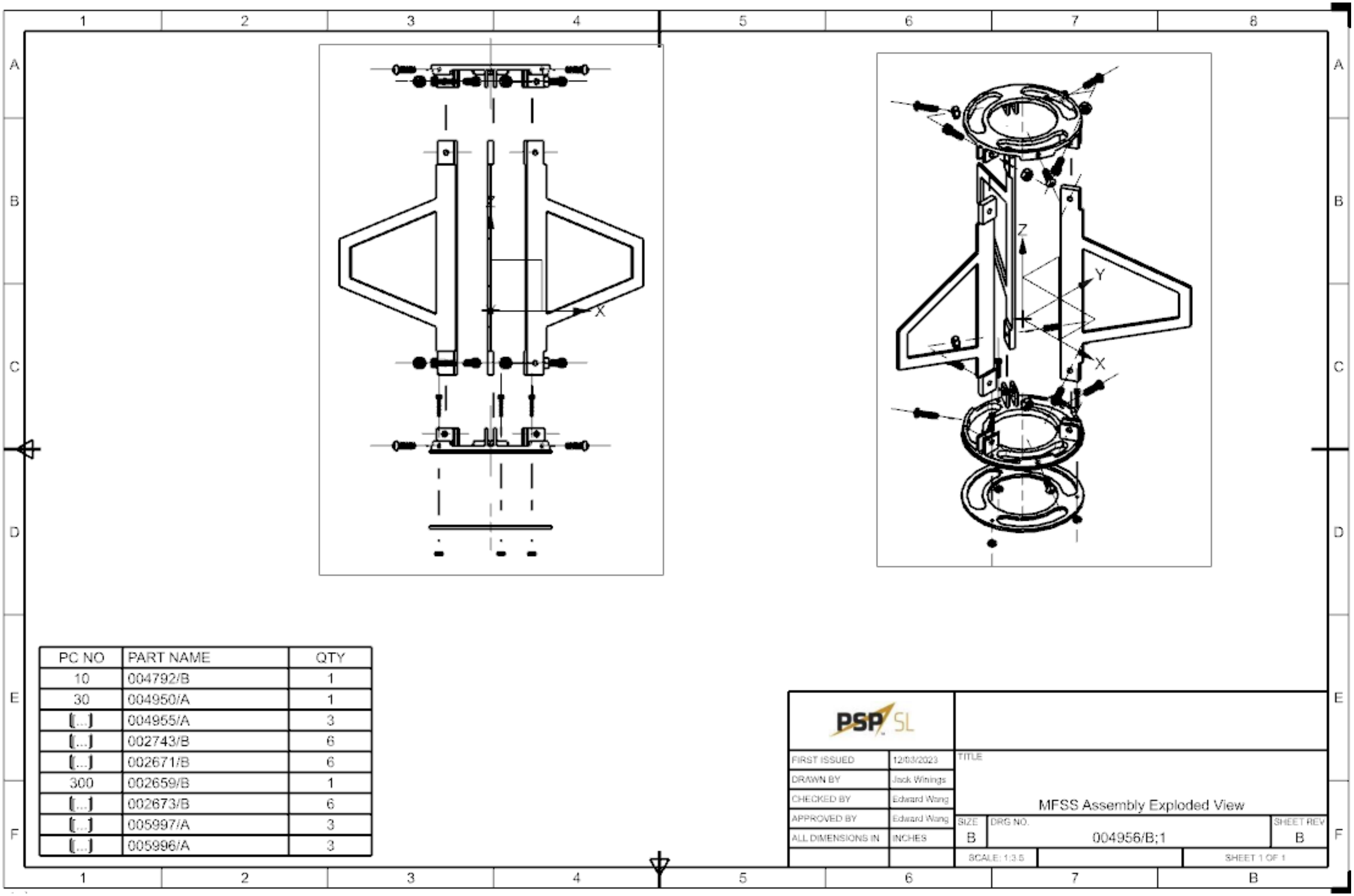


Figure 3.3.1: Booster Section Assembly Cross Sectional Views

3.3.1.1 Motor Fin Support Structure

The MFSS is the structure which holds the motor and fins in place, distributing forces to prevent damage, and protecting against any unwanted motion. The airframe is allowed to absorb most forces due to this mechanism, maintaining stability and structure. It consists of two aluminum centering plates held together by the three fin inserts, with a retaining plate on the aft. From PDR, the thickness of multiple parts was reduced. This resulted in reducing weight and the safety factor, however, since the safety factor was already far over the minimum of 1.5. The final factor of safety for the centering plate is 4.9, 1.81 for the thrust plate, and 5.98 for the full assembly, satisfying S.C. 8, so this change is justified.



PC NO	PART NAME	QTY
10	004792/B	1
30	004950/A	1
[...]	004955/A	3
[...]	002743/B	6
[...]	002671/B	6
300	002659/B	1
[...]	002673/B	6
[...]	005997/A	3
[...]	005996/A	3

Figure 3.3.2: MFSS Assembly Exploded View

Table 3.3.1: MFSS Assembly List

Component	Quantity	Material	Mass per piece (lbm)	Total Mass (lbm)	Manufacturing
Thrust Plate	1	Aluminum 6061-T6	0.2468	0.2468	CNC Milled
Centering Plate	1	Aluminum 6061-T6	0.1740	0.1740	CNC Milled
Motor Retainer Plate	1	Aluminum 6061-T6	0.0924	0.0924	CNC Milled
Fin Insert	3	G10 Fiberglass	0.0766	0.2298	Waterjet
18-8 Stainless Steel Socket Head Screw, 1/4"-20 Thread Size, 3/4" Long	6	18-8 Stainless Steel	0.0141	0.0846	Off-the-shelf
18-8 Stainless Steel Hex Nut, 1/4"-20 Thread Size	6	18-8 Stainless Steel	0.0078	0.0468	Off-the-shelf
18-8 Stainless Steel Button Head Hex Drive Screw, 1/4"-20 Thread Size, 7/8" long	6	18-8 Stainless Steel	0.0129	0.0774	Off-the-shelf
18-8 Stainless Steel Socket Head Screw, 6-32 Thread Size, 3/4" Long	3	18-8 Stainless Steel	0.0036	0.0108	Off-the-shelf
18-8 Stainless Steel Hex Nut, 6-32 Thread Size	3	18-8 Stainless Steel	0.0022	0.0066	Off-the-shelf
Total Component Mass (lbm)				0.743	
Total Fasteners Mass (lbm)				0.2262	
Total Assembly Mass (lbm)				0.9692	

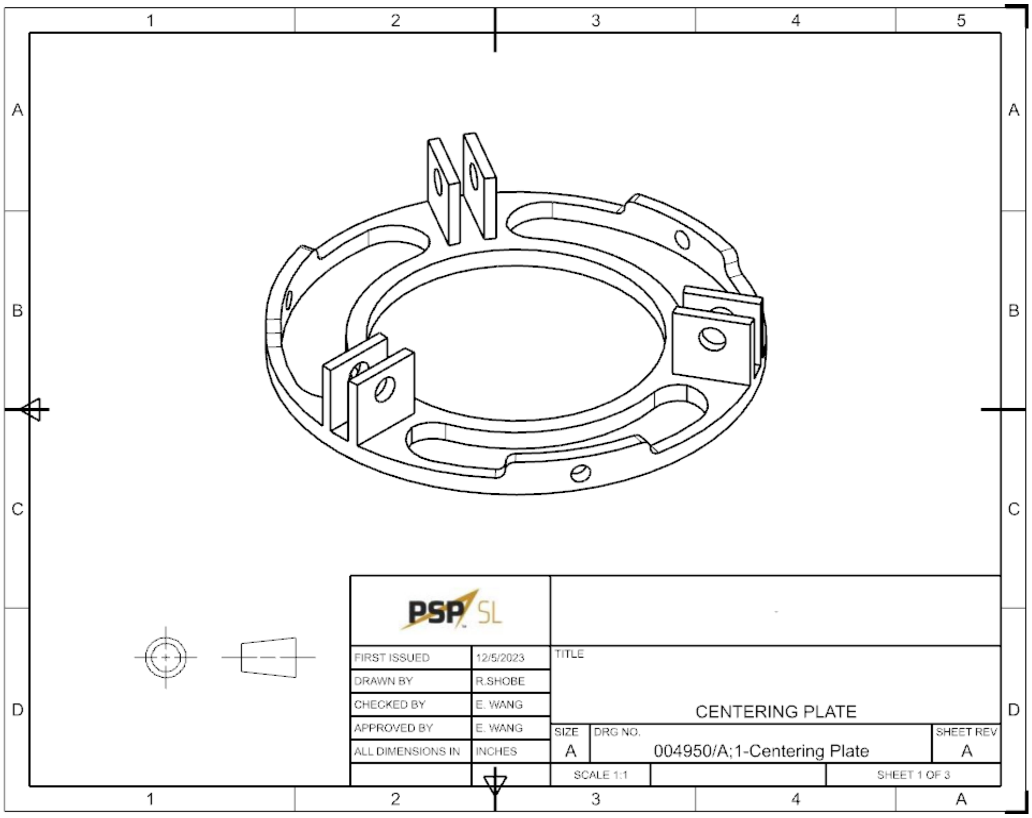


Figure 3.3.3: Centering Plate Technical Drawing

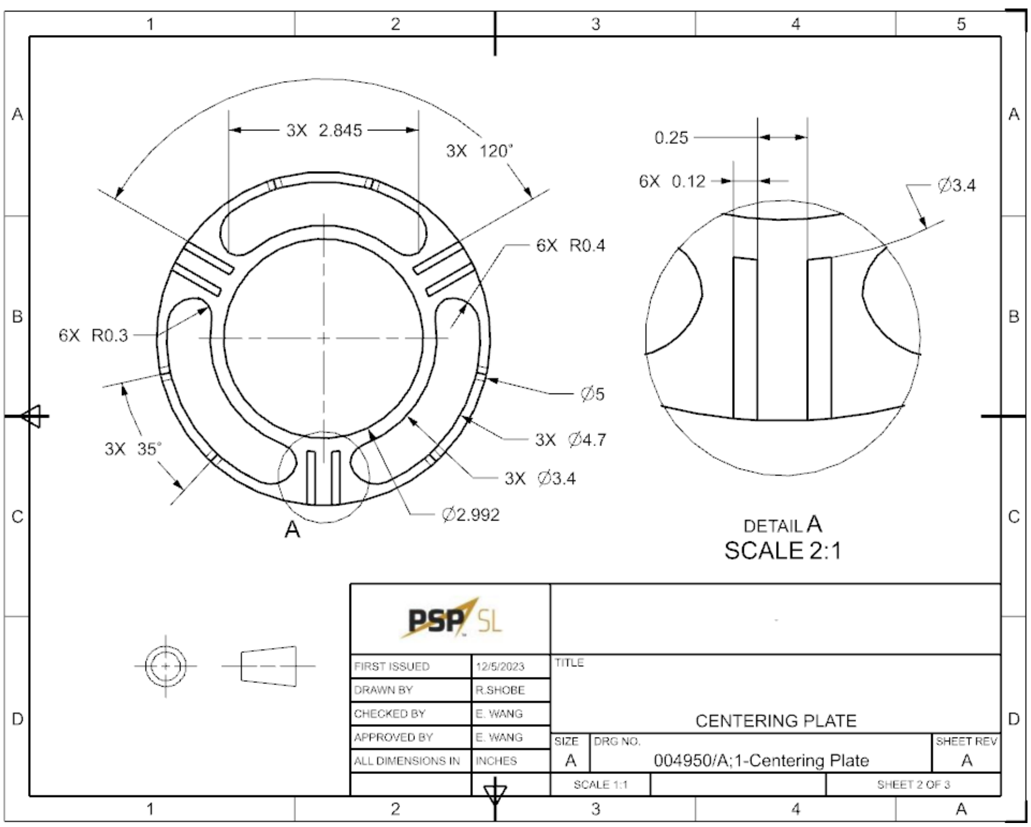


Figure 3.3.4: Centering Plate Technical Drawing

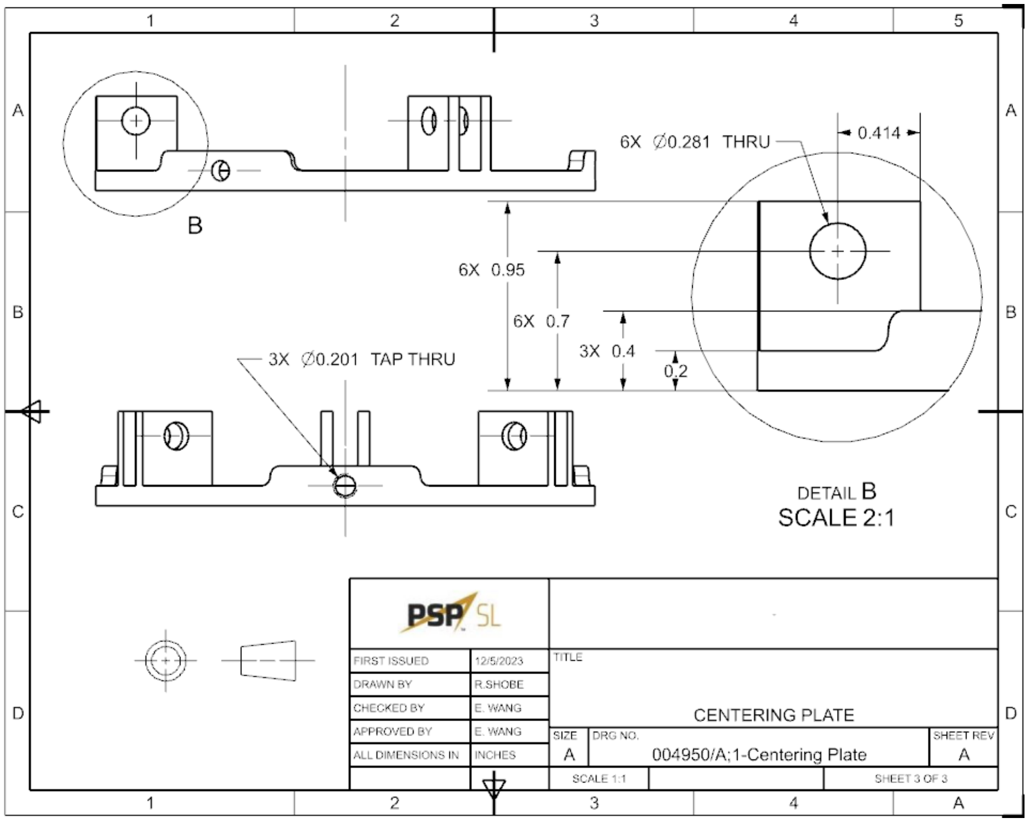


Figure 3.3.5: Centering Plate Technical Drawing

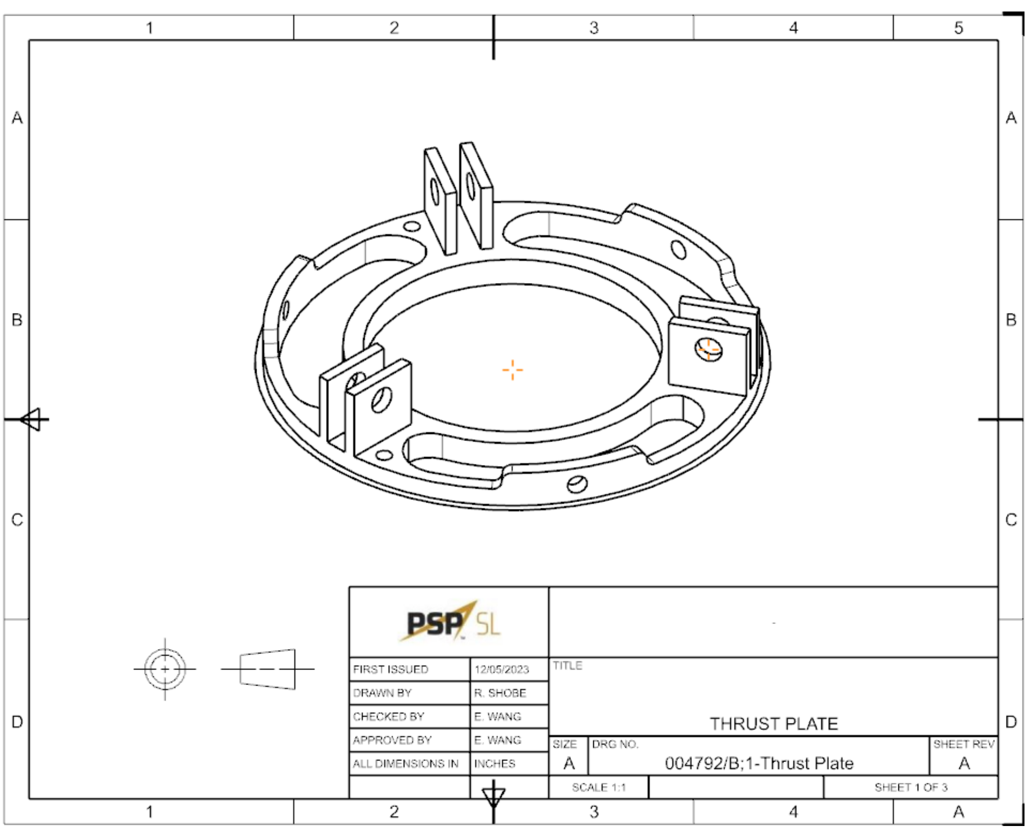


Figure 3.3.6: Thrust Plate Technical Drawing

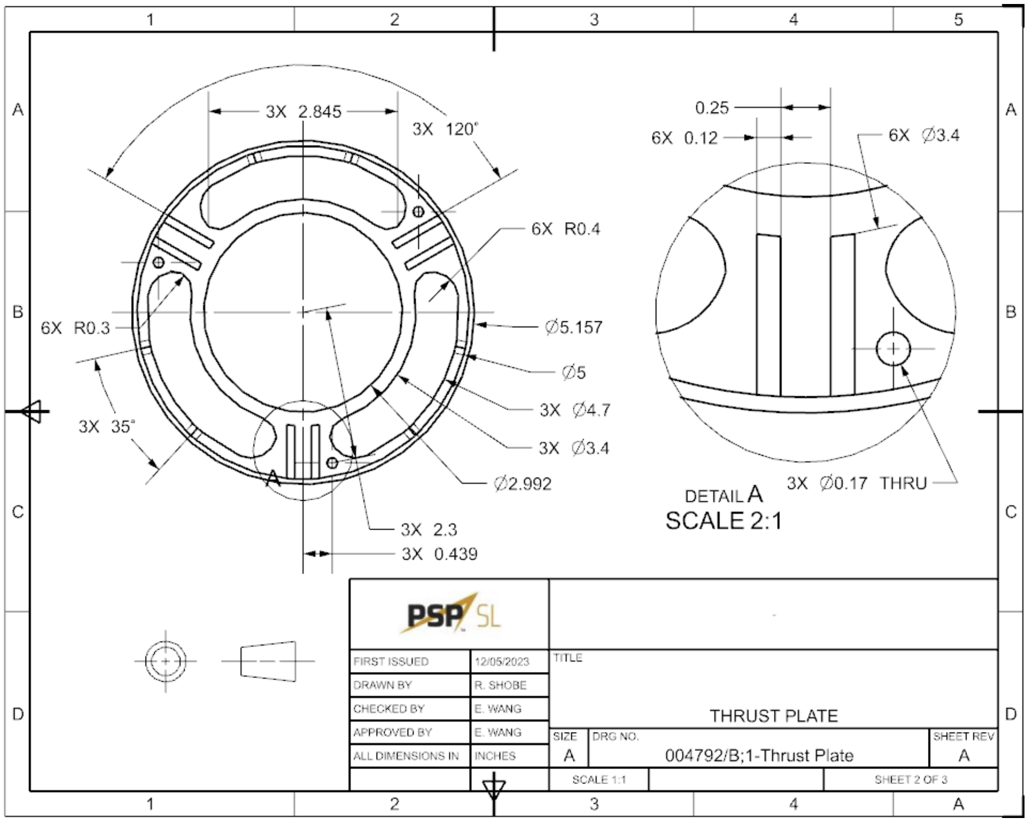


Figure 3.3.7: Thrust Plate Technical Drawing

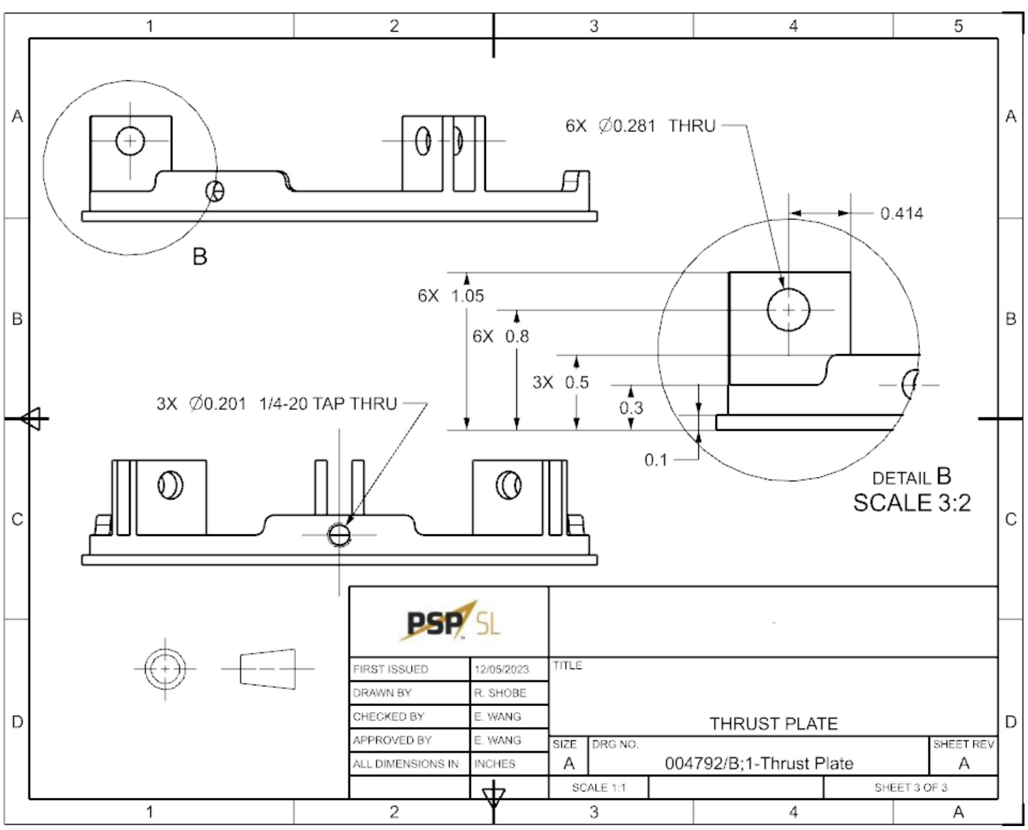


Figure 3.3.8: Technical Drawing for Thrust Plate

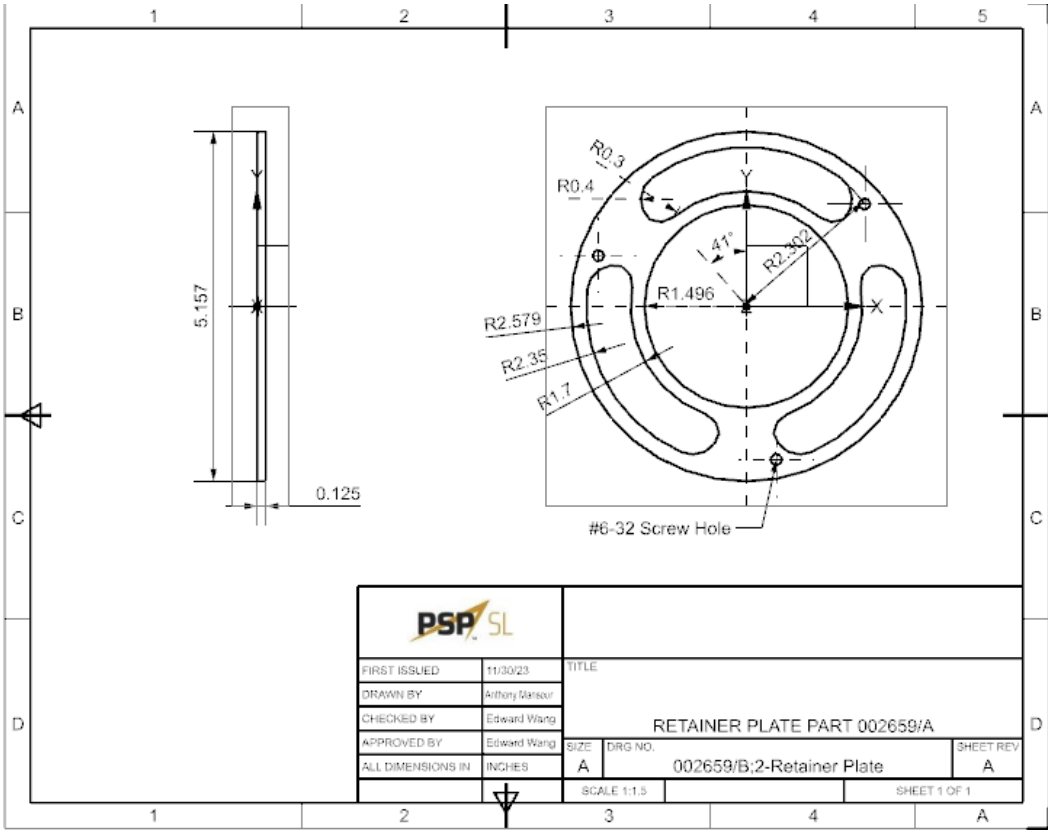


Figure 3.3.9: Technical Drawing for Motor Retainer Plate

3.3.1.2 Fins

The fins are the protruding structure from the airframe typically located towards the aft for the purpose of adding surfaces that increase drag to increase stability. The increase in stability prevents the launch vehicle from veering off course, and moving in undesirable ways. The fins offload the experienced forces onto the aforementioned MFSS. The only change that has occurred since PDR is a minor change to the design of the fin inserts. It was realized that for the purpose of creating as close to a proper seal around the airframe with the fins, the insert should be slightly extended along the portion that mounts to the MFSS. The increase in fiberglass does, though only slightly, increase the mass of the fins.

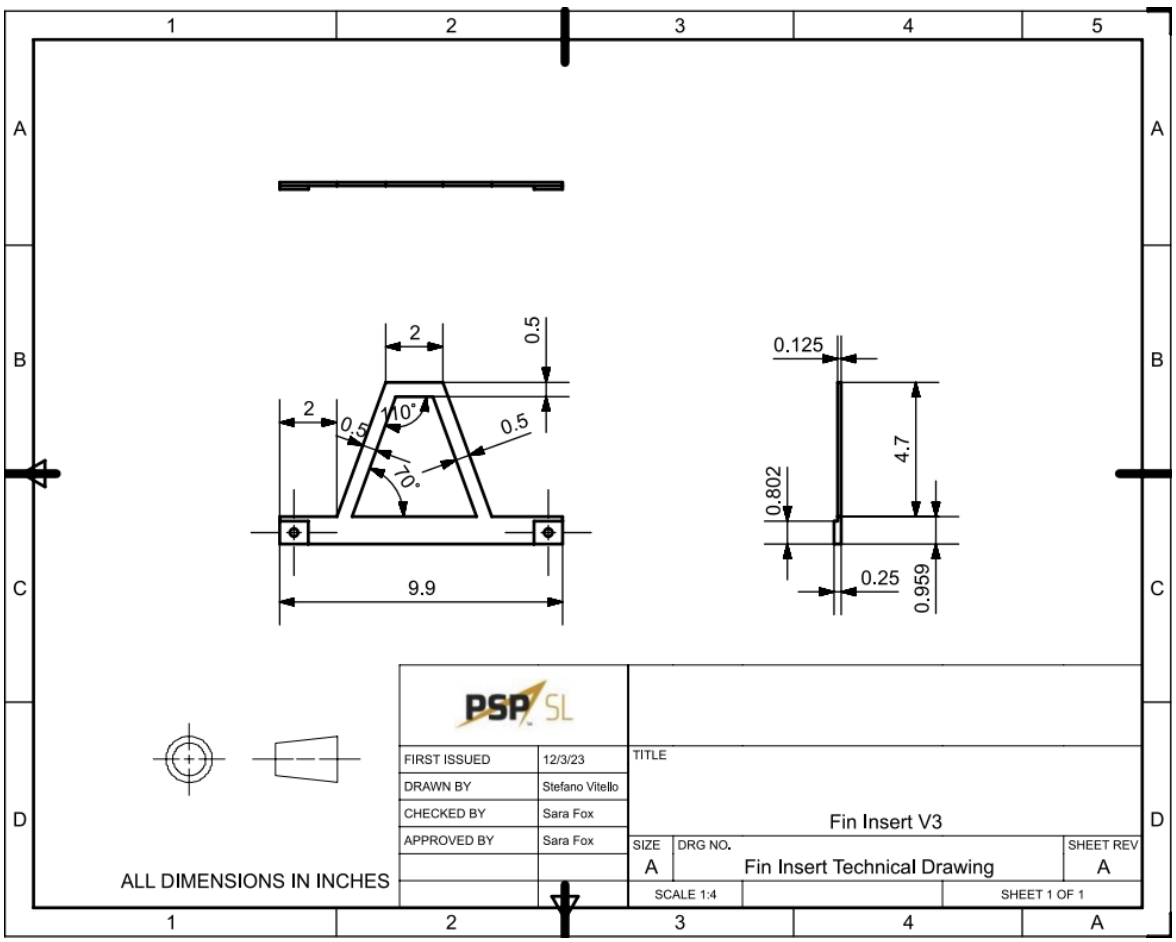


Figure 3.3.10: Technical Drawing for Full Scale Fin Insert

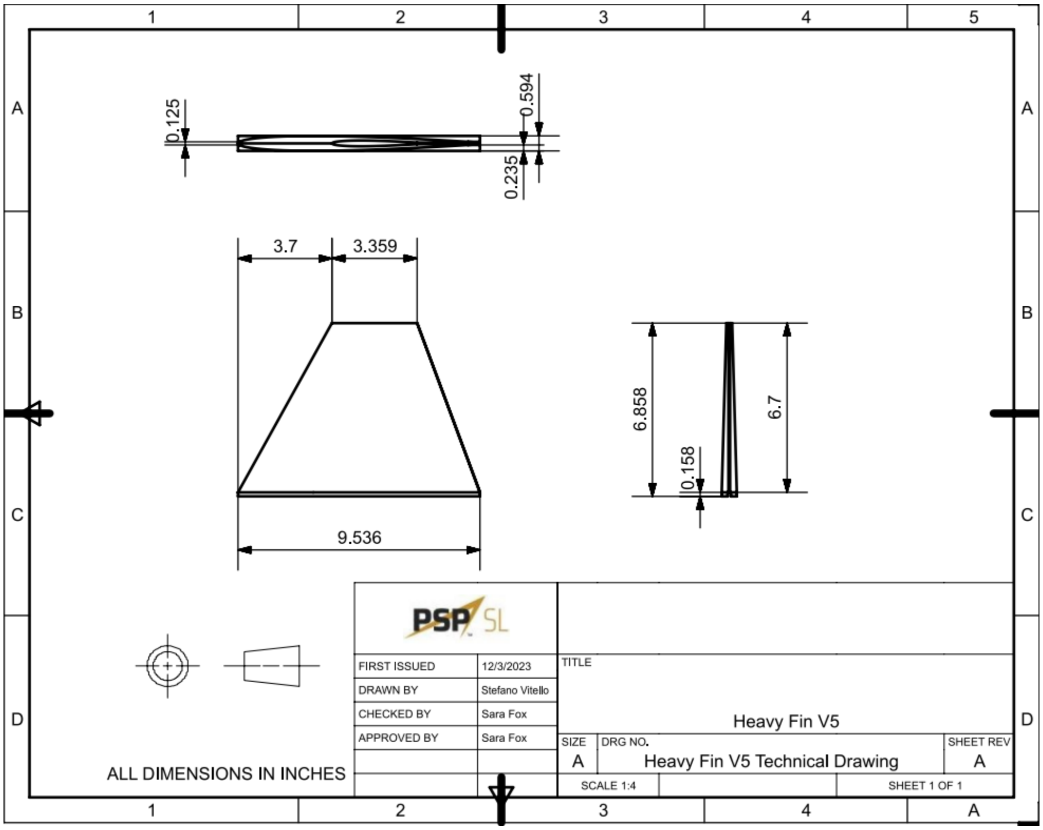


Figure 3.3.11: Technical Drawing for Full Scale Fin

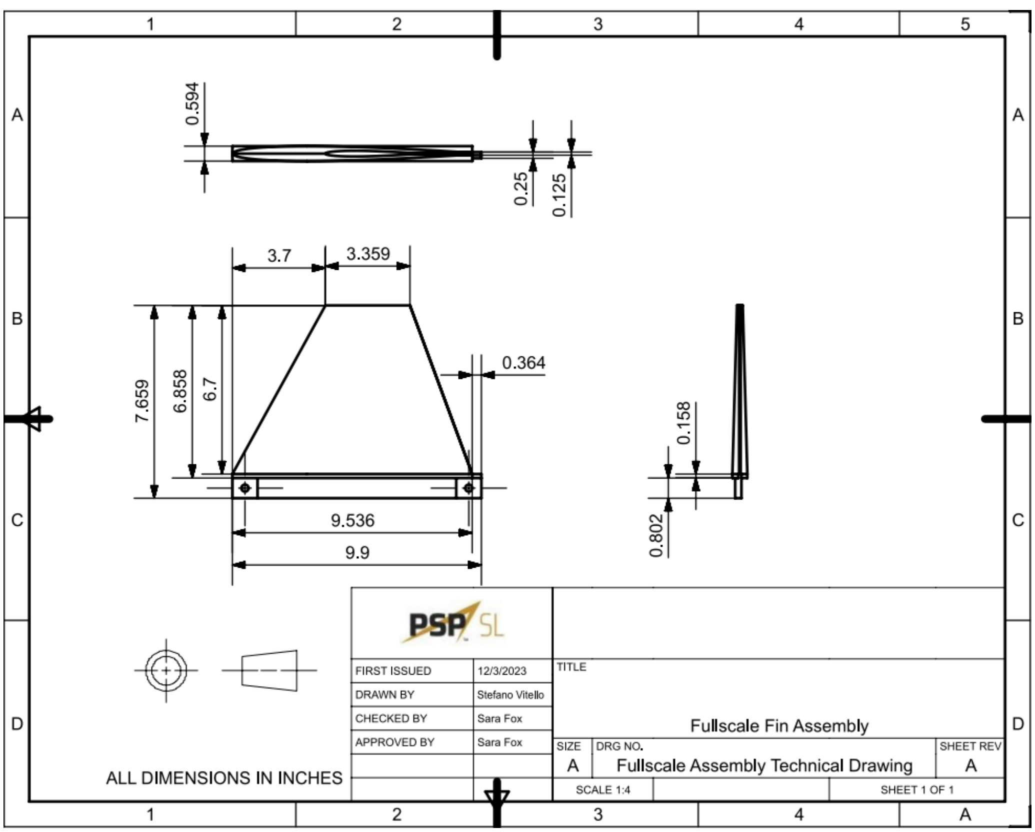


Figure 3.3.12 : Technical Drawing for Full Scale Fin and Fin Insert

The final fin and fin insert design determined to be manufactured is the heavy fin and fin insert design. This decision was made due to the results of top stability being lower than the light fin and fin insert design which decreased the chances of overstability. Additionally the fin inserts were manufactured with fiberglass and were cast with resin.

3.3.1.3 Booster Airframe

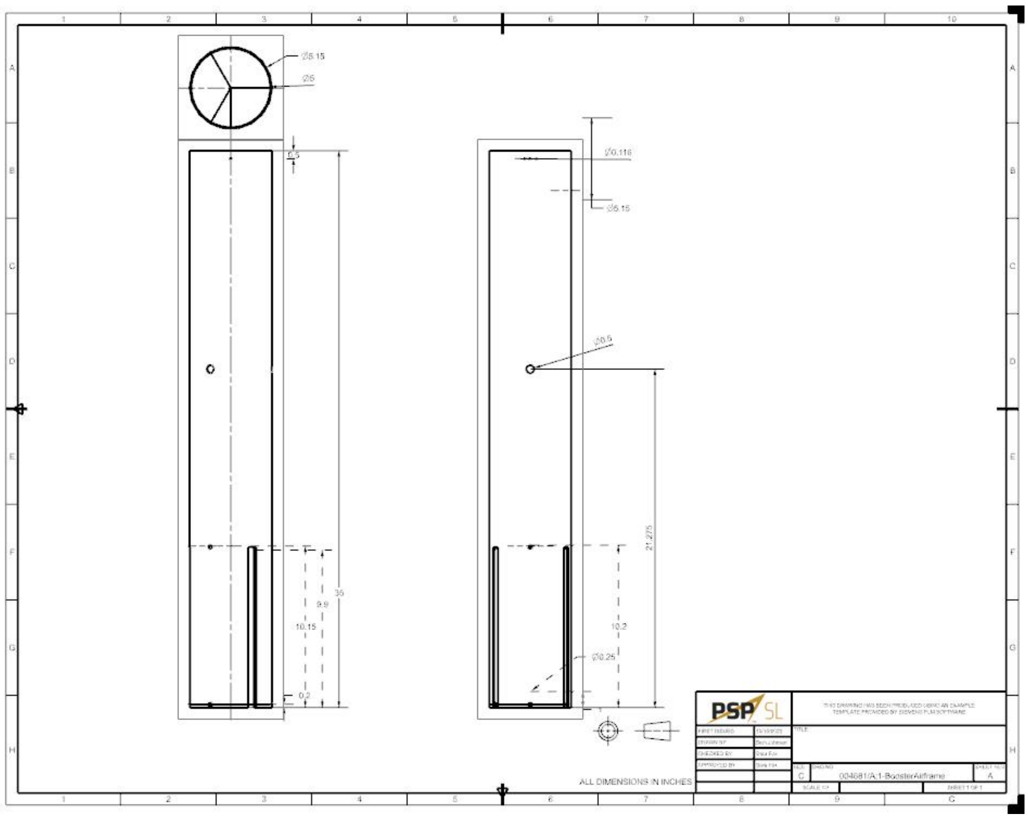


Figure 3.3.13: Booster Airframe Technical Drawing

Since the preliminary design report, the changes made to the booster airframe have been increasing the overall length of the booster by 2 in and decreasing the distance of the rail buttons from the bottom of the booster by 13.85 inches. The top of the booster also has 3 ⅜” inch diameter mounting holes to the avionics coupler to accommodate for shear pins. In addition, three .5 inch bulk plate holes were added 21.275 inches from the bottom of the booster. All other dimensions have remained the same.

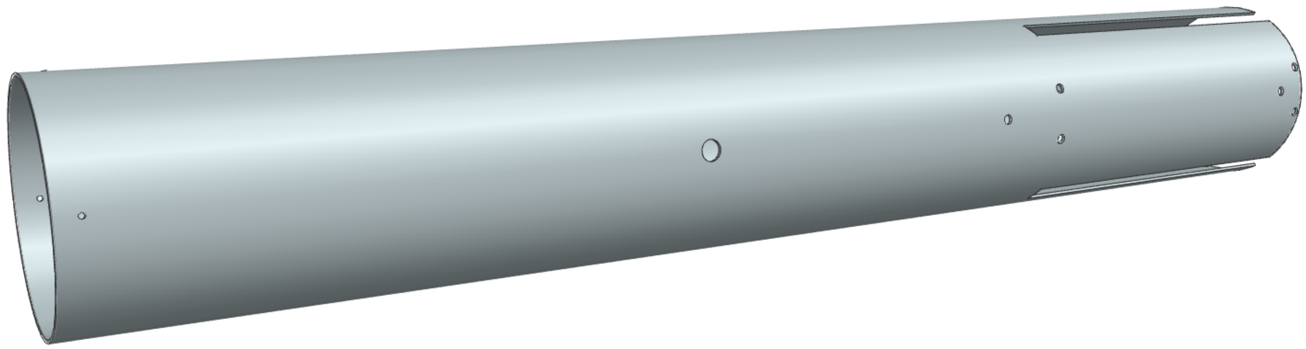


Figure 3.3.14: Booster Airframe CAD Model

3.3.2 Recovery Section

The recovery section consists of the avionics coupler, the upper recovery airframe, and all of the components inside. The avionics coupler, or avionics bay, will hold all the necessary recovery system electronics, including the altimeters and their batteries. The bulkheads of the coupler will contain charge wells that will hold the black powder ejection charges and also each contain an eye bolt which will allow for connection of the shock cords. The upper recovery airframe will house the main parachute and shock cord. Cross sectional views of the recovery system assembly are shown below.

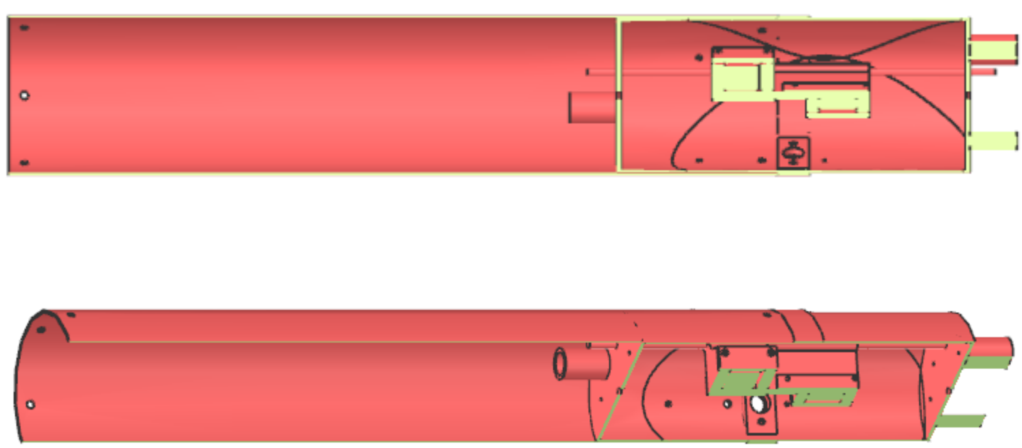


Figure 3.3.15: Recovery Section Cross-Sectional Views

3.3.2.1 Avionics Bay

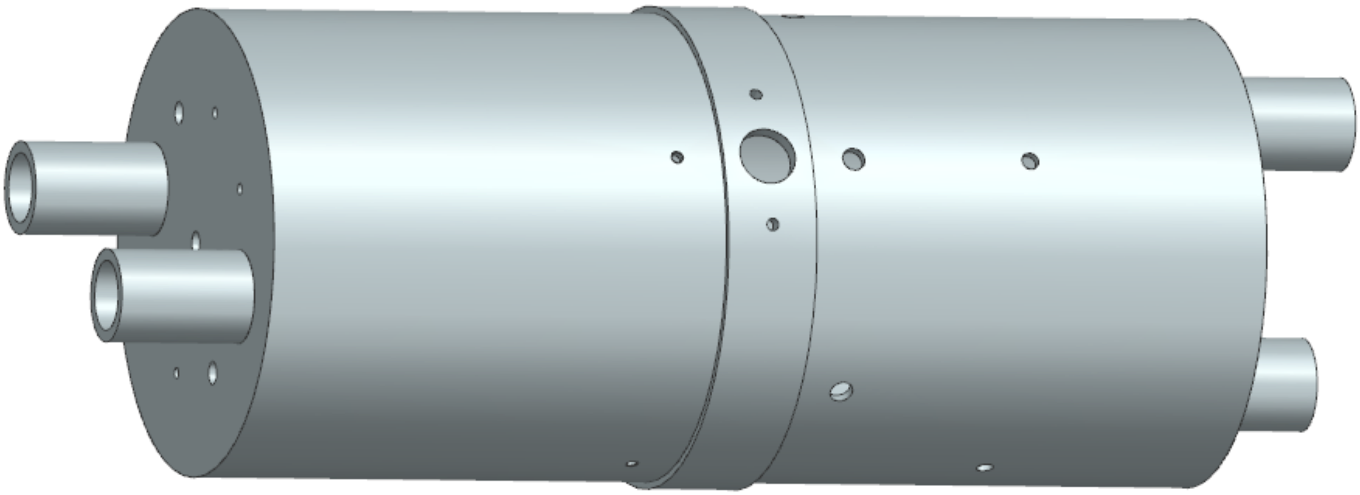


Figure 3.3.16: Avionics Coupler CAD Model

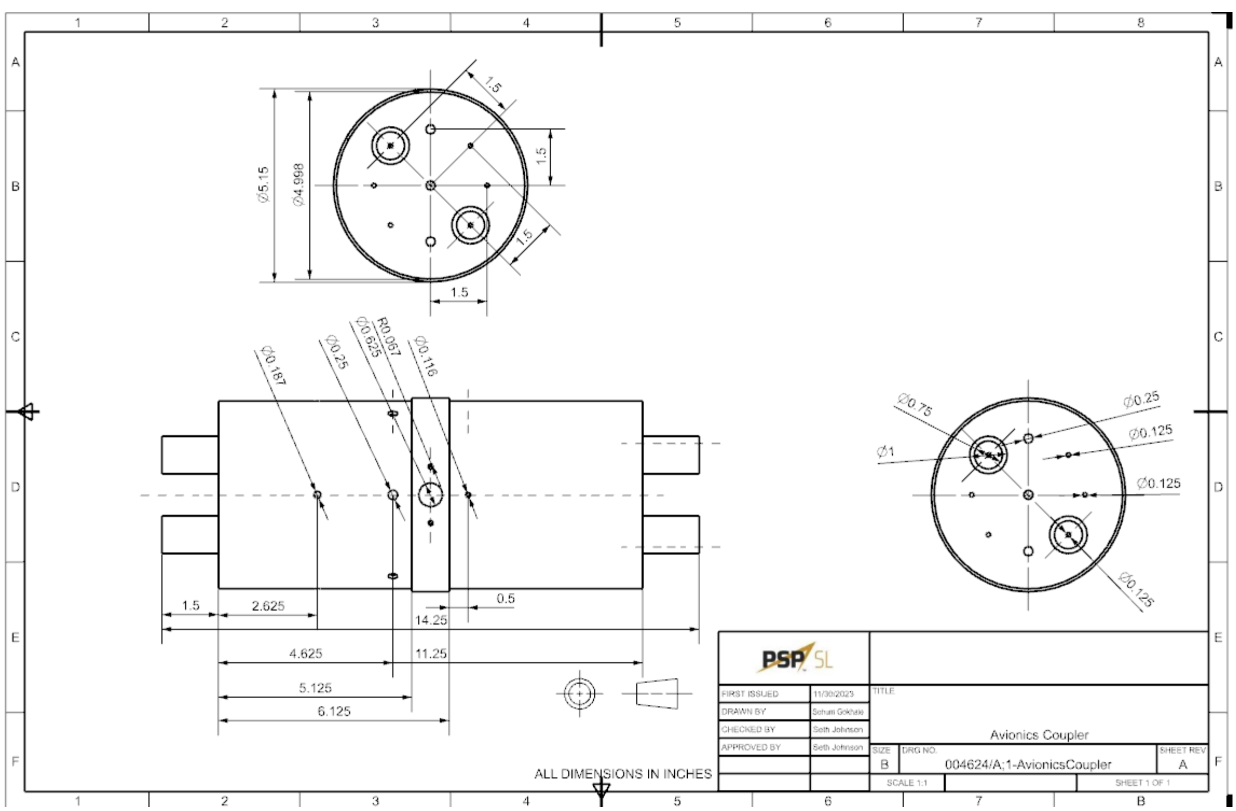


Figure 3.3.17: Avionics Coupler Technical Drawing

Since PDR, the Avionics Coupler has been made 1” longer, there are now static pressure holes along the side of the top section of the coupler, and the diameters of the switch holes have been changed to match the key switches that are being used. Additionally, more holes have been added to the bulkplates. The bulkplates have six 1/8'' holes with one set at 45° from the mounting holes, one set at 90° from the mounting holes, and one set inside the charge wells. The six mounting holes for the booster section have been changed to three 0.116” diameter holes to accommodate shear pins. The switch holes in the center band are now of a diameter of 0.625”. The switch mounting holes are 0.134” in diameter. There are four static pressure holes radially around the top of the coupler that have a diameter of 0.1875”. The switch mounting holes are angularly dimensioned from the switch hole at an angle of 17°.

3.3.2.2 Upper Recovery Airframe

Figure 3.3.18: Upper Recovery Airframe CAD Model

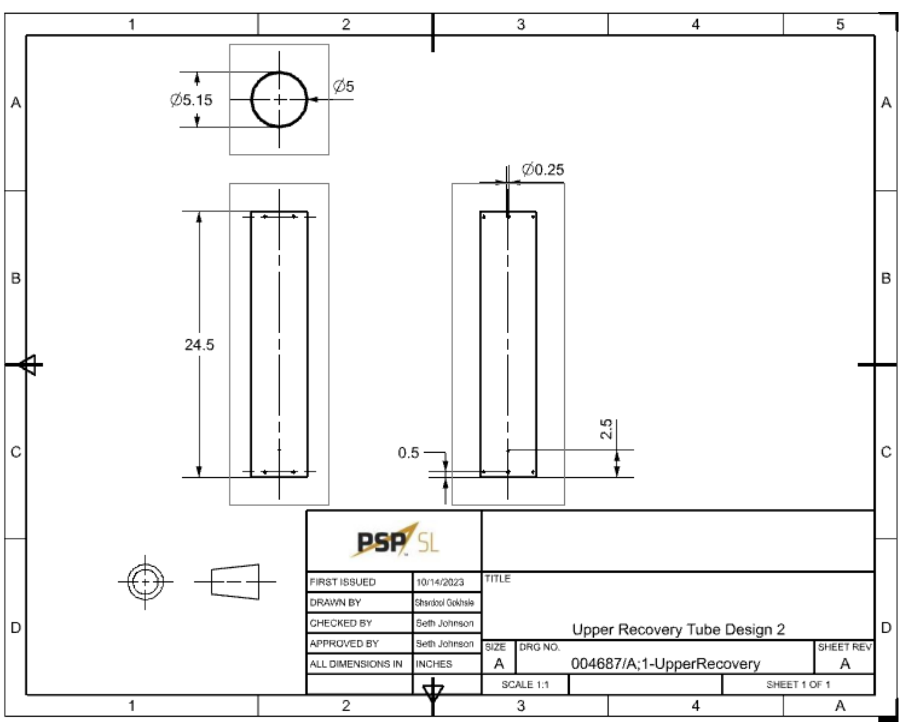


Figure 3.3.19: Upper Recovery Airframe Technical Drawing

The upper recovery airframe is a 24.5” long tube with an inner diameter of 5” and outer diameter of 5.15” made from G12 Fiberglass. There are a total of sixteen holes - six on top and six on the bottom, each 0.25” in diameter and four static pressure holes of diameter 0.1875” radially on the tube.. The top holes will connect the tube to the payload coupler, while the bottom holes will connect to the avionics coupler.

3.3.3 Payload Section

The payload section houses and contains the SAIL during powered flight and ensures it is contained safely until its designated release apogee. This section comprises the payload airframe, payload coupler, SAIL, and all payload electronics. The payload section is tethered to the rest of the launch vehicle, and is separated from the other sections above at the nose cone and below at the payload coupler. Cross-sectional assembly views of the payload section are shown below.

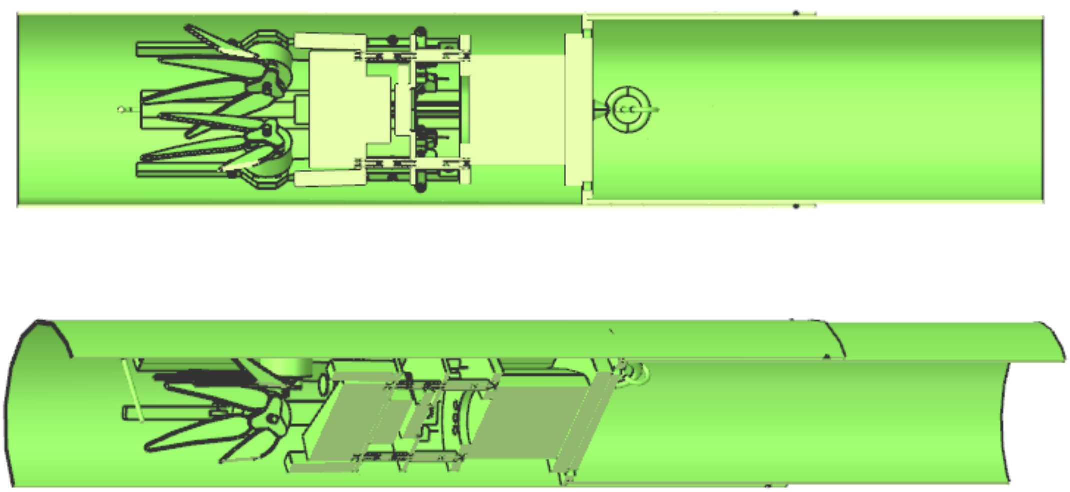


Figure 3.3.20: Payload Section Assembly Cross-Sectional Views

3.3.3.1 Payload Coupler

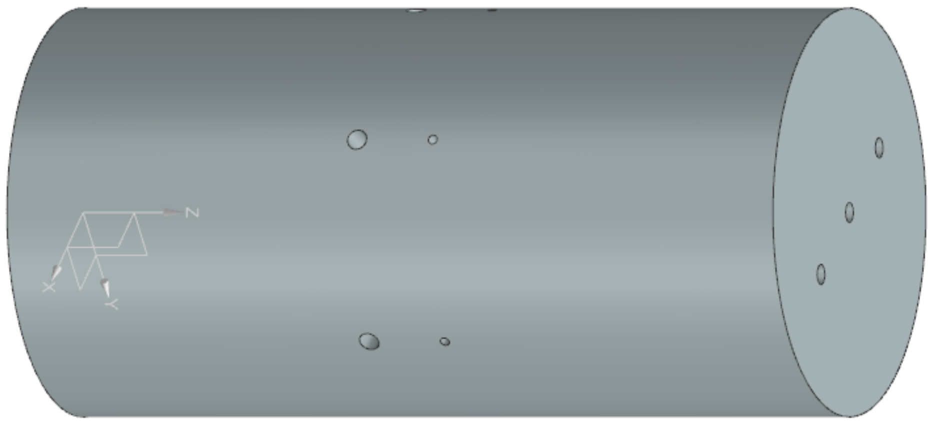


Figure 3.3.21: Payload Coupler CAD Model

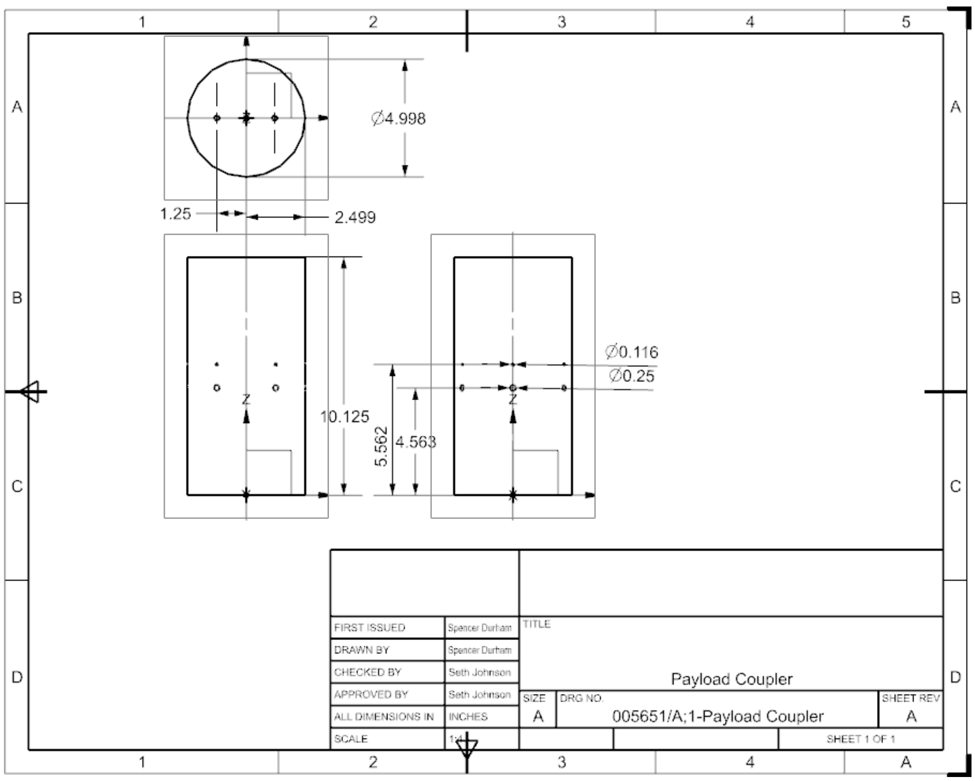


Figure 3.3.22: Payload Coupler Technical Drawing

The upper recovery to lower payload coupler joins and secures the two respective sections of the airframe. The coupler has six holes on one side of center to mount the coupler to the payload airframe using ¾" long ¼" hex screws, and three ⅜" holes on the other side of center to secure the section using shear pins to the recovery section during flight before deployment of the main parachute.

3.3.3.2 Payload Airframe

Figure 3.3.23: Payload Airframe CAD Model

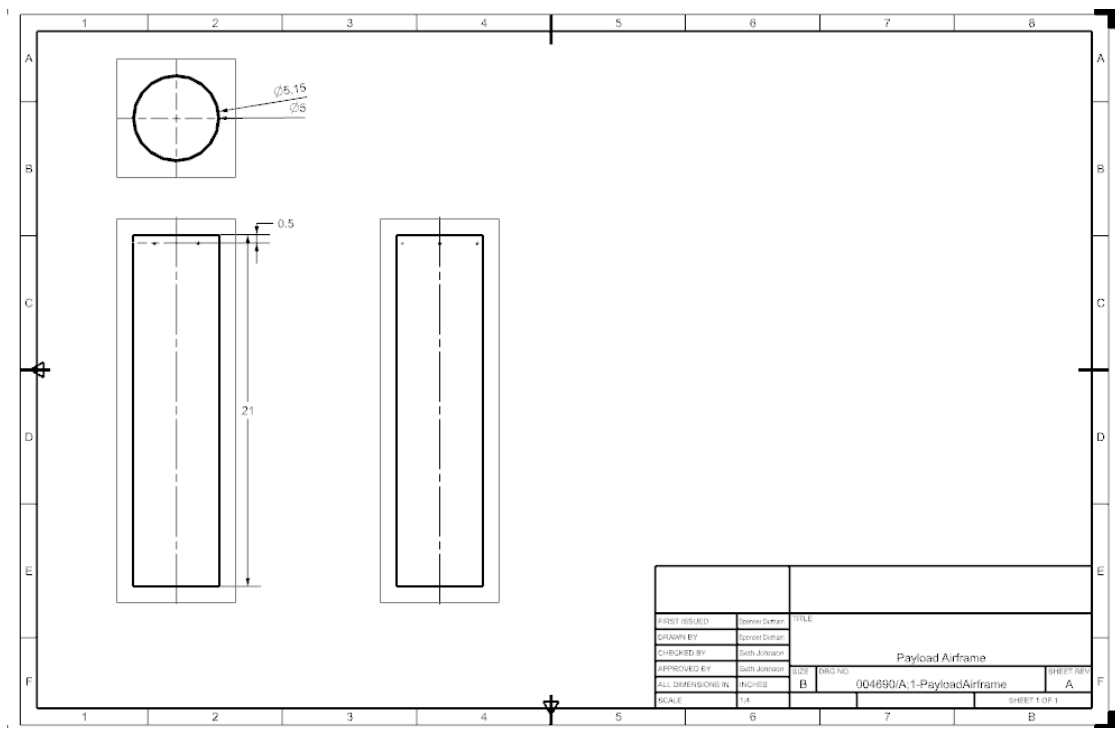


Figure 3.3.24: Payload Airframe Technical Drawing

The payload airframe contains the payload and mounts it to the rest of the launch vehicle. Six equidistant holes are placed along the circumference of the payload airframe, each half an inch from the bottom of the payload airframe. These are used to mount and secure the payload airframe to the payload coupler. These are again secured using six 1/4” holes with 3/4” long hex screws. This connection will allow the recovery parachute to attach to the payload section for a safe landing and recovery. The payload airframe will be made out of G12 fiberglass.

3.3.3.3 Nose Cone

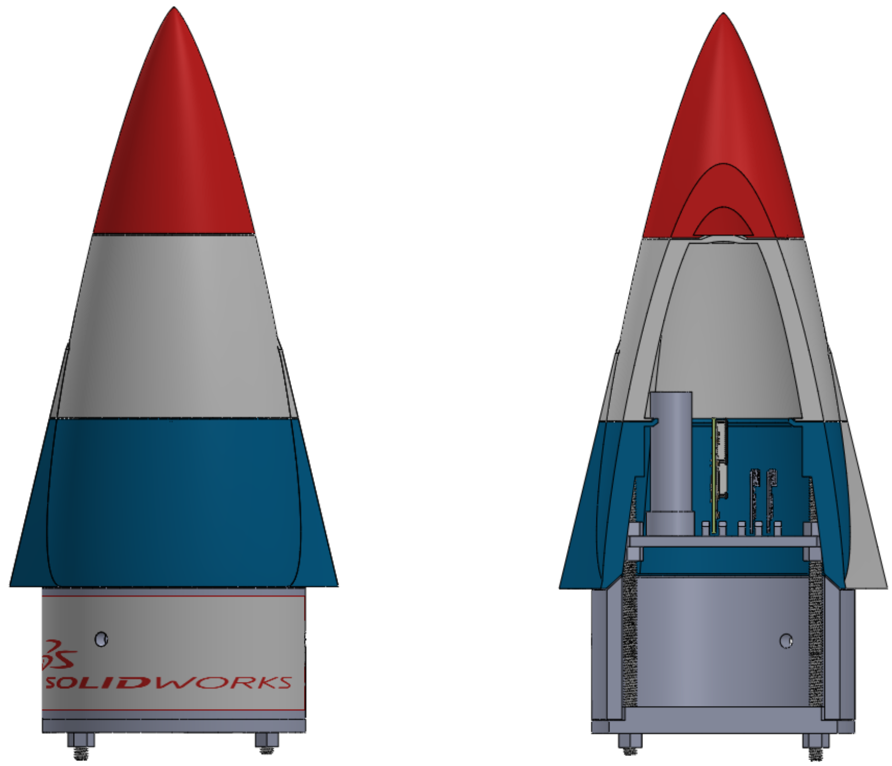


Figure 3.3.25: Nose Cone Assembly CAD Model with Cross Section View

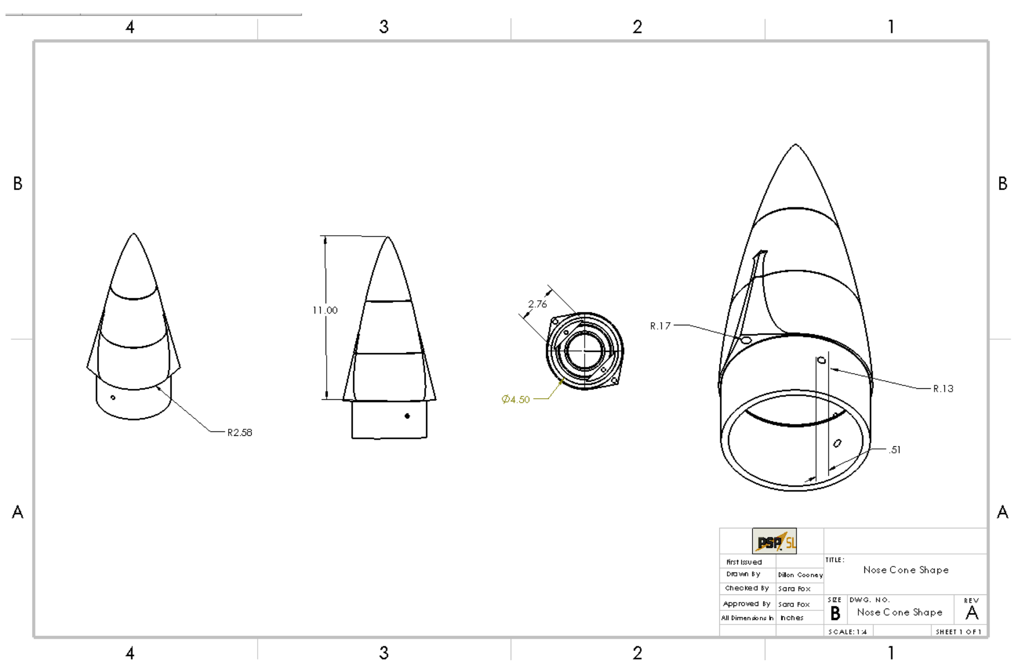


Figure 3.3.26: Nose Cone Technical Drawing

Since PDR, the nose cone height was shortened from 12” to 11” to lower the total mass of the rocket. The nose cone shoulder was also replaced with a bulk plate to connect the nose cone to the airframe, for the same reason of lowering mass. The bulk plate is being secured to the nose cone with two 5” long, 0.25” diameter, threaded rods. Two extrusions were made on the inside of the nose cone, on the same plane as the camera flares, with a hole in the bottom. The rods will be secured by a ¼”-20 nut that will slide into a form fitting hole in the top of the extrusion so that the structure will not twist during flight.

3.4 Points of Separation

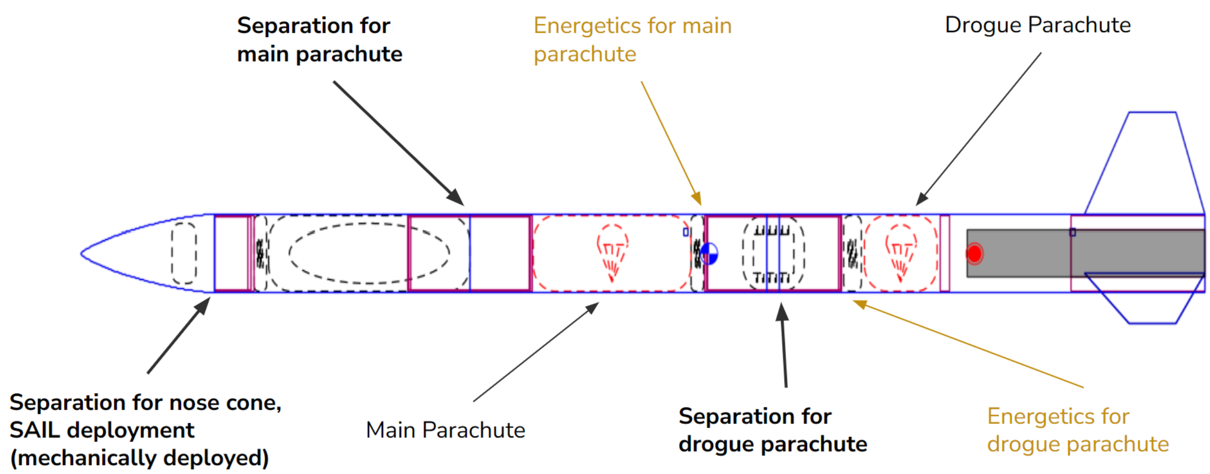


Figure 3.4.1: Locations of energetic material and points of separation

The launch vehicle design for 2024 employs a similar separation method to 2022 and 2023, with one notable change in the separation point for the drogue parachute. Previously, both recovery separation points occurred at couplers separate from the avionics coupler, with one above and one below. This year, the coupler between the booster and recovery sections was eliminated, so the drogue parachute is housed above the motor in the booster airframe with its separation point being located at the avionics coupler. A diagram of the launch vehicle’s separation process is outlined in the figure above, where points of separation are indicated with blue arrows, and the locations of energetic materials are indicated with red arrows. At points of separation for the main and drogue parachutes, charges housed within the bulkheads of the avionics coupler ignite, breaking the shear pins and forcing the two airframes apart, releasing their respective parachutes. A detailed analysis and discussion of the recovery system deployment is delineated in the Avionics and Recovery report in Section 3.8.2. The nose cone is ejected through the use of a mechanical system that is designed to release the nose cone at the desired altitude for SAIL deployment, independent of the recovery modes and systems. The nose cone will also remain tethered to the rest of the launch vehicle for the full duration of flight.

3.5 Manufacturability

3.5.1 Thrust and Centering Plates

Due to the similarity between the thrust and centering plates, both plates will follow similar machining procedures. Both plates will be manufactured from cylinders of aluminum 6061-T6 from Midwest Steel Supply, with a 6.5” diameter and 2” thickness. There will be a total of two operations on the plates, and two operations will be made to manufacture soft jaws. The main operation will be done on the 5-axis Haas UMC-500, where the weight saving slots, fin slots, and screw holes are manufactured. The stock is held in by a Setrite 3-jaw chuck.

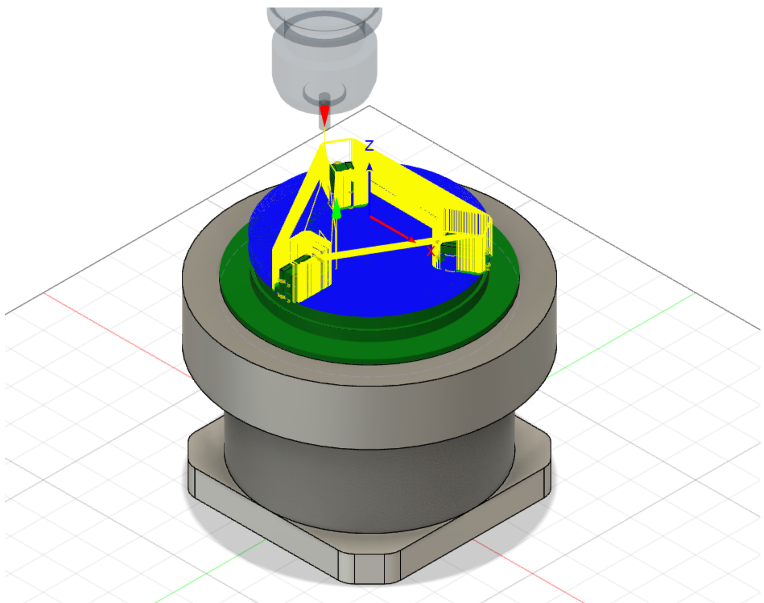


Figure 3.5.1: CAM simulation for UMC-500 operation on thrust and centering plates

The plates then have to be oriented upside down in order to remove the remaining stock, and machine the standoff holes. To hold the plates, soft jaws are machined on the 3-axis Haas VF2 from stock provided by BIDC.

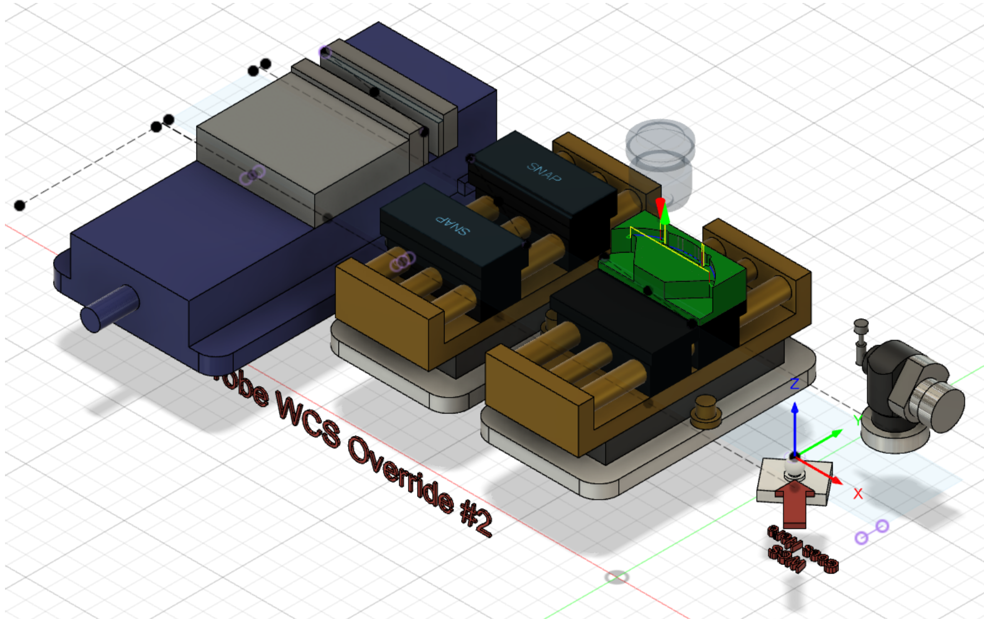


Figure 3.5.2: CAM simulation for VF2 operation on soft jaws

The soft jaws then clamp the plates, and the second operation on the plates is done on the Haas VF2. Here, the additional material used to clamp the stock down on the first operation is cleared, and holes are drilled for the standoff screws.

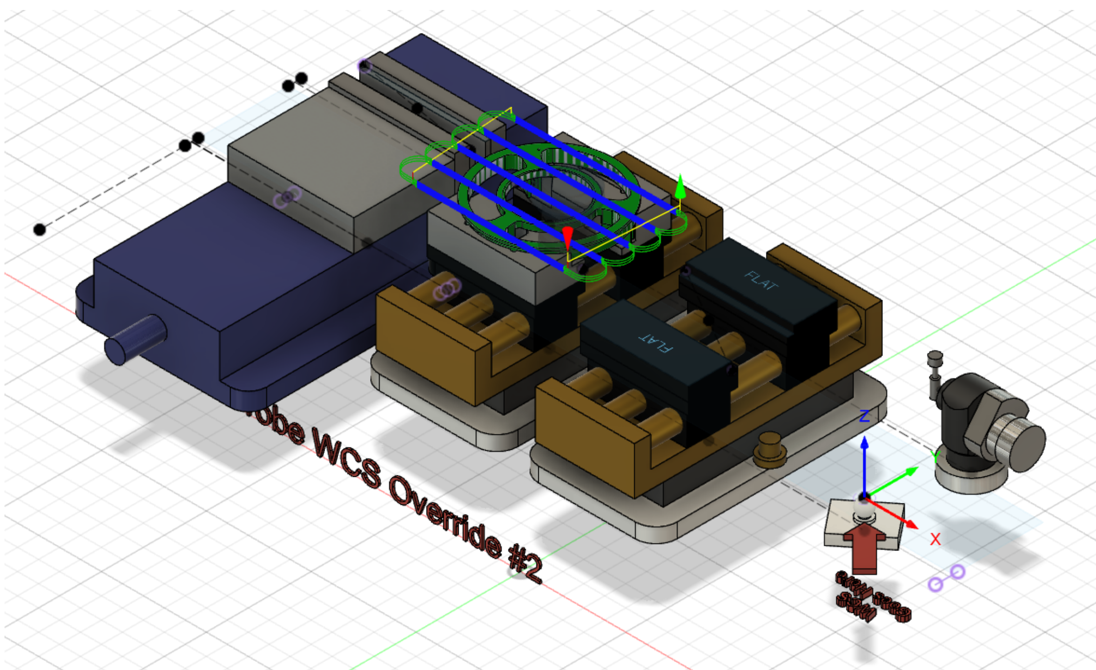


Figure 3.5.3: CAM simulation for VF2 operation on thrust and centering plates

3.5.2 Motor Retainer

The motor retainer has a thickness of 0.125”, and thus can be laser cut. The CAD file was exported as a DWG file, which is what is used by the BIDC laser cutter.

3.5.3 Fins

The fin inserts were manufactured by cutting sheets of fiberglass with a waterjet. The choice of machine was based on practicality, and compatibility with the material: G10 fiberglass. Laser cutters were excluded from consideration due to incompatibility with fiberglass as a material. CNC was considered, though the process would likely be far more complex than necessary for a flat material like the sheets of fiberglass. Instead a waterjet was chosen for its accuracy, simplicity, and relative compatibility with the material.

Figure 3.5.4: Initial waterjet cut of a fin insert

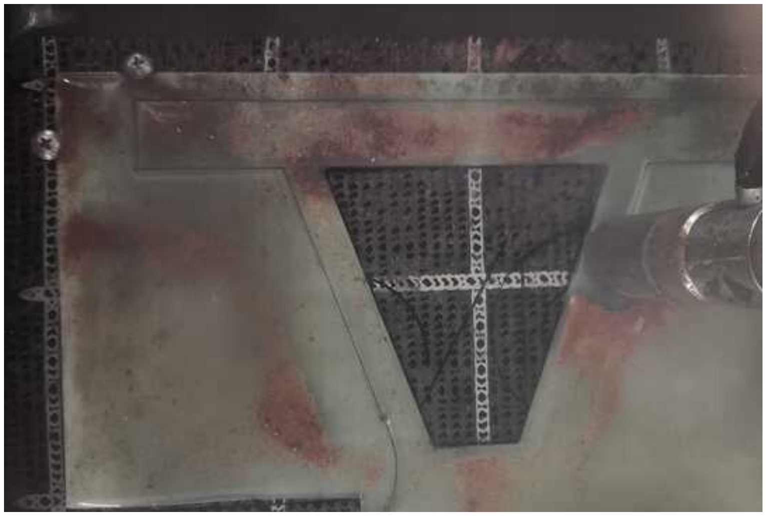


Figure 3.5.5: Fin insert mid cut with center void removed

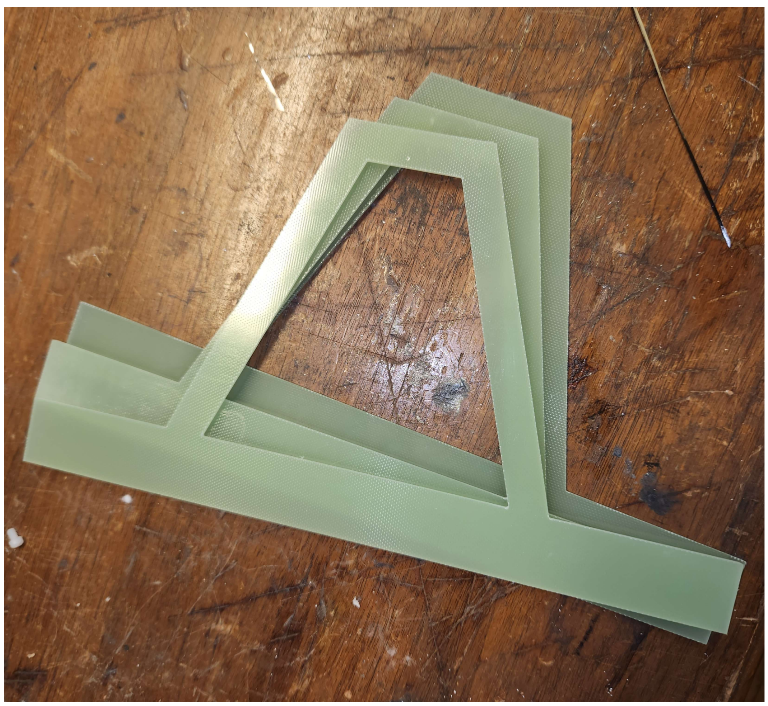


Figure 3.5.6: Water cut fin inserts

The manufacturing of the fin shells is done in a casting process. A box is filled with silicone and a fin is SLA printed to be suspended in the box. After the silicone hardens, the 3D SLA printed fin is taken out of the box which creates a negative in the silicone. This negative is then filled with resin and the fin insert is suspended into the resin. The resin hardens around the insert, creating a composite. Finally, the composite is wrapped in a fiberglass cloth layup, increasing rigidity.

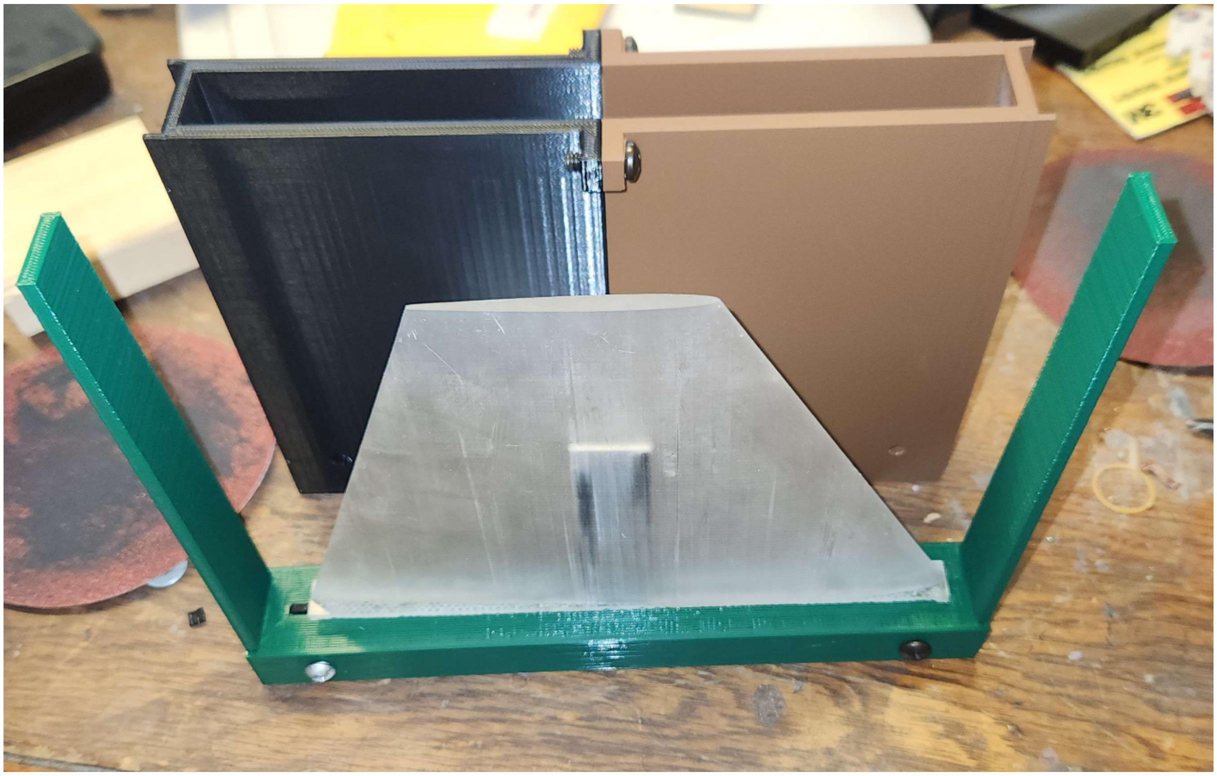


Figure 3.5.7: 3D printed fin for creating negative mold

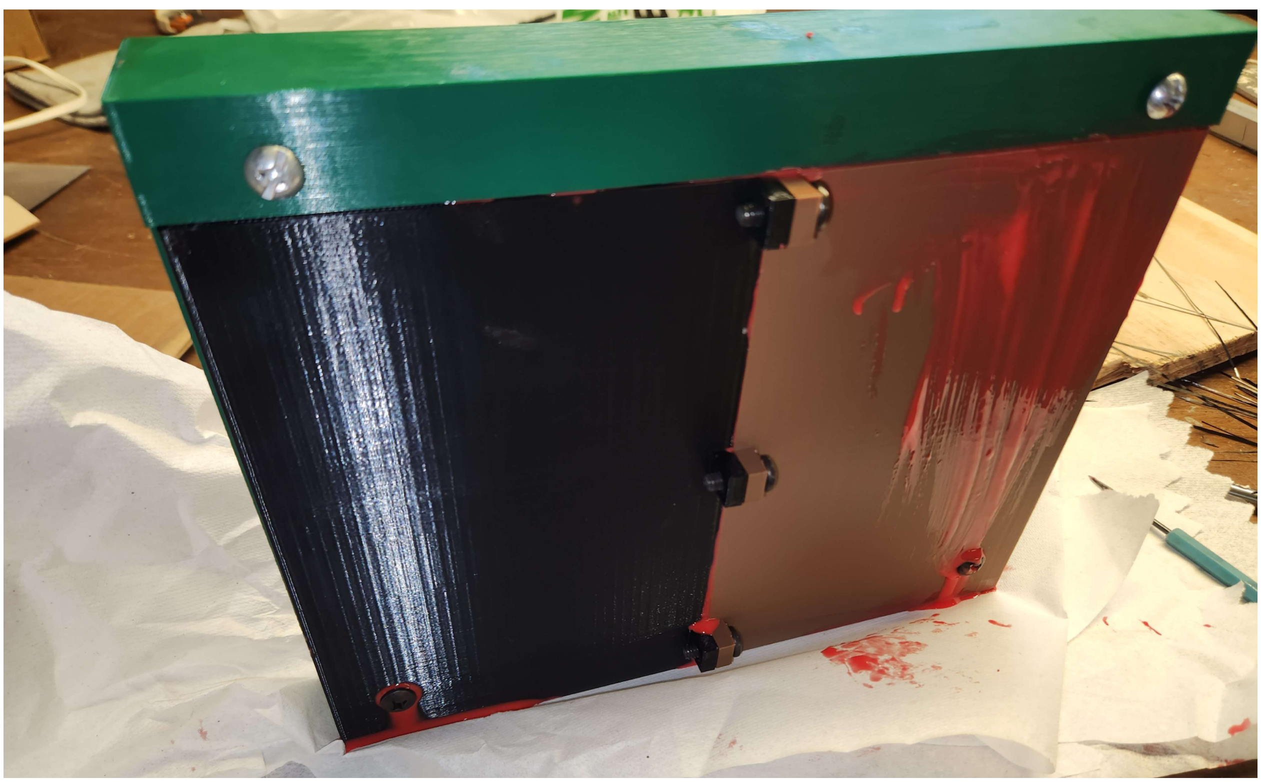


Figure 3.5.8: Casting of negative mold and fin

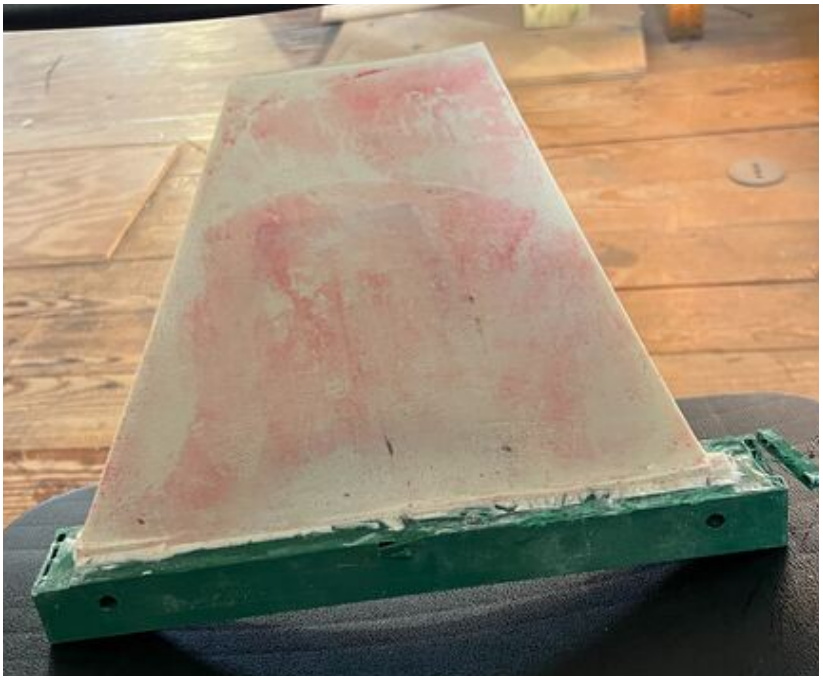


Figure 3.5.9: Finished test fin after removal from mold

3.5.4 Nose Cone

The nose cone will be 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, which will be used to unify and increase the rigidity of the entire structure. The nose cone will be printed on Purdue University printing lab printers that are available to students at little to no cost. This will allow for rapid printing, re-printing, and iteration should the need arise. To simplify the manufacturing process the nose cone will be split into three equal horizontal sections and it will be 3D printed in these three segments using PETG filament. 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. The nose cone design also features sharp internal angles and overhangs which would require significant support in printing and could potentially increase the risk of a printing failure. Printing the nose cone in separate pieces mitigates this issue and significantly cuts the printing time. To reinforce the segmented structure, there will be a fiberglass layup. To create the fiberglass layup, layers of fiberglass will be epoxied on top of each other and then the nose cone will be placed in a negative mold to apply pressure to the layup as it dries.

3.5.5 Airframe

The jigs were designed to print quickly and decrease manufacturing time, while also allowing for precision drilling into the airframe. A hexagonal shape was utilized for the design of all jigs to prevent the parts from rolling and spinning during the manufacturing process. The inner and outer diameter, lengths, and hole spacing of jigs differed depending on the part being manufactured. Some jigs were also skeletonized as shown below in Figure 3.5.10 to decrease printing times. Manufacturing was simplified by using G12 fiberglass, a material the team has experience working with, to construct the airframe. Using G12 fiberglass allowed the team to gain experience using mills, drills, and other tools that will be essential when constructing the full scale launch vehicle. In addition to this, the proportions of the jigs used to construct the subscale launch vehicle can be increased and re-used for the construction of the full scale launch vehicle. Re-using a familiar jig design will significantly simplify the construction process for the full scale launch vehicle.

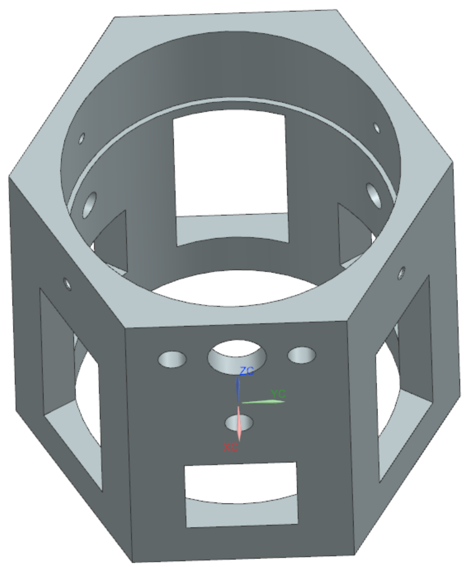


Figure 3.5.10: Avionics Coupler Jig

3.6 Design Integrity

3.6.1 Fins

3.6.1.1 Fin Shape and Style

The selected fin design is a trapezoidal airfoiled fin. Initially a root chord of 9.9”, height of 6.7”, tip chord of 3.8”, and a sweep length of 3.7”. The trailing edge of the fin has been truncated to help decrease the chance of the fin fracturing by ensuring no portion of the fin is too thin. This reasoning is also what influenced the choice to utilize a NACA 0006 airfoil, as it provided an acceptable thickness and rigidity while maintaining a low mass. The shape of the fin was originally found by utilizing OpenRocket to simulate changes in fin shape. This was then run in a few OpenRocket simulations to find important results like apogee, off the rail stability, and top speed stability. These data points were collected for certain increments based on each main defining characteristic of the fin shape for each simulation desired. With this data, it was then easy to find optimal dimensions for the characteristics of the fin to reach a desired stability and apogee. These optimal dimensions were then utilized simultaneously to find an initial optimal design. This design was then further altered multiple times to provide alternatives. With multiple alternatives that met all requirements, a final decision was made by selecting the design that met further self imposed requirements.

3.6.1.2 Fin Flutter Analysis

Seeing the success of our previous year's analysis, and to further reinforce confidence in the chosen design, it was decided to perform a second fin flutter analysis. This was done through modeling the fin as two springs: one torsional, and one bending. The fin, assumed to be straight cantilevered, was mounted to a table and then loaded in such a way as to apply a downwards tip force, and later a torque as well. This allowed for visual data to be collected based upon the loaded weight and measured deflection, giving both a torsional spring constant and a bending spring constant. These were found using $K_H = \frac{P_H}{\delta_t}$ to model the bending spring, and $K_\alpha = \frac{P_\alpha d}{\theta}$ to model the torsion spring. These were then applied in the determinate equation $(m\omega^2 - K_h)(I_\alpha \omega^2 - K_\alpha + C_{L\alpha} qSx_{ac}) - S_\alpha \omega^2 (S_\alpha \omega^2 - C_{L\alpha} qS) = 0$. Where ω represents the harmonic motion, m is mass, I_α is the polar inertia, S_α is the coupling inertia, S is the cross sectional area, q is dynamic pressure, $C_{L\alpha}$ is the lift curve slope, x_{ac} is the distance from the center of lift. K_h and K_α are the spring constants from the previous two equations. Once the determinate equation is solved for ω is is realized that the motion becomes unstable when $B^2 < 4AC$. Where B = $(S_\alpha C_{L\alpha} qS + mC_{L\alpha} qSx_{ac} - mK_\alpha + I_\alpha K_h)$, A = $(A = mI_\alpha - S_\alpha^2)$, and $C = (K_h K_\alpha - K_h C_{L\alpha} qSx_{ac})$. The last remaining changing variable is dynamic pressure. With the altitudes considered for the launch vehicle, air density can be roughly assumed constant leaving velocity to be the main dynamic variable. As such, a model can be created where a change in velocity causes a change in the value of the previous equation. By subtracting $4AC$ from B^2 one can find where the equation first turns negative, resulting in the point of maximum safe velocity.

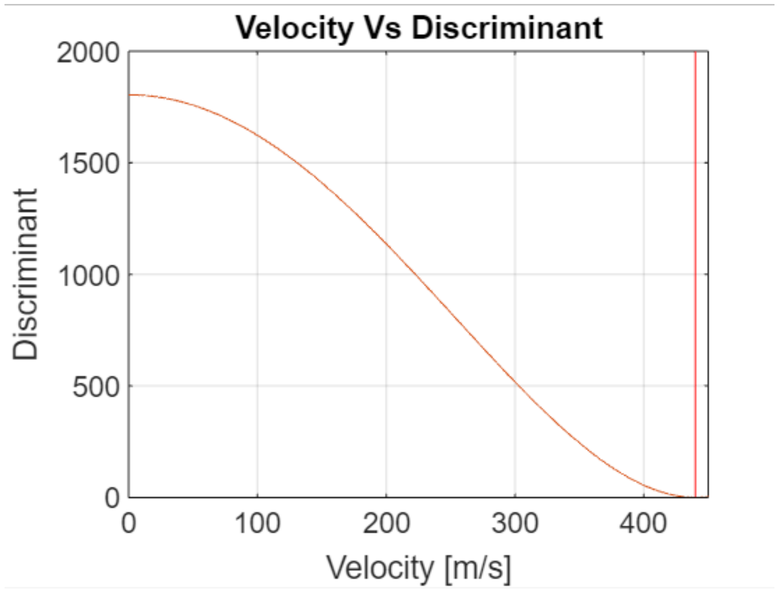


Figure 3.6.1: Value of the discriminant over different velocities

As shown by the graph, the maximum safe velocity is roughly 440m/s. This is well above any expected velocities that the launch vehicle is expected to reach. Unfortunately this is also rather contradictory to our previous analysis which was stated to be significantly higher velocities. The problem likely lies in the fact that not only does this model assume uniform density and material, but also that the spring constants would not change with different loads. All of which is fairly problematic when analyzing composites.

Figure 3.6.2: Torsion spring test

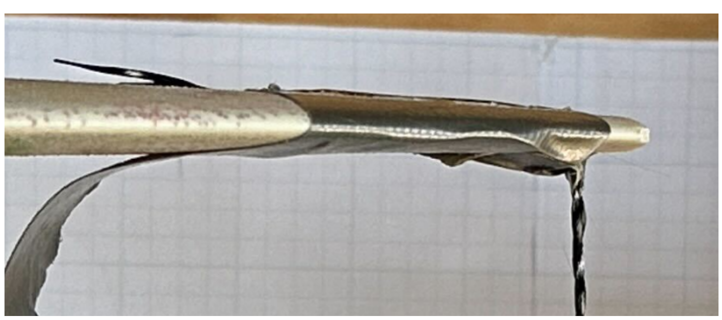


Figure 3.6.3: Bending spring test

3.6.1.3 Flight Stability

Flight stability was one of the major considerations of the design of the fins. Given how the fins are likely the most relevant part to the flight stability, the task of meeting the stability requirements falls primarily to who designs the fins. PSP-SL created a self imposed requirement of a minimum off the rail stability of 2.2, which is above the handbook requirement. This was done while also meeting another self imposed requirement of having less than 5 stability at maximum velocity. The launch vehicle is currently simulated to have an off the rail stability of 2.25 and maximum velocity stability of 4.6. These stabilities ensure that the launch vehicle will not pitch or yaw off course, while also not weather cocking into the wind.

3.6.1.4 Airfoil Design

In regard to the airfoil of the fin, it was determined that a NACA 0006 would be optimal. This is because it allows for smoother flow over the fins while also not producing significant lift due to the symmetrical nature of the airfoil. Further, in comparison to other airfoils used in prior years, 0006 is overall thicker, resulting in a stronger airfoil. This was decided as necessary given the larger fins in comparison to previous years.

3.6.1.5 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:

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

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.

3.6.1.6 Fin FEA

To simulate the potential damage to the fins during a landing, ANSYS was used to model a force of 370N applied to the fin. This force was derived using the formula $F = \frac{mv}{t}$, where the mass is the mass of the booster section, velocity is the maximum expected speed on landing and time is equal to .1 seconds to simulate a landing on soft dirt.

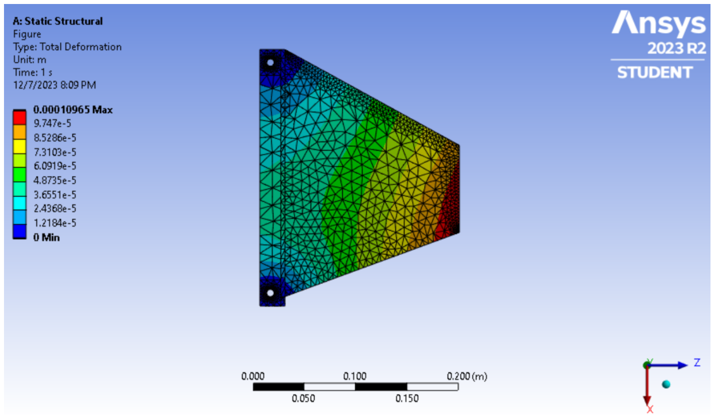


Figure 3.6.4: Landing Deformation of the fin

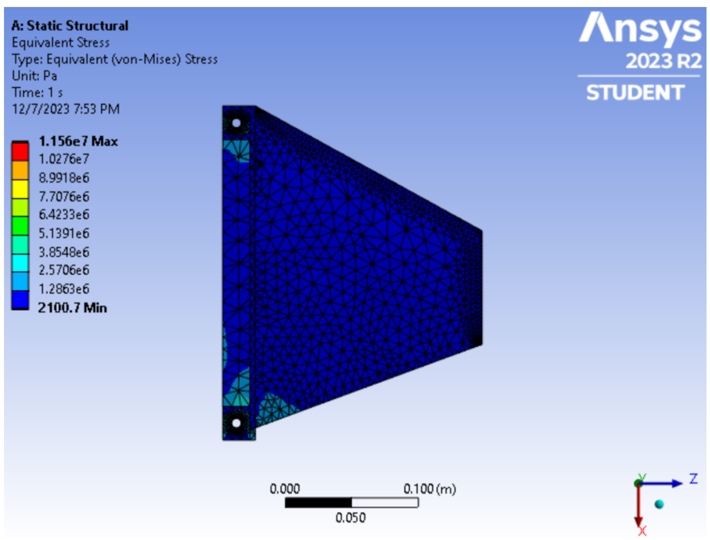


Figure 3.6.5: Landing Stress on the fin

With the previous ANSYS simulation, it is shown that the maximum deformation of the fin during flight is 0.1mm, while the maximum stress experienced during landing is approximately $1.15\text{x}10^7$ pascals. With these values ANSYS still displays a safety factor of 15, which is the program's maximum displayable value. Using the same formula since PDR to calculate the expected in flight pressure on the fins. Since the maximum velocity and altitude has only undergone a minimal change since PDR the expected pressure is roughly the same at 42kPa.

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

Once again, Bernoulli's was used at STP and simplified to account for initial conditions, and it was assumed that the air pressure at the launch site would be roughly that of 500', which is approximately 99.5kPa.

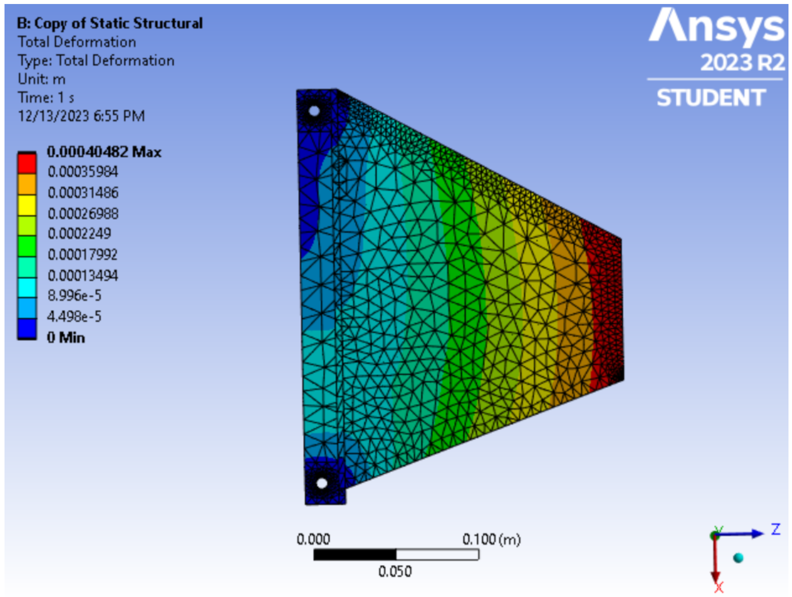


Figure 3.6.6: In flight deformation of the fin

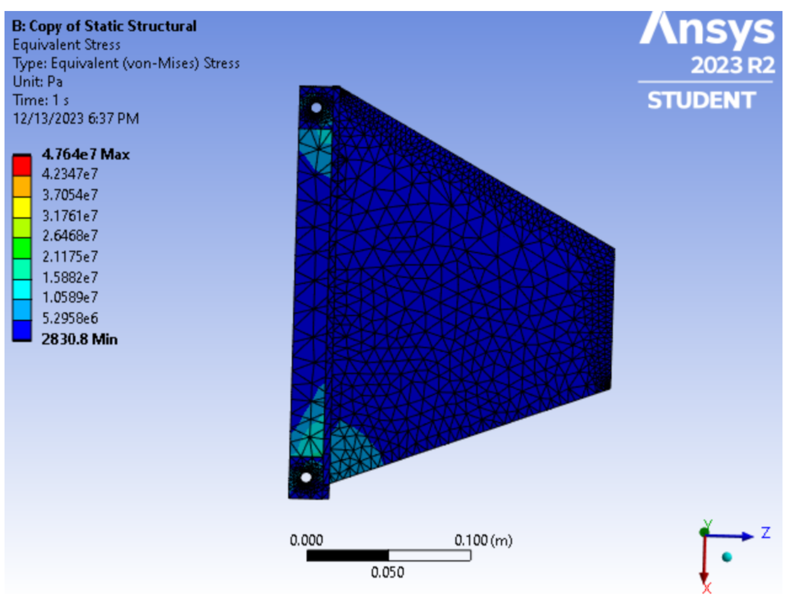


Figure 3.6.7: In flight stress on the fin

ANSYS shows a maximum deformation of .4mm on the fins during flight. It further shows a maximum expected stress of 4.764E7 pascals.

3.6.2 Material Selection

3.6.2.1 Motor Fin Support Structure

Table 3.6.1: MFSS Material Comparison Analysis

Subteam Needs	Technical Needs	Weight	304 STAINLESS STEEL	AL 6061-T6	Ti6AI4V
High Strength	Yield Strength (psi)		30,000	35,000	128,000
		1	$(1)\frac{30,000}{100,000} = 0.30$	$(1)\frac{35,000}{100,000} = 0.35$	$(1)\frac{128,000}{100,000} = 1.28$
Low Weight	Mass Density (lb/in³)		0.29	0.1	0.16
		2	$(2)\frac{.29}{.5} = 1.16$	$(2)\frac{.1}{.5} = 0.4$	$(2)\frac{.16}{.5} = 0.64$
Low Cost	Cost of 6"x6" plate, 1 ± 0.125" thick (USD)		$75.04	$40.36	$800.50
		6	$(6)(1 - \frac{75.04}{100}) = 1.50$	$(6)(1 - \frac{40.36}{100}) = 3.60$	$(6)(1 - \frac{800.5}{100}) =-$
Yield Strength / Mass Density Ratio	Yield Strength / Mass Density Ratio (in)		103,960.62	358,813.57	800,000
		3	$(3)\frac{103,960.62}{500,000} = 1.89$	$(3)\frac{358,813.57}{500,000} = 2.16$	$(3)\frac{800,000}{500,000} = 4.8$
Manufacturability	–	0.5	Good	Excellent	Poor
			(.75)(.5)= 0.375	(1)(.5)= 0.5	(.5)(.5)= 0.25
Totals			**5.225**	**7.01**	**-35.06**

Table 3.6.2: Material Decision Matrix

Subteam Need	Weight
High Strength	1
Low Weight	2
Low Cost	6

Subteam Need	Weight
Yield Strength / Mass Density Ratio	3
Manufacturability	0.5

The team chose commonly used alloys that could potentially be used as the material for the MFSS. To determine which alloy was best for us, we created a decision matrix that factors in the relevant properties of each alloy. The ideal alloy for us would be something lightweight, strong, easy to work with, and cheap. We weighted these properties based on how important each factor is when determining which alloy is better. Multiplying all these values by the weight allows us to quantify how good each alloy is. After tallying up all the points, the alloy with the most points should be the best one for the job. The cost of the alloy was the most important, so the team gave it a weight of 6. Yield strength to mass density ratio, low weight, high strength, and manufacturability were weighted at 3, 2, 1, 0.5 respectively. The cost is weighted heavily because every other metric deals with the structural integrity of the MFSS. Therefore, to justify a more expensive material, the alloy would have to be substantially more stable. The team wanted to minimize the weight and maximize the strength. These desires are reflected in the equations used when calculating the points. The main takeaway from this analysis is: stainless steel is comparable to AL 6061-T6, but it is harder to manufacture, Titanium is much stronger, but it is extremely expensive, and AL 6061-T6 is easy to manufacture, cheap, and strong enough for our purposes.

3.6.2.2 Fins

Unchanged since PDR, the material selection for the fins remains a resin-fiberglass composite. The reasoning behind such also remains. The alternative material would be a 3D printed nylon shell. In previous years this has repeatedly proven to be exceedingly expensive. Not only due to the cost of outsourcing manufacturing, but also due to the fact that fins made of this material were not very survivable, often breaking after landing. This resulted in the need for numerous replacements throughout testing. Instead, utilizing the composite material last year gave proof to its survivability, and relative low cost. FEA as detailed in 3.5.1.6 further backs the idea of the fins being significantly more survivable. The material choice also leads to in-house manufacturing, where members of PSP-SL manufacture the fins themselves. This gives rise to several opportunities for skills to be built for those who participate.

3.6.2.3 Interior Pressurization Bulk Plate

The interior pressurization bulkplate allows for pressurization of the drogue parachute section to separate the vehicle at the avionics bay coupler and deploy the drogue parachute. This bulkplate is assumed to be non-weight bearing, as the eyebolt intended to bear the load of the forces induced during recovery is threaded through the bulkplate and into the top closure of the motor casing. It is assumed that the vast majority of the force is hence transferred into the motor casing, MFSS, and airframe. In the initial design phase, PETG was considered as an option to conserve mass while also being able to easily manufacture complex geometries in 3D printing. However, the heat produced during the black powder ignition was a concern. Initial testing of a PETG bulkplate demonstrated its survivability for one ejection test, but concerns were raised about this solution being fully reusable for several launches. It was then decided that the same material selection standards employed for the MFSS would be applied to this bulkplate, emphasizing strength, durability, and the added element of heat resistance. Aluminum 6061 was selected from the same process as illuminated in Table 3.6.1.

3.6.2.4 Airframe/Coupler Bulkheads

Table 3.6.3: Airframe Material Decision Matrix

Design Criteria	**Design Options**			
Material Criteria	**Weights**	**Carbon Fiber**	**G12 Fiberglass**	**PETG/PTFE**
Price	5	2	5	2
Manufacturability	4	5	4	2
Strength / Toughness	5	2	4	3
Weight	4	5	4	5
Totals		14	17	12
Choice Made				

The final design choice for airframe construction was the G12 fiberglass, which was carefully chosen using the weights presented in the above decision matrix. As this team is a student organization, cost is of heavy consideration and it was found that fiberglass is much cheaper compared to other materials. Furthermore, material strength and toughness were also given greater consideration over other factors. While carbon fiber is a much harder material (2500Mpa to 7000MPa), it is brittle and prone to cracking when bent. Fiberglass on the other hand has a lower hardness (2000MPa to 5600MPa), but has a higher fracture toughness rating. Both material weight and manufacturability were given lower consideration and ultimately did not heavily influence the final decision. Fiberglass tended to perform a little lower in these categories as it can be harder to manufacture due to the need for respirators while working with it and a need for a UV paint coating to be applied. However, due to prior experience working with G12 fiberglass it was chosen over G10 and the other materials. Fiberglass was also found to be heavier than the other materials with PETG/PTFE being around 70% of the weight of fiberglass. Finally, while not included in the decision matrix, consideration was given to which material had the least interference with electronics. It was found that carbon fiber introduces significantly more interference with the avionics and payload electronics, making it a much less favorable option.

Constructing the airframe using the G12 fiberglass ensures that it will withstand the forces experienced during flight without shattering, as well as being economically viable. For these reasons, the bulkheads of the airframe were also constructed using this material, except for the booster bulkhead, which was constructed using PETG as the specific shape of that bulkhead cannot be constructed using the G12 fiberglass. 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 a report written for internal use for Purdue Research (Michalaros & O'Brien, 2021).

Table 3.6.4: Compressive Strength of each layup

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 3.6.5: Shell buckling failure stress and loads 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

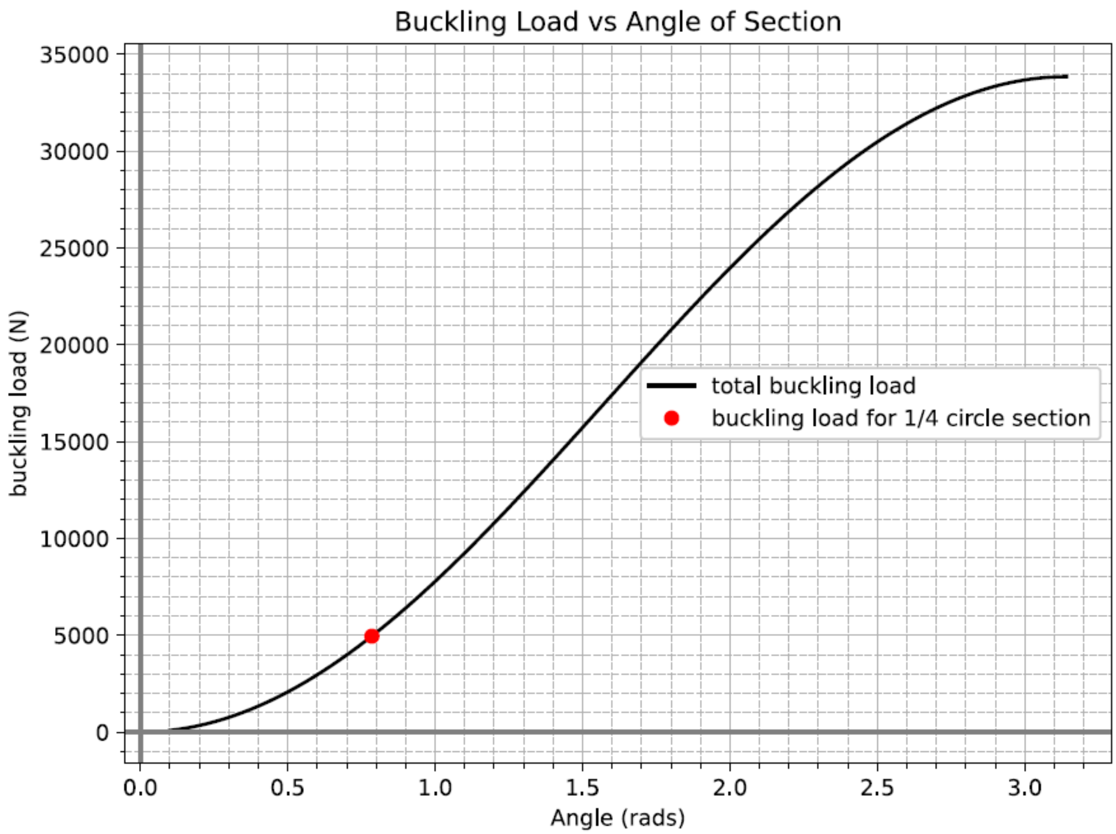


Figure 3.6.8: Buckling Load vs. Angle of Section

3.6.2.5 Nose Cone

The team opted to change the material of the nose cone from ASA to PETG. Both have similar material properties (namely ductility, impact and chemical resistance), but ASA was selected in PDR for its UV resistance. However, ASA produces fumes during the printing process that would require the nose cone to be commercially produced, as the printing labs on campus do not have the capability to use this filament safely. PETG was then chosen so the team could have greater control over the manufacturing process by manufacturing the nose cone on campus. This selection also allows for iteration of the design if necessary.

3.6.3 Motor Mounting and Retention Analysis

To verify the design for the MFSS, FEA was conducted using the ANSYS Static-Structural module. The max predicted stress for each component was applied to the relevant faces, and the equivalent stress, total deformation, and safety factor were calculated. Exaggerated deformation scales are used to show locations of displacement. The minimum safety factor for each MFSS component is 1.5.

3.6.3.1 Thrust Plate

The maximum force of the motor is 1812.7 N, and is applied to the thrust plate through the motor lip area on the bottom face. Fixed support conditions were set for three airframe screw holes on the outer face, and roller supports were set to the relevant inner and outer edges, where rotation around the vertical axis is allowed. The minimum safety factor is 1.82, which is above the 1.5 requirement (S.C. 8).

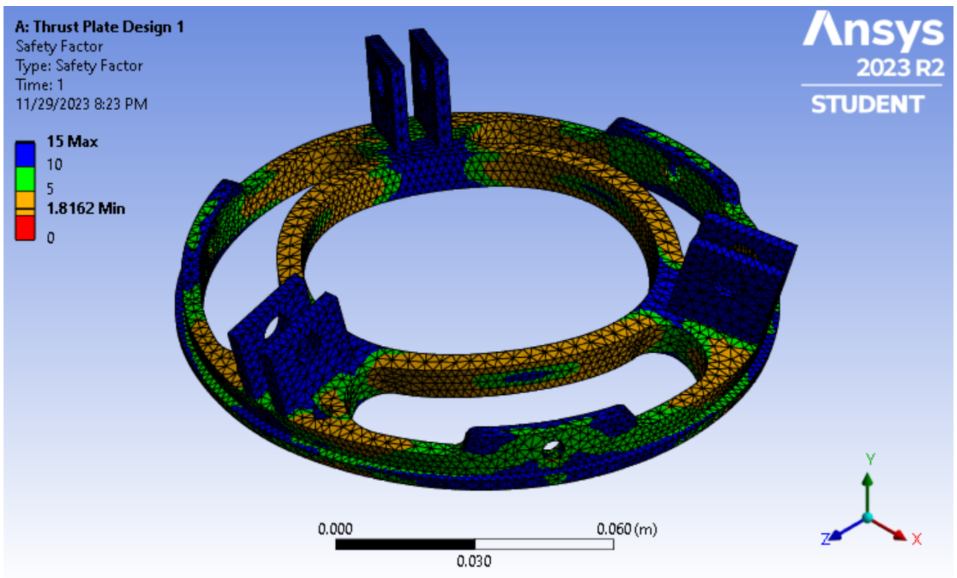


Figure 3.6.9: Safety Factor FEA of Thrust Plate

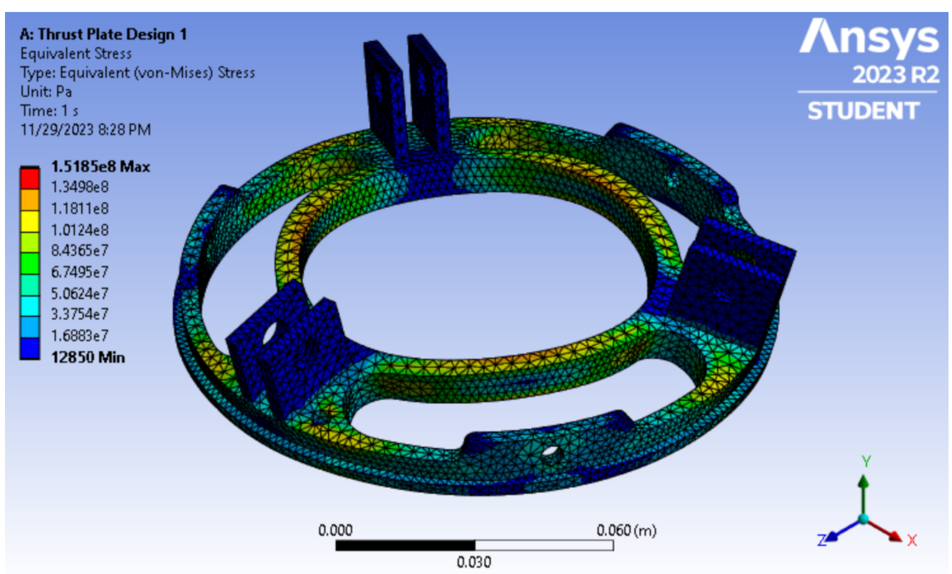


Figure 3.6.10: Equivalent Von-Mises Stress FEA of Thrust Plate

3.6.3.2 Centering Plate

FEA was done through Ansys to determine the safety factor of the MFSS. We looked at the max stress each component would experience as well as the safety factor at those stresses. The analysis was done with the worst case scenario: the thrust plate fails, and maximum motor force of 1812.7N on the top of the centering plate. Fixed supports were defined at the airframe holes and around the centering plate. The deformation scale was adjusted to make deformations more visually identifiable. The minimum factor of safety is 4.9248 which vastly exceeds the minimum requirement of 1.5.

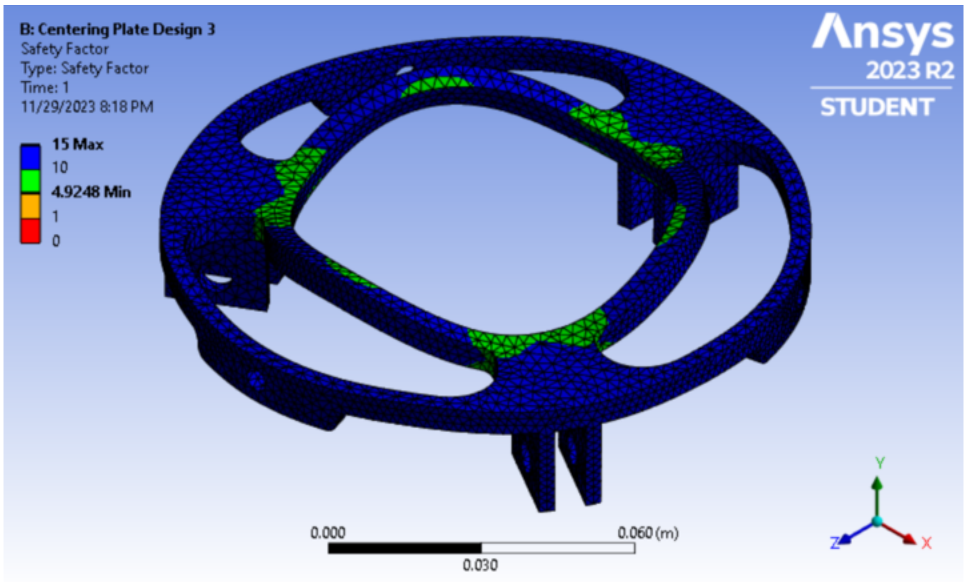


Figure 3.6.11: Safety Factor FEA of Centering Plate

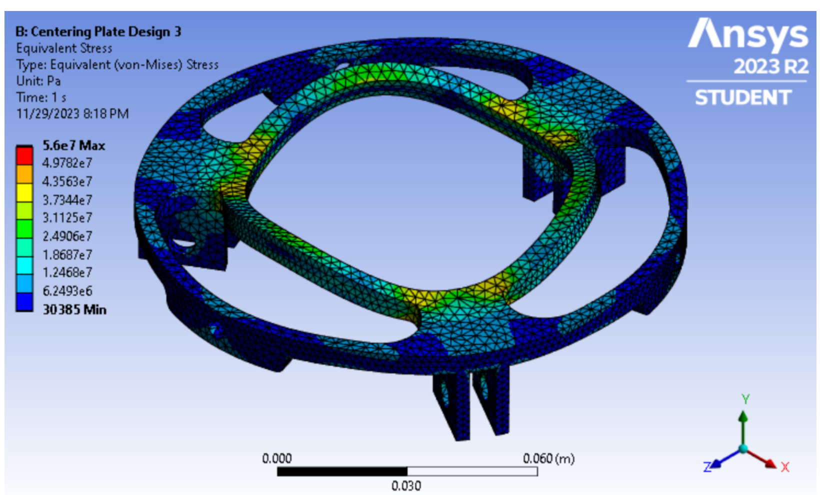


Figure 3.6.12: Equivalent Von-Mises Stress FEA of Centering Plate

3.6.3.3 Retainer Plate

The motor plate does not take any stress from the motor; the main force this plate must withstand is the landing force. This force was calculated using $F = \frac{mv}{t}$, where t is assumed to be .1s for an impact on soft dirt. This equation yields a force of 370 N. We assume this is applied uniformly to the bottom face. The plate design was slightly updated to match the adjusted thrust plate, so our new minimum safety factor is 2.46, which is comfortably above the minimum target of 1.5. This should provide some leeway should the parachute fail, causing the rocket to hit the ground with a greater velocity.

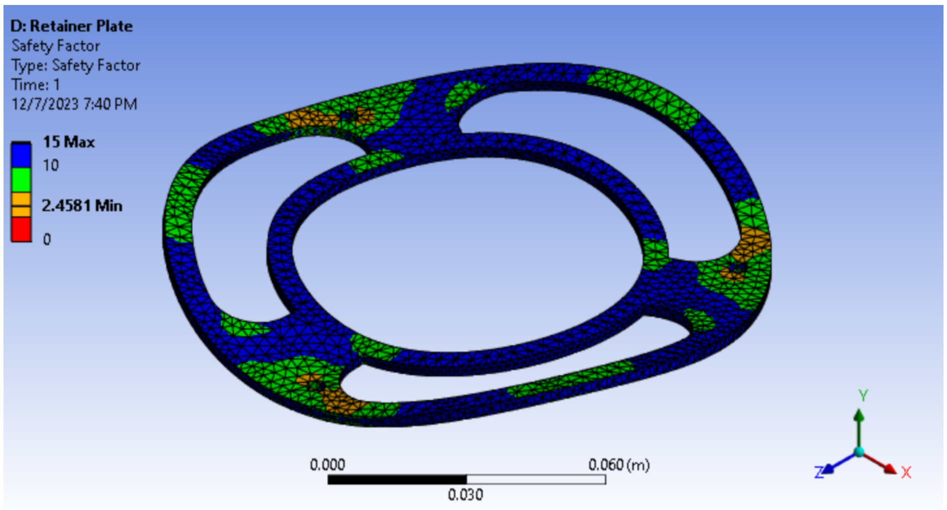


Figure 3.6.13: Safety Factor FEA of Retainer Plate

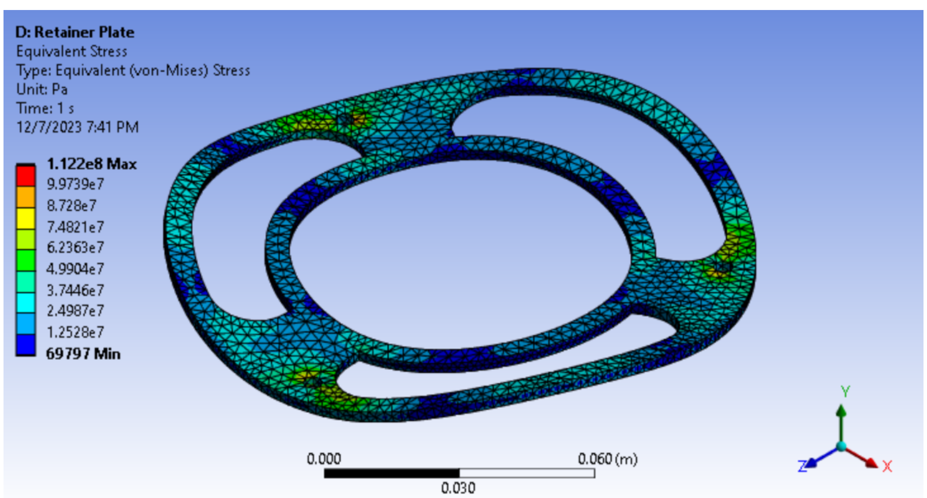


Figure 3.6.14: Equivalent Von-Mises Stress FEA of Retainer Plate

3.6.3.4 Interior Pressurization Bulk Plate

The expected force on the pressurization bulk plate is from the separation charges, which generate a pressure of 22 psi. The plate is machined from aluminum 6061-T6. The minimum safety factor of the plate is 15 in all regions, which is the maximum output value from ANSYS.

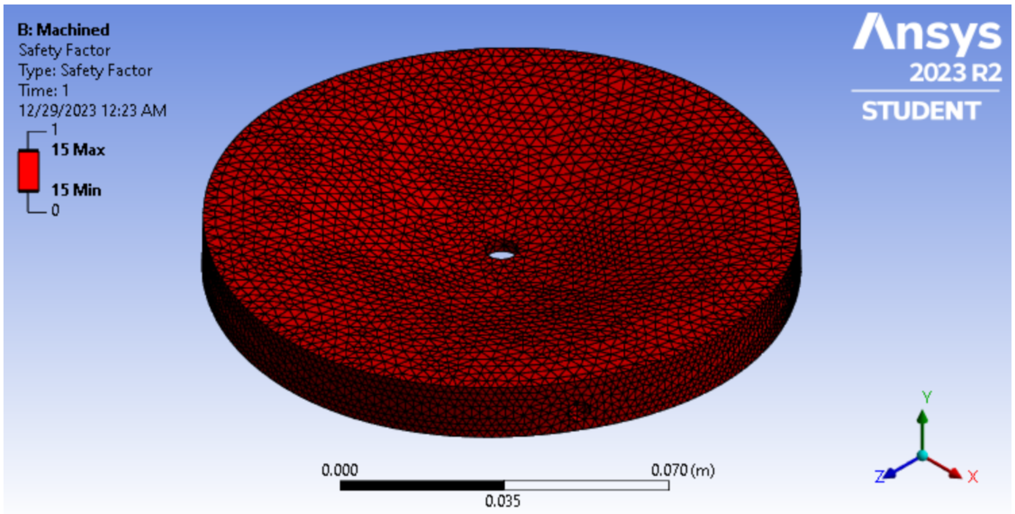


Figure 3.6.15: Safety Factor FEA of Pressurization Bulk Plate

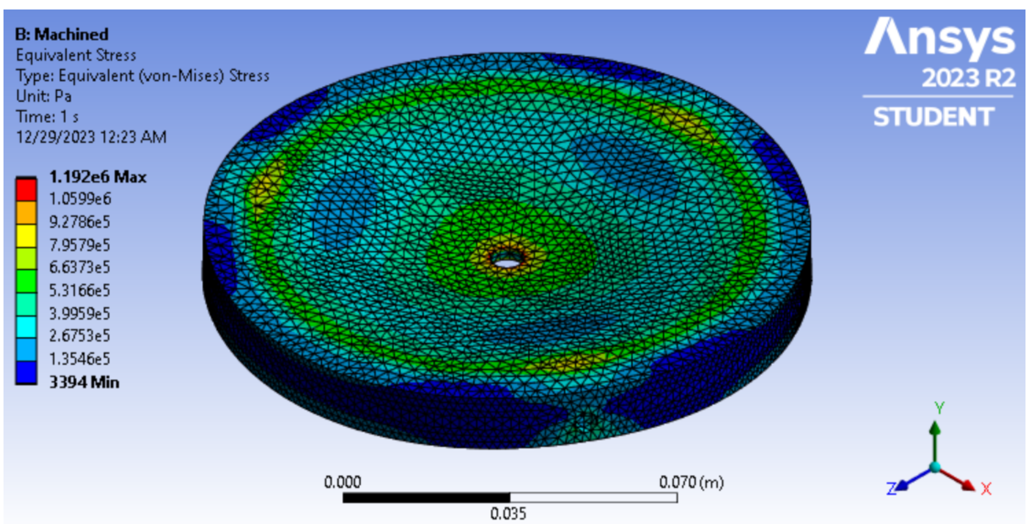


Figure 3.6.16: Equivalent Von-Mises Stress FEA of Pressurization Bulk Plate

3.6.3.5 MFSS Assembly

FEA was performed on the full MFSS assembly to analyze structural performance for the combined structure. The independent FEA simulations assume that the fin inserts have failed and are non-load bearing, so the full FEA simulation provides a better view of structural integrity. The results provide a minimum safety factor of 5.97, which is far above the minimum requirement of 1.5.

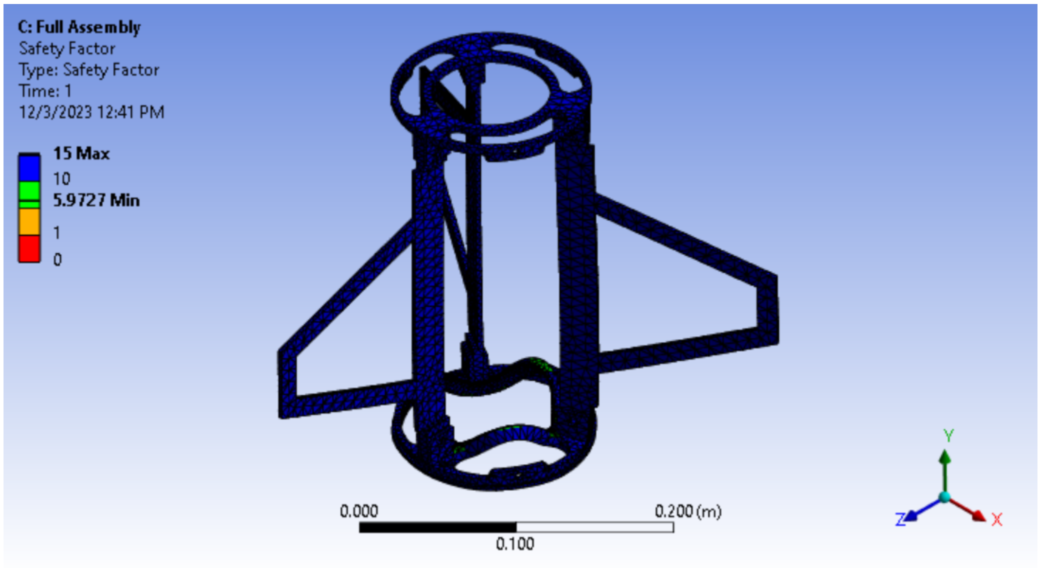


Figure 3.6.17: Safety Factor FEA of MFSS Assembly

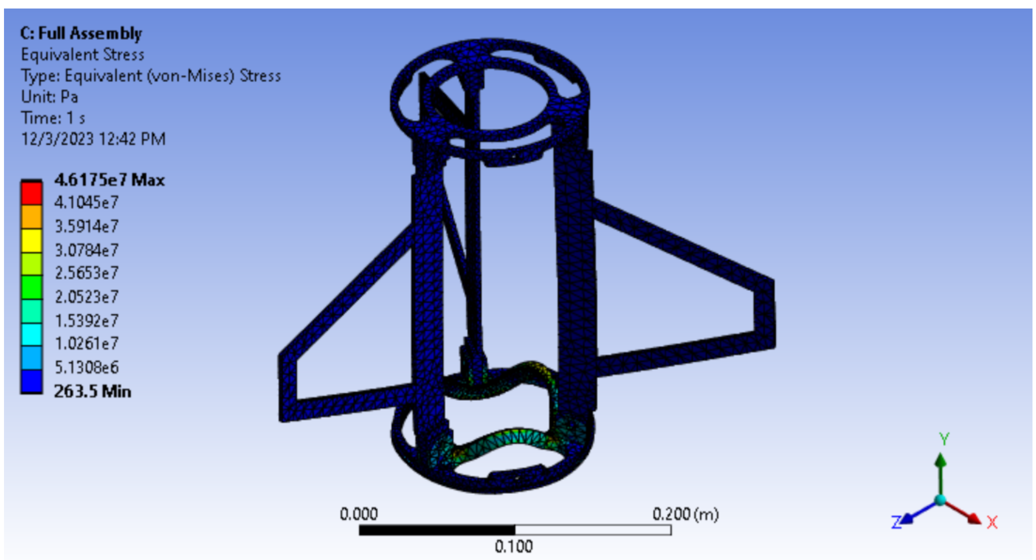


Figure 3.6.18: Equivalent Von-Mises Stress FEA of MFSS Assembly

3.6.4 Full Launch Vehicle CFD

CFD simulations were run on the launch vehicle to ensure that no areas of instability existed and that the pressure-induced temperature remained below the limits of external materials. The figures below show the pressure contour and temperature heat map results. Additionally, the simulations were run at the maximum velocity and the corresponding altitude according to the OpenRocket simulations. The SST k-omega turbulence model was used, with ideal gas compressibility and the Sutherland viscous model. The maximum temperature hit is 315 K (107 F). This is far below the melting temperature of fiberglass, which is 500 F.

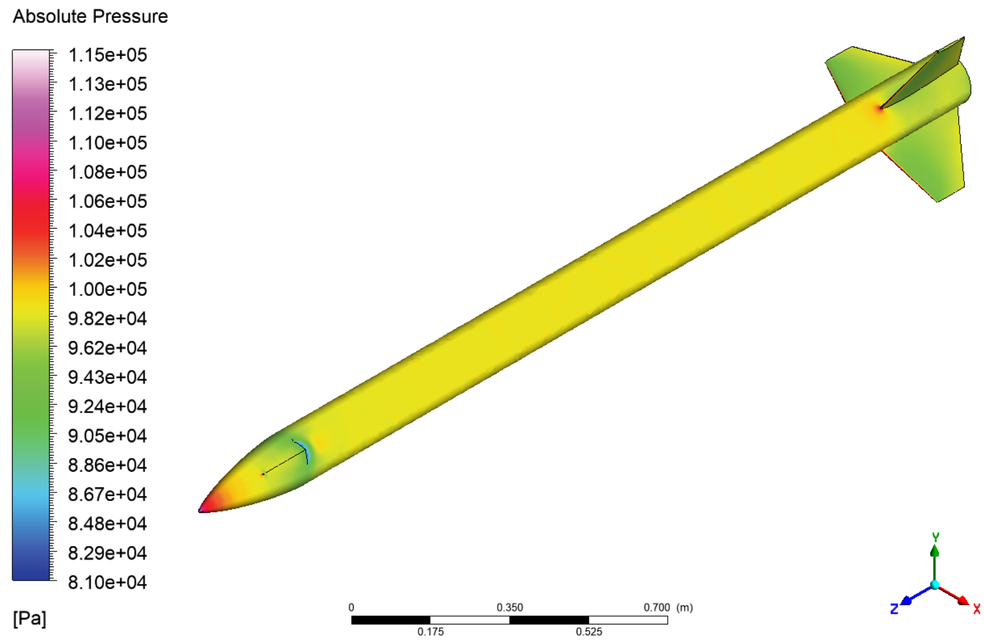


Figure 3.6.19: Pressure Contour Results

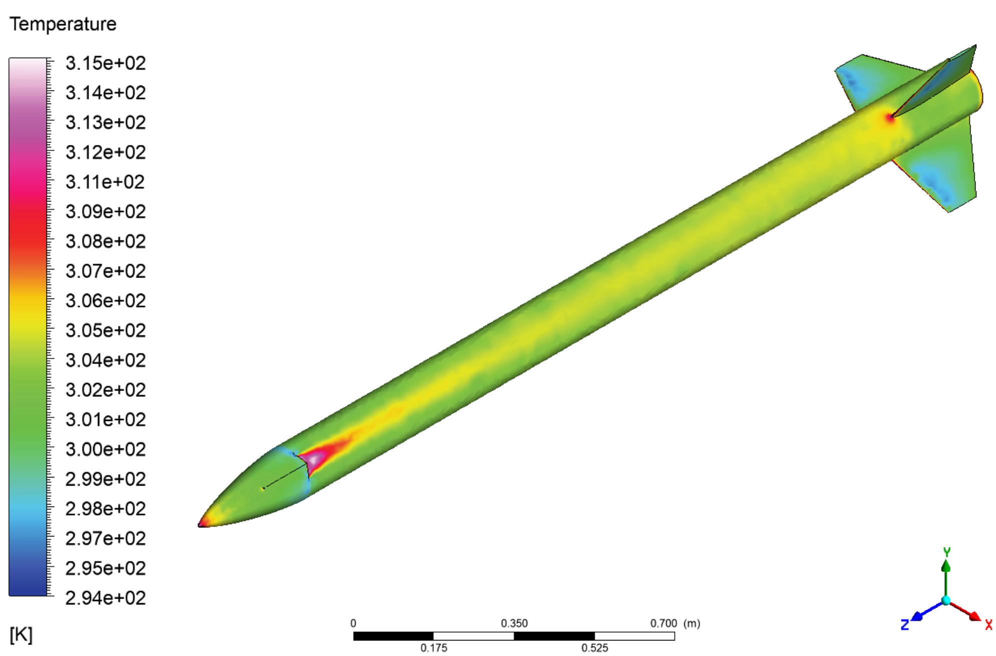


Figure 3.6.20: Temperature contour results

3.6.5 Mass of Vehicle and Sub-Sections

The vehicle's mass was calculated by utilizing estimates made in OpenRocket as well as physically weighing components in the team's possession. Because the launch vehicle is lighter than in previous competition years, it was not necessary to maintain as low of an apogee as possible to be able to hit competition requirements for descent time and landing kinetic energy. This year's vehicle achieves all requirements with a large margin for error, so no ballast is added to decrease the target apogee. Careful attention to mass distribution along the vehicle resulted in a highly stable launch vehicle with a higher minimum stability than was predicted in years past, which also eliminated the need for ballast in the nose cone to improve stability margins. The overall system design was tailored to improve overall efficiency by eliminating unnecessary components, reducing mass and improving performance within competition metrics. The table below presents the weight of each major section.

Table 3.6.6: Section Weight

Full Vehicle	Payload	Recovery	Booster
41.7lb	14.66lb	10.28lb	16.76lb (wet) 12.76lb (dry)

Parts Detail

Sustainer

Nose cone	PVC (1.39 g/cm^3)	Haack series	Len: 11 in	Mass: 1.5 lb
Tube coupler	G10 Fiberglass (2.02 g/cm^3)	Dia_{in} 4.756 in Dia_{out} 4.98 in	Len: 3 in	Mass: 0.376 lb
Camera Bay		Dia_{out} 4 in		Mass: 1 lb
Bulkhead	PETG (1 g/cm^3)	Dia_{out} 4.98 in	Len: 0.5 in	Mass: 0.352 lb
Payload	G10 Fiberglass (2.02 g/cm^3)	Dia_{in} 4.98 in Dia_{out} 5.15 in	Len: 21 in	Mass: 2.08 lb
Payload Coupler	G10 Fiberglass (2.02 g/cm^3)	Dia_{in} 4.756 in Dia_{out} 4.98 in	Len: 10 in	Mass: 1.25 lb
Bulkhead	G10 Fiberglass (2.02 g/cm^3)	Dia_{out} 4.756 in	Len: 0.125 in	Mass: 0.162 lb
Bulkhead	G10 Fiberglass (2.02 g/cm^3)	Dia_{out} 5 in	Len: 0.125 in	Mass: 0.179 lb
Bulkhead	G10 Fiberglass (2.02 g/cm^3)	Dia_{out} 4.756 in	Len: 0.125 in	Mass: 0.162 lb
Bulkhead	G10 Fiberglass (2.02 g/cm^3)	Dia_{out} 5 in	Len: 0.125 in	Mass: 0.179 lb
Payload		Dia_{out} 5 in		Mass: 7.5 lb
Shock Cord	Tubular nylon (14 mm, 9/16 in) (16 g/m)		Len: 14 in	Mass: 0.013 lb
Upper Recovery	G10 Fiberglass (2.02 g/cm^3)	Dia_{in} 4.98 in Dia_{out} 5.15 in	Len: 24.5 in	Mass: 2.42 lb
Main	Ripstop nylon (67 g/m^2)	Dia_{out} 120 in	Len: 13 in	Mass: 1.78 lb
Shroud Lines	Tubular nylon (11 mm, 7/16 in) (13 g/m)	Lines: 8	Len: 120 in	

Shock cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 15.748 in	Mass: 2 lb
Launch lug	Aluminum (2.7 g/cm³)	Dia$_{in}$ 0 in Dia$_{out}$ 0.5 in	Len: 0.4 in	Mass: 0.008 lb
Avionics	G10 Fiberglass (2.02 g/cm³)	Dia$_{in}$ 4.98 in Dia$_{out}$ 5.15 in	Len: 1 in	Mass: 0.099 lb
Unspecified		Dia$_{out}$ 5 in		Mass: 1.25 lb
Tube coupler	G10 Fiberglass (2.02 g/cm³)	Dia$_{in}$ 4.756 in Dia$_{out}$ 4.98 in	Len: 11 in	Mass: 1.38 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.756 in	Len: 0.125 in	Mass: 0.512 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 5 in	Len: 0.125 in	Mass: 0.164 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 4.756 in	Len: 0.125 in	Mass: 0.148 lb
Bulkhead	Fiberglass (1.85 g/cm³)	Dia$_{out}$ 5 in	Len: 0.125 in	Mass: 0.52 lb
Booster	G10 Fiberglass (2.02 g/cm³)	Dia$_{in}$ 4.98 in Dia$_{out}$ 5.15 in	Len: 35 in	Mass: 3.46 lb
Shock cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 15.748 in	Mass: 2 lb
MFSS	Aluminum (2.7 g/cm³)	Dia$_{in}$ 3.15 in Dia$_{out}$ 5 in	Len: 11 in	Mass: 0.755 lb
Fins (3)	EpoxAcast™ 670 HT (1.15 g/cm³)	Thick: 0.594 in		Mass: 2.25 lb
Drogue	Ripstop nylon (67 g/m²)	Dia$_{out}$ 15 in	Len: 6 in	Mass: 0.133 lb
Shroud Lines	Tubular nylon (11 mm, 7/16 in) (13 g/m)	Lines: 8	Len: 20 in	
Interior Pressurization Bulkplate	Aluminum (2.7 g/cm³)	Dia$_{out}$ 4.98 in	Len: 0.8 in	Mass: 0.3 lb
Launch lug	Aluminum (2.7 g/cm³)	Dia$_{in}$ 0 in Dia$_{out}$ 0.5 in	Len: 0.4 in	Mass: 0.008 lb

Figure 3.6.21 OpenRocket Parts Detail with Component Masses

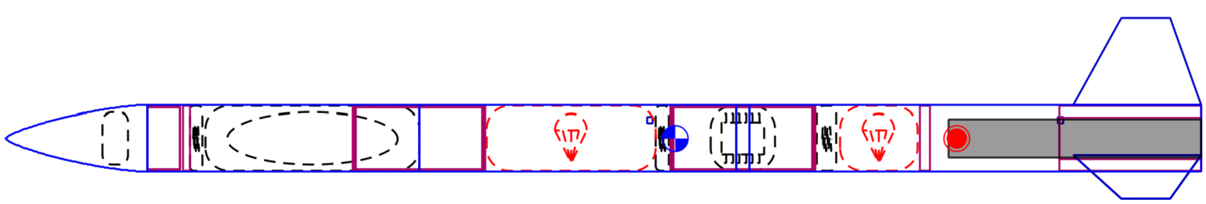


Figure 3.6.22 OpenRocket Model of the Launch Vehicle

3.7 Subscale Flight Results

3.7.1 Subscale Mission Statement

The subscale flight's main mission objective is to verify the aerodynamic design and stability of the full-size launch vehicle on a smaller scale. Scaling of the launch vehicle allows for validation of simulations to be able to assess the team's ability to accurately model the full scale launch vehicle. The subscale flight also gives the payload team an opportunity to test basic electronic hardware and get more experience with flight data. Below is a comprehensive overview of the subscale launch.

3.7.2 Scaling of Launch Vehicle

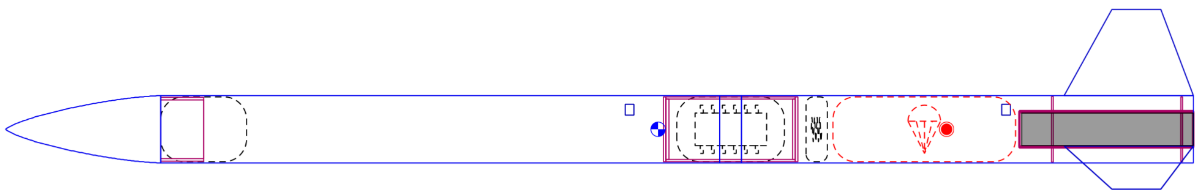


Figure 3.7.1: Subscale Launch Vehicle OpenRocket Model

The subscale flight aims to demonstrate the feasibility of the final launch vehicle by remaining geometrically scalable. To accomplish this, a 60% scaling factor was applied to the diameter and length of each section, as well as to the individual parameters of the nose cone and fins. The subscale vehicle is not a direct scale model of the full launch vehicle, but it maintains many of the same major properties and overall dimensions. Sections are merged to create an upper payload section and a lower booster section, with one separation point at the avionics coupler between the two sections. The subscale vehicle only utilizes one parachute with one separation point. Because of this, one exception to the scale factor was applied. Last year, the team struggled to pack the parachute into the lower section airframe, leading to concerns that tight packing may inhibit deployment, especially since motor ejection is utilized to initiate separation rather than energetics. Furthermore, the team wanted to demonstrate a landing kinetic energy proportional to that of the full scale vehicle. To accomplish both of these tasks, a three foot parachute was selected rather than a four foot, and one inch was subtracted from the scaled version of the upper section airframe and added to the measurement of the lower section to allow for a larger packing volume. Airframe lengths were also rounded to the nearest inch or half inch because the manufacturing method of cutting the airframe by hand with a band saw does not allow for a large enough degree of precision to allow for highly precise measurements. After investigating the differences in flight metrics after incorporating these changes, it was concluded that the effects are negligible with respect to the overall vehicle behavior while allowing for safer assembly. The mass of the launch vehicle was not scaled by 60% because volume does not scale linearly, and the payload includes a simple arrangement of electronics, not a scaled version of the SAIL. The chosen motor, an Aerotech HP-I140W, was appropriately scaled in an effort to achieve the necessary flight metrics, namely the landing kinetic energy, to provide adequate data to compare predictions to the full scale vehicle. Furthermore, size restrictions of the subscale vehicle only permitted the consideration of 38mm motors of 8.5” in length or less, so the motor that best achieves all these metrics was selected. The stability of the launch vehicle was also similar to that of the full scale vehicle, so no ballast was added.

3.7.3 Launch Day Conditions and Predictions

At launch, the temperature was 42° Fahrenheit with winds at 6 mph and a 3 degree launch angle. Both the OpenRocket and Simulink provide data assuming that the parachute deployment would be exactly at apogee, whereas on launch day there was a delay of 8 seconds from motor burnout. As per the predictions of the OpenRocket simulation, the apogee would be an altitude of 1320’ at a time of 9.79 seconds. The maximum velocity would be 272 ft/s, the maximum acceleration would be 158 ft/s^2, the flight time would be 69.8 seconds, the ground hit velocity would be 22.0 ft/s, and the drift distance from the pad would be 174 ft. The Simulink predicts an apogee of 1366’ at 10 seconds. The maximum velocity would be 272 ft/s, the maximum acceleration would be 160 ft/s^2, the flight time would be 72.3 s, the ground hit velocity would be 21.9 ft/s, and the drift distance would be 392 ft. A summary of this data is provided in a table in section 3.7.5 to compare with the actual flight data.

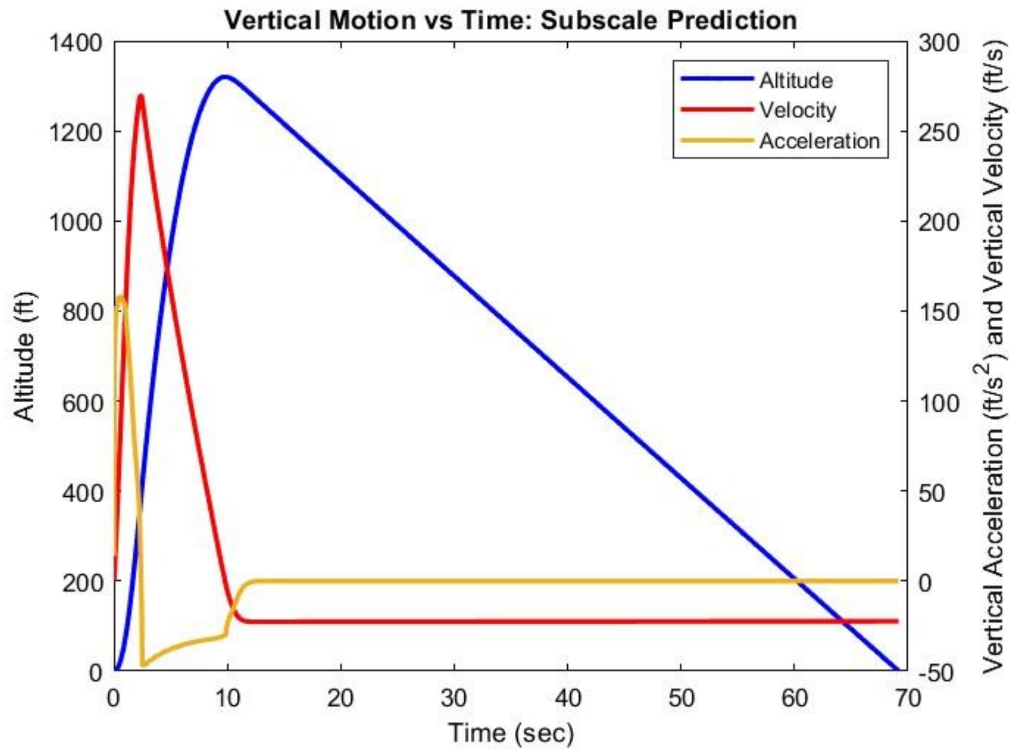


Figure 3.7.2: OpenRocket Subscale Flight Prediction

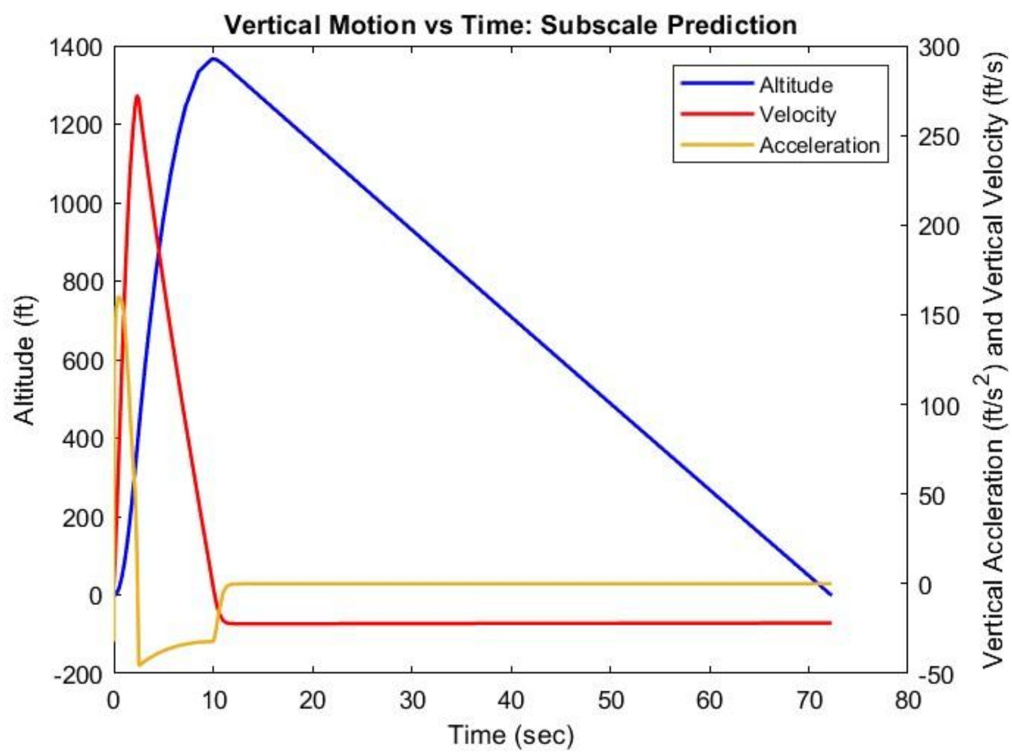


Figure 3.7.3: Simulink Subscale Flight Prediction

3.7.4 Subscale Flight Data

The subscale flight reached an apogee of 1340' at 9.4 seconds. The maximum velocity was 279 ft/s, the maximum acceleration during boost was 218 ft/s^2, with an average acceleration of 131 ft/s^2. The flight time was 57.2 s, the ground hit velocity was 24 ft/s, and the drift distance was 898.2 ft. Below is the table of output data from the Telemetrum altimeter. The descent time under main and drogue can be ignored since there was only a main parachute. The graph below gives the flight data straight from the Telemetrum, including the altitude, acceleration, and velocity vs time. Below that, are the separated altitude, velocity, and acceleration graphs.

Device	TeleMetrum-v3.0	version 1.9.1	serial 5776
Flight	35		
Date/Time	2023-11-18	16:21:07 UTC	
Maximum height	408.3 m	1340 ft	
Maximum GPS height	355.0 m	1165 ft	
Maximum speed	85.2 m/s	279 fps	Mach 0.2
Maximum boost acceleration	66.4 m/s²	218 ft/s²	6.77 G
Average boost acceleration	39.8 m/s²	131 ft/s²	4.06 G
Ascent time	2.1 s boost	7.3 s coast	
Drogue descent rate	9.7 m/s	32 ft/s	
Main descent rate	7.4 m/s	24 ft/s	
Descent time	19.6 s drogue	28.2 s main	
Flight time	57.2 s		
Pad location	N 40° 30.748794'	W 87° 1.129638'	
Last reported location	N 40° 30.835944'	W 87° 0.972894'	

Figure 3.7.4: Flight Statistics from the Altus Metrum Telemetrum Altimeter

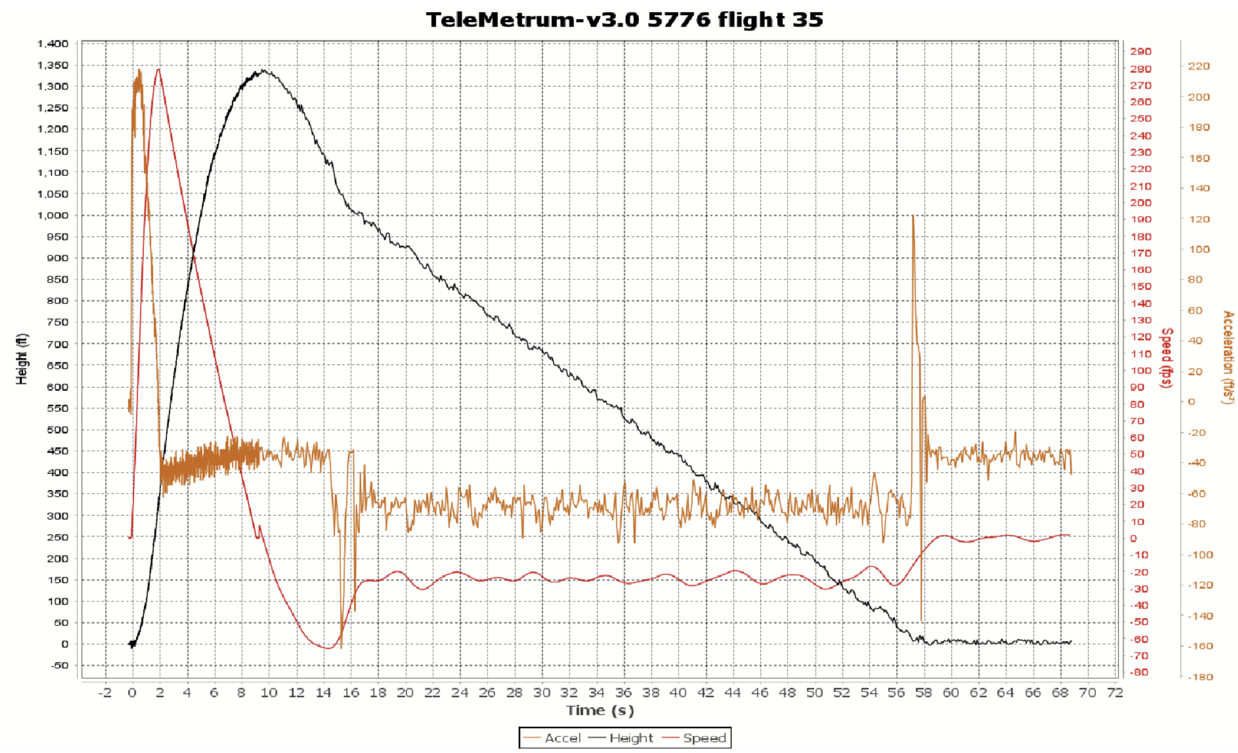


Figure 3.7.5: Flight Statistics from the Altus Metrum Telemetrum Altimeter

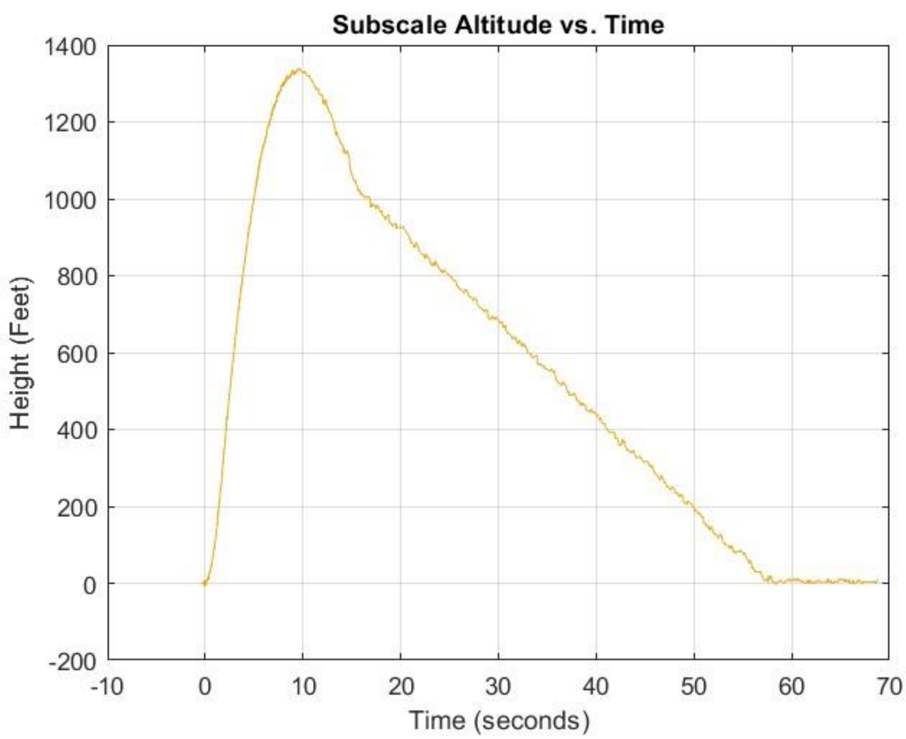


Figure 3.7.6: Altitude vs Time Subscale Flight Data from MATLAB

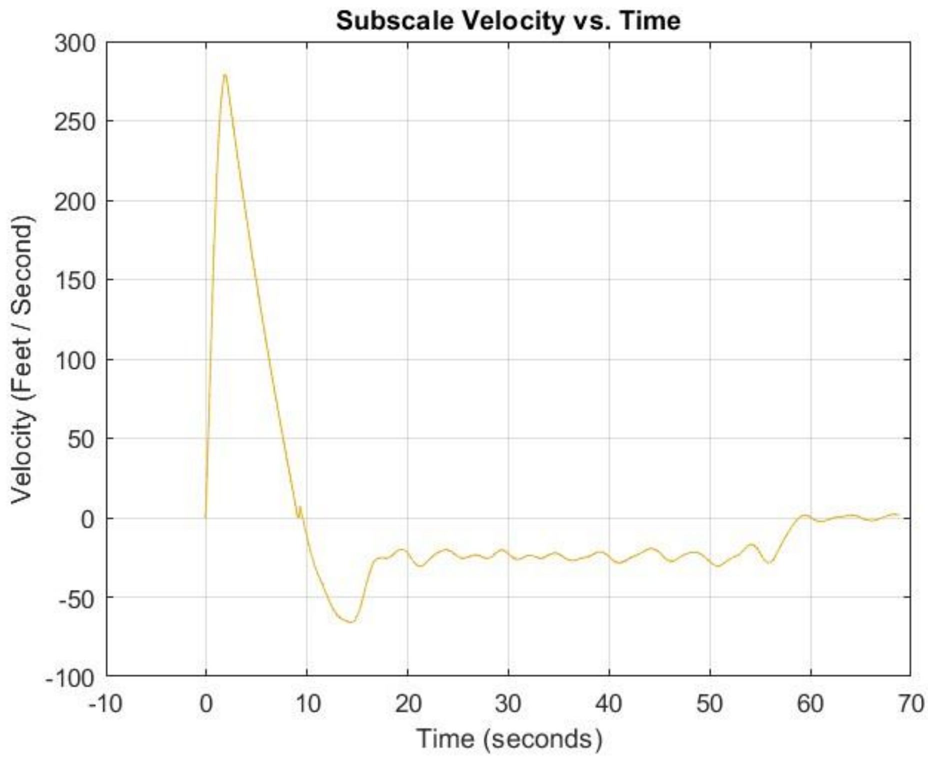


Figure 3.7.7: Velocity vs Time Subscale Flight Data from MATLAB

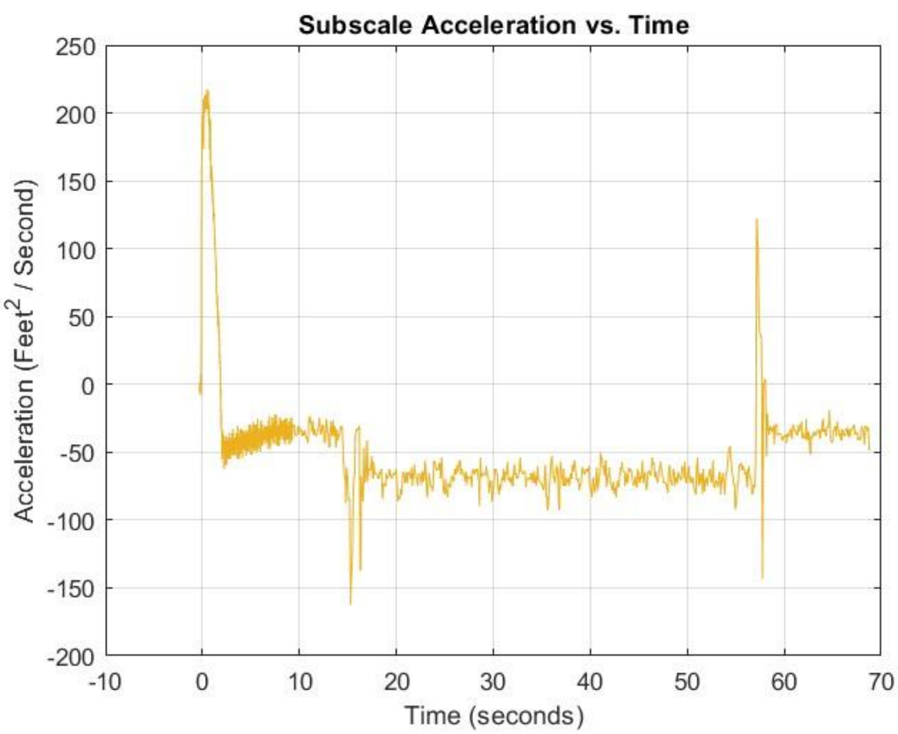


Figure 3.7.8: Acceleration vs Time Subscale Flight Data from MATLAB

Figure 3.7.9: Subscale Vehicle upon landing

Figure 3.7.10: Subscale Vehicle upon landing

Figure 3.7.11: Subscale booster section upon landing

Figure 3.7.12: Subscale upper section (avionics bay and payload section) upon landing

Figure 3.7.13: Subscale nose cone upon landing

Figure 3.7.14: Subscale parachute upon landing

3.7.5 Flight Reliability and Confidence

Table 3.7.1: Comparison of flight prediction simulations and flight data

Statistic	OpenRocket Prediction	Simulink Prediction	Telemetrum Flight Data
Apogee (ft)	1320	1366	1340
Ascent Time (s)	9.79	10	9.4
Descent Time (s)	60.01	62.3	47.8
Max. Velocity (ft/s)	272	272	279
Max. Acceleration (ft/s^2)	158	160	218
Landing Velocity (ft/s)	22	21.9	24
Drift Distance (ft)	174	392	898

The flight demonstrated high reliability and confidence in the design, although there was room for improvement. The subscale apogee was 1340' with percent error of 1.51% from the predicted OpenRocket value and 1.94% from the Simulink value. The apogee occurred at 9.4 seconds with percent error of 4.15% from the predicted value OpenRocket value and 6.38% from the Simulink value. The maximum velocity was 279 ft/s with percent error of 2.51% from both models. The average acceleration was 131 ft/s^2 with a percent error of 20.6% from the simulated OpenRocket maximum acceleration and 22.1% from the Simulink value. The simulation assumed a mostly constant thrust force thus it was decided to compare the average acceleration with the simulation's maximum acceleration as the subscale engine would suffer from variation due to impurities and nonideal conditions. The maximum acceleration achieved during flight was 218 ft/s^2 as compared to the predicted maximum of 158 ft/s^2 from the OpenRocket and 160 ft/s^2 from the Simulink. The total flight time was 57.2 seconds with a percent error of 22.1% from the OpenRocket simulation and 26.40% from the Simulink. The ground hit velocity was 24 ft/s with a percent error of 8.33% from the OpenRocket and 8.75% from the Simulink. Finally, the drift distance was 898.2 feet, which was significantly different from the predicted values from both the OpenRocket and the Simulink.

Overall, the simulated predictions and subscale results were fairly similar. The aberration in flight time was likely due to the engine burn time of subscale being different from the expected engine burn time. The engine used was rated to burn for 2.4 seconds when in actuality flight data indicated it burned for only 2.1 seconds. This would also result in a different maximum acceleration during boost, as the same amount of thrust will be provided by the motor just over a shorter period of time, resulting in a higher actual acceleration compared to the predicted values. This will likely not be an issue during full scale as a different motor will be used. An additional source of error would be that there was an 8 second delay after motor burnout before the parachute was deployed due to the charge timing. This led to the parachute being deployed after apogee instead of at apogee as the simulation did. This led to a shorter descent time than predicted because of the short amount of time in free fall. Other error was likely due to the simulation not having the most accurate data about the parachute drag coefficient. The lower predicted descent rates meant that the simulations would predict a longer flight time than would actually occur. To have a higher fidelity simulation experimental testing must be done using the parachute. The differences in the drift distance may be partially due to changing winds over time. Past flight data has shown that the simulations have under-predicted the subscale drift distance, likely due to how light the launch vehicle is. Overall, the subscale flight performance provides confidence in the fullscale design. To determine the coefficient of drag for the overall rocket, OpenRocket was used and the simulation was backfit and matched with the subscale data by overriding the coefficient of drag in the simulation. Matching occurred with a coefficient of drag of 0.599. This gives the predicted full-scale drag coefficient.

3.7.6 Subscale Impact on Full Scale Design

The subscale launch vehicle validated the team's ability to accurately predict launch behavior. This was attributed to accurate geometric modeling, as well as precise mass measurement and distribution within the launch vehicle. This enforced the importance of accurately representing materials within the CAD and analysis process, precisely measuring the tolerance of the materials received from manufacturers, and continually adapting models and simulations to reflect the physical manifestation of design choices. Generally speaking, the design of the subscale launch vehicle exhibited behavior that was strikingly similar to what was anticipated from simulations. Because of the desirable behavior, no significant changes were made to the design of the full scale launch vehicle. One issue observed with the subscale launch vehicle was that the nose cone sheared off upon landing. The nose cone did not fracture at the tip, but rather sheared cleanly at the junction between the exterior part of the body and the interior nose cone shoulder. The part was printed as one piece. To fix this issue for the full scale flight, the nose cone will be reinforced with a fiberglass wet layup to increase rigidity and impact resistance. Furthermore, the walls of the nose cone were increased in thickness by 0.1”, which does not significantly increase the mass of the nose cone but allows for a closer fit inside the airframe body and increases rigidity of the part. Furthermore, the team is investigating the effects of different infill patterns and infill percentages to prevent shearing at a single layer of the print. Each of these minor changes are anticipated to work together to greatly improve the impact resistance of the nose cone, increasing reusability of the design.

3.8 Recovery Subsystem

The recovery system is a dual-deploy system controlled by a primary and redundant altimeter which consists of a drogue parachute deploying at apogee and a main parachute deploying at 700’ AGL. The primary altimeter will control the primary ejection charges, and the redundant altimeter will control the redundant ejection charges, which will go off 2 seconds after apogee for drogue, and at 500’ AGL for main. The drogue parachute will be 15” in diameter and the main parachute will be 120” in diameter. Black powder ejection will be used to deploy the parachutes. The main parachute will use cannon deployment, and the drogue parachute will use a modified cannon and gravity aided deployment. The primary and redundant deployment systems will be connected to both parachutes and will be independent of each other. Each system consists of its altimeter, battery, and ejection charges. The primary altimeter will be the Altus Metrum Telemetrum, and the redundant altimeter will be the PerfectFlite StratoLogger CF. Key switches will be used to turn on the batteries for both altimeters. The altimeters and other necessary components will be located in the avionics bay, in the avionics coupler.

3.8.1 Final Chosen Components

3.8.1.1 Avionics Bay

The avionics bay is located in the avionics coupler. It houses the required hardware for the recovery system. Inside the avionics bay is the avionics sled, which will hold the altimeters and their batteries. The bulkheads will contain the charge wells for the ejection charges, and the eye bolts that will connect the quick links to the shock cords. There are four #10 static pressure holes in the avionics bay that will allow for the barometric altimeters to sense the correct pressure.

3.8.1.2 Switch Band

The avionics coupler will have a 1” wide switch band around the center of the avionics coupler. The switch band will allow access to the key switches via two 0.5” diameter holes. Each of these holes will have two holes around it to allow for M3 sized screws to be used to mount the switch holders inside the coupler. The switch band is located at an in-flight separation point.

3.8.1.3 Altimeter Sled

The design of the altimeter sled is based heavily around increasing the efficiency and organization of the design. The altimeter sled will be 3D printed and secured with two threaded rods that are attached to each end of the avionics bay and with hex nuts. The layout of the sled consists of two batteries: a 9V battery and a LiPo battery, a primary altimeter, and a redundant altimeter. The primary altimeter is an Altus Metrum Telemetrum with dimensions of 1.00” x 2.750” and a weight of 0.71 oz, and the redundant altimeter is a PerfectFlite StratoLogger CF with dimensions of 2” x 0.84” x 0.5” and a weight of 0.45 oz. When designing the sled, a major factor was the weight distribution of the altimeters and batteries because they can not have any effect on the stability of the launch vehicle. In order to even out the weight distribution, an altimeter is placed on one side and its corresponding battery on the other. The Altus Metrum Telemetrum altimeter must be placed in a vertical orientation to operate correctly and its corresponding battery is mounted on the opposite side of the sled. The decision was also made to orient the PerfectFlite Stratologger CF altimeter vertically to collect the most accurate data possible and keep the design consistent. A big focus with this design was the battery retention and making sure that the batteries stay still during flight and that they are both housed in a non hazardous way. The final design consists of a battery bay for both the 9V and LiPo batteries and a lid that screws on top of both of them. Both battery bays have heat set inserts so that the screws that are being used to fasten the lid are able to have a sturdy and reliable connection to the altimeter sled. In previous designs, a big struggle has been the organization of wires within the avionics bay. To reduce clutter and improve the accessibility of the altimeter sled, cable chains have been incorporated into the design to group together wires that have a common source.

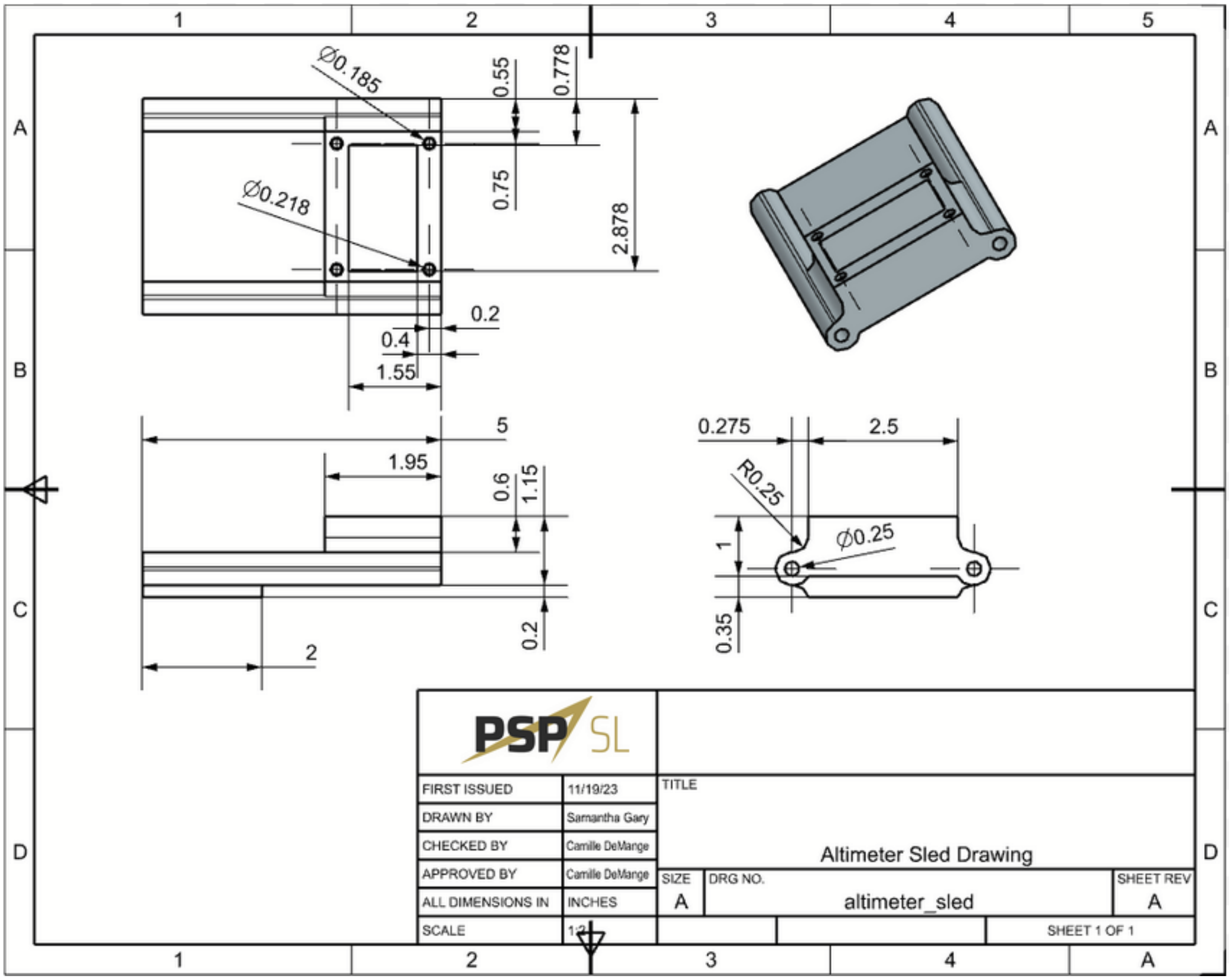


Figure 3.8.1: Altimeter Sled Technical Drawing

3.8.1.4 Ejection Charges and Deployment Mechanism

Cannon configuration deployment will be used to deploy the main parachute, and a modified cannon and gravity aided method will be used to deploy the drogue parachute. Cannon deployment works by essentially shooting the parachute out of the open airframe like a cannon. The drogue parachute deployment will work by pressurizing the section to shear the pins and send the booster section off, while also pushing the drogue parachute out. If the drogue is not pushed out by the ejection charge, gravity will pull the parachute out. This method of deployment has been tested for feasibility, and resulted in the drogue parachute being pushed out successfully by the ejection charge. FFFFg black powder will be used to pressurize the airframe to shear the pins to deploy the parachutes. This grade of black powder has been chosen over FFFg black powder since it is easier to ignite because of the smaller grain size. The amount of black powder needed will be calculated below, but before the Vehicle Demonstration Flight, a ground black powder ejection test will be conducted for both the main and drogue recovery systems to ensure the amount of calculated black powder will shear the pins, separate the airframes, and result in successful parachute deployment.

To find the amount of ejection charge required, it would require 1) finding the force needed to shear one shear pin, and 2) finding the total pressure on the bulkhead. To find the force needed to shear one shear pin, multiply the cross-sectional area (A_{Pin}) of a 4-40 shear pin (radius 0.056”) with the shear strength of nylon (τ_{Nylon}):

$$A_{Pin} = \pi R_{Pin}^2$$
$$A_{Pin} = 3.1415 * (0.056\, in)^2 = 0.009852\, in^2$$
$$F_{Pin,\, Failure} = A_{Pin} * \tau_{Nylon}$$
$$F_{Pin,\, Failure} = 0.009852\, in^2 * 10000\, psi = 98.52\, lbf$$

To find the total pressure on the bulkhead, divide the force required to shear three pins by the area of the bulkhead (5” diameter):

$$3 * F = 3 * 98.52\, lbf = 295.56\, lbf$$
$$A_{Bulkhead} = \pi R_{Bulkhead}^2$$
$$A_{Bulkhead} = 3.1415 * (2.5\, in)^2 = 19.634\, in^2$$
$$P_{Bulkhead} = \frac{4*F_{Pin,\, Failure}}{A_{Bulkhead}} = \frac{295.56\, lbf}{19.634\, in^2} = 15.053\, psi$$

To find the size (mass) of ejection charge (G) in each primary canister, multiply the pressure of the bulkhead ($P_{Bulkhead}$) by pi (π) times the half the diameter of the airframe squared ($(D_{Airframe}/2)^2$) by the length of the airframe section ($L_{Airframe}$). Then, divide that resultant by 266 (gas constant) multiplied by the combustion temperature of the black powder (T= 3300℉). Lastly, multiply that resultant by: 454 (to convert pounds to grams) and by the safety factor (1.2).

All said, the resulting formula is:

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

Calculated values were then rounded to the nearest half gram. To find the size (mass) of ejection charge (G) in each redundant canister, add a half gram from the value obtained when calculating the primary charge.
To calculate the maximum pressure produced by the redundant ejection charge over the section that needs to be pressurized, the previous equation is rearranged to:

Maximum Pressure Formula:

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

Table 3.8.1: Ejection Charge Quantities and Pressures Produced

Charge	Airframe Length (in)	Charge Quantity (g)	Pressure (psi)
Main Primary	13	2.5	15.8
Main Redundant	13	3	18.9
Drogue Primary	7.5	1.5	16.4
Drogue Redundant	7.5	2	21.9

In summary, the main parachute's primary and redundant ejection charges will be 2.5g and 3g respectively. The drogue parachute's primary and redundant charges will be 1.5g and 2g. The maximum pressure exerted by the ejection charges in case of the redundant charge was also calculated to ensure that the launch vehicle could withstand the forces of deployment. Both sides of the bulkhead will hold two Rocket Junkies 8-gram Aluminum Charge wells (for the primary and redundant charge). This size of charge well has been chosen to provide enough room in case charge sizes need to be increased, and will also be able to hold the cellulose recovery wadding. The upper side of the avionics bulkhead will hold the main parachute's charges, while the lower side will hold the drogue parachute's charges. The Wago 2 conductor connector was the best option for the ematch to altimeter sled wire connection, because of its reusability and quick assembly, along with its ability to withstand high-power rocket vibrations (0-2000 Hz). This was chosen over previous years' decisions of screw wire connectors, because screw wire connectors have a greater chance of stripping during flights, and they are not labor and installation efficient.

3.8.2 Avionics and Recovery Concept of Operations

For the avionics and recovery system, there are four separate phases for the Concept of Operations that include preparation, initiation, flight, and retrieval. The preparation phase happens in advance of the launch, both the days before and the day of, before reaching the launch pad. Initiation takes place on the launch pad, and is where the on-board electronics are turned on. The flight phase occurs once the motor begins to launch the vehicle. The final phase, retrieval takes place once the launch vehicle has completed its flight and landed.

3.8.2.1 Phase 1: Preparation

Before the day of launch, the altimeters will be properly configured before assembling the avionics bay. The proper configuration of both altimeters will be implemented to ensure the main and drogue parachutes are deployed at their designated altitude. The altimeter configuration will undergo a test to ensure the system works as intended and ejection charges are initiated at the right time. The avionics bay will also be constructed and assembled in this step. In the assembly stage, the primary altimeter will be connected to the primary ejection charges for the main parachute and the drogue parachute. The secondary altimeter will be connected to the redundant charges for both parachutes. Each altimeter will be connected to their own battery and switch. After ensuring a successful integration of the deployment system, the avionics bay will be implemented into the launch vehicle.

3.8.2.2 Phase 2: Initiation

When the launch vehicle is on the launch pad, the initiation phase will begin by turning on the altimeters via the two switches. A series of beeps will indicate system readiness for the main parachute and the drogue parachute. Each altimeter will be turned on separately to ensure each reaches continuity. At the AGCS, the Altus Metrum's Teledongle will be connected to the laptop in the viewing area to ensure live flight data is collected including deployment status, apogee, and launch vehicle position.

3.8.2.3 Phase 3: Flight

During flight, the avionic's system will monitor altitude of the launch vehicle to properly initiate the deployment system for a timely descent. The primary altimeter will ignite the primary ejection charge for the drogue parachute at apogee. Two seconds later, the secondary altimeter will ignite the redundant charge. Similarly, the main parachute will be deployed at 700' AGL using the primary ejection charge via a signal from the primary altimeter. At 500' AGL, the secondary altimeter will ignite the redundant charge that ensures the main parachute is deployed to minimize impact velocity.

3.8.2.4 Phase 4: Retrieval

Upon descent, the launch vehicle will be tracked visually. If physical sight is lost, position tracking on the system will be utilized to confirm landing location for successful retrieval. Once the launch vehicle is recovered, pictures will record the events of the landing for future reference and all data will be transferred to the laptop. Data analysis will occur soon after conclusion of the flight to record highest apogee and descent analytics.

3.8.3 Recovery Hardware

3.8.3.1 Parachutes

The recovery system will consist of a 120" (10') Rocketman High Performance CD 2.2 Parachute for the main parachute and a 15" Fruity Chutes Elliptical Parachute for the drogue parachute. Both parachutes are made of 1.1 oz ripstop nylon. Based on calculations and additional research for parachute sizing, a 10 foot diameter for the main parachute proved to be the optimal size for the designated weight of the launch vehicle. A decision matrix was utilized to compare other attributes of different main parachutes including price, material, packing volume, descent rate, and coefficient of drag. The Rocketman company proved to be the most cost-efficient option at $315 and produced an optimal descent rate of 15.9 ft/s when simulations were performed with the launch vehicle on OpenRocket. For the drogue parachute, sizing calculations determined that the ideal size would be 15" in diameter. Research into other drogue parachutes confirmed that the 15" size was valid for the launch vehicle. Similar to the decision matrices used in choosing a main parachute, another decision matrix was created to compare the same traits, most importantly, price, decent rate, and material. Although the Fruity Chutes company was slightly more expensive, the other preferred properties including size and descent rate outweighed the minor downfall. At a velocity of 134 ft/s upon drogue deployment, the 15" Fruity Chutes drogue will be the best option.

Figure 3.8.2: Fruity Chutes 15" Elliptical Parachute

Table 3.8.2: Decision Matrix for Main Parachute

Design Criteria	Design Options (Main)					
Final Parachute Criteria	Subteam Desires	8 ft (96") Rocketman	9ft (108") Rocketman	10 ft (120") Rocketman	8ft (96") Fruity Chutes	10ft (120") Fruity Chutes
Price	$350	5	5	5	3	1
Sizes	10ft	3	4	5	3	5
Materials	Ripstop Nylon	5	5	5	5	5
Packing Volume	200 in^3	5	4	5	3	3
Descent Rate	<20 fps	3	4	5	4	5
Coefficient of Drag	1.75	5	5	5	4	4
Totals		26	27	30	22	23
Choice Made				**10 ft (120") Rocketman**		

Table 3.8.3: Decision Matrix for Drogue Parachute

Design Criteria	Design Options (Drogue)					
Final Parachute Criteria	**Subteam Desires**	**12" Rocketman**	**24" Rocketman**	**12" Fruity Chutes**	**15" Fruity Chutes**	**18" Fruity Chutes**	**24" Fruity Chutes**
Price	$70	5	5	5	5	4	3
Sizes	15"	3	2	3	5	4	3
Materials	Ripstop Nylon	5	5	5	5	5	5
Packing Volume	11 in^3	5	3	4	4	5	3
Descent Rate	<150 fps	4	4	4	5	4	4
Descent Time	80s	4	4	5	4	4	3
Coefficient of Drag	0.65	5	5	5	5	5	5
Totals		31	28	31	33	31	26
Choice Made					**15" Fruity Chutes**		

3.8.3.2 Heat Shields

Nomex blankets have been chosen as the form of heat shielding to protect the parachutes from the heat of the black powder ignition. The drogue parachute will be protected with an 18x18" square Nomex blanket, and the main parachute will be protected by a 18x36" double Nomex blanket. The Nomex blankets will completely surround the parachutes to protect from hotspots that could lead to possible holes in the parachutes. While Nomex is not as strong or heat resistant as Kevlar, both its strength and heat resistance meet baseline requirements and will provide sufficient protection of the parachutes, which has been confirmed both with this year's subscale flight and past years' flights. Nomex is more economical, lighter, and easier to work with, and for all of these reasons has been chosen as the heat shield.

Table 3.8.4: Heat shielding options: Kevlar vs Nomex

	Nomex	**Kevlar**	**Baseline**
Price	~$30 per yard	$62 per yard	
Heat Resistance	700° F	800° F	464° F
Weight	1.38g/cm^3	1.44g/cm^3	
Workability	3	2*	*Kevlar requires drill bit modification post-lamination
Strength	340MPa	3600MPa	

3.8.3.3 Harnesses, Bulkheads, and Attachment Hardware

The 15" Fruity Chutes Elliptical drogue parachute has 220 lb nylon shroud lines and a 1000 lb swivel. The 120" Rocketman Higher Performance main parachute has 250 lb flat nylon shroud lines and a 3000 lb swivel. The shock cords will be ⅜'' wide tubular Kevlar. One 30' long shock cord will be used for the drogue parachute and one 50' long shock cord will be used for the main parachute. This shock cord has a strength rating of 3600 lb, and was chosen because Kevlar is characteristically strong, and because it is heat resistant as well. The cord must be able to withstand the heat from the ignition of the black powder, so strength and heat resistance are of the utmost importance. The length of the shock cords were determined since it is common practice to ensure the shock cord is 2 to 5 times the length of the launch vehicle.

Bulkheads are used to separate sections of the launch vehicle while allowing for a place of connection for the shock cords to tether the vehicle together. The bulkheads of the avionics bay each contain an eye bolt, which will be connected to a quick link that is attached to a shock cord. The quick links will be ¼" stainless steel and have a strength rating of 880 lbs. The eye bolts are ¼'' stainless steel and have a strength rating of 500 lbs. One end of the 30' shock cord will attach to the booster section via quick link and an eye bolt attached to the motor and through the pressurization bulkhead. Two-thirds of the length up, the shock cord will be attached via a quick link to the drogue parachute and its Nomex blanket. On the other end of the shock cord, a quick link will attach to the eye bolt that is located on the lower bulkhead of the avionics coupler. One end of the 50' shock cord will attach to the eye bolt on the upper bulkhead of the avionics coupler with a quick link. Two-thirds of the length up, the shock cord will be attached via a quick link to the main parachute and its Nomex blank. The other end of the shock cord will attach to the payload bulkhead's eyebolt with a quick link.

Table 3.8.5: Attachment Hardware Summary

Attachment Hardware	Material	Strength
Shock Cords	⅜" tubular Kevlar	3600 lbs
Quick Links	¼" stainless steel	880 lbs
Eye Bolts	¼" stainless steel	500 lbs

3.8.4 Electrical Components

3.8.4.1 Altimeters

The recovery system will consist of two commercially available barometric altimeters to ensure redundancy in the system. All altimeters that were considered are barometric altimeters. The primary altimeter will be the Altus Metrum Telemetrum and the redundant altimeter will be the PerfectFlite StratoLogger CF, and the decision making process is listed below.

The primary recovery electronics system consists of the Altus Metrum Telemetrum altimeter, a 3.7V LiPo battery, a key switch, a Wagos connector, its wiring, and two e-matches. The primary system wiring diagram is shown below.

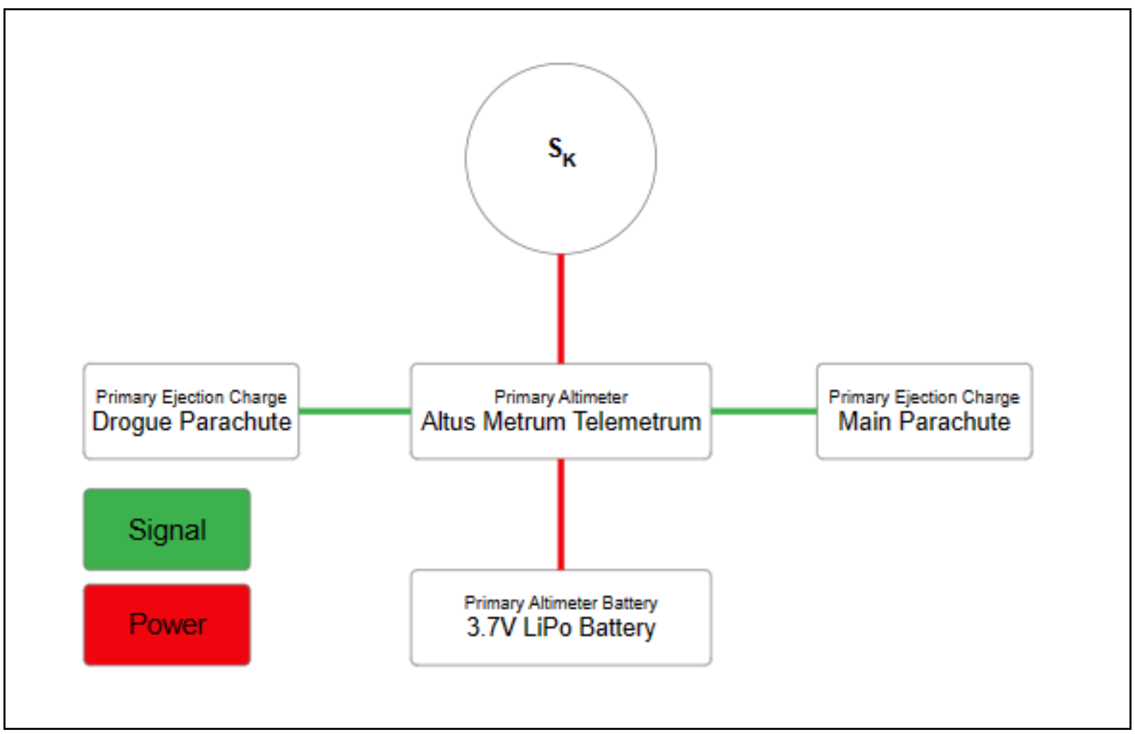


Figure 3.8.3: Primary Systems Wiring Diagram

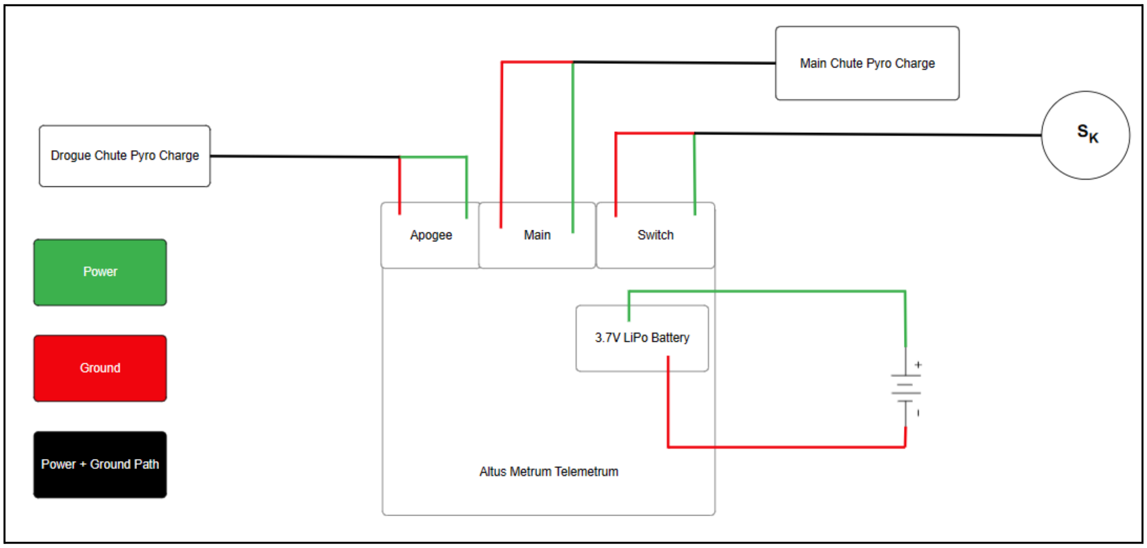


Figure 3.8.4: Primary Circuit Schematic

Table 3.8.6 Primary Altimeter Decision Matrix

Primary Altimeters	Altus Metrum TeleMega	Entracore AIM EXTRA	Altus Metrum TeleMetrum	Baseline requirements
GPS	5	5	5	Yes (5)
Telemetry	5	5	5	Yes (5)
Pyro Outputs	5	3	2	2+ (2)
Acceleration	5	5	5	Desired (3)
Price	2	3	4	<~$300 (5)
OS	5	3	5	Windows at a minimum (5)
Flight Memory	3	4	5	1+ (1)
Total Score	30	28	31	19

The Altus Metrum Telemetrum is a reliable altimeter for dual deploy. The Telemetrum has two pyro outputs, meeting the team's minimum requirement. The terminal connections on the Telemetrum are easy to use, making it more accessible for the majority of the avionics crew who are not electrical engineers. The Telemetrum has multiple options for operational software meaning there are more locations to download the data. More team members' computers can be used as backups at launch if the primary computer is unavailable. The Telemetrum has the ability to store up to eight flights. While it is not a requirement, this is an additional benefit of the Telemetrum if it is necessary to do multiple flights without being able to back up the data in between. The Telemetrum additionally has acceleration tracking. This was not a requirement but was requested to be considered in the team's decision. The Altus Metrum Telemetrum is an altimeter the team has used in past years. There is demonstrated reliability compared to other altimeters used that did not work consistently. The altimeter would also have a greater cost effectiveness as the team already has one in possession. Based on this, and all previously mentioned requirements, the team decided to use the Telemetrum as the primary altimeter for Project Moses.

Figure 3.8.5: Primary Altimeter and GPS - Altus Metrum Telemetrum

The redundant electronics recovery system consists of the PerfectFlite StratoLogger CF altimeter, a standard 9V alkaline battery, a key switch, a Wagos connector, its wiring, and two e-matches. The redundant wiring diagram is shown below.

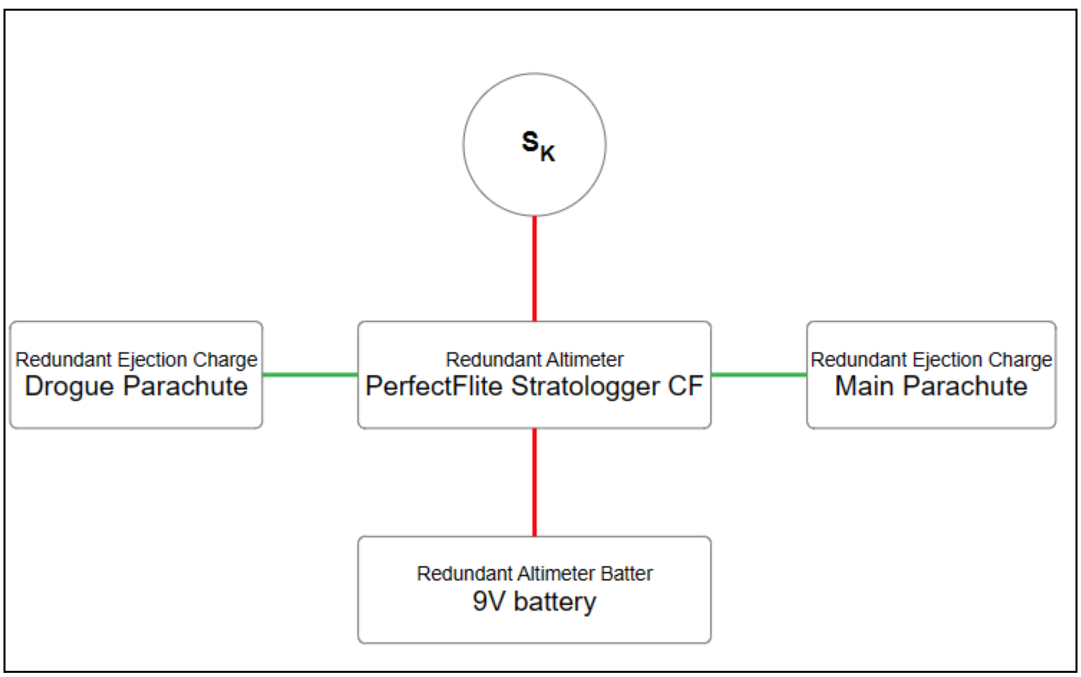


Figure 3.8.6 Secondary Systems Wiring Diagram

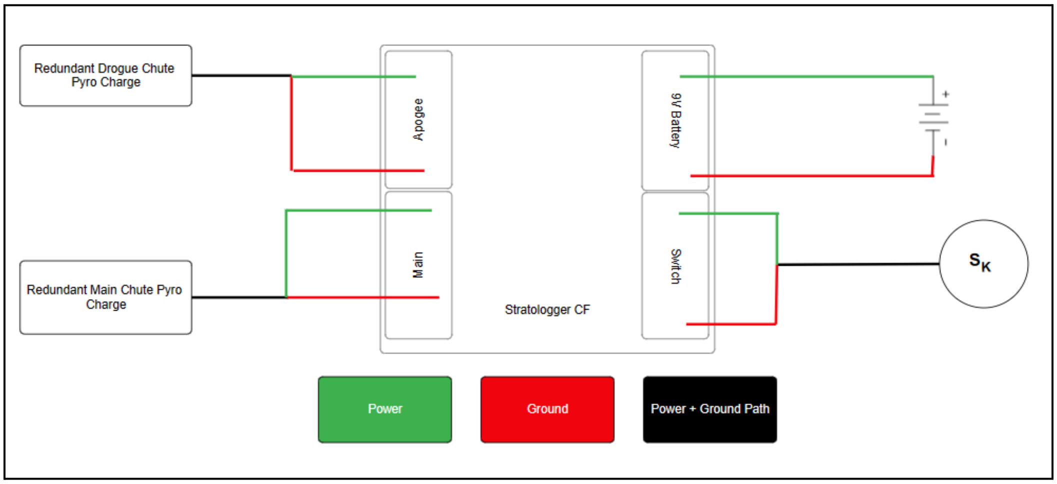


Figure 3.8.7 Secondary Circuit Schematic

Table 3.8.7 Secondary Altimeter Decision Matrix

Secondary Altimeter	MissileWorks RRC3	PerfectFlite StratoLogger CF	Altus Metrum EasyMini	Entracore AIM USB	Baseline Requirement + Rating
Telemetry	5	5	3	3	Not Required (3)
Pyro Outputs	5	5	5	5	2+ (5)
Price	4	5	4	3	<~$100 (5)
OS	5	5	5	5	Windows at minimum (5)
Flight Memory	5	5	4	4	1+ (1)
Total Score	24	25	21	20	19

The PerfectFlite StratoLogger CF meets all minimum requirements set by the Student Launch Handbook and the team. The Stratologger CF meets the two minimum required pyros. The Stratologger additionally records telemetry. This is not a requirement but was a requested feature that placed the StratoLogger over other considerations for the team's redundant altimeter. While it was not a requirement for multiple softwares, the Stratologger has two options for OS, leaving more options for saving the flight data. Additionally, the Stratologger has storage for data from multiple flights. The StratoLogger CF has a wide operational voltage range, which leaves more battery considerations open for the team if size or weight needs to be adjusted. The PerfectFlite StratoLogger CF is another altimeter the team has used in past years with good reliability. The altimeter would also have a greater cost effectiveness as the team already has one in possession.

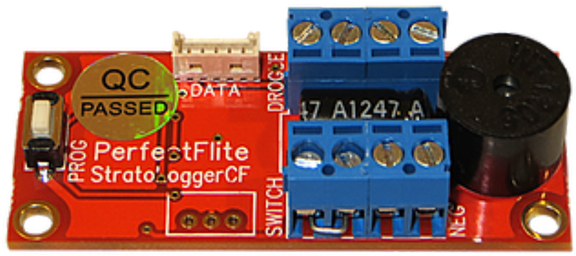


Figure 3.8.8: Redundant Altimeter - PerfectFlite StratoLogger CF

3.8.4.2 GPS Tracker

The Altus Metrum Telemetrum will be used as the primary altimeter, which has an integrated GPS system inside of it already. The receiver is the Altus Metrum altimeter, which is able to find the acceleration of the launch vehicle. The GPS for the launch vehicle will be kept in the avionics sled in the avionics bay. GPS will allow for an easier time locating the vehicle after launch. Frequency for the GPS is 434.55MHz which will start in channel 0. Additionally, the Stratologger CF offers the option for a locator beep. However, the team has elected not to use this feature so that the apogee beeps from the Telemetrum can be utilized to verify data. Since all parts of the launch vehicle will be tethered together, only one GPS device is needed. However, as the SAIL will land separately from the rest of the launch vehicle it will also have its own GPS device for easier tracking that will be entirely separate from the recovery electronics.

3.8.4.3 Switches

The team has decided to use key switches for activation of the pre-launch deployment system batteries. Key switches cannot be accidentally activated, unlike other types of switches. The use of a physical key prevents unrestricted access and ensures that the switch is activated intentionally. The switch cannot be deactivated inflight. The key switch also has a clear indication between off and activated positions. Separate switches will be used to turn on the primary and redundant systems, to ensure separation between the systems.

3.8.4.4 Connectors

The team has chosen to use Wagos connector 221-412 for the connections through the bulkhead to the parachute ejection charges. There will be two connectors for each ejection charge, totaling four connectors on each bulkhead. Each connector body has two contacts, making cable management better because redundant and primary charges can each go to their own connector instead of a 4-contact terminal block as used in previous years. The 221-412 are lever connections so there was concern about the security of connections compared to terminal blocks. Upon reading the CCA DEKRA Certification document, it was decided based on the testing that the connections would be secure enough. When using terminal blocks, it was noted by the team there was some wire fraying and damage if the connector was tightened too much or the wire was not properly prepared. Because this connector is a lever connection that is not arbitrarily tightened and its testing showed no terminal or wire damage, it was decided the 221-412 would be a better connector to lessen wire damage. Additionally, the connector's maximum temperature range was deemed safe for use with the possible temperatures it would experience when the parachute ejection charges ignite.

3.9 Mission Performance Predictions

3.9.1 Flight Profile Simulations

The primary flight profile simulations were done in OpenRocket. A Simulink trajectory simulation model is used as a secondary form of verification for these predictions. OpenRocket uses a six degree of freedom and fourth-order Runge-Kutta differential equation numerical integration of the equations of motion. The Simulink model is a custom two-degree-of-freedom vehicle trajectory simulation that has been used successfully in the past as a verification for the OpenRocket simulations. The OpenRocket simulations were all run with the following conditions: an altitude of 650', a 144" launch rod, International Standard Atmosphere (56.68°F and 990.1mbar), and launch site location of 28.6∘ north, -80.6∘ east. The following 5 graphs are the OpenRocket simulations of altitude, velocity, and acceleration vs time for 0 to 20 mph winds with varying launch angles for the case of the SAIL not deploying.

Table 3.9.1: Summary of Flight Profile Prediction Simulation Graphs

Simulation	SAIL Deployment?	Launch Conditions	Figure Number
OpenRocket	No	0 mph 5 deg	3.9.1
OpenRocket	No	5 mph 5 deg	3.9.2
OpenRocket	No	10 mph 7.5 deg	3.9.3
OpenRocket	No	15 mph 10 deg	3.9.4
OpenRocket	No	20 mph 10 deg	3.9.5
Simulink	No	0 mph 5 deg	3.9.6
Simulink	No	5 mph 5 deg	3.9.7
Simulink	No	10 mph 7.5 deg	3.9.8
Simulink	No	15 mph 10 deg	3.9.9
Simulink	No	20 mph 10 deg	3.9.10
Simulink	Yes	0 mph 5 deg	3.9.11

Simulink	Yes	5 mph 5 deg	3.9.12
Simulink	Yes	10 mph 7.5 deg	3.9.13
Simulink	Yes	15 mph 10 deg	3.9.14
Simulink	Yes	20 mph 10 deg	3.9.15

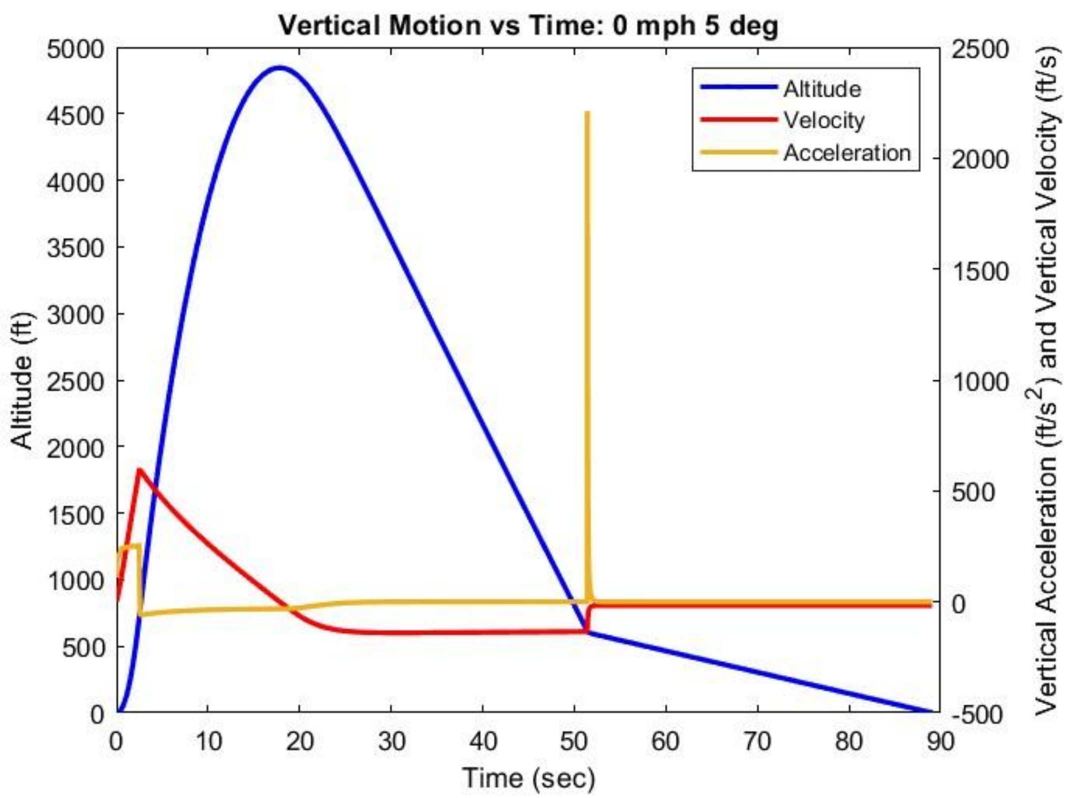


Figure 3.9.1: OpenRocket Altitude, Acceleration, and Velocity vs Time for 0 mph wind speed and 5 degree launch angle for the case of SAIL not deploying

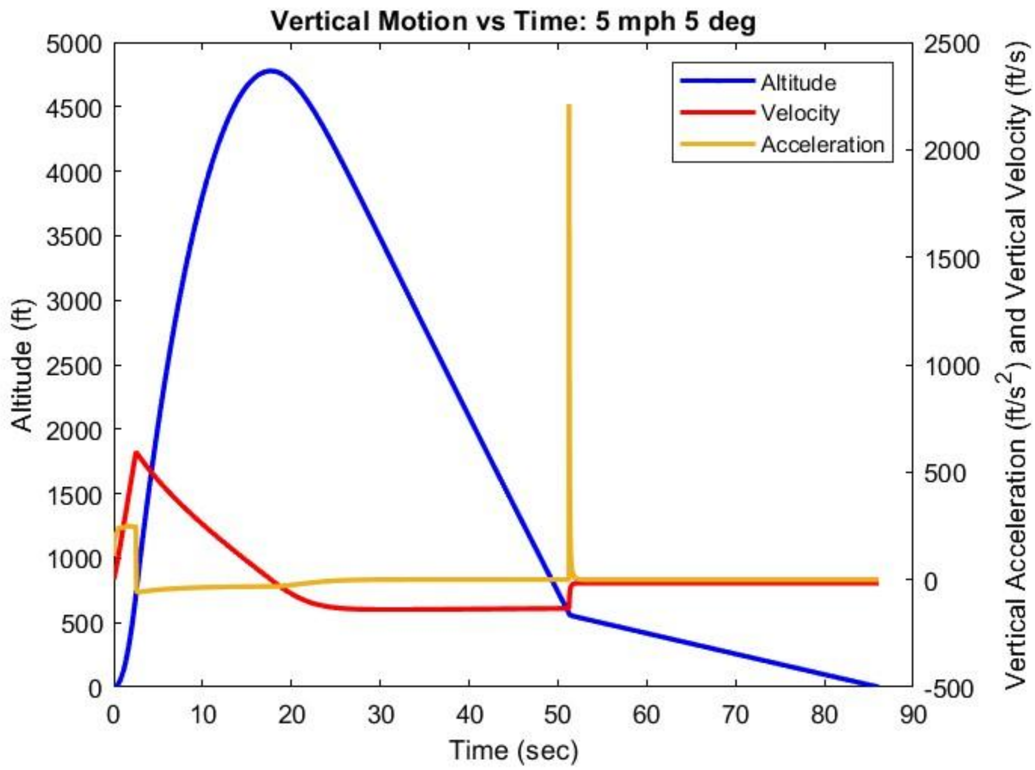


Figure 3.9.2: OpenRocket Altitude, Acceleration, and Velocity vs Time for 5 mph wind speed and 5 degree launch angle for the case of SAIL not deploying

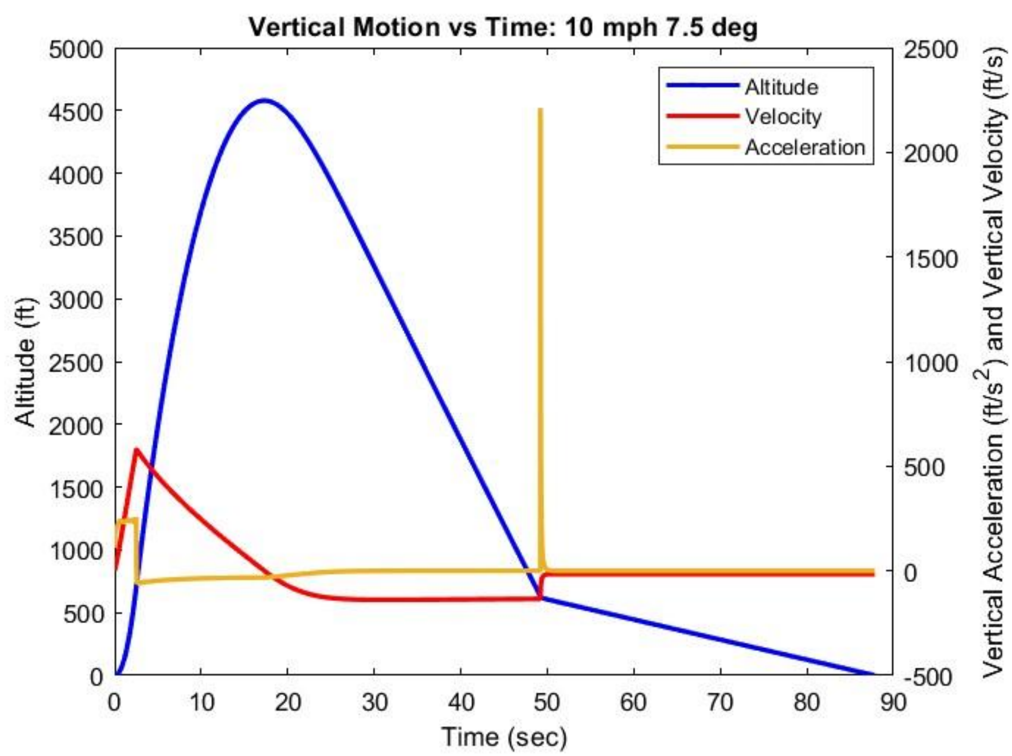


Figure 3.9.3: OpenRocket Altitude, Acceleration, and Velocity vs Time for 10 mph wind speed and 7.5 degree launch angle for the case of SAIL not deploying

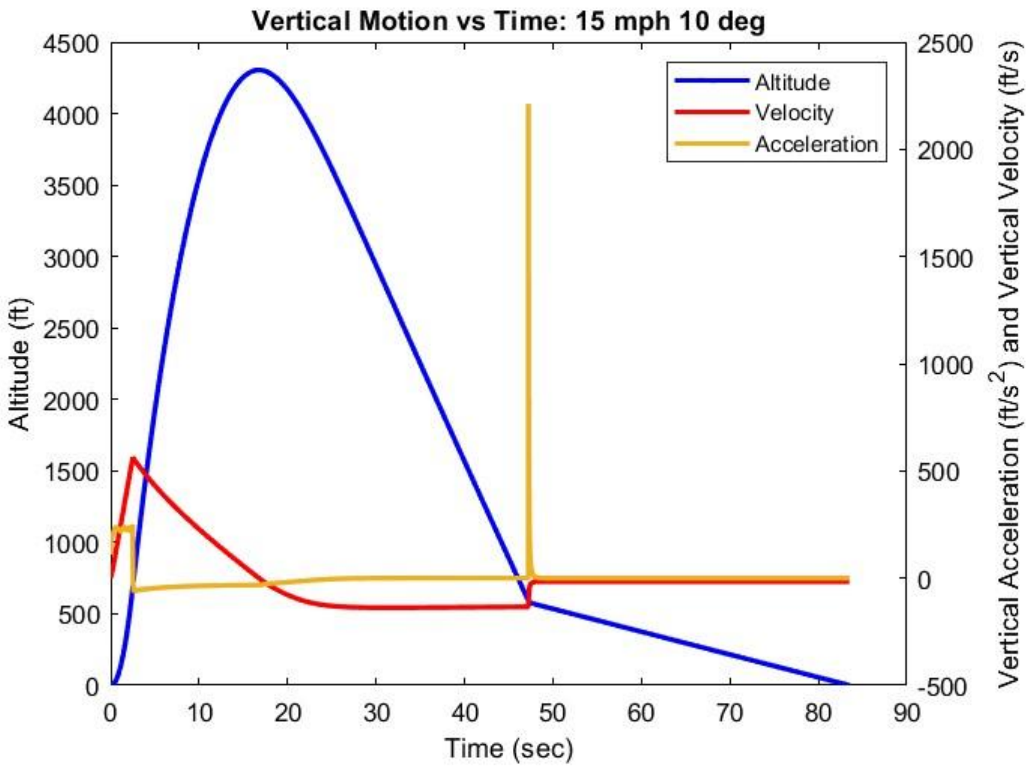


Figure 3.9.4: OpenRocket Altitude, Acceleration, and Velocity vs Time for 15 mph wind speed and 10 degree launch angle for the case of SAIL not deploying

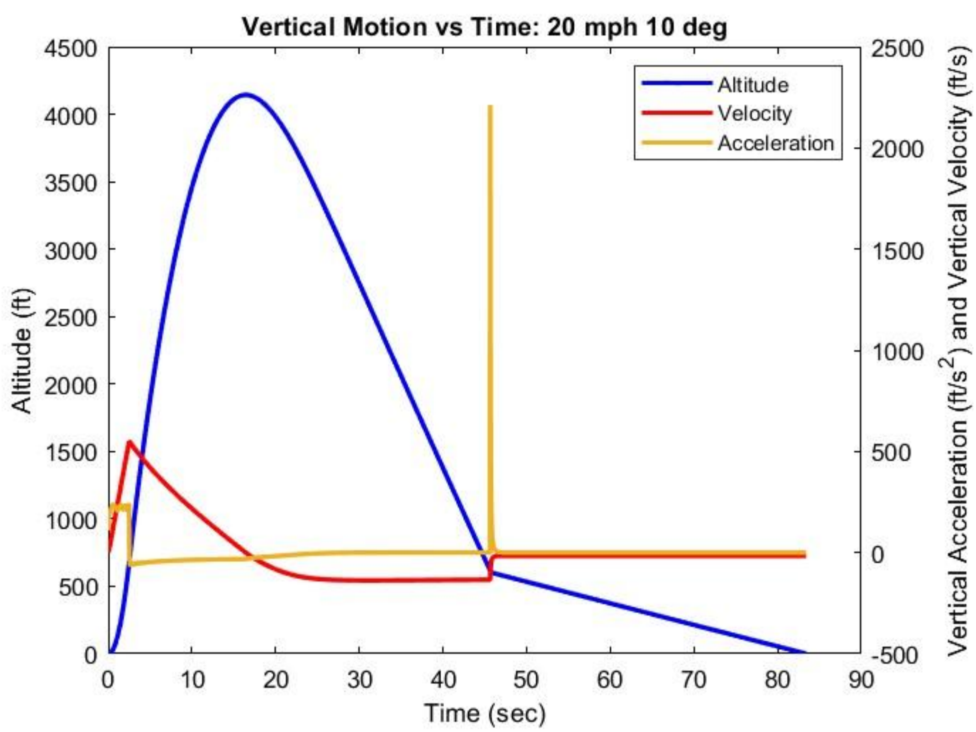


Figure 3.9.5: OpenRocket Altitude, Acceleration, and Velocity vs Time for 20 mph wind speed and 10 degree launch angle for the case of SAIL not deploying

The next 5 graphs are the Simulink simulations of altitude, velocity, and acceleration vs time for 0 to 20 mph winds with varying launch angles for the case of the SAIL not deploying.

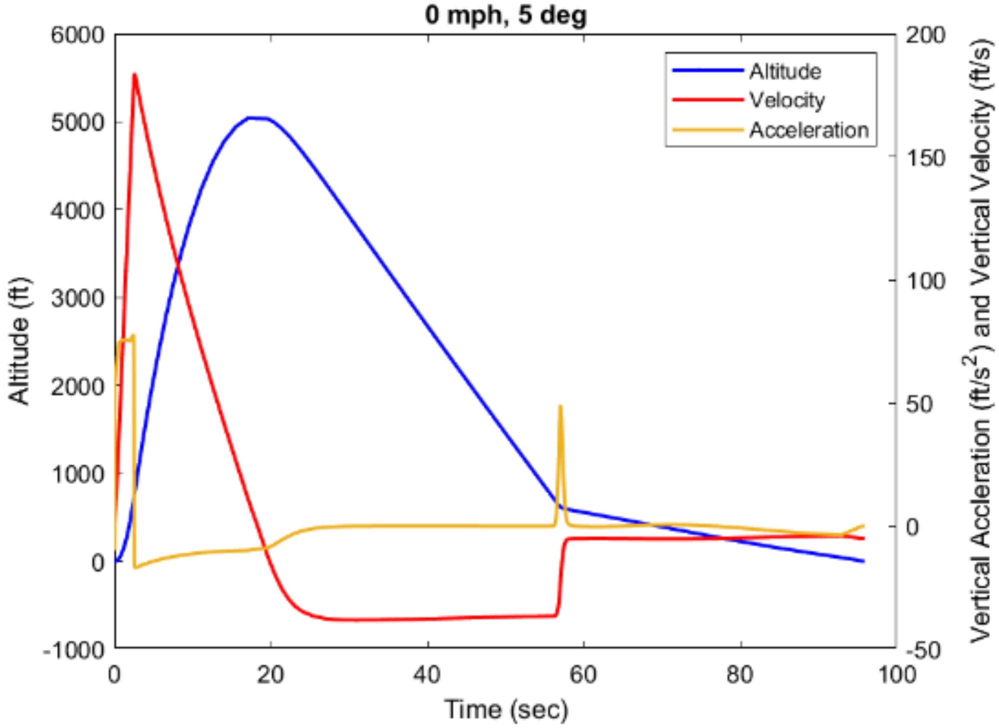


Figure 3.9.6: Simulink Altitude, Acceleration, and Velocity vs Time for 0 mph wind speed and 5 degree launch angle for the case of SAIL not deploying

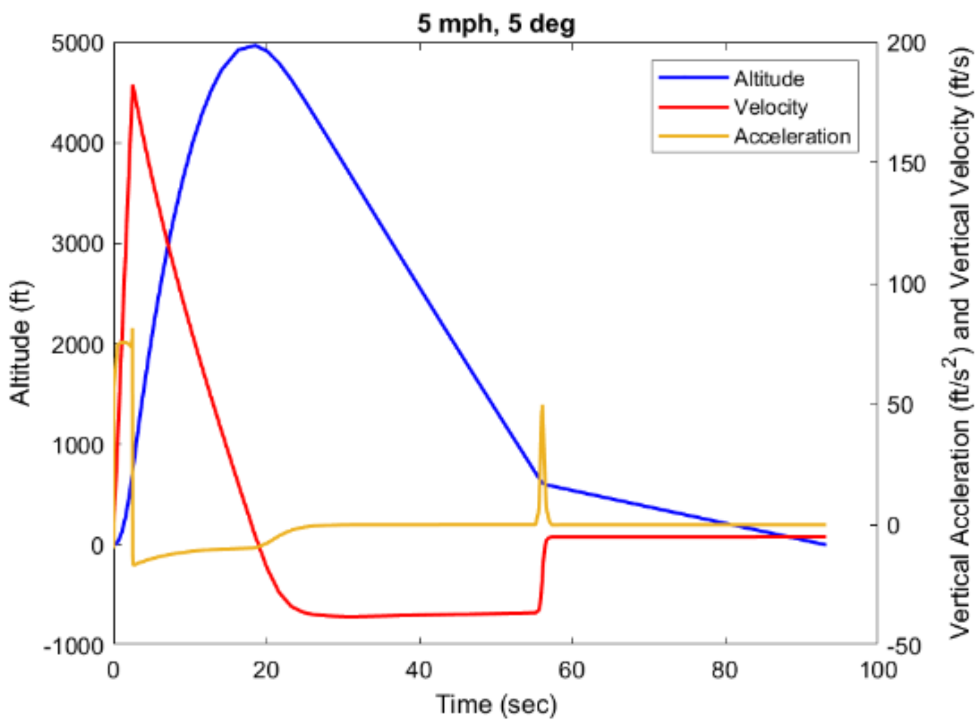


Figure 3.9.7: Simulink Altitude, Acceleration, and Velocity vs Time for 5 mph wind speed and 5 degree launch angle for the case of SAIL not deploying

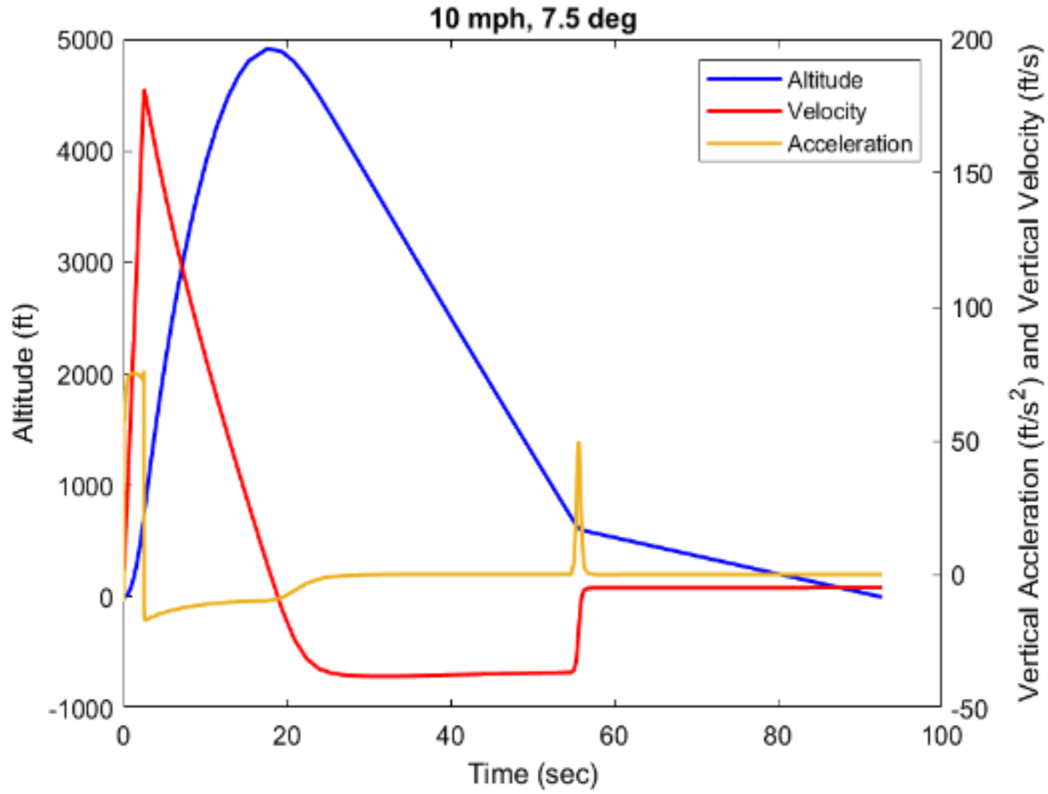


Figure 3.9.8: Simulink Altitude, Acceleration, and Velocity vs Time for 10 mph wind speed and 7.5 degree launch angle for the case of SAIL not deploying

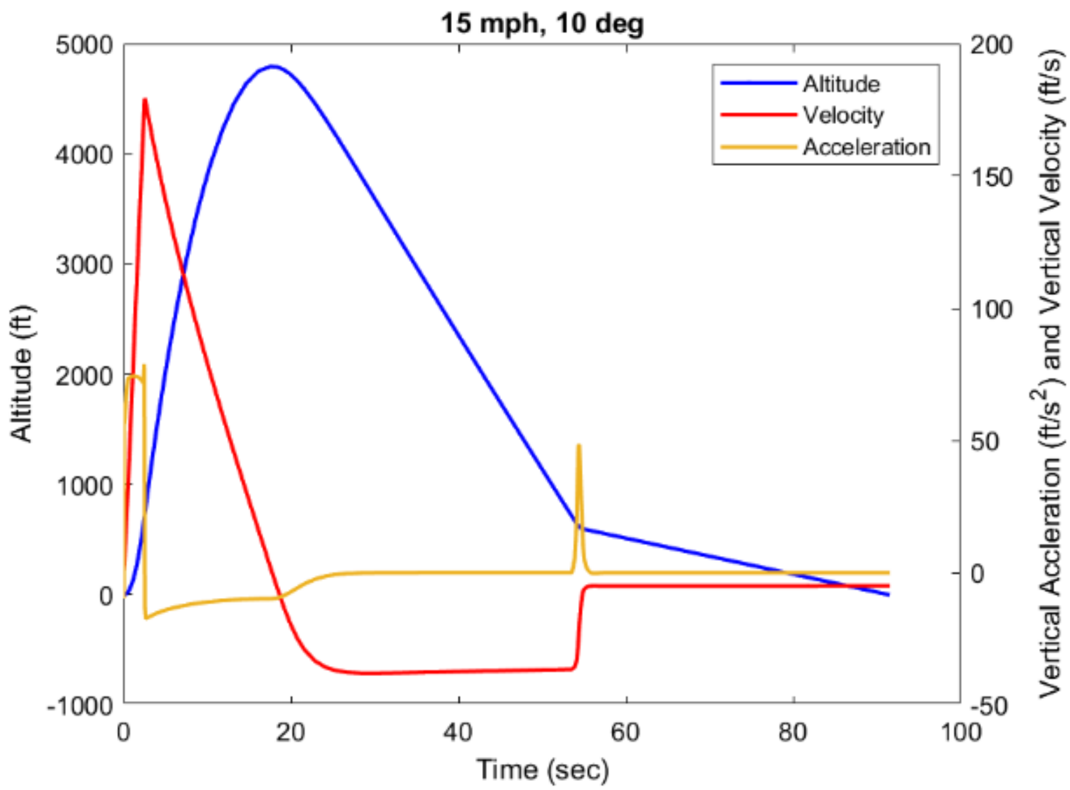


Figure 3.9.9: Simulink Altitude, Acceleration, and Velocity vs Time for 15 mph wind speed and 10 degree launch angle for the case of SAIL not deploying

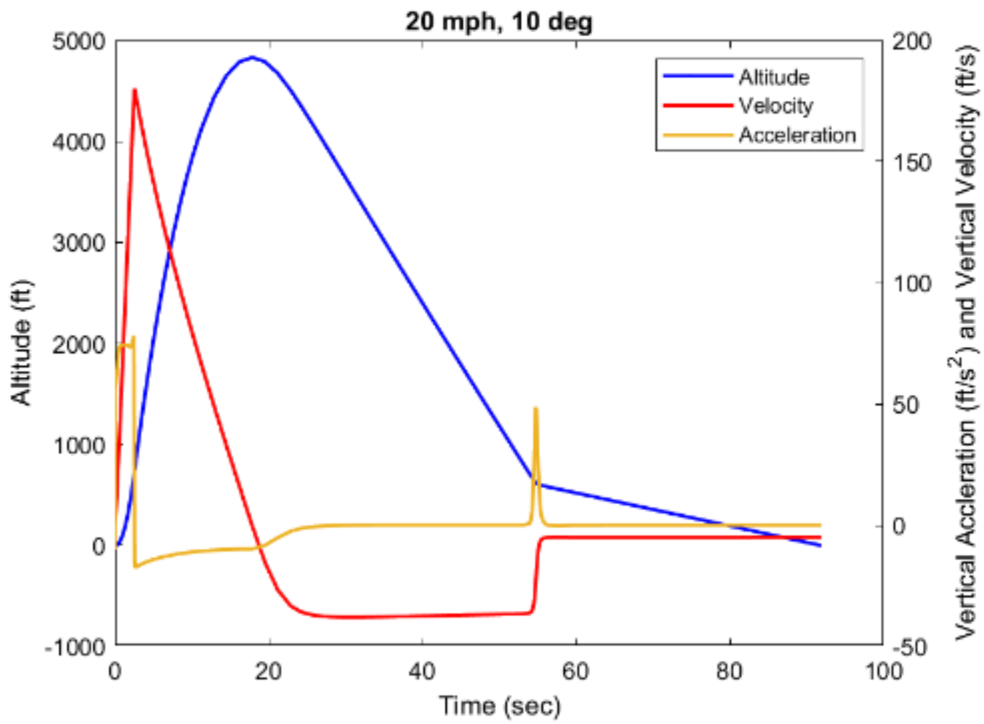


Figure 3.9.10: Simulink Altitude, Acceleration, and Velocity vs Time for 20 mph wind speed and 10 degree launch angle for the case of SAIL not deploying

Since OpenRocket cannot change the mass of the launch vehicle during flight in only one simulation, only Simulink graphs will show the altitude, velocity, and acceleration vs time predictions for the case of the SAIL deploying. This would only affect the final 400' of descent, and the difference between the deployment and non-deployment case would be about the same for the OpenRocket as the Simulink. The following 5 graphs are the Simulink simulations of altitude, velocity, and acceleration vs time for 0 to 20 mph winds with varying launch angles for the case of the SAIL deploying.

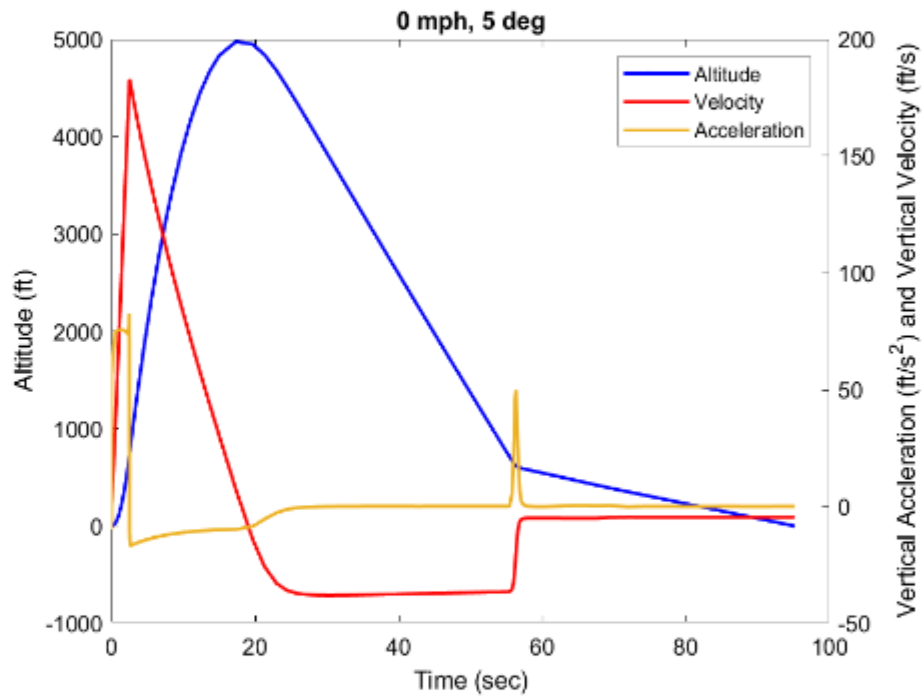


Figure 3.9.11: Simulink Altitude, Acceleration, and Velocity vs Time for 0 mph wind speed and 5 degree launch angle for the case of SAIL deploying

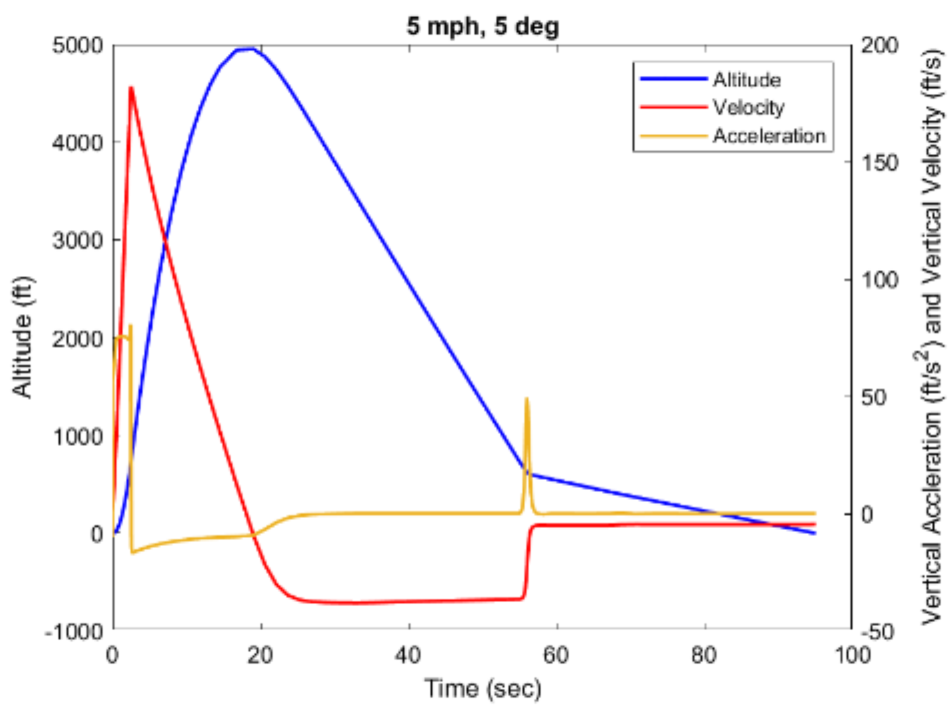


Figure 3.9.12: Simulink Altitude, Acceleration, and Velocity vs Time for 5 mph wind speed and 5 degree launch angle for the case of SAIL deploying

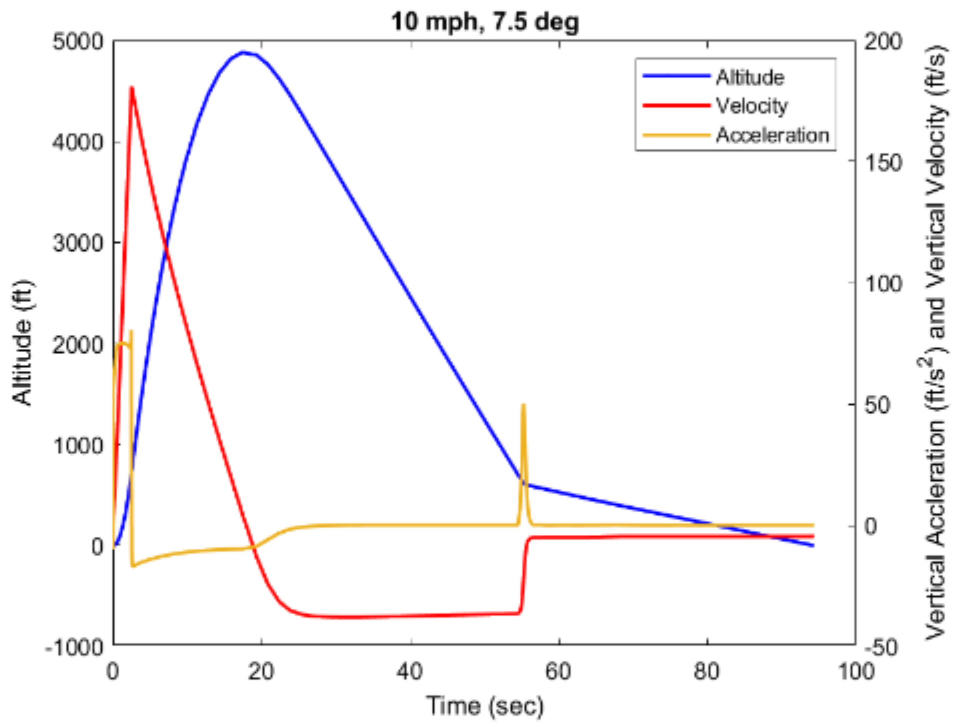


Figure 3.9.13: Simulink Altitude, Acceleration, and Velocity vs Time for 10 mph wind speed and 7.5 degree launch angle for the case of SAIL deploying

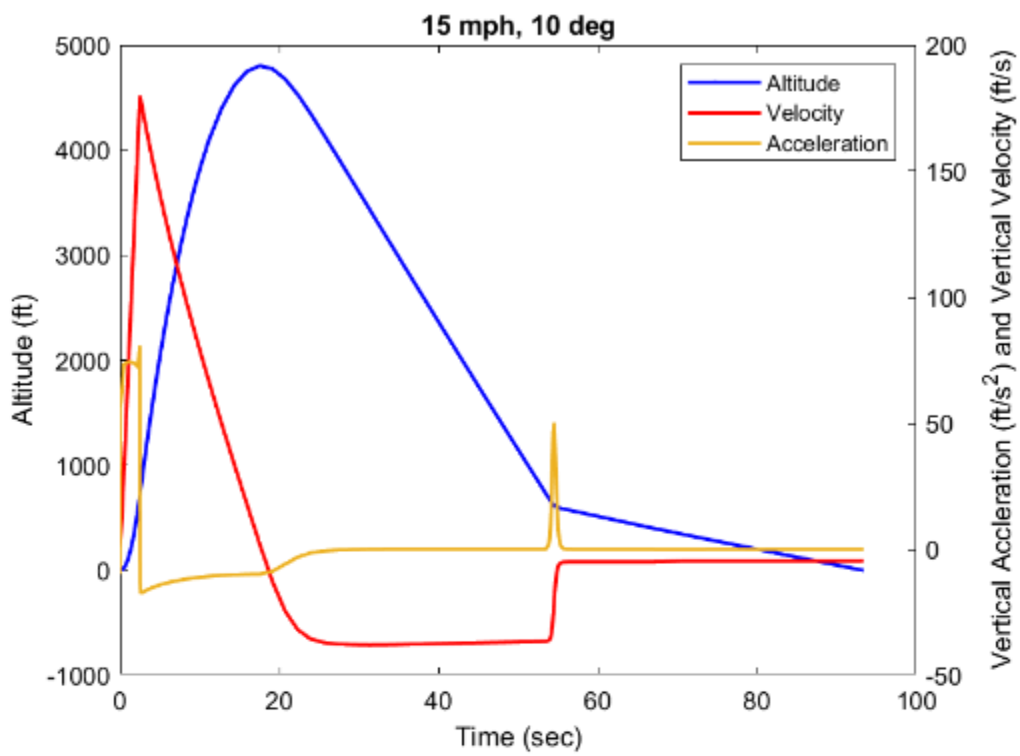


Figure 3.9.14: Simulink Altitude, Acceleration, and Velocity vs Time for 15 mph wind speed and 10 degree launch angle for the case of SAIL deploying

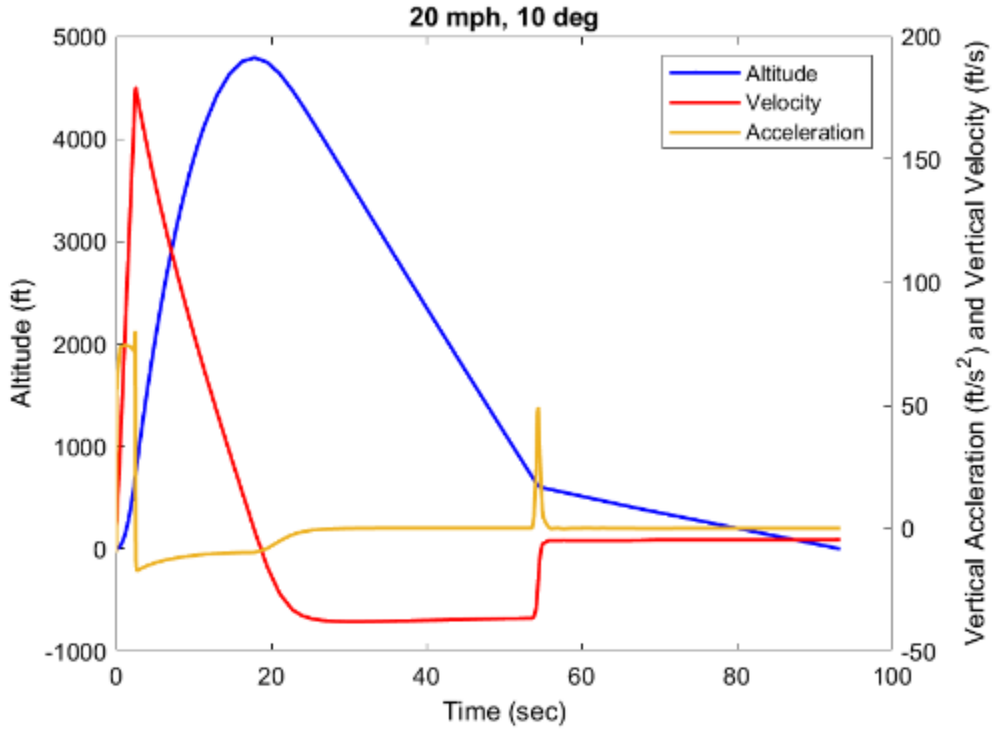


Figure 3.9.15: Simulink Altitude, Acceleration, and Velocity vs Time for 20 mph wind speed and 10 degree launch angle for the case of SAIL deploying

3.9.2 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. 1) 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, followed by a graph demonstrating the stability margin calibers, CP, and CG for the worst case launch scenario (20 mph wind, 10° launch angle)

Table 3.9.2: Stability of Launch Vehicle

Launch Angle (deg)	Wind Speed (mph)	Min Stability (calibers)
5	0	4.28
5	5	3.54
5	10	3.02
5	15	2.65
5	20	2.38

Launch Angle (deg)	Wind Speed (mph)	Min Stability (calibers)
7.5	0	4.26
7.5	5	3.54
7.5	10	3.03
7.5	15	2.67
7.5	20	2.40
10	0	4.25
10	5	3.55
10	10	3.04
10	15	2.68
10	20	2.42

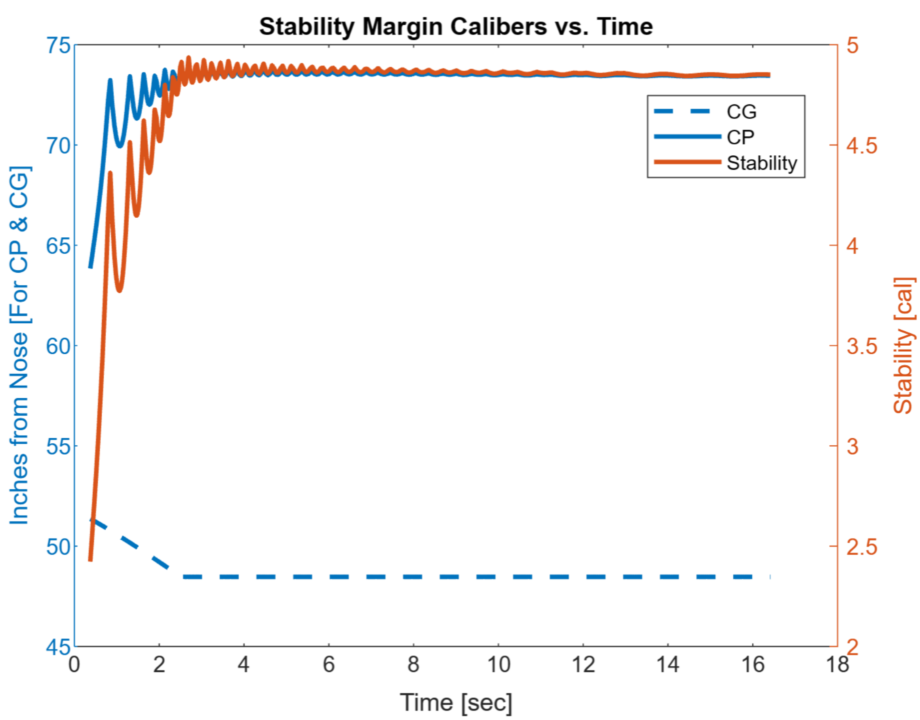


Figure 3.9.16: Stability margin calibers over full flight profile for worst case launch scenario (20 mph wind, 10° launch angle)

All the simulated minimum stability margin calibers shown in the table above are above 2.1 cal of stability at rail exit, so the launch vehicle design meets the team's (minimum 2.1 cal) and NASA's (minimum 2.0 cal) stability requirements.

Table 3.9.3: OpenRocket Generated Center of Pressure and Center of Gravity

OpenRocket Stability Verification	
Center of Pressure (in. from nose) (red)	73.559
Center of Gravity (in. from nose) (blue)	51.761

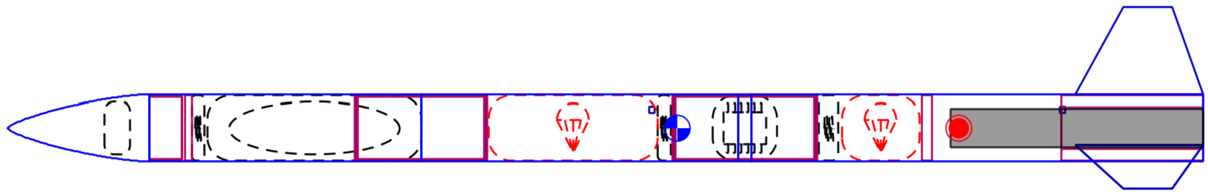


Figure 3.9.17 : Launch Vehicle with CP and CG displayed

The Center of Pressure for the finalized OpenRocket model is 73.6”. The Center of Gravity for the finalized OpenRocket model is 51.8”. Both numbers are measured from the nose cone tip of the rocket.

3.9.3 Landing Kinetic Energy

For the scenario of the SAIL not deploying, the OpenRocket simulation predicts a landing velocity of 15.9 ft/s and the Simulink model predicts a landing velocity of 16.3 ft/s for all launch conditions. In this scenario, the launch vehicle will land with three tethered independent sections: the payload and nose cone combined section, the recovery section, and the booster section. The weights of the parachutes and shock cords were not included in these calculations since these components would not be landing in the airframe. These calculated landing velocities were then used with the weights of each section of the launch vehicle to calculate the kinetic energy upon landing, using the equation:

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

Where the weight in pounds is divided by 32.174 ft/s^2 to convert to mass. In the table below are the calculated landing kinetic energies of these three sections with both the OpenRocket and Simulink landing velocities. This scenario provides an upper bound on the landing kinetic energy of the heaviest section, since the payload and nose cone section would be the heaviest section if the SAIL did not deploy. Even under this assumption, the max landing kinetic energy of the heaviest section is predicted to be 57.6 ft-lbf from the OpenRocket and 60.5 ft-lbf from the Simulink. Both of these values are under the competition requirement of 75 ft-lbf and the

65 ft-lbf bonus point requirement. Both simulations verify that the maximum landing kinetic energy will meet the target value of 65 ft-lbf, even in the worst case scenario of the SAIL not deploying.

Table 3.9.4: Landing Kinetic Energy of Each Independent Section of the Launch Vehicle for no SAIL deployment

Vehicle Section	Section Weight (lb)	OpenRocket Landing Kinetic Energy (ft-lbf)	Simulink Landing Kinetic Energy (ft-lbf)
Payload with Nose Cone	14.66	57.6	60.5
Recovery	6.50	25.5	26.8
Booster	10.63	41.8	43.9

For the case of the SAIL deploying, the launch vehicle will land with four tethered independent sections: nose cone, payload, recovery, and booster. This payload section will not include the SAIL, so its weight will be less. The weights of these sections again do not include the parachutes or shock cords. For this scenario, the OpenRocket predicts a maximum landing velocity of 14.9 ft/s, and the Simulink predicts a landing velocity of 15.1 ft/s. Using the same equation as before, the calculated landing kinetic energy for each independent section of the launch vehicle with the SAIL deploying are shown in the table below. In the case of the SAIL deploying, the maximum landing kinetic energy will be well under the target value of 65 ft-lbf, for both the OpenRocket and Simulink predictions, verifying that the launch vehicle will meet this requirement.

Table 3.9.5: Landing Kinetic Energy of Each Independent Section of the Launch Vehicle for SAIL deployment

Vehicle Section	Section Weight (lb)	OpenRocket Landing Kinetic Energy (ft-lbf)	Simulink Landing Kinetic Energy (ft-lbf)
Nose Cone	3.16	10.9	11.2
Payload	6.50	22.4	23.0
Recovery	6.50	22.4	23.0
Booster	10.63	36.7	37.7

3.9.4 Descent Time

The descent times were also calculated for both scenarios of the SAIL deploying and not deploying. For the scenario of the SAIL not deploying, the descent times were calculated in both OpenRocket and Simulink for various launch conditions, and are shown in the following three tables. All of the predicted descent times are below the competition requirement of 90 seconds and the bonus point target of 80 seconds. The Simulink tends to predict a higher descent time than the OpenRocket, due to its higher predicted apogees and slower drogue descent velocity. The Simulink predicts a drogue descent velocity of 124.2 ft/s, compared to the OpenRocket's predicted drogue descent velocity of 134 ft/s. However, both models follow the same trends and verify the launch vehicle will meet the competition requirement in the scenario of the SAIL not deploying.

Table 3.9.6: Descent times for the launch vehicle containing the SAIL under various flight conditions - OpenRocket

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4845	71.3
5 mph wind, 5° launch angle	4778	68.4
10 mph wind, 7.5° launch angle	4578	70.6
15 mph wind, 10° launch angle	4305	66.7
20 mph wind, 10° launch angle	4143	67.0

Table 3.9.7: Descent times for the launch vehicle containing the SAIL under various flight conditions - Simulink

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4974	74.8
5 mph wind, 5° launch angle	4952	74.7
10 mph wind, 7.5° launch angle	4880	75.3
15 mph wind, 10° launch angle	4803	74
20 mph wind, 10° launch angle	4791	74.1

Table 3.9.8: Descent times for the launch vehicle containing the SAIL under various flight conditions - Combined OpenRocket and Simulink

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4910	73.1
5 mph wind, 5° launch angle	4865	71.6
10 mph wind, 7.5° launch angle	4729	73.0
15 mph wind, 10° launch angle	4554	70.4
20 mph wind, 10° launch angle	4467	70.6

Descent times were also calculated for the case of the SAIL deploying. The SAIL will begin deployment at 400' AGL. It will likely not deploy at exactly 400', but assuming it deploys at 400' will give an upper limit on the descent time of the launch vehicle. The SAIL weighs 5 lbs, so the last 400' are simulated without those 5 lbs included. OpenRocket does not have a way to change the mass of the launch vehicle during flight, so the time to reach 400' AGL was found for the full vehicle weight. Then OpenRocket was run to simulate the weight of the launch vehicle without the 5 lb SAIL, and the time elapsed from 400' AGL until landing was used and added to the previously found time to 400'. The Simulink was modified to account for the changing mass in flight, and was able to calculate the descent time with the payload deploying at 400' AGL. Again, simulations were run in both OpenRocket and Simulink for various launch conditions, and are shown in the following three tables. Both the OpenRocket and Simulink show longer descent times for the case of the SAIL deploying, which makes sense since the last 400' of descent would be with a lighter weight. Even with this lighter weight, all of the calculated descent times are under the 90 second competition requirement and 80 second bonus point target value. Again, the Simulink predicts a higher descent time, due to its higher predicted apogees and slower drogue descent rate. Both the OpenRocket and Simulink show about a 2 to 3 second increase in descent time for all launch conditions when the SAIL deploys. These simulations verify that even in the case of the SAIL deploying, the descent time requirement and target value will be met.

Table 3.9.9: Descent times for the launch vehicle without the SAIL under various flight conditions - OpenRocket

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4845	73.6
5 mph wind, 5° launch angle	4778	70.6
10 mph wind, 7.5° launch angle	4578	72.6
15 mph wind, 10° launch angle	4305	68.8
20 mph wind, 10° launch angle	4143	68.9

Table 3.9.10: Descent times for the launch vehicle without the SAIL under various flight conditions - Simulink

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4974	77.8
5 mph wind, 5° launch angle	4952	76.0
10 mph wind, 7.5° launch angle	4880	77.0
15 mph wind, 10° launch angle	4803	75.9
20 mph wind, 10° launch angle	4791	75.9

Table 3.9.11: Descent times for the launch vehicle without the SAIL under various flight conditions - Combined OpenRocket and Simulink

Launch Conditions	Apogee (ft)	Descent Time (s)
0 mph wind, 5° launch angle	4910	75.7

5 mph wind, 5° launch angle	4865	73.3
10 mph wind, 7.5° launch angle	4729	74.8
15 mph wind, 10° launch angle	4554	72.4
20 mph wind, 10° launch angle	4467	72.4

3.9.5 Drift Distance

Drift distance for the launch vehicle for wind speeds between 0 and 20 mph was calculated in both OpenRocket and Simulink. The competition requirement states that the launch vehicle must land within a 2500' radius of the launch pad. The following drift distance calculations were made assuming that apogee was reached directly above the launch pad. The OpenRocket drift distances were found by running simulations for drift distance east of launch and by subtracting the distance east of the launch pad at apogee from the location east of the launch pad at landing. The Simulink drift distances were found in a similar way, by simulating drift as if apogee had been reached directly above the launch pad. The following three tables show the predicted drift distances from apogee for the case of the SAIL not deploying. Both predict similar drift distances for the 0, 5, and 10 mph wind cases. However, for the 15 and 20 mph wind cases, the Simulink predicts significantly higher drift distances from apogee. This is mostly due to the higher apogees predicted at those launch conditions compared to the OpenRocket, leaving more time during descent for the launch vehicle to drift. Even with these higher drift distances, the Simulink still confirms the OpenRocket's predictions that the launch vehicle will remain within the 2500' radius of the launch pad to meet the drift distance requirement, even for the worst case scenario of 20 mph winds and a 10 deg launch angle. Shown below the tables are the drift distance graphs that show the launch vehicle's distance east of launch throughout the flight, confirming that even with apogee not being reached directly above the launch pad, the launch vehicle will still be within the 2500' radius of the launch pad.

Table 3.9.12: Summary of Drift Distance Graphs

Simulation	SAIL Deployment?	Launch Conditions	Figure Number
OpenRocket	No	0 mph 5 deg	3.9.18
OpenRocket	No	5 mph 5 deg	3.9.19
OpenRocket	No	10 mph 7.5 deg	3.9.20
OpenRocket	No	15 mph 10 deg	3.9.21
OpenRocket	No	20 mph 10 deg	3.9.22
Simulink	No	0 mph 5 deg	3.9.23
Simulink	No	5 mph 5 deg	3.9.24
Simulink	No	10 mph 7.5 deg	3.9.25
Simulink	No	15 mph 10 deg	3.9.26
Simulink	No	20 mph 10 deg	3.9.27

Simulink	Yes	0 mph 5 deg	3.9.28
Simulink	Yes	5 mph 5 deg	3.9.29
Simulink	Yes	10 mph 7.5 deg	3.9.30
Simulink	Yes	15 mph 10 deg	3.9.31
Simulink	Yes	20 mph 10 deg	3.9.32

Table 3.9.13: Drift Distance as a result of the OpenRocket Simulation for SAIL not deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	302
5 mph wind, 5° launch angle	57
10 mph wind, 7.5° launch angle	393
15 mph wind, 10° launch angle	684
20 mph wind, 10° launch angle	1121

Table 3.9.14: Drift Distance as a result of the Simulink simulations for SAIL not deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	399
5 mph wind, 5° launch angle	17
10 mph wind, 7.5° launch angle	531
15 mph wind, 10° launch angle	1202
20 mph wind, 10° launch angle	1912

Table 3.9.15: Drift Distance as a result of the combined OpenRocket and Simulink simulations for SAIL not deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	351
5 mph wind, 5° launch angle	37
10 mph wind, 7.5° launch angle	462
15 mph wind, 10° launch angle	943
20 mph wind, 10° launch angle	1517

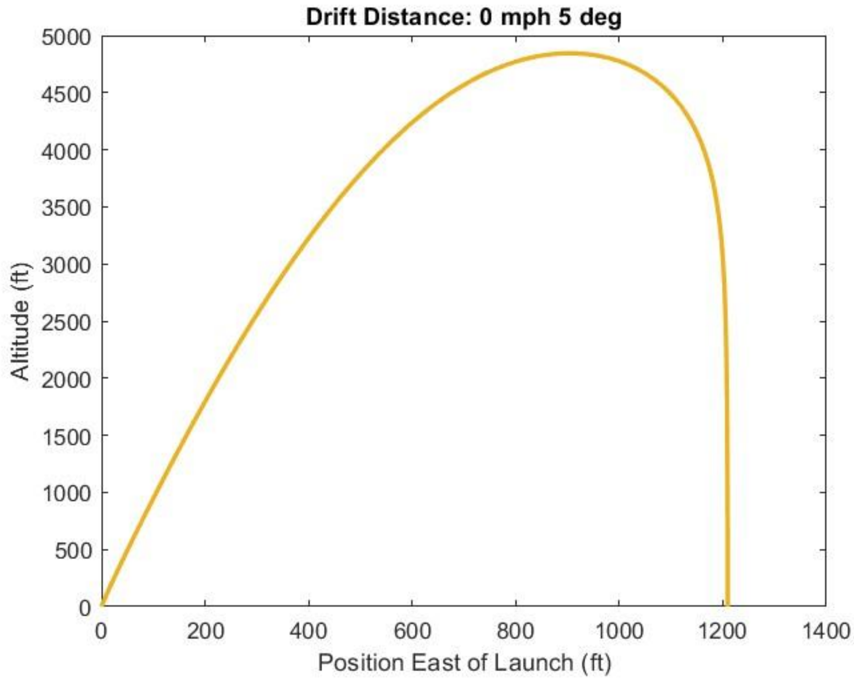


Figure 3.9.18: Drift Distance for 0 mph winds as a result of the OpenRocket Simulation for SAIL not deploying

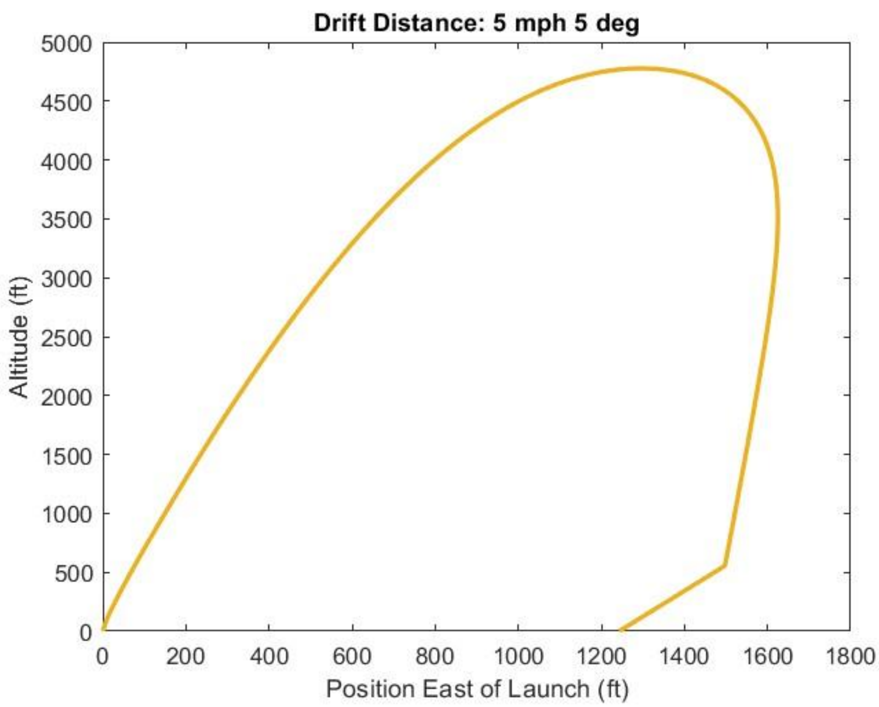


Table 3.9.19: Drift Distance for 5 mph winds as a result of the OpenRocket Simulation for SAIL not deploying

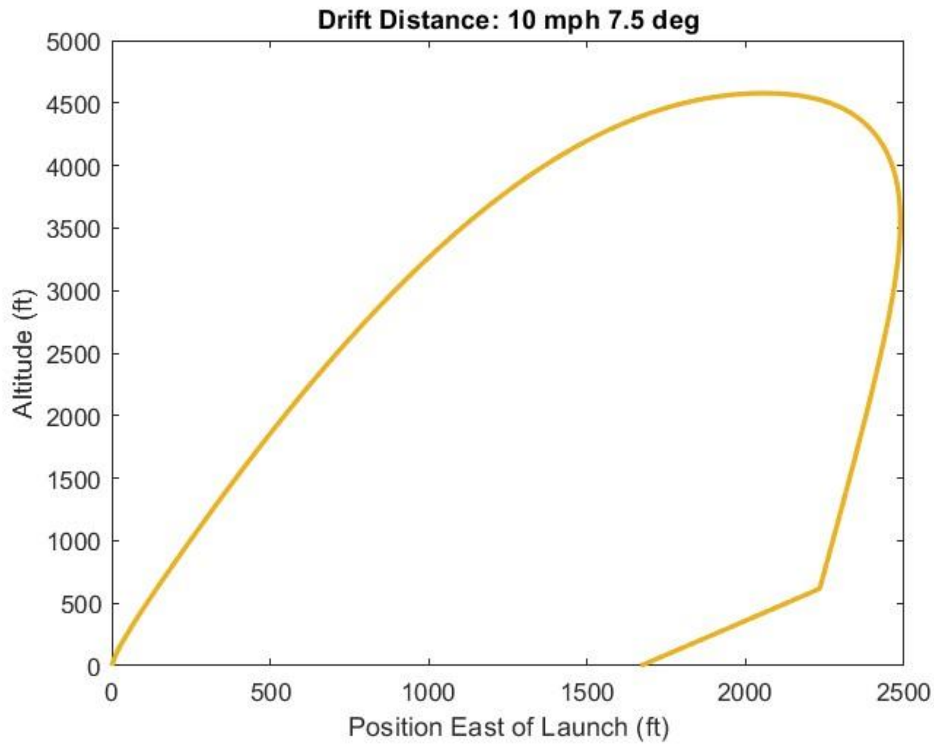


Table 3.9.20: Drift Distance for 10 mph winds as a result of the OpenRocket Simulation for SAIL not deploying

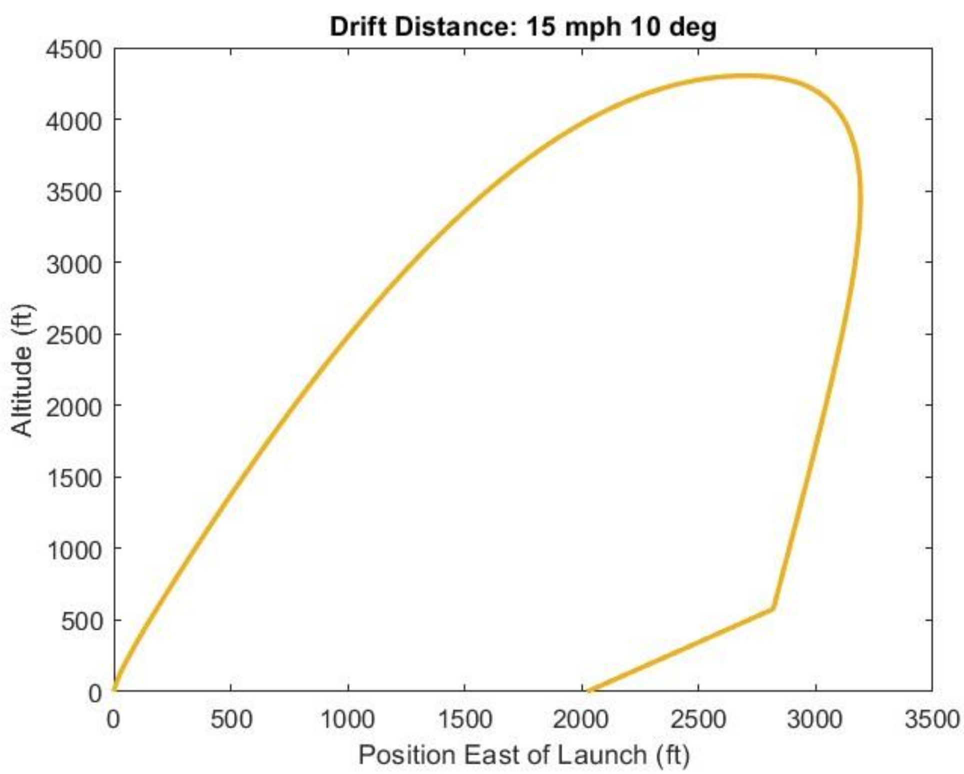


Table 3.9.21: Drift Distance for 15 mph winds as a result of the OpenRocket Simulation for SAIL not deploying

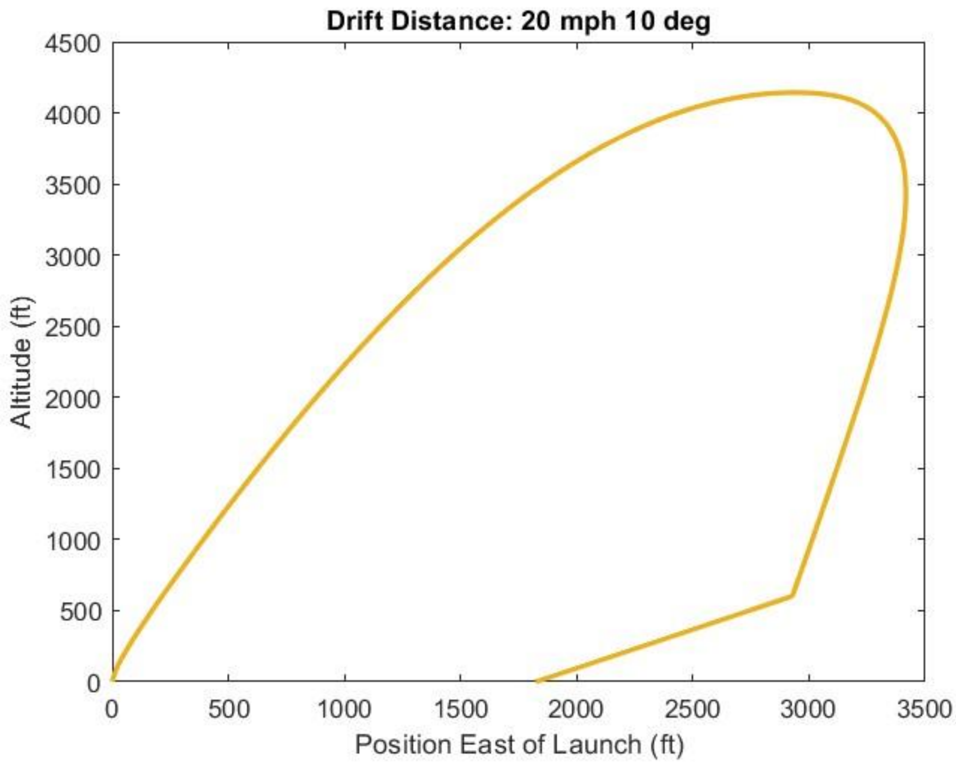


Table 3.9.22: Drift Distance for 20 mph winds as a result of the OpenRocket Simulation for SAIL not deploying

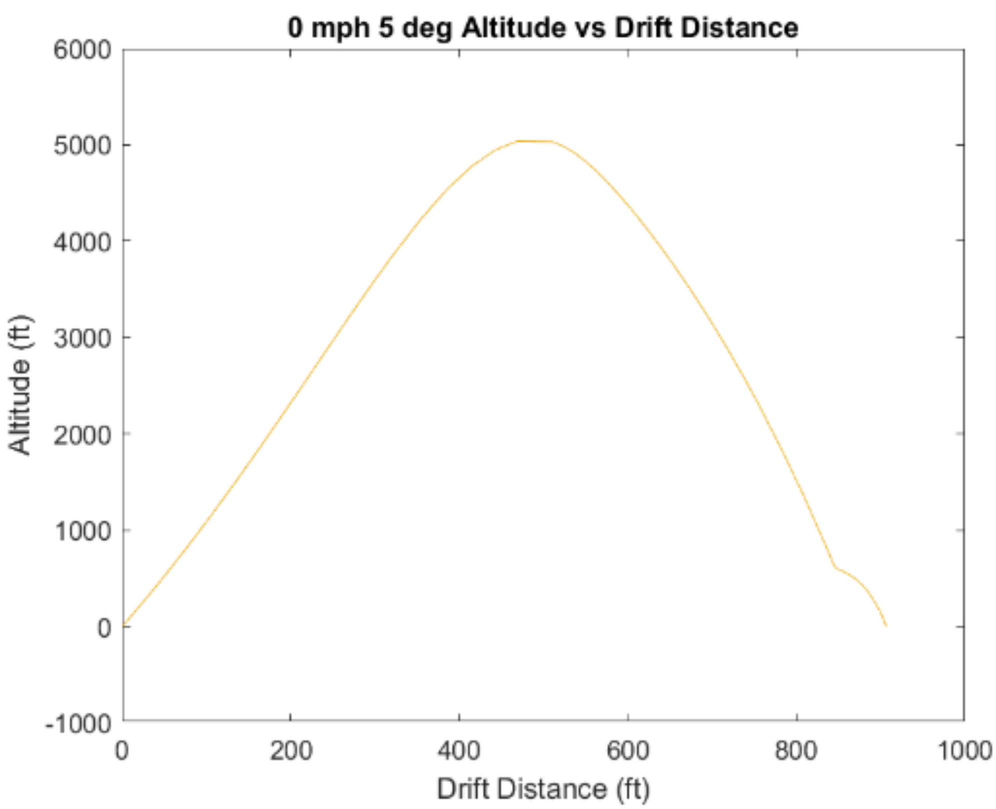


Table 3.9.23: Drift Distance for 0 mph winds as a result of the Simulink Simulation for SAIL not deploying

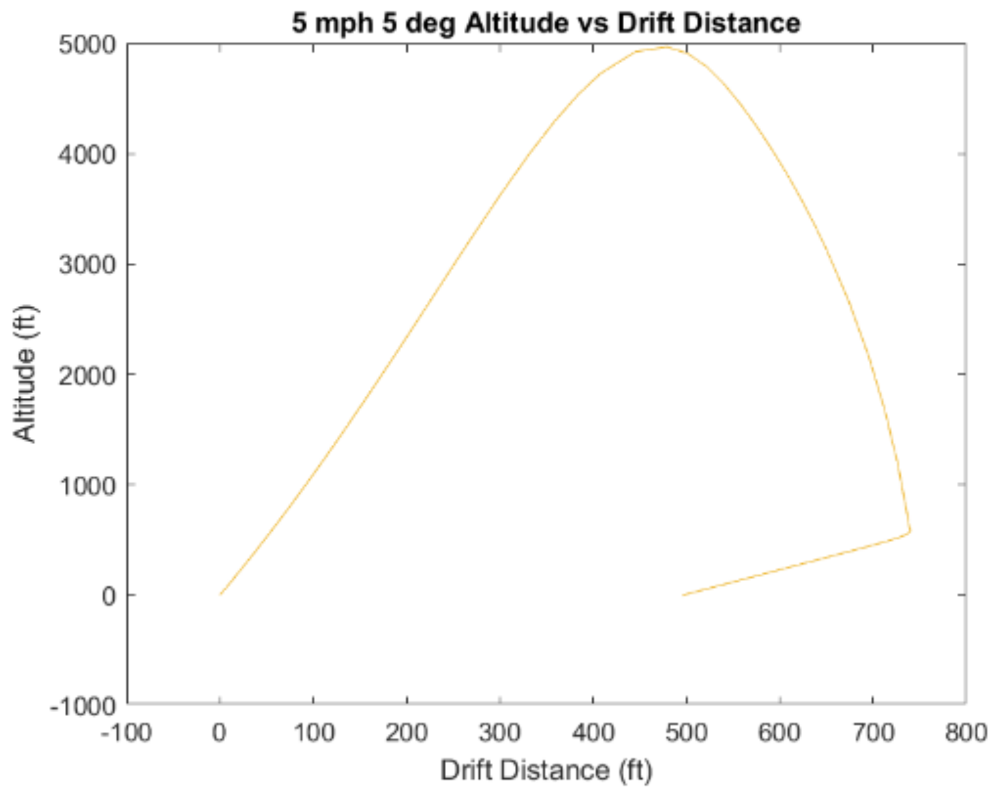


Table 3.9.24: Drift Distance for 5 mph winds as a result of the Simulink Simulation for SAIL not deploying

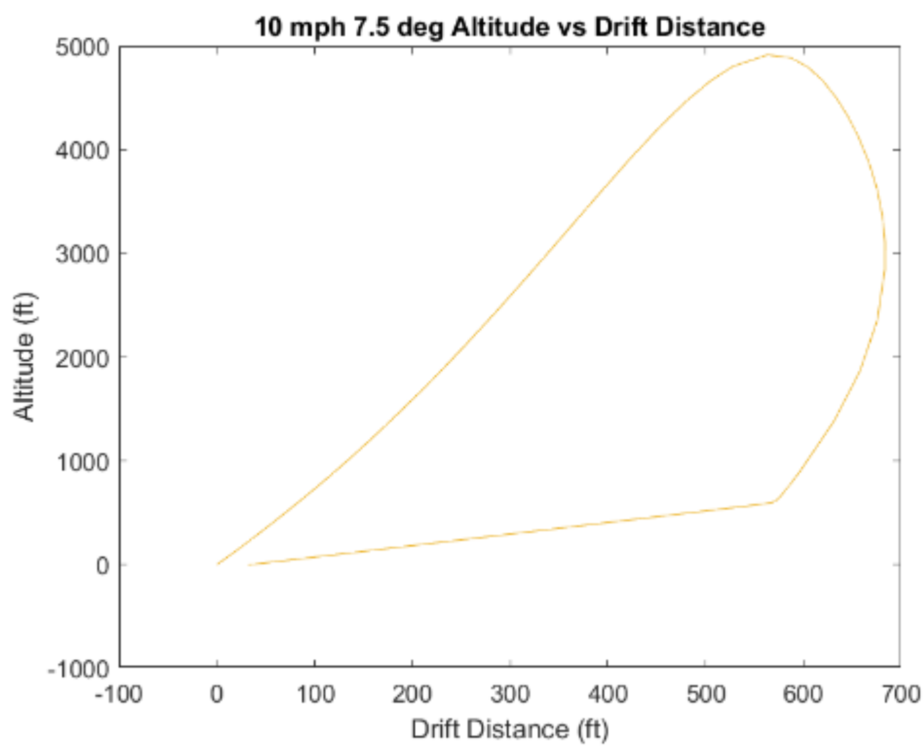


Table 3.9.25: Drift Distance for 10 mph winds as a result of the Simulink Simulation for SAIL not deploying

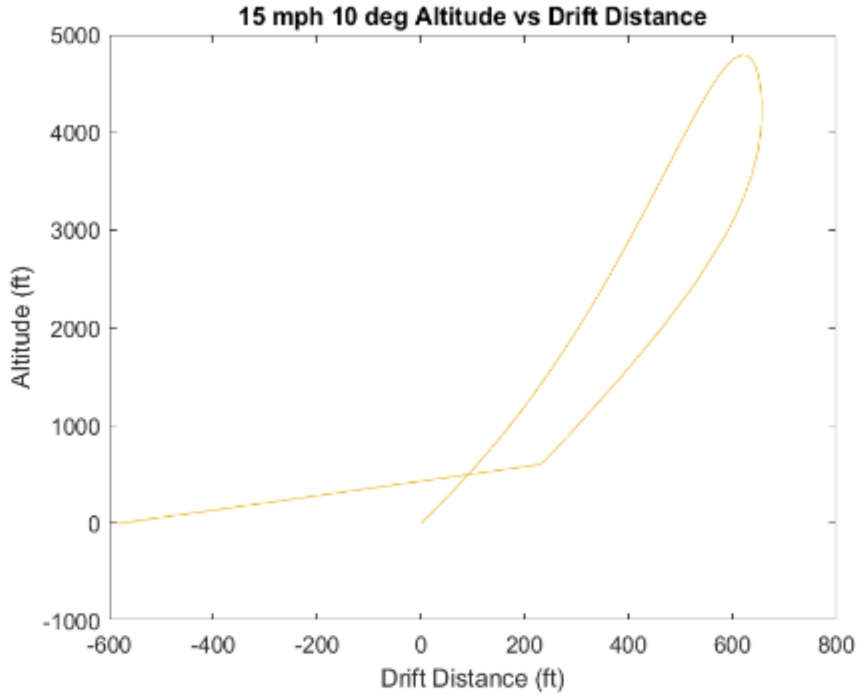


Table 3.9.26: Drift Distance for 15 mph winds as a result of the Simulink Simulation for SAIL not deploying

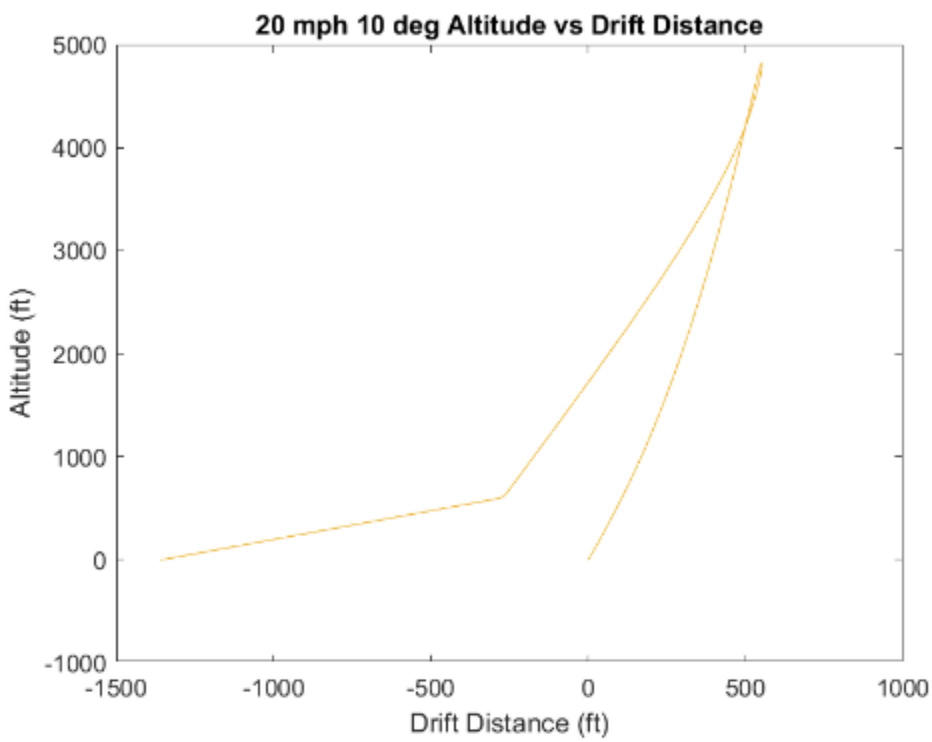


Table 3.9.27: Drift Distance for 20 mph winds as a result of the Simulink Simulation for SAIL not deploying

Drift distance from apogee was also calculated for the case of the 5 lb SAIL deploying at 400' AGL. Again, these drift distances were found for 0 to 20 mph winds with both OpenRocket and

Simulink. Since the Simulink can be modified to drop the weight of the SAIL at 400’ AGL, the drift distance for that scenario could also be calculated. To verify these predictions, the OpenRocket simulation was used. OpenRocket does not have a way to change the weight of the launch vehicle during flight, so the drift distance from apogee to 400’ AGL was found with the weight of the payload. Simulations were then run to determine the drift distance without the weight of the SAIL from 400’ AGL to landing, and then these distances were added together to determine the predicted drift distance with SAIL deploying. For all but the Simulink 5 mph 5 deg case, the OpenRocket and Simulink both predicted slightly higher drift distances when the SAIL deployed versus when it did not. This confirms that this method of calculating drift distance will at least provide a reasonable estimate. For the Simulink 5 mph 5 deg case, the drift distance is less, likely just because of the direcion the model is taking into account. Otherwise, the same idea holds that the Simulink predicts higher drift distances compared to the OpenRocket because of its greater predicted apogees. However, the simulations verify that even in the case of the SAIL deploying, the launch vehicle will meet competition requirements and stay within the 2500’ radius of the launch pad.

Table 3.9.16: Drift Distance as a result of the OpenRocket simulations for SAIL deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	302
5 mph wind, 5° launch angle	72
10 mph wind, 7.5° launch angle	424
15 mph wind, 10° launch angle	730
20 mph wind, 10° launch angle	1174

Table 3.917: Drift Distance as a result of the Simulink simulations for SAIL deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	429
5 mph wind, 5° launch angle	2
10 mph wind, 7.5° launch angle	554
15 mph wind, 10° launch angle	1239
20 mph wind, 10° launch angle	1953

Table 3.9.18: Drift Distance as a result of the combined OpenRocket and Simulink simulations for SAIL deploying:

Launch Conditions	Drift Distance From Apogee (ft)
0 mph wind, 5° launch angle	366
5 mph wind, 5° launch angle	37
10 mph wind, 7.5° launch angle	489
15 mph wind, 10° launch angle	985
20 mph wind, 10° launch angle	1564

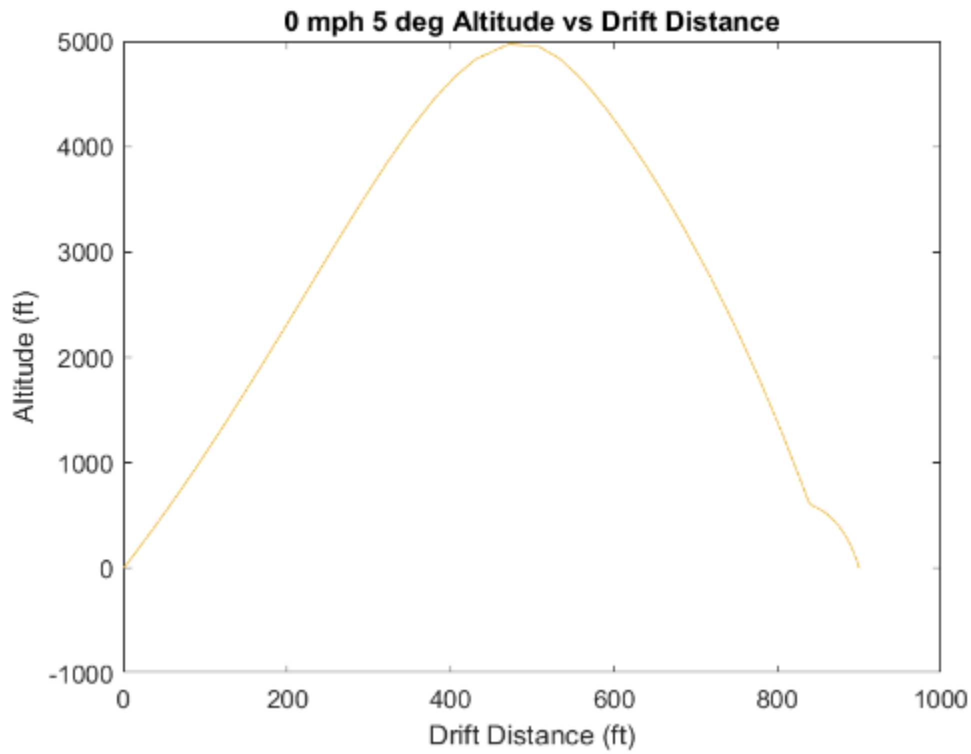


Table 3.9.28: Drift Distance for 0 mph winds as a result of the Simulink Simulation for SAIL deploying

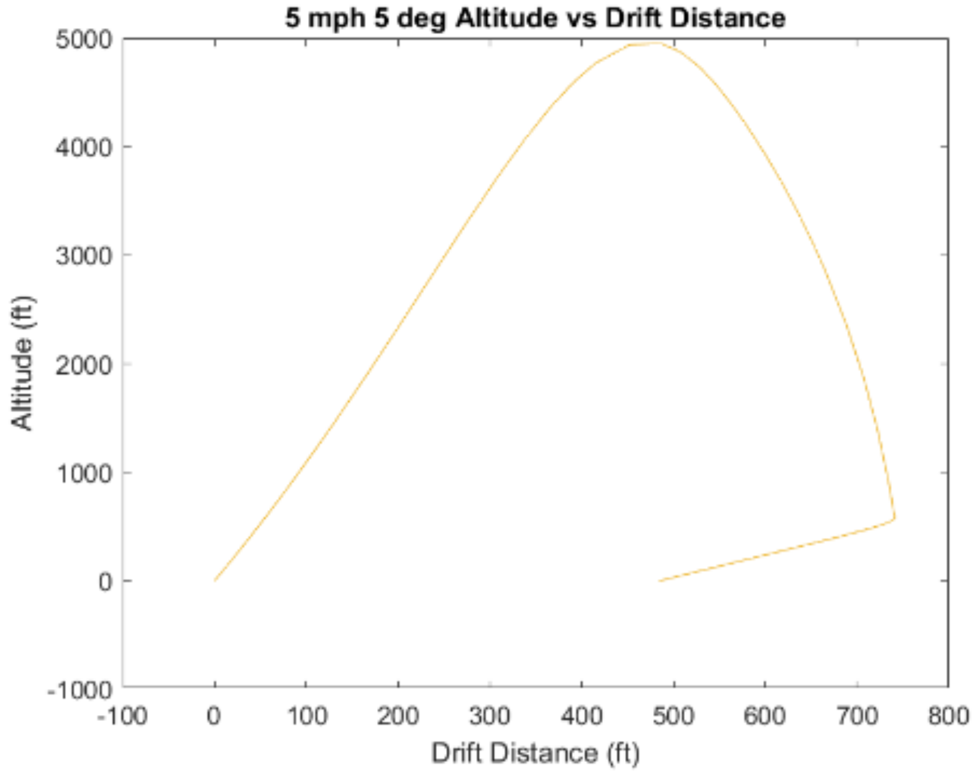


Table 3.9.29: Drift Distance for 5 mph winds as a result of the Simulink Simulation for SAIL deploying

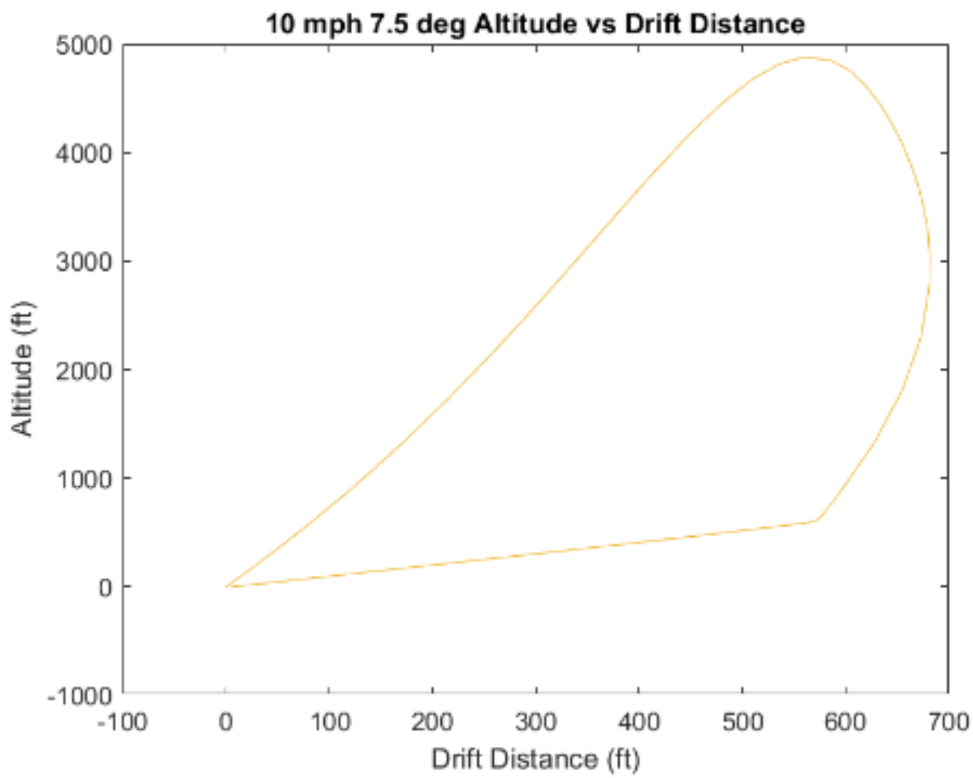


Table 3.9.30: Drift Distance for 10 mph winds as a result of the Simulink Simulation for SAIL deploying

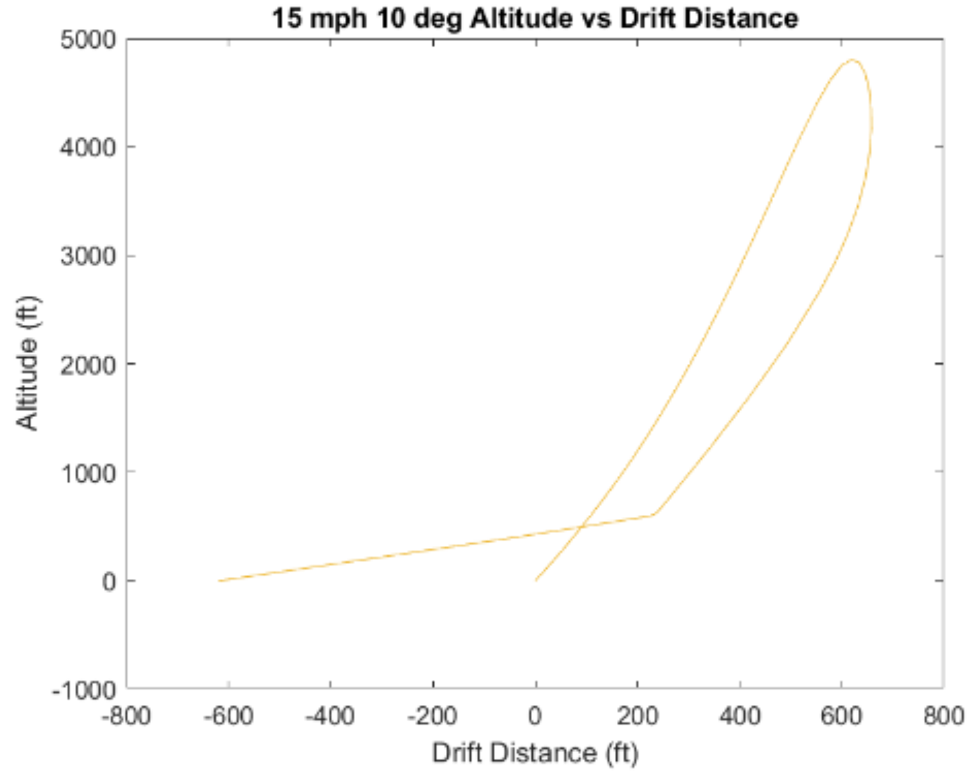


Table 3.9.31: Drift Distance for 15 mph winds as a result of the Simulink Simulation for SAIL deploying

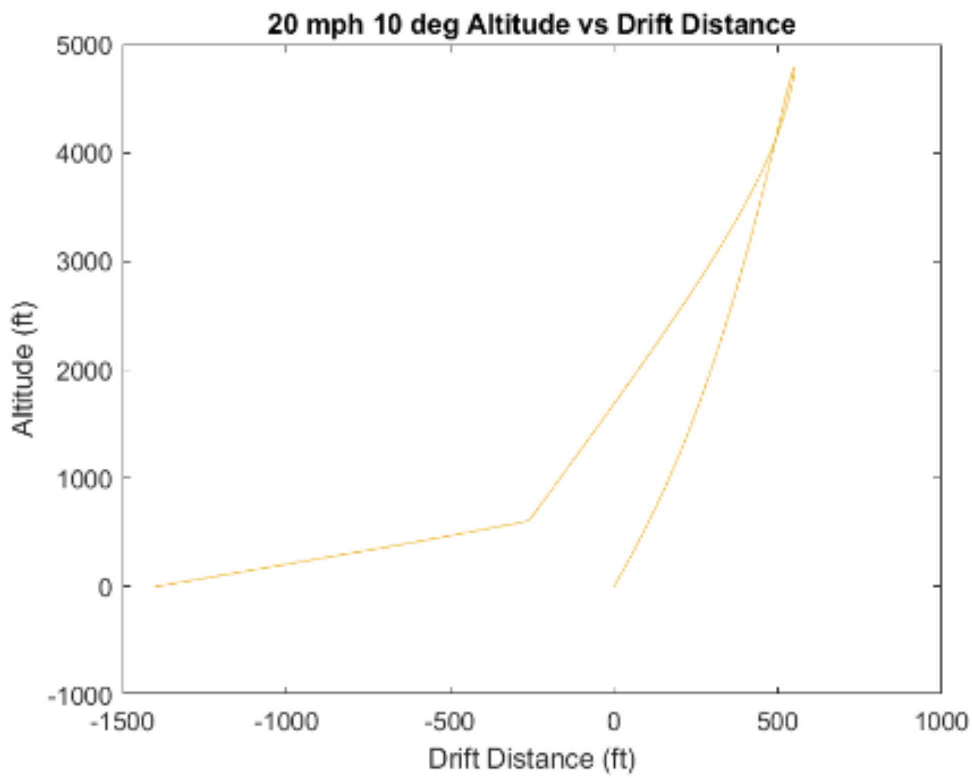


Table 3.9.32: Drift Distance for 20 mph winds as a result of the Simulink Simulation for SAIL deploying

3.9.6 Simulink and OpenRocket Differences

OpenRocket was used as the primary flight profile simulation and Simulink was used to verify the OpenRocket simulation results. Provided in the following four tables are a summary of the OpenRocket and Simulink simulations, for both scenarios of the SAIL not deploying and the SAIL deploying. There were some differences between the two models, but both models verified that the launch vehicle would meet both competition requirements and bonus point target values for all launch conditions and both scenarios of the SAIL deploying and not deploying. The most notable difference between the Simulink and OpenRocket simulations is that the Simulink model predicts higher apogees than does OpenRocket. This difference can mainly be explained by the difference in how drag is taken into account in the different simulations. OpenRocket uses a variable coefficient of drag that changes with time, while the Simulink uses a constant, average drag coefficient that does not change over time. This results in the Simulink model calculating less drag into its calculations, which results in higher and less accurate predicted apogees than the OpenRocket model. The Simulink is also only a two-degree-of-freedom model, while OpenRocket is a six-degree-of-freedom model. This means that it is taking into account motion in less directions, or less overall motion, and will lead to more differences between the simulations, especially for the less ideal launch conditions. This explains why the OpenRocket and Simulink models differ more for the 15 and 20 mph wind cases. The higher predicted apogees for the Simulink help to explain the other differences between it and the OpenRocket. Since the Simulink predicts higher overall apogees, it also predicts higher descent times and drift distances. The Simulink model has been updated since PDR to be able to provide predictions for a launch vehicle with changing mass over time, so that it can provide predictions for the SAIL deploying. The OpenRocket is unable to change mass over time, so simulations had to be combined to provide the OpenRocket predictions for descent time and drift distance. For the more ideal and more likely launch conditions, the OpenRocket and Simulink had similar mission performance predictions. For the 0 mph 5 deg case, the predicted apogees were within 2.7% of each other, and for the 5 mph 5 deg case, the predicted apogees were within 3.6% of each other. It can be seen that the Simulink predicted higher descent times for both the SAIL deploying and not deploying due to its higher overall predicted apogees. However, both the OpenRocket and the Simulink had about the same increase in descent time for the case of the SAIL not deploying and the SAIL deploying, verifying their method of calculation. All of the simulations predicted descent times less than the target value of 80 seconds for bonus points and well under the competition requirement of 90 seconds, verifying that this requirement will be met. The slightly higher landing kinetic energy predicted by the Simulink can be attributed to its slightly higher landing velocity values. For SAIL not deploying, the Simulink predicted a landing velocity of 16.3 ft/s compared to the OpenRocket's 15.9 ft/s. For SAIL deploying, the Simulink predicted a landing velocity of 15.1 ft/s compared with the OpenRocket's maximum landing velocity of 14.9 ft/s.

This difference in landing velocities again can be explained by the Simulink accounting for less drag in its model than the OpenRocket. The maximum landing kinetic energy calculated by the OpenRocket is 57.9 ft-lbf compared with 60.8 ft-lbf from the Simulink model. These values are still relatively close and under the competition requirement of 75 ft-lbf and target value of 65 ft-lbf for bonus points. This is also in the worst case scenario of the SAIL not deploying and the combined payload and nose cone section being the heaviest section. So again, the simulations verify this target value will be met, even in the worst case scenario. The next comparison is between rail exit velocities and stability margin calibers. The Simulink model cannot directly calculate stability margin calibers but since the value is based on the rail exit velocity, because all of the Simulink rail exit velocities are higher than the corresponding OpenRocket ones, that means all of its predicted stability margin calibers would be higher as well. Since all of the launch conditions will have more than the minimum 2.0 stability margin calibers off the rail as predicted by the OpenRocket, the Simulink would also predict that, and verifies that this requirement will be met. All of the predicted rail exit velocities are also over the minimum 52 ft/s requirement, with a minimum of 72.0 ft/s predicted by the OpenRocket and a minimum of 72.6 ft/s predicted by the Simulink, verifying this requirement as well. The final comparison is between drift distances as calculated assuming apogee was reached directly above the launch pad. For the 0 to 10 mph wind cases, the OpenRocket and Simulink predicted similar drift distances for both the SAIL deploying and not deploying. The drift distances varied a lot more with the less ideal conditions, specifically the 15 and 20 mph wind cases, which again is due to the Simulink's higher predicted apogees and that it takes into account less range of motion than the OpenRocket. Both models showed similar trends of a slight increase in drift distance when the SAIL is deployed, and both also verify that the drift distance will be within the 2500' radius of the launch pad. Overall, both simulations provide similar predictions and confirm that the launch vehicle will meet all competition requirements and any bonus point target values.

Table 3.9.19: Summary of OpenRocket Flight Simulations for the SAIL not deploying

Wind Speed (mph)	Launch Angle	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	4845	71.3	57.9	72.0	302
5	5	4778	68.4	57.9	72.0	57
10	7.5	4578	70.6	57.9	72.0	393
15	10	4305	66.7	57.9	72.1	684
20	10	4143	67.0	57.9	72.1	1121

Table 3.9.20: Summary of Simulink Flight Simulations for the SAIL not deploying

Wind Speed (mph)	Launch Angle	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	4974	74.8	60.8	92.0	399
5	5	4952	74.7	60.8	72.6	17
10	7.5	4880	75.3	60.8	80.2	531
15	10	4803	74	60.8	75.9	1202
20	10	4791	74.1	60.8	88.1	1912

Table 3.9.21: Summary of OpenRocket Flight Simulations for the SAIL deploying

Wind Speed (mph)	Launch Angle	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	4845	73.6	35.2	72.0	302
5	5	4778	70.6	35.7	72.0	72
10	7.5	4578	72.6	35.7	72.0	424
15	10	4305	68.8	35.2	72.1	730
20	10	4143	68.9	36.7	72.1	1174

Table 3.9.22: Summary of Simulink Flight Simulations for the SAIL deploying

Wind Speed (mph)	Launch Angle	Apogee (ft)	Descent Time (s)	Landing KE of Heaviest Section (ft-lbf)	Rail Exit Velocity (ft/s)	Drift Distance From Apogee (ft)
0	5	4974	77.8	37.7	92.0	429
5	5	4952	76	37.7	72.6	2
10	7.5	4880	77	37.7	80.2	554
15	10	4803	75.9	37.7	75.9	1239
20	10	4791	75.9	37.7	88.1	1953

3.9.7 Official Competition Launch Target Altitude

The official competition launch target altitude is 4768', as was determined at the PDR milestone.

3.9.8 Motor Thrust Curve

The selected motor for this year's launch vehicle is the Loki Research L1482-LB. The simulated thrust curve data, downloaded from OpenRocket and represented in MATLAB, is shown below.

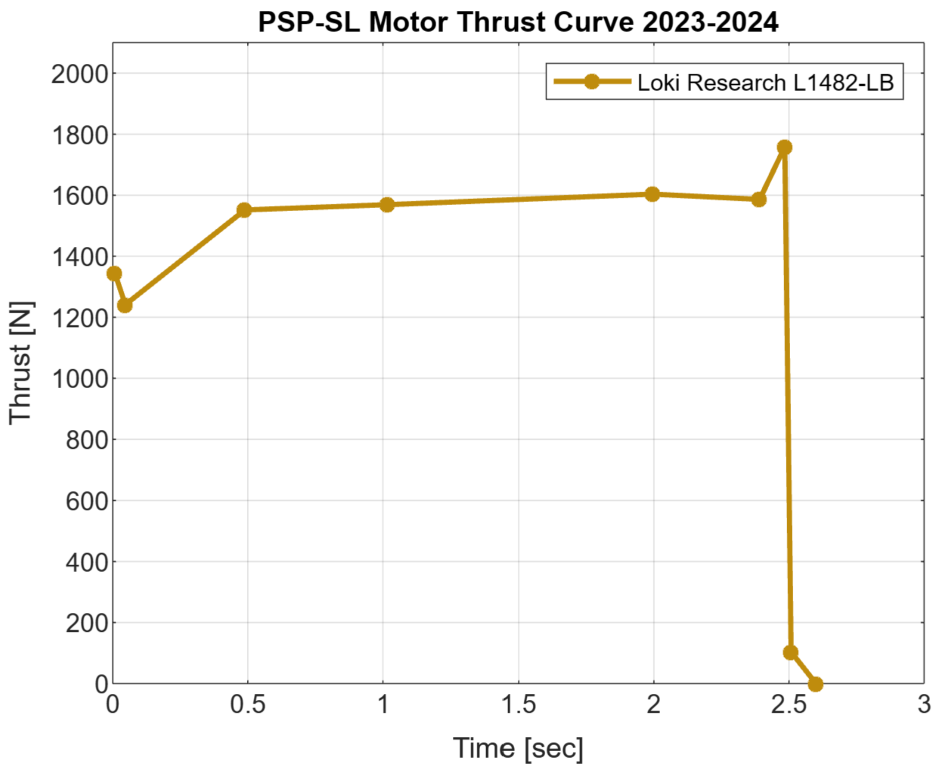


Figure 3.9.33: Loki Research L1482-LB Thrust Curve

3.9.9 SAIL Mission Performance Predictions

Since the SAIL will separate from the launch vehicle during descent and land independently, separate calculations have been completed to determine the characteristics of the quadcopter's flight. This analysis is purely theoretical, and the full design of the quadcopter is discussed in detail in section 4.

To formulate the flight plan of the SAIL, initial conditions were taken from the aforementioned OpenRocket simulations. Combined with design values, an appropriate flight profile for the quadcopter can be plotted.

Table 3.9.23: Basic SAIL Flight Parameters

Descent Time to Release Altitude	T+60.97 s
Release Altitude	400' AGL
Initial Velocity (Main Parachute)	16.03 ft/s
SAIL Mass	5 lb

Table 3.9.24: SAIL Design Parameters

Maximum Motor Thrust	3.31 lb
Deploy Delay (worst case)	2 s
Landing Velocity (worst case)	16.4 ft/s
Maximum Acceleration Endured	39.37 ft/s^2
Maximum Throttle Change	100%/s

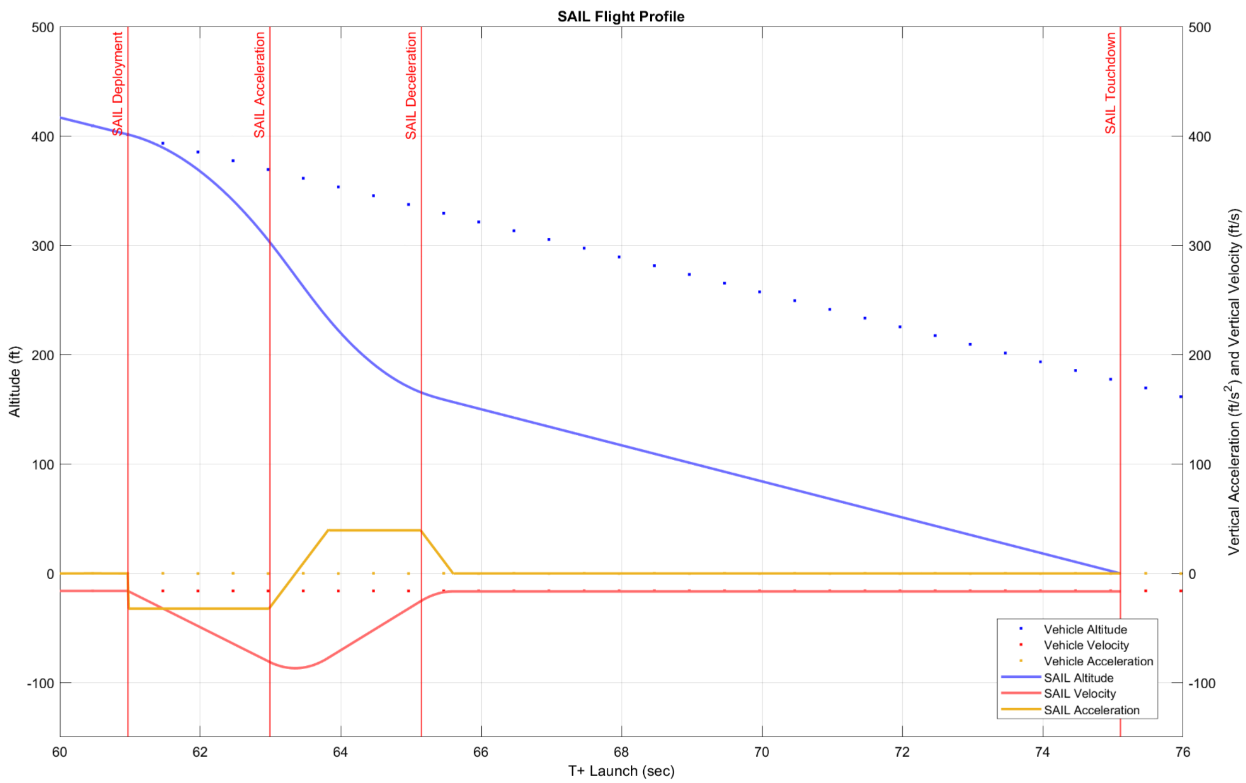


Figure 3.9.34: SAIL Flight Profile

The above graph illustrates the plan for the quadcopter from just before jettison at 400' AGL until touchdown. Upon release, the SAIL will enter free fall and accelerate downwards at 1 G (air drag is ignored for this simulation, see below sections regarding drag calculations). After a 2 second deployment delay to allow the quadcopter to separate from the launch vehicle, the throttle will be raised to decelerate the vehicle to its landing velocity. After that velocity has been reached, the SAIL will be throttled down to maintain its velocity until touchdown 14 seconds later.

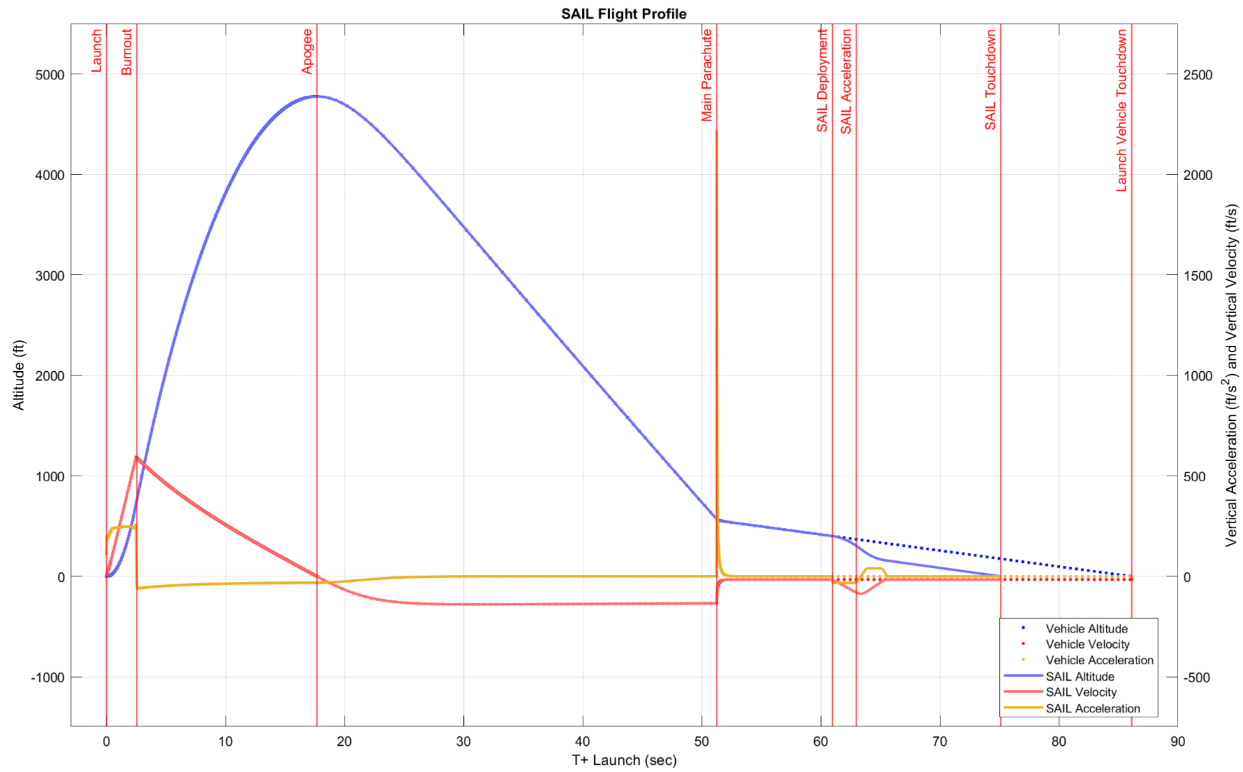


Figure 3.9.35: SAIL flight profile in context of vehicle flight

Illustrated above is the same flight path included in the context of the entire launch vehicle's flight. The SAIL remains dormant inside the vehicle until after the main parachute is deployed. After that event, two criteria will be confirmed: that the RSO has granted permission to jettison the quadcopter and the vehicle has reached an altitude of 400' AGL. If and only if both of those constraints are satisfied, the SAIL will release from the launch vehicle and begin its flight according to the plot above.

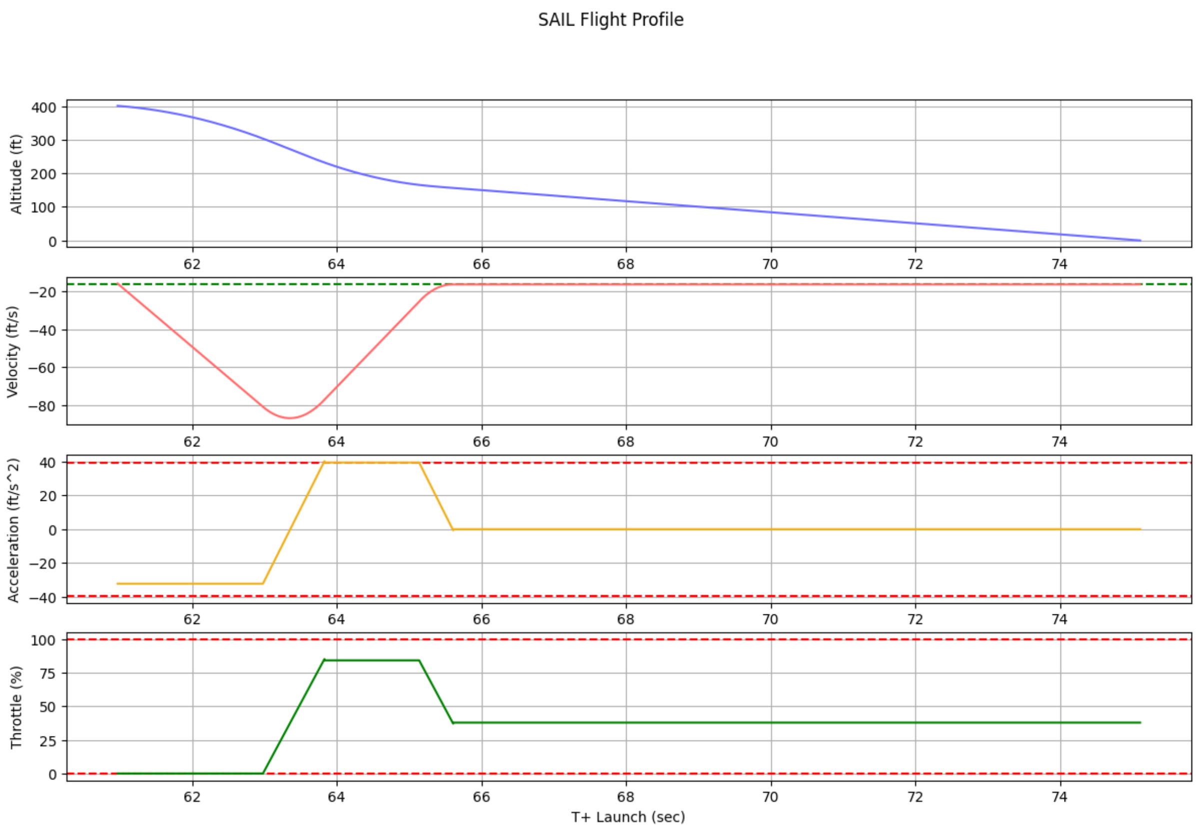


Figure 3.9.36: Detailed SAIL Flight Profile with Throttle Percentage

Finally, a detailed look at the SAIL's flight characteristics are shown above. The green dashed line on the velocity plot represents the ideal landing velocity, chosen based on the team's survivability metrics presented in the Preliminary Design Review. The red dashed lines on the acceleration plot represent the maximum allowable acceleration limits, again chosen from survivability metrics. It should be noted that research shows the human body can withstand much higher accelerations and landing velocities, but these constraints have been established to ensure the safety and comfort of the STEMnauts.

The bottom graph of throttle percentage illustrates the expected thrust needed when piloting the SAIL based on tested values of the electronic motors. These values have been calculated in the worst-case scenario, and will be slightly better than predicted due to the effects of air drag.

3.9.9.1 Free Fall Drag Analysis

For a worst-case analysis, the SAIL can be assumed to be in free-fall during the entire descent. From this it can be understood what speed the SAIL can reach and how this will affect air flow. The following estimations have been made for this analysis:

Table 3.9.25 Assumptions

Data Predicted		Estimations	
Mass	5 lb	C_d (square assumed)	1.05
Diameter	5”	Simplified Assembly (No bolts, hinges, springs...)	—
Height of fall	400’	—	—

It is possible to compute the terminal velocity, the drag created, the time of the fall, and the final velocity reached using basic kinematic equations. When completed, the following results can be obtained:

Table 3.9.26 Free-fall Predictions

Time of fall [s]	5.4
Terminal velocity [ft/s]	170
Maximum velocity reached [ft/s]	130.5

Also, the drag force expected is:

Table 3.9.27 Predicted Drag Force vs. Velocity

Velocity [ft/s]	Drag Force [N]
34.8	0.8298
65.6	3.3193
98.5	7.469
131.5	13.277
164	20.735
196	29.617
34.8	0.8298
65.6	3.3193

The accuracy of these basic predictions will be evaluated in the following section.

3.9.9.2 SAIL CFD

A preliminary CFD analysis was done to get initial numerical results, and check that the integrity of the quadcopter design will be conserved. To do so, the online software SIMSCALE will be used. During the simulation, a fine mesh with a 50% score based on non orthogonality of the mesh itself will be used, which leads to belief that the results will be accurate. Also, only half of the SAIL will be simulated, using a symmetry boundary condition to save processing time, and a finer region for the wake of the body will be ensured.

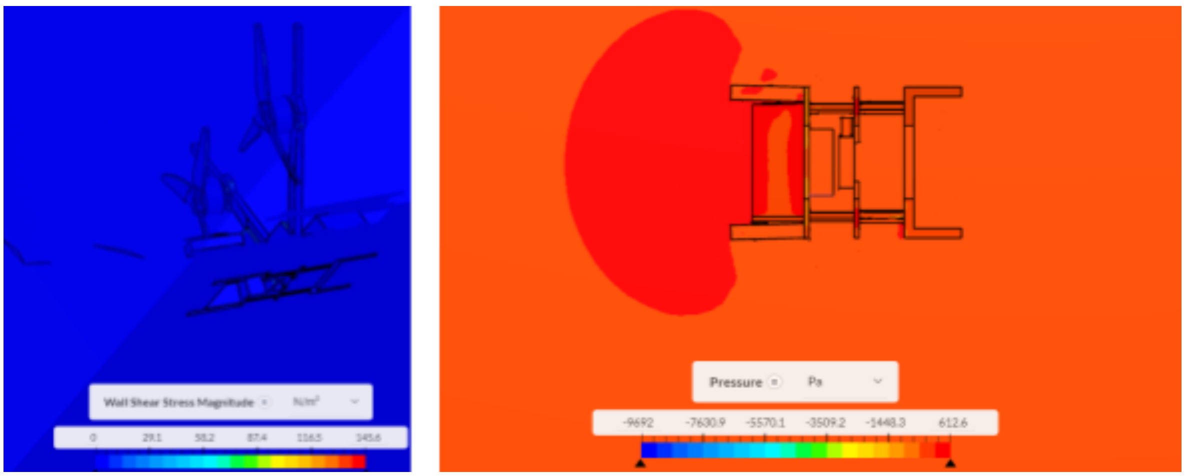


Figure 3.9.37: CFD results for Wall shear stress (Left) and Pressure(right) of the SAIL falling at 30 m/s

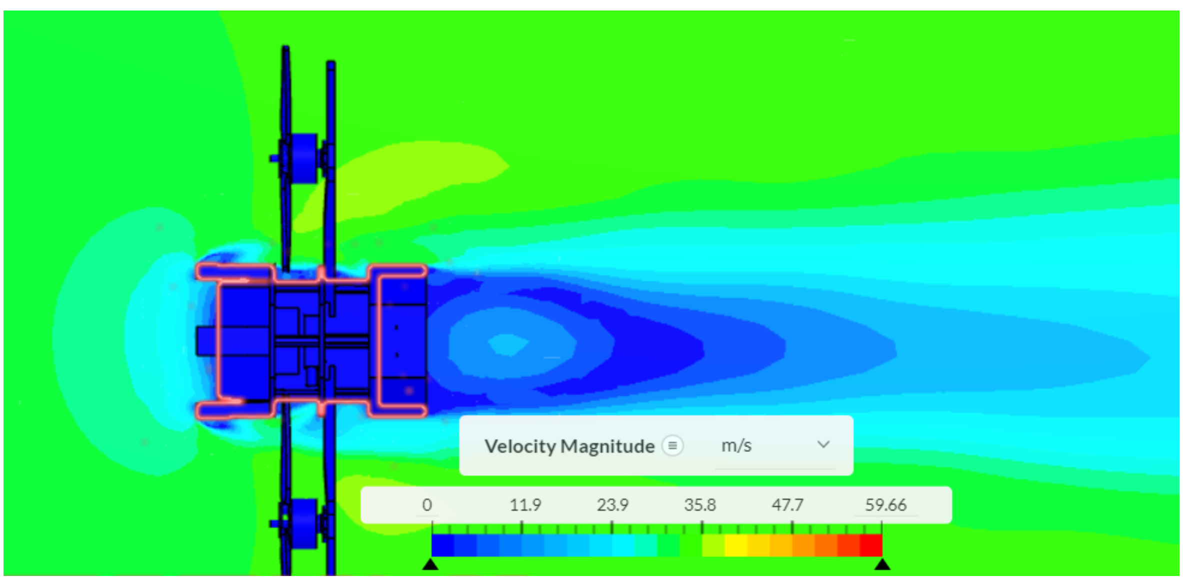


Figure 3.9.38: CFD velocity magnitude at 30 m/s

As it can be seen, wall shear stresses are not extremely high, and do not need to be considered during structural design, even at high speeds. The analysis was performed in SimScale with a Newtonian viscosity model, and air properties were specified as follows: Density 1.196

kg/m^3, Dynamic Viscosity 1.529e-5 kg/ms. Those values were extracted from the standard atmosphere model at 250 m above ground, at 25 degrees. However, the density has been slightly decreased to account for low humidity on the launch day. The output for the wall shear stress magnitude is a pressure difference compared to the atmospheric pressure. The simulation has also been run at the other airspeeds mentioned before, and some conclusions have been drawn:

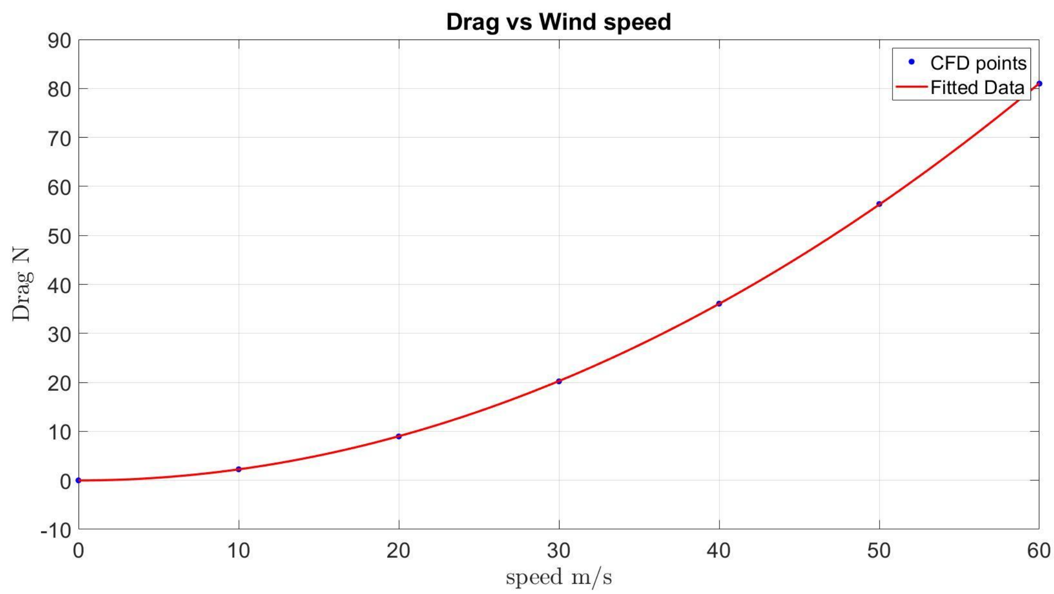


Figure 3.9.39: Drag vs speed of SAIL

As it can be seen, the simulated data for the drag is much lower than the expected one, so the real fall speed can be much higher than the predicted one. It can be concluded that the force that the SAIL will suffer is low, below 14N. In terms of structural integrity, this means that the drag can be neglected and only the force of the propulsion system is to be considered for any future FEM analysis, as the pressure and shear forces can be neglected.

However, to pursue aerodynamic analysis, it is possible to estimate the drag on the SAIL for every position. After fitting the data, an empirical relation can be found:

$$D\ [v\ in\ m/s]\ =\ 0.02249v^2 N$$

Here, the speed is in m/s, and this relation falls within a 95% confidence interval. Also, it can be seen that the expected drag coefficient (1.05) is well above the real drag coefficient. So this data has also been simulated. The real drag coefficient can be found:

$$D\ =\ 0.5\rho\ *\ v^2\ *\ A\ *\ C_d \longrightarrow C_d = 1.1968$$

From which it holds, C_d is approximately 1.1968 on average. By equating this drag to the weight of the SAIL, it is possible to estimate the real terminal velocity of the payload, if the propulsive system is not deployed:

$$D(v) - mg = 0 \ \ -> v_{term} = 103\, ft/s \text{ (31m/s)}$$

The terminal velocity is 103 ft/s. Now, kinematics can be used to solve for v(t) and y(t). First, a differential equation for v(t) can be formulated by following the following procedure:

$$v(t) = 31\, tanh(\, 0.144631047 * t)$$

By integrating v as a function of t, and integrating for y(t):

$$y(t) = 100.8234629 * ln(cosh(0.3119 * t^{0.5}))$$

This has been represented on the following plots:

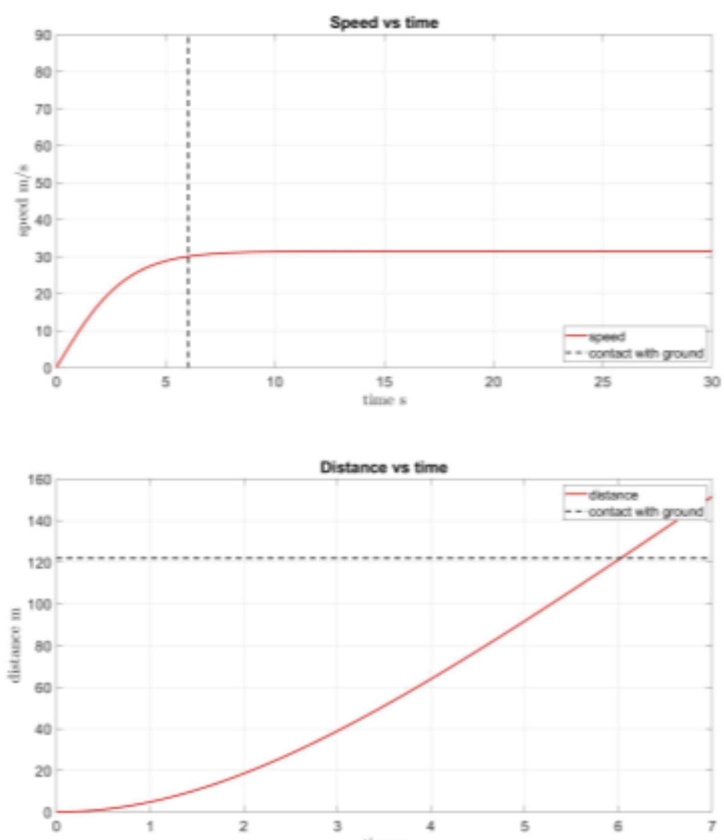


Figure 3.9.40: Speed(top) and Position (Bottom) vs time for SAIL descent

In the above figures, the dashed line represents the point where the SAIL hits the ground, i.e falls 400'. These results are in accordance with the numerical one computed in the online calculator above for a C_d of 1.1968 instead of 1.05, which means the computed data above is correct.

The time for ground can now be computed, as it is the time it will take to reach y = 400’ (121.92 m). This descent time is 6.0250s.

As it can be seen, the difference between the case with drag and the case with no drag is not negligible, as 1s are added to the fall. It can be concluded that the effect of drag can be neglected for the structural integrity criteria only. Also, this means that the SAIL has approximately 6 seconds to deploy, and hence the activation mechanism must be fast.

4 Payload Criteria

4.1 Chosen Design Alternatives

After careful analysis, designs for each major payload system have been selected from the alternatives outlined in the Preliminary Design Review. The alternatives and motivations for selection will be described below.

Table 4.1.1 Payload Systems

System	Function
4.1.1 Deployment System	Retain the SAIL until proper altitude is reached
4.1.2 SAIL	Slow descent speed without parachute
4.1.3 STEMnaut Capsule	Store and protect the four STEMnauts

4.1.1 Deployment System

The first design alternative considered for the payload deployment system was to have a hinged nose cone controlled by a motor, allowing the SAIL to release. The nose cone would be hinged to the airframe with a lateral connection. This motor would require a space in the airframe interior that could not be provided, and its placement would also break the axial symmetry, leading to possible instabilities. In addition, in order to open the nose cone when the launch vehicle is pointing downwards, the required torque should be able to overcome drag by the air, but the motor must also be strong enough at rest so it can withstand both payload and nose cone weight.

Another option considered was to have a movable nose cone that is split and opens laterally with two different hinges. Although the symmetry is not broken with this design, even more space would be required as two motors are being used. Each of them could be less powerful as the load is split between both of them, but due to space reduction and the added weight, this design was rejected.

A third option was to have a tethered nose cone that was connected to the airframe, preferably as high as possible, in the outer part of the airframe. This option was chosen preliminarily for the payload deployment system with some variation.

The final option set up the SAIL to be a part of the nose cone infrastructure itself, so that the nose cone would release itself from the rest of the launch vehicle after initial parachute deployment, and the entire nose cone and SAIL would land together. This option was eventually rejected due to its complications with construction, and designing the legs and arms proved to be difficult with this shape.

The chosen option utilizes a tethered nose cone with the tether inside the airframe. As a result, the deployment system consists of a sliding nose cone that is kept connected to the launch vehicle's airframe by a tether that remains in tension until payload release occurs. Some preliminary calculations have shown that the force of gravity will be sufficient to separate the SAIL and nose cone from the airframe once the tether is free. This event will take place after the main parachute deployment.

The payload release will be controlled with a latch that will perform the tether separation, letting it move free and completely detach the nose cone from the launch vehicle, but being still connected with this tether. A further explanation of the working procedure will be provided in later sections.

The main reason why this release system was chosen is its ease of integration and design flexibility, as well as the low weight added to the launch vehicle. The tether has a section small enough that it does not require a large amount of space in the launch vehicle, and only a few extra components to guide it along its path to connect the nose cone to the rest of the airframe.

4.1.2 Descent System

Several design options for the descent of the SAIL have been discussed in the PDR and evaluated on their suitability for this mission. The most promising designs included an auto-rotating monorotor, a controlled glider, a powered Helicopter, and a powered quadcopter.

An auto-rotating monorotor utilizes the rotation induced during a free fall to temporarily store energy, which slows down the descent. This design, however, was not chosen since it has very little to no controllability, which might let it touch down outside the designated zone, and has the lowest chance of the four preferred designs of STEMnaut survival. Additionally, the other three designs have significantly more controllability because they can be remotely or autonomously controlled. A glider utilizes airfoils to create lift to slow down the descent. This, however, means it must always have a non-zero velocity during landing. The biggest downside of a glider, which led to it not being chosen as the final design, is bulkiness when it comes to packaging it inside the payload bay of the launcher. The remaining two designs are powered, leading to a theoretical infinite descent time as long as power is available and can ensure the lowest touchdown speed. Both helicopters and quadcopters are similar in design and have the same working principle. A helicopter usually has one big main rotor to create lift and often a small tail rotor to cancel out the spin and steer, while quadcopters have, as the name suggests, four individual small rotors with opposing rotation directions. The design was disregarded in favor of a quadcopter, confirming the preliminary choice considered in PDR.

The quadcopter has the advantage over the helicopter to fit in the payload bay more easily because of its smaller rotors. These are additionally not fixed to the center vertical axis and instead attached to arms reaching outwards. This not only increases stability by moving the individual centers of lift to a point of higher leverage but also allows these arms to be folded down along the side of SAIL's main body.

4.1.3 STEMnaut Capsule

Figure 4.1.2: STEMnauts depicted by LEGO® minifigures

To follow up on the details discussed in PDR, a unique component of this competition is the SAIL's capability to transport four STEMnauts to the ground safely and providing them with a method of ingress/egress. In order for the STEMnauts to be compatible with the design of the

SAIL, the STEMnauts needed to be able to fit within the quadcopter. The team has chosen the STEMnauts to be represented by LEGO® minifigures, each depicting a famous figure who has left a long-lasting impact on Purdue University – Neil Armstrong, Mary Ellen Weber, Beth Moses, and Purdue Pete (Purdue University's athletic mascot). With a unique blend of current minifigure designs and LEGO's® famous "pick a brick" feature, each minifigure will resemble the three chosen alumni and Purdue Pete.

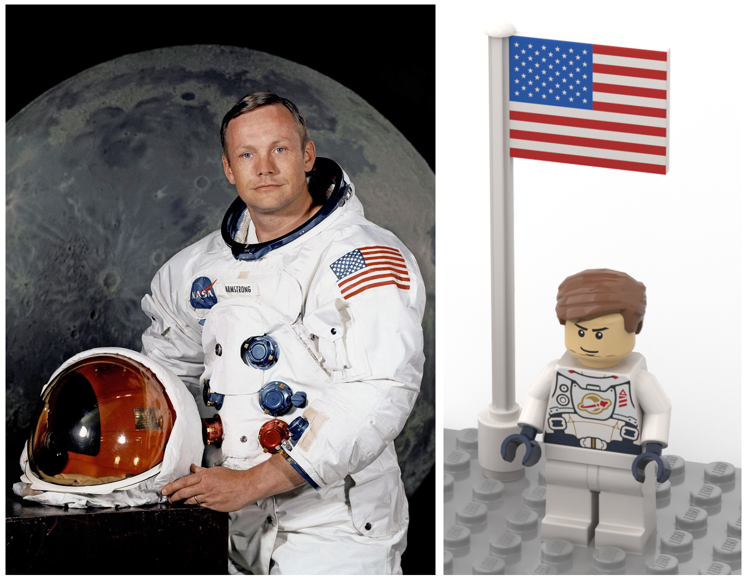


Figure 4.1.3: Neil Armstrong and his LEGO® minifigure counterpart

Born and raised in Wapakoneta, Ohio, Neil Armstrong went on to attend Purdue University and graduated in 1955 with a Bachelor of Science in Aeronautical Engineering. Armstrong spent time as a pilot during the Korean War, was awarded the Air Medal and two Gold Stars, and then went on to work for NASA. In 1966, he commanded Gemini 8 with David Scott to successfully dock two vehicles in space for the first time. Soon after, he was the first man on the moon during the Apollo 11 mission in 1969. Due to his impressive resume and extensive flight experience, Mr. Armstrong has been chosen to be the commander for Project Moses.

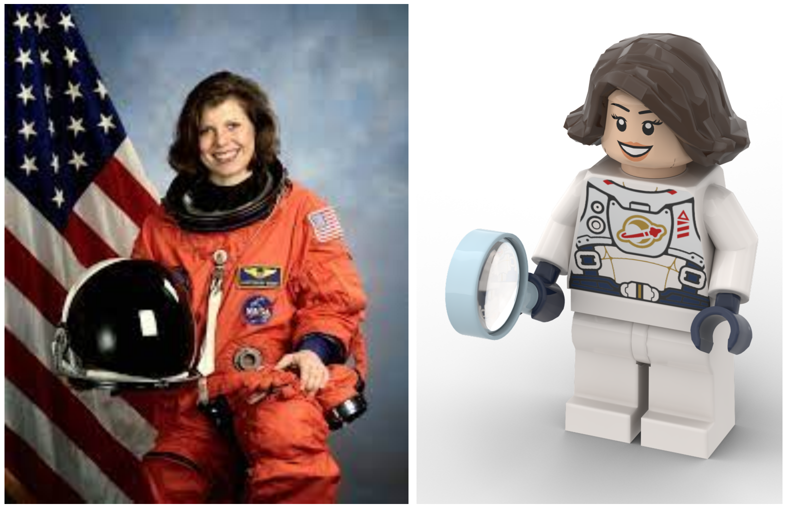


Figure 4.1.4: Mary Ellen Weber and her LEGO® minifigure counterpart

Mary Ellen Weber was born and raised in Cleveland, Ohio, and received a BS in Chemical Engineering with honors from Purdue University in 1984. Dr. Weber has spent over 450 hours in space (as of July 1995) working to develop protocols for experimental work and performed multiple biotechnology experiments to grow colon cancer tissues for the first time. She was a member of both STS-70 and STS-101. Dr. Weber is a skilled skydiver with around 5,000 skydives logged and has won 13 silver and bronze medals to date in the U.S. National Skydiving Championships. Mrs. Weber has been chosen as pilot for the Project Moses mission.

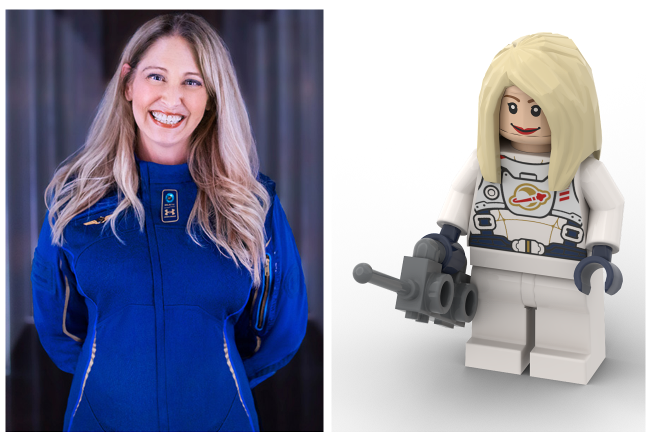


Figure 4.1.5: Beth Moses and her LEGO® minifigure counterpart

Beth Moses was incredibly successful during her time spent at Purdue University, where she received her BS and MS in Aeronautical and Astronautical engineering. She was awarded the National Science Foundation's Microgravity Research Award to further her research in parabolic flight and was the first woman to fly to space in a commercial vehicle as a part of Virgin Galactic's VF01. Purdue's Student Launch team has chosen to name the Student Launch project after Beth Moses in honor of her accomplishments and rich history with Purdue. Mrs. Moses has been chosen as mission specialist for the Project Moses mission.

Figure 4.1.6: 1970 Purdue Pete and his LEGO® minifigure counterpart

In 1940, Purdue's University Bookstore created the fictional persona, Purdue Pete, to be featured on various bookstore items as a fun character. In 1955, a physical character was created so Purdue Pete could attend pep rallies and cheer on the student section. Over the years, his character continued to develop and grow in popularity, and is now the official athletic mascot of Purdue University, attending all sports events, performing skits, and has even made appearances at community events. (Not to be confused with the Boilermaker Special, the official school mascot, a locomotive on an automobile chassis.) This year, Purdue Pete will be taking to the skies as a passenger of the SAIL.

4.2 Payload Concept of Operations

The various phases that the payload will experience after turning on are as follows: Standby, Launch, Payload Deployment, Payload Descent and Payload Landing.

Standby is the phase in between when the payload turns on and when the launch vehicle engine ignites. This phase can last for up to three hours according to G.2.6. Therefore, it must be ensured that both the deployment and SAIL systems can be turned on and not lose functionality within that period. The main concern is that the battery will drain before ignition. Another issue that the team encountered last year was thermal damage. Prior to launch last year, the launch vehicle was idle on the stand for around two hours before ignition. At that time, the inside of the launch vehicle was hot enough to render a vital component to the stepper motor inoperable. Tests are being performed to mitigate potential issues with the battery drain-rate and heat tolerance from recurring.

The second phase is launch. This encapsulates the ignition of the motor, apogee, as well as the deployment of the drogue and main parachute. During this period, the vehicle undergoes high accelerations and vibrations. During this time, the objective of the deployment system is to ensure that the SAIL is properly retained. Analyses will be done to verify that the deployment and SAIL systems can withstand these conditions.

Once 400 feet is reached and RSO permission is given, the payload deployment phase begins which includes the activation of the deployment system and the unfolding of the SAIL. This is a very short period that will only last a few seconds. This phase also marks the beginning of when the STEMnauts are to experience human survivability metrics as stated in Requirements P.4.1 and P.4.2.6. The deployment system will activate at this time and release the SAIL from the launch vehicle.

After the SAIL is clear of the launch vehicle, payload descent begins. From this point on, the deployment mechanism has served its purpose and is not utilized for the remainder of the flight. The goal of SAIL at this time is to decrease its velocity to minimize impact energy as well as ensure that accelerations and rotational rates do not exceed human survivability metrics. Right at the start of this phase, the UAV motors will activate. Then, controlled by the team on ground, SAIL's motors will produce enough thrust to slow down to a safe speed before landing. In addition, the SAIL must ensure that it maintains a proper attitude during this phase in order to land in its predetermined orientation. Once the SAIL has landed, the STEMnauts are able to egress and the flight is complete.

4.3 System-Level Design Review

Now that design alternatives and operations details have been discussed, the next important information is a detailed design review. The three payload systems will be thoroughly explained and evaluated below.

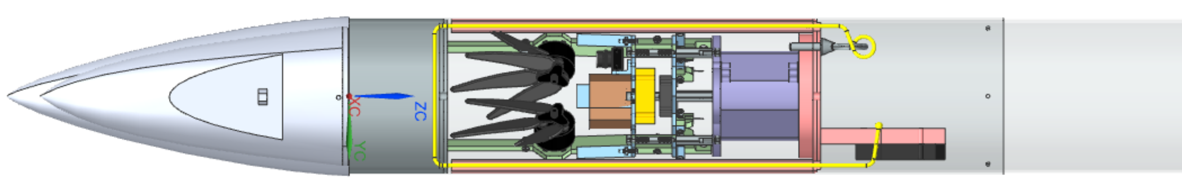


Figure 4.3.1: Top-Level Payload Assembly

4.3.1 Deployment System

Table 4.3.1: Deployment Subsystems

Subsystem	Function
Upper Coupler	Contains retention mechanism and jettison electronics

Nose Cone Bulkhead	Retains nose cone and secures tether release

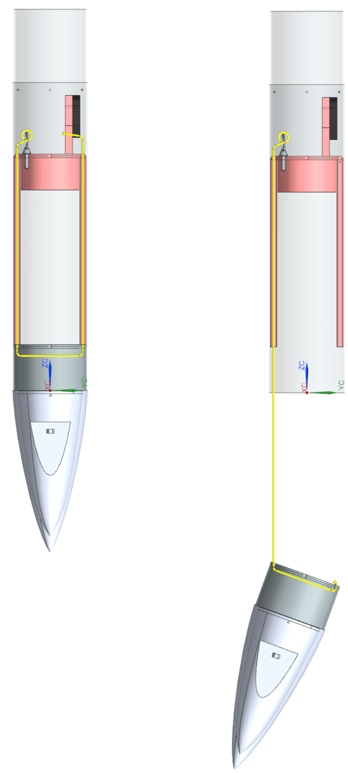


Figure 4.3.2: Deployment Mechanism

The payload bay is housed between two bulk plates beneath the nose cone, and consists of the deployment system, SAIL, and the payload coupler. The SAIL resides between the two bulk plates until deployment, when the nose cone detaches, and the SAIL slides out and begins descent.

The deployment of the SAIL will utilize a tether release. The tether will thread through eye bolts in the nose cone and hook into the release mechanism. The release mechanism, a spring-and-pin design, releases the tether when given RSO permission and when it has reached the designated altitude of 400 feet, allowing the nose cone to detach.

The tether will travel the length of the payload bay, and catch on an eyebolt in the nose cone, allowing it to detach and the SAIL to exit the launch vehicle. The possible use of a spring to ensure the SAIL's successful clearance of the payload bay is also being considered.

To prevent premature deployment, possible failures that may lead to malfunctions have been identified. The determined solution is a ⅛" diameter nylon and poly blend tether that is able to hold 160 pounds. Because of the high weight tolerance of the tether, the team is confident in its ability to hold both the SAIL and nose cone. To prevent the possibility of complete nose cone detachment, the team employed a second redundant eye bolt in the nose cone to catch on the end of the tether in the case the first eyebolt was unsuccessful. While the SAIL will deploy simultaneously with the opening of the nose cone, there is the possibility of entanglement between the SAIL's rotors and the tethers, so the team is employing a system of raceway tracks to ensure the tether does not interact with the SAIL.

4.3.2 SAIL

Table 4.3.2: SAIL Subsystems

Subsystem	**Function**
Motor Arms	Locks descent motors into position after deployment
Electronics Stack	Controls quadcopter & logs flight data
Quadcopter Frame	Connects SAIL components and landing legs
STEMnaut Capsule	Retain and protect the STEMnauts during flight

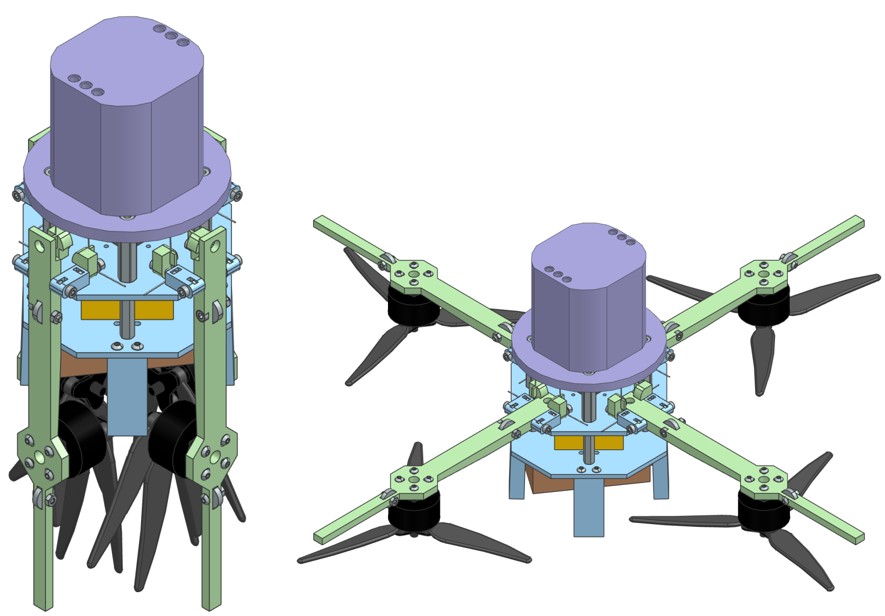


Figure 4.3.3: SAIL Mechanism

To recap, the payload bay is limited to a cylinder with a maximum diameter of 5 inches and a length of 12.5 inches. Therefore, in its stored state, the SAIL must have a rod-like shape for efficient packaging, but for stability during descent and on the ground, a wider-than-higher shape is preferable. To achieve this transformation, the quadcopter arms are loaded elastically and spring outward upon release from the launch vehicle. As the arms fully extend, latches on the SAIL body lock the arms into place so that they remain extended.

Landing legs are attached to the SAIL to ensure the touchdown fulfills all mission requirements. Inside the payload bay, the legs are folded along the sides of the SAIL body, similar to the arms. Furthermore, they are spring-loaded to automatically assume their deployed state after leaving the restriction of the payload bay. Additionally, they absorb the minimal touchdown velocity by flexing to absorb the shock and ensuring STEMnaut survivability. Moreover, they increase the stability after landing and ensure the desired final orientation.

To avoid damage during ascent and deployment, the SAIL must be in contact with the payload bay for the duration of these phases. On the launch pad, the SAIL sits upside down in the launch vehicle with the arms and rotors facing up towards the nose cone. Axially, the SAIL is restricted by a surface on its top side and flanges on the bottom side, which are removed with the nose cone during deployment. Furthermore, the nose cone has separators attached on its payload side, which restrict the movable rotor blades and prohibit them from touching each other or the walls. Radially, the SAIL is restrained by its arms, which have attachments to make contact with the rails of the payload bay. These attachments can move along the rail to guide the SAIL out of the payload bay without colliding with the walls during deployment.

Once deployed, the SAIL will be controlled by a pilot on the ground utilizing a remote control and communicating through a radio receiver to simulate manual control by the STEMnauts. An FPV (first person view) camera will send live video to the ground to support the simulation of piloting from onboard the SAIL. Manual control was chosen over autonomous control because the team has more confidence in a piloted descent versus creating specialized flight software at this point in the design stage. In the future, autonomous descent may be considered if there is available time and resources.

Each of the four rotors will be connected to the main flight controller of the SAIL through four ESCs that will provide the required thrust to maintain a level descent. The ESCs will be located in a 4x1 ESC board on the center of the SAIL in order to optimize space. These ESCs will be wired to the flight controller, which will collect accelerometer and gyroscope data in real time. The pilot inputs will be processed by the flight controller and send instructions through the ESC to the motors to obtain a level flight.

4.3.3 STEMnaut Capsule

Figure 4.3.4: STEMnaut Capsule Exterior

In order to meet competition requirements, a method STEMnaut ingress/egress needs to be included in the chosen SAIL design. To achieve this, a LEGO® compatible capsule will be attached to the upper portion of the SAIL quadcopter to safely contain the four STEMnauts.

This capsule contains several unique design features. Firstly, it employs a 2x2 seating arrangement for the STEMnauts to be space-efficient and safe. Survivability metrics show that a seated position is ideal for handling heavy accelerations, so this arrangement is important.

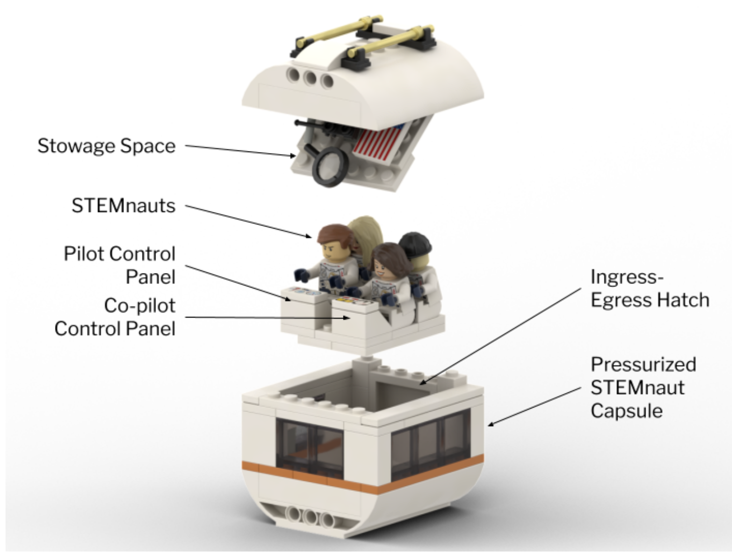


Figure 4.3.5: STEMnaut Capsule Exploded View

In addition, the capsule features control panels for the pilot and co-pilot, as this mission will be manually flown like all NASA landings. It also contains overhead storage space for the STEMnaut's personal items and additional science experiments to be taken on the mission.

4.4 Payload Electronics

4.4.1 Deployment Electronics

4.4.1.1 Electronic Latch

Figure 4.4.1: ATOPLEE Electronic Cabinet Lock

The electronic latch will be implemented in the SAIL, and will function to hold the release tether in place. When activated, the latch will release the tether and the deployment system will commence. The electrical latch needs to be used with an additional control circuit board that is energized when it is unlocked. Some specifications of the ATOPLEE Electronic Cabinet Lock that meet the SAIL requirements include its dimensions being 73x58x13mm and providing 12V of DC at 2A. Its composition is of durable carbon steel parts.

4.4.1.2 Altimeter

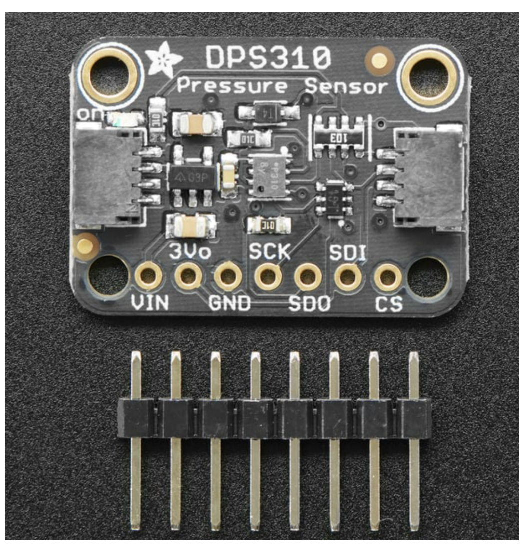


Figure 4.4.2: Adafruit DPS310 Barometric Altitude Sensor

The deployment of the SAIL includes the Adafruit DPS310 as a precision altitude sensor. Additionally, the sensor can be used with 3.3V Raspberry Pi and 5V Arduino logic levels.

4.4.1.3 Battery

Figure 4.4.3: Tattu LiPo Battery Pack for Multirotor FPV 150 Size

The team chose the TATTU Lipo Battery for the SAIL deployment system. Its specifications include 14.8V, 4S1P configuration, 450mAh capacity, 75C discharge rate, and an XT30 Plug. These specifications offer high power for a very long time for the SAIL. Additionally, the battery plug is capable of a multirotor FPV 150 size.

4.4.1.4 Microcontroller

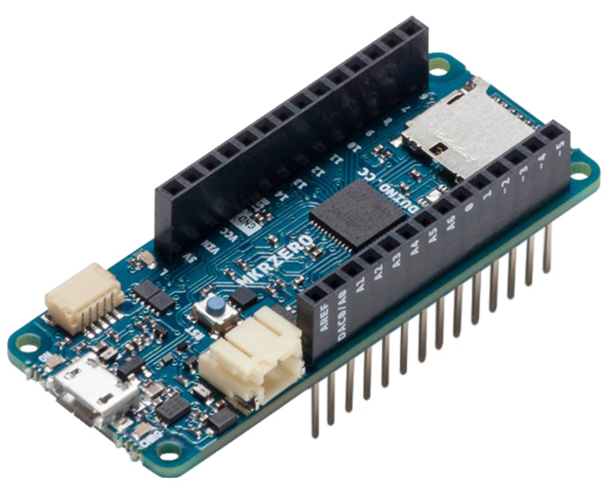


Figure 4.4.4: Arduino MKR Zero ABX00012

The SAIL implements an MKR Zero board with a micro SD card holder and dedicated SPI interfaces (SPI1). The Cortex-M0 32-bit SAMD21 processor can store large media files, making it very useful for storing important information relevant to altitude, acceleration, and time for analysis afterward.

4.4.1.5 Switch

Figure 4.4.5: Latching Push Button

For purposes of safely and reliably powering payload electrical systems, a latching push button is placed in an indent in the launch vehicle airframe. This button features an LED indicator for easy visual signaling of the power state of the payload. It is also intuitive to switch on/off and has proved reliable in testing.

4.4.2 SAIL Electronics

4.4.2.1 Flight Controller

The SAIL utilizes a SpeedyBee F405 V3 flight controller for the ranged operation of the SAIL, as well as data collection and logging. The flight controller features connections for the remote receiver, motors, and camera, and supports a 4GB SD card for altitude and position recording.

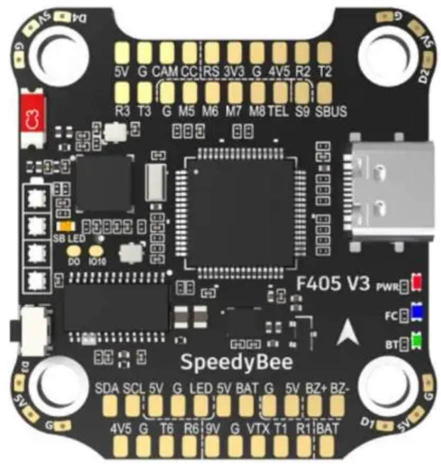


Figure 4.4.6: SpeedyBee F405 V3 Flight Controller

4.4.2.2 Electronic Speed Controller

A SpeedyBee BLHeli_S 4-in-1 ESC is used to control the power output to the SAIL's motors. The ESC communicates with the flight controller during descent to determine and provide the power required by the motors.

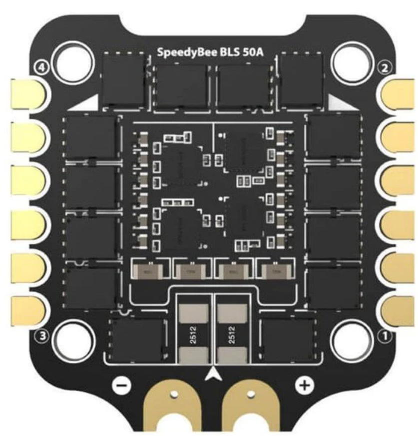


Figure 4.4.7: SpeedyBee BLHeli_S 4-in-1 ESC

4.4.2.3 Motors and Rotors

Four T-MOTOR F100 2810 1350V brushless motors are used by the SAIL to rotate four DALPROP FOLD 2 F7 rotors, which generate lift and slow the descent of the SAIL. The motors are capable of reaching upwards of 20000 RPM at 100% power, so the team elected to use 50% power, or 15000 RPM, for the thrust calculations. The team sourced calculations from

APC Propellers and determined that the motors would require 7” propellers in order to meet the total 5 lbf thrust requirement.

$$7"\ propellers\ @\ 15000\ RPM\ =\ 2.310\ lbf$$
$$2.310\ lbf\ *\ 4\ =\ 9.24\ lbf$$
$$9.24\ lbf\ /\ 5\ lbs\ =\ 1.848\ lbf/lbs$$

Figure 4.4.8: T-MOTOR F100 2810 Brushless Motor

Figure 4.4.9: DALPROP FOLD 2 F7 Rotor

4.4.2.4 GPS Module

A HGLRC M100-5883 GPS Module will be used to transmit live location data to the ground during flight. This ensures the team can track the SAIL at all times during flight and recover the vehicle in the case of extreme drift beyond line-of-sight.

Figure 4.4.10: HGLRC M100-5883 GPS Module

4.4.2.5 Safety Features

Both the flight controller and the ESC have 1000μF capacitors in parallel with their battery contacts to protect their components from voltage spikes. The flight controller also has onboard LED indicators for remote connection and system debugging. Once online, the motors feature an audio recognition system which activates in a series of beeping tones. The team also ensured the battery could be removed from the SAIL by using an XT60 connector as opposed to directly soldering the battery connection to the flight controller board.

4.4.2.6 Further Design

Additional testing of the SAIL's electronics will be required in order to finalize components, most importantly the battery. The team holds concerns with the SAIL maintaining sufficient power for flight given that it may need to idle for over two hours beforehand – plans are in place to measure the drain rate of the SAIL's passive systems to establish the capacity of the battery to be used. Along with that, the switch may be changed to a more secure key switch depending on test forces and vibrations.

5 Safety

The Safety Officer of the 2023-2024 Purdue SL Team is Jenna Smith. The Safety Officer is responsible for the safety and well-being of all team members and attendees throughout the duration of the competition. The Safety Officer shall have a thorough understanding of all equipment and organizational rules for each facility used by the team during the competition. The Safety Officer shall attend all meetings where fabrication, testing, and/or assembly will occur.

5.1 Launch Concerns and Operation Procedure

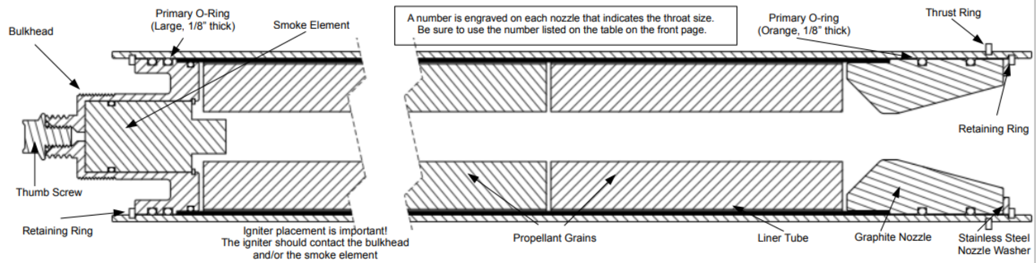
The following procedures will be used during all full scale launches. Each checklist includes a component and personnel list. Team members will verify the packing list and sign off each item before launch preparations begin. These documents include multiple elements to ensure safety including hazard warnings, PPE requirements, and sign-offs by specified personnel. For hazardous items and PPE, the item name in the components list and the number of the step in which the item is introduced is denoted by a specific color as well as a specific character, for those with color vision deficiencies. Energetic hazards, like black powder, and explosive hazards, like LiPo batteries, are denoted by red highlight and two asterisks (**). PPE use required is denoted by yellow highlight and one asterisk (*). Steps required for mission and personnel safety require the named person's signature before subsequent steps may be completed. Troubleshooting (T/S) methods have been included at the end of the procedures along with potential launch concerns and emergency procedures. Step-specific methods have been assigned a T/S ID which is included in the checklist line. The first four checklists may be completed simultaneously or in any order.

5.1.1 Motor Preparation

Item	Qty	Check
Launch Vehicle Components		
**Propellant grains	3-5	
**Tracking smoke element	1	
**Electric motor igniter	1	
Motor case w/ thrust ring	1	
Forward bulkhead	1	
Graphite nozzle	1	
Nozzle washer	1	
Large retaining snap rings (for motor case)	2	
Small retaining snap ring (for bulkhead)	1	
Liner tube	1	
Primary O-rings (⅛”)	3-4	
Tracking smoke O-ring (1.25” OD)	1	
Liner shoulder O-ring (2.625” OD)	1	
Peripheral Components		
O-ring lubricant		
Tools		
*Nitrile gloves (PPE)	4	
*Safety glasses	4	
Internal retaining ring pliers	1	

Personnel	
Project Manager	Alex Edwards
Project Engineer	Alex Loney
Safety Officer	Jenna Smith

Step No.	Action	Check	T/S Id.
1.1.01	*VERIFY all personnel that may contact energetics are wearing gloves and safety glasses.	Safety:	
1.1.02	VERIFY all hardware pieces are clean and free of grease and soot, especially retaining ring grooves and bulkhead’s delay cavity.		
1.1.03	FEEL inside ends of motor case for any nicks or sharp raised metal that may cut/tear o-rings.		
1.1.04	IF FOUND, REMOVE with a sharp knife or small file.		
1.1.05	APPLY a thin layer of grease inside the bulkhead, each end of the case, and over all o-rings.		
1.1.06	PLACE o-rings on a clean surface temporarily.		
1.1.07	PLACE the small 1.25”OD by 3/32” thick o-ring onto the tracking smoke grain.		

1.1.08	APPLY a thin film of grease on the back side of the smoke grain.		
1.1.09	LOOSEN the head bolt at top end of the bulkhead.		
1.1.10	**PUSH smoke grain into smoke well, being careful as the o-ring is compressed.		
1.1.11	TIGHTEN the head bolt down.		
1.1.12	INSTALL small snap ring in the smoke well to retain smoke element.		
1.1.13	INSTALL all o-rings, the larger black 1/8" thick o-rings onto the bulkhead, the smaller 3/32" o-ring onto the bulkhead shoulder, and the orange 1/8" thick o-ring(s) onto the nozzle.  		
1.1.14	VERIFY that the motor liner has one end is sanded and the inside corners are chamfered smooth.		
1.1.15	APPLY light layer of grease to inside end of the liner.		
1.1.16	**SLIDE each propellant grain into the motor liner. If numbered, 1st grain goes to the head end of the motor, then the 2nd grain and so on. The highest numbered grain goes at the nozzle end.		
1.1.17	INSERT the recessed shoulder of the nozzle into the nozzle end of the liner tube and slide together (liner tube first) into the thrust ring end of the motor case.		
1.1.18	PLACE stainless steel nozzle washer behind the nozzle.		
1.1.19	INSTALL the retaining ring using retaining ring pliers.		
1.1.20	INSTALL the assembled bulkhead into the top of the motor and carefully push it in straight until the bulkhead shoulder o-ring is seated into the end of the liner.		
1.1.21	SECURE with the second retaining ring.		
	NOTE: If there is a gap between the bulkhead and retaining ring, pull the bulkhead up flush against the retaining ring. There will be a small amount of empty space in the case and the grains may rattle. This is normal.		
1.1.22	VERIFY both retaining rings are fully seated in their grooves.	PM:	

5.1.2 Black Powder Charges

Item	Qty	Check
Launch Vehicle Components		
**FFFFg black powder	9g	
**Electric-matches	4	
Nitrile glove (for charges)	1	
Small cable ties	8	
Tools		
*Nitrile gloves (PPE)	4	
*Safety glasses	4	
*Anti-static bag	1	
Scissors	1	
Wire strippers	1	
Gram scale	1	
Non-plastic funnel	1	
Permanent marker	1	

Personnel	
Avionics Lead	Camille DeMange
Safety Officer	Jenna Smith
AV support #1	
AV support #2	

Step No.	Action	Check	T/S Id.
2.1.01	*VERIFY all personnel that may contact energetics are wearing gloves and safety glasses. **Failure to complete may cause skin or eye contact with hazardous material**	Safety:	
2.1.02	*VERIFY environment fit for the handling of energetics, ei. No strong wind, no high heat sources. ****Failure to complete may cause contact with hazardous material or premature ignition**	Safety:	
2.1.03	CUT fingertips (2"+) off four fingers of the nitrile glove.		
2.1.04	**CUT four e-matches to length and VERIFY wire ends are twisted together.		
2.1.05	**MEASURE 1.5 grams of FFFFg black powder and FUNNEL into a glove fingertip.		
2.1.06	**INSERT e-match into black powder and SECURE top of glove tip shut with two cable ties.	Safety:	
2.1.07	LABEL (II) to indicate it contains 1.5 grams.		
2.1.08	REPEAT steps 1..1.004-1.1.007 for 2 grams, 2.5 grams, and 3 grams, and LABEL as such.	Avionics Lead:	
2.1.09	*STORE all four charges inside the anti-static bag. ****Failure to complete may cause premature ignition of energetics**		

5.1.3 Avionics and Recovery System Preparations

Item	Qty	Check
Launch Vehicle Components		
**Black Powder charges (in anti-static bag)	4	
**3.7V LiPo battery (in fireproof bag)	1	
9V battery	1	
9V battery connector	1	
Key switch	2	
TeleMetrum Altimeter	1	
StratoLoggerCF Altimeter	1	
Avionics sled	1	
Bay airframe	1	
Bay bulkheads	2	
Cellulose insulation		
50' long, ⅜" tubular Kevlar shock cord	1	
30' long, ⅜" tubular Kevlar shock cord	1	
Main parachute (120")	1	
Drogue parachute (15")	1	
Double Nomex blanket	1	
Single Nomex blanket	1	
Stainless steel quick links (¼")	6	
22 AWG stranded wire	92"+	
Nylon screws (4-40)	8	
Battery lid screws	8	
Threaded rods (¼"-20)	2	
Hex nuts (¼"-20)	16	
Washers (¼" Inner Diameter)	4	
Peripheral Components		
Laptop with USB port and AltOS installed	1	
Micro-USB cable	1	
Keylock switch key	1	
DT4UTx cable	1	
USB-B - USB-A cable	1	
TeleMetrum antenna	1	
Tools		

Item	Qty	Check
*Nitrile gloves	4	
Flat head screwdriver for wire terminals	1	
Green masking tape roll	1	
Wire cutter/stripper	1	
Pliers	1	
¼” open-end wrench	1	

Personnel	
Avionics Lead	Camille DeMange
Safety Officer	Jenna Smith
AV support #1	
AV support #2	

Step No.	Action	Check	T/S Id.
	Charge Batteries		
3.1.01	*VERIFY LiPo battery is in a LiPo fireproof bag when charging. ****Failure to complete may decrease protection in the event of LiPo fire**		
3.1.02	**CHARGE LiPo battery to above 3.3V.	Avionics Lead:	
3.1.03	VERIFY 9 Volt battery charge level is above 8.0V.	Avionics Lead:	
	Programming TeleMetrum Altimeter		
3.2.01	CONNECT LiPo battery and a key switch to the TeleMetrum altimeter.		
3.2.02	CONNECT TeleMetrum into laptop with a micro-USB cable.		
3.2.03	OPEN the AltOS application.		
3.2.04	SELECT "Configure Altimeter".		
3.2.05	LAY TeleMetrum flat on a surface.		
3.2.06	TURN ON the TeleMetrum via the switch.		
3.2.07	SELECT the TeleMetrum as the device; altimeter will stop beeping.		
3.2.08	SELECT "Settings".		
3.2.09	SET Main Deloy Altitude to 700'.		
3.2.10	SET Apogee Delay to 0 seconds.		
3.2.11	SET Frequency to 435.550 MHz Channel 0.		
3.2.12	SET Telemetry/RDF/APRS Enable to Enabled.		
3.2.13	SET Telemetry Baud Rate to 9600 baud.		
3.2.14	SET APRS Interval(s) to 5.		

3.2.15	SET Callsign to KD2IKO		
3.2.16	SET Maximum Flight Log Size (kB) to 8192 (1 flight)		
3.2.17	SET Igniter Firing Mode to Dual Deploy		
3.2.18	SET Pad Orientation to Antenna Up		
	Note: If desired, the accelerometer can be calibrated by choosing Calibrate Accelerometer and the TeleMetrum rebooted by choosing Reboot.		
3.2.19	VERIFY and SAVE new settings	Avionics Lead:	
3.2.20	SELECT "Save Flight Data" and delete all previous flights	Avionics Lead:	
3.2.21	TURN OFF altimeter and PLACE LiPo back into fireproof bag.		
	Programming StratoLoggerCF Altimeter		
3.3.01	CONNECT DT4UTx cable to USB-B - USB-A cable.		
3.3.02	CONNECT DT4UTx cable to data port of StratoLoggerCF altimeter.		
3.3.03	CONNECT USB-B - USB-A cable to laptop.		
3.3.04	CONNECT 9V battery and key switch to StratoLoggerCF.		
3.3.05	TURN ON switch.		
3.3.06	OPEN DataCap software.		
3.3.07	SELECT "Altimeter".		
3.3.08	SELECT "CommPort".		
3.3.09	SELECT "Altimeter".		
3.3.10	SELECT "Setup".		
3.3.11	VERIFY "COM6" is selected.	Avionics Lead:	
	Note: If correct comm port was selected, the serial number and current settings should appear, and the altimeter should halt its initialization beeps and begin beeping once every few seconds as a connection indicator.		
	Note: If the above process does not work, try connecting the altimeter by selecting "Data", then "Acquire" before proceeding with the steps.		
3.3.12	SELECT "Settings".		
3.3.13	SET Preset to 4.	Avionics Lead:	
3.3.14	SET Siren Delay to 0 seconds.	Avionics Lead:	
3.3.15	SELECT "Update Alt".		
	Note: If desired, self-tests can be performed by selecting "Altimeter", then "Test".		
3.3.16	TURN OFF altimeter.		

Prepare Parachutes			
3.3.01	TIE a overhand loop 1/3 of shock cord length from one end in each shock cord.		
3.3.02	MAKE one z-fold for every 10' of shock cord.		
3.3.03	TAPE each z-fold together with one loop of tape around middle with minimal tape overlap.		
3.3.04	ATTACH large quick links to all six loops.		
3.3.05	FLAG link on longer ends with tape for easy identification.		
3.3.06	MAKE two z-folds in the outer shroud lines (all except center) on main parachute.		
3.3.07	TAPE z-folds with one loop of masking tape around the middle with minimal overlap.		
3.3.08	FOLD parachute on tarp so that it is long and thin.		
3.3.09	ATTACH main parachute and double Nomex blanket to middle quick link of 50' shock cord		
3.3.10	ATTACH drogue parachute and Nomex blanket to middle quick link of 30' shock cord		
3.3.11	FLAG closed parachute quick links with orange tape to signify closure		
3.3.12	VERIFY proper configuration.	Avionics Lead:	
Assembling Avionics Bay			
3.4.01	*VERIFY all personnel that may contact energetics are wearing gloves and safety glasses.	Safety:	
3.4.02	**INSERT 2.5g and 3g black powder charges into corresponding black powder canisters on upper (main) bulkhead.		
3.4.03	PACK canisters tightly with cellulose insulation.		
3.4.04	SEAL canisters with masking tape.	Avionics Lead:	
3.4.05	**INSERT 1.5g and 2g black powder charges into corresponding black powder canisters on lower (drogue) bulkhead.		
3.4.06	PACK canisters tightly with cellulose insulation.		
3.4.07	SEAL canisters with masking tape.	Avionics Lead:	
3.4.08	INSERT e-match wires into corresponding terminal blocks.	Avionics Lead:	
3.4.09	CUT 4 pieces of 22 AWG stranded wire to 3" length for key switch wires.		
3.4.10	TWIST pairs of wire together into two sets.		
3.4.11	CRIMP female metal JST contacts onto one end of each wire on each set, slide into female JST connector, and add wire sleeve at interface.		
3.4.12	CUT 8 pieces of 22 AWG stranded wire to 10" length for ejection charge wire.		
3.4.13	TWIST pairs of wire together into four sets.		
3.4.14	SCREW pair of 3” wires into Telemetrum terminals 1 and 2 for switch output and input.		
3.4.15	SCREW pair of 10” wires into Telemetrum terminals 3 and 4 for main chute charge.		

3.4.16	SCREW pair of 10" wires into Telemetrum terminals 5 and 6 for drogue chute charge.		
3.4.17	SCREW pair of 3" wires into StatoLogger "SWITCH" terminals for switch output and input.		
3.4.18	SCREW pair of 10" wires into StatoLogger "MAIN" terminals for main chute charge.		
3.4.19	SCREW pair of 10" wires into StatoLogger "DROGUE" terminals for drogue chute charge..		
3.4.20	SCREW Telemetrum and StratoLoggerCF altimeters to corresponding sets of mounting posts on altimeter sled with nylon mounting screws.		
3.4.21	INSERT fully charged 3.7V LiPo and 9V batteries into corresponding compartments in altimeter sled.		
3.4.22	CONNECT 3.7V LiPo battery to TeleMetrum.		
3.4.23	CONNECT 9V battery connector to 9V battery.		
3.4.24	SCREW connector into battery terminals on StratoLogger CF.		
3.4.25	VERIFY TeleMetrum altimeter and battery continuity by turning it on.	Avionics Lead:	
3.4.26	VERIFY StratoLogger CF altimeter and battery continuity by turning it on.	Avionics Lead:	
3.4.27	COVER batteries with corresponding battery lid.		
3.4.28	SCREW battery lids in place.		
3.4.29	VERIFY avionics sled configuration.	Avionics Lead:	
3.4.30	SCREW two hex nuts on each threaded rod so that there is about 0.5" between the bottom of the rod and bottom face of the nuts.		
3.4.31	PLACE washer on top of nuts on each rod.		
3.4.32	SLIDE lower bulkhead down onto the rods, so the face with canisters rests on washers.		
3.4.33	SCREW two hex nuts down each rod so there is about 0.5" between bulkhead and first hex nut.		
3.4.34	SLIDE altimeter sled (with LiPo up) down onto the rods so it rests on the hex nuts.		
3.4.35	SCREW two hex nuts down each rod to secure the altimeter sled.		
3.4.36	FEED main parachute wires from each altimeter through corresponding hole in lower bulkhead.		
3.4.37	SCREW main e-match connection wires into other ends of their corresponding connectors on exterior of lower bulkhead.	Avionics Lead:	
3.4.38	*VERIFY switches on coupler band are turned off. **Failure to complete may cause premature ignition of energetics**	Avionics Lead:	
3.4.39	SLIDE coupler over sled to rest on the bulkhead and VERIFY proper orientation..		
3.4.40	CONNECT both altimeters to their switch via JST connectors.		
3.4.41	FEED drogue parachute wires from each altimeter through corresponding hole in upper bulkhead.		
3.4.42	SLIDE upper bulkhead onto threaded rods to seal coupler.		

3.4.43	SCREW drogue e-match connection wires into other ends of their corresponding connectors on exterior of upper bulkhead.	Avionics Lead:	
3.4.44	PLACE washer on each rod.		
3.4.45	SCREW two hex nuts down each rod to secure bulkhead and entire avionics bay.	Avionics Lead:	
3.4.46	TURN ON and turn off keylock switch to listen for the initialization beeps from Telemetrum Altimeter.	Avionics Lead:	
3.4.47	TURN ON and turn off keylock switch to listen for the initialization beeps from StratoLogger Altimeter.	Avionics Lead:	

5.1.4 Payload Preparations

Item	Qty	Check
Launch Vehicle Components		
**1S LiPo battery	1	
Payload sled w/ SD card	1	
Peripheral Components		
Radio transmitter	1	
Tools		
*LiPo fireproof bag	1	
LiPo charging cord	1	

Personnel	
Payload Lead	Gabriel Kurfman
Safety Officer	Jenna Smith
Payload support #1	
Payload support #2	
Payload support #3	

Step No.	Action	Check	T/S Id.
	Charge Batteries		
4.1.001	*VERIFY LiPo battery is in a LiPo fireproof bag when charging. ****Failure to complete may decrease protection in the event of LiPo fire**	Payload Lead:	
4.1.002	**CHARGE LiPo battery to 25.2V.	Payload Lead:	
4.1.003	VERIFY AA batteries in radio transmitter charge level is above 0.7V.	Payload Lead:	
	Assemble Payload Sled		
4.2.001	VERIFY latest flight code is pushed to GitHub.	Payload Lead:	
4.2.001	**STRAP LiPo battery onto SAIL.		
4.2.002	PLUG power line into battery.		
4.2.003	VERIFY launch code is flashed to MKR Zero (int mode = 0).	Payload Lead:	
4.2.004	PRESS power button to turn on payload sled.		
4.2.005	VERIFY all systems initialize (1 beep). IF FAILURE, reference T/S.	Payload Lead:	PL1
4.2.006	POWER ON radio transmitter and VERIFY bind light is activated on SAIL receiver.	Payload Lead:	

4.2.007	POWER OFF radio transmitter and payload.		
4.2.008	SECURE all velcro components using tape.		
4.2.009	RE-PACK all payload components for transportation (packing list minus the batteries).	Payload Lead:	

5.1.5 Full Vehicle Integration

Item	Qty	Check
Launch Vehicle Components		
Payload sled w/ SD card	1	
M3 screws	2	
**Assembled AV bay (w/ energetics)	1	
Upper recovery	1	
Payload bay	1	
Booster section	1	
Drogue chute w/ shock cord and quicklinks	1	
Main chute w/ shock cord and quicklinks	1	
Shear pins	6	
¼” Buttonhead screws	36	
¼” Hex nuts	6	
ANSI #6 screws	3	
Peripheral Components		
Avionics bay		
Payload/SAIL components		
Tools		
Green masking tape	1	
¼” Hex screwdriver	1	
ANSI Screwdriver	1	

Personnel	
Project Manager	Alex Edwards
Project Engineer	Alex Loney
Safety Officer	Jenna Smith
Construction Lead	Sara Fox
Payload Lead	Gabriel Kurfman
Avionics Lead	Camille Demange

Step No.	Action	Check	T/S Id.
Booster			
5.1.01	SECURE fins to MFSS using six (6) ¼” buttonhead screws and six ¼” hex nuts.		
5.1.02	SECURE MFSS in booster airframe using six ¼” buttonhead screws.		
5.1.03	SECURE payload coupler within the payload airframe using six ¼” buttonhead screws.		

Payload			
5.2.01	VERIFY SD card is in payload sled slot.	PL #1:	
5.2.02	VERIFY all components are secure with shake test.	Payload Lead:	
5.2.03	VERIFY no loose wires.	PL #2:	
5.2.04	INTEGRATE SAIL and deployment method with payload airframe, switch last, following markings.		
5.2.05	SECURE payload with six ¼" button head screws.		
5.2.06	SECURE power button to airframe with two M3 screws.		
5.2.07	PRESS power button and VERIFY all systems initialize (1 beep). IF INITIALIZATION FAILS, reference T/S.	Payload Lead:	6
5.2.08	POWER ON radio transmitter and VERIFY bind light is activated on receiver	PL #3:	
5.2.09	INTEGRATE nosecone to payload section using quick links and tether.	Construction Lead:	
Avionics			
5.3.01	**ATTACH quick link of shorter end of drogue shock cord (no tape mark) to eyebolt on upper bulkhead of avionics bay.		
5.3.02	ATTACH longer end (tape mark) to eyebolt on bulkhead of payload section by passing through upper recovery section.		
5.3.03	FLAG each quick link with green tape to signify closure.	Avionics Lead:	
5.3.04	CONNECT upper recovery section to payload section using shear pins, placing tape to secure pins during transport.		
5.3.05	INSERT drogue parachute and shock cord into upper recovery section, making sure they are adequately covered from charge blast by Nomex blanket.	Avionics Lead:	
5.3.06	SECURE avionics bay to upper recovery using six ¼" button head screws		
5.3.07	ATTACH shorter end of main shock cord to bulkhead of booster section.		
5.3.08	ATTACH longer end to eyebolt on bulkhead of main side of avionics bay.		
5.3.09	FLAG each quick link with green tape to signify closure.	Avionics Lead:	
5.3.10	INSERT folded main parachute, then shock cord into upper recovery section and make sure they are adequately covered on top with Nomex blanket.	Avionics Lead:	
	Note: The main parachute should be as loose as possible while still fitting in length into the upper recovery section		
5.3.11	CONNECT avionics bay to booster section using shear pins, placing tape to secure pins during transport.		

5.3.12	TURN ON and turn off keylock switch briefly through switch band to listen for initialization beeps from each altimeter	Avionics Lead:	
Final Checks			
5.4.01	VERIFY rail button alignment and connection.	Construction Lead:	
5.4.02	INSPECT motor for damage.	PM:	
5.4.03	INSERT motor into MFSS.		
5.4.04	SECURE motor by screwing the motor retainer plate below the motor casing lip to the thrust plate using three ANSI #6 screws.		
5.4.05	VERIFY motor is secure and properly aligned.	Construction Lead:	
5.4.06	WEIGH fully integrated vehicle to verify model values.	Construction Lead:	
5.4.07	VERIFY all launch initiation components and T/S materials are prepped to move to launch area.	PM:	
5.4.08	DETERMINE desired rail angle per weather conditions and simulations.	Avionics Lead:	

5.1.6 Launch Initiation

Item	Qty	Check
Launch Vehicle Components		
**Fully integrated launch vehicle	1	
**Electrical motor igniter	2	
Peripheral Components		
Radio transmitter	1	
Laptop with USB port and AltOS installed	1	
Micro-USB cable	1	
TeleMetrum antenna	1	
Tools		
Key for keylock switch	1	
Extra AA batteries for radio transmitter	1	

Personnel	
Project Manager	Alex Edwards
Project Engineer	Alex Loney
Safety Officer	Jenna Smith
Construction Lead	Sara Fox
Payload Lead	Gabriel Kurfman
Avionics Lead	Camille Demange

Step No.	Action	Check	T/S Id.
	Load Vehicle on Rail		
6.1.01	SLIDE launch vehicle on to launch rail.		
6.1.02	VERIFY proper rail button connection.		
6.1.02	ADJUST angle of rail to value in step 5.4.04.		
6.1.03	CONSTRUCTION GO FOR LAUNCH? Construction Lead:		
	Payload		
6.2.01	PRESS power button and VERIFY all systems initialize (1 beep). IF INITIALIZATION FAILS, reference T/S.	Payload Lead:	6
6.2.02	POWER ON radio transmitter and VERIFY bind light is activated on receiver.	PL #3:	
6.2.03	VERIFY radio transmitter switch is in the "0" setting.		
6.2.04	SWITCH payload into "sleeper mode" to reduce power consumption while idle.		

6.2.05	PAYLOAD GO FOR LAUNCH? Payload Lead:		
	Avionics		
6.3.01	*CLEAR all but essential personnel (Avionics Lead, Safety Officer, one Avionics support).	Safety:	
6.3.02	**TURN ON keylock switch for TeleMetrum and VERIFY initialization beeps.	Avionics Lead:	
6.3.03	**TURN ON keylock switch for StratoLogger and VERIFY initialization beeps.	Avionics Lead:	
6.3.04	VERIFY all static port holes are clear of debris.		
6.3.05	AVIONICS AND RECOVERY GO FOR LAUNCH? Avionics Lead:		
	Igniter Installation		
6.4.01	**SLIDE the igniter through the nozzle all the way up until it touches the smoke element.		
6.4.02	SECURE in place with tape or use other means to prevent the igniter from sliding down.		
6.4.03	PROJECT MANAGEMENT GO FOR LAUNCH? Project Manager:		
	Set Up Ground Station		
6.5.01	ASSEMBLE TeleMetrum antenna, longest prongs go at bottom and shortest go at top.		
6.5.02	PLUG antenna into TeleDongle.		
6.5.03	PLUG TeleDongle into a laptop with AltOS installed.		
6.5.04	OPEN AltOS.		
6.5.05	SELECT "Monitor Flight".		
6.5.06	SELECT TeleDogle device.		
6.5.07	CONTINUE to telemetry window.		
6.5.08	SET frequency to 434.550 MHz Channel 0.	Avionics Lead:	
6.5.09	SET baud rate to 9600 baud.	Avionics Lead:	
6.5.10	VERIFY live telemetry from TeleMetrum is appearing on screen.		
6.5.11	VERIFY all lights are green.		
6.5.12	VERIFY battery voltage is above 3.3V.		
6.5.13	ENSURE on-board Data Logging is ready to record.		

6.5.14	ENSURE at least 4 GPS satellites are in solution, this may take a few minutes.		
6.5.15	ENSURE GPS Ready is "Ready".		
6.5.16	ENSURE Site Map tab is filled with launch area.		
6.5.17	VERIFY launch ignitor continuity.	PM:	8

5.1.7 Flight

Item	Qty	Check
Peripheral Components		
Radio transmitter	1	
Laptop with USB port and AltOS installed	1	
Micro-USB cable	1	
TeleMetrum antenna	1	
Tools		
Camera/phone cameras		
Fire extinguisher		

Personnel	
Payload Lead	Gabriel Kurfman
Avionics Lead	Camille Demange

Step No.	Action	Check	T/S Id.
7.1.01	*PROVIDE safety briefing before launch.		
7.1.02	**REPORT suspected fires immediately to RSO and spectators.		4
7.1.03	VIDEO RECORD launch.		
7.1.04	VISUALLY track launch vehicle.		
Avionics			
7.2.01	TRACK vehicle's progress through CONOPS.		
7.2.02	*ALERT RSO and spectators of off-nominal flight conditions.		5
Payload			

5.1.8 Retrieval

Item	Qty	Check
Tools		
*Safety glasses	4	
*Nitrile gloves	4	
*Fire Extinguisher	1	
*First aid kit	1	
Key for keylock switch	1	
Camera/phone cameras		

Personnel	
Project Manager	Alex Edwards
Project Engineer	Alex Loney
Safety Office	Jenna Smith
Payload Lead	Gabriel Kurfman
Payload member #1	
Avionics Lead	Camille DeMange
Avionics member #1	

Step No.	Action	Check	T/S ID
8.1.01	*VERIFY all personnel that may contact energetics are wearing gloves and safety glasses.	Safety Lead:	
8.1.02	APPROACH vehicle slowly, conscious of terrain.		
8.1.03	*VERIFY visually a nominal landing, else proceed to proper T/S. Fire: 4 Hazardous landing location: 11	Safety Lead:	
8.1.04	IF PARACHUTE IS INFLATED AND PULLING VEHICLE, PULL the canopy down and hold with hands.		
8.1.05	*VERIFY all four energetic charges were detonated during flight.	Avionics Lead:	
8.1.06	**IF CHARGES REMAIN, CLEAR landing area and contact RSO.		
8.1.07	RECORD altimeter beeps.	Avionics Lead:	
8.1.08	TURN OFF avionics bay.		
8.1.09	PHOTOGRAPH landed vehicle.		
8.1.10	ANNOUNCE vehicle is safe for all members to approach.	Safety Lead:	
8.1.11	TURN OFF payload.		

8.1.12	COLLECT all launch vehicle segments and RETURN to staging area.		
8.1.13	IF PARTS HAVE FALLEN OFF, SEARCH for them, especially if potentially harmful to environment.		

Altimeter Initialization

Beep Meaning	Value	Desired
Telemetrum Altimeter		
Battery Voltage (2-3 digit counts, to the tenth)		≥ 3.3 V
Mode T/S: if *dit dit* – indicates Idle Mode, verify proper orientation (pointing up); *Dah dit dit dah*– indicates error during sensor calibration		*dit dah dah dit* (Pad Mode)
Continuity T/S: If 2 *dits* – only main continuity; 1 *dit* – only drogue continuity; *brap* – no continuity; *warble* – storage is full		3 continuity *dits*
StratoLogger Altimeter (two second pause between lines)		
IF ABNORMAL PREVIOUS FLIGHT, Error Code (short siren, 1+ digit counts)		No Error Code
Preset # (single digit count)		4 beeps
Main Deploy Altitude (3-4 digit counts, to the ones in feet)		6, 10, 10 beeps
Apogee Delay (tone means delay is set)		One long beep
Previous Flight Apogee		(no check)
Battery Voltage (2-3 digit counts, to the tenth)		≥ 8 V
Continuity T/S: If 2 beeps– only main continuity; 1 beeps– only drogue continuity; no sound– no continuity		3 continuity beeps

Altimeter Post-Flight Readout

Beeps	Value
Telemetrum Altimeter	
Apogee (digit counts, *dah* for zero digit)	meters
StratoLogger Altimeter (Long tone between lines)	
Apogee (3-6 digit counts)	feet
Max. Velocity (2-5 digit counts)	mph

5.1.9 Troubleshoot and Emergency Procedures

1. **Accidental Black Powder Ignition
Clear the area of personnel and additional energetic or flammable materials.
Extinguish any flames with a fire extinguisher.
Inspect personnel for injuries. *If found:* administer first aid or call 911 if necessary.

2. **Spilled Black Powder
Clear the area of personnel and additional energetic or flammable materials.
*Verify all clean-up personnel are wearing gloves and safety glasses.
Acquire black powder funnel.
With a gloved hand to sweep, funnel black powder back into the container.
Clean remaining powder with a wet disposable towel.
Inspect personnel for hazardous eye or skin contact. *If found:* Rinse thoroughly.

3. **Premature Motor Ignition
Take cover if the motor becomes a projectile.
Clear the area of personnel and additional energetic or flammable materials.
Extinguish any flames with a fire extinguisher.
Inspect personnel for injuries. *If found:* administer first aid or call 911 if necessary.

4. **Launch Pad or Landing Site Fire
Clear the area of personnel.
Extinguish flames with a fire extinguisher.
Inspect for damage to launch vehicle(s), ignition system, and/or surrounding environment. *If found*: report to the appliquable authorities and personnel.
Inspect personnel for injuries. *If found:* administer first aid or call 911 if necessary.

5. Ballistic trajectory
If vehicle is free-falling for longer than four seconds without indication of parachute ejection.
Loudly announce “Scatter”.
Launch spectators will turn away from vehicle and run for a minimum of 20 seconds or all clear is called.

6. Payload initialization failure
IF “1,3” beeps– all sensors initialized successfully
IF “2” beeps– IMU failure
IF “3” beeps– RTC failure
IF “4” beeps– SD failure
IF “5” beeps– Radio failure
IF “6” beeps– Altimeter failure
IF “0” beeps– Battery failure
IF “-1” beeps– Time failure

7. Component Failure on Pad
Disarm avionics bay.
Personnel near the pad remove the vehicle from the rail.
*If handling ignitors or motors, wear gloves.
Team Mentor removes the ignitor from the motor.
Technical Team Lead in problem area determines severity. *If severe*: scrub the launch. *Else*: conduct repair in the field.
Determine if another launch attempt is feasible.
If making another attempt: follow the launch initiation list.

8. No Ignitor Continuity
Disarm launch controller.
*If handling spent ignitors or motors, wear gloves.
Team Mentor approaches the vehicle and inspect connectors.
If lack of continuity persists, install a new ignitor.

9. No Motor Ignition
Disarm launch controller.
Wait a minimum of one minute before approaching the vehicle.
Disarm avionics bay.
*If handling spent ignitors or motors, wear gloves.
Replace ignitor or motor if needed.
Determine if another launch attempt is feasible.
If making another attempt: follow the launch initiation list.

10. Hazardous Landing Location
Do not attempt to climb trees or power lines to retrieve launch vehicle, payload, or components.
Alert RSO of the situation.
If in a tree and can be done safely: use suitable access equipment to retrieve vehicle.
If in a power line: contact appropriate authorities to report.

11. Component Failure on Landing
Technical Team Lead in problem area determines severity.
If irreparably damaged: new test flight must be completed.

5.2 Safety and Environment Hazards

These hazards were then evaluated according to the RAC found in Appendix A. Each hazard is scored on likelihood (L) and on consequence severity (C). These scores are then compared in the RAC diagram to produce an overall risk score (RAC 1). The hazards are then ranked by this number, higher values representing higher risks. Mitigation actions were developed and new RAC scores calculated (RAC 2). The following tables rank the hazards by their mitigated RAC scores. The RAC was created following the guidelines provided in S3001: Guidelines for Risk Management and ISO 31000:2018 - Risk Management as well as other NASA and industry documents.

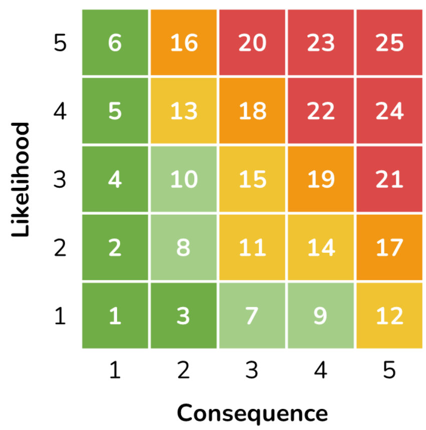


Figure 5.2.1 - RAC diagram

The final column tells the current status of the mitigation plan and where, if included, to find more information in this document. Many of the more general safety topics were covered during weekly team meetings. Each general meeting will include a Safety Minute, a brief discussion of a safety topic. These will include topics relevant to this competition, like energetics etiquette, as well as more general topics encountered everyday but not often discussed, like safe driving during harvest season. This inclusion will promote an atmosphere of safety in all team activities.

Table 5.2.1. Personnel Hazards Analysis

Hazard	Causes	Effects	C-L 1	RAC 1	Mitigation	C-L 2	RAC 2	Status
Terrain around the launch area.	Uneven/unsteady ground. Poisonous plants. Fast-moving water.	Moderate bruising and lacerations. Severe skin irritation. Drowning.	5-3	21	Approach slowly and determine if it is a hazardous landing site.	5-1	12	**In Practice** ***See RETRIEVAL (Step 8.1.02)***
					Do not attempt to recover vehicle from dangerous areas; seek professional aid.			**In Practice** ***See RETRIEVAL (Step 8.1.03) and EMERGENCY PROCEDURES***
Projectiles and debris.	Debris created by machines during construction. Ground debris kicked up by vehicle launch. Vehicle fragments created during major launch failure. Vehicle during descent under parachutes.	Minor bruising. Moderate lacerations. Debris in the eye. Severe head injury. Death.	5-3	21	Use proper PPE while operating machines.	2-2	8	**In Practice** ***Covered during Safety Minute at team meeting***
					Follow NAR Minimum Distance regulations.			**In Practice**
					Only essential personnel near vehicle during arming.			**In Practice** ***See LAUNCH INITIATION (step 6.3.01)***
					Reduce vehicle failure modes.			**In Progress** ***See Table 5.2.2***
					Brief personnel on tracking vehicle during descent.			**In Practice** ***See Appendix B: Safety Briefing***
Hot surfaces, liquids.	Contact with recently machined parts, uninsulated electrical components, or recently ignited flammables/explosives. Improper PPE.	Moderate to major thermal burns.	3-3	15	Clearly label potential burn hazards. Acknowledge potential hot surfaces created during machining. Appropriate wait time before contact with spent flammables/explosives. Use proper PPE.	2-2	8	**In Practice** ***Covered during Safety Minute at team meeting***
Moving and rotation machinery components.	Loose hair, clothing, or jewelry. Improper PPE. Missing or not utilized machinery guard. Contact with pinch points.	Entanglement. Severe friction burns. Amputation. Death.	5-3	21	Require training in safe operation before using each machine. Secure loose hair; remove loose clothing and jewelry. Wear long pants, closed toe shoes, and proper PPE.	3-1	7	**In Practice** ***Covered during Safety Minute at team meeting***
Loose, uneven, or slippery surfaces.	Improper storage of materials and equipment. Improperly placed cords. Spills and debris.	Slips, trips, and falls. Minor bruising or abrasion. Head bump.	3-3	15	Ensure proper lighting in work areas. Return all tools and materials to designated storage areas after use. Avoid placing cords in foot traffic areas; if unavoidable, tape down cables. Immediately clean-up spills or dropped trash.	3-4	5	**In Practice** ***Covered during Safety Minute at team meeting***

Exposure to high noise levels.	Close proximity. Prolonged exposure. Improper PPE.	Minor and temporary to major and permanent standard threshold shift (STS).	5-3	21	Acknowledge potential loud noise exposure before starting operation. Use proper PPE. Follow OSHA's permissible exposure limit.	1-3	4	**In Practice** ***Covered during Safety Minute at team meeting***
Sharp corners/edges.	Careless or improper use of machinery. Missing or not utilized machinery guard. Improper PPE. Inadvertent contact with corners/edges of raw or machined materials.	Minor to major laceration or puncture. Amputation.	5-2	17	Require training in safe operation before using each machine. Wear long pants, closed toe shoes, and proper PPE. Acknowledge potential sharp surfaces created during machining.	2-1	3	**In Practice** ***Covered during Safety Minute at team meeting***
Electrical sources and components.	Improper use or storage of electrical components. Improper use of extension cords or power strips. Working in wet conditions.	Minor to major electrical burns. Shocks, loss of balance. Disrupted heart rhythm and loss of consciousness.	4-2	14	Use proper PPE. Clearly label electrical circuits, especially high voltage equipment. Maintain a dry work area. Properly use extension cords and plugs.	2-1	3	**In Practice** ***Covered during Safety Minute at team meeting***
Fire.	Improper storage or handling of flammable/explosive materials. Improper use of or unsupervised heating element. Faulty motor or explosive charges. Flammable materials not cleared from work or launch area.	Moderate to major thermal burns.	4-2	14	Clear flammable materials from work and launch areas. Follow all guidelines set for hazardous materials.	2-1	3	**In Practice** ***Covered during Safety Minute at team meeting***
					Ensure all extraneous personnel are a proper distance from explosives before arming.			**In Practice** ***See LAUNCH INITIATION (Step 6.3.01)***
					Have fire suppression systems nearby. Use PPE when handling explosives is required.			**In Practice** ***See multiple times in procedures***
					Report any suspected fires immediately.			**In Practice** ***See FLIGHT (Step 7.1.02)***
Lifting and moving objects.	Improper lifting technique. Lifting heavy objects. Unstable packing or stacking. Repeated motions.	Muscle strain. Back and spine injury. Injury from dropped objects.	3-4	18	Brief personnel on the following practices: Maximum weight per person is 40 lbs, may be lower depending on factors like shape, lack of handholds, etc. Take multiple trips rather than unstable stacks. Use proper lifting technique.	1-2	2	**In Practice** ***Covered during Safety Minute at team meeting***
Hazards to STEMnauts								
High acceleration or dynamic loads.	Nominal ascent and descent. Parachute deployment. Tumbling during descent. Landing.	Decrease in blood pressure. Difficulty breathing. Loss of consciousness.	5-4	24	Test that all acceleration and dynamic loads are within the limits described in NASA- Standard 3001 Volume 2.	2-5	16	**In Progress** ***Subscale measurements collected, full scale test will verify within limits***

High rotational velocities and accelerations.	Nominal ascent and descent. Uncontrolled tumble during descent.	Decrease in blood pressure. Difficulty breathing. Loss of consciousness. Brain injury.	5-5	25	Analyze model to verify all rotational velocities and accelerations are within the limits described in NASA-Standard 3001 Volume 2.	2-5	16	**In Progress** ***Subscale measurements collected, full scale test will verify within limits***
High vibration exposure.	Nominal ascent and descent. Improperly secured personnel.	Damage to internal organs and tissues..	5-4	24	Analyze model to verify all vibrations experienced by personnel are within the limits described in NASA-Standard 3001 Volume 2 .	3-3	10	**In Progress** ***Subscale measurements collected, full scale test will verify within limits***
					Include verification of proper securement in launch preparation procedures.			Incomplete
Blunt force trauma from contact points with vehicle.	Nominal ascent and descent. Parachute deployment. Uncontrolled tumble during descent. Landing. Improperly secured personnel.	Minor discomfort to major injury.	4-5	23	Limit blunt force to values described in NASA-Standard 3001 Volume 2 by properly securing personnel. Perform a ground test to verify.	2-3	10	**In Progress** ***Subscale measurements collected, full scale test will verify within limits***
					Include verification of proper securement in launch preparation procedures.			Incomplete
Personnel on back with elevated feet for long periods.	Delayed/scrubbed launch. Issue with release mechanism.	Muscle discomfort or pain Effects on cognitive abilities.	3-5	20	Limit stated position to less than 3 hours and 15 minutes.	1-5	6	**Complete**
Personnel in an inverted orientation for long periods.	Vehicle lands in an inverted position.	Suspension trauma. Reduced cognitive abilities. Decreased blood pressure. Loss of consciousness.	3-5	20	Limit inverted state to less than seven minutes by design of payload.	1-5	6	**Complete**

Table 5.2.2. Failure Modes and Effect Analysis

Hazard	Causes	Effects	C-L 1	RAC 1	Mitigation	C-L 2	RAC 2	Status
Stages fail to separate	Faulty ejection charge. High friction between couplers.	No parachute deployment. Ballistic trajectory.	5-3	21	Perform ejection ground tests to ensure charges can separate stages.	5-1	12	**Complete** ***See VT.A.4***
Flight instability	Poor design. Poor construction.	Potentially dangerous flight path. Loss of vehicle.	5-3	21	Model launch vehicle to estimate stability.	5-1	12	**Complete**
					After assembly, measure the physical center of gravity and pressure to compare to estimated stability.			**In Practice** ***See FULL VEHICLE INTEGRATION (Step 5.4.03)***
Loss or damage of fins	Poor design or construction method. Improper materials used.	Partial or total destruction of vehicle.	5-2	17	Analyze fin support structure and fin flutter velocity regime.	5-1	12	**Complete** ***See VT.C.1***

Destruction of nose cone	Poor design or construction method. Improper materials used.	Partial or total destruction of vehicle.	5-2	17	Use materials and building methods appropriate for high-power rocketry.	5-1	12	**In Progress**
Launch vehicle disconnects from launch rail	High wind speeds. Incorrect connection method or type. Failure of connectors.	Partial or total destruction of vehicle. Ballistic trajectory.	5-2	17	During design, ensure proper connector type.	5-1	12	**Complete**
					Check attachment points before flight.			**Complete** ***See FULL VEHICLE INTEGRATION (Step 5.4.01) and LAUNCH INITIATION (Step 6.1.02)***
Airframe failure	Poor structural design, construction method. Improper materials. Incorrect stress modeling.	Buckling, shearing. Partial or total destruction of vehicle. Ballistic trajectory.	2-5	**16**	Mathematically and physically analyze body tube, bulkheads, fasteners, and shear pins. Use reliable building techniques. Confirm use of proper materials.	1-5	6	**Complete**
Hazards from Motor								
Motor detonation	Accidental activation of launch controller.	Partial to total destruction of vehicle.	5-2	17	Follow all assembly instructions provided. Assembly verified by a second person.	5-1	12	**In Practice** ***See MOTOR PREPARATION***
Motor expulsion	Improper retention methods. Failure in retention device.	Low apogee. Falling debris. Loss of vehicle.	5-2	17	Use a positive retention method.	5-1	12	**Complete**
					Include motor securement into the launch procedures.			**In Practice** ***See FULL VEHICLE INTEGRATION (Step 5.4.05)***
Incorrect motor angle	Poor construction. Damage from previous flight or transportation.	Lower vehicle stability. Does not follow the desired flight path.	4-2	14	Ensure proper alignment during construction. Check alignment during launch procedures.	4-1	9	**In Practice** ***See FULL VEHICLE INTEGRATION (Step 5.4.05)***
Propellant fails to burn for desired duration	Manufacturing defect. Assembly error.	Low apogee. Failure to reach set high for recovery system actions.	3-2	11	Purchase motors and propellant from reliable sources.	3-1	7	**Complete**
					Check for damage during launch procedures.			**In Practice** ***See FULL VEHICLE INTEGRATION (Step 5.4.02) and MOTOR PREPARATION (Step 1.1.02)***
Motor ignition failure	Faulty ignitor. No ignitor continuity.	Minor delay to cancellation of launch.	1-4	**5**	Check for continuity prior to attempted launch.	1-1	1	**In Practice** ***See LAUNCH INITIATION (Step 6.5.17)***
					Have additional igniter and ignition methods on hand at launches.			**In Practice** ***See T/S #8 and #9***
Hazards from Avionics and Recovery System								

Premature parachute ejection	Altimeter programming. Poor venting. Accidental dual deployment.	Zippering, loss of vehicle. High decent time.	5-3	21	Check altimeter settings during pre-flight checklist.	5-1	12	**In Practice** ***See AVIONICS AND RECOVERY SYSTEM PREPARATIONS***
					Check vent holes before flight.			**In Practice** ***See FLIGHT INITIATION (Step 6.3.04)***
					Separate parachutes in design.			**Complete**
Ejection charge failure	Not enough power, electrical failure, improper charge sizing.	Ballistic trajectory, destruction of vehicle	5-3	21	Ground test charge sizes vs e-match.	5-1	12	**Complete** ***See VT.A.3***
					Conduct voltage test readings on the power source.			Incomplete *See VT.A.2*
Loss of parachute	Failure of shock cord, slacklines, or connector. Unconnected shock cords.	Partial to total destruction of vehicle. Ballistic trajectory.	5-3	21	Use materials and building methods appropriate for high-power rocketry.	5-1	12	**Complete**
Power loss	Faulty wiring. Battery failure or lack of charge.	Failure to trigger ejection charges. Ballistic trajectory.	5-3	21	Test wiring during design and construction phases.	5-1	12	**Complete**
					Check battery power during the launch preparation procedure.			**In Practice** ***See FLIGHT INITIATION (Step 6.5.12)***
Main parachute failure	Poor sealing of the parachute chamber. Poor parachute packing. Ejection charge failure.	Recovery failure. Ballistic trajectory. Loss of vehicle.	5-3	21	Test packing methods. Have a secondary ejection charge.	5-1	12	**Complete**
					Examine parachutes and charges before launch.			**In Practice**
Altimeter failure	Loss of connection. Dead battery.	Partial to total destruction of vehicle. Ballistic trajectory.	5-2	17	Secure all components to their mounts and check settings prior to launch. Confirm securement in launch preparation procedure.	5-1	12	**In Practice** ***See AVIONICS AND RECOVERY SYSTEM PREPARATIONS***
Heat damage to recovery system	Insufficient protection from ejection charge.	Parachute damage. High landing velocity and kinetic energy.	5-2	17	Use appropriate methods according to scale of blast and parachute.	5-1	12	**Complete** ***See VT.A.3***
Drogue parachute failure	Poor sealing of parachute chamber. Poor parachute packing. Ejection charge failure.	No action at apogee. Failure to meet competition requirements.	3-3	15	Test packing methods. Have a secondary ejection charge.	3-1	7	**Complete**
					Examine parachutes and charges before launch.			**In Practice**
GPS does not lock to satellites.	Interference. Poor weather. Dead battery.	Loss of whole vehicle.	5-2	17	Ensure proper GPS lock and battery charge before flight.	3-1	7	**In Practice** ***See FLIGHT INITIATION (Step 6.5.15)***

Hazards from Payload System								
Premature release of payload system	Structural failure. Premature release command.	Decrease or total loss of stability. Partial or total destruction of vehicle/payload. Failure payload objectives.	5-3	21	Verify retention system is able to withstand flight-like conditions through model analysis and ground tests.	5-1	12	**In Progress** ***See VT.P.1 and VT.P.2***
					Test release command to ensure it is given at desired point of flight.			**In Progress** ***Success during subscale flight***
Descent system does not provide safe landing conditions	Design fundamentally is unable to create conditions. Damage caused during launch or deployment. Failure in mechanical or electrical components during descent.	High velocity descent and landing. Partial or total destruction of payload. Failure to meet payload objectives.	4-3	19	Verify descent method is able to create safety landing conditions through model analysis and ground tests.	4-1	9	Incomplete
Payload is not released or released late	Interference from other launch vehicle components. Release command not sent. Release command not received. Release operation fails.	Failure to meet payload objectives. Modified expected flight path of launch vehicle.	3-4	18	Perform ground tests to verify no interference from other components.	2-2	8	Incomplete
					Test release command to ensure it is given and received at desired point of flight. Analysis flight dynamics for landing with payload retained in the launch vehicle.			**In Progress** ***Success during subscale flight***
Descent system does not deploy	Interference from other launch vehicle components. Damage caused during launch or release. Mechanical or electrical component in deployment method failure. Deployment command not sent or not received.	Uncontrolled descent of payload system. Interference with recovery system. Partial or total destruction of vehicle/payload. Failure to meet payload objectives.	5-3	21	Perform ground tests to verify no interference from other components.	3-1	7	Incomplete
					Verify retention system is able to withstand flight-like conditions through model analysis and ground tests. Ground test deployment command to ensure it is given at desired point of flight.			**In Progress** ***Success during subscale flight***
					Develop a contingency plan for failure case to ensure personnel and vehicle safety.			**In Progress**

5.2.1 Environmental Hazard Analysis

All team actions are subject to federal, state, and local environmental regulations; the team will also adhere to NASA environmental guidelines. Environments that may impact or be impacted by this team and competition include:

- Purdue University Airport and Zucrow Labs (West Lafayette, IN);
- Purdue Dairy Farm (West Lafayette, IN);
- Bragg Farms (Toney, AL)- competition launch location;
- The global environment.

5.2.1.1 Purdue University Airport and Zucrow Laboratories

This area includes the Aerospace Science Laboratory and Maurice J. Zucrow Propulsion Laboratories. The Aerospace Sciences Laboratory (ASL) is the primary construction and storage location for the launch vehicle and its non-energetic components. Maurice J. Zucrow Propulsion Laboratories is the energetic material storage and test location.

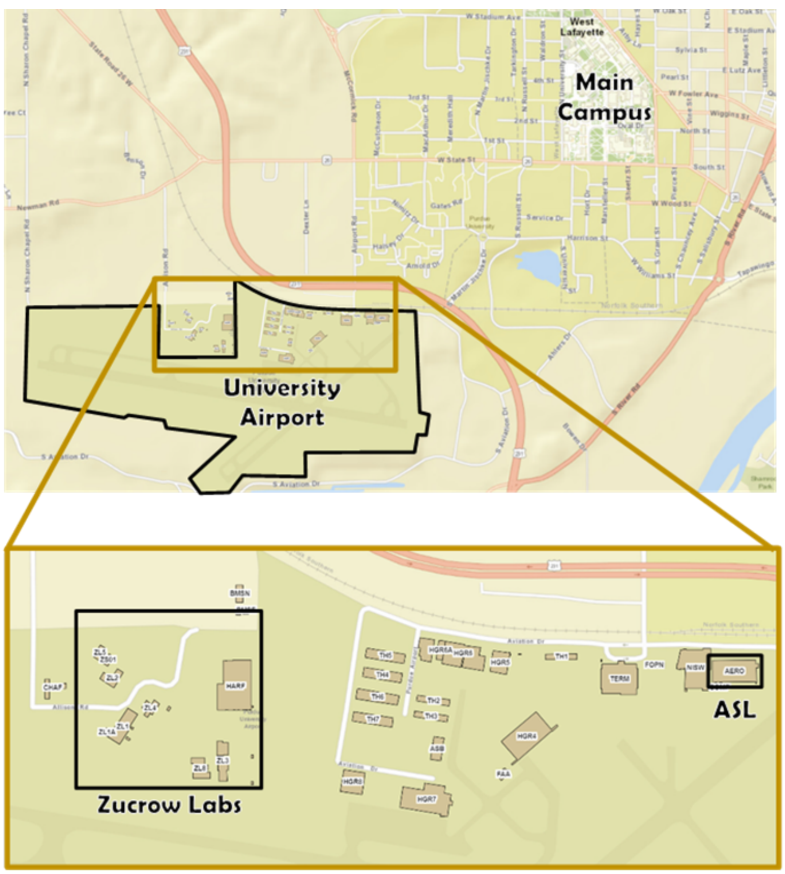


Figure 5.2.2: Purdue campus map with inset showing lab spaces

Land

The Purdue University Airport, covering 537 acres [1], and its neighbor Zucrow Laboratories, covering 24 acres [2], are located less than one mile from campus. Major land uses include airport operations, university academic buildings, and research lab infrastructure. It is in an industrial zone.

Uses of land surrounding the airport and labs include railways, agriculture, and education facilities.

Climate and Air

Annually, temperature varies between 20°F and 85°F. Average wind speed in winter through mid-spring is 12.5 mph with gusts up to 55 mph [3]. Average snowfall in winter is 4 inches, and historically, snow is possible as late as April. Spring holds a high chance for rain; on average, precipitation is observed one in four days of the month of March and one in three days of the month of April [3]. Majority of the humidity level between November and April is dry or comfortable, with some more humid to muggy days in late April [3].

Few natural disasters frequent this area. Only one tornado has been recorded in the county during the last five years, and none of a magnitude higher than EF1 in the last ten years [4].

Federal air quality requirements stated in the National Ambient Air Quality Standards (NAAQS) were cited for Indiana's air quality requirements set by the Department of Environmental Management's Office of Air Quality. These values are compared to the county's current values in Table 5.2.2.

Table 5.2.3. Pollutant Standards and Current Levels

Pollutant	Federal Standard (Averaged Over)	Tippecanoe Level
Carbon Monoxide Primary Primary	 9 ppm (8 hr) 35 ppm (1 hr)	0.330 ppm
Lead Primary & Secondary	 0.15 μg/m^3 (3 months)	0.0167 μg/m^3
Nitrogen Dioxide Primary Primary & Secondary	 100 ppb (1 hr) 53 ppb (1 year)	0.532 ppb
Ozone Primary & Secondary	 0.070 ppm (8 hr)	0.031 ppm
Particle Pollution - $PM_{2.5}$ Primary Secondary Primary & Secondary	 12.0 μg/m^3 (1 year) 15.0 μg/m^3 (1 year) 35 μg/m^3 (24 hr)	8.87 μg/m^3
Particle Pollution - PM_{10} Primary & Secondary	 150 μg/m^3 (24 hr)	13.22 μg/m^3
Sulfur Dioxide Primary Secondary	 75 ppb (1 hr) 0.5 ppm (3 hr)	1.332 ppb

Noise Pollution

According to the municipal code of the area, it is unlawful to:

- "Operate any mechanically powered saw, drill, sander, grinder, lawn or garden tool, or similar device between eight p.m. and seven a.m. in such a manner that disturbs or annoys any reasonable person nearby";
- "Participate in a party or gathering between ten p.m. and seven a.m. that produces a noise plainly audible across property boundaries or between partitions common to two or more persons within a building";
- "Cause the sound pressure level to exceed the limit for the zoning on which the person is located" (66 dBA for industrial zones).

The code states exemptions to these laws include "alerting persons to the existence of an emergency" and efforts to "prevent or alleviate physical or property damage threatened or caused by public calamity or other emergency".

5.2.1.2 Purdue Dairy Farm

This area is the location of the following vehicle launches: sub-scale, full scale, and payload demonstration flight.

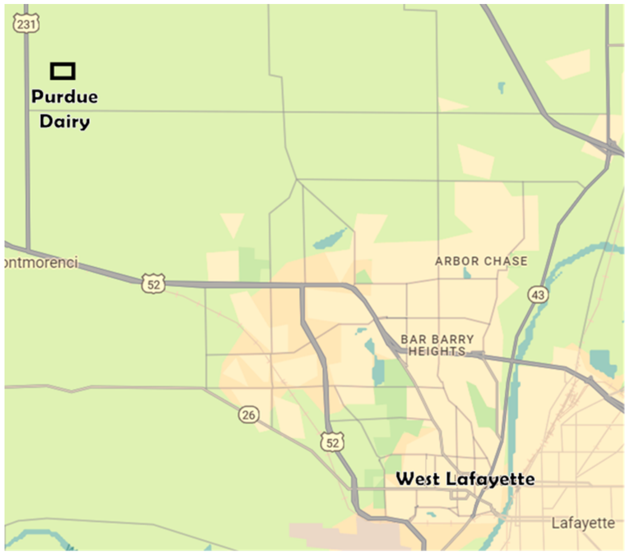


Figure 5.2.3: Map showing Purdue Dairy Farm relative to West Lafayette and Purdue Campus

Land

The Purdue Dairy Farm and the 1440 acre field used as the primary launch location are located five miles north-west of campus. Major land uses include university agricultural operations, both livestock and crops. It is in an intensive agricultural district.

Main use of land surrounding the farm is agricultural.

Climate and Air

The Purdue Dairy Farm has the same climate and air pollution restrictions as Purdue University Airport and Zucrow Laboratories.

Noise Pollution

There are no noise restrictions for this zone.

Table 5.2.4. Environmental hazard and effects analysis

Hazard	Causes	Effects	C-L 1	RAC 1	Mitigation	C-L 2	RAC 2	Status
Hazards to Environment								
Irreversible and irretrievable commitment of resources	Use of non reusable or recyclable materials and components. Using farm land for a non-agricultural event.	Permanent loss of or effect on a resource.	4-5	23	Strive from a completely reusable launch vehicle by minimizing single-use components. Use recycled materials where possible (ei. Doesn't affect structural integrity or predictability.) Laminate procedures and use wet-erase pen to allow for re-use of papers.	4-3	19	**In Practice**
Fire	Exhaust from motor during launch. Remaining fire during landing.	Damage to landscape and wildlife.	4-3	19	Clear ground around launch pad per NAR standard. Have fire suppression systems nearby. Report any suspected fires immediately.	4-1	9	**In Practice**
Pollution from personnel	Improper disposal of waste including trash, paper scraps. Personnel tread on important plants, farm fields, etc.	Litter may deposit unwanted chemicals in soil. Harm to the property. Litter may be eaten by wildlife.	4-3	19	Brief personnel in "Leave No Trace" mindset, in terms of trash and trails. Inforce limit on number of personnel walking through fields to retrieve the vehicle.	4-1	9	**In Practice**
Kinetic damage to buildings	Launch vehicle veers off trajectory causing landing in occupied area.	Repairable destruction to building.	4-2	14	Ensure minimum distance from building exceeds minimum personnel distance as established by NAR safety standard.	3-1	7	**In Practice**
Pollution from exhaust	Combustion of APCP motors.	Release of small amounts of greenhouse gasses.	2-5	16	Use only motors approved for use by the National Association of launch vehicle, Canadian Association of launch vehicle, or Tripoli Rocketry Association.	1-5	6	**Complete**
Pollution from vehicle	Loss of vehicle components.	Materials degrade extremely slowly, possible harm to wildlife or water contamination.	3-2	11	Properly fasten all components. Scavenge for fallen parts after launch is completed. Reduce use of hazardous materials.	3-1	3	**Complete**
Battery leakage	Absence of casing or damage to battery casing.	Possible toxic acid leak, heavy metal contamination.	3-2	11	Enclose the battery in a plastic casing. Check casing before launch.	3-1	3	**Complete**
Kinetic damage to terrain.	Launch vehicle has an excessive landing speed.	Creation of small ground divots. Mild inconvenience to wildlife and flora.	1-4	5	Simulate landing conditions to ensure the parachute generates sufficient drag to slow the launch vehicle to acceptable parameters.	1-1	1	Incomplete
Hazards from Environment								
Landscape	Trees, brush, water sources, powerlines, wildlife.	Inability to recover launch vehicle	5-3	21	Inspect launch site before launch to verify that it is a suitable area to launch.	5-1	12	**In Practice**

Wind	Poor forecast.	Excessive drift. Delay or cancellation of launch.	4-3	19	Angle into wind as necessary, abort launch if wind exceeds 15 mph. Check weather beforehand.	3-1	7	**In Practice**
Low Temperatures	Poor forecast.	Cold-related injuries. Ice formations on ground. Changes in launch vehicle rigidity and mass. Higher drag.	3-3	15	Personnel wear appropriate clothing. Keep launch vehicle indoors when possible. Do not launch if ice forms on vehicle.	3-1	7	**In Practice**
High temperatures	Poor forecast.	Heat related injury. Damage to vehicle components.	3-3	15	Keep the launch vehicle in a shaded area until before launch. Check weather beforehand.	2-1	3	**In Practice**
Humidity	Climate, poor forecast.	Rust on metallic components. Failure of electronic components	2-3	10	Minimize use of ferrous metal. Store vehicle indoors when not in use. Check weather before launch.	1-2	2	**In Practice**
Plant pollen	Local flora. Peak pollen season.	Red, itchy eyes. Sneezing, runny nose. Mild difficulty breathing.	3-3	15	Warn personnel of environment, ei. Cornfield or near animals, to allow them to make necessary precautions.	1-1	1	**In Practice**
					Include an antihistamine in the first aid kit.			**Complete**

6 Project Plan

6.1 Testing

6.1.1 Avionics and Recovery

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	1	In Progress	**Altimeter Continuity and Battery Drain Test**	S.A.1, S.A.2, S.A.3, S.A.6
Verification Plan Objective					
This test will verify that the altimeters and their batteries will function across all likely launch temperatures, and that they will maintain continuity throughout flight. It will also verify that the batteries will supply usable voltage for the maximum expected duration of flight and pad time.					
Success Criteria				**Dependent Variables**	
Both altimeters must maintain continuity and receive adequate power from their respective batteries for 4 hours powered on in both temperature extremes, and the voltages of both batteries must remain the same after 18 hours powered off in warm weather. -- Warm-weather test: Must be above 70°F. -- Cold-weather test: Must be below 35°F. -- Every continuity measurement of both the StratoLoggerCF and the TeleMetrum altimeters must be 3 beeps (full dual-deployment continuity). -- In the powered-on test, the voltage of the 9V battery must not drop below 8V. -- In the powered-on test, the voltage of the 3.7V LiPo battery must not drop below 3.3V.				The dependent variables are the number of continuity beeps emitted by both the TeleMetrum and StratoLoggerCF altimeters and the voltages of both the 3.7V LiPo and 9V batteries.	
Why is this necessary?				**Test Articles**	
This test verifies that both altimeters will be able to maintain continuity and receive adequate power from their respective batteries for 4 hours (1 hour longer than the pad time of 3 hours) powered on in both temperature extremes, and the voltages of both batteries will remain the same after 18 hours powered off in warm weather.				StratoLoggerCF Altimeter, Telemetrum Altimeter, 9V Battery, 3.7V LiPo Battery	

Test Equipment and Methodology
Test Equipment StratoLoggerCF altimeter, TeleMetrum altimeter, 9V battery, 9V battery connector, 3.7V LiPo battery, two switches, wires, multimeter, screwdriver set **Methodology** Powered-On Test (Warm and Cold Weather) 1. The current temperature was recorded. 2. One new 9V battery will be connected to the StratoLoggerCF altimeter using a 9V battery connector, along with a switch. 3. The altimeter will be turned on with the switch and will go through its initialization routine. Then, the system will be left for 4 hours. 4. Every 0.5 hours (including at 0 hours and 4 hours), use a multimeter to record the voltage of the 9V battery. Also record the continuity beeps. 5. The procedure will be repeated with the 3.7V LiPo battery and the TeleMetrum altimeter. The voltage of the TeleMetrum can be recorded by switching it off and then on again and recording the initialization beeps (first set of beeps is ones place of voltage, second set of beeps is tenths place of voltage). This is because the multimeter cannot measure the 3.7V LiPo battery's voltage. The number of initialization beeps was then recorded as the voltage measured for that interval of time. Note: The entire test will be conducted in both the warm and cold temperatures in order to verify that full continuity and adequate voltage supplied to the altimeters can consistently be achieved in both warm and cold weather. Powered-Off Test (Warm Weather Only) 1. In warm weather only with the same setup as in the powered-on test, but with the altimeters powered off, a voltage reading of each battery will be taken before and after 18 hours of everything being wired together in flight configuration.
Potential Impact of Results
If both altimeters and batteries pass this test, it will be expected that the altimeters will have enough power to deploy the parachutes without problems during flight. The selection of these components would be confirmed. If one or both altimeters/batteries fail this test, a retest will occur for those components, and if necessary a new altimeter or battery will be considered.

Test Data

Warm Weather Trial: 71°F Altimeter/Battery	Reading 1 (0 hours)	Reading 2 (0.5 hours)	Reading 3 (1 hour)	Reading 4 (1.5 hours)
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3, 4.1	3, 4.1	3, 4	3, 4

StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 5 (2 hours)	**Reading 6 (2.5 hours)**	**Reading 7 (3 hours)**	**Reading 8 (3.5 hours)**
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3, 4	3, 3.9	3, 3.9	3, 3.9
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 8 (4 hours)			
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3, 3.8			
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
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				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 5 (2 hours)	**Reading 6 (2.5 hours)**	**Reading 7 (3 hours)**	**Reading 8 (3.5 hours)**
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
	Reading 8			

	(4 hours)			
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage				
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
Powered Off Test: 71°F Altimeter/Battery	**Reading 1 (Before 18 hours)**		**Reading 2 (After 18 hours)**	
TeleMetrum/3.7V LiPo Number of Continuity Beeps/Battery Voltage	3, 4.1		3, 4.1	
StratoLoggerCF/9V Number of Continuity Beeps/Battery Voltage				
Test Results				
Altimeter/Battery		**Warm Weather: 71°F**	**Cold Weather: 33.0°F**	**Powered-Off Test: 71°F**
TeleMetrum/3.7V LiPo		PASS		PASS
StratoLoggerCF/9V				
Conclusions				
So far, this test has only been conducted on the Telemetrum/3.7V LiPo battery for warm weather, and it has passed both the powered-on and powered-off tests for this condition. The rest of this test is expected to be completed in January of 2024.				

<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>2</td><td>Incomplete</td><td>Altimeter Ejection Vacuum Test</td><td>S.A.19</td></tr>
<tr><th colspan="6">Verification Plan Objective</th></tr>
<tr><td colspan="6">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.</td></tr>
<tr><th colspan="4">Success Criteria</th><th colspan="2">Dependent Variables</th></tr>
<tr><td colspan="4">Both altimeters must ignite the drogue parachute e-matches at apogee (or 2s after apogee) and the main parachute e-matches at the correct altitude during descent.
-- For the TeleMetrum altimeter, the magnitude of the difference between the apogee altitude and the altitude the drogue e-match ignites at must be less than 500’ for all three trials.
-- For the TeleMetrum altimeter, the altitude the main e-match ignites at must be between 700 ± 50’ for all three trials.
-- For the StratoLoggerCF altimeter, the drogue delay (the time between ignition of the TeleMetrum drogue e-match and ignition of the StratoLoggerCF drogue e-match) must be between 0.75 and 1.75s (as it is programmed to be 2s) for all three trials.
-- For the StratoLoggerCF altimeter, the altitude the main e-match ignites at must be between 500 ± 50’ for all three trials.</td><td colspan="2">The dependent variable is the times in flight the e-matches are ignited by the TeleMetrum and StratoLoggerCF altimeters.</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 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.</td><td colspan="2">StratoLogger CF Altimeter, Telemetrum Altimeter</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, twelve e-matches, screwdriver set, glass bowl, sheet of plexiglass, wine stopper, wine bottle air remover pump, plumber's putty, AltimeterOne altimeter, drill, and drill bits

Methodology
1. Drill one hole into the sheet of plexiglass. Place the wine stopper into this hole and seal the hole with a small ring of plumber's putty in order to prevent air from escaping.
2. Drill a smaller hole to the side of the previous hole. This is a pressure release hole to simulate descent.
3. For each altimeter, connect an e-match to the drogue and main outputs and a battery (9V for StratoLogger and 3.7V for Telemetrum) and switch to the altimeter.
4. Turn on the AltimeterOne and set it to Real Time.
5. Place the testing altimeter system and the AltimeterOne in a glass bowl at the same time. The switch and the e-matches should be 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. If the testing altimeter is the Telemetrum, ensure that it is pointing up.
6. Place a large ring of plumbers' putty around the rim of the bowl and over the e-matches and switch wires. Rest the prepared sheet of plexiglass over the bowl and press down until there was a uniform seal around the entire perimeter. If necessary, extra plumbers' putty can be placed around the exposed wires to ensure a complete seal.
7. Use a small piece of plumbers' putty to seal the pressure release hole.
8. Switch the altimeters on and allow them to complete their initialization routines. It is important that these steps are completed after sealing the pressure release hole because if the chamber is sealed after the altimeters are switched on, they might detect the small drop in pressure and start the launch.
9. Remove air through the stopper using the wine bottle air remover pump. Once the vacuum reaches the expected apogee altitude as indicated by the digital display of the AltimeterOne, the drogue e-match is expected to ignite (or 2 seconds after apogee for the StratoLoggerCF altimeter).
10. Slightly lift the small piece of plumbers' putty in the second drilled hole in the plexiglass in order to slowly allow air back inside it. This will cause the altitude to decrease according to the AltimeterOne. The main e-match is expected to ignite at pressures corresponding to an altitude of 700' (or 500' for the StratoLoggerCF altimeter).
11. Download the flight data to a computer for analysis
12. Repeat all above two more times for a total of three trials for both altimeters.

Potential Impact of Results

If both altimeters pass this test, no action will be required to correct the performance of e-match ignition, and it can be expected that the altimeters will eject the parachutes with no issues during launch. If one or both altimeters fail this test, a complete retest will need to be conducted on the altimeter(s) that failed in order to determine and correct the issue, and new altimeters may be considered.

Test Data

Telemetrum Trial	Apogee Altitude (ft)	Drogue Ignition Altitude	Main Ignition Altitude (ft)

		(ft)	
1			
2			
3			
StratoLoggerCF Trial	Time Stamp (From Recorded Video) of TeleMetrum Drogue Ignition (s)	Time Stamp (From Recorded Video) of StratoLoggerCF Drogue Ignition (s)	Main Ignition Altitude (ft)
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 been completed yet. It is planned for early spring of 2024.			

<table>
<tr><td colspan="3">Verification Plan ID</td><td>Status</td><td>Verification Plan Title</td><td>Requirements Satisfied</td></tr>
<tr><td>VT</td><td>A</td><td>3</td><td>Incomplete</td><td>Black Powder Ejection Test</td><td>S.A.12, S.A.14, S.A.18</td></tr>
<tr><td colspan="6">Verification Plan Objective</td></tr>
<tr><td colspan="6">This test verifies that the amount of black powder will properly separate the airframe sections, that the parachutes will be completely protected on all sides, and will slide out easily during ejection.</td></tr>
<tr><td colspan="4">Success Criteria</td><td colspan="2">Dependent Variables</td></tr>
<tr><td colspan="4">Both the drogue and main black powder charges must separate their correct airframe sections the appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes.
-- Black powder canister on the upper side of the avionics bay to separate the payload section: ignition must result in at least 6’ of separation between the recovery section and the payload section for at least one amount of black powder equal to or greater than 2.5g.
-- Black powder canister on the lower side of the avionics bay to separate the booster section: ignition must result in at least 6’ of separation between the lower recovery section and the booster section for at least one amount of black powder equal to or greater than 1.5g.</td><td colspan="2">The dependent variables are the amount of separation on the ground between the correct airframe sections for both the drogue and main parachute sides, whether any vehicle components are damaged, and whether the parachutes are fully ejected from the airframe.</td></tr>
<tr><td colspan="4">Why is this necessary?</td><td colspan="2">Test Articles</td></tr>
<tr><td colspan="4">This test verifies that the amount of black powder will be appropriate to shear the pins and separate the airframe sections the appropriate amount on the ground, not damage any vehicle components, and fully eject the parachutes. This ensures the successful recovery of the vehicle and validates the choices of all of these components.</td><td colspan="2">Drogue and Main Ejection Systems</td></tr>
<tr><td colspan="6">Test Equipment and Methodology</td></tr>
</table>

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

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

Potential Impact of Results

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

Test Data

Black Powder Canister Side	Amount of Black Powder Used (g)	Distance Between the Two Sections	Damage to any vehicle components?	Parachute ejected?
Drogue				
Main				
Test Results				
Black Powder Canister Side	Pass/Fail			
Drogue				
Main				
Conclusions				
This test is planned for early spring of 2024.				

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	A	4	Complete	**Black Powder Ejection Proof of Concept**	S.A.18
Verification Plan Objective					
This test will act as a proof of concept for the gravity-aided deployment parachute mechanism. This test will verify that the black powder will create appropriate separation between the airframe sections, that the parachute will either leave the airframe or be loose enough for gravity deployment, and that the parachute will be completely protected on all sides.					
Success Criteria				**Dependent Variables**	
The black powder must separate the booster and recovery section at least 6', not damage any vehicle components, and either eject the parachute or be loose enough for gravity deployment.				The dependent variables are the amount of separation on the ground between the booster and recovery sections, whether or not any vehicle components are damaged, and whether or not the parachutes are fully ejected.	
Why is this necessary?				**Test Articles**	
This test verifies that this method of airframe pressurization and parachute deployment results in successful parachute deployment and will not damage any vehicle components.				Modified drogue recovery system	
Test Equipment and Methodology					

Test Equipment
Avionics bay, recovery section, booster section, PETG bulkplate, screws, shear pins, screwdriver set, hex wrench set, black powder, gram scale, paper cup, disposable latex gloves, small zip ties, e-matches, fireproof cellulose insulation, masking tape, 10’ wires, drogue parachute, Nomex blanket, 30’ shock cord, quick links, rubber mallet, remote detonator, measuring tape

Methodology
1. The black powder canister on the booster section side of the avionics bay was filled with 2g of black powder. This was done by measuring the black powder into a paper cup using a gram scale, then using a paper funnel to pour the black powder into the cut finger tip of a disposable latex glove. The end of an e-match was placed in the glove, and it was then zip-tied closed. The glove was placed into the charge well, and then packed with fireproof cellulose insulation. The top of the charge well was covered with masking tape to keep everything in place.
2. The other end of the e-match was connected to the terminal block on the avionics bay, and the 10’ extension wire was also connected to the other end of the terminal block.
3. The 30' shock cord was attached to the drogue parachute and its Nomex blanket via the middle quick link, as in flight orientation. The longer end of the shock cord was attached to the eyebolt on the PETG bulk plate on the booster section, and the shorter end of the shock cord was attached to the eyebolt on the lower side of the avionics bay.
4. The extension wire was threaded through the avionics bay switch hole for access outside of the vehicle, and then the remote detonator was connected to that extension wire.
5. All persons conducting the test stood 40’ away from the system and, and the one with the remote detonator set off the remote detonator. A count-down was conducted before ignition. The ejection charge was then expected to ignite and result in the separation of the two sections connected by shear pins.
6. If the airframes did not separate far enough or the parachute was not successfully deployed, the procedure was repeated using increasing amounts of black powder (in 0.5g increments) until 6’ of separation was achieved. This last amount of black powder was then recorded as the ideal amount of black powder.

Potential Impact of Results

If the black powder results in at least 6' of separation between the airframe sections and the parachute is ejected from the airframe, without any damage to vehicle components, then this test would be considered successful. If this test is successful, it verifies that a modified gravity-aided deployment with black powder will result in successful parachute deployment, and this method of deployment will be used for the full scale vehicle. If this test is not successful even after increases in black powder, more consideration will be put into the method of parachute deployment.

Test Data

Black Powder Canister Side	Amount of Black Powder Used (g)	Distance Between the Two Sections is Greater than 6'?	Damage to any vehicle components?	Parachute ejected?
Drogue	2	Yes	PETG bulkhead is slightly	Yes

			singed, otherwise all components are good	

Test Results	
Black Powder Canister Side	**Pass/Fail**
Drogue	PASS

Conclusions
This test was conducted on 12/13/2023. This method of deployment resulted in successful separation of the airframe sections and deployment of the parachute. The PETG pressurization bulkhead was able to pressurize the section, however it became singed and there are slight concerns over its reusability so alternative pressurization bulkplate materials are being considered. Otherwise, no vehicle components were damaged, so the test can be considered a success and the gravity-aided method should result in successful recovery events. Further testing with the full scale vehicle will be completed in early spring of 2024 to ensure the correct black powder amounts for the full scale vehicle.

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	A	5	In Progress	**Parachute Drop Test**	S.A.11
Verification Plan Objective					
This test verifies that the parachute will open consistently within an appropriate distance range or time frame to allow for full deployment after ejection.					
Success Criteria				**Dependent Variables**	
The parachute must fully deploy within their respective maximum parameter. - The elapsed time between the weight being dropped and the drogue parachute fully opening must be below 1.5 seconds for each trial. - The final drop distance estimate for the subscale and main parachute to fully open should be less than 150'				The dependent variables are the elapsed time between the weight being dropped and the parachute fully opening and the final estimate for the total drop distance required for the main parachute to open fully, including shock cord extension.	
Why is this necessary?				**Test Articles**	
This test verifies that the parachute is able to fully deploy within its respective maximum parameter in order to ensure the successful recovery of the vehicle and validate the choices of parachutes.				Subscale parachute, drogue parachute, main parachute	
Test Equipment and Methodology					

Test Equipment

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

Methodology

Testing:

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

Analysis:

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

Potential Impact of Results

If each parachute passes this test, no action will be required to correct the deployment performance, and it can be expected that the parachutes will deploy with no issues during launch. If a parachute fails this test, a

complete retest will need to be conducted on the parachute(s) that failed in order to determine and correct the issue, and new parachutes or packing methods may be considered.

Test Data			
Parachute	**Trial 1**	**Trial 2**	**Trial 3**
Subscale (36” diameter) Distance to open (not including extension of shock cord)	19'	20'	25'
Drogue (15” diameter) Distance to open (not including extension of shock cord)			
Main (120” diameter) Distance to open (not including extension of shock cord)			
Test Results (Data Analysis Not Shown)			
Parachute	**Trial 1**	**Trial 2**	**Trial 3**
Subscale	PASS	PASS	PASS
Drogue			
Main			
Conclusions			
The subscale parachute was tested on 11/16/2023. All trials resulted in the parachute fully deploying in less than 150', meeting the metric for successful test. The main and drogue parachutes will be tested in early spring of 2024.			

6.1.2 Construction

Verification Plan ID			**Status**	**Verification Plan Title**	**Requirements Satisfied**
VT	C	1	Complete	Fin Flutter Test	S.C. 16
Verification Plan Objective					
Satisfies requirement S.C.16: 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.					
Success Criteria				**Dependent Variables**	

Data collected from the test fin is sufficient to prove that fin flutter will not be a risk.	Vertical and angular displacement
Why is this necessary?	**Test Articles**
Fin flutter is a dangerous phenomenon that needs to be accounted for in high-powered rocketry. Though the geometry of the fins makes them more resistant to flutter than the large aspect ratios successfully utilized in previous years' competitions, quantifying the flutter serves to validate the integrity of the design.	Epoxacast 670 Proof of concept fin with a G10 fiberglass insert.
Methodology	
- Secure the fin by the root chord over the edge of a table - Apply 7lb to the tip and measure deflection - Attach a 12" 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	
Potential Impact of Results	
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.	
Test Data	
Vertical Displacement	.375"
Angular Displacement	~4°
Test Results (Data Analysis Not Shown)	
Fin Flutter Speed: 400 m/s (Analysis not shown)	
Conclusions	
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	Complete	Retention Load Test	S.P.3

Verification Plan Objective
Satisfies requirement S.P.3: The weight data collected from this test will ensure the tether being used to deploy the nose cone and SAIL will safely and correctly hold them with the launch vehicle.

Success Criteria	Dependent Variables
Amount of weight is well over the weight of the launch vehicle before breaking.	Tether strength
Why is this necessary?	**Test Articles**
The tether used will need to hold the necessary weight to not deploy too early or late. This is for safety reasons as deployment is only allowed if safe to do so.	Airframe and deployment system

Methodology
- Secure the mechanism being used - Add weight until the wire breaks or until no more weight can be added
Potential Impact of Results
If the tether is not able to hold the necessary amount of weight in order to deploy safely and in safe altitude, a different tether will need to be used.

Test Data	
Load withstood with no noticeable deformation	30 lbs

Conclusions
The deployment equipment designed will withstand the launch forces and safely retain the SAIL during flight.

<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>P</td><td>2</td><td>Complete</td><td>Deploy Latch Test</td><td>S.P.14</td></tr>
<tr><th colspan="6">Verification Plan Objective</th></tr>
<tr><td colspan="6">Satisfies requirement S.P.14: The data collected from this test will confirm the tether and latch being used is detaching properly and releasing the nose cone and SAIL in a suffect amount of time for a safe deployment.</td></tr>
<tr><th colspan="4">Success Criteria</th><th colspan="2">Dependent Variables</th></tr>
<tr><td colspan="4">Safely disengages the nose cone and SAIL without damaging payload bay components.</td><td colspan="2">SAIL deployment</td></tr>
<tr><th colspan="4">Why is this necessary?</th><th colspan="2">Test Articles</th></tr>
<tr><td colspan="4">To check that the tether does not get caught and ensure a safe deployment without breaking anything that could potentially damage the launch vehicle or harm bystanders.</td><td colspan="2">Airframe and deployment system</td></tr>
<tr><th colspan="6">Methodology</th></tr>
<tr><td colspan="6">- Set up the launch vehicle
- Wire in the nose cone and the payload bay
- Release the wire and ensure the nose cone and SAIL detach
- Repeat multiple times to ensure successful outcome</td></tr>
<tr><th colspan="6">Potential Impact of Results</th></tr>
<tr><td colspan="6">If the tether does not successfully detach the nose cone and SAIL or if the wire breaks another piece in the compartment, a different mechanism to release the nose cone and SAIL will need to be used.</td></tr>
<tr><th colspan="6">Test Data</th></tr>
<tr><td colspan="4">Consecutive Successful Ground Deployments</td><td colspan="2">5</td></tr>
<tr><td colspan="4">Ground Failures</td><td colspan="2">0</td></tr>
<tr><th colspan="6">Conclusions</th></tr>
</table>

The deployment equipment designed can reliably deploy the SAIL when triggered to do so.

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	P	3	Incomplete	SAIL Flight Test	S.P.7
Verification Plan Objective					
Satisfies requirement S.C.S.P.7: The data collected from this test will confirm that the quadcopter being used for the SAIL can accelerate the necessary 5 lbs and land with the desired velocity.					

Success Criteria	Dependent Variables
The quadcopter is able to decelerate the 5 lbs and land successfully.	SAIL flight
Why is this necessary?	**Test Articles**
To ensure a safe landing for the STEMnauts and prevent damage to the SAIL after deployment	SAIL quadcopter

Methodology
- Start the quadcopter wings in the closed position as they would be in the launch vehicle - Throw the quadcopter from a reasonable height, simulating its deployment from the launch vehicle - Start the rotors as would be during the flight - Land quadcopter - Repeat as necessary to ensure success
Potential Impact of Results
If the arms do not extend in a reasonable time or the rotors do not start in a reasonable time, a different concept for the SAIL will need to be used or the quadcopter will need to be placed in the payload bay differently.

Verification Plan ID			Status	Verification Plan Title	Requirements Satisfied
VT	P	4	Incomplete	SAIL Survivability Test	S.P.4

Verification Plan Objective
Satisfies requirement S.P.4: The acceleration data collected from this test will ensure the SAIL can withstand the forces of launch and decent pre-deployment.

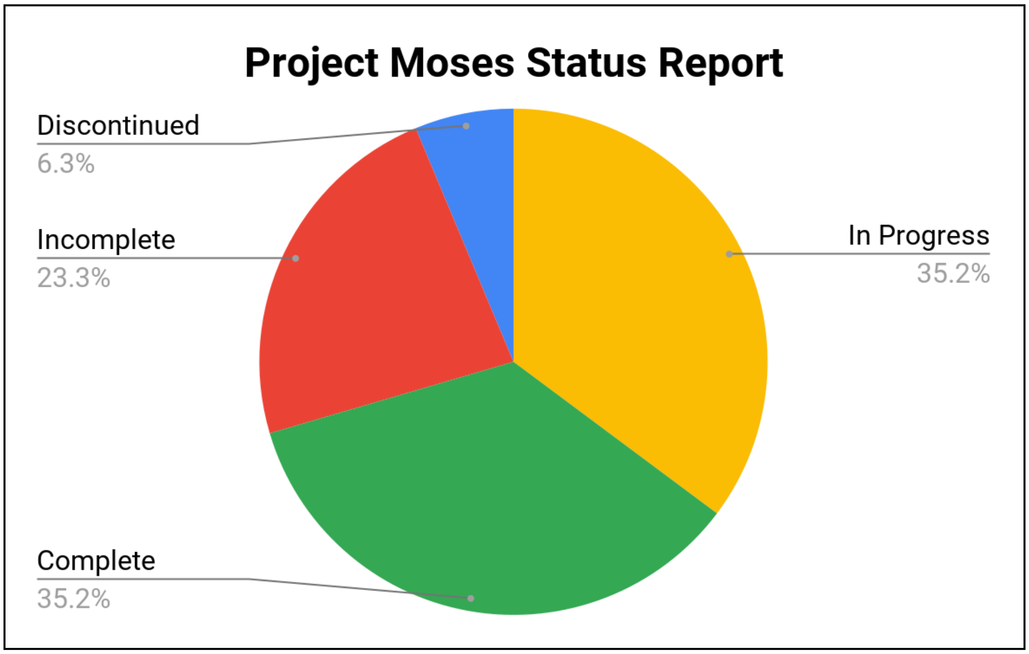
Success Criteria	**Dependent Variables**
Data collected from the test is sufficient to prove that the quadcopter can withstand launch forces.	SAIL structural integrity
Why is this necessary?	**Test Articles**
The quadcopter is required to withstand launch forces to ensure it can land undamaged.	SAIL quadcopter

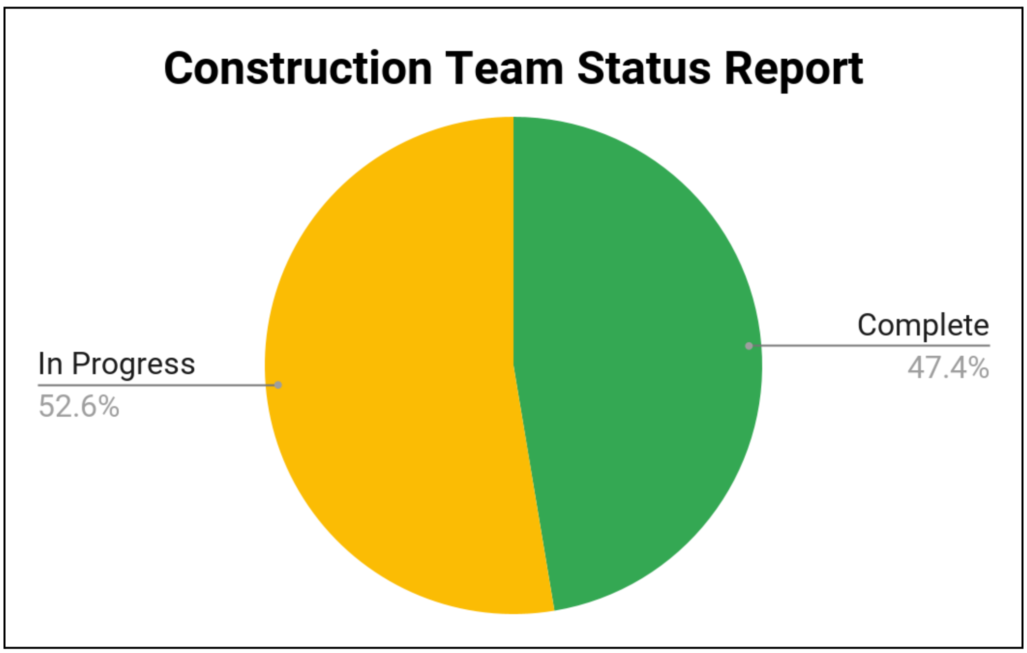
Methodology
- Determine maximum launch forces from flight data and multiply factor of safety - Calculate drop height required to simulate aforementioned forces - Drop-test the SAIL in the desired orientation from the calculated height to effectivity ground test the launch forces

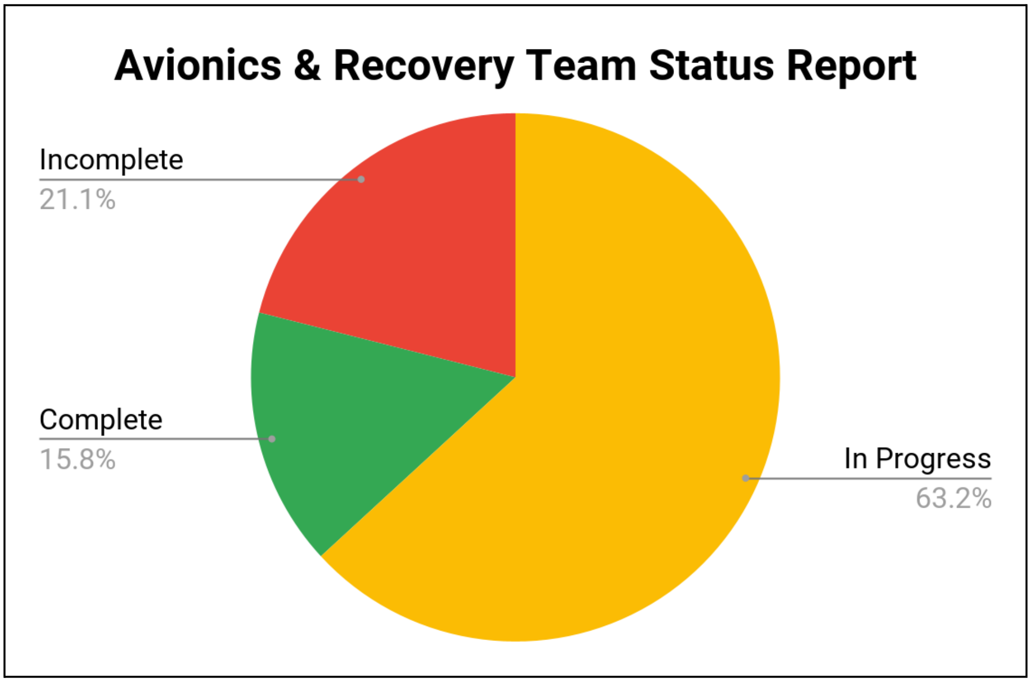
Potential Impact of Results
If the SAIL cannot maintain structural integrity within the requirements, redesign of problematic components must be undertaken to ensure the SAIL is not damaged in-flight.

6.2 Requirements Compliance

In order to meet all requirements set by NASA, our team has organized the criteria given in the NASA SL 2024 Handbook and derived our own team based requirements. All team based requirements are meant to either be subordinates to a NASA derived criteria, or are team level objectives. All requirements are labeled with an originator and are determined if they meet mission critical status. Additionally, the teams follow a verification type and are as follows: prerequisite, analysis, inspection, demonstration, and testing. Teams work to complete all requirements, with mission critical requirements at a top priority. As work progresses in the year, the status of each requirement is updated to be complete, in progress, incomplete, or discontinued. Completed work meets the requirement and is proved through the respective verification type. In-Progress status indicates work that is ongoing or has been completed and awaiting verification. Incomplete work is work that has not been started yet. Finally, requirements that the team has moved away from are considered discontinued. The status of the overall Project Moses and each of our technical teams, Construction, Avionics & Recovery, and Payload, are outlined in Figures 6.2.1 below.







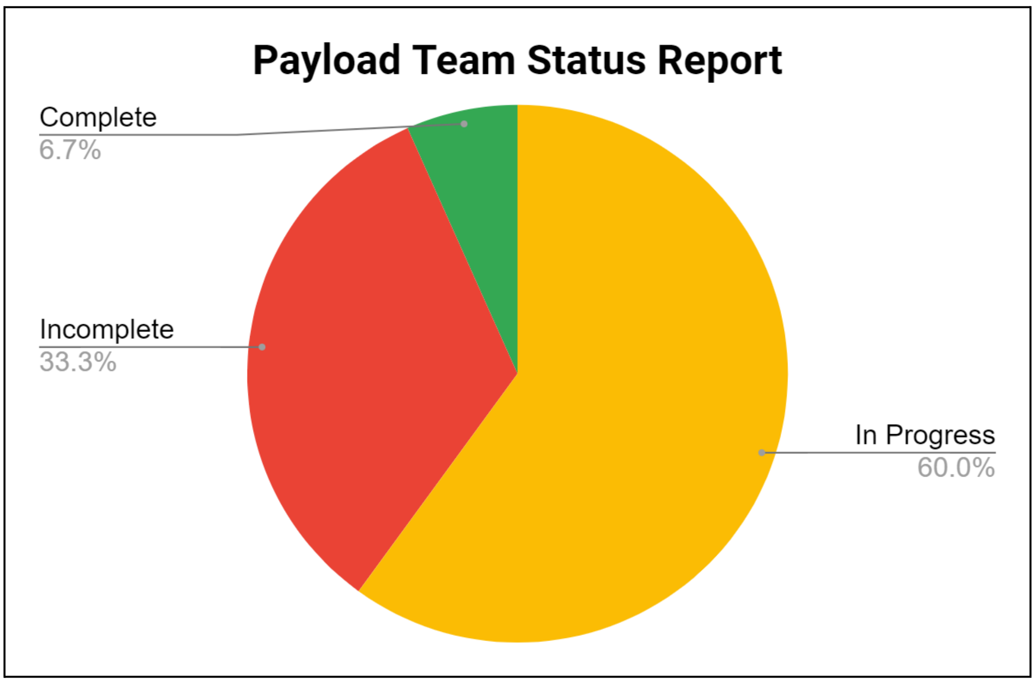


Figure 6.2.1: Overall project status including technical teams

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). Student team members shall only be a part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit penalties.		☐	☐	☑	☐	☐		
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.		☐	☐	☑	☐	☐		
G	1.3	☑	In Progress	NASA	Team members who will travel to the Huntsville Launch shall have fully completed registration in the NASA Gateway system before the roster deadline. Team members shall include:		☐	☐	☑	☐	☐		
G	1.3.1	☑	In Progress	NASA	Students actively engaged in the project throughout the entire year;		☑	☐	☐	☐	☐		
G	1.3.2	☑	Complete	NASA	One mentor (see Requirement 1.13);		☑	☐	☐	☐	☐		
G	1.3.3	☑	Complete	NASA	No more than two adult educators.		☑	☐	☐	☐	☐		
G	1.4	☑	In Progress	NASA	Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR addendum due date. A template of the STEM Engagement Activity Report can be found on pages 40 – 43.		☐	☐	☑	☐	☐		
G	1.5	☑	Complete	NASA	The team shall establish and maintain a social media presence to inform the public about team activities.		☐	☐	☑	☐	☐		
M	1.6	☑	In Progress	NASA	Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, FRR milestone documents will NOT be accepted. Teams that fail to submit the PDR, CDR, FRR milestone documents will be eliminated from the project.		☐	☐	☑	☐	☐		
M	1.7	☑	In Progress	NASA	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) will be provided action items needed to be completed following their review and will be required to address action items in a delta review session. After the delta session the NASA management panel will meet to determine the teams' status in the program and the teams will be notified shortly thereafter.		☐	☐	☑	☐	☐		
N	1.8	☑	In Progress	NASA	All deliverables shall be in PDF format.		☐	☐	☐	☑	☐		
N	1.9	☑	In Progress	NASA	In every report, teams will provide a table of contents including major sections and their respective subsections.		☐	☐	☐	☑	☐		
N	1.10.	☑	In Progress	NASA	In every report, the team shall include the page number at the bottom of the page.		☐	☐	☐	☑	☐		
G	1.11	☑	Complete	NASA	The team shall provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.		☐	☐	☑	☐	☐		
G	1.12	☑	Incomplete	NASA	All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 – 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.		☐	☐	☑	☑	☐		

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Label	ID	Mission Critical	Status	Originator	Requirement Summary	Req's Subordinate To	PR	A	D	I	T	Verification ID's or Prerequisites	Verification or Prerequisite Summary
G	1.13	☑	Complete	NASA	Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The team mentor shall not be a student team member. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 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.		☐	☐	☑	☐	☐		
G	1.14	☑	In Progress	NASA	Teams will track and report the number of hours spent working on each milestone.		☐	☑	☑	☐	☐		
C	2.1	☑	In Progress	NASA	The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.		☐	☑	☑	☐	☐		
G	2.2	☑	Complete	NASA	Teams shall declare their target altitude goal at the PDR milestone. The declared target altitude shall be used to determine the team's altitude score.		☐	☑	☐	☐	☐		
A	2.3	☑	Complete	NASA	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.		☐	☐	☑	☐	☑		
C	2.4	☑	Complete	NASA	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.		☐	☐	☑	☐	☐		
C	2.4.1	☑	Complete	NASA	Coupler/airframe shoulders which are located at in-flight separation points shall be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section).		☑	☐	☑	☐	☐		
C	2.4.2	☑	Complete	NASA	Coupler/airframe shoulders which are located at non-in-flight separation points shall be at least 1.5 airframe diameters in length. (0.75 body diameter of surface contact with each airframe section.		☑	☐	☑	☐	☐		
C	2.4.3	☑	Complete	NASA	Nosecone shoulders which are located at in-flight separation points shall be at least ½ body diameter in length.		☑	☐	☑	☐	☐		
G	2.5	☑	Complete	NASA	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.		☐	☐	☑	☐	☐		
G	2.6	☑	In Progress	NASA	The launch vehicle and payload shall be capable of remaining in launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.		☐	☐	☑	☑	☐		
G	2.7	☑	Complete	NASA	The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system. The firing system shall be provided by the NASA-designated launch services provider.		☐	☐	☑	☐	☐		
G	2.8	☑	Complete	NASA	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).		☐	☐	☑	☐	☐		
G	2.9	☑	Complete	NASA	Each team shall use commercially available ematches or igniters. Hand-dipped igniters shall not be permitted.		☐	☐	☑	☐	☐		
C	2.10.	☑	Complete	NASA	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).		☐	☐	☑	☐	☐		
C	2.10.1	☑	Complete	NASA	Final motor choice shall be declared by the Critical Design Review (CDR) milestone.		☑	☐	☐	☐	☐		
C	2.10.2	☑	Discontinued	NASA	Any motor change after CDR shall be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment shall not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.		☑	☐	☐	☐	☐		
C	2.11	☑	Complete	NASA	The launch vehicle shall be limited to a single motor propulsion system.		☐	☐	☑	☐	☐		

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C	2.12	☑	Complete	NASA	The total impulse provided by a College or University launch vehicle shall not exceed 5,120 Newton Seconds (L-class).		☐	☑	☑	☐	☐		
G	2.13	☑	Discontinued	NASA	Pressure vessels on the vehicle must be approved by the RSO and shall meet the following criteria:		☐	☐	☑	☐	☐		
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	2.13.2	☑	Discontinued	NASA	Each pressure vessel shall include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.		☑	☐	☑	☐	☐		
G	2.13.3	☑	Discontinued	NASA	The full pedigree of the tank shall be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.		☑	☐	☐	☑	☐		
G	2.14	☑	Complete	NASA	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.		☐	☑	☐	☐	☐		
G	2.15	☑	Complete	NASA	The launch vehicle shall have a minimum thrust to weight ratio of 5.0:1.0.		☐	☑	☑	☐	☐		
G	2.16	☑	Discontinued	NASA	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.		☐	☐	☑	☐	☐		
G	2.17	☑	In Progress	NASA	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.		☐	☐	☑	☐	☐		
G	2.18	☑	Complete	NASA	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).		☐	☑	☑	☑	☑		
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 shall not be used as the subscale model.		☑	☐	☑	☐	☑		
A	2.18.2	☑	Complete	NASA	The subscale model shall carry an altimeter capable of recording the model's apogee altitude		☑	☐	☑	☐	☐		
G	2.18.3	☑	Complete	NASA	The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.		☑	☐	☑	☐	☐		
G	2.18.4	☑	Complete	NASA	Proof of a successful flight shall be supplied in the CDR report.		☑	☐	☐	☑	☐		
A	2.18.4.1	☑	Complete	NASA	Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) will not be accepted.		☑	☑	☐	☐	☐		
G	2.18.4.2	☑	Complete	NASA	Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the CDR report. This includes but is not limited to nosecone, recovery system, airframe, and booster.		☑	☑	☐	☐	☐		
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.		☑	☐	☑	☑	☐		
G	2.19	☑	Incomplete	NASA	All teams shall complete demonstration flights as outlined below.		☐	☐	☐	☐	☐		
G	2.19.1	☑	Incomplete	NASA	Vehicle Demonstration Flight— All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (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	2.19.1.1	☑	Incomplete	NASA	The vehicle and recovery system shall have functioned as designed		☑	☐	☑	☐	☑		

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C	2.19.1.2	☑	Incomplete	NASA	The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.		☑	☐	☑	☐	☐		
P	2.19.1.3	☑	Incomplete	NASA	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:		☑	☐	☐	☑	☑		
P	2.19.1.3.1	☑	Incomplete	NASA	If the payload is not flown, mass simulators shall be used to simulate the payload mass.		☑	☐	☑	☐	☐		
P	2.19.1.3.2	☑	Incomplete	NASA	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.		☑	☐	☐	☑	☐		
P	2.19.1.4	☑	Discontinued	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	2.19.1.5	☑	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	2.19.1.6	☑	In Progress	NASA	The vehicle will be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast shall not be added without a re-flight of the full-scale launch vehicle.		☑	☐	☑	☐	☐		
G	2.19.1.7	☑	Incomplete	NASA	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).		☑	☐	☑	☑	☐		
G	2.19.1.8	☑	Incomplete	NASA	Proof of a successful flight shall be supplied in the FRR report.		☑	☐	☐	☑	☐		
A	2.19.1.8.1	☑	Incomplete	NASA	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted.		☑	☑	☐	☐	☐		
G	2.19.1.8.2	☑	Incomplete	NASA	Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes but is not limited to nosecone, recovery system, airframe, and booster.		☑	☑	☐	☐	☐		
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	2.19.2	☑	Incomplete	NASA	Payload Demonstration Flight— All teams shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:		☑	☑	☑	☑	☑		
P	2.19.2.1	☑	In Progress	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.		☑	☐	☑	☐	☐		
P	2.19.2.2	☑	Incomplete	NASA	The payload flown shall be the final, active version.		☑	☐	☑	☐	☑		
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	2.19.2.4	☑	Incomplete	NASA	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.		☑	☐	☑	☐	☐		
G	2.20.	☑	Incomplete	NASA	An FRR Addendum shall be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.		☐	☐	☑	☐	☐		

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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.		☑	☐	☐	☐	☐		
G	2.20.2	☑	Incomplete	NASA	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.		☑	☐	☐	☐	☐		
G	2.21	☑	In Progress	NASA	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.		☑	☐	☐	☑	☐		
G	2.22	☑	In Progress	NASA	All Lithium Polymer batteries shall be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.		☑	☐	☐	☑	☐		
G	2.23	☑	Complete	NASA	Vehicle Prohibitions		☐	☐	☐	☐	☐		
G	2.23.1	☑	Complete	NASA	The launch vehicle shall not utilize forward firing motors.		☑	☐	☑	☐	☐		
G	2.23.2	☑	Complete	NASA	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)		☑	☐	☑	☐	☐		
G	2.23.3	☑	Complete	NASA	The launch vehicle shall not utilize hybrid motors.		☑	☐	☑	☐	☐		
G	2.23.4	☑	Complete	NASA	The launch vehicle shall not utilize a cluster of motors.		☑	☐	☑	☐	☐		
G	2.23.5	☑	Complete	NASA	The launch vehicle shall not utilize friction fitting for motors.		☑	☐	☑	☐	☐		
G	2.23.6	☑	Complete	NASA	The launch vehicle shall not exceed Mach 1 at any point during flight.		☑	☑	☑	☐	☐		
G	2.23.7	☑	Complete	NASA	Vehicle ballast shall not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).		☑	☑	☐	☐	☐		
G	2.23.8	☑	Complete	NASA	Transmissions from onboard transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter).		☑	☐	☑	☐	☐		
G	2.23.9	☑	Complete	NASA	Transmitters shall not create excessive interference. Teams shall utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.		☑	☐	☑	☐	☐		
C	2.23.10	☑	Complete	NASA	Excessive and/or dense metal shall not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses		☑	☐	☑	☐	☐		
A	3.1	☑	In Progress	NASA	The full scale launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.		☐	☐	☑	☐	☐		
A	3.1.1	☑	In Progress	NASA	The main parachute shall be deployed no lower than 500 feet.		☑	☑	☐	☐	☐		
A	3.1.2	☑	In Progress	NASA	The apogee event shall contain a delay of no more than 2 seconds.		☑	☑	☐	☐	☐		
A	3.1.3	☑	Discontinued	NASA	Motor ejection is not a permissible form of primary or secondary deployment.		☑	☐	☑	☐	☐		
A	3.2	☑	In Progress	NASA	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.		☐	☑	☑	☐	☑		
A	3.3	☑	In Progress	NASA	Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by vehicle demonstration flight data, stays under 65 ft-lbf will be awarded bonus points.		☐	☑	☐	☐	☐		
A	3.4	☑	Complete	NASA	The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.		☐	☐	☑	☐	☐		
A	3.5	☑	Complete	NASA	Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.		☐	☐	☑	☐	☐		
A	3.6	☑	Complete	NASA	Each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.		☐	☐	☑	☐	☐		

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A	3.7	☑	Complete	NASA	Each arming switch shall be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).		☐	☐	☑	☐	☐		
A	3.8	☑	Complete	NASA	The recovery system, GPS and altimeters, electrical circuits shall be completely independent of any payload electrical circuits.		☐	☐	☑	☐	☐		
A	3.9	☑	Complete	NASA	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.		☐	☐	☑	☐	☐		
A	3.10.	☑	Discontinued	NASA	Bent eyebolts shall not be permitted in the recovery subsystem.		☐	☐	☐	☑	☐		
A	3.11	☑	In Progress	NASA	The recovery area shall be limited to a 2,500 ft. radius from the launch pads.		☐	☑	☑	☐	☐		
A	3.12	☑	In Progress	NASA	Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.		☐	☑	☐	☐	☐		
A	3.13	☑	Complete	NASA	An electronic GPS tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.		☐	☐	☑	☐	☐		
A	3.13.1	☑	In Progress	NASA	Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic GPS tracking device.		☑	☐	☑	☐	☐		
A	3.13.2	☑	In Progress	NASA	The electronic GPS tracking device(s) shall be fully functional during the official competition launch.		☑	☐	☑	☐	☐		
A	3.14	☑	In Progress	NASA	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).		☐	☐	☐	☑	☐		
A	3.14.1	☑	Complete	NASA	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.		☑	☐	☑	☐	☐		
A	3.14.2	☑	Complete	NASA	The recovery system electronics shall be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.		☑	☐	☑	☐	☐		
A	3.14.3	☑	Complete	NASA	The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.		☑	☐	☑	☐	☐		
A	3.14.4	☑	Complete	NASA	The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.		☑	☐	☑	☐	☐		
P	4.1	☑	In Progress	NASA	USLI Payload Mission objective: College/University Division — Teams shall design a STEMnauts Atmosphere Independent Lander (SAIL). SAIL is an in-air deployable payload capable of safely retaining and recovering a group of 4 STEMnauts in a unique predetermined orientation without the use of a parachute or streamer. The landing shall occur under acceptable descent and landing parameters for the safe recovery of human beings. A STEMnaut shall be defined as a non-living crew member, to be physically represented as the team chooses, and is assumed to have human astronaut survivability metrics. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to a proposed payload.		☐	☑	☑	☑	☑		
P	4.2	☑	In Progress	NASA	SAIL Mission Requirements		☐	☐	☐	☐	☐		
P	4.2.1	☑	Complete	NASA	Teams shall not use parachutes or streamers that are commercially available or custom made. A parachute is defined as an open-faced canopy whose primary function is to reduce descent speed or increase drag. A streamer is defined as a long, narrow strip of material (typically affixed at one end) whose primary function is to reduce descent speed or increase drag.		☑	☐	☑	☐	☐		
P	4.2.2	☑	In Progress	NASA	The SAIL shall be a minimum of 5 lbs inclusive of the jettisoned or separated landing capsule and the 4 STEMnauts.		☑	☑	☐	☐	☐		
P	4.2.3	☑	In Progress	NASA	Deployment of the SAIL shall occur between 400 and 800 feet AGL. See requirement 4.3.3 for deployment/jettison of payloads		☑	☑	☐	☐	☐		
P	4.2.3.1	☑	Discontinued	NASA	Chemical energetics will not be permitted below 500 feet AGL.		☑	☐	☑	☐	☐		
P	4.2.4	☑	In Progress	NASA	The team shall pre-determine and land in a unique landing orientation to be verified by NASA personnel in Huntsville or by a non-affiliated NAR/TRA rep for at-home launches.		☑	☑	☐	☐	☐		

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
P	4.2.5	☑	Complete	NASA	Teams shall design and implement a method of retention and ingress/egress for the STEMnauts.		☑	☐	☑	☐	☐		
P	4.2.6	☑	In Progress	NASA	Teams shall determine acceptable descent and landing parameters, to be approved by NASA, and design their lander to meet those requirements		☑	☑	☐	☐	☐		
P	4.2.6.1	☑	In Progress	NASA	Teams may, at their discretion, measure and verify the descent and landing parameters.		☑	☑	☐	☐	☐		
P	4.2.6.2	☑	In Progress	NASA	Teams shall at a minimum demonstrate and verify safe landing parameters as part of the Payload Demonstration Flight.		☑	☑	☐	☐	☐		
P	4.3	☑	In Progress	NASA	General Payload Requirements		☐	☐	☐	☐	☐		
P	4.3.1	☑	Complete	NASA	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.		☑	☐	☑	☐	☐		
P	4.3.2	☑	In Progress	NASA	Teams shall abide by all FAA and NAR rules and regulations.		☑	☐	☑	☐	☐		
P	4.3.3	☑	In Progress	NASA	Any payload experiment element that is jettisoned during the recovery phase shall receive realtime RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.		☑	☐	☑	☐	☐		
P	4.3.4	☑	In Progress	NASA	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.		☑	☐	☑	☐	☐		
P	4.3.5	☑	In Progress	NASA	Teams flying UASs shall abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs).		☑	☐	☑	☑	☐		
P	4.3.6	☑	In Progress	NASA	Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.		☑	☐	☑	☐	☐		
H	5.1	☑	In Progress	NASA	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.		☐	☐	☑	☑	☐		
H	5.2	☑	Complete	NASA	Each team shall identify a student safety officer who will be responsible for all items in Section 5.3.		☐	☐	☑	☐	☐		
H	5.3	☑	In Progress	NASA	The role and responsibilities of the safety officer shall include, but are not limited to:		☐	☐	☐	☐	☐		
H	5.3.1	☑	In Progress	NASA	Monitor team activities with an emphasis on safety during:		☑	☐	☐	☑	☐		
H	5.3.1.1	☑	Complete	NASA	Design of vehicle and payload		☑	☐	☐	☑	☐		
H	5.3.1.2	☑	In Progress	NASA	Construction of vehicle and payload components		☑	☐	☐	☑	☐		
H	5.3.1.3	☑	In Progress	NASA	Assembly of vehicle and payload		☑	☐	☐	☑	☐		
H	5.3.1.4	☑	In Progress	NASA	Ground testing of vehicle and payload		☑	☐	☐	☑	☐		
H	5.3.1.5	☑	Complete	NASA	Subscale launch test(s)		☑	☐	☐	☑	☐		
H	5.3.1.6	☑	In Progress	NASA	Full-scale launch test(s)		☑	☐	☐	☑	☐		
H	5.3.1.7	☑	Incomplete	NASA	Competition Launch		☑	☐	☐	☑	☐		
H	5.3.1.8	☑	In Progress	NASA	Recovery activities		☑	☐	☐	☑	☐		
H	5.3.1.9	☑	In Progress	NASA	STEM Engagement Activities		☑	☐	☐	☑	☐		
H	5.3.2	☑	Complete	NASA	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.		☑	☐	☐	☑	☐		
H	5.3.3	☑	In Progress	NASA	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data.		☑	☑	☑	☐	☐		
H	5.3.4	☑	In Progress	NASA	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.		☑	☐	☑	☐	☐		
G	5.4	☑	Incomplete	NASA	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams shall communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		☐	☐	☑	☐	☐		
G	5.5	☑	In Progress	NASA	Teams shall abide by all rules set forth by the FAA.		☐	☐	☑	☐	☐		
G	6.1	☑	Incomplete	NASA	NASA Launch Complex		☐	☐	☐	☐	☐		

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	6.1.1	☑	Incomplete	NASA	Teams are not permitted to show up at the NASA Launch Complex outside of launch day without permission from the NASA management team.		☑	☐	☑	☐	☐		
G	6.1.2	☑	Incomplete	NASA	Teams shall complete and pass the Launch Readiness Review conducted during Launch Week.		☑	☐	☑	☐	☐		
G	6.1.3	☑	Incomplete	NASA	The team mentor shall be present and oversee rocket preparation and launch activities.		☑	☐	☑	☐	☐		
G	6.1.4	☑	Incomplete	NASA	The scoring altimeter shall be presented to the NASA scoring official upon recovery.		☑	☐	☑	☐	☐		
G	6.1.5	☑	Incomplete	NASA	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch, will not be scored and will not be considered for awards.		☑	☐	☑	☐	☐		
G	6.2	☑	Incomplete	NASA	Commercial Spaceport Launch Site		☐	☐	☐	☐	☐		
G	6.2.1	☑	Incomplete	NASA	The launch shall occur at a NAR or TRA sanctioned and insured club launch. Exceptions may be approved for launch clubs who are not affiliated with NAR or TRA but provide their own insurance, such as the Friends of Amateur Rocketry. Approval for such exceptions shall be granted by NASA prior to the launch.		☑	☐	☑	☐	☐		
G	6.2.2	☑	Incomplete	NASA	Teams shall submit their rocket and payload to the launch site Range Safety Officer (RSO) prior to flying the rocket. The RSO shall inspect the rocket and payload for flightworthiness and determine if the project is approved for flight. The local RSO shall have final authority on whether the team's rocket and payload may be flown.		☑	☐	☑	☐	☐		
G	6.2.3	☑	Incomplete	NASA	The team mentor shall be present and oversee rocket preparation and launch activities.		☑	☐	☑	☐	☐		
G	6.2.4	☑	Incomplete	NASA	BOTH the team mentor and the Launch Control Officer shall observe the flight and report any offnominal events during ascent or recovery on the Launch Certification and Observations Report.		☑	☐	☑	☐	☐		
G	6.2.5	☑	Incomplete	NASA	The scoring altimeter shall be presented to BOTH the team's mentor and the Range Safety Officer		☑	☐	☑	☐	☐		
G	6.2.6	☑	Incomplete	NASA	The mentor, the Range Safety Officer, and the Launch Control Officer must be three separate individuals who must ALL complete the applicable sections of the Launch Certification and Observations Report. The Launch Certification and Observations Report document will be provided by NASA upon completion of the FRR milestone and shall be returned to NASA by the team mentor upon completion of the launch		☑	☐	☑	☐	☐		
G	6.2.7	☑	Incomplete	NASA	The Range Safety Officer and Launch Control Officer certifying the team's flight shall be impartial observers and shall not be affiliated with the team, individual team members, or the team's academic institution.		☑	☐	☑	☐	☐		
G	6.2.8	☑	Incomplete	NASA	Teams may launch only once. Any launch attempt resulting in the rocket exiting the launch pad, regardless of the success of the flight, will be considered a launch. Additional flights beyond the initial launch will not be scored and will not be considered for awards.		☑	☐	☑	☐	☐		

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	☑	Complete	Sara Fox	The vehicle shall maintain a minimum stability of 2.1cal throughout the flight	G.2.14	☐	☑	☐	☐	☐		The launch vehicle will be designed and analyzed with OpenRocket to verify a 2.0cal stability margin.
S.C	2	☐	In Progress	Sara Fox	The number of vehicle components that need to be repaired or replaced between flights shall be equal to 0 (not including the motor)		☐	☐	☐	☑	☐		Team will perform launch vehicle inspections no later than 24 hours after launch. The number of components that need to be repaired or replaced after a flight will be counted and reported.
S.C	3	☐	In Progress	Sara Fox	Each independent section of the launch vehicle shall have a maximum kinetic energy of 65 ft-lbf upon landing	A.3.3	☐	☑	☐	☐	☐		Team will gather velocity data from avionics to calculate the kinetic landing energy for each section upon descent.
S.C	4	☑	In Progress	Sara Fox	The recovery area shall be limited to a 2,500' radius from the launch pads.	A.3.11	☐	☐	☑	☑	☐		The selected launch field will have a minimum 2,500' radius from the launch pad. Drift distance will be calculated from altimeter data.
S.C	5	☐	In Progress	Sara Fox	Descent time of the launch shall be limited to 80 seconds.	A.3.12	☐	☑	☐	☐	☐		Team will analyze altimeter data to determine descent time.
S.C	6	☑	In Progress	Sara Fox	The number of recovery systems that deploy during flight shall be equal to the number of recovery systems onboard. The number of components damaged by deployment of recovery systems shall be equal to zero.	C.2.4	☐	☐	☑	☐	☐		Number of recovery systems deployed, number of components damaged by deployment of recovery systems
S.C	7	☐	In Progress	Sara Fox	The number of internal components damaged upon landing shall be equal to zero.		☐	☐	☐	☑	☐		The number of damaged internal components will be determined within 24 hours post-launch.
S.C	8	☑	In Progress	Sara Fox	All components shall withstand the forces of flight and recovery with a safety factor of at least 1.33.		☐	☑	☐	☐	☐		OpenRocket and Simulink simulations
S.C	9	☐	In Progress	Sara Fox	All components can be manufactured in house		☐	☐	☑	☑	☐		
S.C	10	☑	Complete	Sara Fox	Selected motor will utilize a total impulse that is a designated L-class or lower (5120 Ns)		☐	☑	☐	☑	☐		OpenRocket and Simulink simulations and inspection of motor parameters designated by manufacturer
S.C	11	☐	Complete	Sara Fox	Launch vehicle assembly will not require additional onsite component modification		☐	☐	☐	☑	☐		Tolerances of each component will be individually verified after each manufacturing process and integration will be verified for each sub-assembly
S.C	12	☑	Complete	Sara Fox	Nose cone camera bay does not significantly disturb launch vehicle profile		☐	☑	☐	☐	☐		Vehicle FEA and CFD analysis
S.C	13	☐	Complete	Sara Fox	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 overstrengthened components.
S.C	14	☐	In Progress	Sara Fox	Fins, MFSS, and motor can be easily inserted and removed from launch vehicle during integration	G.2.5	☐	☐	☐	☑	☐		Each design will be modular in nature and the use of adhesives (such as epoxy) to secure components will not be utilized. Friction fitting will also not be utilized.
S.C	15	☐	Complete	Sara Fox	Airframe modifications (screw holes and fin slits) are made with use of custom alignment aids		☐	☐	☑	☐	☐		Custom alignment aids will be created by team members for each section of the airframe
S.C	16	☑	Complete	Sara Fox	Fin design is strengthened to resist fin fluttering and improve reusability		☐	☑	☐	☐	☐		FEA and physical strength tests conducted on proof of concept fin. Theoretical analysis done to supplement results.
S.C	17	☐	In Progress	Sara Fox	All fins are consistent in casting process and launch vehicle alignment		☐	☐	☐	☑	☐		Precise measuring equipment and consistancy focused manufacturing methods chosen
S.C	18	☐	Complete	Sara Fox	Subscale launch vehicle mimics the geometry of the full scale launch vehicle design	G.2.18.1 , C.2.18.5	☐	☐	☐	☑	☐		OpenRocket modeling and visual inspection to verify geometric similarities
S.C	19	☑	Complete	Sara Fox	Couplers will be designed in accordance with NASA guidelines		☐	☑	☐	☑	☐		OpenRocket and SolidWorks modeling

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	Camille DeMange	Altimeter batteries will be tested for possible extreme ranges for temperature to ensure functionality for all possible launch conditions.		☐	☐	☐	☐	☑		The Altimeter Continuity and Battery Drain Test will test the batteries in temperatures ranging from 35-75°F, to ensure the batteries function at the minimum and maximum likely launch temperatures.
S.A	2	☑	In Progress	Camille DeMange	Altimeter batteries will function for the entirety of the flight and will result in successful altimeter performance.		☐	☐	☐	☐	☑		The Altimeter Continuity and Battery Drain Test will test the continuity of the altimeters for a minimum of 3 hours. The continuity beeps will be checked every 30 minutes an will show that continuity will be established and maintained throughout the flight.
S.A	3	☑	In Progress	Camille DeMange	Altimeter batteries will supply usable voltage for a minimum of 3 hours.	G.2.6	☐	☐	☐	☐	☑		The Altimeter Continuity and Battery Drain Test will test the continuity of the altimeters for a minimum of 3 hours. Battery voltage will be checked every 30 minutes to ensure usable voltage throughout.
S.A	4	☑	Complete	Camille DeMange	The altimeter batteries will be shielded in order to prevent damage in the case of ballistic impact.		☐	☐	☑	☑	☐		The batteries will be protected by a 3D printed battery guard to protect from ground impact.
S.A	5	☑	Complete	Camille DeMange	The altimeter batteries and ejection system will only be disarmed by the switch. Flight forces will not be able to disengage the system.	A.3.6, A.3.7	☐	☐	☑	☑	☐		The subscale flight will test that flight forces cannot disengage the switch. The team will also inspect the avionics coupler prior to all launches to ensure proper set-up of the system.
S.A	6	☑	In Progress	Camille DeMange	Altimeter continuity will be established at the launch pad and maintained throughout flight.		☐	☐	☐	☐	☑		The Altimeter Continuity and Battery Drain Test will test the continuity of the altimeters for a minimum of 3 hours. This will show that continuity will be established and maintained throughout the flight.
S.A	7	☐	In Progress	Camille DeMange	Descent time of the launch vehicle shall be less than 80s, including both scenarios of the payload ejecting and not ejecting.	A.3.12	☐	☑	☐	☐	☐		Descent time will be simulated both in OpenRocket and Simulink and will be recorded and verified during launches.
S.A	8	☐	In Progress	Camille DeMange	Landing kinetic energy of the heaviest section of the launch vehicle shall be less than 65 ft-lbf, including both scenarios of the payload ejecting and not ejecting.	A.3.3	☐	☑	☐	☐	☐		Impact velocity will be simulated both in OpenRocket and Simulink and used to calculate landing KE. Impact velocity will also be recorded to calculate landing KE in launches to verify this.
S.A	9	☑	In Progress	Camille DeMange	The descent velocity for the drogue parachute shall be within range for a safe opening of the main parachute.		☐	☑	☐	☐	☐		The drogue descent velocity should be calculated and simulated to be less than 150 ft/s in OpenRocket and Simulink. This will be verified during launches.
S.A	10	☑	In Progress	Camille DeMange	All avionics components will be secured during flight and landing.		☐	☐	☐	☑	☐		Prior to launch the team will inspect the avionics coupler to ensure they are secure.
S.A	11	☑	In Progress	Camille DeMange	The recovery system components shall be strong enough to withstand shockloads during launch, parachute deployment, and landing.		☐	☐	☑	☑	☐		Prior to launch the team will inspect the avionics coupler to ensure they are secure. The subscale flight will also test the strength and that the components will remain in place.
S.A	12	☑	Incomplete	Camille DeMange	Parachutes shall be shielded from the heat from the black powder charges.		☐	☐	☐	☑	☑		The Black Powder Ejection Test will verify that the heat shielding used, Nomex blanket, will protect the parachutes from the ejection charges. Prior to launch, the team will inspect the parachutes to ensure they are properly wrapped in the Nomex blankets.
S.A	13	☑	In Progress	Camille DeMange	Shock cords will be of adequate length and strength.		☐	☐	☑	☐	☐		The shock cords will be at least 50' and 30' for the main and drogue parachutes.
S.A	14	☑	Incomplete	Camille DeMange	Parachutes shall be packed in a way to ensure full deployment.		☐	☐	☐	☑	☑		The Black Powder Ejection Test will verify that the parachutes are fully ejected when the launch vehicle separates. Prior to launch, the team will also inspect the parachutes to ensure correct the packing method was used.
S.A	15	☑	In Progress	Camille DeMange	Shock cords shall be tied to prevent mid-air collisions between sections of the launch vehicle.		☐	☐	☑	☑	☐		Shock cords will be tied unaligned to prevent mid-air collisions. Prior to launch the team will inspect the shock cords to confirm this. Subscale can be used to verify that this method prevents mid-air collisions.
S.A	16	☑	In Progress	Camille DeMange	Shock cords will be folded when stored to minimize shock at deployment and to prevent tangling.		☐	☐	☐	☑	☐		Prior to launch, the team will verify that the shock cords are folded in a z-fold configuration.
S.A	17	☑	In Progress	Camille DeMange	Parachutes will be properly sized to ensure safe deployment and landing for the launch vehicle.	A.2.3	☐	☑	☑	☐	☐		Preliminary analysis and calculations combined with the simulation tools of OpenRocket and Simulink will allow the team to find the correct size for the drogue and main parachutes for safe descent and landing. The subscale launch will provide a smaller scale verification of this.
S.A	18	☑	Incomplete	Camille DeMange	Black powder will be used to separate the airframe sections.		☐	☐	☐	☐	☑		To calculate the sizes of the ejection charges, analysis will be done to ensure they will achieve vehicle section separation. The Black Powder Ejection Test will verify that the airframe separates at least 6' between independent sections.
S.A	19	☑	Incomplete	Camille DeMange	The altimeters will read the correct altitude and deploy the parachutes at the correct times.	A.2.18.2, A.2.18.4.1, A.2.19.1.8.1	☐	☐	☐	☐	☑		The Altimeter Ejection Vacuum Test will simulate the ascent of the launch vehicle. It will test that the altimeters can deploy the parachutes at the correct times by igniting the ematches at the detected apogee (primary)+2s delay (redundant) and 700' AGL (primary) +500' AGL (redundant).
S.A	20	☐	Complete	Camille DeMange	The avionics bay shall be easily accessible and assemblable.		☐	☐	☑	☑	☐		The avionics sled will be designed with ease of assembly in mind. The team will inspect the avionics bay to ensure it is easily accessible.

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	☑	In Progress	Gabriel Kurfman	The chosen payload design must be deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	P.4.3.2	☐	☑	☐	☐	☐		Regular design reviews of the payload system will be held to confirm safety and legal compliance.
S.P	2	☑	In Progress	Gabriel Kurfman	All payload electronic components shall be capable of withstanding launchpad conditions for a minimum of 3 hours.	G.2.5	☐	☐	☐	☐	☑		The SAIL and payload bay will be subject to a simulated launchpad test in conditions up to 100°F will be run for 3 hours before confirming that the electronic components are able to function as intended.
S.P	3	☑	In Progress	Gabriel Kurfman	The SAIL retention & deployment mechanism shall reliably prevent unscheduled jettisoning when subjected to conditions up to twice that of flight forces.	P.2.19.2.1	☐	☑	☐	☐	☑		The payload bay retention mechanism will be subject to a simulated flight force test with forces twice that of what is predicted to ensure retention at those conditions.
S.P	4	☐	Incomplete	Gabriel Kurfman	The SAIL shall be designed to prevent damage when subjected to launch forces.		☐	☑	☐	☐	☐		The SAIL will be subject to a simulated flight force test to ensure mechanical soundness at those conditions.
S.P	5	☐	In Progress	Gabriel Kurfman	The SAIL shall attain an autonomously stable or actively controlled state while airborne after deployment from the launch vehicle.		☐	☐	☑	☐	☐		The SAIL will be subject to drop tests to simulate deployment from the launch vehicle and expected to perform in-flight stabilization.
S.P	6	☐	In Progress	Gabriel Kurfman	The SAIL shall absorb sufficient energy upon touchdown to prevent damage to onboard components.		☐	☑	☑	☐	☐		The SAIL will be subject to drop tests to simulate landing and expected to maintain mechanical soundness.
S.P	7	☐	Incomplete	Gabriel Kurfman	The SAIL shall land with a maximum vertical velocity of 6.8 m/s.	P.4.1	☐	☑	☐	☐	☐		The SAIL will be subject to drop tests to simulate deployment from the launch vehicle and expected to land under the maximum velocity, as verified by the onboard telemetry sensors.
S.P	8	☐	Incomplete	Gabriel Kurfman	The SAIL shall not exceed the acceptable translational acceleration limits	P.4.1	☐	☑	☐	☐	☐		The SAIL will be subject to drop tests to simulate deployment from the launch vehicle and expected to remain within acceleration bounds, as verified by the onboard telemetry sensors.
S.P	9	☐	Incomplete	Gabriel Kurfman	The SAIL shall not expose the STEMnauts to excessive rotational velocities in the yaw, pitch, and roll axes.	P.4.1	☐	☑	☐	☐	☐		The SAIL will be subject to drop tests to simulate deployment from the launch vehicle and expected to remain within rotational velocity bounds,as verified by the onboard telemetry sensors.
S.P	10	☐	In Progress	Gabriel Kurfman	All payload software shall 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	11	☐	In Progress	Gabriel Kurfman	Onboard transmissions from the SAIL and payload bay must not exceed 250mW.		☐	☑	☐	☐	☐		The team will select a transmitter that will not output power over 250mW.
S.P	12	☐	In Progress	Gabriel Kurfman	The weight of the SAIL and components inside the payload bay shall not exceed 7.5 pounds.		☐	☐	☐	☐	☑		The team shall accound for mass during the CAD development stage and individual part will be weighed before launch vehicle integration.
S.P	13	☐	In Progress	Gabriel Kurfman	The SAIL and payload bay components shall be intuitive to disassemble and reassemble, and a full disassembly - reassembly process shall take no more than twenty (20) minutes.		☐	☐	☑	☐	☐		Comprehensive assembly instructions will be created and a full disassembly - assembly process will be timed to ensure compliance.
S.P	14	☐	Complete	Gabriel Kurfman	The SAIL retention & deployment mechanism shall reliably release the SAIL within 0.5 seconds of all factors being met.								The depoloyment system will be repeatedly triggered in test mode to ensure reliable release of the SAIL.
S.P	15	☐	Incomplete	Gabriel Kurfman	The SAIL deployment mechanism shall not jettison until RSO permission has been recieved.	P.4.3.3	☐	☐	☐	☐	☐		The deployment system will be designed with a radio reciever to relay RSO permission to the onboard electronics.

6.3 Budgeting and Timeline

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 below.

Table 6.3.1: Updated Line Item Budget Summary

SUMMARY		
SUBTEAM	ESTIMATED COSTS	COSTS TO DATE
Avionics and Recovery	$(879.15)	$(236.08)
Construction	$(3,012.44)	$(2,782.98)
Payload	$(1,193.77)	$(596.78)
Project Management	$(5,567.25)	$(3,408.86)
	TOTAL ESTIMATED COSTS	$(10,652.61)
	TOTAL COSTS TO DATE	$(7,024.70)
	TOTAL ESTIMATED BUDGET	$14,159.58
	BUDGET TO DATE	$9,459.58
	ESTIMATED REMAINING BALANCE	$3,506.97
	CURRENT REMAINING BALANCE	$2,434.88

Table 6.3.2: Updated Income Summary

INCOME		
Category	Projected Amount	Current Amount
SOGA Grant	2,500.00	2,500.00
BOSO Account	1,809.58	1,809.58

General PSP Funding	2,250.00	2,250.00
SPARK Challenge Award	1,600.00	1,600.00
PEPC Grant	300.00	300.00
L3Harris Grant	1,000.00	1,000.00
AAE Department	1,500.00	0.00
ECE Department	2,000.00	0.00
Local Funding	1,000.00	0.00
PESC (Spring Cycle)	500.00	0.00
	PROJECTED TOTAL	14,459.58
	CURRENT TOTAL	9,459.58

Table 6.3.3: Updated Expenses Summary

EXPENSES					
Item	Vendor	Item Cost	Added Fees	Estimated Item Total	Actual Item Total
AVIONICS AND RECOVERY					
Shear Pins	Apogee Rockets	19.11	7.42	26.53	26.53
Altimeter Mount	Apogee Rockets	12.06	5.14	17.20	17.20
Ematches	MJG Technologies	56.80	13.72	70.52	70.52
Subscale Parachute	Fruit Chutes	105.18	16.65	121.83	121.83
Main Parachute	Rocketman	315.00	22.05	337.05	0.00
Drogue Parachute	Fruity Chutes	59.26	4.15	63.41	0.00
Lipo Battery	Amazon	7.99	0.56	8.55	0.00

4-40 Nylon Pins	Amazon	7.16	0.50	7.66	0.00
Charge Wells	Rocket Junkies	35.80	4.00	39.80	0.00
Heat Set Inserts	Amazon	9.79	0.69	10.48	0.00
Cable Sleeve	Amazon	7.63	0.53	8.16	0.00
Flux	Amazon	7.99	0.56	8.55	0.00
JST Connectors	Amazon	6.99	0.49	7.48	0.00
9V Batteries	Walmart	12.59	0.88	13.47	0.00
50’ Shock Cord	OneBadHaw k	80.00	5.60	85.60	0.00
Wagos Connectors	Amazon	19.95	1.40	21.35	0.00
¼” Eye Bolts	Amazon	6.97	0.49	7.46	0.00
Key Switches	AliExpress	17.99	6.07	24.06	0.00
				ESTIMATED TOTAL	**879.15**
				CURRENT TOTAL	**236.08**
CONSTRUCTION					
Fullscale Motors	Loki Research	1,990.00	99.62	2,089.62	2,089.62
EpoxAcast	Smooth-On	56.19	30.87	87.06	87.06
G10 FR4 ⅛ Inch Sheet	Composite Warehouse	102.00	0.00	102.00	102.00
3 Inch G12 Fiberglass Tube	Composite Warehouse	78.00	0.00	78.00	78.00
3 Inch G12 Fiberglass Coupler Tube	Composite Warehouse	30.00	0.00	30.00	30.00
3 Inch Av-Bay Lid	Composite Warehouse	20.00	0.00	20.00	20.00

Subscale Motor	Apogee Rockets	69.54	78.12	147.66	147.66
Motor Tube and Retainer Ring	Apogee Rockets	38.89	51.09	89.98	89.98
3D Printing Components	Purdue BIDC	25.00	1.63	26.63	0.00
General Fasteners	McMaster-Carr	150.00	52.83	202.83	0.00
Glue, Brushes, Spray Paint	Menards	55.35	3.89	59.42	59.42
Rosin Rolder	Walmart	19.84	1.39	21.23	21.23
Hex Nutes	Menards	2.94	0.21	3.15	3.15
Socket	Menards	1.39	0.10	1.49	1.49
Electrical Tape, Cutting Kit, Hex Nuts	Menards	39.31	2.75	42.06	42.06
Frog Tape and Screws	Menards	10.57	0.74	11.31	11.31
				ESTIMATED TOTAL	**3,012.44**
				CURRENT TOTAL	**2,782.98**
PAYLOAD					
OLED Graphic Display	Adafruit	19.95	12.97	32.92	32.92
Telemetrum	Christ Rocket Supplies	300.00	6.92	306.92	306.92
Pin Header Componenets, PCB Panel Mount, Push Button Switch, PCB Board	Amazon	70.14	15.50	85.64	85.64

Accelerometer and Gyroscope	Amazon	20.22	8.14	28.36	28.36
Screws and Hex Nuts	McMaster-Carr	45.61	20.24	65.85	65.85
Hardboard, Dish Foam Roll, Super Glue, Polycarbonate Lexan, Storage Bin	Home Depot	56.07	3.92	59.99	59.99
Lithium Polymer Battery and Connectors	Steve's Hobby World	15.98	1.12	17.10	17.10
Micro Antenna	Amazon	17.47	1.11	18.69	0.00
Quadcoptor Components	GetFPV	450.08	31.51	481.59	0.00
Camera	Amazon	30.38	2.13	32.51	0.00
SAIL Hardware	Amazon	129.21	9.04	138.25	0.00
SAIL Lipo Battery	Amazon	60.00	4.20	64.20	0.00
SAIL Manufacturing Materials	Amazon	20.00	1.40	21.40	0.00
				ESTIMATED TOTAL	**1,353.42**
				CURRENT TOAL	**596.78**
PROJECT MANAGEMENT					
Huntsville Hotel Rooms	Comfort Suite Inn	2,490.85	413.60	2,904.45	2,904.45
Team Lunch	Papa Johns	129.22	9.05	138.27	138.27
Team Event	Union Rack and Roll	240.00	0.00	240.00	240.00
Safety Equipment	Menards	97.91	6.85	104.76	104.76

(Masks, Gloves, First Aid Kit)					
Safety Equipment (Lipo-Safe Bag, Anti-Static Bag)	Amazon	19.98	1.40	21.38	21.38
Huntsville Travel Expenses	N/A	1,995.46	162.93	2,158.39	0.00
				ESTIMATED TOTAL	**5,567.25**
				CURRENT TOTAL	**3,408.86**

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. With the continued difficulty in department funding , more time is being spent exploring grant-based funding. There are several grants available to Purdue student organizations on a semester basis. These programs, similar to the PEPC grant, will become available in January 2023.

The allocation of these funds and the plan to coordinate material acquisition has also changed slightly. A table giving the overall budget allocation has been provided below. This is now based on an overall budget of $15,000, with the distribution between each area of the project changing slightly to accommodate for purchase estimations greater than anticipated.

Table 6.3.4: Projected Budget Allocation

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)	5,000.00
Outreach	1,000.00
TOTAL BUDGET	**$15,000.00**

6.3.3 Timeline

Below is the updated table of deadlines and team meetings as listed out on the team calendar. This is the team's most top-level schedule, only highlighting the external competition deadlines along with general team meetings and school institution deadlines. Q&A sessions are highlighted in green, competition milestone deadlines are highlighted in red, important school dates are highlighted in orange, and the competition date in Huntsville is highlighted in yellow. Milestones are crossed off as the date passes to better visualize progression through the competition.

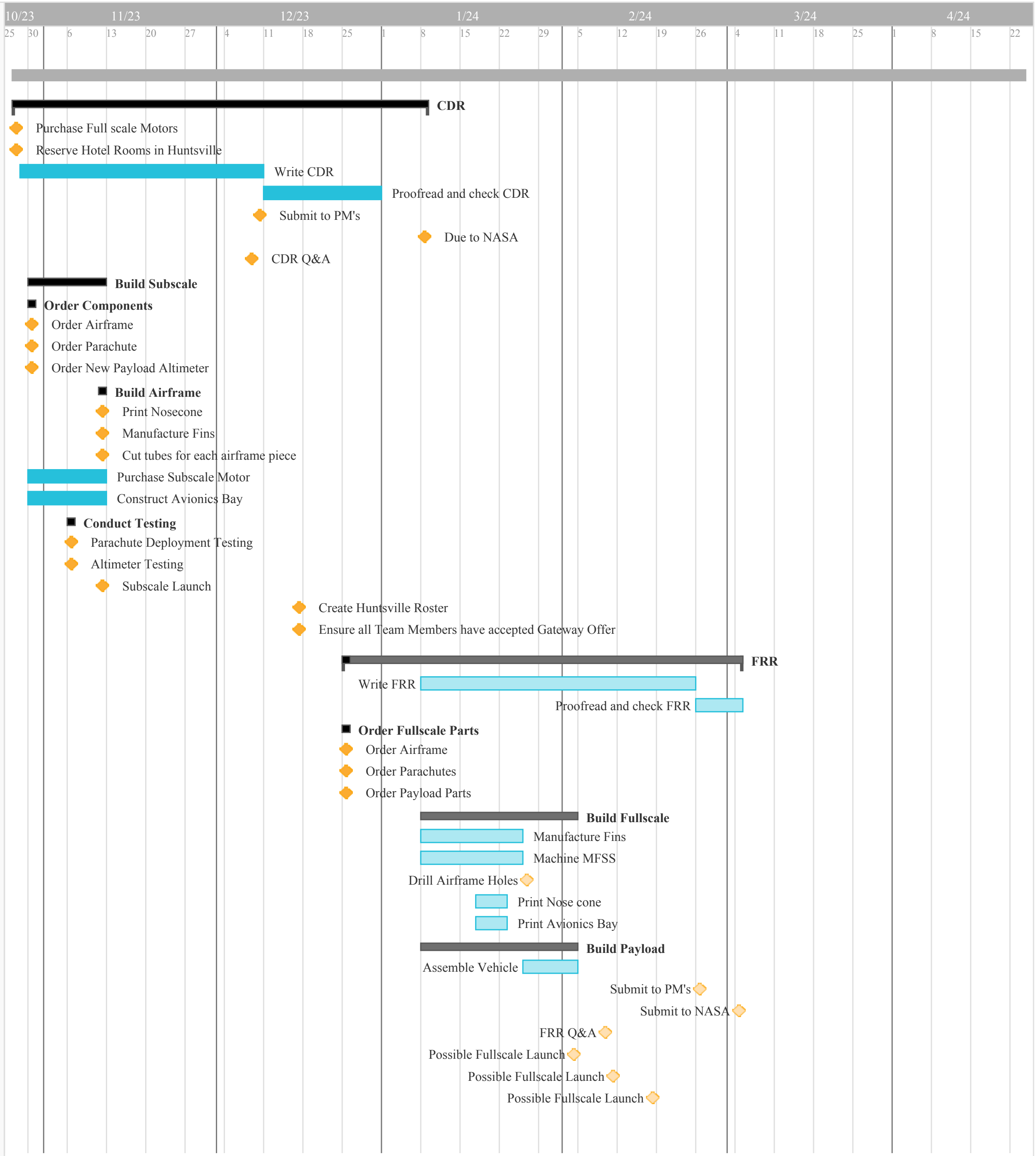
Table 6.3.5: Table of Deadlines and Meetings

Date	Event	Date	Event
~~8/15/2023~~	~~First Leads meeting~~	~~9/1/2023~~	~~Club Callout~~
~~9/10/2023~~	~~General Team Meeting~~	~~9/11/2023~~	~~Proposal Due to NASA~~
~~9/17/2023~~	~~General Team Meeting~~	~~9/24/2023~~	~~General Team Meeting~~
~~10/1/2023~~	~~General Team Meeting~~	~~10/4/2023~~	~~PDR Q&A~~
~~10/15/2023~~	~~General Team Meeting~~	~~10/16/2023~~	~~PDR Due to Project Management for Review~~
~~10/22/2023~~	~~General Team Meeting~~	~~10/26/2023~~	~~PDR Due to NASA~~
~~10/28/2023~~	~~Purdue Space Day~~	~~10/29/2023~~	~~General Team Meeting~~
~~11/4/2023~~	~~Potential Subscale Launch Date~~	~~11/5/2023~~	~~General Team Meeting~~
~~11/11/2023~~	~~Potential Subscale Launch Date~~	~~11/12/2023~~	~~General Team Meeting~~
~~11/18/2023~~	~~Final Potential Subscale Launch Date~~	~~11/19/2023~~	~~General Team Meeting~~
~~11/22/2023 - 11/26/2023~~	~~Thanksgiving Break~~	~~12/3/2023~~	~~General Team Meeting~~
~~12/7/2024~~	~~CDR Q&A~~	~~12/8/2023~~	~~CDR Due to Project Management for Review~~

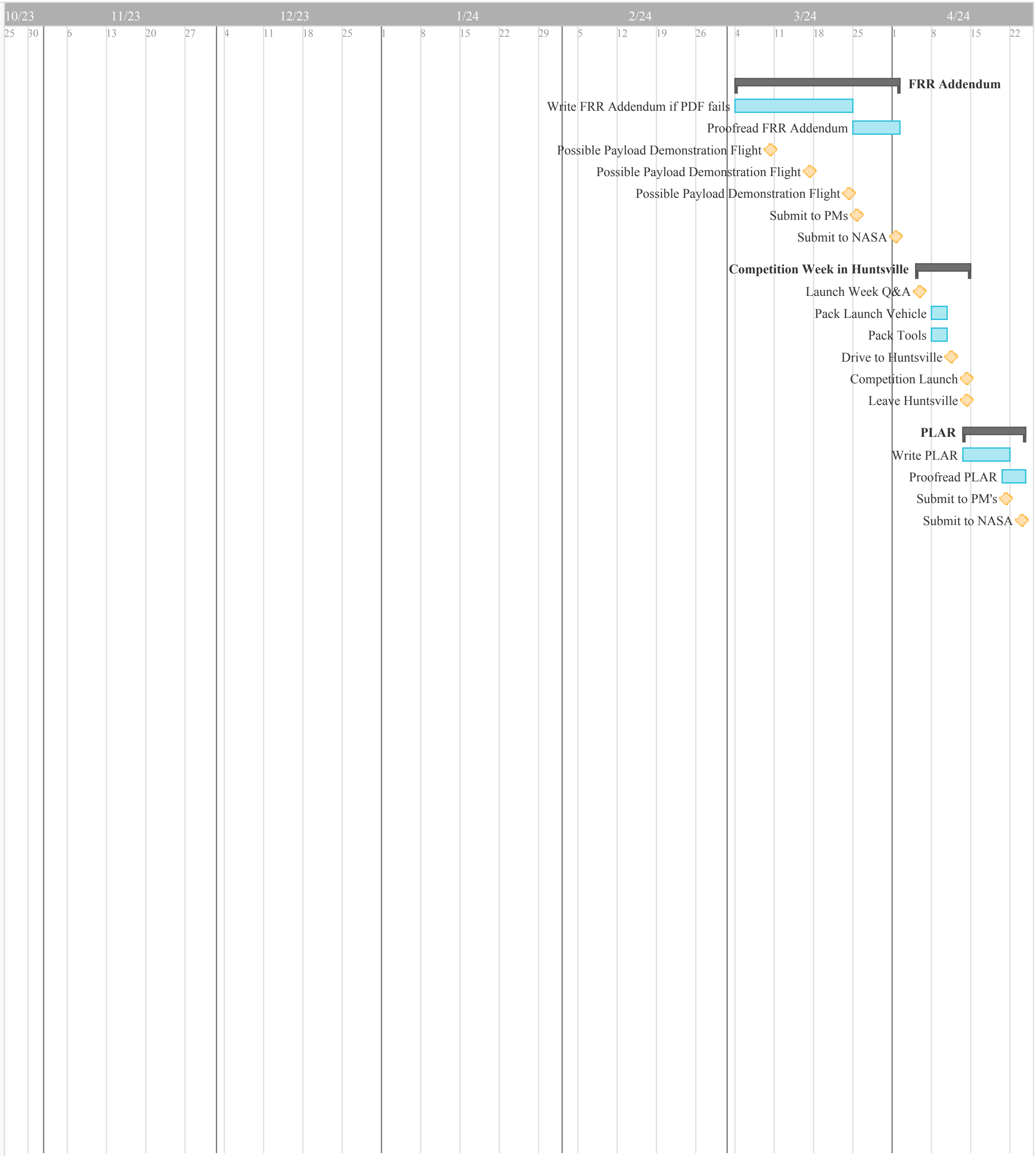
~~12/15/2023~~	~~End of Fall Semester~~	~~12/15/2023 — 1/8/2024~~	~~Winter Break~~
~~1/8/2024~~	~~CDR Due to NASA~~	1/8/2024	First Day of Spring Semester
1/14/2024	General Team Meeting	1/21/2024	General Team Meeting
1/28/2024	General Team Meeting	2/3/2024	VDF
2/4/2024	General Team Meeting	2/8/2024	FRR Q&A
2/10/2024	Backup VDF	2/11/2024	General Team Meeting
2/17/2024	Backup VDF	2/18/2024	General Team Meeting
2/25/2024	General Team Meeting	2/26/2024	FRR to Project Management for Review
3/3/2024	General Team Meeting	3/4/2024	FRR Due to NASA
3/9/2024	PDF	3/10/2024	General Team Meeting
3/16/2024	Backup PDF	3/17/2024	General Team Meeting
3/23/2024	Backup PDF	3/24/2024	General Team Meeting
3/25/2024	FRR Addendum Due to Project Management for Review	3/31/2024	General Team Meeting
4/1/2024	FRR Addendum Due to NASA	4/4/2024	Launch Week Q&A
4/7/2024	General Team Meeting	4/10/2024 - 4/14/2024	Launch Week Activities in Huntsville Alabama
4/19/2024	PLAR Due to Project Management for Review	4/21/2024	General Team Meeting
4/23/2024	PLAR Due to NASA	4/28/2024	Team Elections / End of Year Wrap Up Meeting

Secondary to the above table, project management has developed a low-level Gantt Chart and Jira page with more specific deadlines for the team to follow. Effort has been taken to ensure that the suppliers chosen have a high confidence level of delivering on time and quality materials. In tandem with the team Gantt Chart, the team has a Jira page which is used to assign and track task completion for all items on the Gantt Chart, as well as requirements from the above R&VP tables. The Jira page is the most straightforward and efficient method to communicate task assignments and keep team members accountable to deadlines.

SL 2023-2024	start	end	33%
CDR	**10/26/23**	**01/08/24**	**100%**
Purchase Full scale Motors	10/26	10/26	100%
Reserve Hotel Rooms in Huntsville	10/26	10/26	100%
Write CDR	10/27	12/08	100%
Proofread and check CDR	12/11	12/29	100%
Submit to PM's	12/08	12/08	100%
Due to NASA	01/08	01/08	100%
CDR Q&A	12/07	12/07	100%
Build Subscale	**10/30/23**	**11/10/23**	**100%**
Order Components	**10/30/23**	**10/30/23**	**100%**
Order Airframe	10/30	10/30	100%
Order Parachute	10/30	10/30	100%
Order New Payload Altimeter	10/30	10/30	100%
Build Airframe	**11/10/23**	**11/10/23**	**100%**
Print Nosecone	11/10	11/10	100%
Manufacture Fins	11/10	11/10	100%
Cut tubes for each airframe piece	11/10	11/10	100%
Purchase Subscale Motor	10/30	11/10	100%
Construct Avionics Bay	10/30	11/10	100%
Conduct Testing	**11/06/23**	**11/06/23**	**100%**
Parachute Deployment Testing	11/06	11/06	100%
Altimeter Testing	11/06	11/06	100%
Subscale Launch	11/10	11/10	100%
Create Huntsville Roster	12/15	12/15	100%
Ensure all Team Members have accepted Gate...	12/15	12/15	100%
FRR	**12/25/23**	**03/04/24**	**2%**
Write FRR	01/08	02/23	0%
Proofread and check FRR	02/26	03/04	0%
Order Fullscale Parts	**12/25/23**	**12/25/23**	**100%**
Order Airframe	12/25	12/25	100%
Order Parachutes	12/25	12/25	100%
Order Payload Parts	12/25	12/25	100%
Build Fullscale	**01/08/24**	**02/02/24**	**0%**
Manufacture Fins	01/08	01/24	0%
Machine MFSS	01/08	01/24	0%
Drill Airframe Holes	01/25	01/25	0%
Print Nose cone	01/17	01/22	0%
Print Avionics Bay	01/17	01/22	0%
Build Payload	**01/08/24**	**02/02/24**	**0%**
Assemble Vehicle	01/25	02/02	0%
Submit to PM's	02/26	02/26	0%
Submit to NASA	03/04	03/04	0%
FRR Q&A	02/08	02/08	0%
Possible Fullscale Launch	02/02	02/02	0%
Possible Fullscale Launch	02/09	02/09	0%
Possible Fullscale Launch	02/16	02/16	0%



FRR Addendum	**03/04/24**	**04/01/24**	**0%**
Write FRR Addendum if PDF fails	03/04	03/22	0%
Proofread FRR Addendum	03/25	04/01	0%
Possible Payload Demonstration Flight	03/08	03/08	0%
Possible Payload Demonstration Flight	03/15	03/15	0%
Possible Payload Demonstration Flight	03/22	03/22	0%
Submit to PMs	03/25	03/25	0%
Submit to NASA	04/01	04/01	0%
Competition Week in Huntsville	**04/04/24**	**04/14/24**	**0%**
Launch Week Q&A	04/04	04/04	0%
Pack Launch Vehicle	04/08	04/09	0%
Pack Tools	04/08	04/09	0%
Drive to Huntsville	04/10	04/10	0%
Competition Launch	04/13	04/13	0%
Leave Huntsville	04/14	04/14	0%
PLAR	**04/14/24**	**04/23/24**	**0%**
Write PLAR	04/14	04/19	0%
Proofread PLAR	04/21	04/23	0%
Submit to PM's	04/19	04/19	0%
Submit to NASA	04/23	04/23	0%



Sources

[1] About the airport. Purdue University - Airport Operations. (2023). https://www.purdue.edu/airport/about/index.html

[3] 2023 Weather History in West Lafayette Indiana, United States. Weather Spark. (2023). https://weatherspark.com/h/y/14811/2023/Historical-Weather-during-2023-in-West-Lafayette-Indiana-United-States#Figures-WindSpeed

[4] US Department of Commerce, N. (2023, May 2). *Tippecanoe County tornadoes*. National Weather Service. https://www.weather.gov/ind/tippecanoe_torn

Appendix A: Risk Assessment Code

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

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

Consequence					
	1 **Negligible**	**2** **Minor**	**3** **Moderate**	**4** **Major**	**5** **Serious**
Personnel	Discomfort or annoyance, no recovery time required	Requires minimal care, adhesive bandage or less, 5-10 minutes recovery time	Any other care defined by OSHA as first aid, up to one day recovery time	Loss of consciousness or requires medical treatment as defined by OSHA, no permanent effects	Life-threatening or debilitating, immediate medical treatment as defined by OSHA required, permanent effects
Assets	No signs of damage, no repair required	Cosmetic damage or damage of consumable asset, repairable	Damage to consumable asset requires replacement or repairable damage to non-consumable asset	Significant damage of asset, aid from external sources required for repairs	Un-repairable damage of non-consumable asset
Environment	No OSHA/EPA violation, no remedial action required	Minor OSHA/EPA violation, little to no remedial action required	OSHA/EPA violation, reversible, remedial action required	Major OSHA/EPA violation, reversible with external assistance, temporary stop of work	Repeated or irreversible OSHA/EPA violation, immediate action required, termination of work

Appendix B: Safety Briefing

- Location of first aid kit and fire extinguisher
- Launch procedure:
  - Minimum personnel distance of 100 ft
  - Countdown to launch to ensure all personnel are aware
  - Film from launch through landing
  - If there is a misfire, wait at least 60 seconds before approaching vehicle
- Descent:
  - Visually track vehicle's descent
  - If chutes fail to deploy/inflate, stay calm and be prepared to move in if vehicle is headed toward spectators
  - If vehicle returns toward spectators, issue a "head up" call at which time all spectators will locate and point towards vehicle while moving away from its path
- Landing:
  - Do not attempt to catch any part of vehicle
  - If off-nominal landing, do not attempt to retrieve vehicle from tree or powerline
    - Call the power company
  - Given the go-ahead, approach the vehicle on foot, up to 15' away
  - Check vehicle for smoke/flame, extinguishing if necessary
  - Deflate parachute if dragging vehicle
  - No unnecessary personnel will approach more than 15' while avionics bay is armed
    - Verify detonation of all charges
    - Record apogee
    - Disarm avionics bay
  - Photograph landing
  - Collect vehicle and return to staging area