Project Elijah

Critical Design Review

Cedarville Student Launch 2024-2025

Cedarville University
251 N. Main St.
Cedarville, OH 45314
January 8, 2025

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Acronym	Full Name
AB	Airbrakes Subsystem
AGL	Above Ground Level
APRS	*Automatic Packet Reporting System*
CAD	Computer Aided Design
CDR	Critical Design Review
CE	Chief Engineer
CFD	Computational Fluid Dynamics
CG	Center of Gravity
CNC	Computer Numerical Control
CP	Center of Pressure
CSL	Cedarville Student Launch
CSO	Chief Safety Officer
DMM	Digital Multimeter
EPL	Engineering Project Laboratory
FBD	Free-Body Diagram
FCC	Federal Communications Commission
FDM	Fused Deposition Modeling
FEA	Finite Element Analysis
FEM	Finite Element Method
FMEA	Failure Modes and Effect Analysis
GLOW	Gross Lift-Off Weight
GPS	Global Positioning System
HPR	High Power Rocketry
HPRSC	High Power Rocketry Safety Code
I^2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
LED	Light Emitting Diode
LiPo	Lithium-Ion Polymer
LO	Launch Officer
MGA	Mass Growth Allowance
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
Ni-Cd	Nickel–Cadmium
PCB	Printed Circuit Board
PDF	Portable Document Format
PDR	Preliminary Design Review
PETG	Polyethylene Terephthalate Glycol

PLA	Polylactic Acid
PM	Project Manager
PPE	Personal Protective Equipment
PTT	Push-to-Talk
RRC	Rocket Recovery Controller
RSO	Range Safety Officer
RTC	Real-Time Clock
SDK	Software Development Kit
SL	Student Launch
SPI	Serial Peripheral Interface
STEM	Science, Technology, Engineering, and Mathematics
TRA	Tripoli Rocketry Association
USLI	University Student Launch Initiative
WBS	Work Breakdown Structure
WSR	Wright Stuff Rocketeers

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1. Summary of CDR Report

1.1. Team Summary

Team Name	Cedarville Student Launch (CSL)
Team Mailing Address	251 N. Main St, Cedarville, OH 45314
Team Email Address	custudentlaunch@cedarville.edu
Team Mentor Information	Dave Combs davecombs@earthlink.net (937) 248 – 9726 NAR #86830, High HPR Level 2
Hours Spent on CDR	623 Hours
From Home Launch Plans	Primary & Secondary Locations: 5995 Federal Rd, Cedarville, OH 45314 / 8345 S Charleston Pike South Charleston OH 45368 Primary & Secondary Dates: 4/12/25 or 4/19/25

1.2. Launch Vehicle Summary

Target Apogee	4100 ft
Motor Choices (Primary & Secondary)	Aerotech K1000T-P
	Aerotech K1800ST-P
Fore Section Length/Weight	30.02 in / 7.89 lb
Avionics Bay Section Length/Weight	27.25 in / 4.45 lb
Aft Section Length/Weight	51.22 in / 11.48 lb (wet)
Dry Mass with/without Ballast	21.5 lb / 18.5 lb
Wet/Burnout/Landing Masses	27.4 lb / 24.75 lb / 24.75 lb
Recovery System	Dual deployment: Drogue at apogee/Main at 600’
Rail Size	1515, 8 ft long

1.3. Payload Summary

The primary payload, titled “Elijah“ is a STEMnaut flight capsule in the rocket’s fore section that will remain contained in the airframe of the launch vehicle “Chariot” from launch to landing. Post landing, Elijah will have safely retained four STEMnauts as well as the equipment necessary to transmit, via radio frequency, relevant rocket and STEMnaut landing site data to a receiver at the launch site.

2. Changes Made Since PDR

2.1. Changes Made to Vehicle Criteria

The changes to the launch vehicle criteria are given in Table 2.1.1 below. The effects of these summarized changes are found throughout the Vehicle Criteria section.

Table 2.1.1. *Changes made to launch vehicle criteria.*

Subsystem	Description of Design Change	Effects of Design Change
Tailcone	Tailcone construction method was changed from **sheet metal forming** to **FDM 3D printing**. Tailcone shape was changed from a **conical profile** to an **ogive profile** to increase the amount of material at the convergent end of the printed part.	Subsystem mass was reduced, overall rocket length was reduced from 103" to 102"; Increased drag caused an altitude reduction of about 32'.
Nosecone	The camera was removed from the **nosecone** and will be affixed to the **airframe** instead since there was not enough room in the nose cone for a camera system. The nosecone will no longer feature **fiberglass layups** but will be reinforced by an **epoxy layer** only.	Camera viewing angle was improved; transmitter obstruction was removed from the payload bay.
Airframe	A non-in-flight separation point was added to the airframe just above the airbrakes to improve battery and electronics access. Payload bay bulkhead was moved 0.5" forward in the coupler to increase glue area.	New coupler was added to the airframe stack, introducing eight more fasteners and another potential point of failure on the airframe; CG moved back slightly
Airbrakes	Airbrake flap area was **reduced** to **increase** the amount of airframe material supporting the body of the rocket around the airbrakes	Maximum drag produced by the airbrake control system was reduced.
Fins	Fin shape was changed from **trapezoidal** to **clipped delta** to increase uncontrolled apogee.	CP was moved to the aft of the rocket; apogee increased.
Primary Payload	Primary ballast location was moved from the **primary payload bay** to the **nose cone** because the amount of ballast needed increased as subsystem mass estimates matured.	Static stability was increased from 0.427 cal to 2.29 cal.
Recovery System	The hole in the center of the shock cord mount was **removed** to protect the airbrakes battery.	Minor increase in GLOW.

2.2. Changes Made to Payload Criteria

2.2.1. Mechanical Changes

Much of the mechanical design has been refined and small changes have been made since the PDR. First, the smaller size of the secondary PCB has allowed the STEMnauts to be moved directly below that PCB. These STEMnauts as well as the PCBs will be covered by a translucent shield which will slide in from the bottom of the payload. Both PCBs will be mounted to the payload via M3 bolts which will thread into brass heat-set inserts.

2.2.2. Electrical Changes

An additional, independent, microcontroller system on a separate printed circuit board (PCB) was added to the payload's electrical system to override the push-to-talk (PTT). The team also no longer intends to use the AD5700-1 chip for encoding data to the Automated Packet Reporting System (APRS) protocol for transmission over radio. There was a significant number of external components that were required to support the chip's functionality. Instead, the team intends to use an analog multiplexer with a voltage divider for encoding, which was another option discussed in the PDR.

2.3. Changes Made to Project Plan

Changes to the project plan involved additions to and clarifications to mission requirement validation. These validations consisted of an updated and refined requirement tracking system, as well as analyses, tests, and demonstration plans for requirement verification.

NASA and CSL project requirements are given in an updated format in the Project Plan section. CSL requirements now have their own dedicated table, and all requirement statuses have been updated as of 1/08/25. A project requirement verification table has also been included that provides a verification method and description for the NASA and CSL project requirements. These verifications will be completed with inspection, analysis, demonstration, and testing. Analysis and testing plans have been described in the Vehicle Criteria and Payload Criteria sections. The bulk of testing and analysis for the secondary payload (airbrakes) has been completed. Future plans involve drop testing, wind tunnel testing, and other analysis.

The project timeline, work breakdown structure, and full scale predicted apogee (4100') remain unchanged. The Chief Engineer has assumed responsibility as manufacturing head, and team members have all taken part in manufacturing the sub scale and full-scale rocket components.

3. Vehicle Criteria

3.1. Mission Statement and Success Criteria

CSL's mission is to safely fly the launch vehicle Chariot, which contains the STEMnaut flight capsule, Elijah, to a desired apogee and after landing transmit capsule and landing site data to a designated receiver. CSL will also continue to establish knowledge bases that can be passed on to future teams as part of Project Elijah's mission.

Mission success involves validating launch vehicle and payload design, verifying adherence to all mission criteria as outlined in the 2025 SL Competition and in CSL's internal standards, and successfully performing a predicted vehicle flight, landing, and data transmission with flight survivability. CSL's mission solution is a launch vehicle with a dual bay parachute deployment system, self-contained STEM craft for STEMnaut flight and data transmission, and secondary payload airbrakes system to control vehicle apogee. The success criteria and verification processes for CSL's launch vehicle and payloads are further discussed in the Vehicle Criteria and Project Plan section.

CSL has begun to establish a knowledge base by recording contacts, procedures, and other team information in handbooks on safety, STEM engagement, and general rocketry design. These knowledge bases will be expanded and refined as Project Elijah matures, such that following years of CSL personnel have reliable and informative guidelines when they participate in the NASA USLI competition.

3.2. Final Vehicle Design Overview

Chariot is an 8.5 foot long, 4 inch-diameter rocket whose design has been optimized for minimal use of machined parts and maximum utilization of 3D printed material and simple composites. The launch vehicle uses a standard dual-bay, dual deploy recovery system with two "in-flight" separation points and three "non-in-flight" separation points. The following four report sections provide a detailed description of the three independent segments of the rocket as well as a report on Chariot's mass properties. By way of overview, Figure 3.2.1 shows the full stack of Chariot's sections and their separation points. Figure 3.2.2 lays out the arrangement of the independent sections after recovery device deployment.

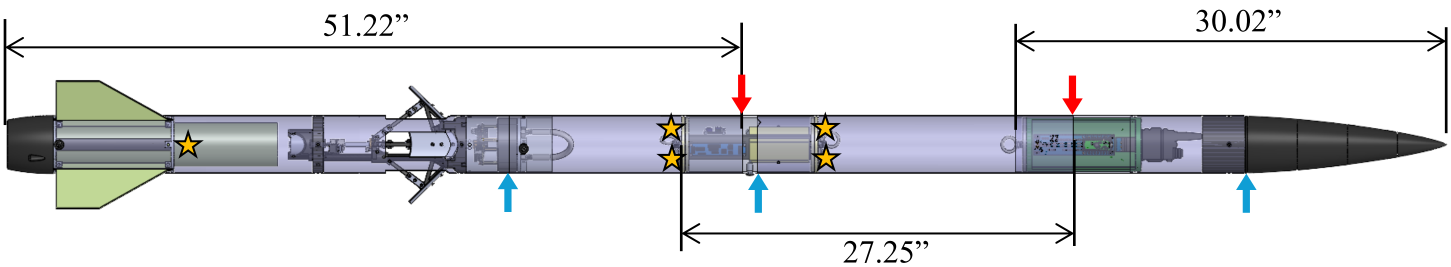

Figure 3.2.1. *Full CAD model of the full-scale Chariot assembly with independent sections and separation points shown. Red arrows denote in-flight separation points in the airframe, and blue arrows denote non-in-flight separation points. Stars indicate the location of energetic materials inside the rocket.*

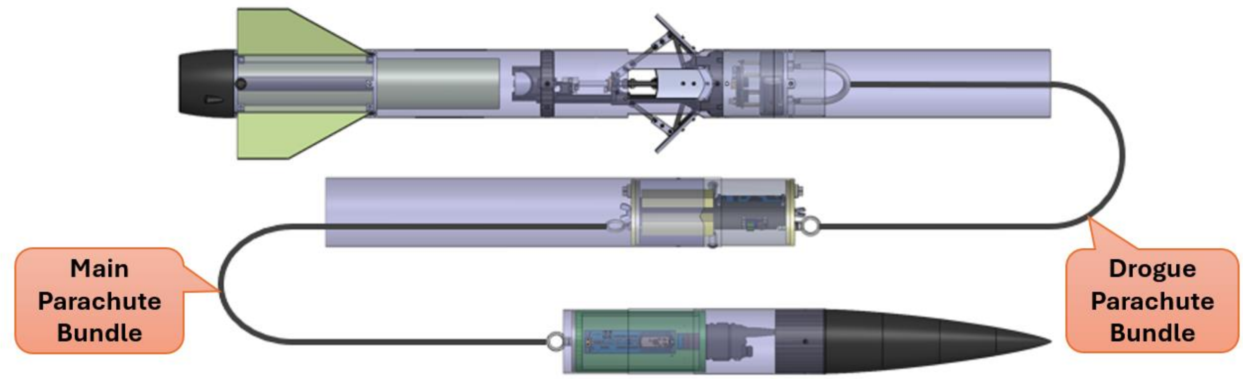

Figure 3.2.2. *The layout of the three independent rocket sections.*

3.2.1. Payload Section

Figure 3.2.3 below shows the forwardmost independent section of Chariot, which contains the primary payload electronics and ballast. The payload section consists of a fiberglass coupler epoxied into a 4.0" fiberglass airframe section, with a ¼" fiberglass bulkhead sealing off the aft end of the bay. The bulkhead is recessed ½" into the coupler to facilitate epoxy fillet placement as is described in Section 3.10.

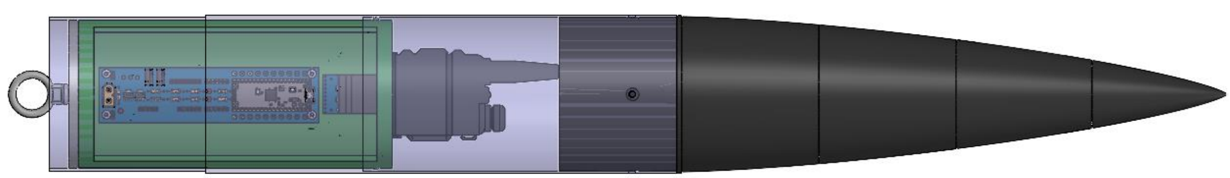

Figure 3.2.3. *CAD rendering of Chariot's payload section. Couplers and airframes are shown as translucent for clarity.*

Figure 3.2.4 shows the planned ballast location inside the nose cone. CSL plans to impregnate epoxy resin with a high density of 304 steel cold-casting powder and pour the mixture in several layers into the tip of the nosecone to firmly secure the metal powder weight into the nose.

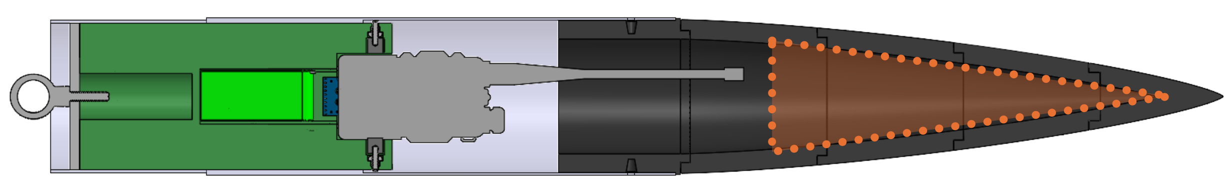

Figure 3.2.4. *Cutaway view of the payload section indicating the volume available inside the nosecone for steel powder ballast.*

The nosecone and payload will be secured from the exterior of the airframe with 10-32 screws, leaving the coupler and bulkhead as the only components in this section attached using epoxy. In compliance with NASA requirements stated in the handbook sections 2.4.1 – 2.4.3, the coupler extends one body diameter (4.0 inches) into the lower airframe as an in-flight separation point, and the nosecone shoulder affords at least 75% of a body diameter of surface contact with the payload bay airframe as a non-in-flight separation point. Figure 3.2.5 contains a fully dimensioned schematic of the payload section. Report Sections 4 and 3.4 provide more detailed information on the primary payload and the nosecone subsystems, respectively.

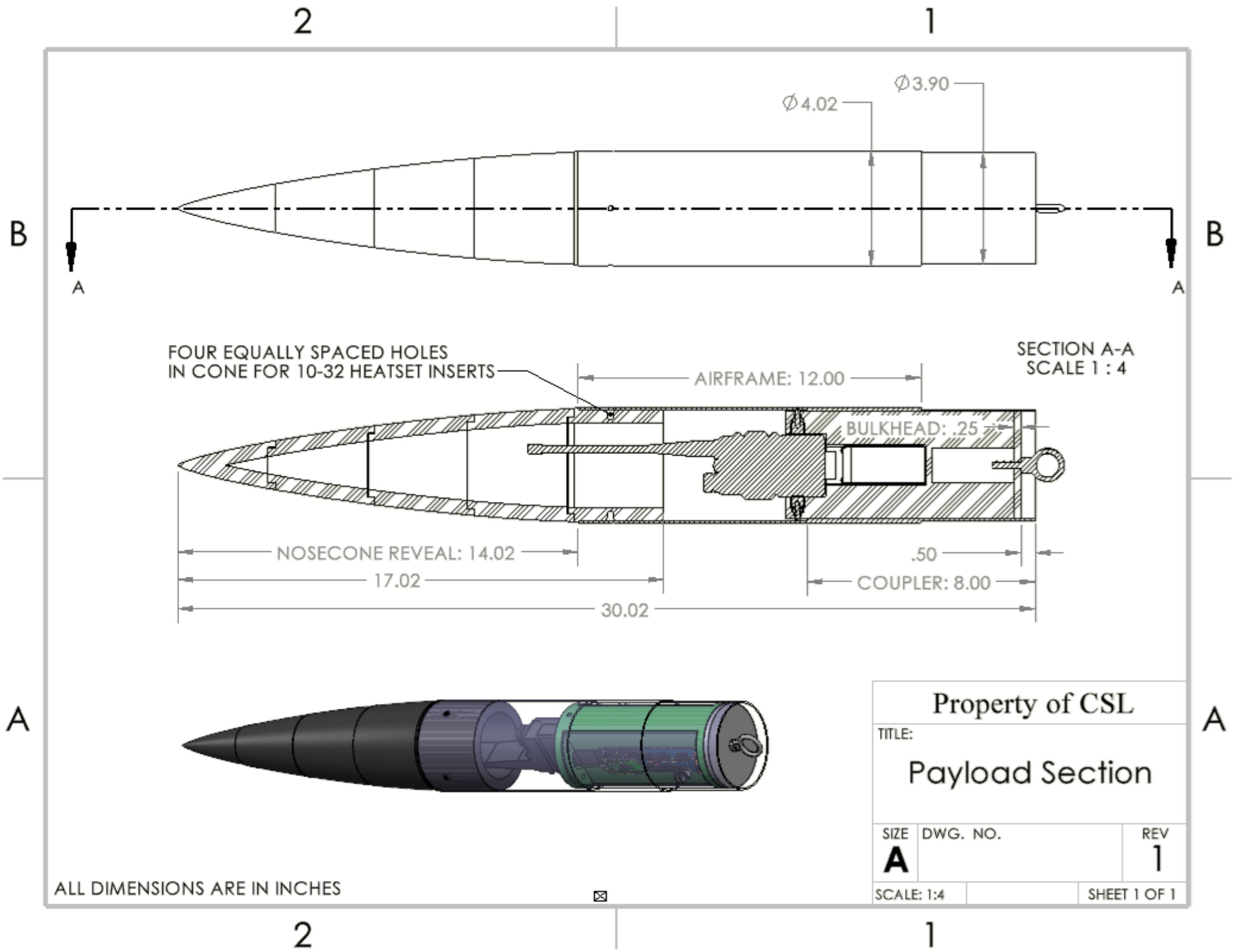

Figure 3.2.5. *Dimensioned CAD schematic of the payload section. Fasteners are removed for clarity.*

3.2.2. Avionics Section

Figure 3.2.6 shows the avionics section, the middle independent section of the rocket. The avionics section consists simply of the avionics bay with a length of airframe serving as the main parachute bay attached to one end with two 10-32 screws. The eyebolt inside the parachute bay and the aft eyebolt on the payload bay are how the two sections are tethered via a nylon shock cord. To satisfy the 2.4.1 – 2.4.2 NASA requirements, both ends of the avionics bay extend 4.0 inches into their respective ends of the rocket airframe. Figure 3.2.7 shows a dimensioned schematic of the avionics section.

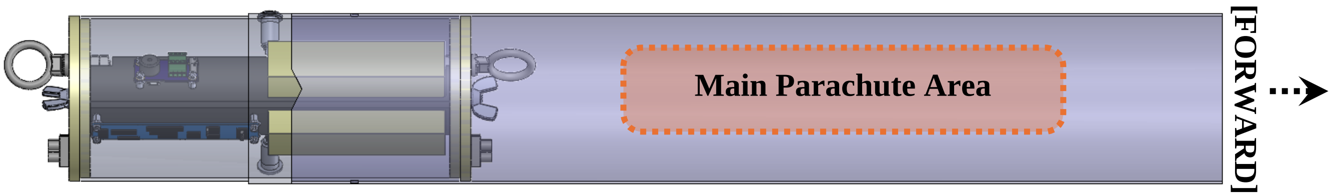

Figure 3.2.6. *CAD rendering of the avionics section, with the area apportioned for the main parachute and shroud lines indicated. Couplers and airframes are shown as translucent for clarity.*

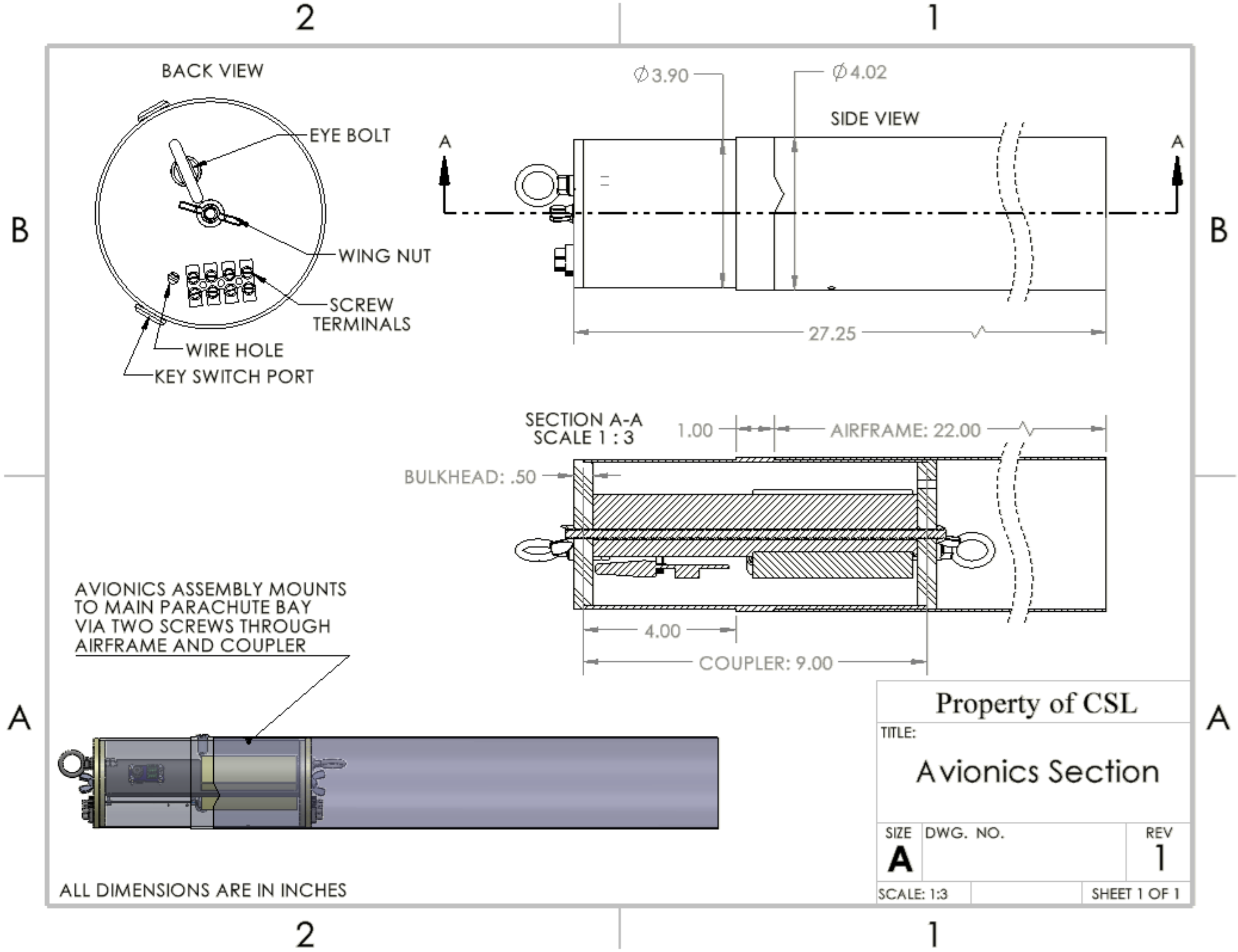

Figure 3.2.7. *Dimensioned CAD schematic of the avionics section. Fasteners are removed for clarity. Note that the main parachute bay is truncated in this drawing.*

3.2.3. Booster Section

Chariot's booster section is the most complex of the three independent rocket segments since it contains the motor retention method (Section 3.8), the fin retention system (Section 3.6), the airbrake flight control system (Section 3.7), and the shock cord mount (Section 3.10.2). The booster is composed of two main airframe components that are joined just above the airbrakes, forming a non-in-flight separation point. Figure 3.2.8 shows the forwardmost section of the booster, which serves as the drogue parachute bay.

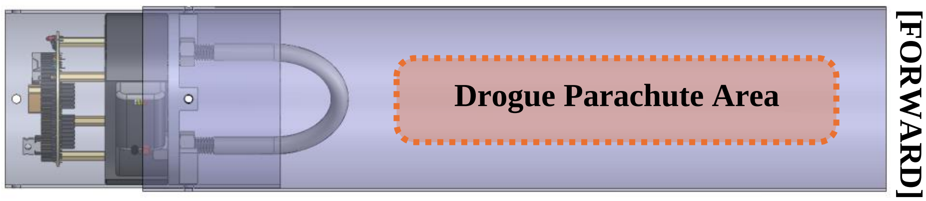

Figure 3.2.8. *CAD rendering of the airbrake can section, which also contains the drogue parachute. The area apportioned for the drogue parachute and shroud lines is indicated, with couplers and airframes shown as translucent for clarity.*

The airbrake electronics can is constructed separately from the rest of the booster so that the battery and electronics associated with the airbrakes, as shown in Figure 3.2.9, can be easily accessed and serviced. These electronics sit behind the shock cord mount inside of a coupler that joins the two halves of the booster together, screwing into the airframe at both ends. The coupler is sized appropriately to comply with NASA Requirement 2.4.2, as shown in Figure 3.2.10.

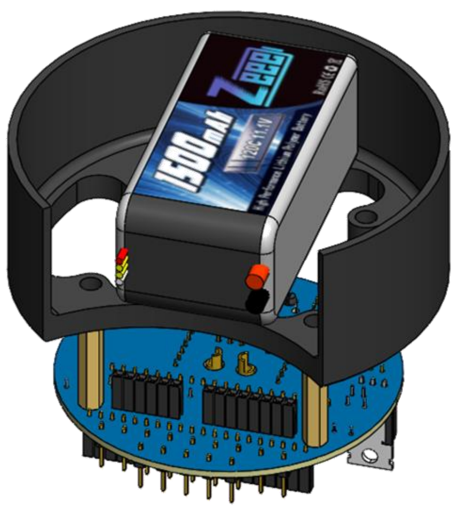

Figure 3.2.9. *The airbrakes electronics can be housed in the aft segment of the drogue parachute bay.*

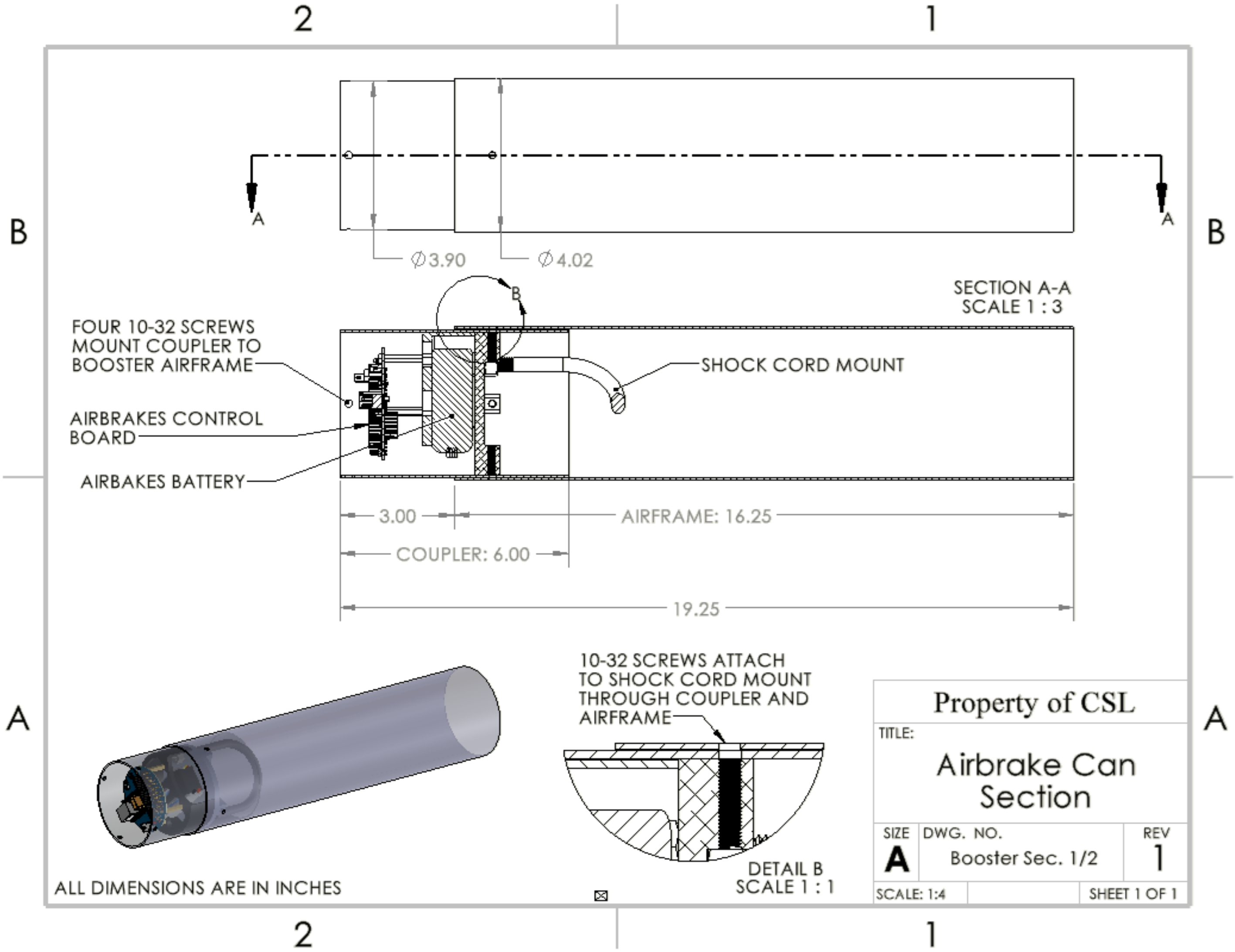

Figure 3.2.10. *Dimensioned CAD schematic of the drogue parachute bay portion of the booster, with special detail of the mounting mechanism involving the shock cord mount. Fasteners are removed for clarity.*

The second half of the booster, as shown in Figure 3.2.11, is contained in the longest length of airframe on the rocket. In addition to featuring four large cutouts for airbrake flaps, this airframe section is completely filled with removable components involving the airbrakes and fin/motor retention. No epoxy is used in this section at all, and only four components are mounted radially directly to the body tube via screws on the exterior of the airframe: the forward 3D printed airbrake mount, the 3D printed airbrake motor mount, and the two machined centering rings. Figure 3.2.12 shows how these four main components are attached to the body tube.

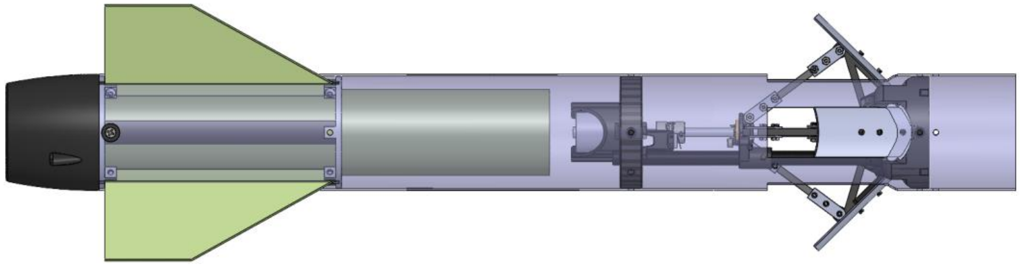

Figure 3.2.11. *Booster section without the drogue parachute bay/airbrakes can.*

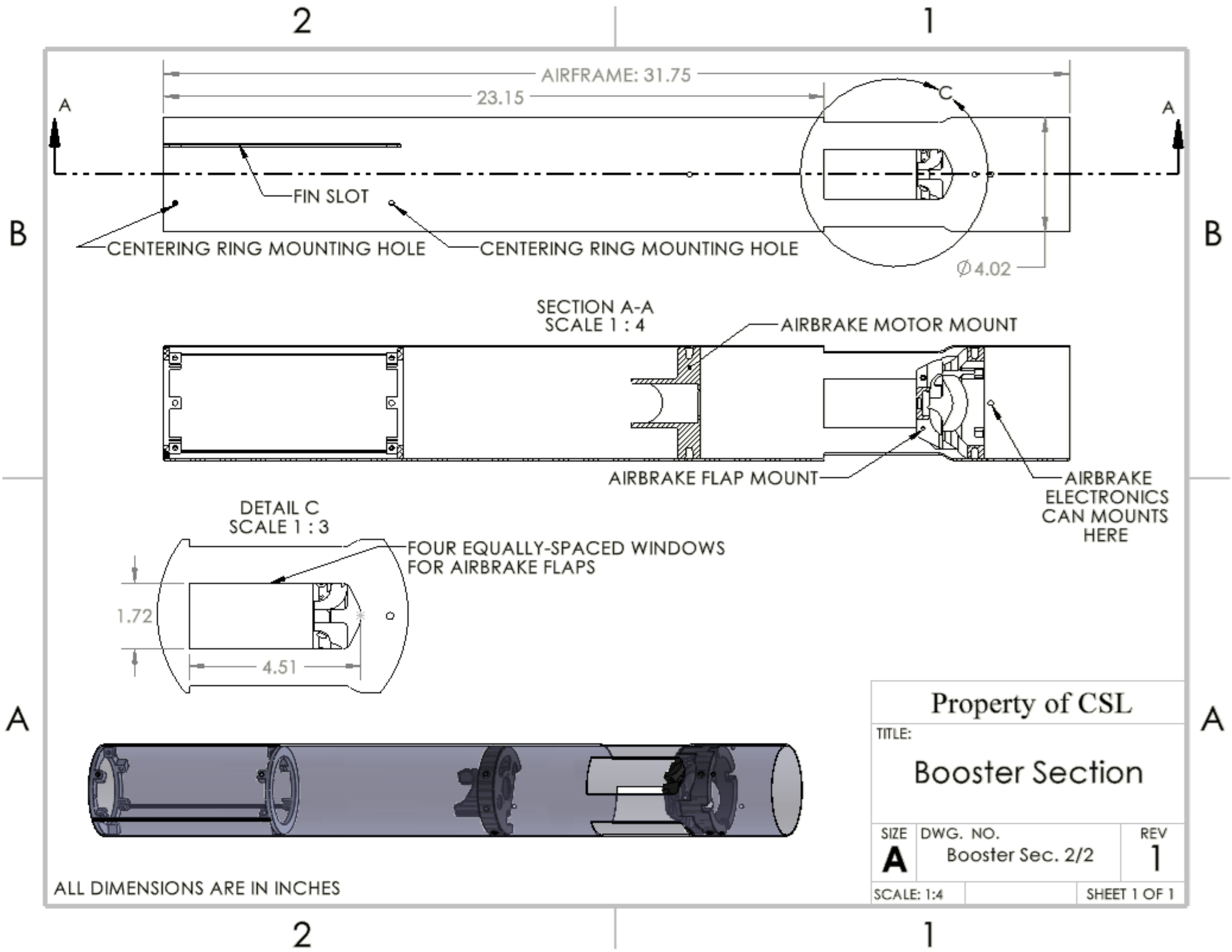

Figure 3.2.12. *Dimensioned CAD schematic of the aft segment of the booster, with fins, motor tube, fasteners, and airbrakes removed for clarity.*

When both halves of the booster are assembled, a mounting hole on both the aft centering ring and the shock cord mount are used as attachment points for two 1515 rail buttons as shown in Figure

3.2.13. This approach of mounting rail buttons to removable machined aluminum parts allows CSL to both replace damaged buttons and conceal the end of a rail button machine screw so that it does not protrude into the airframe and snag on the recovery devices.

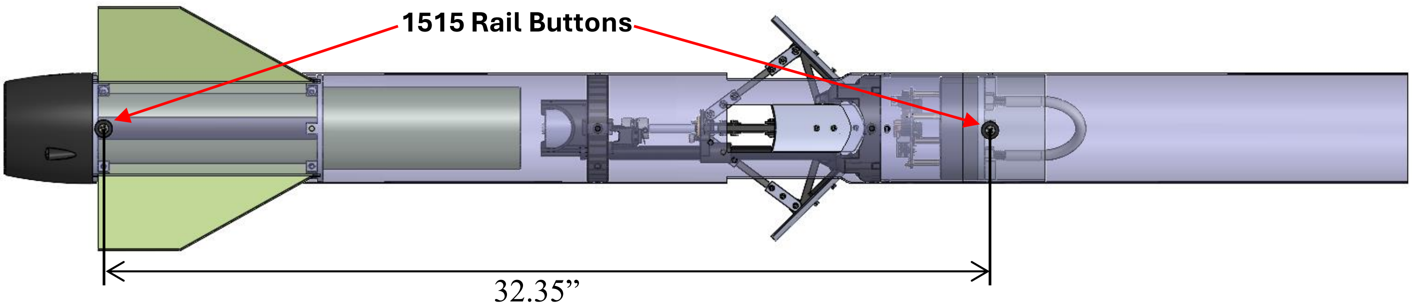

Figure 3.2.13. *Rail button locations on the booster section with the drogue parachute bay attached.*

Epoxied to the motor tube inside of the booster airframe are three, 3D printed ribs that interlock with the aluminum centering rings and transfer the thrust from the motor to the rest of the airframe. This assembly provides a fixture for the three G10 fiberglass fins to be screwed into, as is explained in detail in report Section 3.6. At the back end of this assembly, the 3D printed tail cone screws into the aft centering ring and features a flange that seals the motor casing in place. Report Section 3.8 provides more information on this motor retention solution, and Figure 3.2.14 contains an exploded view of the fin/motor retention assembly that is mounted inside the booster section.

CSL has remained dedicated to pursuing a modular design philosophy that minimizes the need for epoxy bonds and instead allows major components to be simply unscrewed and removed for maintenance or replacement. This strategy permits more parts to be 3D printed since there is no need to commit to permanently bond relatively low strength parts inside the rocket. Because of these modularity decisions, CSL has also been able to reduce reliance on CNC machined aluminum parts with long lead times, improving CSL’s ability to rapidly iterate on Chariot’s design.

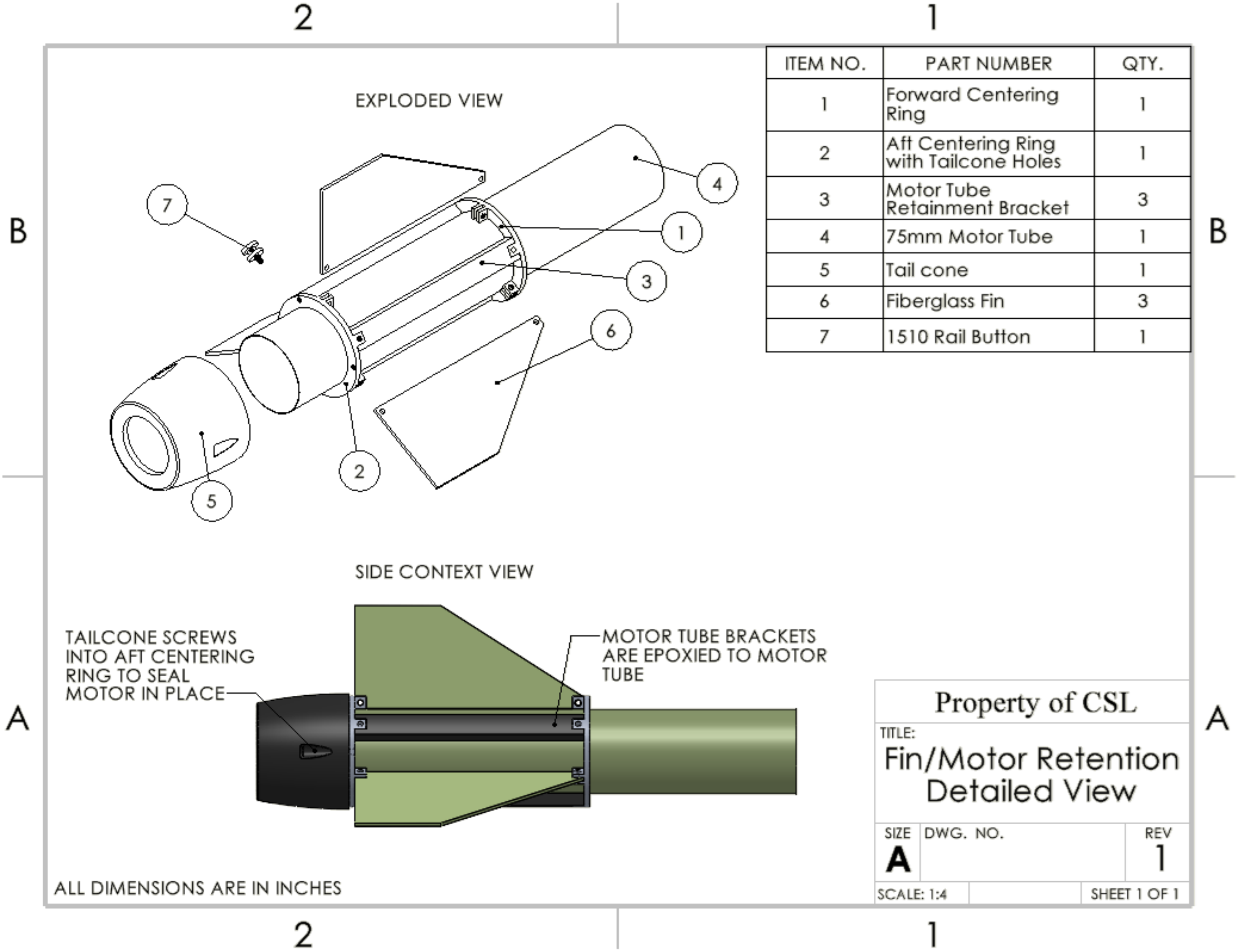

Figure 3.2.14. *CAD schematic of the fin/motor retention system. Fasteners are removed for clarity.*

3.2.4. Mass Properties Control Plan Report

CSL has continued to monitor Chariot's mass properties over the course of the design process. As Figure 3.2.15 indicates, the basic mass measurements have shrunk over time, and as the critical design has come to shape there is a much narrower disparity between the basic mass estimates shown here and the mass estimates obtained through other means, like OpenRocket. In CSL's MPCP, the Allowable mass is the vehicle mass beyond which the airbrakes cannot be used to control the ascent, and the mass limit is the GLOW at which the rocket will not be able to reach the 3500-foot competition minimum altitude. The mass properties of the final Chariot design are predicted to land far below these theoretical limits.

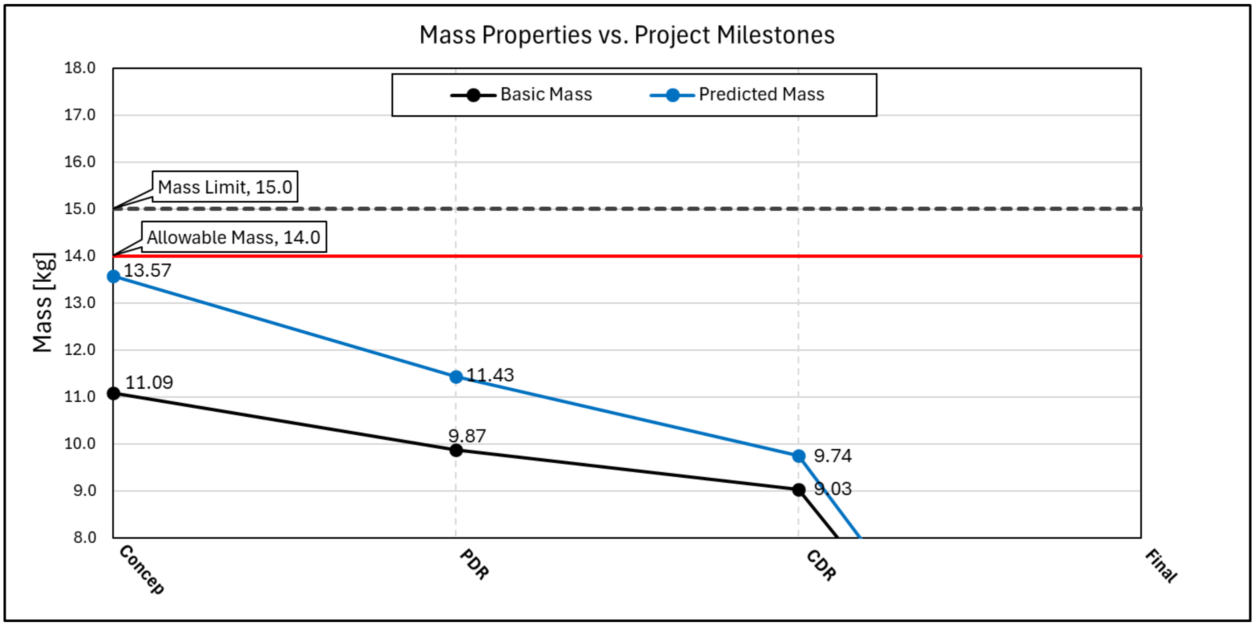

Figure 3.2.15. *Current mass properties trend circa the critical design review. In this case, basic mass is the mass of components on hand or the mass estimated through CAD drawings, and predicted mass is the estimated basic mass growth based on a percentage mass growth allowance (MGA).*

Table 3.2.1 summarizes the basic mass measurements that CSL members have tabulated for each of their subsystems. To obtain Figure 3.2.15, MGA factors for every subsystem (see A.4) were applied to the basic mass estimates and the values were plotted with respect to the mass limit and the allowable mass.

Table 3.2.1. *Summary of basic mass estimates categorized by subsystem.*

Design Maturity	Basic Mass Figures [g]															
	Nose Cone			Payload			Avionics			Airbrakes			Thrust Structure			
	Cone	Camera System	Airframe	Body	Electronics	Recovery Devices	Body	Electronics	Shock Cord Mount	Frame	Brakes	Electronics	Fin Retention	Fins	Tail Cone	Motor
Conceptual	2038.0	16.0	2957.0	226.0	531.4	1510.0	557.6	364.1	160.0	454.0	364.0	312.0	638.1	306.9	653.1	2183.6
PDR	2039.0	16.0	3231.6	208.0	395.5	1186.3	331.7	450.0	160.0	359.0	187.2	531.0	291.2	306.9	180.5	2183.6
CDR	1285.0	22.0	2917.7	200.0	369.5	1121.7	633.1	450.0	164.3	385.0	187.2	545.0	291.2	301.0	160.0	2183.6
Final	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3.3. Airframe

3.3.1. Airframe Material

The CSL team performed a trade study to determine the best material for the airframe of the rocket. The materials considered were blue tube, carbon fiber, and fiberglass. Each material was compared to best fit the needs of CSL, including durability, weight, cost, and the properties of strength. Ultimately, CSL chose a G12 fiberglass airframe due to its affordability while offering substantial strength and durability. It is also lightweight and can withstand heavy use without showing signs of damage. Choosing fiberglass will save CSL both construction time and money. There are three main airframe sections that include the booster airframe section, the main parachute bay, and the main payload body tube. CAD drawings of each airframe section can be seen in Figure's 3.2.7, 3.2.10, and 3.2.12. Table 3.3.1 provides the length of each component and the overall mass.

Table 3.3.1. *Dimensions and Mass Estimate of Airframe Components.*

Length of Booster Airframe	31.75 [in]
Length of Main Parachute Bay	22 [in]
Length of Payload Tube Bay	14 [in]
Length of Drogue Parachute Bay	16.24 [in]
Total Length of Airframe	84 [in]
Total Mass of Airframe	4.27 [lbs]

3.3.2. Camera Mount

As described in the PDR, CSL wanted to install a camera into the nose cone for confirmation of secondary payload deployment as well as for social media purposes. Unfortunately, the team ran into an unforeseen design complexity that impeded mounting the camera into the nose cone. As a result, CSL decided to mount the camera directly to the outside of the airframe to avoid increasing design complexity.

The new design incorporates an Estes Universal Astrocam HD Rocket Camera to record video and audio during full scale vehicle launches This camera was chosen due to its compact size, lightweight design, and its video quality, which can be viewed in Table 3.3.2.

Table 3.3.2. *Dimensions and Mass Estimate of Airframe Components.*

Length	1.88 [in]
Width	0.847 [in]
Height	0.486 [in]
Weight	0.0178 [lb]
Battery Life	40 [min]
Charging	USB
Video Frame Rate	30 [fps]
Memory Card	16 [GB]
Resolution	720p

The Estes camera was mounted to the vehicle using a 3D printed carriage epoxied to the outer diameter of the rocket. The carriage was constructed using PETG 3D filament which provided sufficient strength to support the camera while minimizing the amount of weight offsetting the center of gravity. This design gave CSL the flexibility to mount the camera onto virtually any section of the airframe provided it remains aft of the burn out CG. According to OpenRocket calculations, the burnout CG is predicted to be located 52.29 inches behind the tip of vehicle. Requiring the camera be positioned aft of this point. Based on these constraints, CSL determined that the camera should be mounted on the airframe of the drogue parachute bay. Figure 3.3.1 shows the proposed mounting location on the rocket.

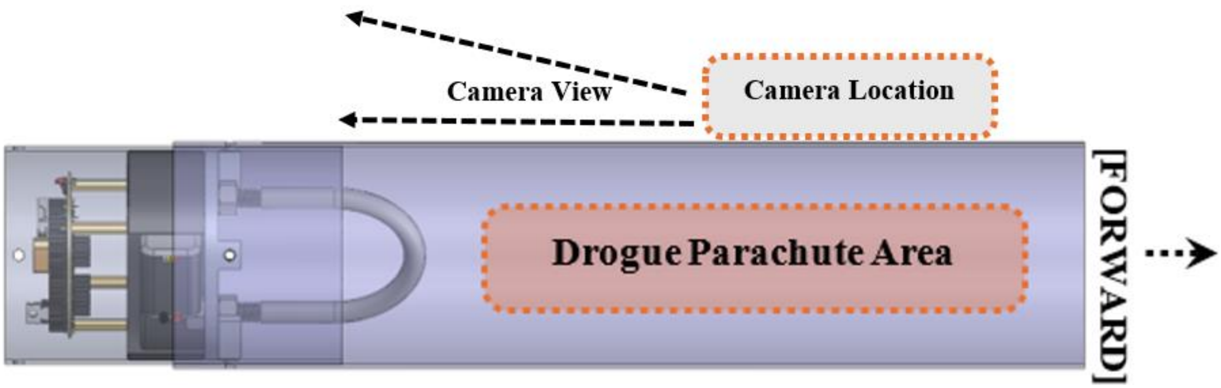

Figure 3.3.1. *Proposed Mounting Location for Camera*

Figure 3.3.2 depicts the fully assembled camera mount along with its major dimensions. The mount is constructed from a top and a bottom which can be viewed in Figures 3.3.2 and 3.3.3 respectively. The two parts are held together by using 4-40 black oxide alloy screws and their appropriate fasteners, which will allow easy access to the camera. The critical dimensions for the camera carriage can be viewed in Table 3.3.3.

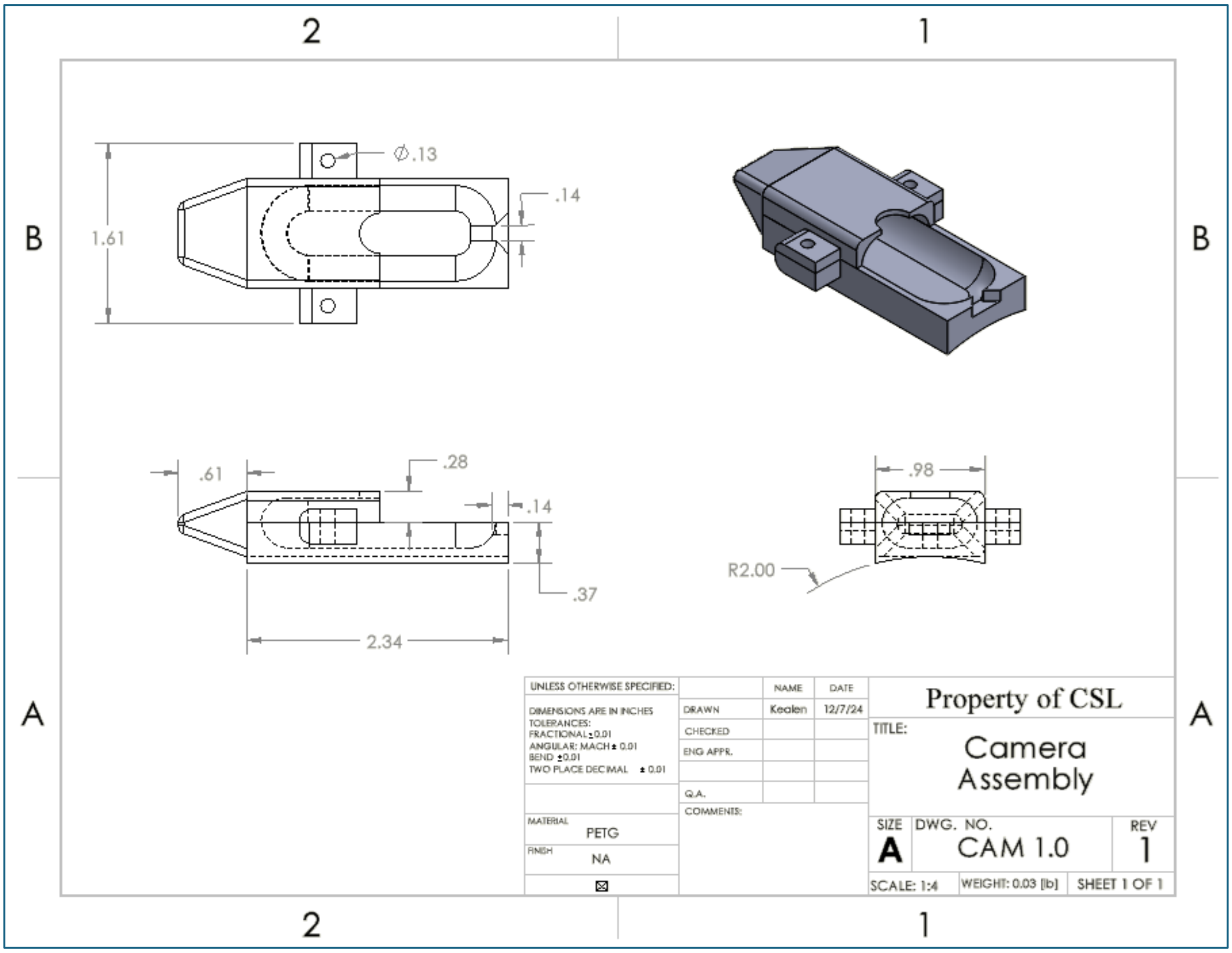

Figure 3.3.2. *SolidWorks drawing of the Camera Assembly with critical dimensions.*

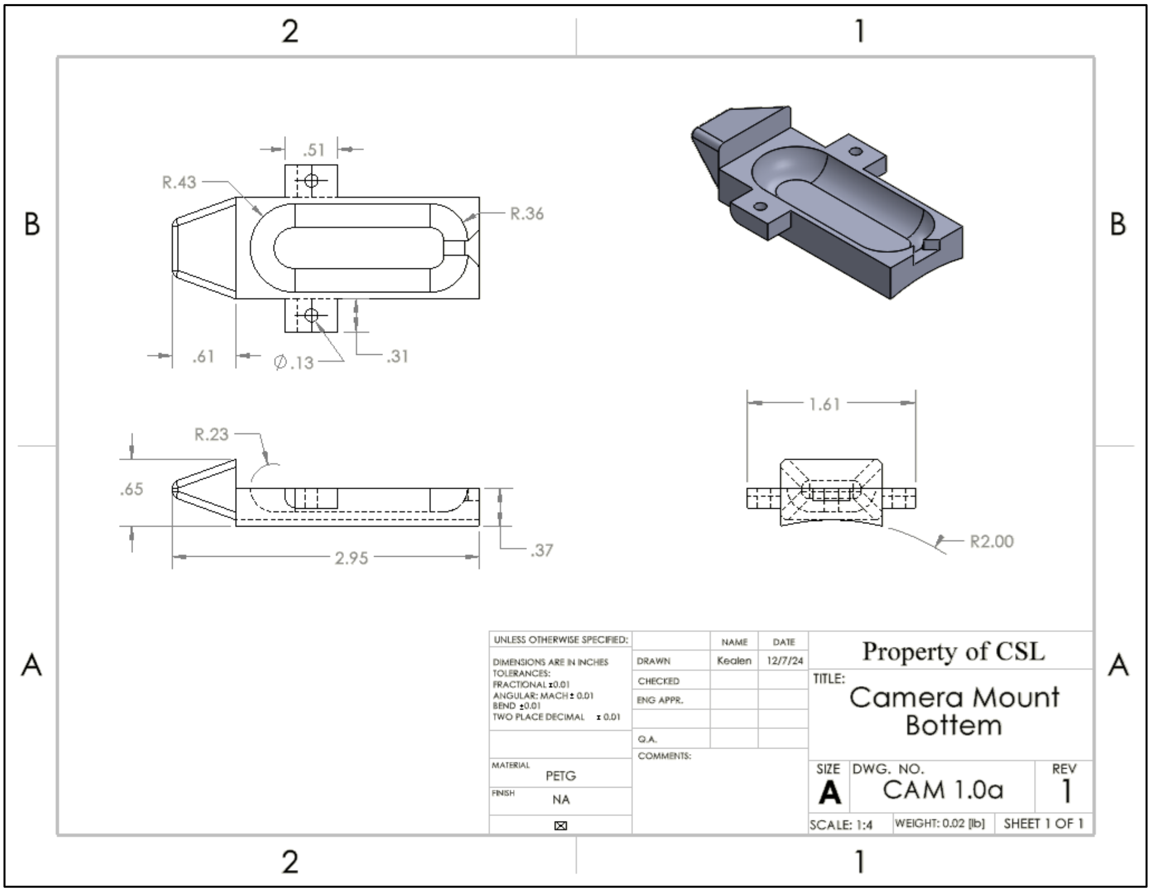

Figure 3.3.3. *Drawing of the Camera Mount's Lower Portion with critical dimensions.*

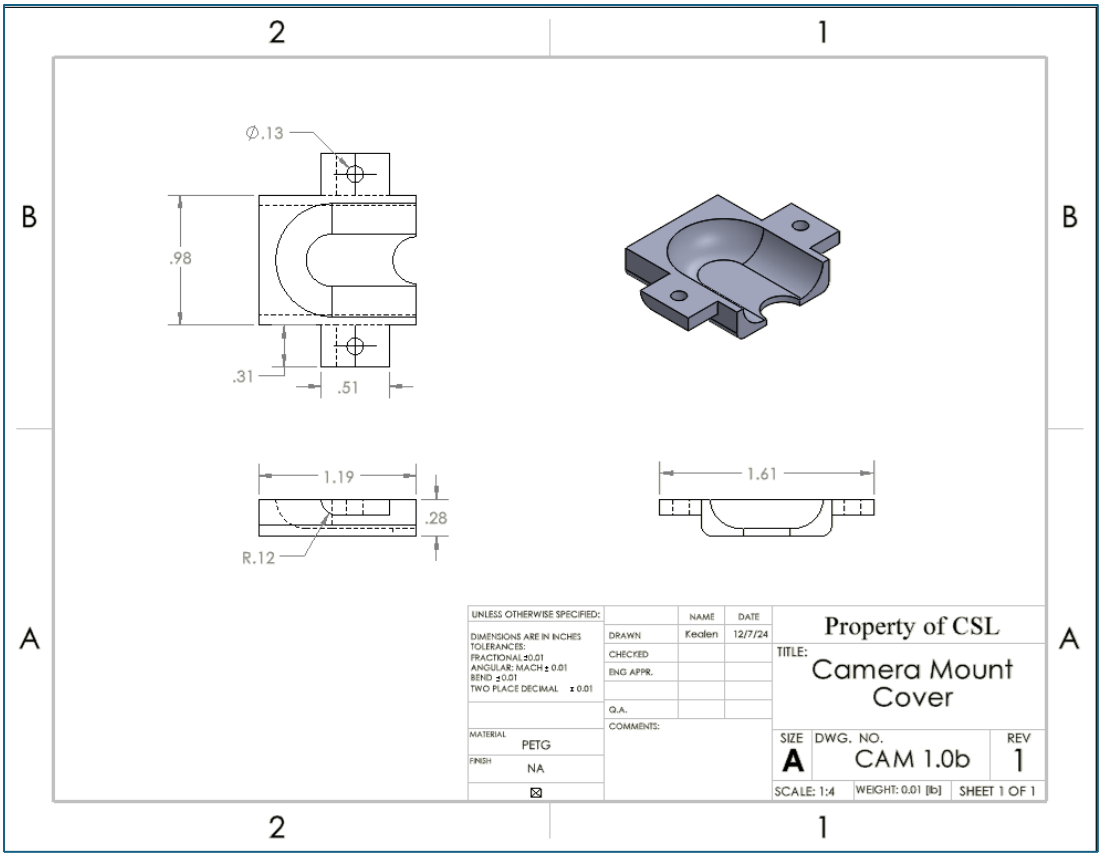

Figure 3.3.4. *Drawing of the Camera Mount's Upper Portion with critical dimensions.*

Table 3.3.3. *Dimensions for Camera Carraige.*

Length	2.95 [in]
Width	0.98 [in]
Height	0.65 [in]
Weight	0.03 [lb]

3.3.3 Camera Analysis

Mounting the camera on the outside of the airframe came its own set of difficulties. It was feared that the camera carriage's mass would offset the CG and cause the rocket to become unstable. An analysis was completed to determine the distance the CG was radially offset from the central axis of the rocket. This was accomplished by using Equation 3.3.3 where d_{CG} is the CG offset, W_{total} is the total weight of the rocket at burnout, d_{cam} is the camera offset from the central axis, and W_{cam} is the weight of the camera assembly.

$$d_{CG}W_{total} = d_{cam}W_{cam} \tag{3.3.1}$$

$$d_{CG} = \frac{d_{cam} W_{cam}}{W_{total}} = \frac{2.325\,[in] * 0.0478\,[lbs]}{24.75\,[lbs]} = 0.00449\,[in]$$

As observed in Equation 3.3.1, the CG offset is an incredibly small value and proves that mounting the camera carriage on the outside of the vehicle will have negligible impacts on the rocket's CG. However, NASA requires further verification to prove that the objects protruding from the rocket are determined to have minimal effects on the aerodynamics of the vehicle. As such, CFD analysis will be conducted on the camera carriage to confirm that the design does not severely alter the overall aerodynamic stability of the rocket. These results will be submitted in the FFR.

3.4. Nosecone

Nosecone subsystems play a crucial role in reducing aerodynamic drag, providing flight stability, and maintaining structural integrity. The cone developed for the CSL rocket follows these principles with a design that minimizes drag while remaining strong and lightweight, with little to no impact on the rocket's CG. The design also allowed for quick manufacturing and modularity which allowed for quick replacement.

3.4.1. Nose Cone Mission Criteria

A successful mission for the nosecone is characterized based off the following criteria:

NC.S.1 Reduce drag acting on the rocket during flight time
NC.S.2 Remain attached to the vehicle for the entire flight duration to provide flight stability
NC.S.3 Provide structural stability to the forward section of the rocket and facilitate portions of the payload
NC.S.4 Survive impact with the ground with minimal damage and be reusable

3.4.2. Changes Made Since PDR

From the various alternatives given in the PDR, a Haak Series cone was chosen for the CSL rocket. This alternative was chosen over the others due to the unique combination of strengths it offered, which included: aerodynamic properties, robustness, size, and manufacturing difficulties. The low drag properties and its size meant the cone could both reduce drag acting on the rocket and facilitate the communications portion of the vehicle's payload. The additional ability to 3D-print the cone further influenced the choice on the leading design.

The overall dimensions of the cone were altered slightly to better improve the manufacturing process and performance of the cone. These included resizing the shoulder length to adhere to NASA guidelines, changing the internal spacing of the cone, and redesigning the individual modular cone components for easier assembly. Additionally, as mentioned previously, it was decided that mounting a camera into the nose cone added an additional amount of complexity. The camera relocated from the cone and was to mount on the airframe itself as discussed in Section 3.3.2. Furthermore, it was decided that reinforcing the 3D-print with both fiberglass and epoxy was excessive and that only epoxy would be used to strength the design moving forwards.

3.4.3. Current Design

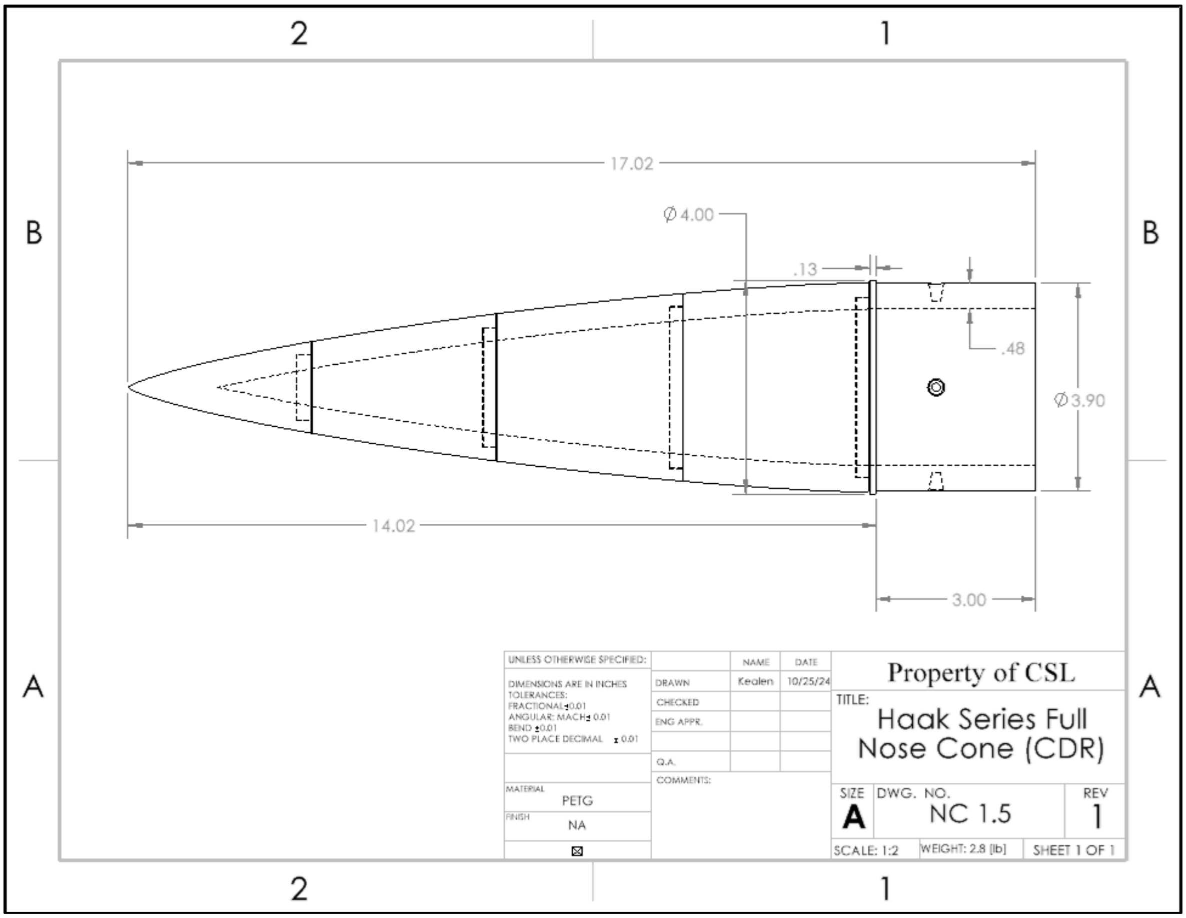

Figure 3.4.1. *SolidWorks drawing of the nose cone with critical dimensions.*

The current nose cone integrates adjustments made to the design from the PDR and can be seen in Figure 3.4.1. While a shorter cone would reduce the drag due to friction forces, a longer cone was required to meet the overall criteria for the nosecone. The total cone length is 17.02 inches long to provide ample space for the communication portion of the payload and to help keep the vehicle's CG in its desired location by positioning weight higher in the rocket. The outer diameter at the base of the cone is 4 inches allowing the cone to sit flush with the outer edge of the airframe and ensure smooth airflow to reduce drag. This allows for the overall design to have a fineness ratio of 3.505 which compares favorably for subsonic nosecones (Iyer & Pant, 2020). There is a gap between the cone's base outer diameter and the surface of the cone. This gap accounts for a strengthening layer of epoxy as past experiences have shown that solely 3D-printed cones do not tend to survive to be reusable.

The cone was split into five different sections to streamline the 3D-printing process and assembly of the cone. Figures 3.7.2 through 3.7.6 show each individual cone section. The base cone portion also includes the cone's shoulder which sits inside the airframe. It has a diameter of 3.9 inches and includes four 10-32 inserts and screws used to attach the cone to the airframe.

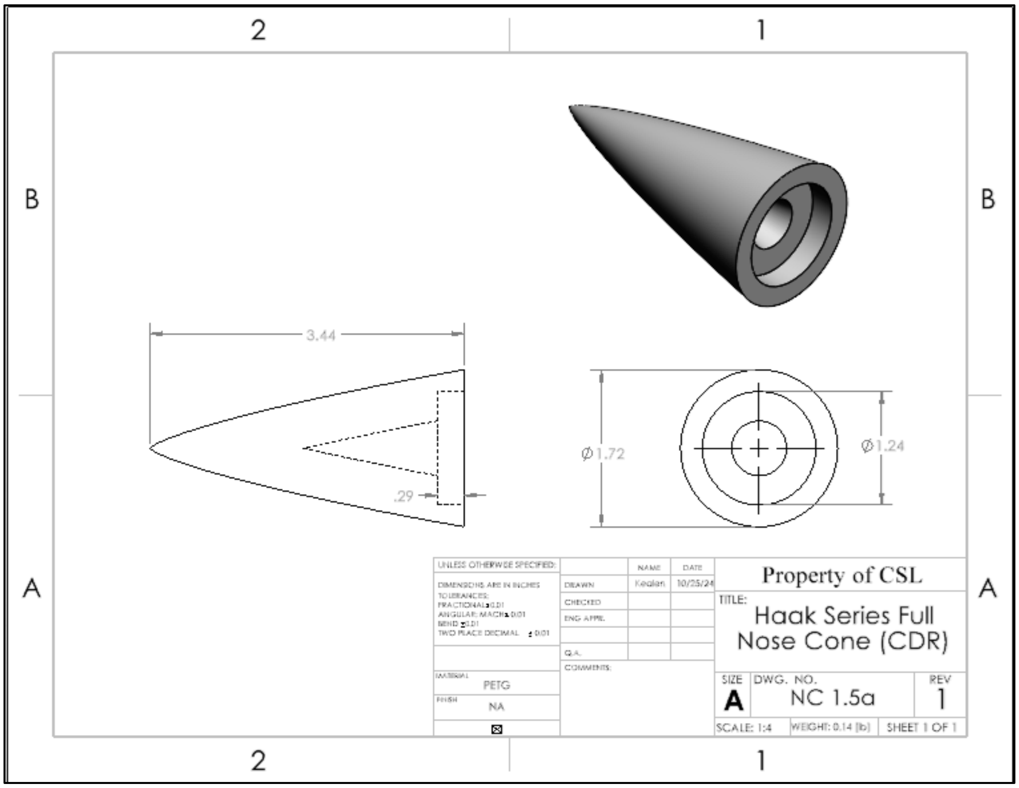

Figure 3.4.2. *SolidWorks drawing of the cone tip.*

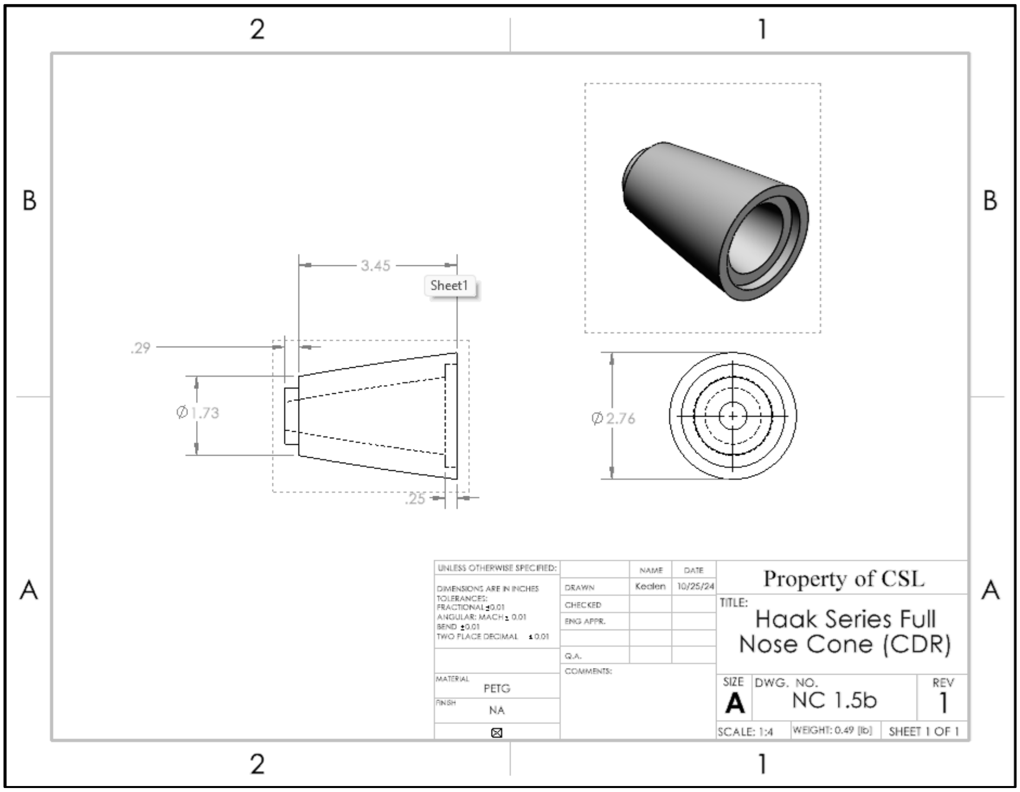

Figure 3.4.3. *SolidWorks drawing of the cone upper middle.*

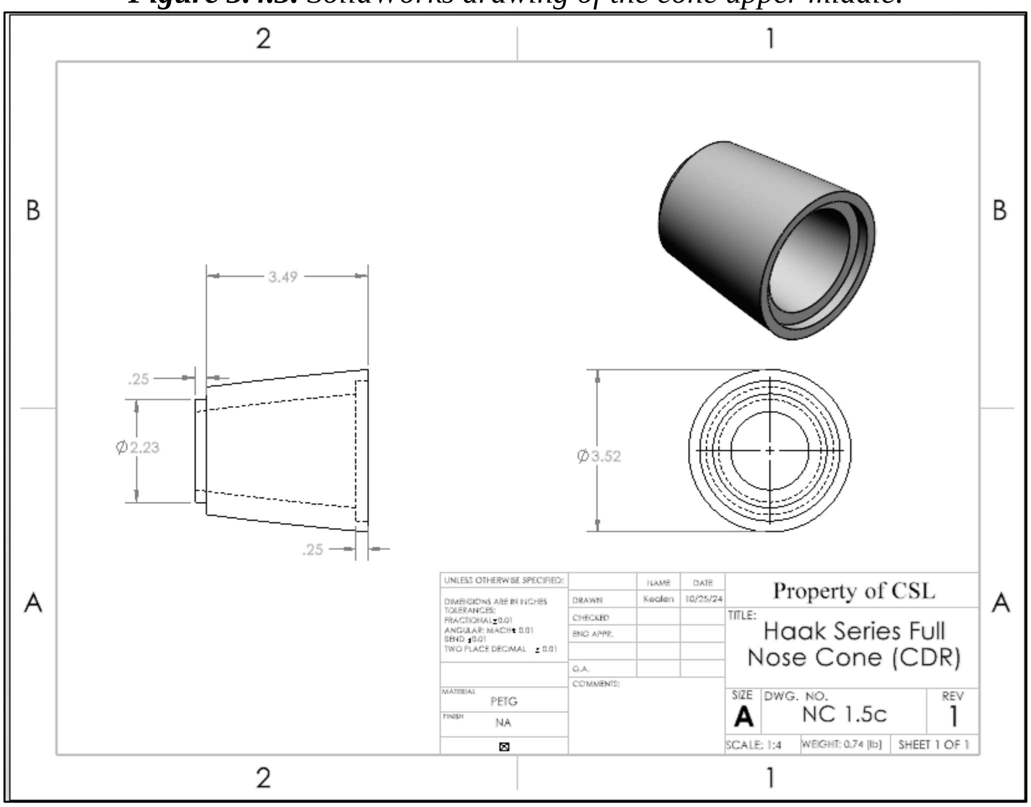

Figure 3.4.4. *SolidWorks drawing of the cone middle.*

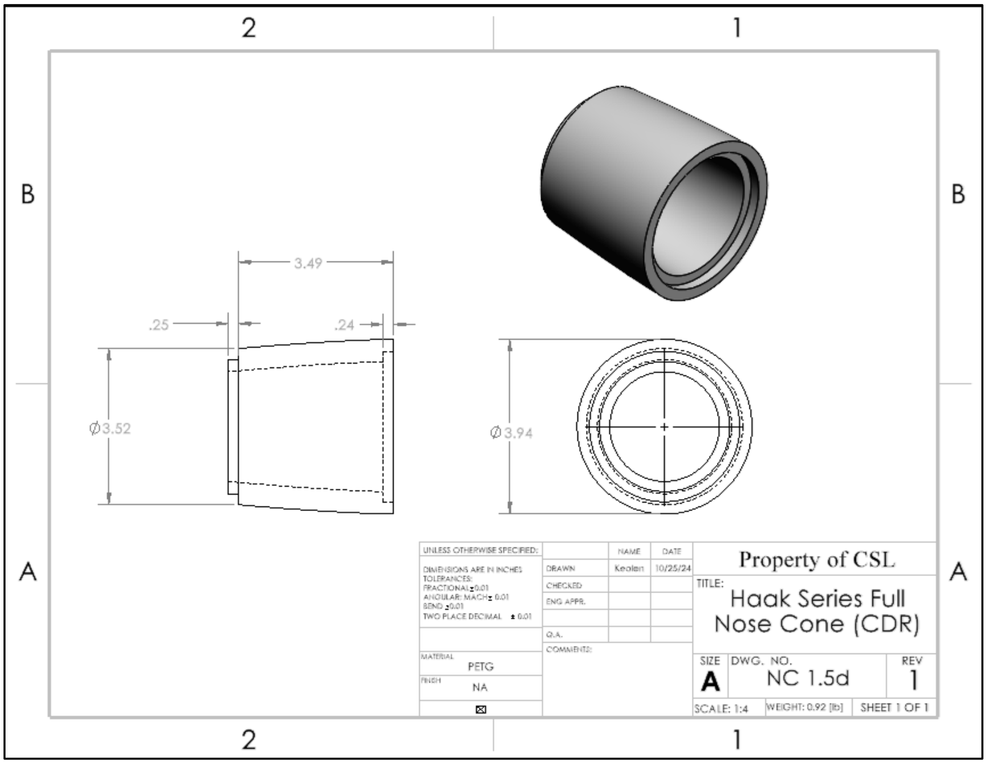

Figure 3.4.5. *SolidWorks drawing of cone lower middle.*

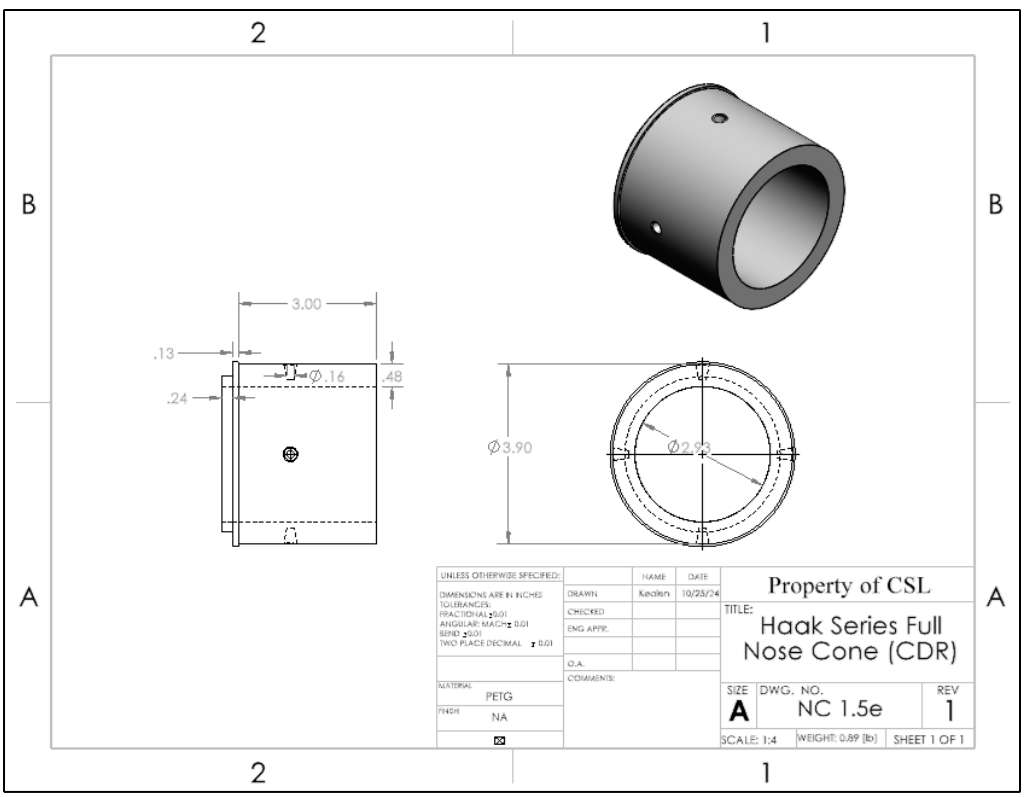

Figure 3.4.6. *SolidWorks drawing of cone base.*

3.4.4. Leading Design Verification

In addition to refining the dimensions of the subsystem, verification tests and experiments were performed on the nose cone to further validate CSL's design choice. These verifications adhered to the regulations described by NASA.

3.4.4.1. Drag Coefficient Analysis

The main purpose of the nose cone is to reduce drag. As a result, the most important piece of analysis performed on the subsystem was to determine that the leading design reduced drag compared to the other design alternatives. A model of the vehicle was set up in the program OpenRocket and different nose cone geometries were simulated to calculate their drag coefficients. The recorded drag coefficients were then compared to confirm that the design was reducing drag compared to the alternative designs suggested in the PDR.

All cone geometries in OpenRocket were standardized with a 14-inch cone length and a 4-inch base diameter. Geometries tested included conic, ¾ parabolic, elliptical, and Haak series. The simulations were conducted at the vehicle's predicted maximum velocity of Mach 0.529 and their drag characteristic results are displayed in Figures 3.4.7 through 3.4.10.

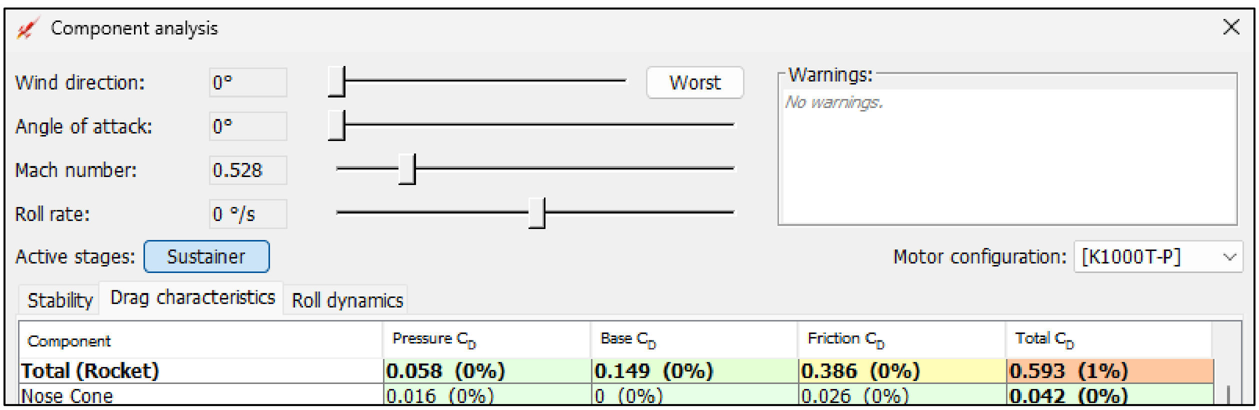

Figure 3.4.7. *OpenRocket simulation for conic design alternative.*

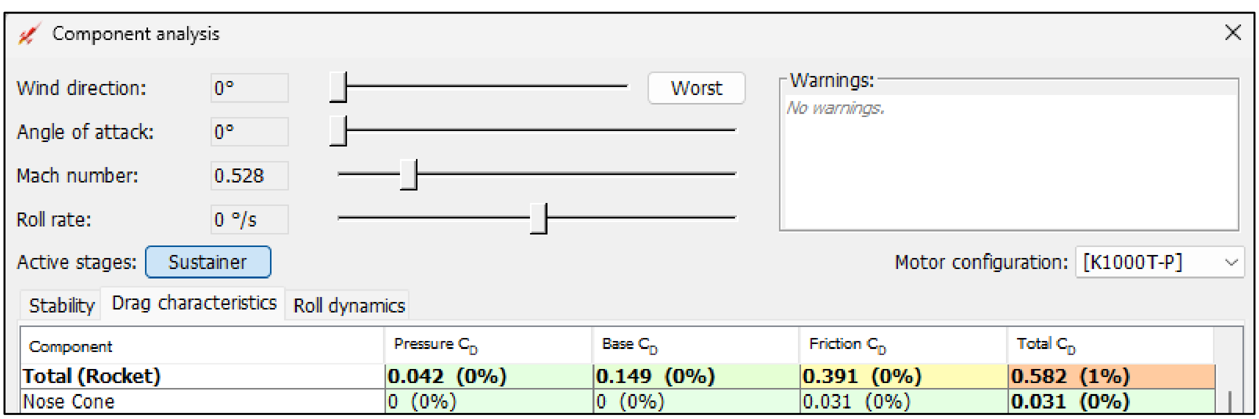

Figure 3.4.8. *OpenRocket simulation for ¾ parabolic design alternative.*

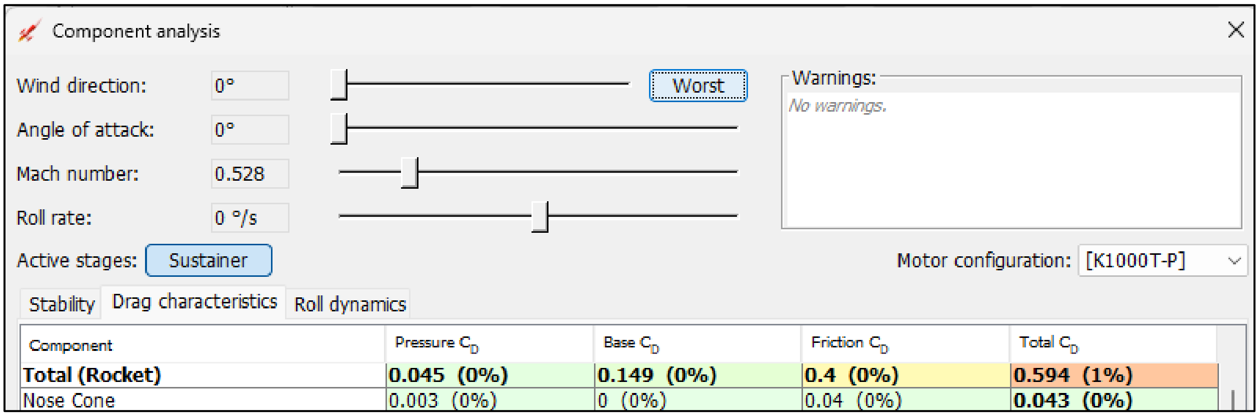

Figure 3.4.9. *OpenRocket simulation for elliptical design alternative.*

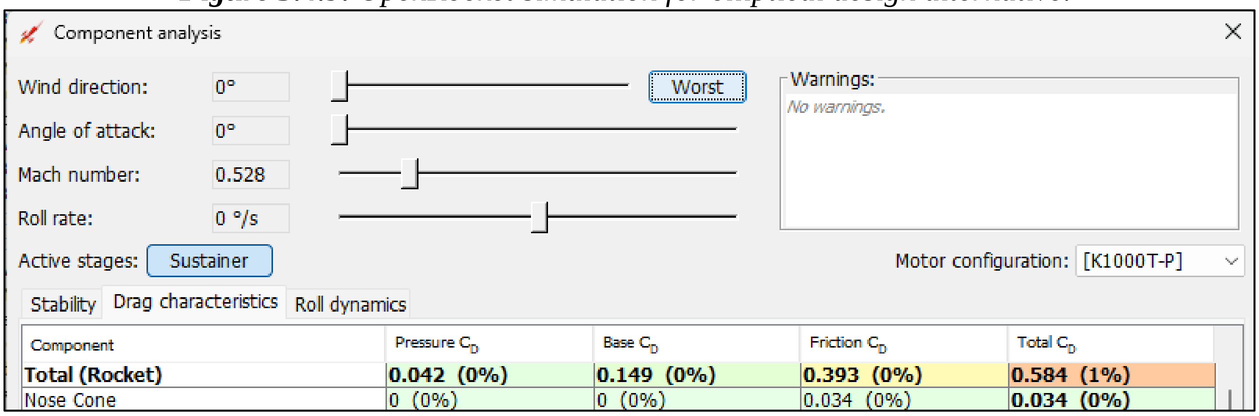

Figure 3.4.10. *OpenRocket simulation for Haak series design alternative.*

From the OpenRocket simulations, it was observed that the Haak (leading) design had the second-lowest drag with only a 0.003% difference between it and the lowest value. Because the difference between these two values was so small, it was deemed negligible. From these analysis results, it was verified that the leading cone design does indeed reduce drag compared to other the design alternatives.

3.4.4.2. Physical Testing (Drop Test)

In addition to reducing drag acting on the vehicle, the mission criteria for the nose cone demands that the cone be reusable and structurally sound. It was desired that the subsystem would be strong enough to stay attached to the rocket for the whole flight duration, survive impacts with the ground, and facilitate the payload. In other words, this means that the nose cone needs to survive impact with the ground after the deployment of both the main and drogue parachutes. The greatest challenge in verifying that the nose cone would meet these criteria was due to the design being constructed using PETG 3D print material. Because 3D-printed material is anisotropic and highly dependent on print orientation, it is extremely difficult to apply mechanical property testing procedures too. To overcome these restrictions regarding the analysis of the leading design's structural strength and integrity, verification turned to physical testing via drop testing which will be conducted in late January or early February.

The best way to physically test the nose cone's survivability is to perform a drop test to simulate landing impact with the ground. The overall goal of the test is to verify that the cone will survive landing impacts and that it proves its reusability. This test will be conducted by taking both the mass and the predicted kinetic energy impact values for the fore section of the vehicle and using them to determine the corresponding height needed to drop the nose cone to simulate the cone impacting the ground at that given amount of energy. The nose cone would then be dropped from this calculated height and inspected to see if it suffers any damage. The experiment could be repeated as many times as needed and at different angles of attack. Furthermore, the height could be increased to determine the maximum impact kinetic energy the cone could take before failing.

Nose Cone Drop Test Procedure

Objective: The goal of the drop test is to assess the survivability and reusability of the leading nose cone design by simulating landing impacts. The test will verify whether the nose cone can withstand impacts at various kinetic energy levels and determine its failure threshold.

Materials and Equipment

1. Fully assembled 3D printed nose cone
2. Drop test stand (15 ft ladder)
3. Scale to measure the mass of the nose cone
4. Crafting putty to be used as mass ballast
5. MATLAB code from Appendix A.3 to predict impact kinetic energy
6. Camera to record impact for analysis (Phone camera)
7. Proper PPE
8. Tape measurer and meter stick to precisely determine drop height

Variables

There are multiple variables that must be accounted for in the drop test. The independent, dependent, and controlled variables are listed below.

- **Independent Variables**
  - Drop Height (h) measured in [m]
  - Impact Angle of Attack (α) measured in [deg]
- **Dependent Variables**
  - Cone Damage
  - Kinetic Energy (KE) measured in [Nm]
- **Controlled Variables**
  - Mass of Cone (m) measured in [kg]
  - Environmental Conditions
  - Impact Surface

Steps

For the drop test to be performed successfully, it must follow the laid-out procedure:

1. **Preparation**
    - Measure and record the mass of the fore section of section of the rocket including the payload bay and the nose cone using the weight scale.
    - Insert the mass value into the descent performance prediction MATLAB code displayed in Appendix A.3 to calculate the predicted kinetic energy that the fore section will have when it impacts the ground from the rocket's descent.
    - Take the predicted kinetic energy and the recorded mass and insert them into the kinetic energy formula shown in Equation 3.4.1. Rearrange the equation to solve for the velocity of the fore section as it impacts the ground as shown in Equation 3.4.2.

$$KE = \frac{1}{2} * m * v^2 \quad (3.4.1.)$$

$$v = \sqrt{\frac{2 * KE}{m}} \quad (3.4.2.)$$

    - Insert the calculated impact velocity into the potential energy equation shown in Equation 3.4.3 to calculate height.

$$v = \sqrt{2gh} \quad (3.4.3.)$$

    - This is the height value that the nose cone must be dropped from to simulate the predicted kinetic energy that it will endure on impact with the ground.

2. **Test Setup**
    - Insert ballast into the nose cone to correctly simulate the mass of the entire fore section of the rocket using the scale for accuracy.
    - Set up the phone camera to record the test

3. **Perform the Drop Test**
    - Raise the cone to the desired height and position it at the desired angle of attack if applicable.
    - Drop the nose cone from the calculated height over level open ground to simulate the ground that the rocket would descend towards from the CSL launch location.

4. **Data Collection**
    - After the cone hits the ground, observe the cone for cracks or damage.
    - Record the impact using the phone camera

5. **Repeat the Test**
   - Conduct multiple drops at the same height and angle to verify consistency
   - Change the angle of attack and repeat to simulate different impact scenarios
   - Gradually increase the drop height or mass to simulate higher impact kinetic energies to determine the failure threshold of the cone

Pass / Fail Criteria

For the cone to pass the drop test, the cone must be able to withstand at bare minimum, the impact kinetic energies predicted by the MATLAB code from Appendix A.3 with minimal damage and be reusable over the course of at least 3 drop tests at different angles of attack. If possible, the goal is to also determine the maximum kinetic energy that the cone can withstand before failing. However, if the damage to the cone is found to be severe enough that the cone's mission criteria (decreasing drag, facilitating the payload) are at risk of failure, then the cone does not pass the test. The results of this test will be used to validate the survivability and reusability of the nose cone. The data collected will be submitted to the FFR.

3.5. Fin Structure

3.5.1. Changes Made Since PDR

The fin design has undergone some minor changes since the PDR. The CSL team has decided to move from trapezoidal fins to clipped delta fins. The SolidWorks drawing is shown in Figure 3.5.1. There are multiple reasons for this design change. The first reason is the increased apogee from the geometry change. The increased apogee allows for the airbrakes to have an increased time window to accurately bring down the altitude of the rocket to the targeted apogee. This is beneficial to the rocket because now the electronics in the airbrakes have more time to actuate according to the current altitude. The rocket loses a very small amount of stability from this change; however, it is not enough to cause any concern. In Table 3.5.1, the changes in the apogee and stability are shown.

Table 3.5.1. *Changes since PDR due to Fin Change.*

	Apogee	Stability
Clipped Delta	4930 ft	2.25 cal
Trapezoidal	4550 ft	2.44 cal

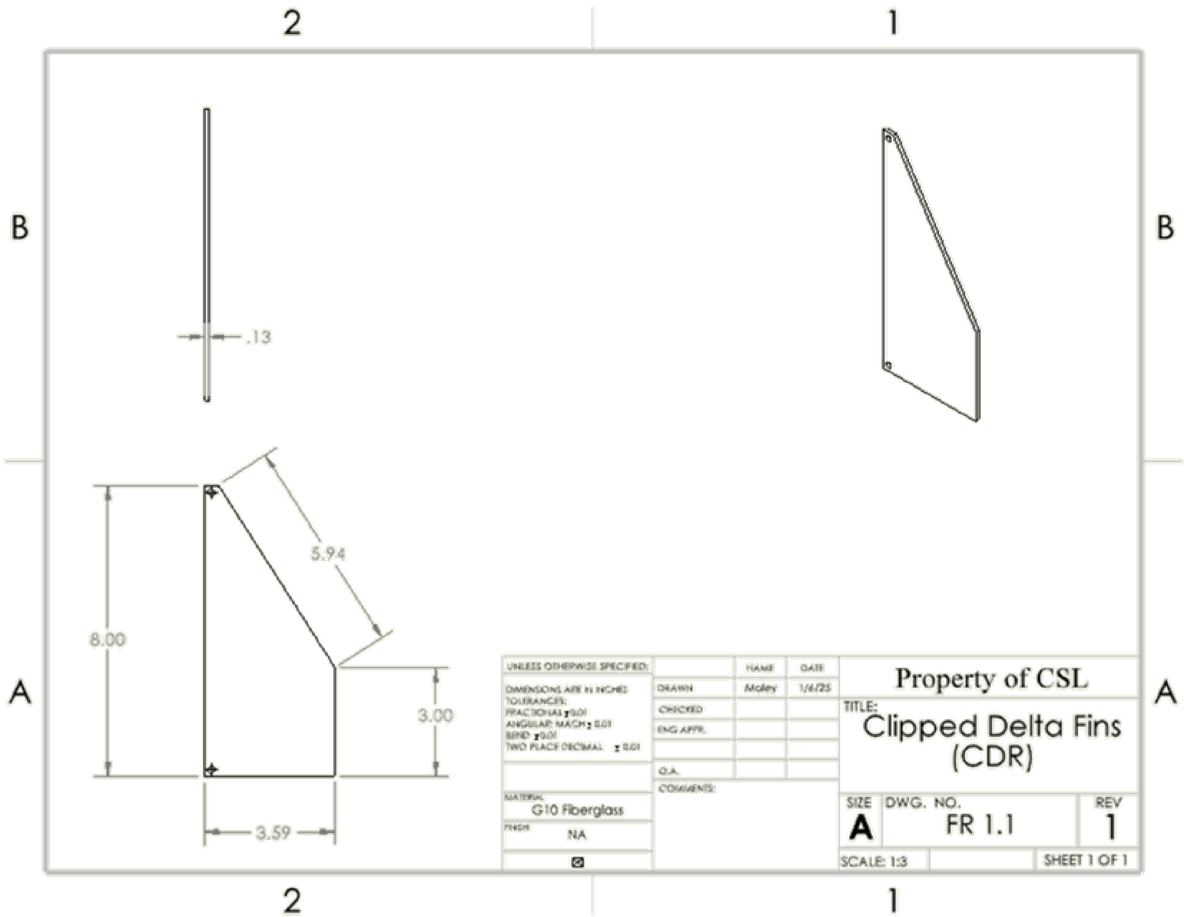

Figure 3.5.1. *SolidWorks Drawing of Clipped Delta Fins.*

3.5.2. Mechanical Design Analysis

One concern that came up during the design phase of the fins was the mechanical design. The CSL team had a concern that there would not be enough fin area to fully support the fins, and the fiberglass would fail under the load from the wind. To analyze this, the CSL team used mechanical design principles to determine whether the fiberglass would fail under the wind load.

The first step is to design a free body diagram of one of the fins with the loads acting on it. That free body diagram is shown in Figure 3.5.2. Fw is the force of the wind, Fg is the force of gravity, Ax and Ay are the pin reactions at pin A, and Bx and By are the pin reactions at point B.

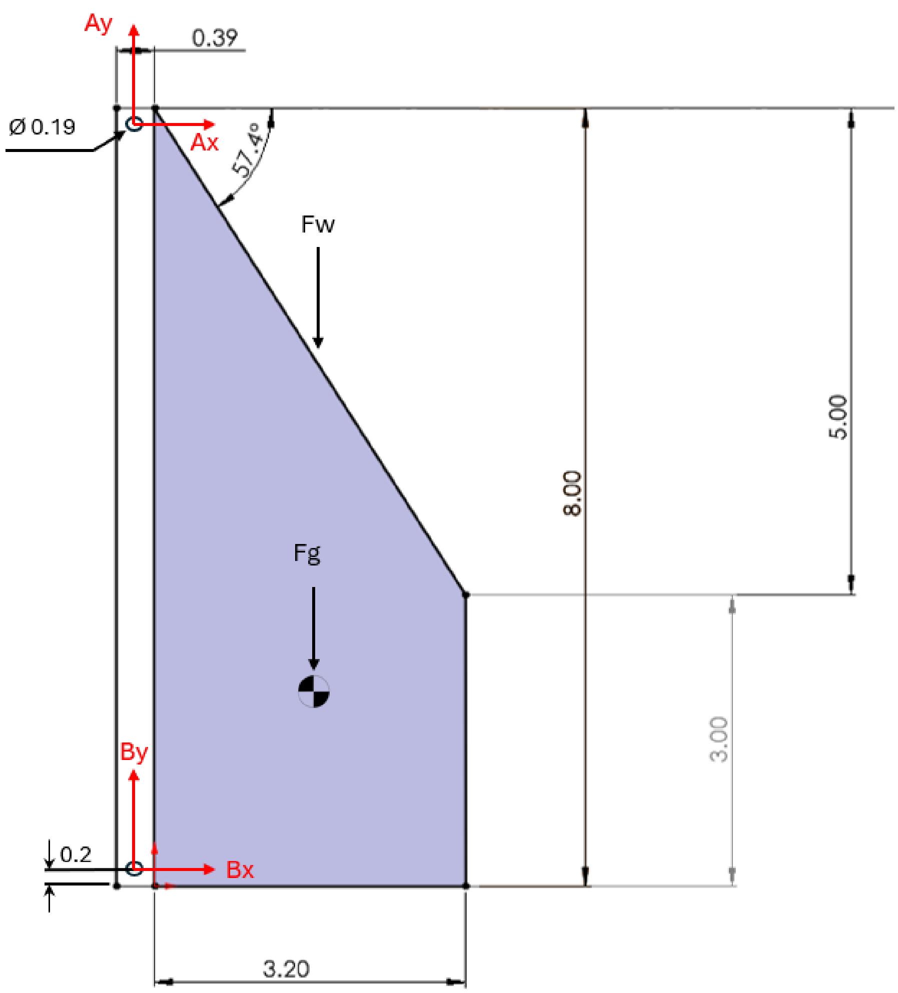

Figure 3.5.2. *Free Body Diagram of a Fin During Flight.*

Before the analysis can be done, a few assumptions need to be made. The first assumption is that in this moment in time, the rocket will be traveling at its maximum velocity which means this analysis will be done for the worst possible scenario. The second assumption that will be made is that the force of the wind can be resolved into a point load. The wind force is actually a distributed load across the cross section that is exposed to the air flow. This assumption makes it easier to calculate the whole force of the wind which will help in analysis. The third assumption is that the speed of the rocket will be used as the speed of the wind, and any horizontal wind movement is negligible compared to the speed of the wind in the vertical direction. The last assumption that was made was that the pin stresses at point A will be much have much more significance than the pin stresses at B. The reason for this is that by inspection the pin forces at A will be in tension, while the pin forces at B will be in compression. Fiberglass fails in tension before compression due to their ultimate tensile and compression strengths. The ultimate tensile strength of G10 fiberglass is 38 ksi, while the ultimate compressive strength is 65 ksi according to a data sheet from matweb.com. That means to analyze the worst-case scenario, the reactions at A will be analyzed, and the pin at point B can be simplified to a roller, which makes the problem significantly easier to solve and more conservative.

The goal of this analysis is to calculate the magnitude of the reaction at point A, then use that force to calculate the bearing stress and the tensile stress at those points. Those stresses will be compared to the ultimate tensile strength of G10 fiberglass to see if the fiberglass is in danger of failing during flight.

The force of the wind can be calculated with Equation (3.5.1.) This equation was originally derived using Bernoulli's Principle. In this equation, ρ is the density of the air, V is the velocity of the air, C_d is the coefficient of drag, and A_s is the cross-sectional area exposed to the air flow. The coefficient of drag and velocity was obtained from an OpenRocket simulation.

$$F_w = \frac{1}{2}\rho V^2 C_d A_s \qquad (3.5.1.)$$

This analysis has three equations and three unknowns. Summing the moments about pin A yields the unknown B_x, summing the forces about the X axis yields the unknown A_x, and summing the forces about the Y axis yields the unknown A_y. These equations are shown in Equations (3.5.2-3.5.4.) In these equations, F_w is the force of the wind, b is the span of the fin, L_c is the length of the fin that is attached to the fin retention system, and c_r is the length of the root chord.

$$\sum M_A = 0 = F_w\left(\frac{b}{2}+\frac{L_c}{2}\right) - B_x(c_r - L_c) + F_g\left(\frac{b}{2}+\frac{L_c}{2}\right) \qquad (3.5.2.)$$

$$\sum F_x = 0 = A_x + B_x \qquad (3.5.3.)$$

$$\sum F_y = 0 = A_y - F_w - F_g \qquad (3.5.4.)$$

Using those equations, the magnitude and direction of the forces at pin A can be solved for. Using that force, a simple calculation can be made to solve the bearing and tensile stress in those areas. Using Equations (3.5.5) and (3.5.6), the magnitude of the tensile stress and bearing stress can be found. In these equations, d is the diameter of the screw hole, t is the thickness of the fin, and L_1 and L_2 characterize the lengths on each side of the screw hole where the fiberglass would fail. The failure would occur exactly perpendicular to the reaction force at pin A (R_A). Figure 3.5.3 shows the location of L_1 and L_2 on the fin. The angle of the reactionary force (103.27°) was found using simple trigonometry.

$$\sigma_T = \frac{\sqrt{A_x^2 + A_y^2}}{(L_1 + L_2)(t)} \qquad (3.5.5.)$$

$$\sigma_b = \frac{\sqrt{A_x^2 + A_y^2}}{(d)(t)} \tag{3.5.6.}$$

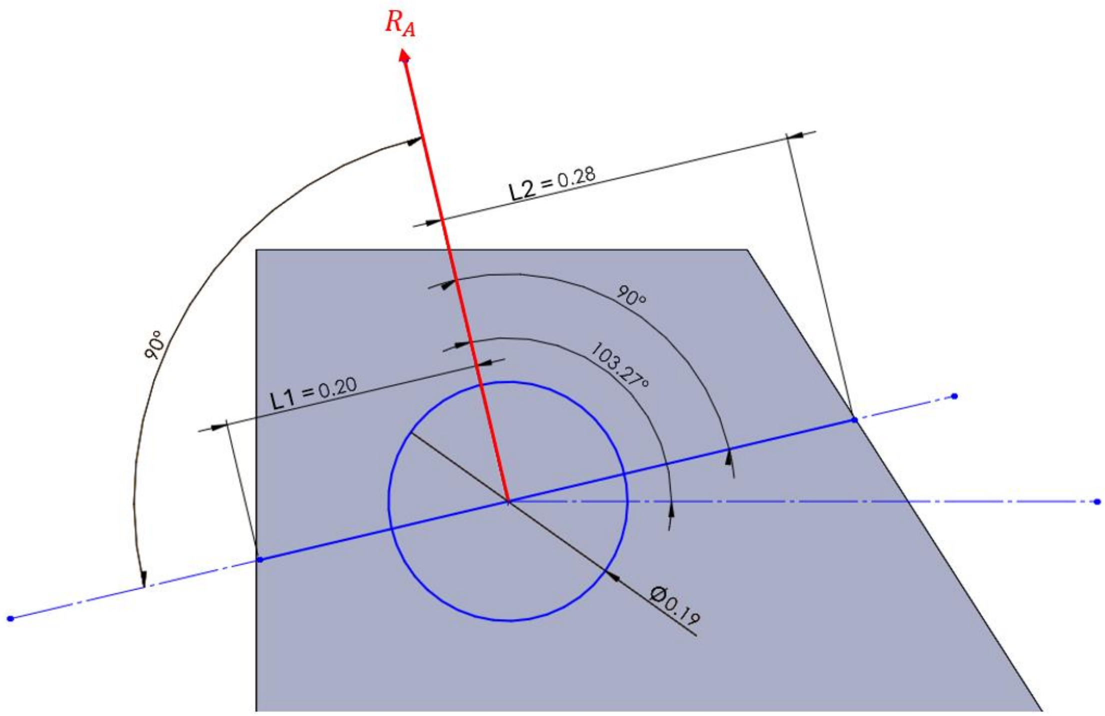

Figure 3.5.3. *Close Up of Screw Hole.*

The results from this mechanical design analysis are shown in Table 3.5.2. The results show that the fiberglass is far from failing even in the worst-case scenario from the load of the wind.

Table 3.5.2. *Results from Mechanical Design Analysis for Fins.*

Bearing Stress	Tensile Stress	Ultimate Tensile Strength
10.67 psi	3.647 psi	38,000 psi

3.5.3. Manufacturing

The CSL team has acquired all the fiberglass needed to manufacture the fins for the full-scale rocket. The team has decided to move forward with the process of cutting out the fins with the university's CNC machine. This takes out the potential human error of cutting out the fins by hand with a saw. The CNC machine will allow for the fins to be cut out with a great degree of precision.

3.6. Fin Retention System

3.6.1. Centering Rings

The centering rings are crucial in high-power rocketry by securing the motor tube and fins within the rocket's airframe. They ensure proper alignment, which is essential for stable flight. Figure 3.6.1 provides the primary design choice of the centering ring. Figures 3.6.2 and 3.6.3 highlight the dimensioned drawings. Both centering rings are identical, except that one has extra tapped holes for connection to the tail cone. These will be manufactured using Cedarville University's CNC machine from Aluminum 6061-T6, with all holes tapped using either a drill press or a mill. This design positions the holes that attach to the airframe offset from the fin connections. This chosen centering ring iteration prioritizes weight reduction and simplicity.

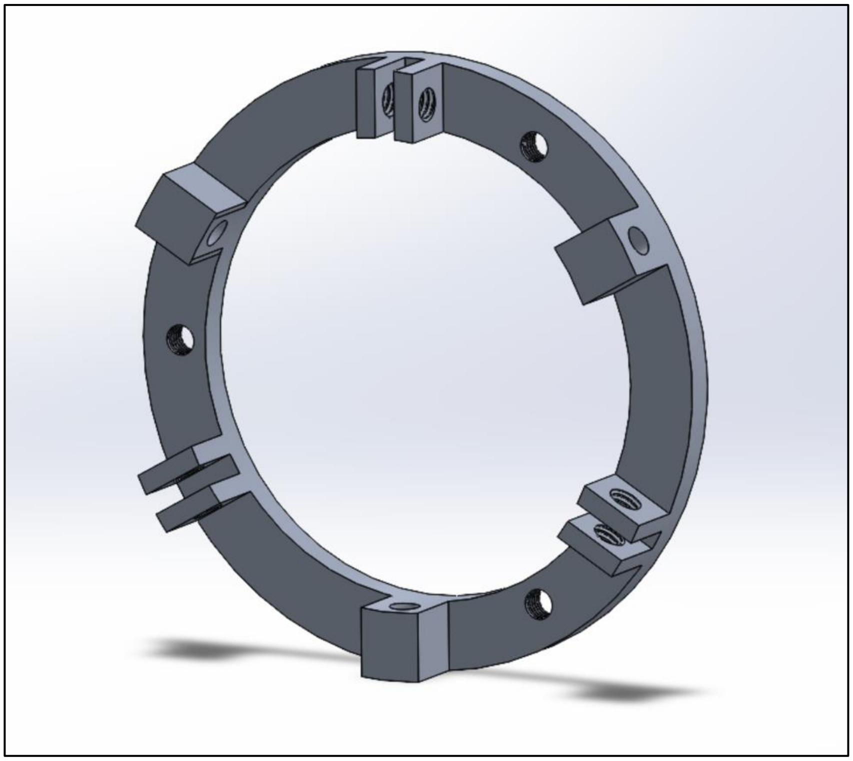

Figure 3.6.1. *Primary Design Choice for the Centering Ring.*

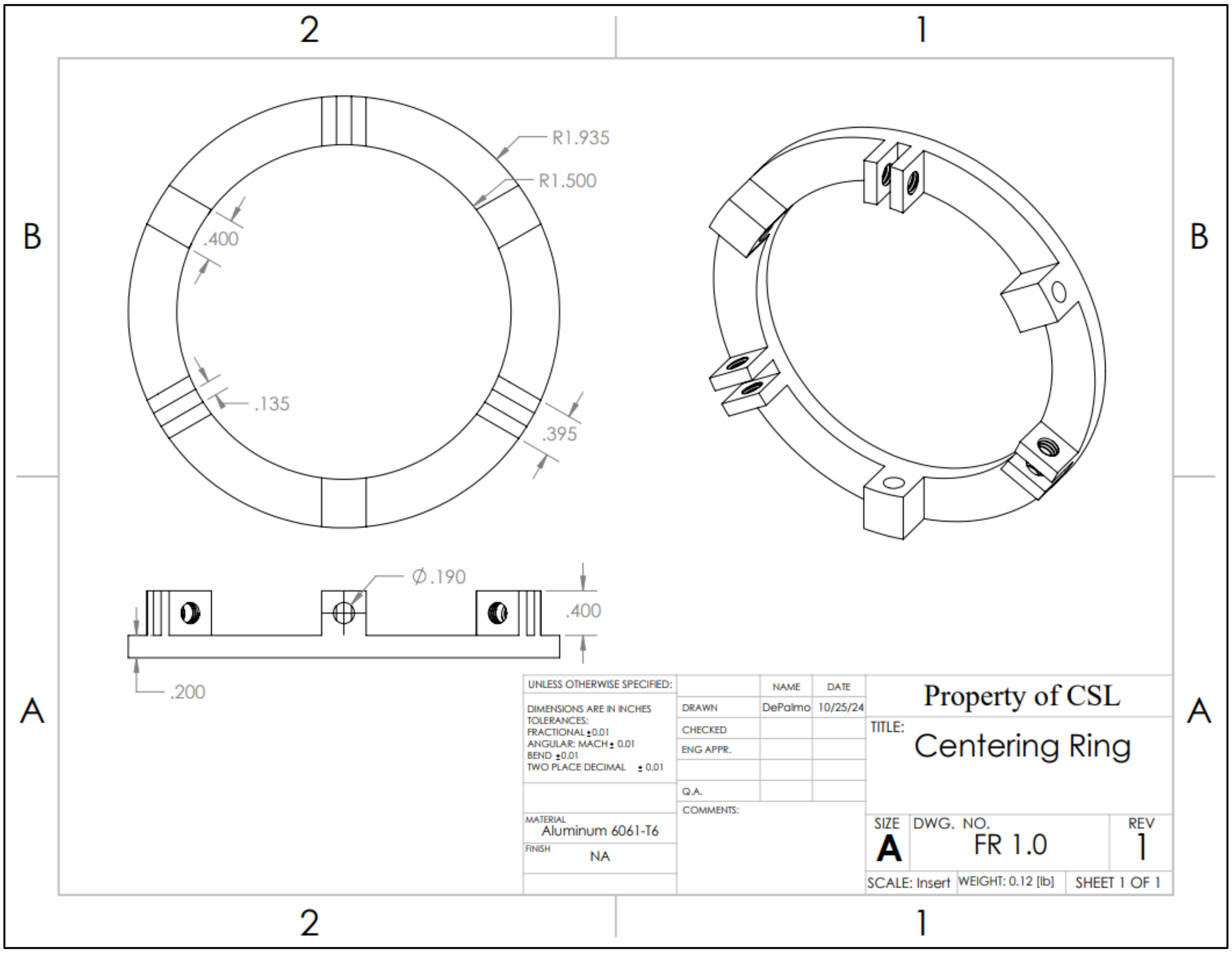

Figure 3.6.2. *Dimensioned SolidWorks Drawing of Centering Ring.*

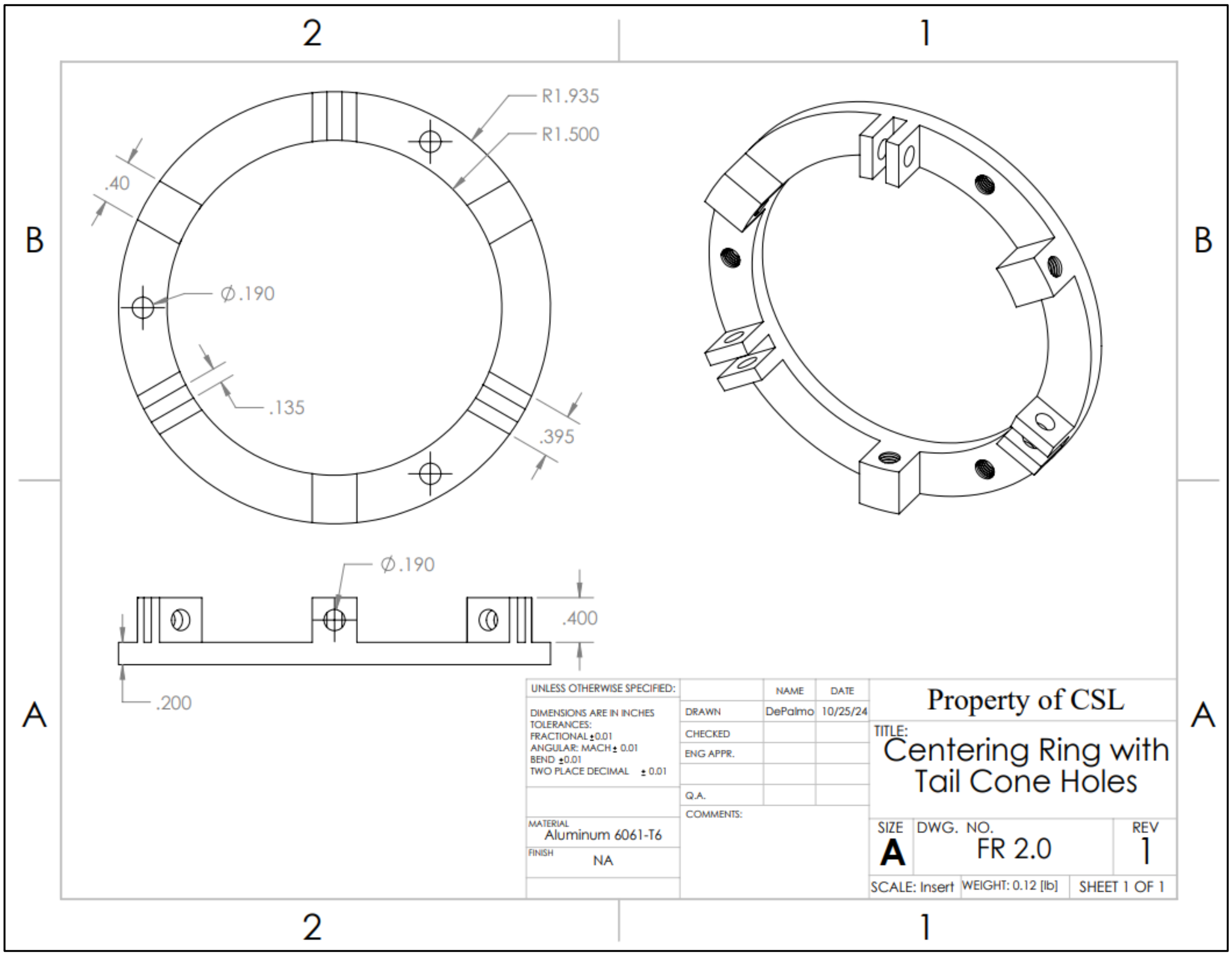

Figure 3.6.3. *Dimensioned SolidWorks Drawing of Centering Ring with Tapped Tail Cone Holes.*

3.6.2. Motor Retainment

The primary way CSL secures the motor in place is by using a 3D-printed flange designed to keep the motor centered within the aft section of the vehicle. The goal of this design is to reduce the weight of the assembly by using 3D-printed components. The flange will be glued to the motor retainer using epoxy so that the motor tube will be installed correctly. Figure 3.6.4 provides the primary design choice for the motor retainment, while Figure 3.6.5 provides a dimensioned SolidWorks drawing of the component.

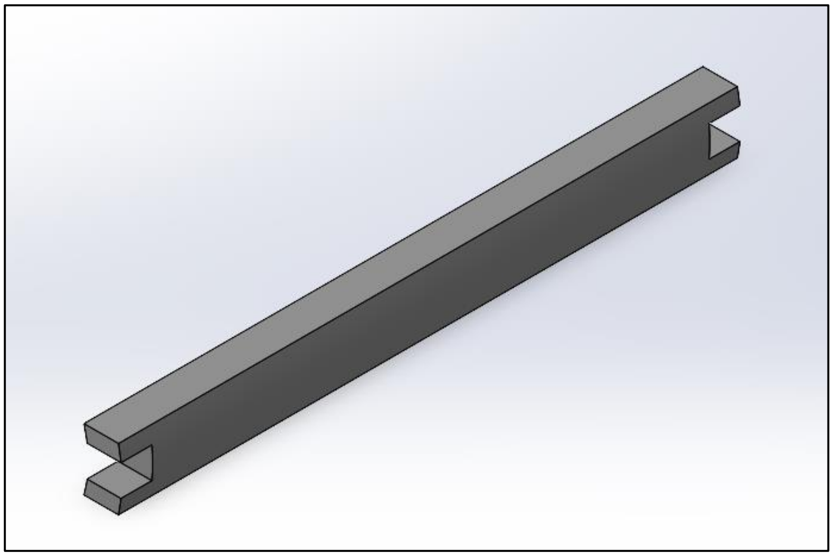

Figure 3.6.4. *Primary Component Design for Motor Retainment.*

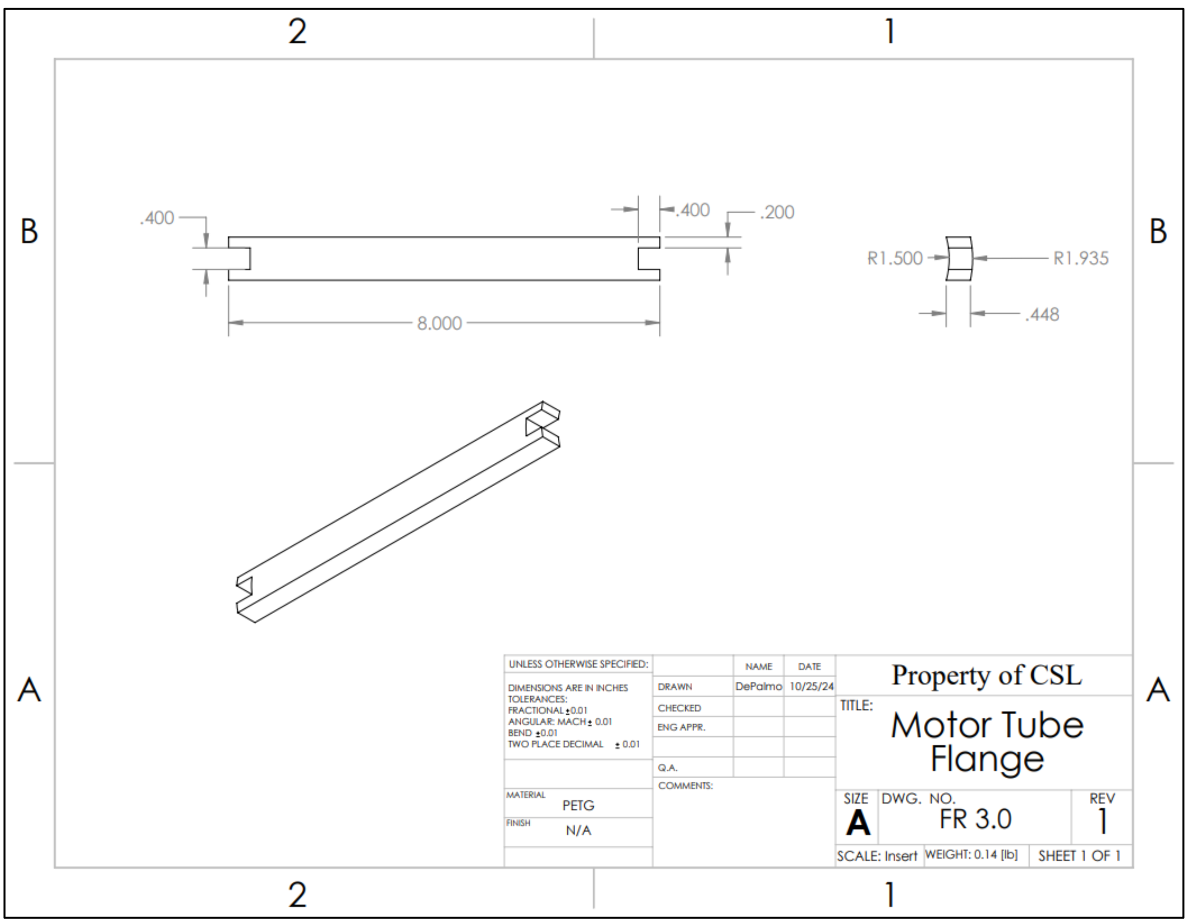

Figure 3.6.5. *Dimensioned SolidWorks Drawing of the Motor Retainment Flange.*

3.6.3. Design Analysis

An important part of selecting the primary designs is to ensure that the components will be able to withstand the high thrust forces undergone during the propelled ascension stage of flight. To determine that the selected design was adequate to meet this requirement, CSL performed an FEA analysis in SolidWorks on the primary centering ring design. Figure 3.6.7 shows the full-scale static simulation study performed on the centering ring.

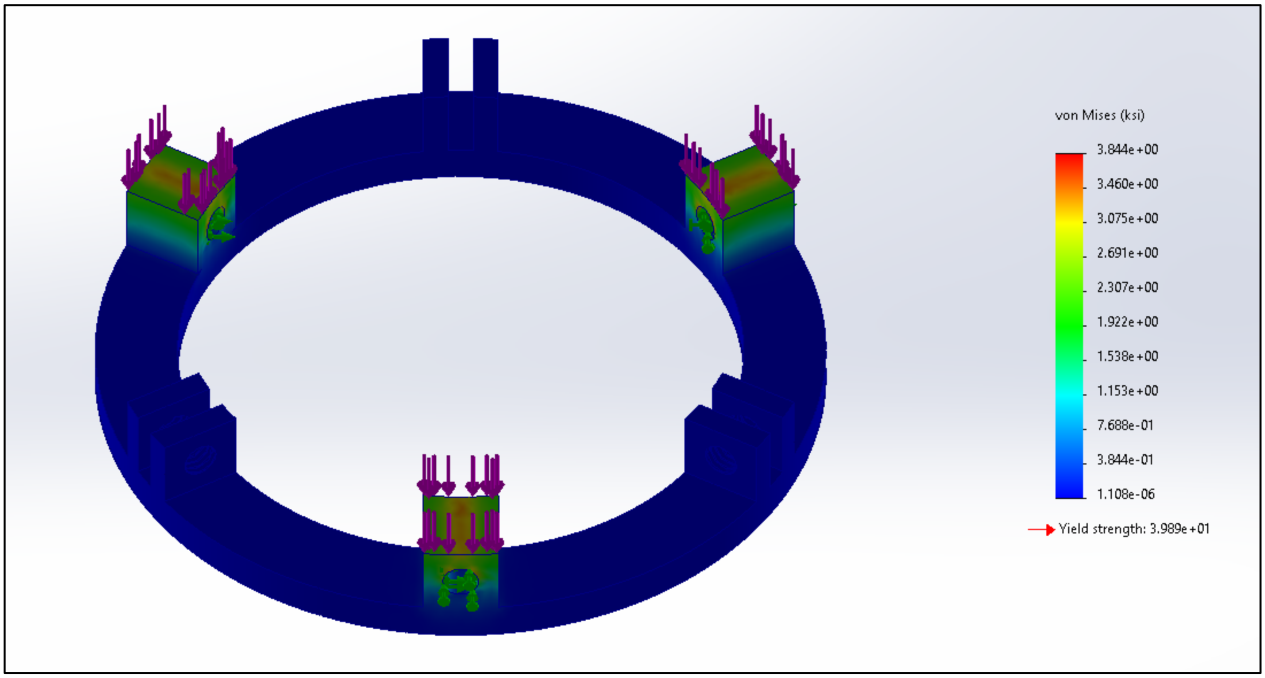

Figure 3.6.6. *FEA Analysis of the Full-Scale Centering Rings.*

The figure above shows the static simulation study performed on the centering rings. For the FEA analysis, it was assumed that the maximum thrust of the motor would be transferred from the motor retainment flange onto the centering rings. CSL assumed that the ring would be contained in the screw holes. The force was assumed to be 376.33 lbf, the maximum thrust of the AeroTech K1000T motor. It can be observed that the maximum von Mises stress on the centering ring is 3.298 ksi. Using these quantities, the safety factor, according to this FEA analysis, is approximately 12. Initially, CSL had wanted a safety factor of at least three, but this has far exceeded the initial safety margins. This design is well within safety margins and deemed acceptable for construction and flight.

CSL demonstrated that the motor retainment flanges would successfully hold the maximum thrust of the rocket during the subscale launch. Using 3D-printed parts in the aft section caused CSL to be concerned with the amount of force the motor would act on them. However, the subscale flight demonstrated success and provided valuable insight into motor retainment and proved it would hold with the full-scale launches. Since the motor used during the subscale was the AeroTech

J450DM-14A, where the maximum thrust is only 125.44 lbf, additional analysis is required to ensure the strength and stability of the motor retainment.

CSL will perform analysis on the 3D-printed parts, verifying that they can support the full-scale's high maximum thrust. This will be done by modeling the parts as isotropic because the flanges will be printed using full infill. If the failure criteria applied to the 3D-printed flanges are compared to the lowest strength of the appropriate material, then the flanges will predict non-failure under the most conservative conditions. This analysis will provide CSL confirmation that the motor retainment flanges will not fail due to the maximum thrust of the full-scale motor.

3.6.4. Manufacturing and Assembly

This fin and motor retainment design was chosen to reduce the complexity and weight of the entire subsystem. By integrating the 3D-printed flange, the turn-around time for manufacturing greatly decreased compared to using aluminum machined parts. The centering rings are CNC machined from Aluminum 6061-T6 with the holes tapped by using a drill press or a mill. The motor retainment flanges will be manufactured using PETG.

To ensure the components are in the correct place for assembly, CSL will measure where the flanges will sit on the motor tube and glue them into place using epoxy. Then, the motor tube can easily slide through the two centering rings and allow seamless integration between the components. The three fins will slide into the slots and screw in using stainless steel 1/2" 10-32 button head screws. These screws will also be used to attach the centering rings to the airframe. Using the same screw provides simplified assembly and disassembly procedures. Table 3.6.1 provides a bill of materials for the fin and motor retention assembly.

Table 3.6.1. *Complete Bill of Materials for the Fin and Motor Retainment Subsystem.*

Component	Material	Quantity
Fins	G10-Fiberglass Tube	3
Centering Ring	Aluminum 6061-T6	1
Centering Ring with Tail Cone Holes	Aluminum 6061-T6	1
1/2" 10-32 Button Head Screw	Stainless Steel	18
Motor Retainment Flange	PETG	3

3.7. Airbrakes

The airbrakes subsystem regulates apogee by controlling a set of deployable drag flaps in real time. These flaps adjust dynamically to reduce the apogee from expected altitude to the target of 4100 ft. During flight, the onboard control system manages the deployment and retraction of the flaps to optimize drag to achieve the precise apogee. Once near apogee, the flaps retract and remain stowed for the rest of the flight.

3.7.1. Mission Success Criteria

A successful flight will ideally carry the rocket to the desired apogee of 4100 ft with minimal mission and safety hazards. To verify the airbrake objectives were met, the following success criteria are shown below:

AB.S.1 Confirmation of AB deployment during launch.
AB.S.2 AB were stowed within ± 2 seconds of apogee.
AB.S.3 Rocket apogee achieved within ± 25 feet of target altitude.
AB.S.4 Confirmation of drag flaps actuation in the onboard camera.
AB.S.5 The drag flaps should be located no further than 2 inches behind the CP to ensure aerodynamic stability.
AB.S.6 No components of the system shall experience mechanical failure during any stage of flight.
AB.S.7 No electrical brownout or blackouts shall occur.

3.7.2. Subsystem Overview

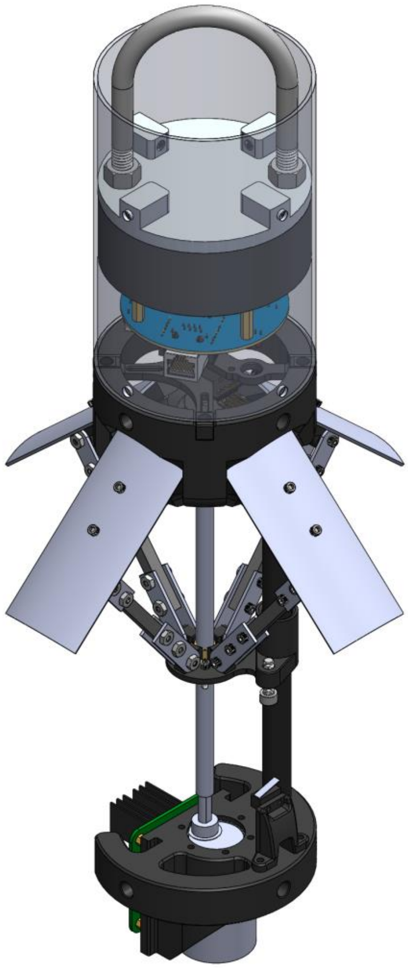

Figure 3.7.1. *Picture of the full Airbrakes CAD.*

The airbrakes, located in the aft section of the rocket, integrate mechanical and electrical subsystems (Figure 3.7.1). The mechanical components are housed at the base, directly above the rocket motor, while the electrons are positioned above, adjacent to the drogue chute bay. A shock chord and mount connect the system to the drogue chute bay. For terminology using in this section, refer to Figure 3.7.2.

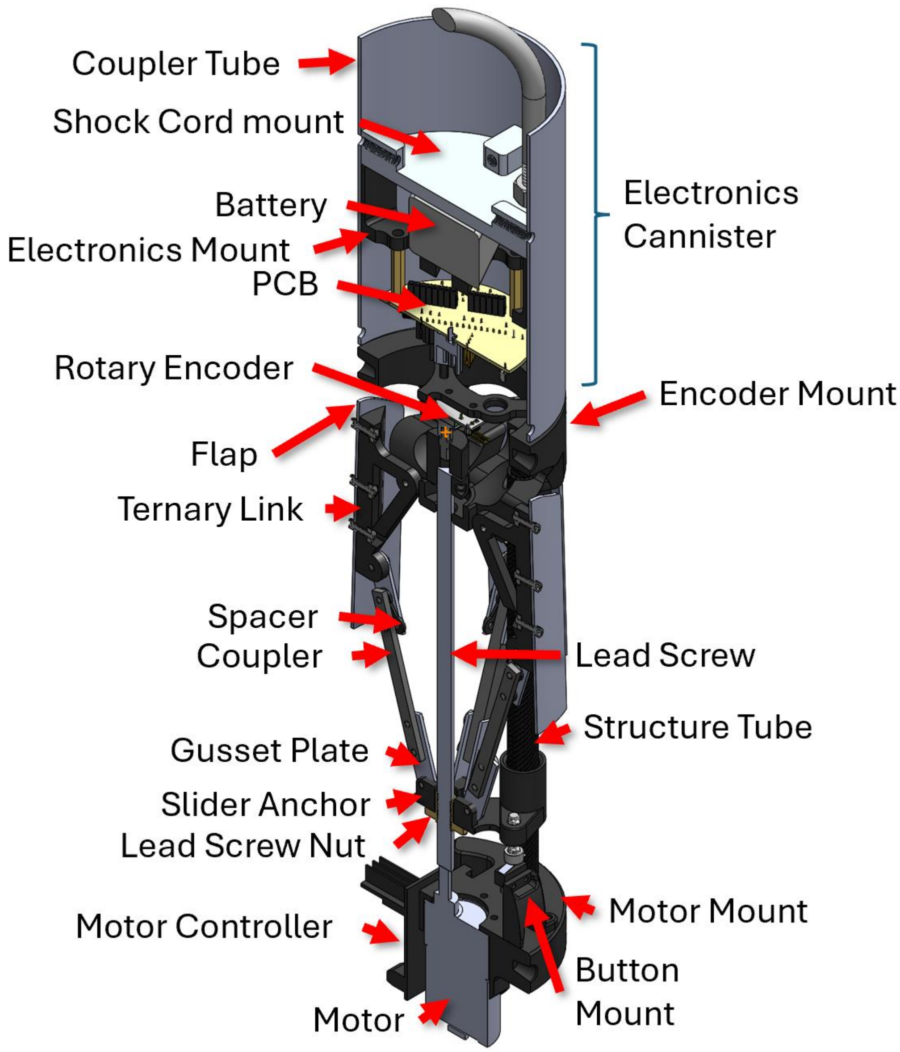

Figure 3.7.2. *The fully labeled section view of the airbrakes.*

To enhance modularity, the airbrakes are designed with independent mounting hardware for mechanical and electrical systems (Figure 3.7.2). The electronics are enclosed within a coupler tube, with a separation point above the encoder mount to facilitate assembly and maintenance.

The mechanical system activates by driving a motor which turns a lead screw, transmitting torque along the shaft. This motion pushed the lead screw nut and slider anchor upward, engaging the coupler, which transmits force through the gusset plate into the ternary. The ternary link actuated the flap, deploying it into the airstream to generate drag and reduce the rocket's overall velocity. This process, referred to as the "force transmission system," will be discussed in detail throughout this section.

3.7.2.1. Changes Since PDR

Several modifications have been made since the Preliminary Design Review (PDR), which are summarized here and expounded in the mechanical and electrical design analysis sections.

1. **Flap Size Adjustment:** The airbrakes flap size was reduced to limit the apogee reduction to approximately 750 ft, as the initial design could decrease apogee by over 1800 ft if deployed from motor burnout to ascent.
2. **Electrical Mounts:** CAD models now include mounts for the rotary encoder and button to improve integration.
3. **Ternary Link Updates:** The flap mount surface area was increased to mitigate flow-induced oscillations from vortex shedding. Lug attachment points to coupler link were adjusted due to increased gusset plate size.
4. **Structural Tube Revision:** The structural tube diameter was increased to accommodate additional wiring between the electronics housing and the system base.
5. **PCB Simplification:** The Ethernet cable now connects to a single puck-style PCB instead of multiple boards, streamlining the design.
6. **Separation Point:** A separation point in the rocket body fuselage was introduced beneath the electronics canister to enhance modularity and facilitate assembly.

3.7.2.2. Current Design

The current design incorporates minor adjustments to address functional assembly requirements:

1. An Ethernet cable and power wires will run from the electronics canister to the motor controller and button. While the CAD model lacks an Ethernet cable adapter with the required dimensions, this will be introduced in the final assembly.
2. Store-bought components, such as a helical shaft coupler connecting the motor shaft and lead screw and shaft collars to secure the structure tube, are not shown in the CAD model, but will be part of the final build.

3.7.2.3. System Integration

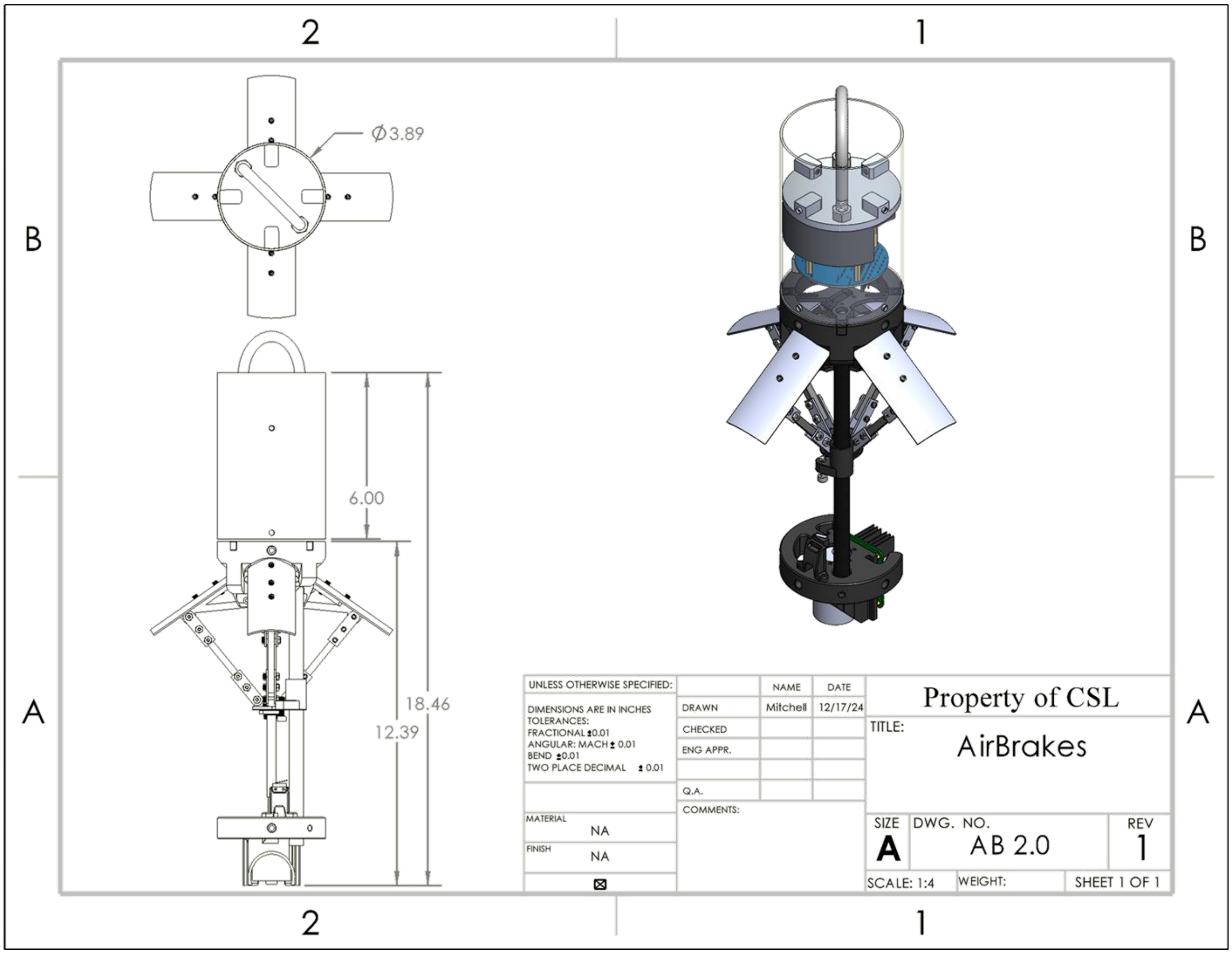

Figure 3.7.3. *Technical drawing of airbrakes subsystem with critical dimensions.*

Figure 3.7.3 illustrates the airbrakes subsystem with critical dimensions. The subsystem has diameter of just under 4 inches to ensure a snug fit with the airframe while minimizing friction. It measures 18.46 inches tall, accommodating the crank-slider mechanism—which ensures a constant angular velocity ratio without using gears—within the constraints of a narrow body tube. Increasing the subsystem height was preferred over enlarging the body tube diameter to preserve aerodynamic efficiency.

The bulkhead at the top protects the sensitive electronics from the black powder discharge during drogue chute deployment. Proper stowage of the airbrakes at apogee is critical to prevent parachute entanglement with the flap mechanism, which could compromise the mission.

The flap size was reduced to limit drag and mitigate adverse aerodynamics effects. Decreasing the flap surface area minimized these risks while maintaining functionality.

Although not shown in the CAD model, four holes will be added to the electronics canister to allow pressure and temperature sensors to acclimate to external conditions. The size of these holes will be calculated in the same way as the size of the pressure relief holes in the avionics bay.

3.7.3. Mechanical Design & Analysis

The airbrakes subsystem is constructed from multiple materials, selected based on dimensional and strength requirements and verified through analysis and testing.-

3.7.3.1. Fluid Analysis

The initial fluid flow analysis determined the forces acting on each flap using the PDR CAD model dimensions. Figure 3.7.4 illustrates the analytical approach, which Equation 3.7.1 defines the drag force calculations:

Where:

- $\rho = air\ density$
- $u_\infty\ =\ air\ velocity$
- $A_{projected} = projected\ area$
- $\theta = flap\ angle$

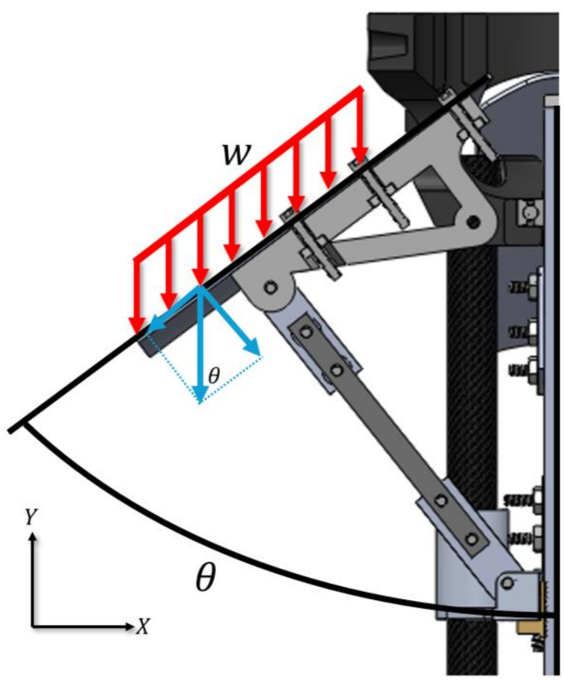

Figure 3.7.4. *The analytical technique for the fluid flow over the airbrakes flap.*

At an altitude of 3,030 ft above sea level, the conditions resulted in a drag force of approximately 30.57 N (6.85 lbs). This analysis assumed deployment at five seconds into the flight to avoid premature activation, allowing the algorithm sufficient data for predictive modeling and ensuring the flight is not impeded. Refer to Figure 3.7.5 to see the flight path characteristics at certain altitudes.

$$Drag = \rho u_{\infty}^{2} A_{projected}\, sin^{2}(\theta) \quad (3.7.1.)$$
$$= (1.123\left[\frac{kg}{m^3}\right])(137.16\left[\frac{m}{s^2}\right])(2.686 \cdot 10^{-3}[m^2])\sin^2(47.25°)$$
$$= 30.574[N]$$
$$= 6.85[lbs]$$

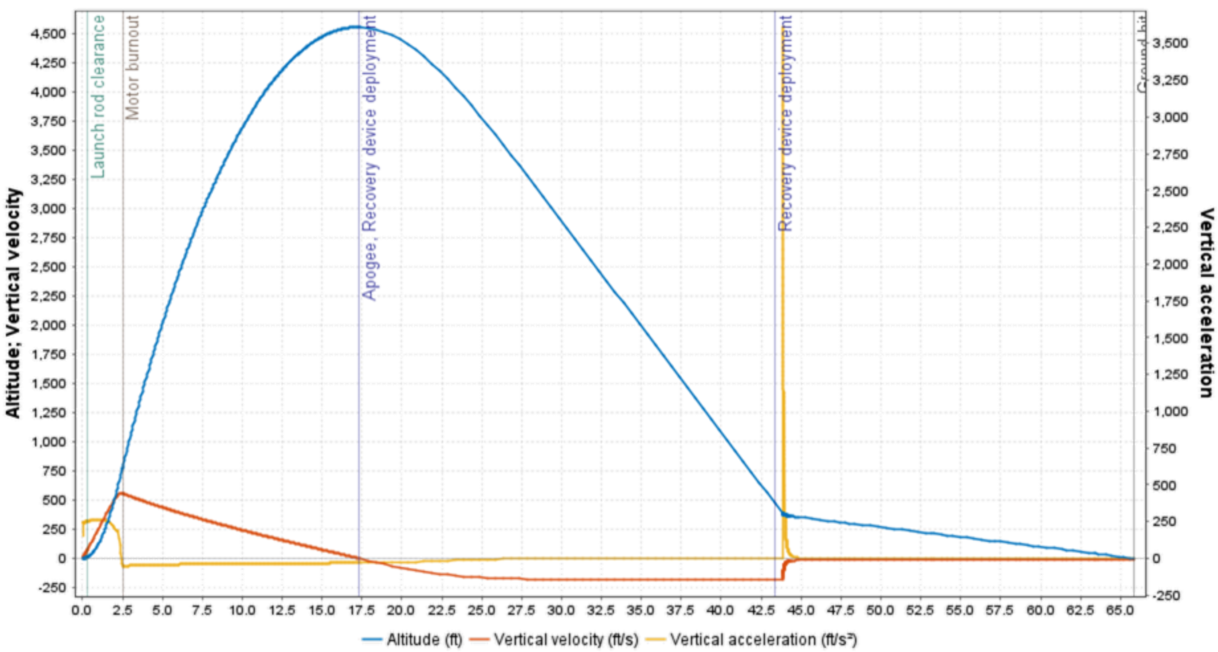

Figure 3.7.5. *The flight path curve given in the PDR, used to calculate the airbrakes fluid force.*

CFD simulations using ANSYS Fluent validated these critical results. By modeling the airbrakes and rocket with varying boundary conditions, the software calculated forces, drag coefficients, and flow characteristics. Figure 3.7.6 presents a pressure and velocity contour for the flaps at a 45° angle with the wind velocity of 450 ft/s. CFD estimated a force of 46.6 N (10.48 lbs) per flap, aligning with the analytical results and confirming a conservative design load of 10.5 lbs.

Figure 3.7.6. *CFD results for the airbrakes when positioned at 45deg with a pressure contour over the airbrakes and a velocity contour for the wind flowing around them.*

Due to the flaps being oversized, the area of the flap was later recalculated. The flaps were set to decrease the apogee of the rocket by over 1800 ft, which far exceeded the amount needed to reach the target altitude. Thus, the airbrake flap area was decreased. The new cross-sectional area of the rocket with airbrakes fully deployed was determined using a simple MATLAB program. This MATLAB program simulates the coast phase of the flight using the drag coefficient, burnout velocity, and burnout altitude obtained from an OpenRocket simulation. The new cross-sectional area was found by assuming the airbrakes were deployed fully at motor burnout and finding the area that produced enough drag to lower the apogee by 750' rather than the 1800' of the previous design.

3.7.3.2. Pin Force Analysis

A pin force analysis was performed using the results from the fluid flow analysis to determine forces at each joint. This ensured optimal metal selection and avoided premature failure due to overloading. Figure 3.7.7 illustrates the free-body diagram (FBD) for the airbrake's mechanism, where:

- F_x and F_y are forces in the x- and y-directions.
- w is the distributed force applied at the centre of pressure.
- A is the reaction force at Pin A.
- α is the angle between the coupler axis and the y-axis.
- D_{yo}, D_{xo}, D_{x1} are the distances from respective forces application points.

Static Equilibrium Equations:

Equation 3.7.2-3.7.4 model the static equilibrium equations of the mechanism. For this simple three equations three unknowns, a MATLAB code was used to solve for the three forces at the pins (this code can be seen in Appendix A.1.).

$$\sum F_x = 0 = F_x + A\sin(\alpha) \tag{3.7.2.}$$
$$\sum F_y = 0 = F_y - w - A\cos(\alpha) \tag{3.7.3.}$$
$$\sum M_o = 0 = F_y(D_{xo}) - F_x D_{yo} + wD_{x1} \tag{3.7.4.}$$

The forces calculated at the pins are shown in Equation 3.7.5 when the 6.85-pound force is applied.

$$\begin{aligned} F_x &= 5.4105[lb] \\ F_y &= 1.0788[lb] \\ A &= 7.9108[lb] \end{aligned} \tag{3.7.5.}$$

These results confirm that the system experiences relatively low forces under static loading. The two-force member adjacent to the load absorbs most of the force, while the left-hand pin provides stability and prevents moments on the ternary link. If the flap length increased (not planned), F_x would increase monotonically with it. The following analysis will determine if the system operates within operational limits.

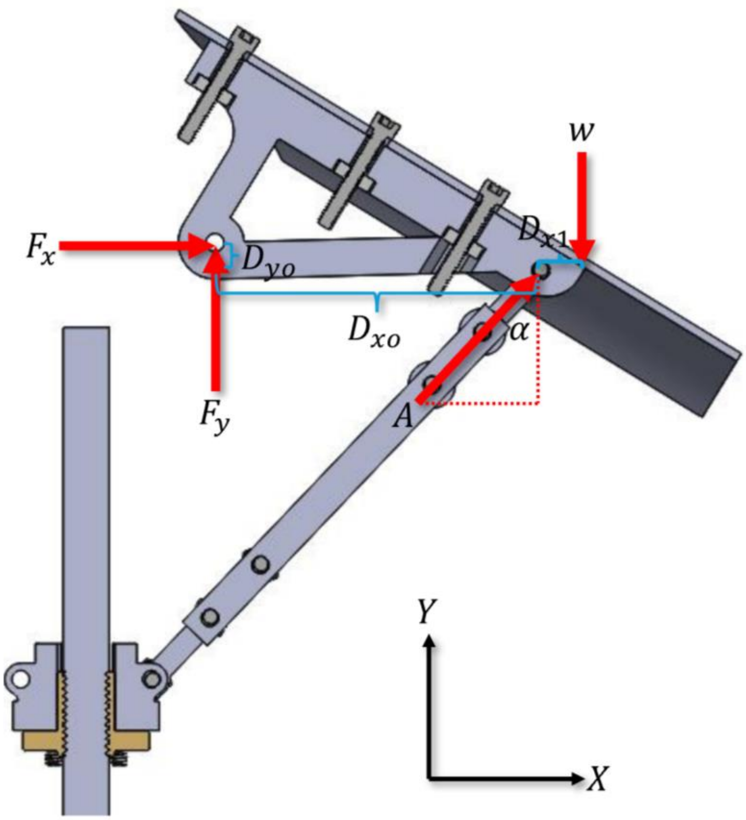

Figure 3.7.7. *FBD to model the pin joints.*

3.7.3.3. *Slider Anchor Analysis*

An analysis of the slider anchor, shown in Figure 3.7.8, was conducted to assess its ability to withstand the expected static forces in the "force transmission system." Given its small size and critical role in the airbrakes system, the slider anchor was prioritized for scrupulous evaluation.

Finite Element Analysis (FEA)

Using ABAQUA, an FEA was conducted to determine if the slider anchor could fail under static loading conditions given its specific material. The 3D-Printed material (PETG) was modeled isotopically, assuming full infill for conservative analysis (Zou et al., 2016). The analysis focused on the "lug," the loaded portion most susceptible to failure. Boundary connections replicated physical constraints by fixing the base of the loaded section, as shown in Figure 3.7.9.

A safety factor of 2 was applied, resulting in a load of 15.28 pounds distributed over the lug's lower quarter. PETG's reported ultimate compressive strength of 8402.26 psi was compared against the maximum bearing stress of 1246 psi predicted by the model (Lakshman S.V. et al.,2024). This result indicates the lug will not fail under the expected static loads.

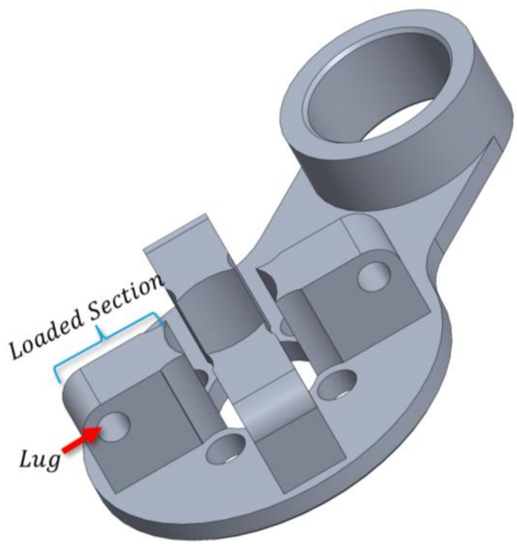

Figure 3.7.8. *Slider anchor CAD model during iteration process.*

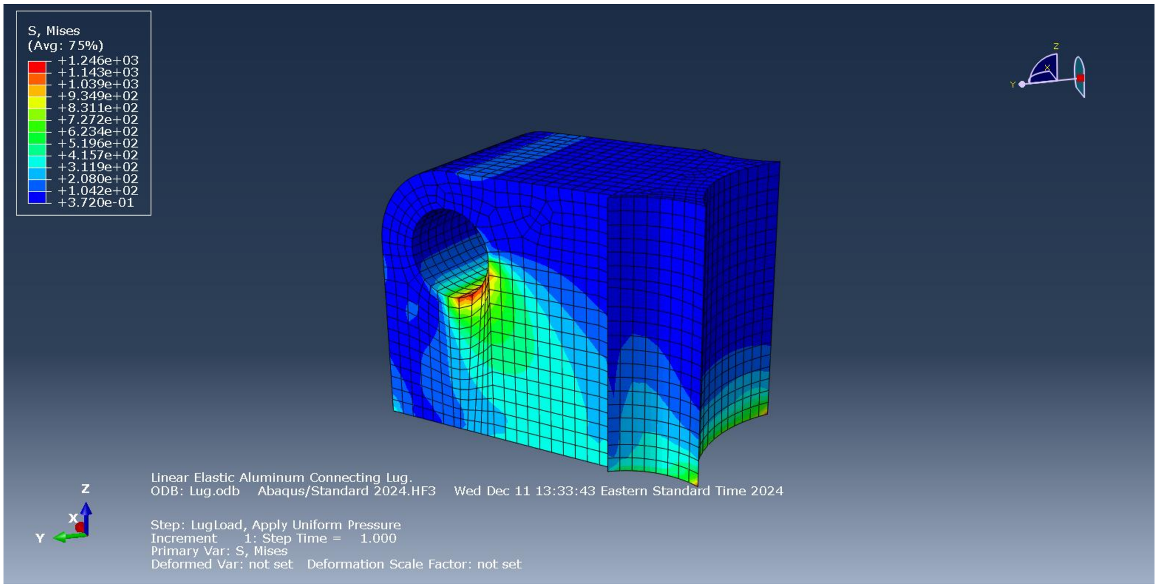

Figure 3.7.9. *FEM of the loaded section with a pressure load applied to the lug in the orientation of application from the coupler.*

Kinematic Analysis

In addition to structural analysis, the kinematic performance of the slider anchor was calculated. The anchor's design included a loop that slides along a carbon fiber rod. Improper slider height could cause binding due to static friction, like a misaligned drawer hinge. If binding occurs, increasing force would exacerbate the issue, hindering operability. Figure 3.7.12 illustrates the forces acting on the slider anchor. Equations (3.7.6) through (3.7.10) model the static kinematic connections of the slider during lock-up scenarios. The critical variable, μ (the coefficient of friction), is defined geometrically in Equation 3.7.11:

$$\sum F_y = 0 = -F_1 + f_2 + f_3 \tag{3.7.6.}$$

$$\sum F_x = 0 = N_2 - N_3 \tag{3.7.7.}$$

$$\sum M_2 = 0 = (l - r)F_1 - N_3 a + f_3(2r) \tag{3.7.9.}$$

$$f_2 \leq \mu N_2 \tag{3.7.8.}$$

$$f_3 \leq \mu N_3 \tag{3.7.9.}$$

$$\mu = \frac{a}{2l} \tag{3.7.10.}$$

Where a is the slider height, and l is he fixed geometric parameter.

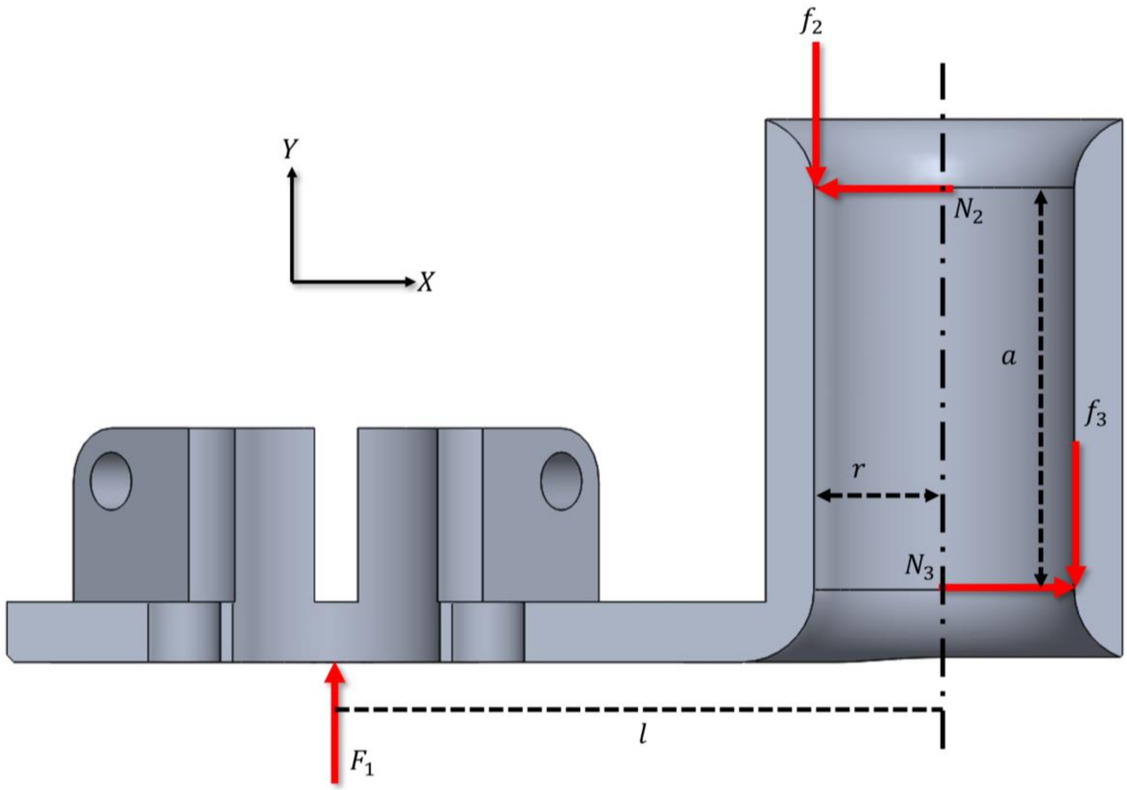

Figure 3.7.10. *FBD of the slider anchor for kinematic analysis.*

Literature reports a coefficient of friction of $\mu \approx 0.65$ for carbon fiber against itself (Schön, 2004). Testing revealed that for $a = 0.5, \mu = 0.1984$, resulting in lock-up. Increasing a to 1.0 produced $\mu = 0.3968$, which allowed smooth operation. Experimental results confirmed that $a = 1.0$ is sufficient to prevent lock-up without further material failure testing.

By addressing both static forces and kinematic constrains, the slider anchor design ensures reliable operation within the airbrakes force transmission system

3.7.3.4. Gusset Plate Analysis

The force transmission system culminates at the slider anchor, where forces are balanced in three-dimensional space as established in the PDR. Beyond this point, the force transmits through the gusset plate and connecting screws, requiring an analysis to optimize connection points.

Material Selection

6061 T6 aluminum was chosen for the gusset plate due to its superior impact resistance. While 3D-printed material was considered, their significantly lower impact energy (around 2.73 to 3.1 lb-ft for PETG vs. 13.7 to 17 lb-ft for aluminum) rendered aluminum the more reliable choice for handling unpredictable external loads.

Failure Modes

1. Shear Failure in Connecting Screw

The connecting screw, a "Black-Oxide Alloy Steel Socket Head Screw 4-40 Thread Size, 3/8" Long," experiences double shear (McMaster-Carr, 2019). The allowable shear stress was calculated using the Von Mises criterion (Equation 3.7.12), yielding at $9.8150 \cdot 10^4 [psi]$ (Norton, 2020).

$$\tau_{allowable} = \frac{\sigma_t}{\sqrt{3}} = \frac{17 \cdot 10^4 [psi]}{\sqrt{3}} = 9.8150 \cdot 10^4 [psi] \quad (3.7.11.)$$

The applied shear stress, adjusted for a safety factor, was found to be $803.96\ [psi]$, well below the allowable limit, confirming the screw's structural integrity (Figure 3.7.11).

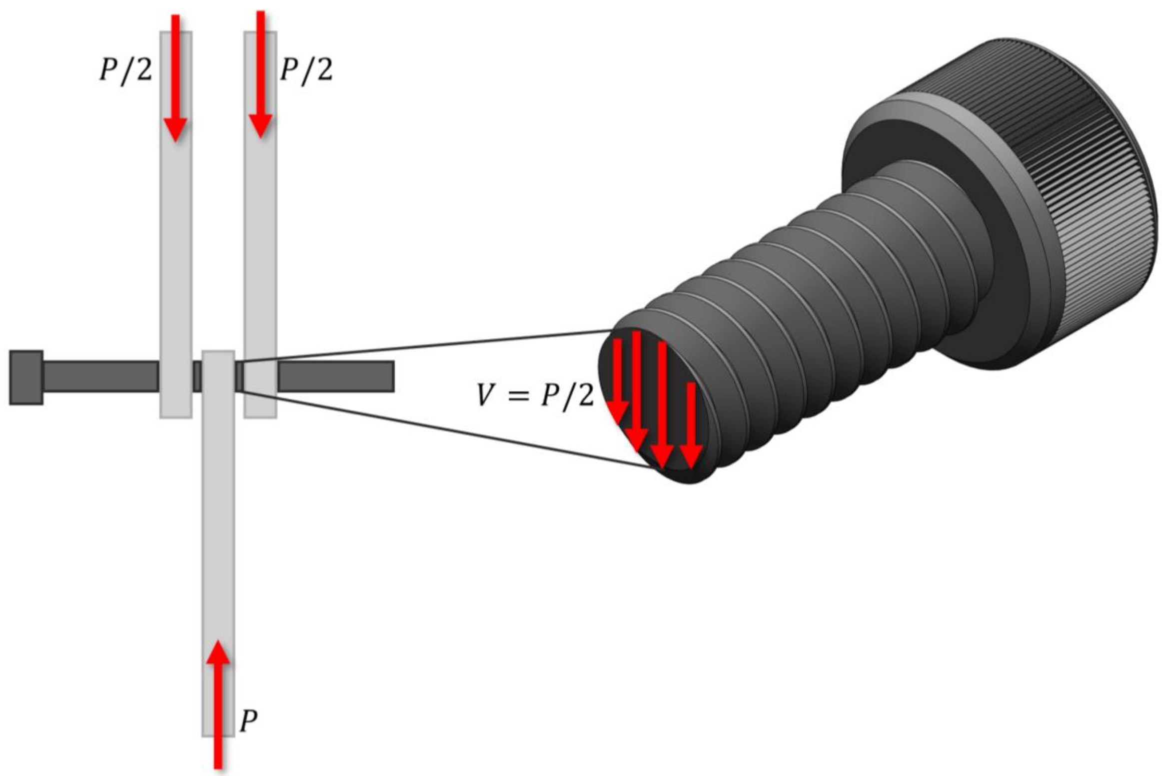

Figure 3.7.11. *Failure of bolt via pure shear.*

2. Tensile Failure in Gusset Plate

The gusset plate's thickness, h, was calculated using Equation 3.7.13:

$$h = \frac{\frac{F(SF)}{2}}{(2D + 0.03)\sigma_{allow}} \quad (3.7.13.)$$

$$h = 0.001318\ [in]$$

Where $\sigma_{allow} = 40 \cdot 10^4\ [psi]$. The computed thickness, $h = 0.0013\ [in]$, was increased to 1/32" for manufacturability and robustness. See Figure 3.7.12 for gusset plate failure illustration.

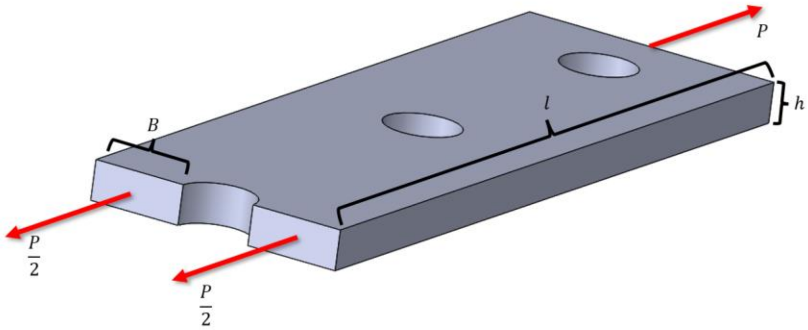

Figure 3.7.12. *Failure in gusset plate due to pure tension.*

3. **Bearing Stress Failure**

Bearing stress, modeled in Equation 3.7.14, install output a safe force limit of 4.43 pounds under the initially very small thickness of the plate, which prompted an increase in material thickness to 1/32". This adjustment raised the bearing stress capacity to about 105 pound per side, or 210 pounds total, ensuring structural reliability under loading (Figure 3.7.13)

$$N_{safe} = Dh\sigma_{allowable}(SF) \qquad (3.7.14.)$$

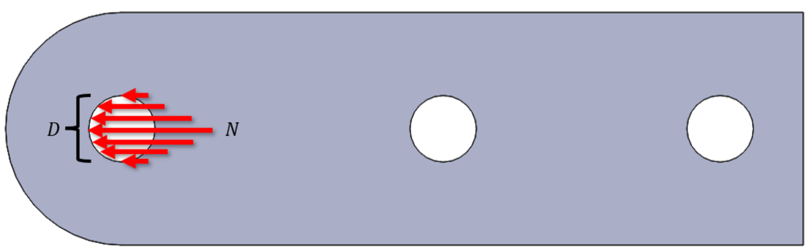

Figure 3.7.13. *Failure in the gusset plate due to bearing.*

4. **Tear-Out Failure**

Tear-out was evaluated using Equation 3.7.15:

$$\tau_{allow} = \frac{V}{A} = \frac{P}{zh}(SF) \qquad (3.7.15.)$$

The allowable shear stress for the plate ($\tau_{allow} = 3 \cdot 10^4[psi]$) comfortably exceeded the maximum stress of 937.57 psi, confirming the gusset plate's resistance to tear-out under operational loads (Figure 3.7.14).

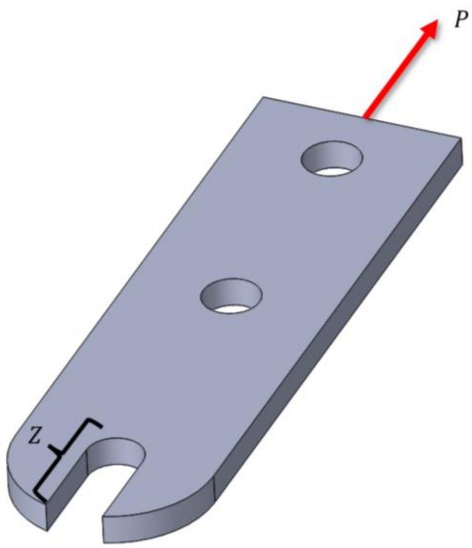

Figure 3.7.14. *Failure in the gusset plate due to tear out.*

Conclusion

The gusset plate, with its dimensions and material selection, is capable of withstanding all analyzed failure mode, ensuring reliable force transmission and structural integrity in the air brakes system with a safety factor of at least two.

3.7.3.5. Coupler Testing

The coupler, a key component of the force transmission system, underwent testing to evaluate failure modes.

Initial Test

The first, unexpected failure (Figure 3.7.15) occurred due to fiber reinforced anisotropic delamination (Wisnom, 2012). This failure was caused by the introduction of a stress concentration at the screw hole when a slightly oversized screw was threaded though. The stress propagated a crack in the material, which expanded through the brittle matrix until it reached a critical length. To prevent recurrence, only specific screws (4-40 coarse thread) will be used.

Figure 3.7.15. *Failure in the coupler due to fiber reinforced anisotropic delamination.*

Tensile Testing

With the correct screws installed, a tensile test was conducted to evaluate the bearing strength and failure mechanism of the coupler material. The coupler, made from a 6mm pultruded carbon fiber composite with an epoxy matrix and a 4mm hollow center, was selected for its exceptional strength and lightweight properties. Figure 3.7.16 shows the test apparatus prior to testing.

Figure 3.7.16. *Tensile test apparatus before the test commenced.*

During the test (Figure 3.7.17), the coupler held approximately $230[lbs]$ before failure. Although the failure mode was expected to be compression, tensile testing was conducted due to alignment challenges. Misalignment could lead to eccentric buckling in compression, thus compromising test validity. The distance from the end to the hole matched the compression failure configuration (~0.5 inches).

Figure 3.7.17. *Tensile test of coupler link in the INSTRON machine.*

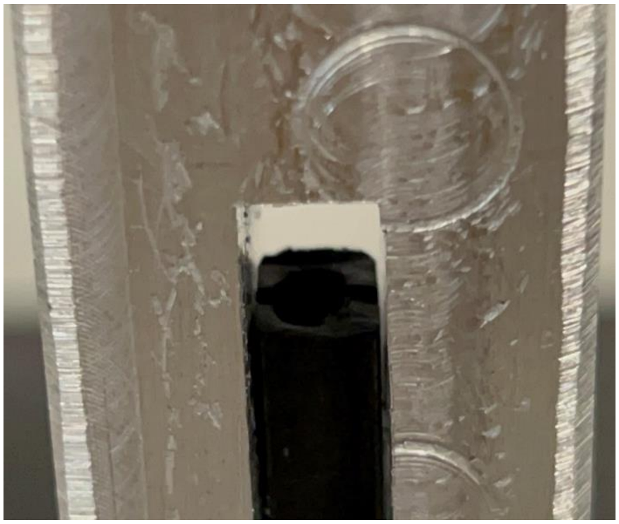

Figure 3.7.18. *Tensile test of coupler link in the INSTRON machine after failure.*

As shown in Figure 3.7.18, the coupler failed via the same fiber-reinforced anisotropic delamination observed in the initial screw-induced fracture. Although only one specimen was tested, the failure force of $230\ [lbs]$ far exceeded the expected operational load. This made additional tensile testing unnecessary. See Figure 3.7.19 for post tensile test failure specimen.

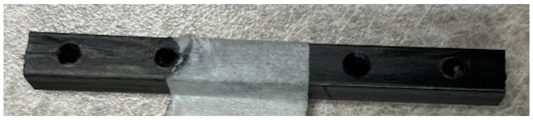

Figure 3.7.19. *Tensile specimen after failure.*

Compression Testing

To validate gusset plate calculation, a compression buckling test was conducted. The test setup (Figure 3.7.20) simulated the coupler and gusset plate load case in the airbrakes. The first test (Figure 3.7.21) demonstrated a peak load of $351\ [lbs]$, significantly exceeding the expected load. A second test recorded a lower but acceptable load of $258\ [lbs]$, well above the operational requirement of 10.5 $[lbs]$.

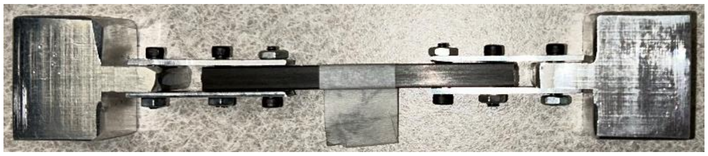

Figure 3.7.20. *Compression buckling test on the coupler.*

Figure 3.7.21. *Compression test of the full coupler link and gusset connector plates in the INSTRON machine.*

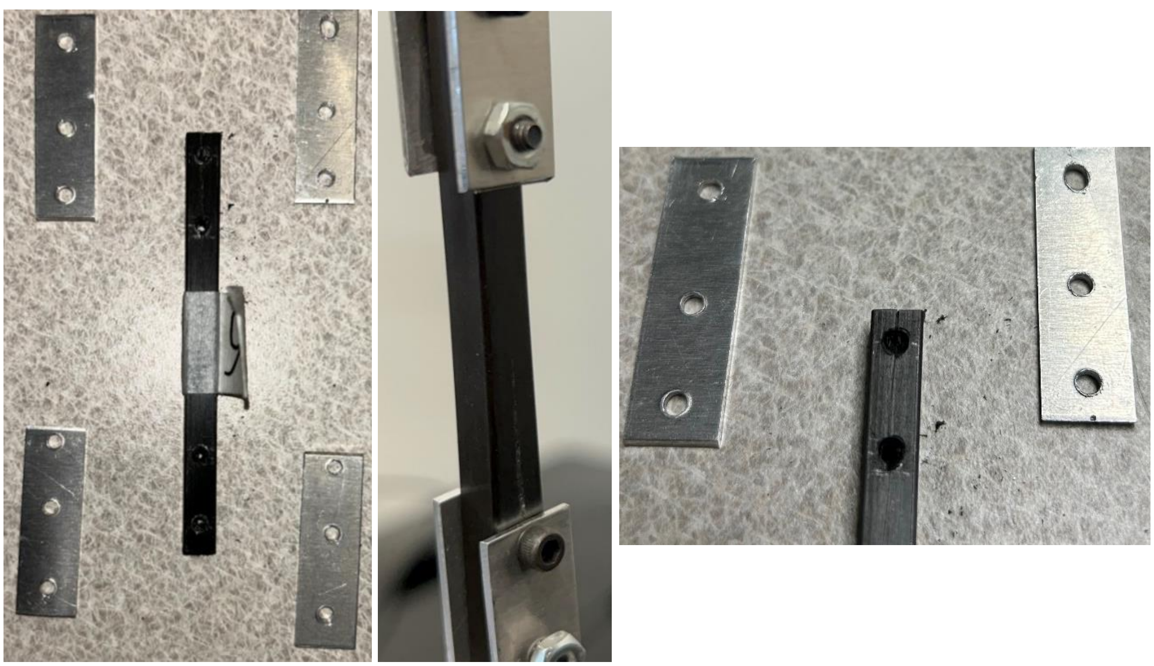

Figure 3.7.22. *Post test processing photos: failure in rod.*

Post-test analysis (Figure 3.7.22) showed minimal damage to the gusset plates, with failure localized to the carbon fiber rod. All tests consistently exhibited fiber-reinforced anisotropic delamination at the primary failure mode.

Conclusion

The coupler is overdesigned, but very easily manufacturable given the current materials, providing a high safety margin for unknown flight loads. While the current design is robust, future revisions may optimize material usage if currently unknown loads are confirmed to be negligible.

3.7.3.6. Ternary Link Analysis

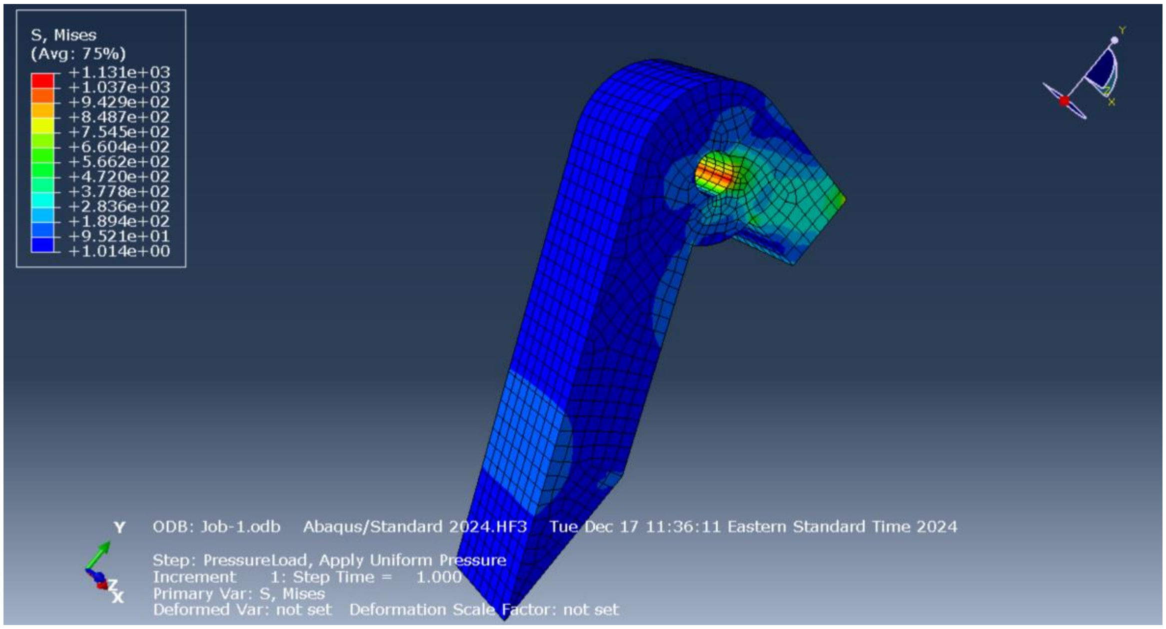

Figure 3.7.23. *The FEM of the ternary link in ABAQUS with* $24\ [lbs]$ *of load applied.*

The final component in the force transmission system is the ternary link. This component features two connection points with different geometries. Bearing failure was analyzed at one connection using the maximum expected load. A pressure load of $F[lb](SF) = 24\ [lb]$ (where F is the pin force and $SF = 2$) was applied. Figure 3.7.23 illustrates the FEM simulation in ABAQUS, with stationary boundary conditions applied at the cutoff points.

The same assumptions used in prior FEM analyses were applied, as the ternary link is 3D-printed. The Von Mises stress was compared to the lowest ultimate tensile stress of PETG, and the material was assumed to be isotropic. The FEM predicted a stress of $1.131\ [kpsi]$, while PETG's ultimate compressive strength is approximately $8.4\ [kpsi]$. Thus, the ternary link is not expected to fail under bearing stress.

3.7.3.7. Flap Analysis

A literature review confirmed that fiberglass is a suitable material for airbrake flaps due to its tensile strength and flexural modulus. According to Laminated Platics Distributors (2017), G-10 Fiberglass has a tensile strength of $38\ [kpsi]$ in its weakest configuration, far exceeding the expected $5.85\ [psi]$ per flap. The flexural modulus of $2400\ [kspi]$ ensures negligible deflation under load, as calculated using Hooke's law in Equation 3.7.16:

$$\epsilon = \frac{\sigma}{E_f} = 2.4375 \cdot 10^{-6}[in] \quad (3.7.16.)$$

Resonant frequencies of the airbrake flaps were analyzed in SolidWorks to mitigate risks of vibration-induced damage. Custom material properties for PETG and G12 fiberglass were input, and a $15\ [lb]$ wind force was applied to achieve a safety factor of 1.5. Fixtures were defined at attachment points to the airframe and stationary elements like the lead screw and structure tube. The analysis produced five resonant modes (Table 3.7.1), with frequencies ranging from $173\ [Hz]$ to $246\ [Hz]$ (Figure 3.7.20, Gilmore et al., 2018).

Figure 3.7.24. *Vibrational Analysis Done in SolidWorks.*

Table 3.7.1. *Resonant Frequencies Under Wind Load.*

Mode Number	Frequency (rad/s)	Frequency (Hz)
1	1087.8	173.12
2	1154.3	183.71
3	1179.5	187.73
4	1250	198.95
5	1549.8	246.66

To evaluate the risk of vortex shedding, the Strouhal number was calculated using the Reynolds number derived from Equation 3.7.17:

$$Re = \frac{\rho V L}{\mu} \quad (3.7.17.)$$

For this analysis, $Re = 8.382 \cdot 10^5$, corresponding to a Strouhl number of approximately 0.225 (Figure 3.7.21, White, 2008). The vortex shedding frequency was then calculated using Equation 3.7.18,

$$f = \frac{St \cdot V}{L} \tag{3.7.18.}$$

where:

- $St = Strouhl\ Number$
- $V = Velocity$
- $L = Characteristic\ Length$

The resulting frequency, 499.6 $[Hz]$, is significantly higher than the resonant frequencies of the airbrakes. Therefore, the design is robust against vibration-induced oscillatory damage caused by vortex shedding.

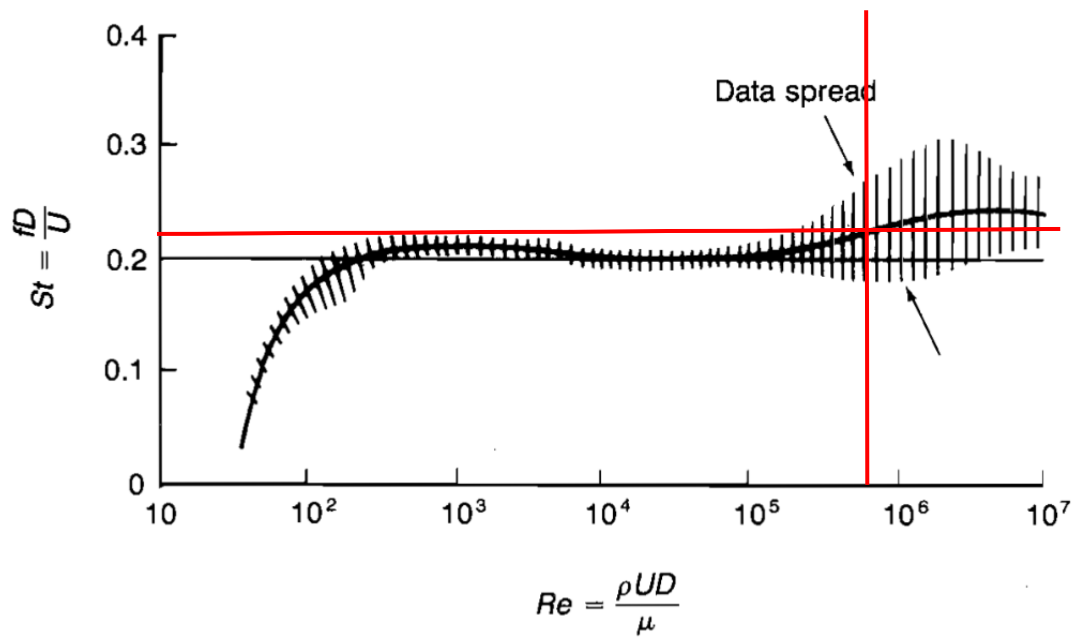

Figure 3.7.25. *Strouhal Number as a Function of Reynold's Number.*

3.7.3.8. Mechanism Components

The airbrakes system comprises various components made from different materials, as outlined in Table 3.7.2. This table summarizes the material, cost, and manufacturing method for each component.

Table 3.7.2. Material cost breakdown of each component in the Airbrakes.

Component	Material	Cost	Manufacturing Method
Flaps	G10-Fiberglass Tube	Owned	Stencil and Dremel
Ternary Link	PETG	Owned	3D printing
Ternary Link Fasteners	Black-Oxide Alloy Steel Socket Head Screw 4-40 Thread Size, 1" Long, Fully Threaded	8.68	N/A
Coupler	Pultruded Carbon Fiber - Square Tube-Round Center	50	Milling Machine, Band Saw
Coupler Fastener	Black-Oxide Alloy Steel Socket Head Screw 4-40 Thread Size, 5/8" Long, Fully Threaded	11.65	N/A
Gusset Plate	Aluminum 1/32" Sheet	Owned	Milling Machine, Sheet Metal Shear Machine
Slider Anchor	PETG	Owned	3D Printing
Lead Screw	Fast-Travel Precision Acme Lead Screws and Nuts	Owned	N/A
Lead Screw Nut	Flange Nut with M16 x 5 mm Thread for Fast-Travel Ultra-Precision Lead Screw	Owned	N/A
Lead Screw	Ultra-Precision Lead Screw, Fast-Travel, 1/4"-20 Thread Size,	Owned	N/A
Motor Mount	PETG	Owned	3D Printing
Electronics Mounts	PETG	Owned	3D Printing
Electronics Canister	PETG	Owned	3D Printing
Encoder Mount	PETG	Owned	3D Printing
Stability Rod	Carbon Fiber Rod	Owned	Band saw
Stability Rod Clamps	Collar Clamps	25.92	N/A
Lead Screw Stopper	Lead Screw Collar Clamp	9.75	N/A

Manufacturing Process Summary:

- **Flaps:** Constructed from leftover G-10 Fiberglass tubes to minimize cost, the fiberglass is precision cut with a Dremel and finished with sanding and epoxy for durability.
- **Ternary Links:** 3D printed using PETG with 80-100% infill and six sidewall layers to ensure bearing strength. Ultimaker Cura software and an Ender-3 printer will be used. Fasted with 4-40 screws (1" long).
- **Coupler:** Manufactured from carbon fiber tubing, precision holes are drilled using a milling machine, and the tube is cut to length using a band saw.
- **Gusset Plate:** Fabricated from 1/32" aluminum sheet, prices are cut using a metal shear and machined to precise dimensions with an end mill. Holes are drilled for attachment with 4-40 screws and lock washers.
- **Slider Anchor:** 3D printed with 100% infill and 6-8 sidewall layers for durability.
- **Other Structural Components:** The remaining structural components are printed out of PETG using about 20% infill to reduce as much weight as possible. Hardware components will be purchased as necessary.

The detailed manufacturing plan ensures cost-efficiency while maintaining the structural integrity of the airbrakes.

3.7.4. Electrical Design

The electrical design of the airbrake system implements a live feedback control loop, enabling real-time adjustments based on the rocket's state and trajectory. The system predicts the rocket's future path, compares it to the desired apogee, and minimizes the error by activating the airbrakes. While computations are performed multiple times per second, the system's speed is limited to match the mechanical response time.

3.7.4.1. Sensors

The sensors serve as the system's "senses," collecting data essential for decision-making. The components include three pressure/temperature sensors, one accelerometer, one rotary encoder, and a button. Their roles are as follows:

- **Pressure/temperature Sensors:** Calculate altitude using atmospheric pressure and temperature.
- **Accelerometer and Gyroscope:** Determine trajectory and orientation, providing a basis for accurate apogee calculations.
- **Rotary Encoder:** Tracks lead screw rotation to measure flap deployment angles.
- **Button:** Serves as a positional reset mechanism to correct any mechanical slippage.

Accelerometer (MPU6050)

The MPU6050 combines an accelerometer and gyroscope for orientation and motion sensing. With a high output frequency of 1024 $[Hz]$, it provides more than sufficient data for this application, even when sampled at 25-50$[Hz]$ to balance precision and noise filtering. Key specifications are detailed in Table 3.7.3. The device communicates via I^2C, which is adequate given the simplicity of the sensor network.

Table 3.7.3. *MPU6050 accelerometer sensor specifications.*

Output Frequency [/sec]	1024
Gyro Range [°/sec]	±2000
Acceleration Range [g]	±16
Supply Voltage Range [V]	2.375-3.46
Average Supply Current [mA]	3.6
Max Supply Current [mA]	3.9
Communication Type	I^2C

Pressure/Temperature Sensor (BMP280)

The BMP280 offers precise altitude measurements with an accuracy of ± 1 meter. Operating at up to $157[Hz]$, it provides real-time data with minimal current draw, as shown in Table 3.7.4. Communication via SPI ensures efficient data transmission, particularly when three sensors are used for redundancy.

Table 3.7.4. *BMP280 pressure and temperature sensor specifications.*

Pressure measurement range [kPa]	+30 ... +110
Pressure accuracy [Pa]	±12 Pa
Temperature Range [°C]	-40 ... +85
Output frequency [Hz]	157
Supply Voltage Range [V]	1.20-1.71
Average Supply Current [mA]	0.00274
Max Supply Current [mA]	0.00416
Communication Type	SPI

Rotary Encoder (Hw-040)

The Hw-040 rotary encoder provides positional feedback for the lead screw, outputting 20 pulses per rotation via 2-bit Gray code PWM signals. Specifications are summarized in Table 3.7.5.

Table 3.7.5. *HW-040 rotary encoder specifications.*

Operating Voltage [V]	5
Pulses/rotation	20
Output	2-bit Gray Code
Dimensions [mm]	30x30x18

3.7.4.2. Motor

The ZYTD520 12V DC motor drives the airbrake system, tested under various loads to validate its capability (Figure 3.7.22). Under a medium (~2.5 lbs), the motor actuated the flaps from 0° to over 60° within 5 seconds. Calculations confirmed that the motor's maximum torque of 15.6 $[lb - in]$ exceeds the worst-case torque requirement of 12.19 $[lb - in]$, derived using Equation 3.7.19 using the model in Figure 3.7.23 (Budynas & Nisbett, 2015). ; d_m is the average diameter of the lead screw; μ is the coefficient of friction, which in this case was taken to be 0.8 for steel on steel, but it is likely much lower; lastly l is the rise of the threads, which was calculated as $l = pitch \cdot \# \; of \; starts$, and the pitch is the inverse of the threads per inch.

$$T_r = \frac{F d_m}{2}\left(\frac{1 + \pi \mu d_m}{\pi d_m - \mu l}\right) = 12.1867[lb - in] \quad (3.7.19.)12$$

Key specifications, including a no-load current of 0.9 A and a load current of approximately 1.25 A, to ensure the motors power consumption is manageable within the systems design constraints (Table 3.7.6).

Table 3.7.6. *ZYDT520 DC 12V motor specifications.*

Weight [g]	203
Speed [RPM]	10
No Load Current	0.9
Load Current [A]	0.15-1
Stall Current	2
Size [in]	3.5
Torque [lb-in]	15.6
Operating Voltage [V]	12
Max Power [W]	15

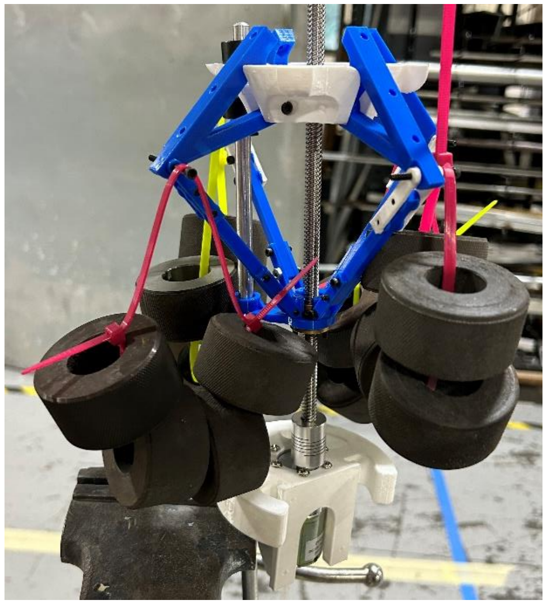

Figure 3.7.26. *Airbrakes motor being practically tested for speed under medium load.*

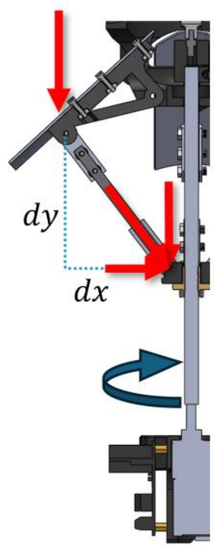

Figure 3.7.27. *Model of force system applied to the motor with motor reaction torque.*

3.7.4.3. Microcontroller

The Raspberry Pi Pico was chosen for this application due to its high system clock rate, enough pins, low power consumption, and compatibility with selected sensors. Its ability to perform millions of calculations per second is crucial for real-time processing during flight. Furthermore, the Raspberry Pi Pico is compatible with the Arduino IDE, which offers extensive libraries for sensor integration and simplifies coding. Table 3.7.7 summarized the key specification of the Raspberry Pi Pico (Raspberry Pi, 2024).

Table 3.7.7. Raspberry Pi Pico microcontroller specifications.

System Clock [MHz]	133
RAM [kB]	264
Number of Pins	30
Supply Voltage [V]	3.3
Average Current [mA]	93.5
Max Current [mA]	95.6
Flash Memory [MB]	2

3.7.4.4. Mission PCB

Figure 3.7.24 illustrates the custom PCB designed for both the main and secondary payloads. In the airbrakes system, this PCB serves as the primary controller. Designed in a puck shape to fit within the confined space of the airbrakes, it consolidates all components efficiently. While transistors on the right-hand side of the PCB are exclusive to the main payload, the airbrakes PCB includes slots for the raspberry Pi Pico and necessary sensors.

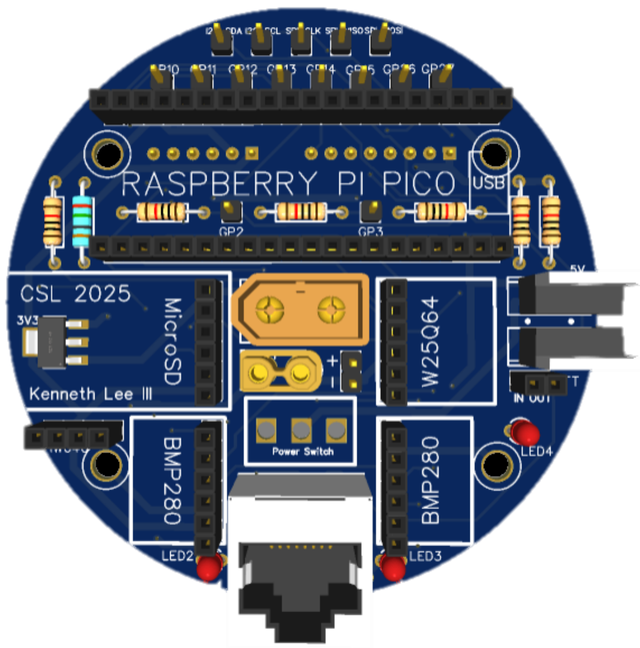

Figure 3.7.28. *Airbrakes PCB.*

Key Features:

- **Power Input:** A 12V battery connects via the XT-60 connector.
- **Output:** The motor controller is powered through a voltage and ground connector.
- **Switch:** A dedicated power switch controls PCB operation.

- **Ethernet Cable Output:** Routes signal and ground wires for the button and motor controller.

3.7.4.5. Battery

A compact Zeee Li-Po battery (1500mAh, 120c, 11.1V, 16.65Wh) was selected for its high discharge rate, capacity, and compatibility with the motor's load requirements. Battery testing confirmed its suitability, as shown in Table 3.7.8. During testing, the battery discharged only 4% after sustaining a 1.2A load for two minutes, which exceeds the airbrakes' expected operational duration.

Table 3.7.8. *Battery test results.*

Starting Voltage [V]	12.5
Starting Percentage [%]	96
Ending Voltage [V]	12.4
Ending Percentage [%]	92
Current Draw [A]	1.2
Duration [min]	2
Charge Drained [mAh]	40

3.7.4.6. Memory

To ensure reliable data storage during flight, the system employs two storage methods: a flash memory module (W25Q64) and an SD card reader. Flash memory was prioritized over the SD card for in-flight data storage due to its resilience against connection disruptions. Key specifications are presented in Tables 3.7.9 and 3.7.10.

Table 3.7.9. *W25Q64 flash memory module specifications.*

Communication Type	SPI
Average Current [mA]	15
Max Current [mA]	25
Operating Voltage [V]	2.7-3.6
Density [Mb]	64
Frequency [MHz]	104

Table 3.7.10. *SD card reader specifications.*

Communication Type	SPI
Average Current [mA]	0.4
Max Current [mA]	100

3.7.5. Control Structure

The airbrakes control system has four key stages: sensor input, data filtering, a probabilistic state-space model, and a control algorithm. Figure 3.7.25 provides a flowchart of the decision-making process, while Table 3.7.11 explains each stage.

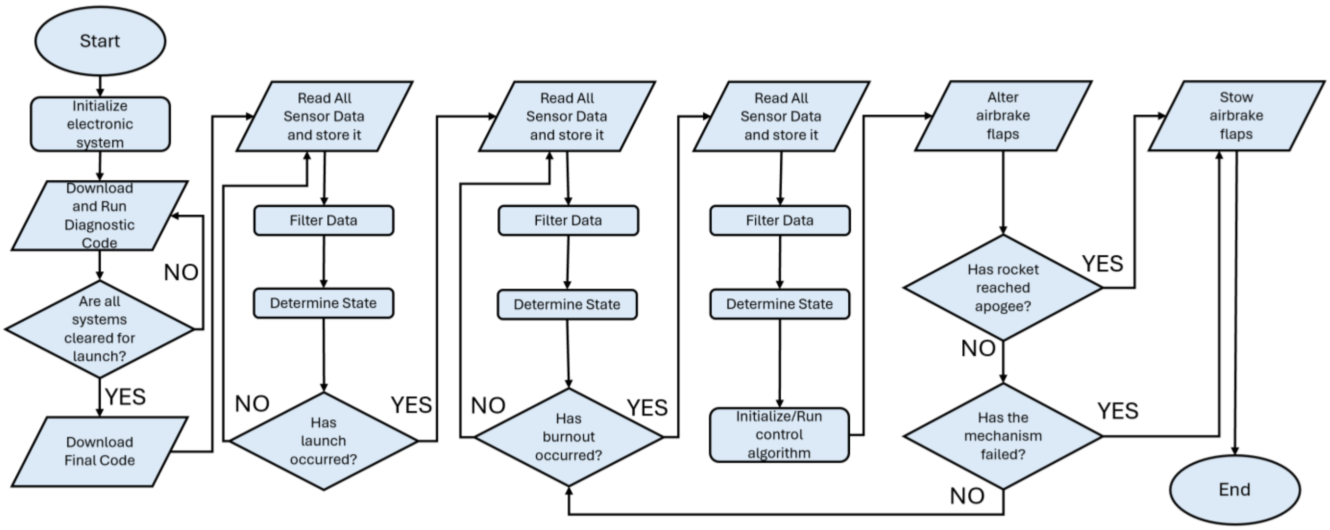

Figure 3.7.29. *Process flowchart of air brakes electromechanical decision logic.*

Table 3.7.11. *Control stages of control algorithm.*

Stage	Description
Armed	Pre-flight checks and preparation for liftoff, with initial data readings.
Liftoff	Detects a spike in acceleration or altitude to transition to the next stage.
Burnout	Activates the control algorithm as acceleration decreases below a threshold.
Apogee	Switches to apogee mode when altitude peaks or starts decreasing.
Landed	Stops data collection and transfers data from flash memory to the SD card.

3.7.5.1. Data Filtering

Real-time data filtering is essential for accurate sensor readings. The system applies three types of filtering:

1. **Bias Error Reduction:** Calculates average sensor values to correct offsets.
2. **Low-Pass Filter:** Removes high-frequency noise for cleaner data.
3. **Outlier Rejection:** Compares readings from multiple sensors and excludes inconsistent data.

For example, temperature sensor readings (T_1=20.989, T_2=24.876, T_3=21.450) are averaged in pairs to compute three values. The pair with the smallest difference is used for the final weighted average. Figures 3.7.26-29 illustrate raw sensor data before filtering.

Say the temperature sensor took three readings such as $T_1 = 20.989$, $T_2 = 24.876$, and $T_3 = 21.450$. Then an average was taken of a combination of the three being $(AVG)_{1,2} = 22.9325$, $(AVG)_{1,3} = 21.2195$, and $(AVG)_{2,3} = 23.163$. Then to find which ones are the most "accurate," each of these values are subtracted from one another being $|S_{1,2-1,3}| = 1.713$, $|S_{1,2-1,3}| = 0.2305$, and $|S_{1,3-2,3}| = 1.9435$. Finally, since $S_{1,2-1,3}$ has the lowest value, the final value for this algorithm is $\frac{(AVG)_{1,2}+(AVG)_{1,3}}{2} = 22.076$. This algorithm can delete data if it is not behaving, and it takes a sort of weighted average of the data that seems to line up better with one another.

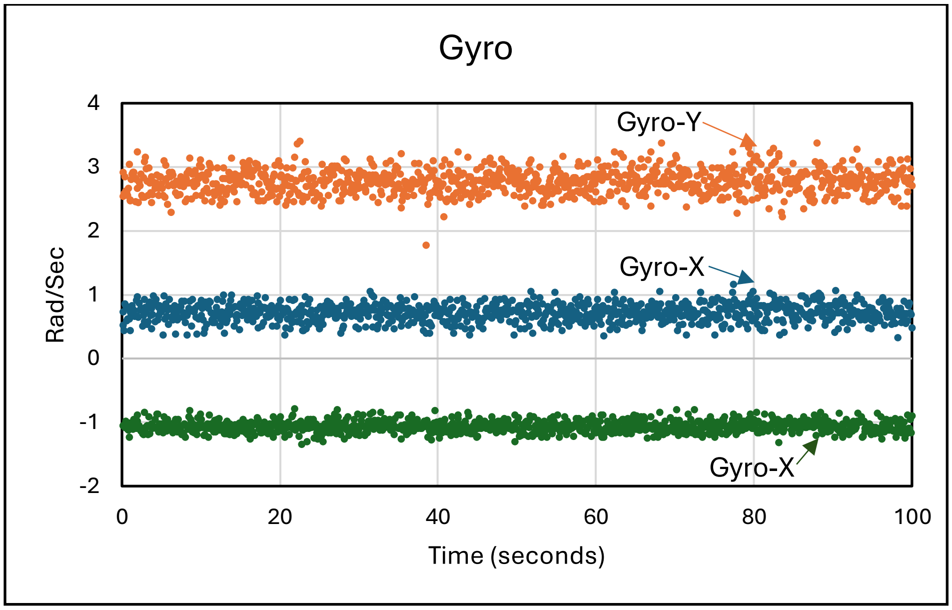

Figure 3.7.30. *Gyroscope raw data with no post processing.*

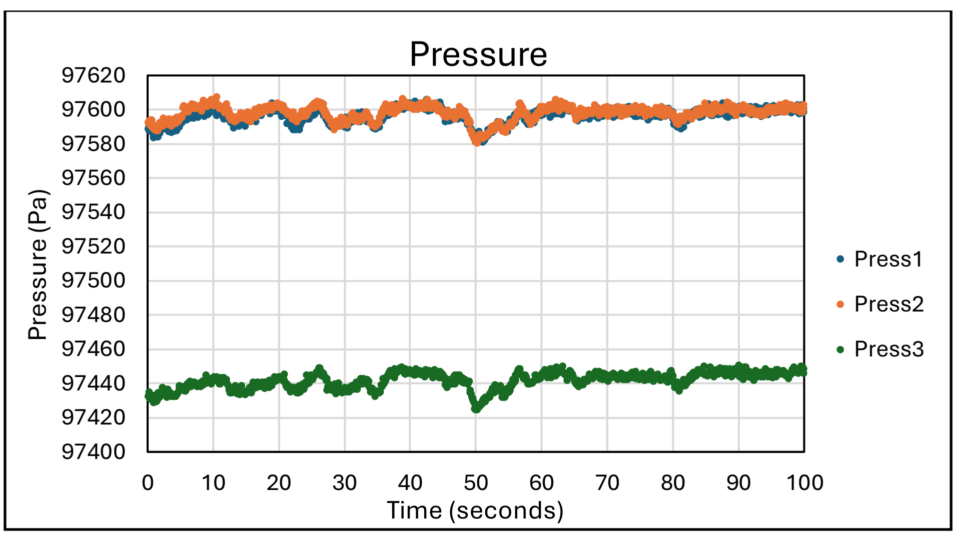

Figure 3.7.31. *Raw pressure data with no post processing.*

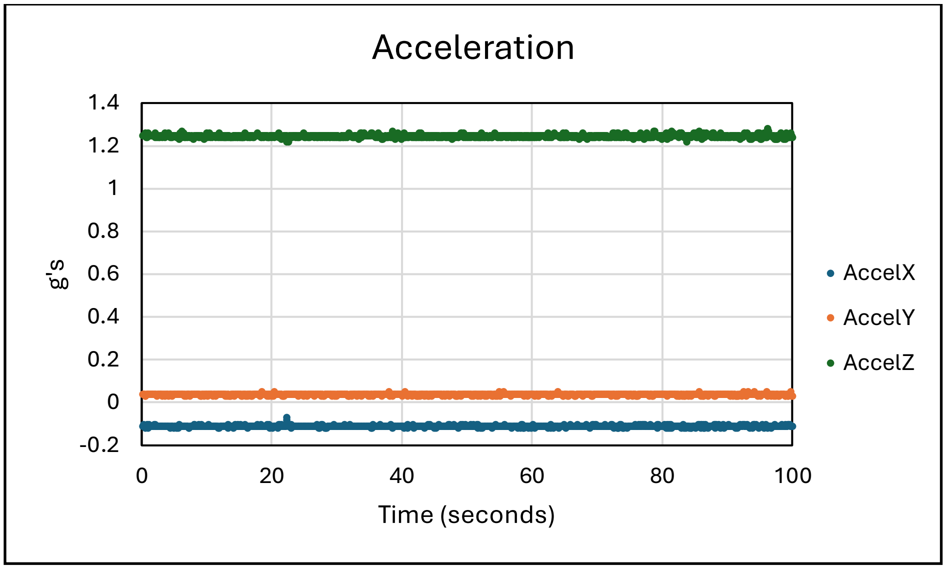

Figure 3.7.32. *Raw acceleration data with no post processing.*

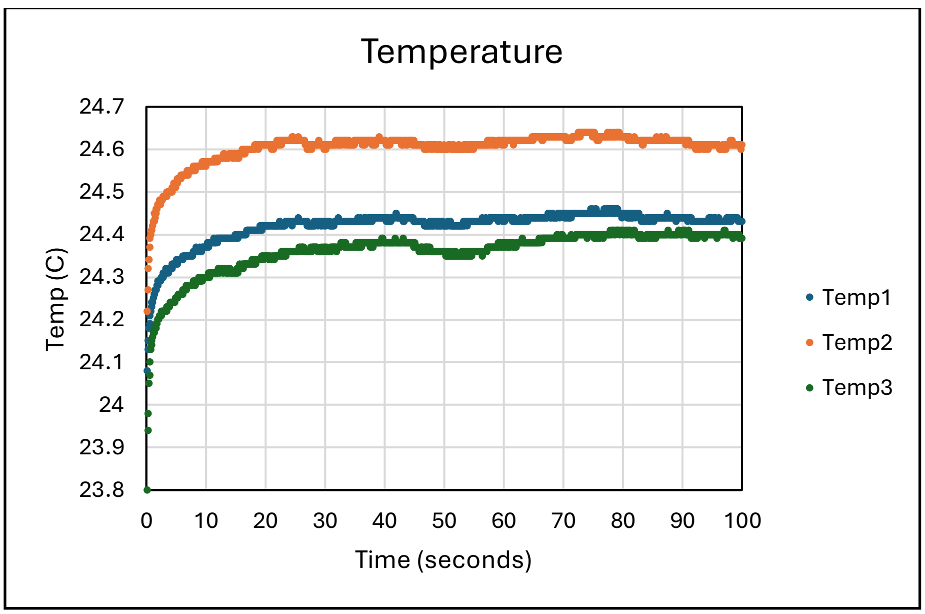

Figure 3.7.33. *Raw temperature data with no post processing.*

3.7.5.2. Probabilistic State-Space Model

To achieve precise apogee control with uncertainty in the atmospheric conditions and uncertainty in the AB system itself. CSL will be using a probabilistic state-space model to control the AB subsystem. This model uses dynamic equations to predict the evolution of the state of the rocket over time. These equations model ranges of the various factors that have uncertainty in the system such as the wind speed, air density, as well delays in actuator response. During flight the system uses probabilistic inference methods to estimate the current state of the system at each point in time using data already collected and previous simulations using the varying uncertainties. This method is commonly used to control systems that evolve over time and possess uncertainty. This method will enhance the reliability and accuracy of the AB system compared to a quantitative model that is unable to adjust for varying conditions and is only accurate in the specific scenarios for which the equations were derived.

3.8. Tail Cone Motor Retention

3.8.1 Changes Made Since PDR

The conical, sheet-metal tailcone design presented in the PDR as a primary design for the motor retention system has since been replaced by an ogive, PETG 3D printed tailcone. The sheet-metal cone was originally chosen for its robust material that offers heat and impact resistance at a lower mass than a solid metal retention system. However, CSL encountered issues when attempting to fabricate such a tailcone, as the complicated tab geometry and roll angle were not manufacturable with CSL's current sheet metal tools. This is due to the relatively small size of the tailcone, which has been constricted by the airframe diameter and motor nozzle size. A sheet-metal cone could be manufactured with a custom jig or outsourced to a different manufacturing facility, but CSL's research into the capabilities of 3D printed parts and a subscale flight demonstration led to this change in design choice.

This shift in design choice resulted in changes of tailcone material, shape, construction geometry, and length to maximize launch vehicle performance. It also changed testing and validation plans for tailcone performance verification.

3.8.2 Tailcone Mission Criteria

To achieve mission success, the tailcone will be evaluated by the following criteria:

TC.S.1 The tailcone will improve launch vehicle performance.
TC.S.2 The tailcone will remain attached to the aft centering ring and retain motor tube.
TC.S.3 The tailcone will survive vehicle landing within expected descent energies and be reusable for future flights.
TC.S.4 The tailcone will survive heat from vehicle launch with minor/no damage and be reusable for future flights.

3.8.3 Current Design

The PETG 3D printed tailcone can be seen in the SolidWorks drawing in Figure 3.8.1. Similarly to the tailcone design submitted in the PDR, the printed cone is fastened to the thrust structure's aft centering ring by three 3/8" 10-32 socket head fasteners.

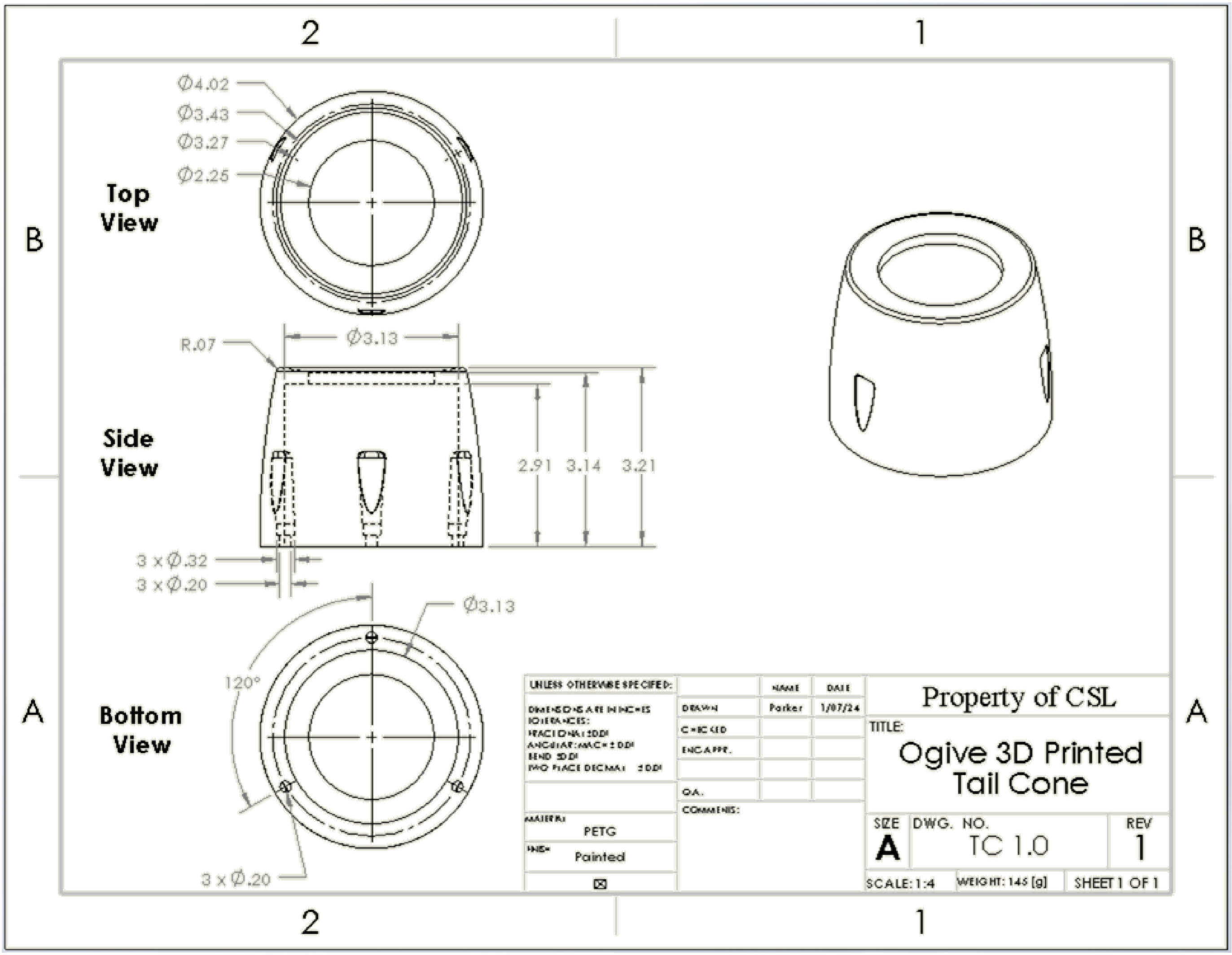

Figure 3.8.1. *SolidWorks drawing of Full Scale PETG 3D Printed tailcone with dimensions.*

This design choice has several advantages over the previous sheet metal cone and other design alternatives presented in CSL's PDR. The PETG material produces a lighter tail cone than sheet metal, and the component being based off a SolidWorks model allows it to be easily edited and iterated upon.

To ensure the tail cone performs according to its success criteria, the design must be verified to be impact and heat resistant. Based on the subscale launch vehicle performance as described in Section 3.9, a PETG 3D printed tail cone survived vehicle flight with minimal to no surface damage and minimal scoring from the vehicle's flame plume during launch. This performance indicates design competency, but to verify that the tail cone is impact resistant, other tests and analysis will be performed. Drop testing will be completed to evaluate impact resistance and the tailcone will be tested on full scale test flights to verify resistance to heat damage during motor burn. These tests will be discussed in the next subsection.

To evaluate the tail cone's benefit to launch vehicle performance, CSL considered the achievable apogee the vehicle and how it is affected by tail cone geometry and length. As discussed in the PDR, the small size of the tail cone's diameter reduction causes tailcone geometries to perform similarly. Because of this, the full-scale launch vehicle's apogee is not affected if the geometry is conical, ellipsoid, or ogive. CSL designed the tailcone with an ogive geometry as it increases the amount of material at the convergent end of the printed part.

As Project Elijah has matured, the tail cone has changed from decreasing drag to increasing drag on the launch vehicle, according to simulations run in OpenRocket. In the most updated models, this increase in drag resulted in an altitude reduction of about 10 meters, or around 33 feet. However, the tail cone is still a necessary component in the launch vehicle. This is due to the motor tube being unable to move any further towards the fore of the rocket without changing the design of the airbrakes and other subsystems. If the airframe was extended to meet this length, the apogee would be improved by the aforementioned 10 meters, but the stability would increase to 5 caliber (this is evaluating the launch vehicle without ballast, meaning this situation could not be improved with added ballast). A caliber of 5 would cause the system to be over stable, and crash. This would be caused by the thrust structure moving with the change in airframe length, shifting the center of pressure aft, and causing the vehicle to be over stable. In summary, a tail cone reduces the launch vehicles apogee but improves its stability by a dangerous margin. It is therefore an essential component, but not for the benefits CSL predicted it would grant.

To improve vehicle performance, CSL utilized OpenRocket to minimize loss in apogee by changing tailcone dimensions. The fore and aft component diameters are fixed by the airframe and motor nozzle, but the length was optimized by using OpenRocket's tools, given in Figure 3.8.2.

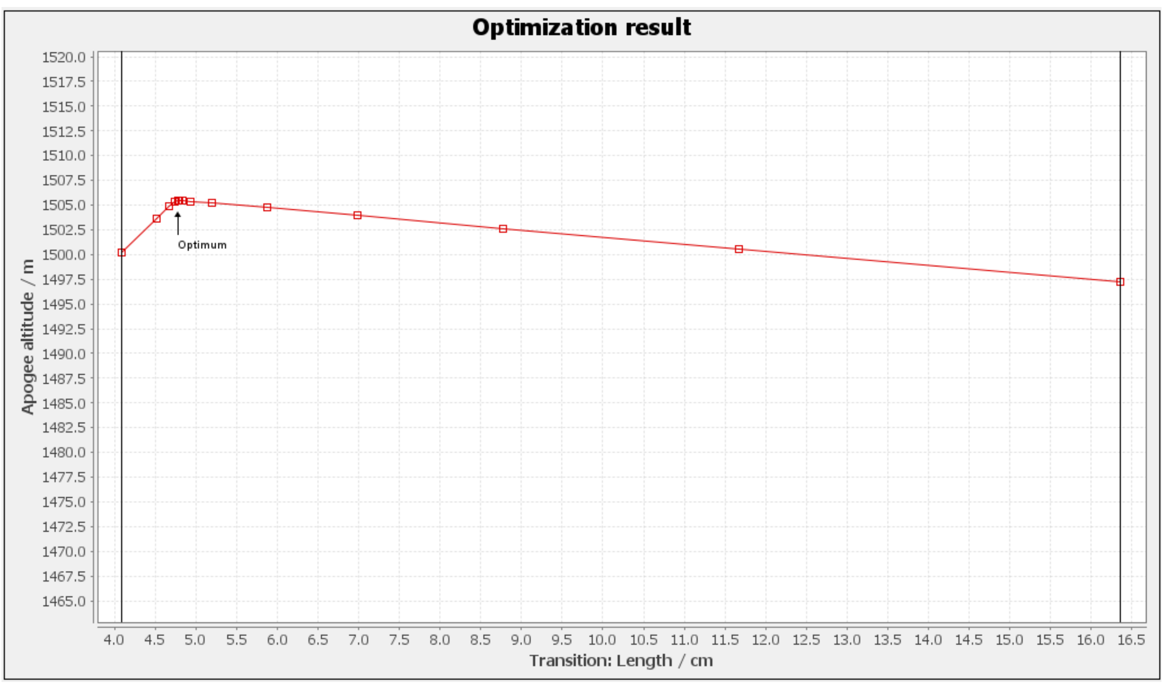

Figure 3.8.2. *Relationship between apogee and tailcone length produced by OpenRocket.*

By allowing a minimum stability of 2 caliber, OpenRocket reported a maximum apogee of 1506 meters with a tailcone length of 4.77 cm. As the length is increased from this value, the predicted apogee decreases. Because the launch vehicle has a minimum length of 260 cm, the tailcone must have a minimum length of 8.18 cm. Because the predicted apogee decreases as the length increases from 4.77 cm, the minimum length of 8.18 cm produces a maximum apogee of 1503 meters.

These optimized dimensions produce the most beneficial tailcone for the launch vehicle and will be reviewed and checked as the project matures and testing enhances design choices.

3.8.4 Manufacturing and Next Steps

This tailcone design allows for simple manufacturing and assembly. With the finalized design, CSL will 3D print the tailcone and fasten it to the aft centering ring of the thrust structure using 10-32 fasteners and a hex head driver. If any minor or major design changes are made to the tailcone as more is learned during full scale test flights, they can be implemented to the SolidWorks model and the tailcone can be reprinted.

Next steps for tailcone success verification involve testing for tailcone impact testing. Testing will be carried out similarly to nosecone drop testing. This involves verifying if the tailcone can survive landing impacts while suffering minimal or no damage. Tests will be conducted by taking the mass and predicted kinetic energy impact values for the aft section of the launch vehicle and using them to find the corresponding height needed to drop that tailcone to simulate the tailcone impacting the ground as in a real flight. This kind of testing can be repeated multiple times, varying landing energies and landing angles to simulate different scenarios.

Tailcone Drop Test Procedure

Objective: To assess the survivability and reusability of a 3D printed tailcone by simulating vehicle landing impacts. This test will validate if the tailcone design can withstand expected loads.

Materials and Equipment:

1. Tailcone fastened to mass equivalent of aft launch vehicle
2. Drop test stand (ladder)
3. Scale to measure mass of tailcone and mass of aft launch vehicle section replacement
4. MATLAB code from Appendix A.3 to predict kinetic energy
5. Camera to record impact for analysis
6. Safety glasses, pants, close toed shoes, gloves, and other PPE as needed.
7. Tape measure

Variables:

- **Independent Variables**
  - Drop height (h) measured in meters
  - Impact angle of attack (α) measured in degrees
- **Dependent Variables**

- Cone damage
- Kinetic energy (KE) measured in newton meters

- **Controlled Variables**
  - Mass of tailcone (m) and equivalent aft section measured in kilograms
  - Impact surface
  - Winds
  - Other environmental conditions

Test Steps

Perform the drop test with the following steps:

1. **Preparation**
   - Measure and record the mass of the aft section of the launch vehicle using the scale.
   - Insert the mass value into the descent performance prediction MATLAB code in Appendix A.3 to calculate the predicted kinetic energy that the section will have when it impacts the ground from the rocket's descent.
   - Take the predicted kinetic energy and the recorded mass and insert them into the kinetic energy formula shown in Equation (3.4.1). Rearrange the equation to solve for the velocity of the fore section as it impacts the ground as shown in Equation (3.4.2).

$$KE = \frac{1}{2} * m * v^2 \tag{3.4.1}$$

$$v = \sqrt{\frac{2 * KE}{m}} \tag{3.4.2}$$

   - Insert the calculated impact velocity into the potential energy equation shown in Equation (3.4.3) to calculate height.

$$v = \sqrt{2gh} \tag{3.4.3}$$

   - This is the height value that the tailcone must be dropped from to simulate the predicted kinetic energy that it will endure on impact with the ground.
2. **Test Setup**
   - Prepare the tailcone with the appropriate mass equivalent to model the weight of the aft rocket section.
   - Set up the phone camera to record the test

3. **Perform the Drop Test**

- Raise the cone to the desired height and position it at the desired angle of attack if applicable.
- Drop the tailcone from the calculated height to simulate the ground that the rocket would descend towards from the CSL launch location.

4. **Data Collection**
   - After the tailcone hits the ground, observe it for cracks or other surface damage.
   - Record the impact using the phone camera.

5. **Repeat the Test**
   - Conduct multiple drops at the same height and angle to verify consistency.
   - Change the angle of attack and repeat to simulate different impact scenarios.
   - Change the type of ground that the tailcone lands on and the orientation that it impacts the ground with.
   - Gradually increase the drop height or mass to simulate higher impact kinetic energies to determine the failure threshold of the tailcone.

Pass / Fail Criteria

For the cone to pass the drop test, the tailcone must be able to withstand at bare minimum the impact kinetic energies predicted by the MATLAB code from Appendix A.3. Withstanding this energy means receiving minimal damage and being completely reusable regardless of the amount of drops. However, if the damage to the cone is found to be severe enough that the tail cone's mission criteria (decreasing drag, facilitating the payload) are at risk of failure, then the cone does not pass the test. The results of this test will be used to validate the survivability and reusability of the tailcone.

Verification for tailcone heat resistance success will be further developed as full-scale launch vehicle testing begins.

3.9. Subscale Flight Results

3.9.1. Design Process

CSL's subscale launch vehicle was designed to be 75% of the full-scale design's dimensions. This scale factor was chosen so that the team members involved in constructing a large, fiberglass-composed subscale would gain safety training and experience with epoxy and power tools required to construct the full-scale rocket. Additionally, a 75% subscale of Chariot was large enough that a dual-bay, dual-deployment recovery system would still be necessary, providing CSL with valuable experience in implementing such systems.

Since the CG of a rocket is the imaginary point about which a body pivots in motion and since the CP is the point related to the rocket surface area at which the aerodynamic forces on the rocket balance, these two points were the basis by which CSL designed the subscale rocket to be dynamically equivalent to the full-scale rocket. A subscale rocket as similar as possible geometrically to the full-scale rocket with the same relative CG/CP locations and therefore a similar static stability margin will adequately demonstrate the full-scale design in flight.

To this end, the rocket diameter, overall length, nosecone profile, tail cone profile, and fin shape were the design parameters that CSL chose to scale to be precisely 75% of their full-scale counterpart parameters. Keeping these parameters properly scaled ensured that the subscale would be geometrically similar to the full scale. The only external features that CSL did not scale accordingly were the thickness of the fins and the wall thickness of the fiberglass tubes used in the airframe, as properly scaled thicknesses of fiberglass for these applications are not commercially available. Internally, the mass equivalents for the airbrake system and primary payload were also not 75% of their mass in the full-scale design but were chosen as was necessary to achieve the proper static stability margin for the J540R motor that CSL already had on hand. Again, CSL deems this design practice as acceptable since the relative locations of the CG and CP were held in roughly the same place as predicted for the full scale. Table 3.9.1 summarizes the rocket parameters that were maintained at the scaling factor and those that were not held to scale.

Table 3.9.1. *Scaling rationale for subscale rocket parameters.*

Parameters Held to Scale	Rationale
Overall length	Maintain geometric similarity, proper relative CG/CP location
Airframe diameter	Maintain geometric similarity
Nosecone profile	Maintain geometric similarity, proper relative CG/CP location
Tailcone profile	Maintain geometric similarity, proper relative CG/CP location
Fin shape	Maintain geometric similarity, proper relative CG/CP location
Parameters *Not* Held to Scale	**Rationale**
Fin thickness	Proper G10 fiberglass thickness not commercially available
Airframe wall thickness	Proper G12 fiberglass thickness not commercially available
Airbrake mass equivalent	Achieves proper relative CG location, static stability margin
Primary payload mass equivalent	Achieves proper relative CG location, static stability margin

An OpenRocket model of the subscale was employed to test the combination of rocket dimensions, mass distribution, and motor selection that placed the CG and CP in their appropriate locations. Figure 3.9.1 shows the location and amount of ballast in the subscale rocket. Table 3.9.2 contains an overview of the subscale launch vehicle parameters and how they compare to the full-scale counterpart.

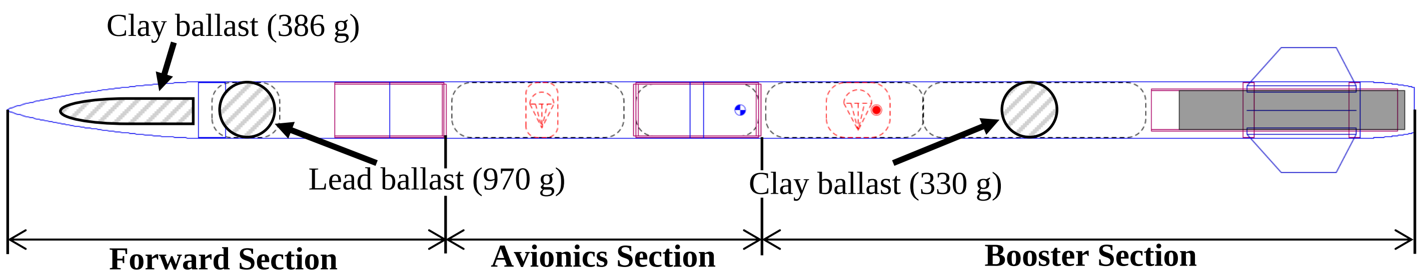

Figure 3.9.1. *OpenRocket schematic of the subscale rocket showing the ballast locations and amounts that were required for achieving similar static stability margins and CG/CP locations between full scale and subscale.*

Table 3.9.2. *Comparison between full scale and subscale rocket parameters. Subscale simulation results were performed with predicted launch conditions for the Federal Rd field where CSL conducts its flights.*

	Fullscale Rocket	Subscale Rocket
Vehicle Weight [lb]	27.4	15.9
Vehicle Diameter [in]	4.024	3.098
Vehicle Length [in]	103.00	77.25
Static Stability [cal]	2.26	2.41
Max Altitude [ft]	4830	3322
Motor Selection	K1000T-P	J540R-0
Total Impulse [N*s]	2511.5	1161.0

3.9.2. Subscale Launch

The subscale test launch was conducted by CSL on November 18, 2024. The team arrived at the WSR launch site at 11:35 am. The rocket was assembled for flight and pop tests for both the main and drogue parachutes were conducted at 1:19 and 1:23 pm respectively. The rocket experienced clean separation during both pop tests which verified that enough black powder was used to ensure complete separation of the rocket during flight.

After the pop tests were completed, the rocket was prepared for launch and the internal wiring for the avionics was completed. Before the black powder charges were wired to the terminal blocks both altimeters were powered on to ensure proper functionality. During this test, the altimeters were beeping continuity for 3 of the 4 deployment charges when no continuity should have existed. The initial theory for this was melted insulation which short circuited the wires going through the bulkheads as slight charring was observed. This theory was rejected when continuity was lost and then regained when the wires were removed from and then reconnected to the terminal blocks. The team did not have a multimeter on hand to independently verify if continuity existed, but because both altimeters were experiencing this issue on at least one of the deployment event circuits, and this issue was not present before the pop tests, the problem was assumed to be with the terminal blocks. The terminal blocks were inspected, and no apparent damage was observed besides a fine layer of black powder residue left behind from the pop tests. At some point during the troubleshooting process, the Altus Metrum Easymini stopped powering on and the cause for this is unknown. A small puff of smoke was observed while connecting wires for a deployment charge to the altimeter while it was powered off, but the cause of this smoke and whether it is related to the Easymini malfunctioning is unknown.

With one working altimeter, and terminal blocks that were short-circuited for an unknown reason, a decision needed to be made whether to continue to attempt a launch or not. The decision was made to push ahead with the launch using the primary RRC3 as the only working altimeter and by wiring the black powder charges directly to the altimeter and sealing the hole in each bulkhead with clay that the WSR mentor had on hand. This decision was made since redundant altimeters are not necessary for a successful subscale launch and the team was confident in the RRC3 altimeter as it has functioned well in the past for CSL and had functioned normally up until that point. The black powder charges were wired directly to the altimeter to ensure a complete connection with no short circuits. After recovery of the rocket, the issue with continuity through the terminal blocks was unable to be recreated in the lab and the reason for this anomaly remains unknown.

After a final go/no go poll was taken, final assembly of the rocket was completed, and the subscale rocket was loaded onto the launch rail. The current weather conditions were recorded at the Springfield-Beckley Municipal Airport, which is the closest airport approximately 10 miles to the northwest of the launch site. The temperature was recorded to be 62.1˚ F with a sustained wind of 4 mph from the south-southeast, there was complete cloud cover at greater than 10,000 feet with a humidity of 81% and a sea level pressure of 28.83 inHg. After a nominal countdown and motor ignition, liftoff occurred at 3:40 pm and a nominal ascent was observed with a slight wobble at around 100' AGL where the rocket oriented itself into the airflow after a minor disturbance to its attitude. The drogue parachute was observed to deploy at apogee and the main was observed to deploy several hundred feet above the ground. The rocket landed under parachute 2,089' northeast of the launch site, and the launch and landing positions are shown in Figure 3.9.3. Figure 3.9.2 shows the rocket laid out on the floor of the Engineering Laboratory ensuring the separate sections of the rocket do not collide while under parachute.

Figure 3.9.2. *View of the subscale rocket spread out to ensure the rocket sections do not collide while under parachute due to improper shock cord length.*

Figure 3.9.3. *Arial view of the launch and landing location of the 11-18-2024 subscale rocket flight.*

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Upon recovery of the rocket, the RRC3 altimeter was still functioning properly and was beeping out an apogee of 3,007’. The flight data was collected from the mDACS program used to communicate with the RRC3 using a USB connection and a complete flight profile graph from the altimeter is shown in Figure 3.9.4. The altimeter recorded an ascent time of 13.9 seconds and a descent time of 58.6 seconds well within the required 90 second descent time. The altimeter data shows the main parachute event at 550’ and nominal inflation of the parachute was observed by the team with an average descent rate under main of 25 ft/s. Figure 3.9.5 shows the assembled rocket before the launch as well as the rocket shortly after rail ex

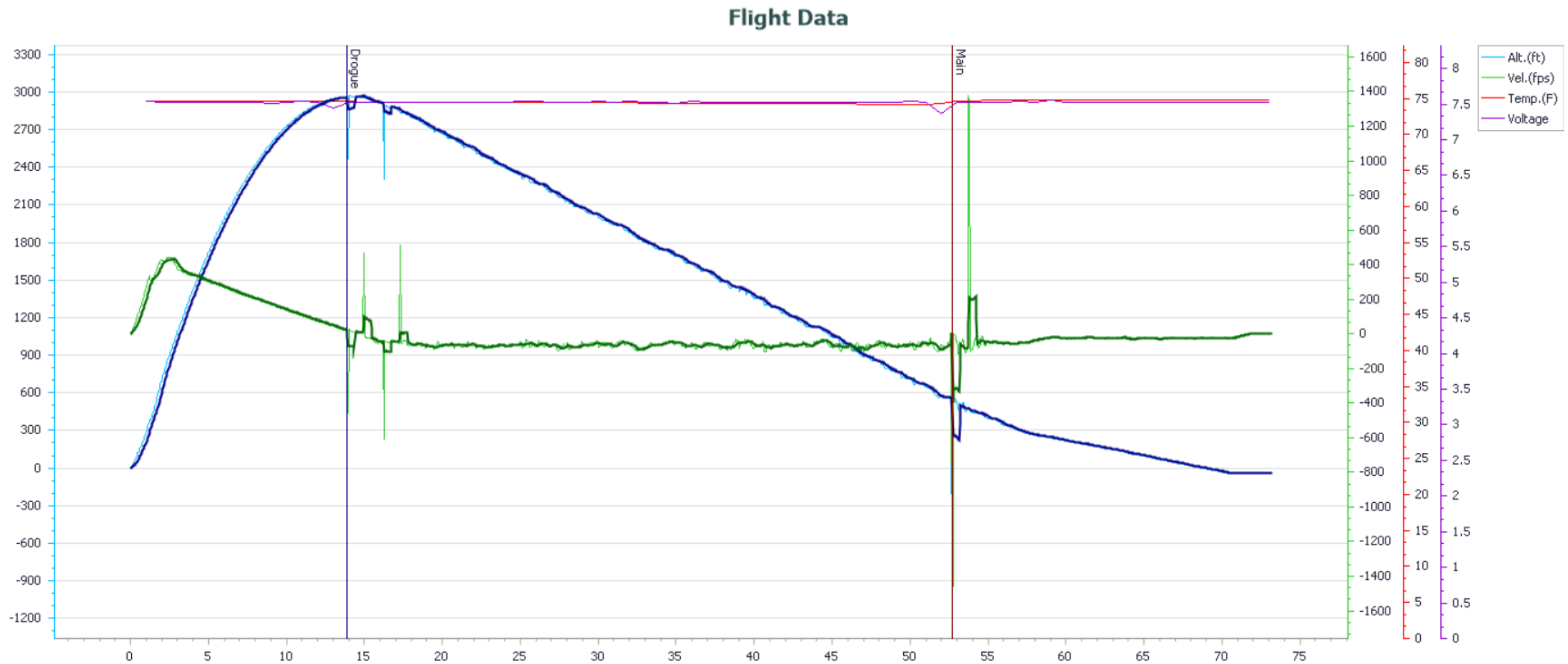

Figure 3.9.4. *Complete graph of subscale flight profile from RRC3 altimeter.*

Figure 3.9.5. (Left) *assembled rocket before launch;* ***(Right)*** *rocket during ascent after rail exit.*

3.9.3. Subscale Post-Launch Conditions

Though the main and drogue recovery events fired successfully and at the expected points in the rocket's flight, the rocket experienced some breakage during the recovery sequence. Figure 3.9.6 shows the landing orientation of the two sections of the launch vehicle that remained tethered at recovery.

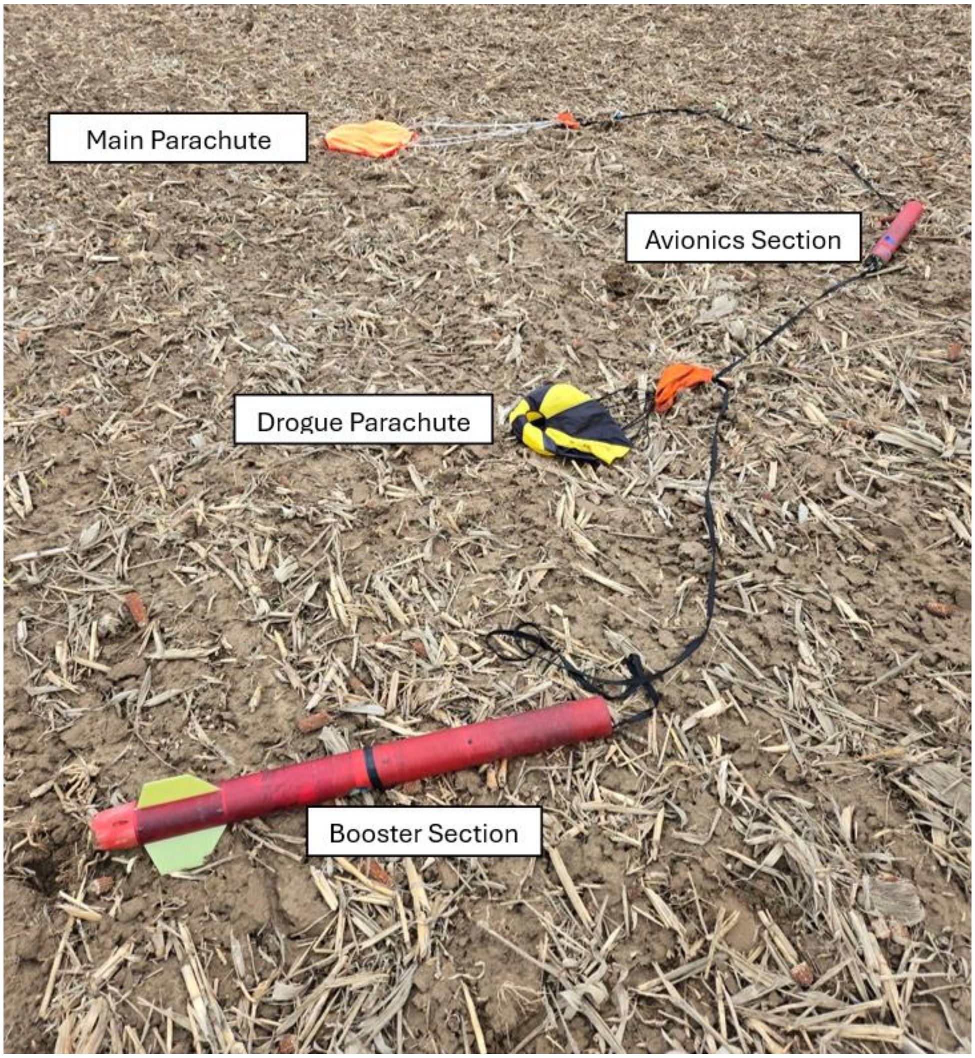

Figure 3.9.6. *Landing orientation of the tethered subscale rocket pieces. The forward section of the rocket that separated during recovery is not shown in this picture.*

Figure 3.9.7 shows the aft end of the rocket, which took the brunt of the landing impact. The tail cone was not deformed by the heat of the exhaust plume, nor was it cracked from impact; the motor was still securely in place. Additionally, all three of the fins were undamaged and still solidly affixed to the centering rings. No damage was observed on any section of the airframe, and all parachutes and shock cords were undamaged as shown in Figure 3.9.8

Figure 3.9.7. *Aft end of the booster section. Note the surprisingly minimal charring due to exhaust.*

Figure 3.9.8. (Left) *Main parachute and flame blanket;* ***(Right)*** *Drogue parachute and flame blanket.*

The bulkhead holding the eye bolt connecting the forward section of the rocket to the avionics bay pulled free from the payload tube coupler, letting the payload bay fall freely and impact the ground far from the rest of the rocket. Figure 3.9.9 gives a close-up view of the payload bay bulkhead and its failure mode

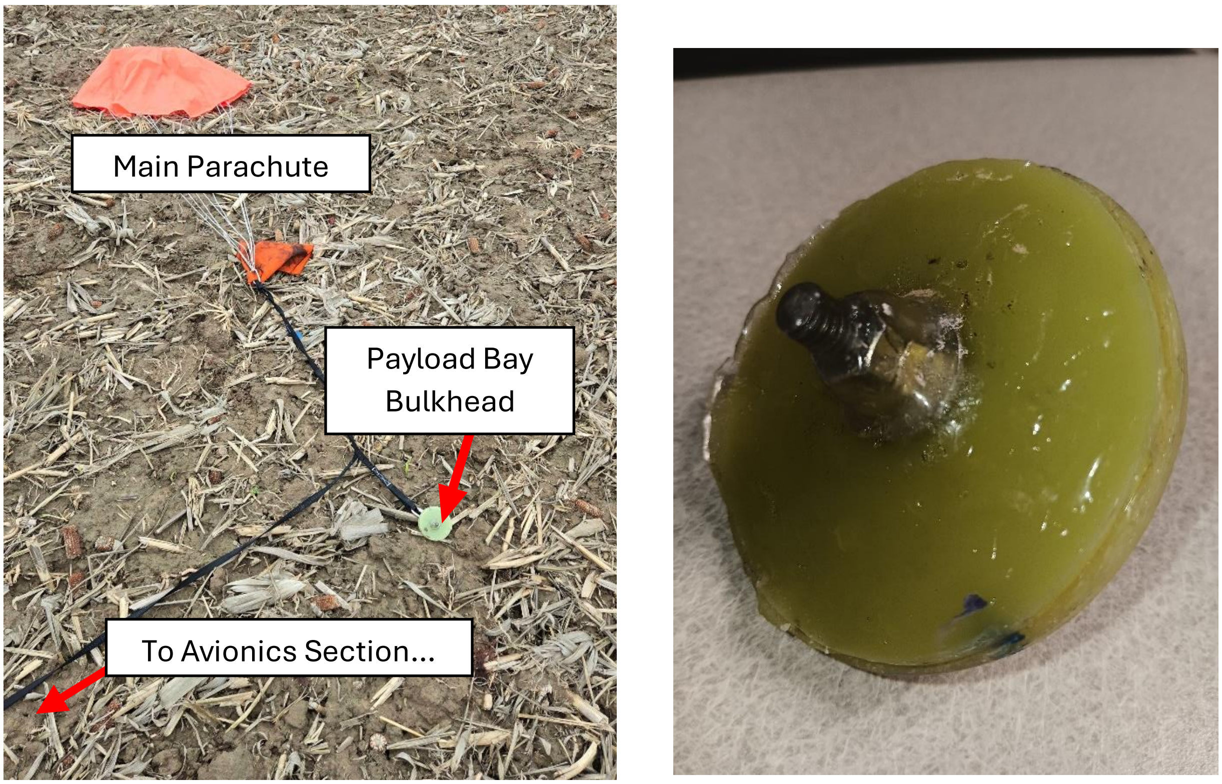

Figure 3.9.9. (Left) *The remaining tethered piece of the rocket's forward section as it was recovered;* ***(Right)*** *Closeup view of the failed bulkhead, showing signs of improperly applied epoxy.*

As Figure 3.9.9 indicates, the epoxy on the bulkhead capping off the payload bay coupler was not applied evenly. CSL believes that the force exerted on the eye bolt during the main parachute ejection, combined with the fact that the forward section had over a kilogram of ballast in motion, was enough to shear the insufficient amount of epoxy on the bulkhead. Unfortunately, CSL was unable to capture clear video of the rocket recovery events. Since the total flight time recorded by the altimeter was almost exactly the same as the OpenRocket simulation predicted, it is assumed that the heavy forward section remained tethered to the rocket for most of the flight as the rocket's descent time would have been much longer if the bulkhead failed during the drogue event.

The forward section of the rocket, once it became untethered from the rest of the rocket, stuck into the ground approximately 75 feet away from the other two rocket sections. Figure 3.9.10 shows the landing location of the forward section relative to the rest of the rocket. While the payload bay airframe and coupler were completely intact, the fiberglass-reinforced 3D printed nosecone fractured at the shoulder and buried itself as shown in Figure 3.9.11.

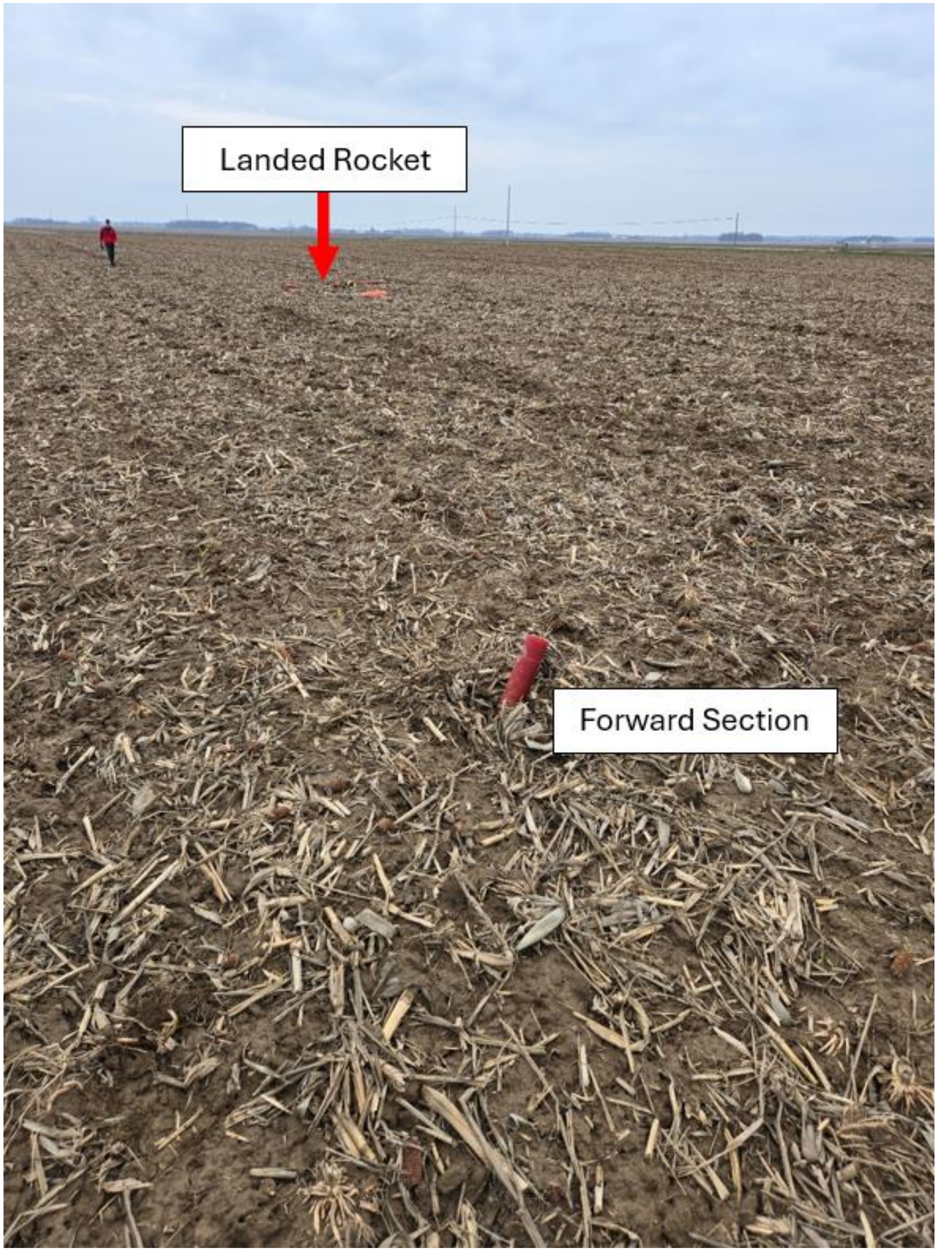

Figure 3.9.10. *Site of forward section impact relative to the landing location of the rest of the rocket.*

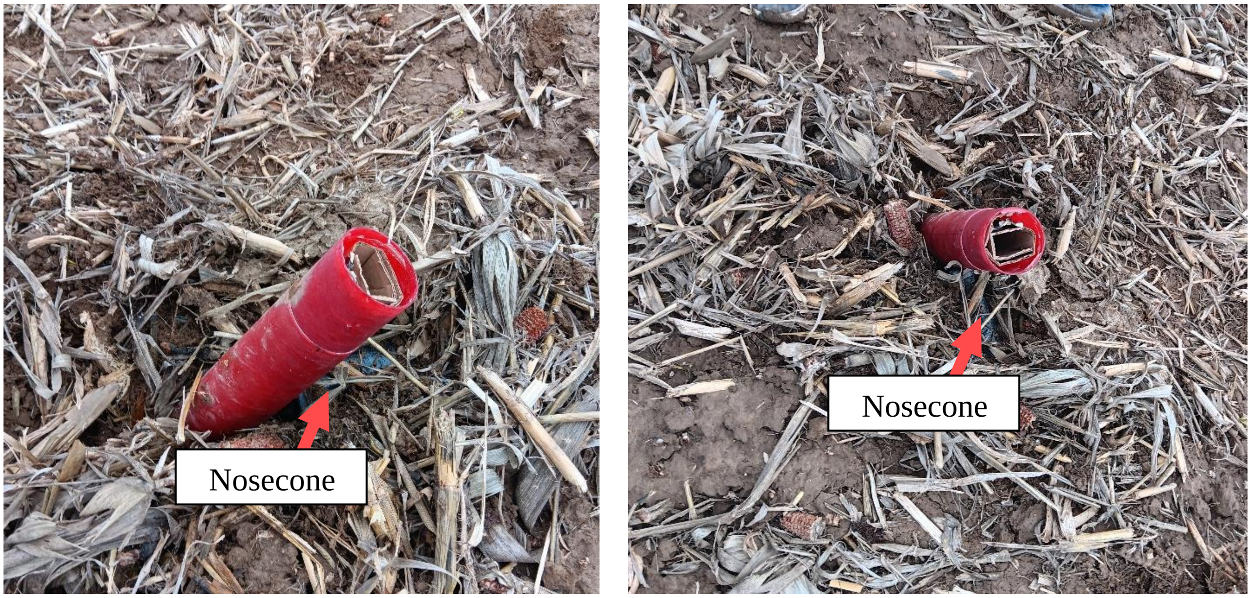

Figure 3.9.11. *Forward section after impact. The black nosecone is faintly visible underneath the red fiberglass airframe.*

The significant impact that the forward section endured evidently suddenly slammed the lead ballast weight into the clay nose ballast. The shock fractured the 3D printed cone at the shoulder, where the material was thinnest due to the heatset inserts used to mount the cone to the payload bay. This theory is supported by the form of the cracks propagating across the shoulder shown in Figure 3.9.12. The rest of the cone, which was armored by three heavy fiberglass-epoxy layups, was completely unharmed in the crash.

Figure 3.9.12. *Nose cone failure point focused at the heatset inserts.*

3.9.4. Analysis

After the subscale flight data was recovered, CSL developed a new OpenRocket simulation model to interpret the altimeter readings. The purpose of this simulation was twofold: 1) It gave the design team an opportunity to see what degree of simulation detail was necessary for accurately predicting rocket flights, and 2) it allowed the simulation lead to investigate the launch conditions and vehicle parameters that most affected the rocket's performance. The improved simulation included more precise details on the amount and location of mass components inside of the subscale rocket. The actual launch day conditions such as temperature, windspeed, wind direction, and launch rail angle were also represented in the improved simulation. Table 3.9.3 summarizes the two OpenRocket flight simulation predictions.

Table 3.9.3. *Performance differences between the initial and improved subscale simulations.*

Simulation	Configuration	Velocity off rod	Apogee	Max. velocity	Max. acceleration	Time to apogee	Flight time
Initial	[J540R-0]	67.9 ft/s	3322 ft	477 ft/s	287 ft/s^2	14.7 s	73.9 s
Improved	[J540R-0]	65.7 ft/s	3139 ft	463 ft/s	278 ft/s^2	14.4 s	68.5 s

The drag coefficient of the subscale rocket was estimated using two separate methods. The first uses the formula for drag force and Newton's 2nd law to calculate the drag coefficient over a specified time interval during the coast phase of the ascent. The time interval chosen was 3-3.5 seconds into the coast phase of flight. This is where the data appeared to have the least noise, and the rocket was still traveling fast enough to have a noticeable drag force. The acceleration during this time interval based off the first and last data point was -37.2 ft/s^2 and the average speed was 275.7 ft/s. The drag coefficient was calculated using this method to be 0.525 and the calculations are shown below. This method is reasonably accurate and is close to the estimate of 0.65 found in the OpenRocket simulation. The variance between the two drag coefficients could be explained by the surface finish of the rocket not being accounted for properly in OpenRocket.

$$C_d = \frac{2F_d}{\rho v^2 A} = \frac{2m(g-a)}{\rho v^2 A}$$

$$= \frac{2 * 14.509[lb]\left(-32.2\left[\frac{ft}{s^2}\right] + 37.24\left[\frac{ft}{s^2}\right]\right)}{0.06806\left[\frac{lb}{ft^3}\right]\cdot\left(275.7\left[\frac{ft}{s}\right]\right)^2\cdot .0538[ft^2]} = 0.525$$

The second method that was used to calculate the drag coefficient was using the OpenRocket model and running simulations with varying drag coefficients for. The vertical velocity vs the vertical acceleration during the coast phase of flight for each of the drag coefficients was plotted and the resulting curves can be compared to the same curve from the flight data with the best matching curve being the actual drag coefficient of the rocket. This method should be highly precise and accurate because it uses data from the entire coast phase of flight and each value for the drag coefficient produces a unique distinguishable curve.

The only functional data gathering device on this rocket was the aforementioned RRC3 altimeter which measures the pressure, converts it to an altitude, and then differentiates it to find the velocity. To find the acceleration of the rocket the altitude was numerically differentiated a second time. This method produced a very noisy and unusable curve due to the noise in the pressure readings being magnified by each successive derivative. To reduce this issue, a 3rd order polynomial curve fit was used to smooth out the velocity data and allow for cleaner data after it was differentiated. A moving average of the acceleration was taken, and the resulting acceleration vs velocity was overlayed on the curves from the OpenRocket simulations and is shown in Figure 3.9.13. Due to the error introduced by taking a noisy signal for altitude and using numerical differentiation twice to estimate the acceleration the result does not match any of the drag coefficient curves very well.

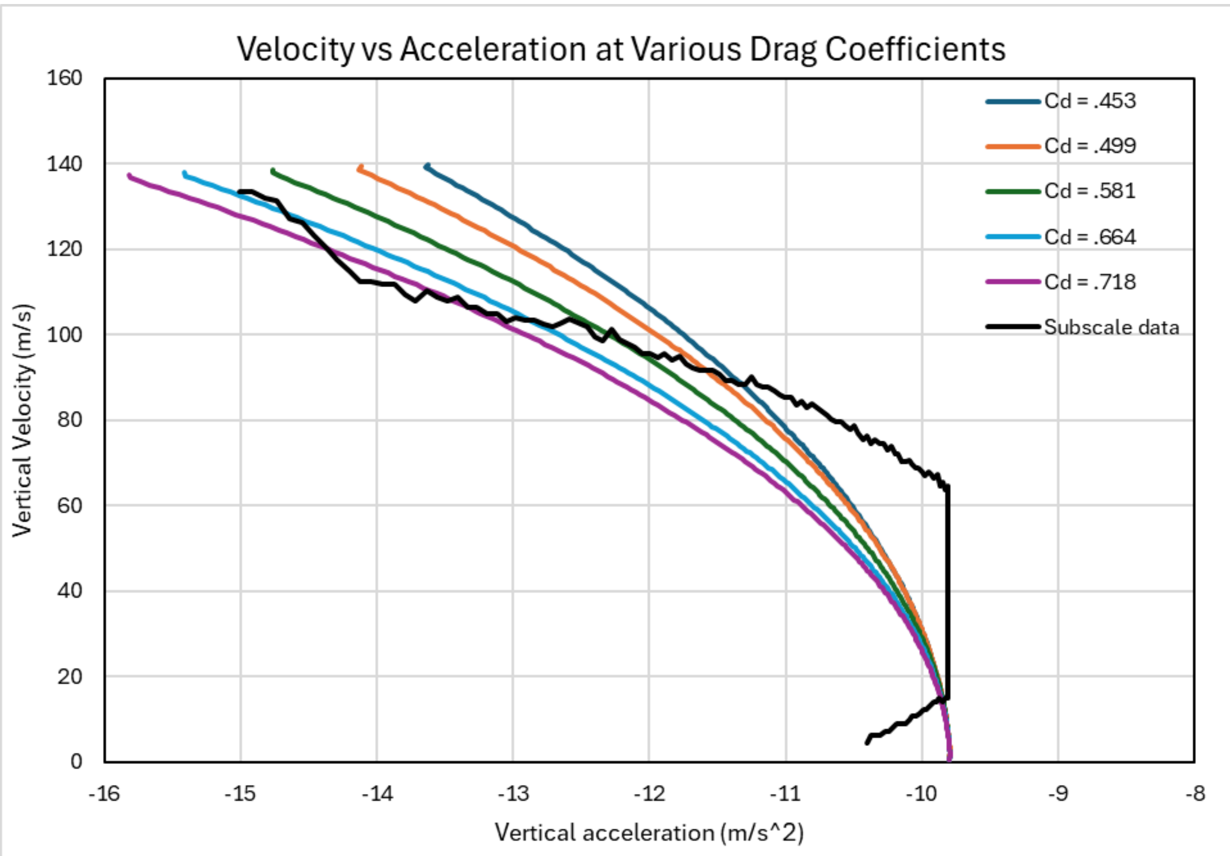

Figure 3.9.13. *Simulated velocity vs acceleration for increasing drag coefficients overlayed onto the velocity vs acceleration of the subscale rocket during the coast phase of flight. Note that the subscale data has been clipped on the right side to reflect the known bounds of acceleration experienced by the rocket.*

There are two useful pieces of information that can be gathered from the above graph. The first is the verification that the estimated drag coefficient of 0.525 is reasonable. The second, and more important, is the knowledge that this method will prove useful for finding the drag coefficient of the full-scale rocket. The full-scale rocket will be equipped with an accelerometer which will directly measure acceleration, and the velocity can be found by averaging the velocity from the altimeters with the integral of the acceleration from the accelerometer. This will provide curves with more accuracy and less noise that can be used to directly estimate the drag coefficient of the full-scale rocket. The estimated drag coefficient for the subscale rocket of 0.525 should compare relatively well to the drag coefficient of the full-scale rocket. Any major differences will mostly be attributed to poor construction quality of the subscale nosecone resulting in a nosecone that is further from the ideal nosecone that CSL is striving to achieve for the full-scale.

In spite of the improvements added to the OpenRocket simulation model, a significant disparity still existed between the altimeter's apogee reading (3007 feet) and the predicted apogee from the simulation (3139 feet). Figure 3.9.14 shows the altitude prediction differences for the rocket's ascent to apogee, and Figure 3.9.15 shows the total velocity prediction differences on the same tie scale. CSL attributes the simulation differences to OpenRocket's inability to model surface variations on the subscale's nosecone. The fiberglass layups on the cone were not smoothly applied, particularly at the base of the cone. Adding a hypothetical discontinuity to the rocket body diameter at the cone shoulder in the improved simulation had the biggest effect on lowering the rocket's predicted apogee of any of the other varied parameters, though its exact impact would be difficult to estimate since the cone's rough shape could not be accurately modelled. For this reason, and for the fact that all other aspects of the rocket appear to be accurately modelled, CSL believes that the major differences between the OpenRocket simulations and the actual flight data shown in Figures 3.9.14 and 3.9.15 are the result of poor nosecone construction quality.

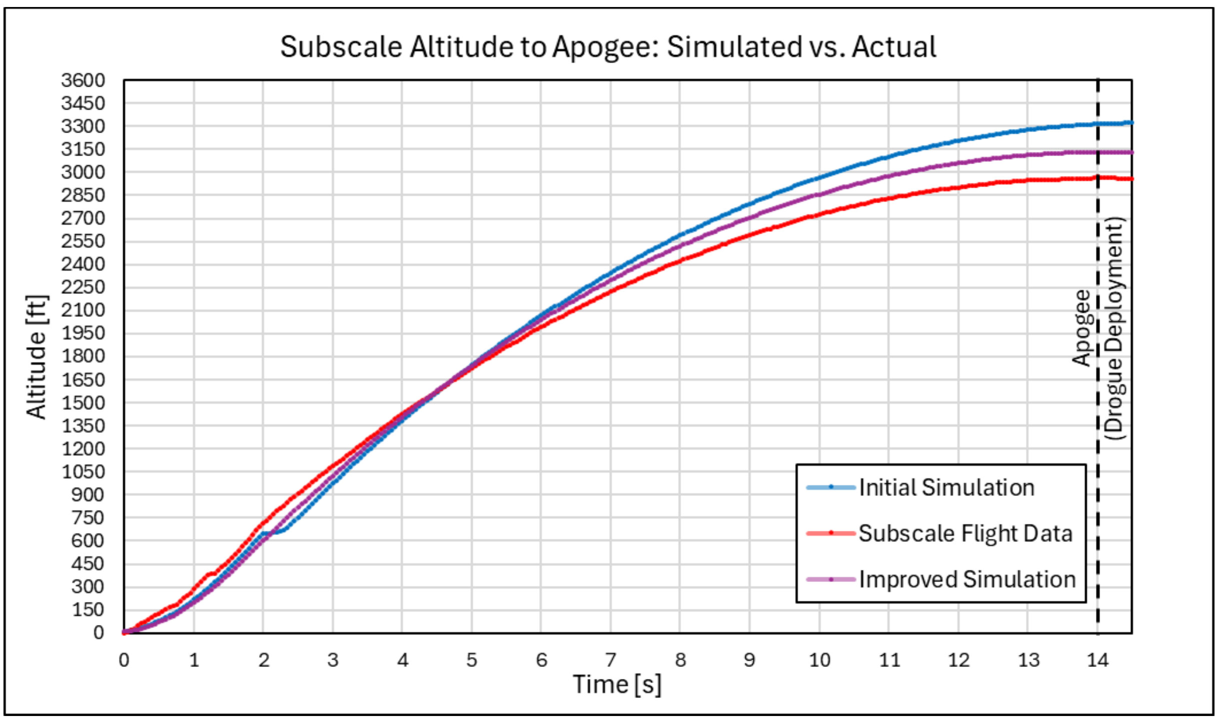

Figure 3.9.14. *OpenRocket's altitude estimations for the subscale ascent compared with the actual flight data.*

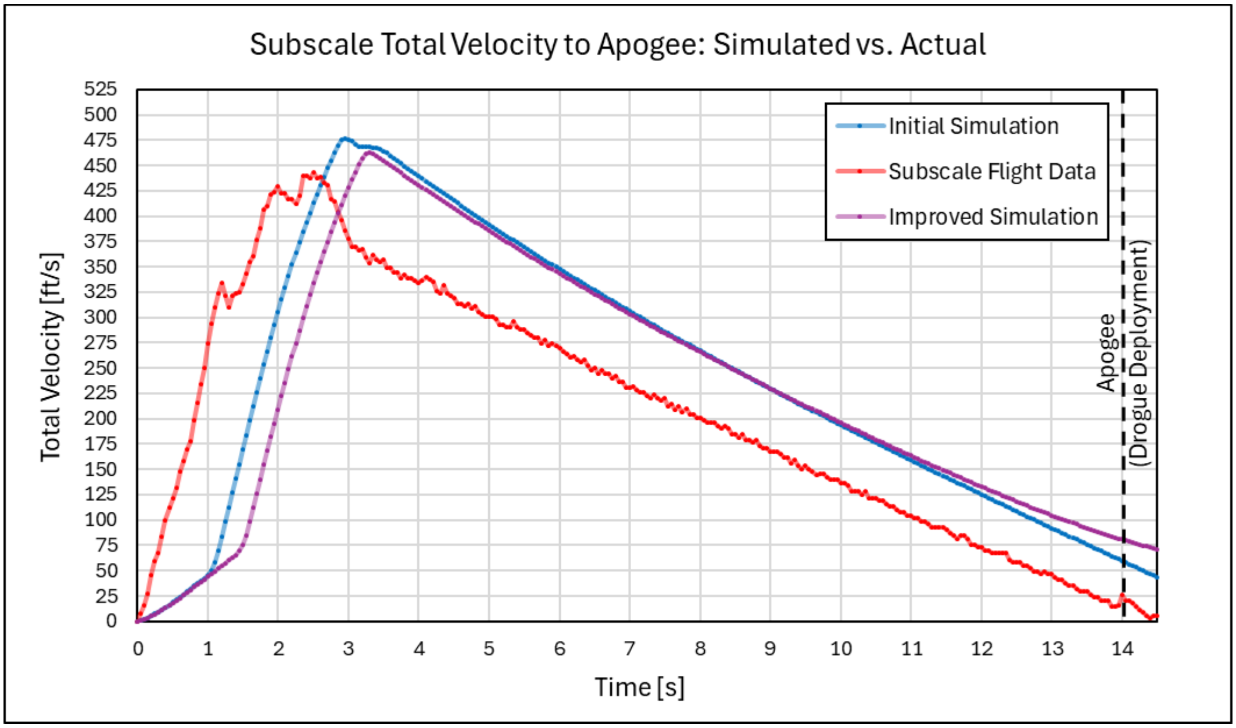

Figure 3.9.15. *OpenRocket's total velocity estimations for the subscale ascent compared with the actual flight data.*

3.9.5. Impact on Full Scale Design

The subscale's performance demonstrated the viability of many previously unverified design decisions. The effects of high temperatures and landing impact on the 3D printed tailcone and thrust structures were previously unknown. However, after evaluating the thrust structure's performance and structural integrity after launching, CSL is willing to proceed with testing and eventually incorporating these 3D printed parts into the formal full-scale design.

The subscale flight showed that a new method of gluing the forward bulkhead into the payload bay coupler will be required for the full scale. During the subscale construction, the coupler was glued into the payload bay tube before the bulkhead was glued. The issue with this approach was that the small airframe and the length of the payload bay made it difficult to cleanly and evenly apply epoxy to the inside of the coupler, where the bulkhead needed an epoxy fillet. For the construction of the full scale, CSL will change the bulkhead design to sit ½" farther forward into the coupler tube and will also glue the coupler into the payload bay last so that the bulkhead epoxy can be applied in adequate amounts while both ends of the coupler are accessible. Figure 3.9.16 demonstrates this new gluing technique informed by the bulkhead failure in the subscale launch.

Additionally, while the fiberglass-covered portion of the nose cone survived a catastrophic crash, CSL is going to explore the possibility of reducing the cone-strengthening measures so that it can be more accurately modelled on the full-scale launch vehicle. Formal testing procedures on this component are to follow, but since proper gluing techniques are applied to the bulkhead out to prevent further extreme impacts, CSL believes that weakening the cone for the sake of simulation integrity may be desirable.

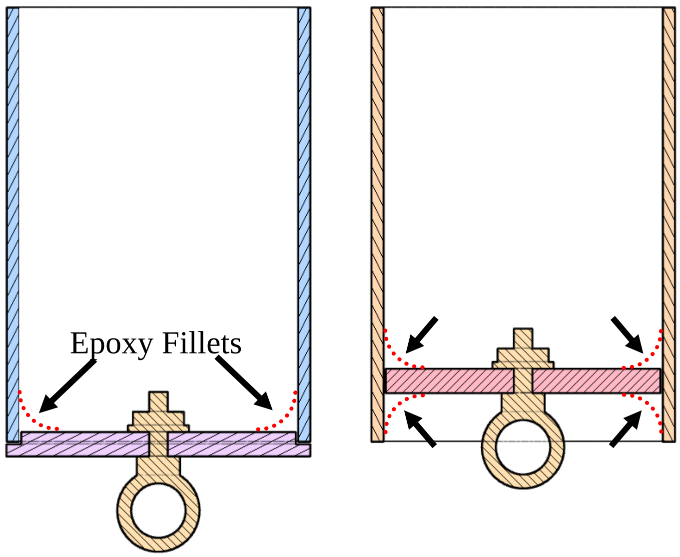

***Figure 3.9.16. (Left)** Cutaway view of the bulkhead gluing method that failed during the subscale flight; **(Right)** The proposed gluing method that will be used during full scale construction. Note the increased epoxy fillet area that this method allows.*

3.10. Recovery Subsystem

3.10.1. Recovery Subsystem Overview

CSL's *Project Elijah* utilizes a dual bay recovery system which has a drogue parachute that deploys at apogee and a main parachute that deploys at 600 [ft] AGL (Figure 3.10.1). Both parachute bays will also contain a slightly larger charge set to combust a couple of seconds (about 50 [ft]) later in case separation does not occur with the first charges. The drogue parachute bay will be in the aft section of the rocket in between the avionics bay and the secondary payload while the main will be in the fore, in between the primary payload and avionics bay. Placing both parachute bays on either side of the avionics bay allows for the black powder charges to be easier to connect and allow for shorter wires connecting them to the altimeters. As well as allowing for a single avionics bay reducing the complexity of the overall design.

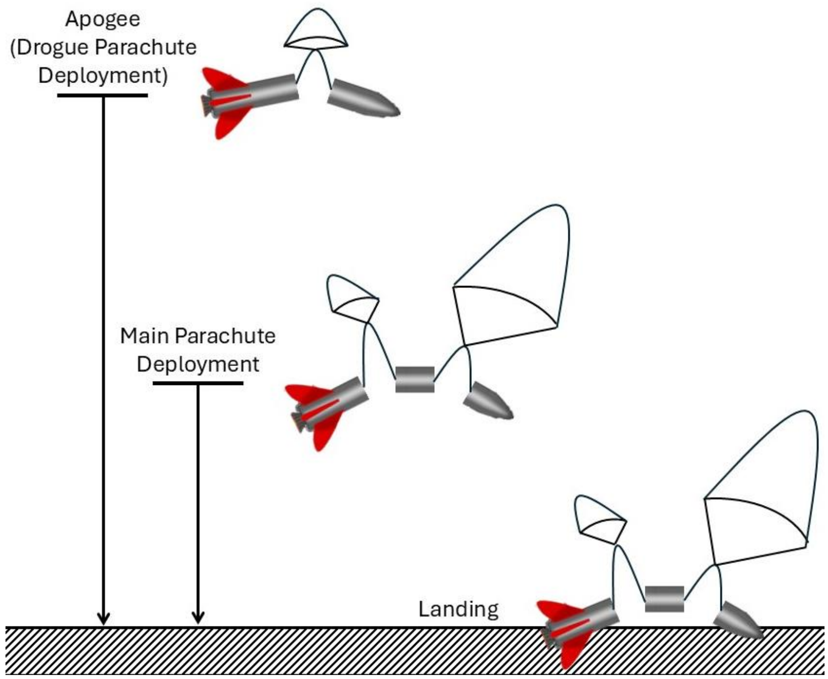

Figure 3.10.1. *Visual depiction of the three main events that occur in the descent of the launch vehicle. The first is at apogee when the drogue parachute is deployed, the second is when the main parachute deployment, and the third is when the rocket lands.*

The drogue parachute that CSL has decided to utilize for the launch vehicle is a Parabolic with a 12 [in] diameter from Rocketman Parachutes. This parachute was chosen due to the faster descent rate and smaller packing size it gives which helps ensure CSL's descent predictions and performance fulfill the requirements given out in the 2025 NASA SL Handbook. This same decision-making process was used for the main parachute which will be a Toroidal with a 7 [ft] diameter that also comes from Rocketman Parachutes. It is through these parachute sizes and types which will deploy at their respective altitudes that will allow for the performance of CSL's *Project Elijah* to have a successful and complete recovery. More complete analysis of the descent predictions can be seen in Section 3.11.

The shock cords chosen are the same for both parachute bays and are 30 [ft] in length, roughly 3.5 times the length of the body. CSL is using 9/16 [in] tubular Nylon due to its strength properties with a tensile strength of 1500 [lbf] and its ability to deform and lessen the stress placed on the bulkheads and shock mounts when the parachutes deploy. The team then worked to increase the amount of energy and stress by creating frangible ties by rolling up and taping part of the excess length. This will take out some of the energy by the tape being broken. Through all of this we aim to create a safety factor for the connections to the rocket body by decreasing the actual stress applied to them when the lines become taut. Attached to the shock cords beside the parachutes are the flame blankets. CSL decided on flame blankets instead of deployment bags because they can be placed to cover and protect more as well, they are cheaper. Each parachute bay has its own flame blanket that can be placed around the parachutes and shock cords to protect everything from the combustion of the black powder. For the attachment of the shock cords to the rocket and the placement of the parachutes along their respective shock cord three quick links will be attached to each shock cord. One will be attached at each end and then one at 1/4th of the length with an overhand knot which the parachutes will attach to. The main parachute's shock cord will have the shorter line attached to an eye ring on the payload bay of the rocket with the longer on the forward eye ring of the avionics bay. The drogue's shock cord will have the shorter line attached to the aft eye ring of the avionics bay and the longer attached to the shock cord mount inside of the booster tube.

Upon performing the proof-of-concept through launching CSL's subscale it came to the team's attention that a lot more black powder was needed than originally calculated. Due to the volume and shear pins being used for both bays it was originally calculated that less than 1 gram of black powder was needed for both bays. In launching the subscale, it was found that 3 grams were needed for each bay. After this the code used was rechecked and it was found that a unit change was missing. By fixing this, CSL was able to confirm the amount of black powder needed for the subscale and fix the predicted amounts for the full-scale. Table 3.10.1 contains the new black powder amounts after the corrections were made.

Table 3.10.1. *Primary and secondary black powder charges for the main and drogue bays of Project* Elijah's *full-scale rocket.*

	Drogue	Main
First Charge [g]	3.3	5.0
Secondary Charge [g]	3.8	5.5

3.10.2. Shock Chord Mount Specifications

The shock chord mount absorbs the pulling force from the shock chord after the black powder is detonated. The final drawing for the shock chord mount is shown in Figure 3.10.2. The shock chord mount has changed little since the PDR. The main change is that it is no longer hollow, which will act as a seal and protect the airbrakes battery from ejection gases. This only adds a few grams to the overall rocket.

The strength of the shock chord mount can be defined as the part on the mount that will fail first. In this case, it would be the U-bolt. The U-bolt has a rated capacity of 1075 pounds.

A theoretical analysis is currently in the works to determine if the force from the shock chords will surpass the rated capacity. This analysis will be verified using experiments.

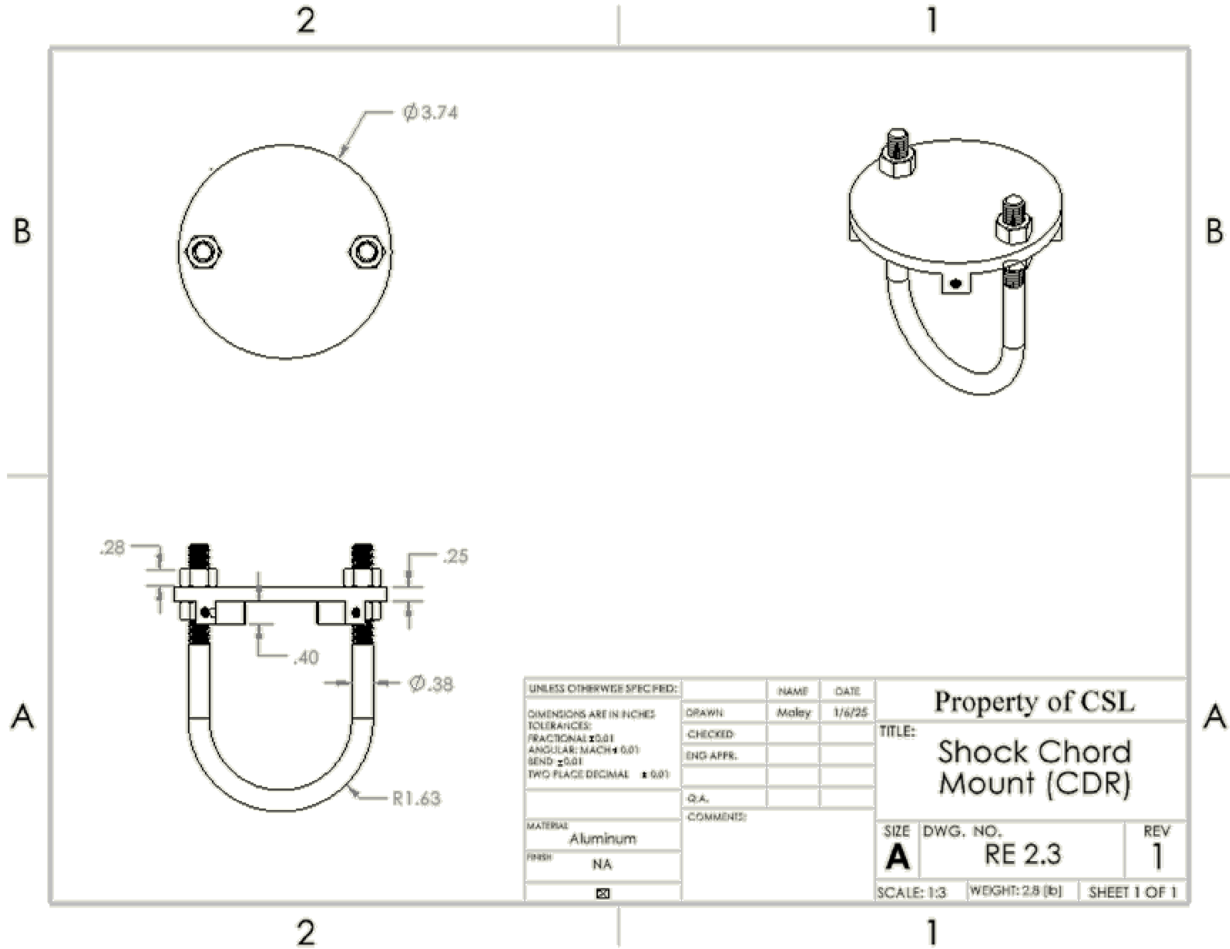

Figure 3.10.2. *Shock Chord Mount SolidWorks Drawing*

Before the analysis can be done, multiple assumptions must be made to make this analysis doable. The first assumption is that the explosion from the black powder will have almost the same impact on the shock chord mount whether the rocket is descending or not moving at all. The justification behind this is that the blast from the black powder will cause a much greater velocity change to the two parts of the rocket than the rocket's descent. The second assumption is that not all the energy from the black powder will be used for propulsion, but only a portion of it. Some of the energy is lost due to heat and light. The third assumption is that the shock chord obeys Hooke's law and acts like a spring. In reality, this is not entirely true, since the shock chord becomes stiffer once it approaches its ultimate tensile strength. This assumption also makes the calculations more conservative if the shock chord would approach its ultimate tensile strength. The last assumption that will be made is that the energy consumed from the shear pins is going to be negligibly small. The reason for this is because energy is force multiplied by displacement, and the shear pins have a very small displacement right before they shear, so this value can be ignored.

This is going to be an idealized collision type problem, so conservation of energy and momentum will need to be employed. Initially, as stated previously, the rocket can be treated as initially stationary since the inertial plane is relatively constant. The conservation of momentum is shown in Equation (3.10.1). In this equation m_1 and m_2 are the masses of each section of the rocket after the black powder explosion, and v_1 and v_2 are their respective velocities right after the explosion.

$$(m_1 + m_2)v_o = m_1 v_1 + m_2 v_2 \tag{3.10.1.}$$

Then, the black powder explodes and separates the main bay. The potential energy from the black powder charges is going to be the same as the kinetic energy after the explosion due to conservation of energy. The conservation of energy is shown in Equation (3.10.2).

$$PE_{black\ powder} = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 \tag{3.10.2.}$$

There is no concise value for the potential energy of the black powder used in this flight, however, there are multiple ways that the team has thought on how to calculate it. The first is to use the chemical formula to calculate the change in enthalpy of the reaction. Another way to calculate the energy released in the black powder would be to take a video of the pop test with a way to measure the distance traveled of the nose cone section. These ideas are in the works but have not been finalized yet.

The kinetic energy from the force is going to equal the energy from the displacement of the shock chord. Because of the conservation of energy, the potential energy from the explosion is going to directly equal the energy from the displacement of the shock chord. The best way to acquire a value for the stiffness of the shock chord would be to do an experiment. This experiment would include hanging various weights off the shock chord and measuring the deflection. The deflection would be plotted against the force and an interpolation between points would be used as the stiffness.

The stiffness calculated from that experiment would then be used to calculate the actual deflection in the shock chord from the potential energy of the black powder. This equation is shown in Equation (3.10.3).

$$PE_{black\ powder} = \frac{1}{2}k\delta^2 \tag{3.10.3}$$

Using this formula, it is possible to calculate the force generated from the shock chord pulling force. Using the stiffness constant and the displacement, the pulling force can be calculated from Equation (3.10.4).

$$F_{chord} = k\delta \tag{3.10.4}$$

If the force of the chord is found to be significantly less than 1075 pounds, then the shock chord mount will be considered safe to use.

3.10.3. Avionics Bay

The avionics bay sits inside the coupler tube separating the main and drogue parachute bays. It houses two redundant altimeters which control the ejection of both parachutes as well as a GPS transmitter used for locating the rocket after landing. Figures 3.10.3 and 3.10.4 show the final avionics design for the full-scale rocket. The leading design from the PDR milestone was decided on with the design being updated based on lessons learned from building and flying the subscale rocket.

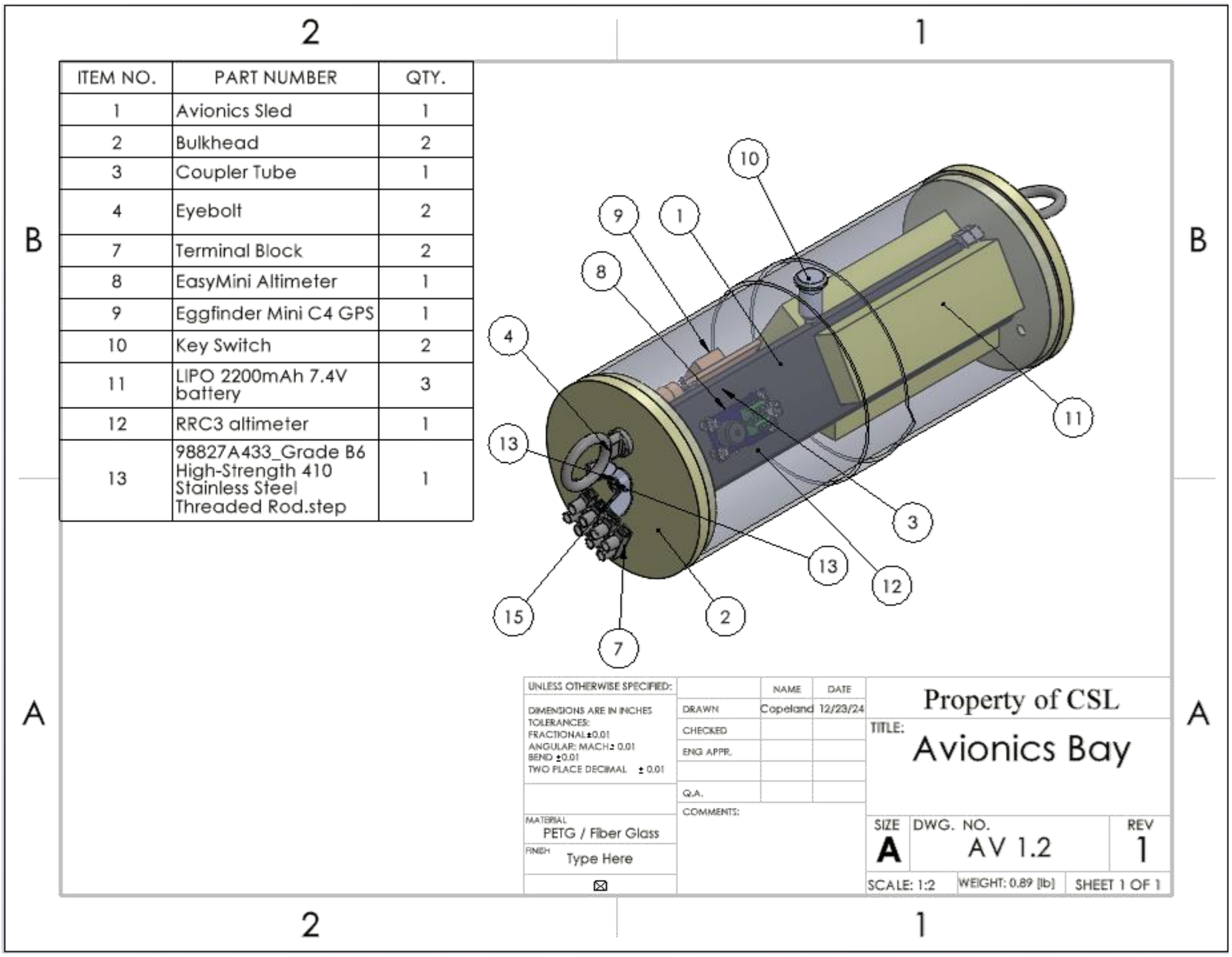

Figure 3.10.3. *Full-scale avionics bay isometric view with bill of materials.*

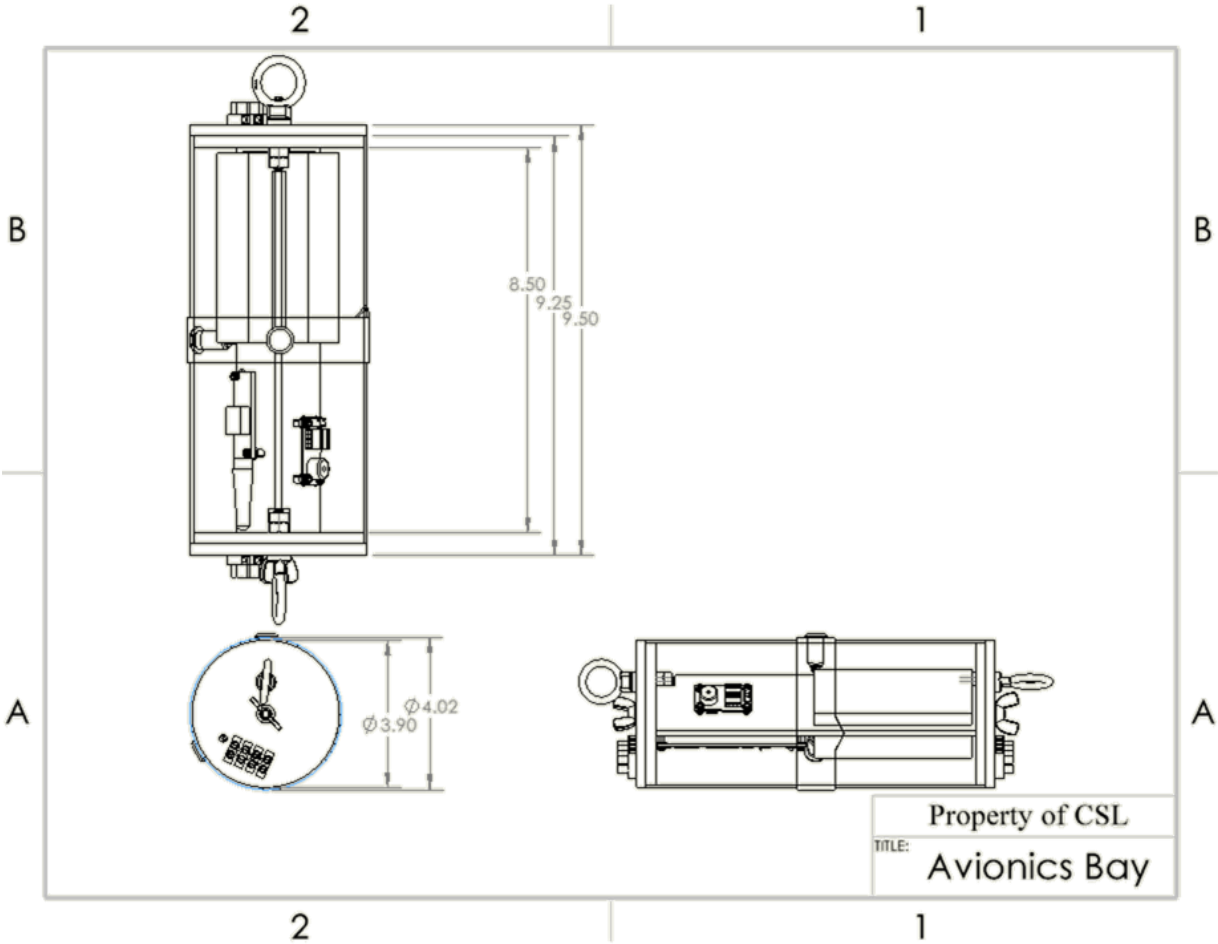

Figure 3.10.4. *Dimensioned drawing of full-scale avionics bay.*

The shock cords for both parachutes will be connected to closed eyebolts on either side of the avionics bay. The force from the shock cords during recovery will be transmitted from the eyebolts, through the fiberglass bulkhead, to the stainless-steel threaded rod going through the middle of the coupler tube that holds the electronics and bulkheads in place. The 410 stainless-steel of the threaded rod has a yield strength of 85 ksi and an ultimate tensile strength of 110 ksi, this allows the ¼ inch thick rod to withstand a tensile force of 4,172 pounds before experiencing plastic deformation and 5,400 pounds before failing. Each bulkhead is made from two sheets of G10 fiberglass that are epoxied together with one that is smaller to fit inside the coupler tube which prevents the bay from sliding relative to the coupler tube. Because fiberglass is an anisotropic material it is hard to find the strength characteristics of it because it is highly dependent on the exact way that the fiberglass was manufactured. Given the difficulty of conducting stress analysis on anisotropic materials, CSL has determined that ½ inch of fiberglass will be more than enough to transfer any forces during recovery to the threaded rod for a couple of reasons. The first is that the bulkheads on either end of the avionics bay for the subscale rocket where only ¼ inch thick and they survived the subscale launch with no signs of fracture or damage. The second reason is that using two sheets of fiberglass or plywood to create a load bearing bulkhead similar to this is standard practice in the Student Launch competition and high-powered rocketry in general. Finally, CSL intends to use an Instron tensile testing machine to fatigue test the structure of the avionics bay to find the point and method of failure. This testing mechanism does not necessarily imitate the loading mechanism experienced during flight due to the Instron machine not being able to replicate the impulse loading experienced during flight. This test will still provide valuable data to ensure the structural integrity of the avionics bay.

The avionics bay utilizes redundant altimeters powered by independent batteries and are each connected to separate ejection charges for both the drogue and main parachutes. This allows for inherent redundancy in the recovery system and eliminates the potential for a single point of failure in the avionics bay to cause a failure of the recovery system. Both the primary RRC3 altimeter and the redundant Altus Metrum EasyMini altimeter are commercial altimeter solutions and as such the wiring for them is simple. Each altimeter is connected to a Liperior 2200 mAh 7.4V battery and utilizes a key switch that is accessible from outside the rocket enabling the altimeters to be armed while the rocket is on the launch rail. The required wiring diagrams for both altimeters are shown in Figures 3.10.5 and 3.10.6.

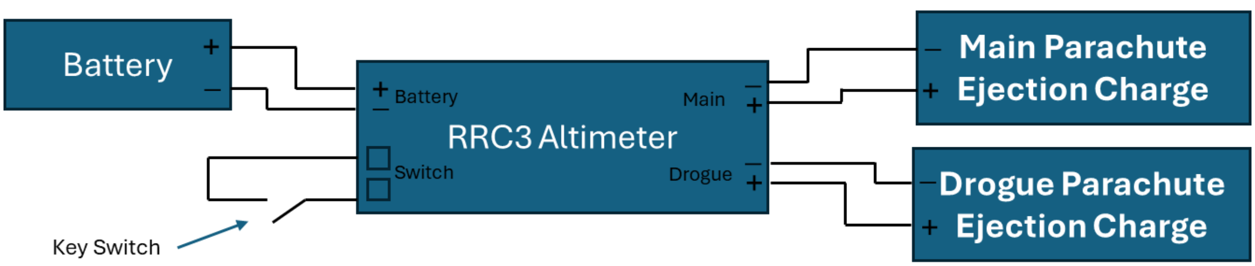

Figure 3.10.5. *RRC3 altimeter wiring diagram.*

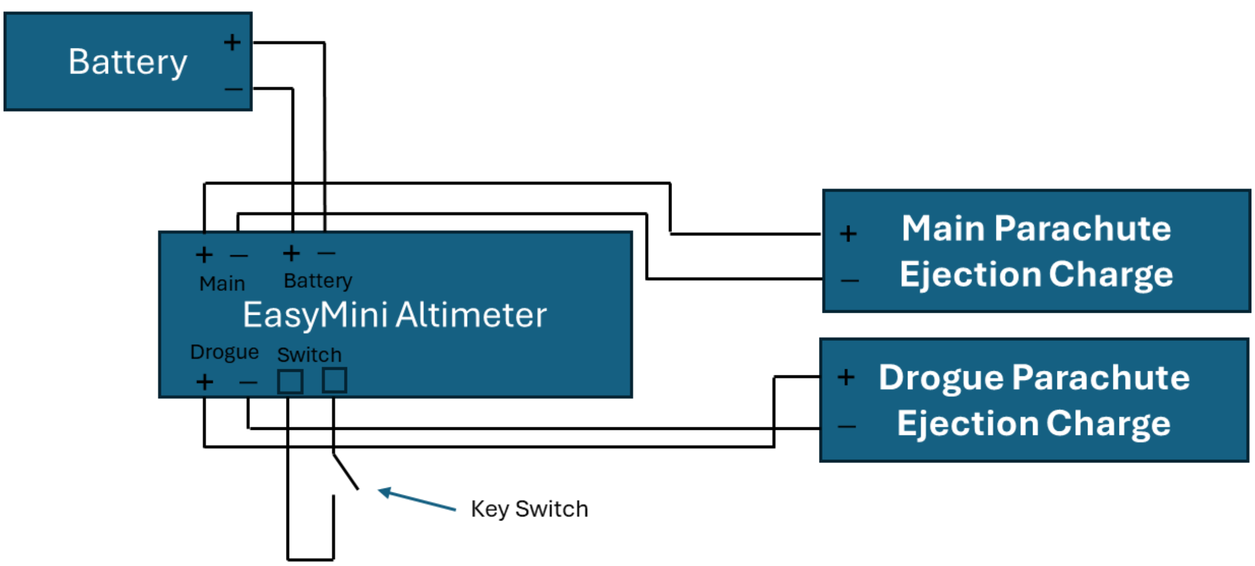

Figure 3.10.6. *Easymini altimeter wiring diagram.*

The final component inside the avionics bay is an Eggfinder Mini C4 GPS from Eggtimer. The transmitter is set to transmit on the 915 MHz frequency and will continuously send its location to the receiver when it is powered on. The GPS enables the rocket to be quickly and safely located even when line of sight is lost to the rocket. This GPS is powered by a third battery that is identical to the batteries supplying power to the altimeters.

3.11. Mission Performance Predictions

3.11.1. Ascent Predictions

The full-scale motor to be used for Chariot is a K1000T-P motor manufactured by AeroTech. The thrust curve for the motor found from experimental testing is shown in Figure 3.11.1 (*AeroTech K1000T Thrust Curve*). The motor produces thrust for a duration of 2.5 seconds, and the thrust is close to constant at 250 lb for the first 1.6 seconds of flight. The thrust decreases to just under 200 lb over the next 0.6 seconds and finally the generated thrust linearly decreases to 0 lb over the final 0.3 seconds. Using an accurate thrust curve of the specific motor to be used during flight is important for obtaining accurate flight simulations from programs such as OpenRocket. Table 3.11.1 shows some of the various performance metrics that the selected motor is capable of producing for the launch vehicle. This motor, with an inactive AB system, will carry the rocket to an apogee of 4931 ft with a maximum velocity and acceleration of 592 ft/s and 278 ft/s^2 respectively.

Table 3.11.1. *Performance metrics of AeroTech K1000T-P motor in full-scale rocket.*

Motor	Velocity off rod	Apogee	Max. velocity	Max. acceleration	Time to apogee	Flight time
K1000T-P	66.9 ft/s	4931 ft	592 ft/s	278 ft/s^2	17.8 s	71 s

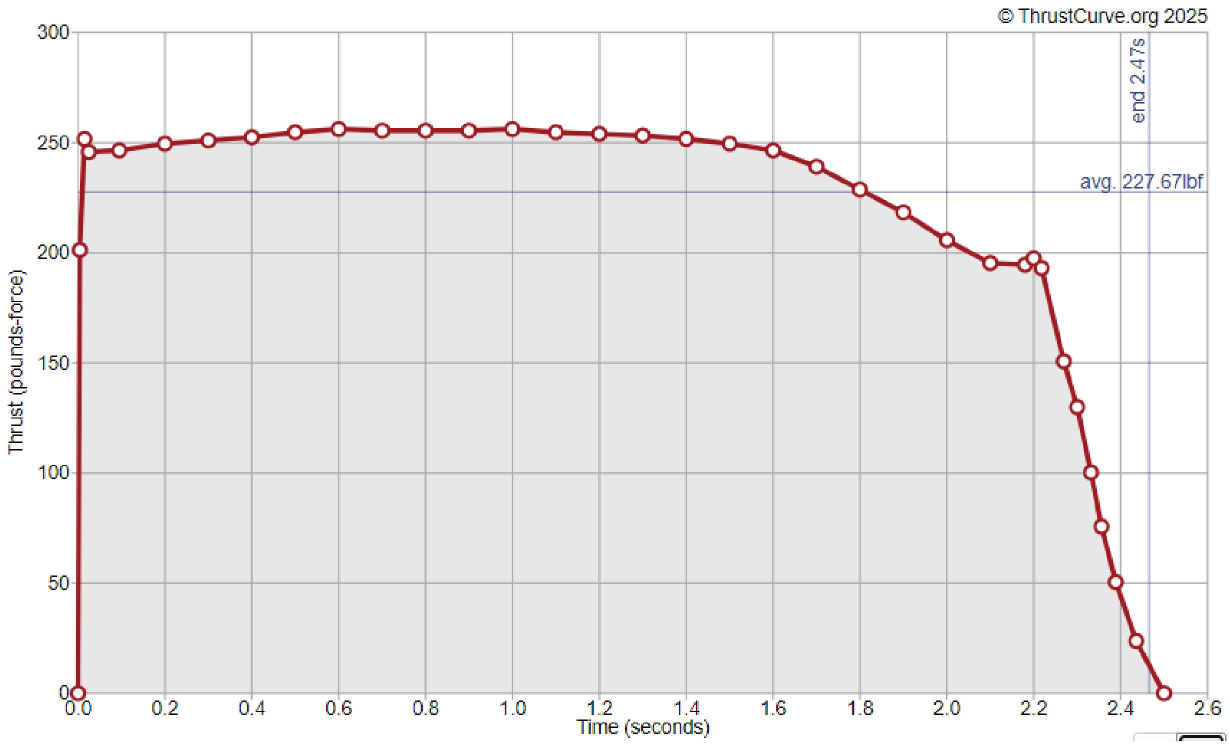

Figure 3.11.1. *Experimental thrust curve of primary AeroTech K1000T-P motor. Source (thrustcurve.org).*

Figure 3.11.2 contains the most up-to-date OpenRocket model of the full-scale launch vehicle with the locations of the wet center of gravity and center of pressure with airbrakes stowed being shown. The static stability margin was calculated by dividing the distance between these points by the diameter of the rocket. The static stability margin was calculated to be 2.29 cal as shown in Table 3.11.2 fulfilling NASA Req 2.14. This static stability margin calculation should be highly accurate if the OpenRocket model is current and refined to the vehicle design. CSL believes this to be the case and has taken great care to develop a highly accurate OpenRocket of the launch vehicle.

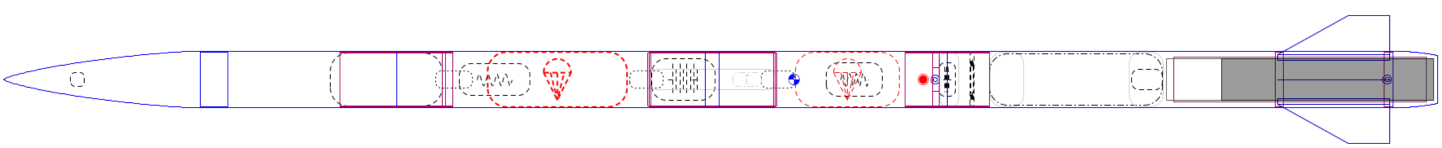

Figure 3.11.2. *OpenRocket model of the full-scale launch vehicle showing the locations of the center of pressure (red dot) and center of gravity (blue dot).*

Table 3.11.2. *Stability calculation using wet mass of the launch vehicle to find the center of gravity.*

CG (from tip)	56.33 in
CP (from tip)	65.53 in
Static Stability Margin	2.29 cal
GLOW	27.4 lb

To verify the locations of the center of gravity and the center of pressure found from OpenRocket, it is possible to use hand calculations using Equation (3.11.1) and (3.11.2). In Equation 3.11.1 $\bar{x}_n$ is the location of the centroid of the projected area onto a 2D surface of each section of the rocket and A_n is the projected area of each section of the rocket. In Equation 3.11.2, $\bar{x}_n$ is the location of the center of mass of each component of the rocket and W_n is the weight of each section of the rocket. Using this method of hand calculation the center of gravity was calculated by estimating the center of gravity of each of the subsections and was close to the center of gravity found in OpenRocket. The center of pressure has not yet been found accurately using this method due to the complexity of accurately calculating the projected area and centroid of each of the sections of the rocket. This analysis will be completed in the future and will be used to verify the static stability margin found using OpenRocket.

$$X_{CP} = \frac{\sum(\bar{x}_n A_n)}{\sum A_n} \tag{3.11.1}$$

$$X_{CG} = \frac{\sum(\bar{x}_n W_n)}{\sum W_n} \tag{3.11.2}$$

OpenRocket was used to create simulations of the profile of the launch vehicle during flight using wind speeds ranging from 0-20 mph and launch rail angles of 0-25°. Figure 3.11.3 shows a simulated flight profile from OpenRocket using the K1000T motor, a vertical launch rail, under a wind speed of 5 mph. The simulation was run for wind speeds of 0-20 mph and launch rail angles of 0-25° in increments of 5 mph and 5 degrees respectively, for a total of 30 simulations.

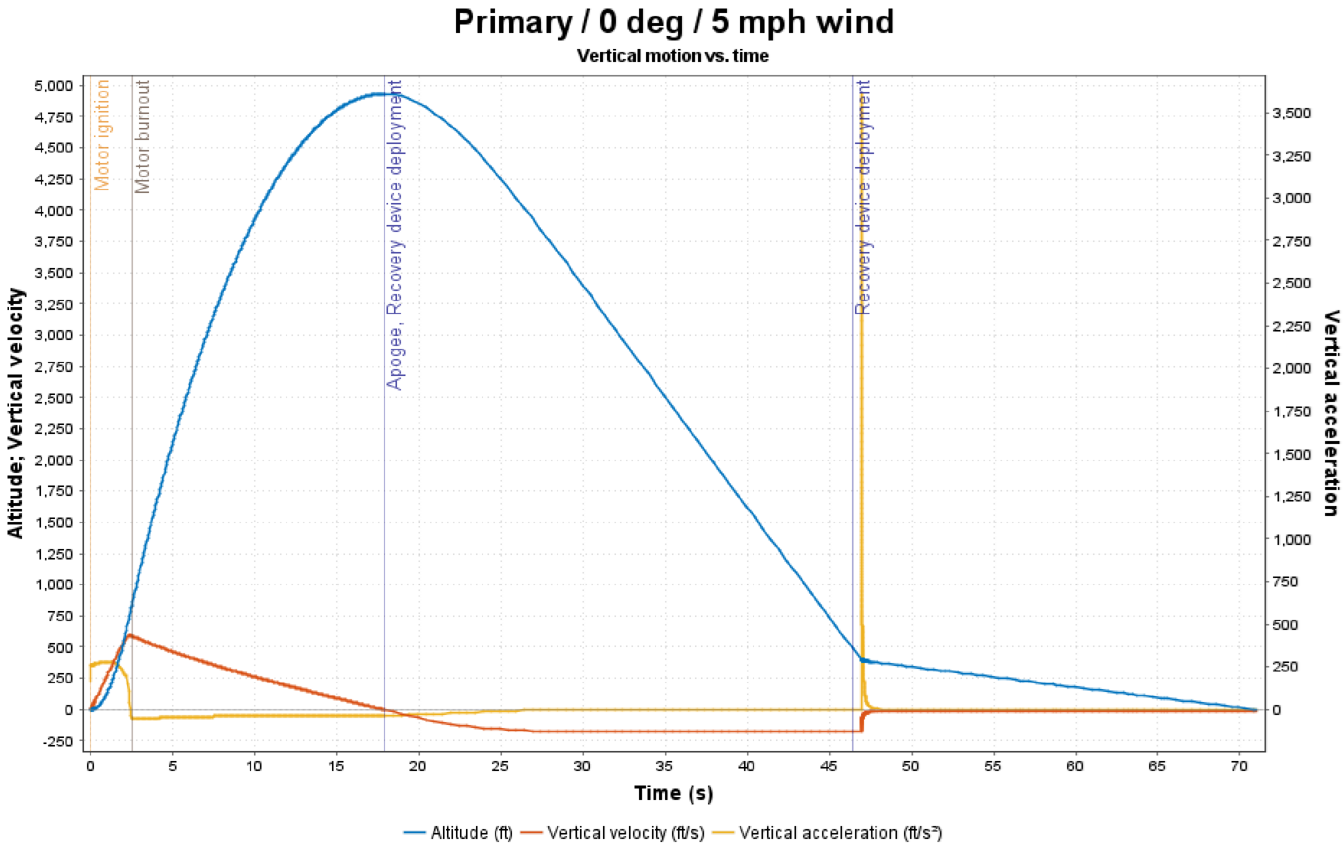

Figure 3.11.3. *Simulation of the flight profile of the full-scale launch vehicle using the primary AeroTech K1000T-P motor, under a wind speed of 5 mph, and a launch rail cant of 0°.*

The achieved uncontrolled apogee (inactive AB system) from each of the 30 simulations described above are summarized in Figure 3.11.4. In this figure, under constant wind speed, as the angle of the launch rail is increased, the apogee decreases following a quadratic curve ($R^2 > 0.999$). Additionally, as the wind speed is increased, the apogee decreases due to the launch vehicle experiencing a steeper cant during the flight reducing the vertical speed imparted by the motor as well as increasing the total displacement per unit of altitude gain. Similar plots to study how the maximum velocity and maximum acceleration are affected by windspeed and launch rail angle. The results showed that the windspeed has little to no effect on the maximum velocity and maximum acceleration. The other thing that was learned is that as the launch angle is increased the maximum acceleration and maximum velocity increases slightly due to vertical velocity vector decreasing reducing the amount of energy lost to gravity.

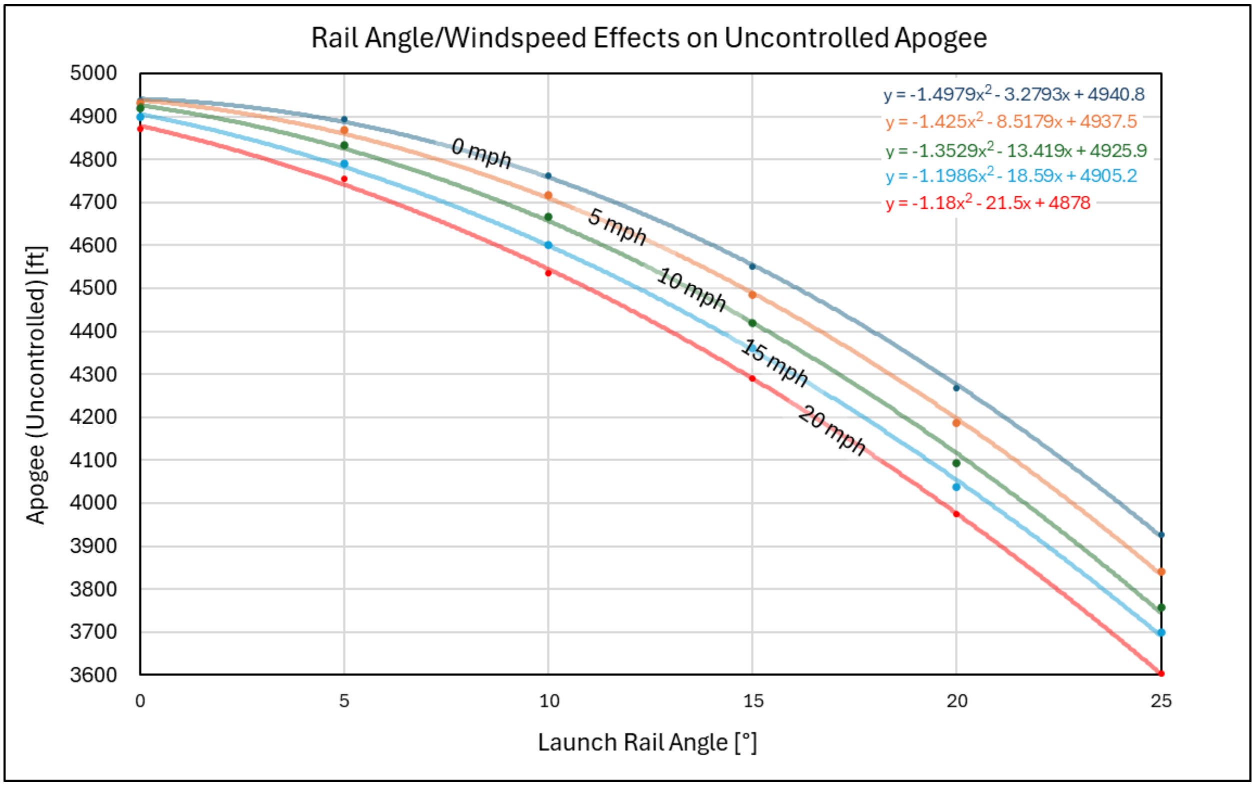

Figure 3.11.4. *Results of analysis using an OpenRocket simulation to study the effects of windspeed and launch rail angle on apogee.*

While OpenRocket is a useful and generally accurate tool for characterizing rocket performance, it does not easily allow for large numbers of simulations to be conducted while varying multiple parameters. To allow for potential "Monte Carlo"-style analysis and to evaluate the accuracy of OpenRocket's results, CSL is in the process of developing its own rocket simulation tool to develop flight performance graphs in a lightweight, "code-loop-addressable" format. The simulator is being developed using the Python coding language, utilizing an Euler integration numerical method to solve differential equations associated with the rocket's ascent. Figure 3.11.5 shows the simulation output for an ideal rocket flight straight upwards on a 59°F day with no wind.

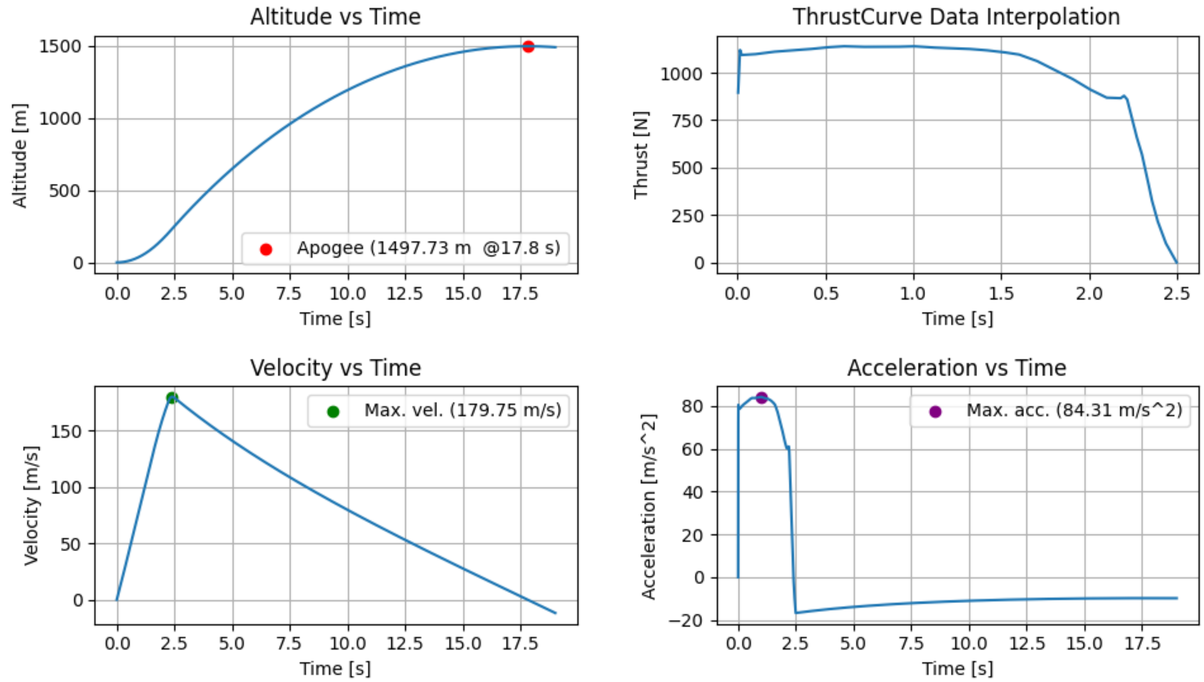

Figure *3.11.5.* *Python rocket simulation output.*

The simulation model shown in Figure 3.11.5 is currently very rudimentary, as it is a single-axis simulation with no wind support, no variable launch angles, and no consideration for the restoring moment afforded by the rocket's fins. However, since it uses real, interpolated thrust curve data for the K1000T-P motor, its predictions for the maximum acceleration and the maximum velocity are superbly similar to the OpenRocket predictions. While CSL plans to implement wind, angle of attack, and restoring moments to the simulation, the current Python script confirms OpenRocket's speed predictions. This simulation, once improved thus, will be an invaluable tool for testing complex flight paths and scrutinizing other analysis methods.

3.11.2. Descent Predictions

CSL's descent predictions are based off the current predicted weight of the launch vehicle and its individual sections as well as the predicted timing for the parachute deployment. Placing this data into MATLAB along with the data for the chosen parachutes the descent time, drift, and the kinetic energy that each section of the rocket will hit the ground with can be found. Through these different predictions the team can confirm that NASA's requirements are met theoretically and give the experimental data a better chance of confirming the same. In Appendix A.3 is a copy of the MATLAB code used, from this code Table 3.11.3 and 3.11.4 of the various descent predictions can be found based on the weight of each rocket section and the parachutes chosen for the full-scale (given in Section 3.10).

Table 3.11.3. *Descent predictions for Team* Elijah's *full-scale launch vehicle from the MATLAB code. Includes the descent time, the landing velocity, and the kinetic energy for each of the three sections when they touchdown.*

Descent Time [s]	58.5		
Velocity @ Landing [ft/s]	16.82		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf] (MATLAB)	43.63	19.57	34.70

Table 3.11.4. *The drift predictions for Team* Elijah's *full-scale launch vehicle from wind speeds of 5 [MPH] to 20 [MPH] assuming apogee happens directly over the launch pad using the descent time from MATLAB.*

Wind Speed [MPH]	5	10	15	20
Drift [ft]	429.0	858.0	1287.0	1716.0

To create the MATLAB code, equations for the three different descent events shown in Figure 3.11.6 were used. By placing the position, velocity, and acceleration occurring during each event with different kinematic relationships to find Equations (3.11.3) through (3.11.5). Equation (3.11.3) represents the rocket at apogee when the drogue parachute first deploys and Equation (3.11.4) is when the main parachute deploys at 600 [ft] AGL. The final event when the three sections of the rocket land is represented in Equation (3.11.5).

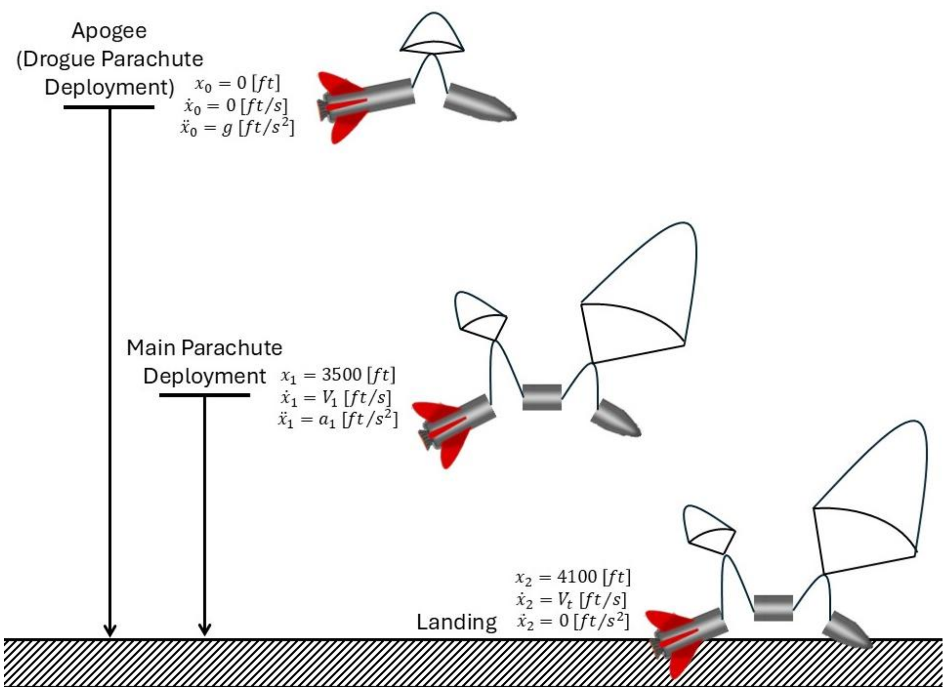

Figure 3.11.6. *Visual depiction of the three main events that occur in the descent of the full-scale launch vehicle. The first is at apogee when the drogue deploys, then at 600 [ft] AGL the second occurs when the main parachute deploys. The third event is when the three sections of the launch vehicle land back onto the ground.*

$$ma_0 = W - \frac{1}{2}\rho C_{D,d} A_d V_0^2$$

$$mg = W \quad (3.11.3)$$

$$ma_1 = W - \frac{1}{2}\rho C_{D,d} A_d V_1^2 \quad (3.11.4)$$

$$ma_2 = W - \frac{1}{2}\rho V_2^2 (C_{D,d} A_d + C_{D,m} A_m)$$

$$W = \frac{1}{2}\rho V_2^2 (C_{D,d} A_d + C_{D,m} A_m) \quad (3.11.5)$$

By manipulating these equations as shown in the PDR and placing them into the equations for drift (3.11.6) and kinetic energy (3.11.7) those values (as shown in Table 3.11.1 and 3.11.2) can be found.

$$drift = t_2 V_{wind} \quad (3.11.6)$$

$$T = \frac{1}{2} m V^2 \quad (3.11.7)$$

The kinetic energy of the three sections could also be found from OpenRocket as well as MATLAB by using the highest landing velocity found. By placing that into Equation (3.11.7) along with the different section masses. The values found this way can be seen in Table 3.11.5. Similarly, the descent time from OpenRocket can be placed into Equation 3.11.6 to find the drifts shown in Table 3.11.6.

Table 3.11.5. *Descent predictions for Team Elijah's full-scale launch vehicle from the OpenRocket Simulation. Includes the descent time, the landing velocity, and the kinetic energy for each of the three sections when they touchdown.*

Descent Time [s]	53.2		
Velocity @ Landing [ft/s]	16.31		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf]	40.98	18.38	32.59

Table 3.11.6. *The drift predictions for Team* Elijah's *full-scale launch vehicle from wind speeds of 5 [MPH] to 20 [MPH] assuming apogee happens directly over the launch pad using the descent time from OpenRocket.*

Wind Speed [MPH]	5	10	15	20
Drift [ft]	390.13	780.27	1170.40	1560.53

When comparing the different descent predictions from MATLAB and OpenRocket to one another it can be seen that they agree fairly well with each other, with percent differences shown in Table

3.11.7. From this table it can be seen that none of the values have a greater percent difference than 10% .

Table 3.11.7. *Descent predictions for OpenRocket and MATLAB as well as their percent differences based off Table 3.11.3 and 3.11.5.*

Descent Time [s] (MATLAB)	58.5		
Descent Time [s] (OpenRocket)	53.2		
Descent Time Percent Difference	**9.49%**		
Velocity @ Landing [ft/s] (MATLAB)	16.82		
Velocity @ Landing [ft/s] (OpenRocket)	16.31		
Velocity Percent Difference	**3.08%**		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf] (MATLAB)	43.63	19.57	34.70
Kinetic Energy [ft*lbf] (OpenRocket)	40.98	18.38	32.59
KE Percent Difference	**6.26%**	**6.27%**	**6.27%**

The drift values from MATLAB and OpenRocket (Tables 3.11.4 and 3.11.6) can similarly be compared and as shown in Table 3.11.8 have a percent difference below 10% as well.

Table 3.11.8. *Drift predictions for OpenRocket and MATLAB as well as their percent difference based off Table 3.11.4 and 3.11.6.*

Wind Speed [MPH]	5	10	15	20
Drift [ft] (MATLAB)	429.0	858.0	1287.0	1716.0
Drift [ft] (OpenRocket)	390.13	780.27	1170.40	1560.53
Drift Percent Difference	9.49%	9.49%	9.49%	9.49%

4. Payload Criteria

4.1. Chosen Design Alternatives

Three changes were made to the design of the payload in the time since the PDR. Two of these were component changes. First, the team decided to change the battery used for both the primary and override PCBs to an Ovonic 2S 1000mAh 7.4V LiPo battery. The team had initially considered using a 700mAh 6V Ni-Cd battery for the primary PCB because of the low power requirements of this year's payload and a 9900mAh 18650 Li-ion battery for the override PCB. The team ultimately decided against the Ni-Cd batteries because of their larger size. The team decided against the Li-ion batteries because they rely on a spring connection. Instead, the team has opted to use two Ovonic 2S 1000mAh 7.4V LiPo batteries, which have much more secure connectors (Amazon: *OVONIC*, 2025) and can be easily used for both the primary and override circuits. One battery will be used for each PCB. The second change made to the payload was to use the voltage divider and analog multiplexer circuit discussed in the PDR instead of the AD5700-1 chip the team had originally intended to use. This change is the result of further research, which indicates that the AD5700-1 chip would require significantly more external circuitry than originally thought. An electrical schematic for the voltage divider and analog multiplexer circuit will be shown below in the system-level design review. The last change made to the design was a change of the location of the STEMnauts within the payload. This was mainly due to a revision of the structure of the override PCB. Instead of a rectangular PCB, the override PCB is now circular, which leaves much more room open on the back face of the payload. This allowed the team to simplify the structure of the payload by removing the side faces and moving the STEMnauts onto the back face of the PCB. The physical structure of the payload, including the STEMnaut placement, will be shown later.

4.2. Concept of Operations

The goal of the primary payload is to collect data during flight and after landing and transmit this data to a receiver after landing via a 2-meter band radio transmission. The payload portion of the CSL team is responsible for the design, development, and deployment of the primary payload.

The sensors will take in data during flight and after landing. The microcontroller will process the data and send it to the APRS encoder formatted as APRS packets. The APRS encoder will then transform the digital bits into APRS tones, which the radio will transmit via the 2-meter band to the receiver located at the launch site.

4.3. System Level Design Review

4.3.1. Electrical Design

The payload's electrical components consist of the Raspberry Pi Pico, the DS1307 real time clock (RTC), the BMP280 pressure and temperature sensor, the MPU6050 accelerometer, the W25Q64FV flash memory module, and a MicroSD card reader. The Raspberry Pi Pico was chosen due to its cheap cost, fantastic documentation, and widespread community support. An RTC was chosen over GPS since the team did not want to increase complexity with unnecessary information. The DS1307 was a cheap RTC which the university already owned. The BMP280 was chosen due to its relatively high accuracy in comparison with its cost. The BMP390 (the newer model) offered more accuracy, but was several times as expensive, and the BMP180 (the older model) was around the same price as the BMP280 but had lower accuracy. The MPU6050 was chosen because it was a cheap and widely used accelerometer which the university already had on hand. Figure 4.3.1 shows the data flow of all components in the payload system.

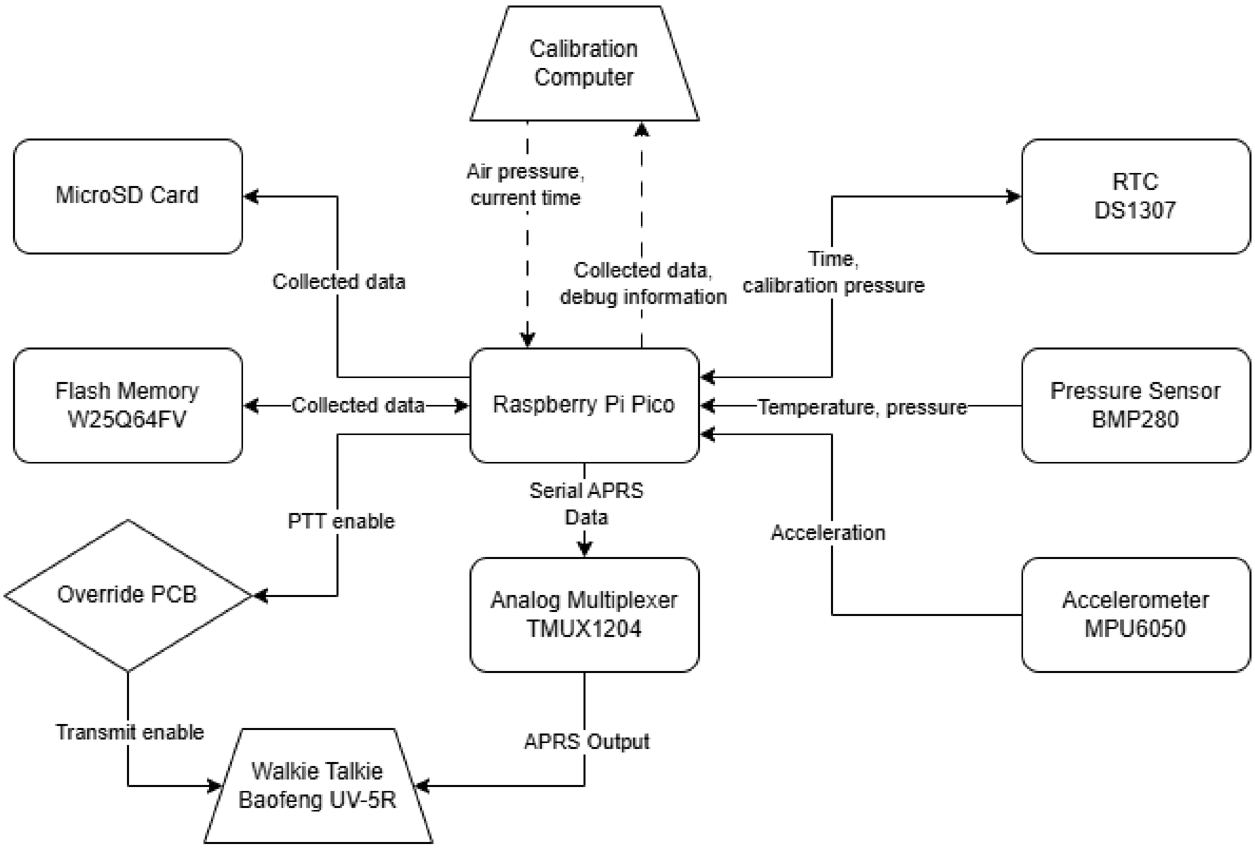

Figure 4.3.1. *Overall Payload Schematic.*

All three sensors in conjunction can be used to determine seven of the eight given payload objectives. Only battery voltage cannot be computed from these sensors. To compute battery voltage, a voltage divider will be used with an analog to digital converter built into the Pico. The data the team is aiming to transmit is the temperature of the landing site, the apogee reached, the orientation of on-board STEMnauts, the time of landing, and the payload's power status.

For debugging and payload performance analysis, the payload also includes a MicroSD card. This contains the collected flight data, which can be analyzed after the payload is recovered. However, if the MicroSD card loses contact during flight, there is a risk of the data being corrupted. To resolve this, data is first written to flash memory. Due to the data size not being able to fit on the Pico's onboard flash memory, external flash memory is used. Data is first written to the external flash memory, then to the MicroSD card after the rocket lands.

All sensors will communicate with the payload over two separate I^2C buses. The MPU6050 uses a separate bus because it has an address collision with the DS1307. The Raspberry Pi Pico will continuously read data from the BMP280 and DS1307, while the MPU6050 accelerometer will set its interrupt pin when data is ready to prevent the reading of duplicate data from the sensor.

All circuits in the payload will be implemented on printed circuit boards (PCBs), because they allow for reduction in size, weight, and complexity compared to breadboards or point-to-point electronics construction. Each PCB is custom designed by the payload team using EasyEDA as the modeling software and the boards are manufactured by JLCPCB. Most electrical components are through-hole components, instead of surface-mount components, which allows for in-house soldering and component changes as needed. The payload team has already completed this entire process once and the result can be seen in Figure 4.3.4.

The primary PCB is a daughterboard for the Raspberry Pi microcontroller as well as the sensors and memory modules. The responsibility of the primary PCB is to do data collection, data transformation, data storage, and APRS encoding of signals to be sent to the transmitter. The design and implementation of the primary circuit is shown in Figure 4.3.2. The three-dimensional render for the primary PCB is shown below in Figure 4.3.3 and a picture of the manufactured primary PCB is shown in Figure 4.3.4.

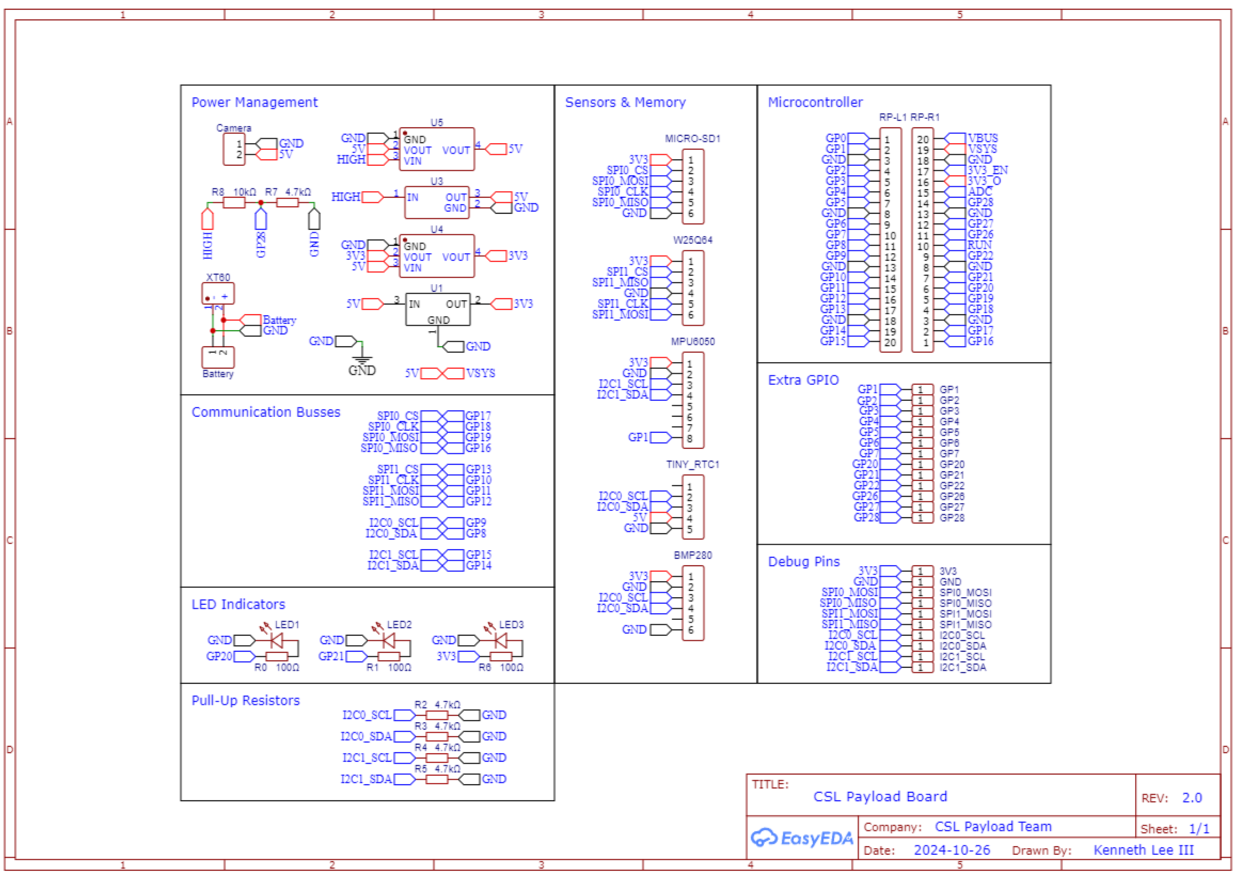

Figure 4.3.2. *Primary PCB Electrical Schematic.*

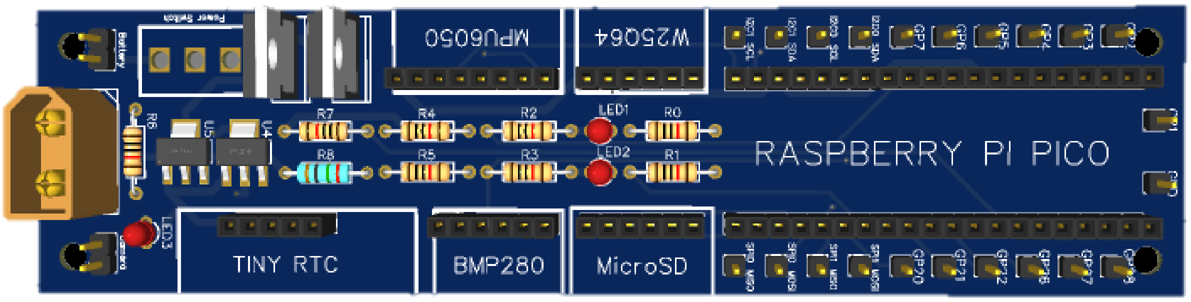

Figure 4.3.3. Primary PCB Render.

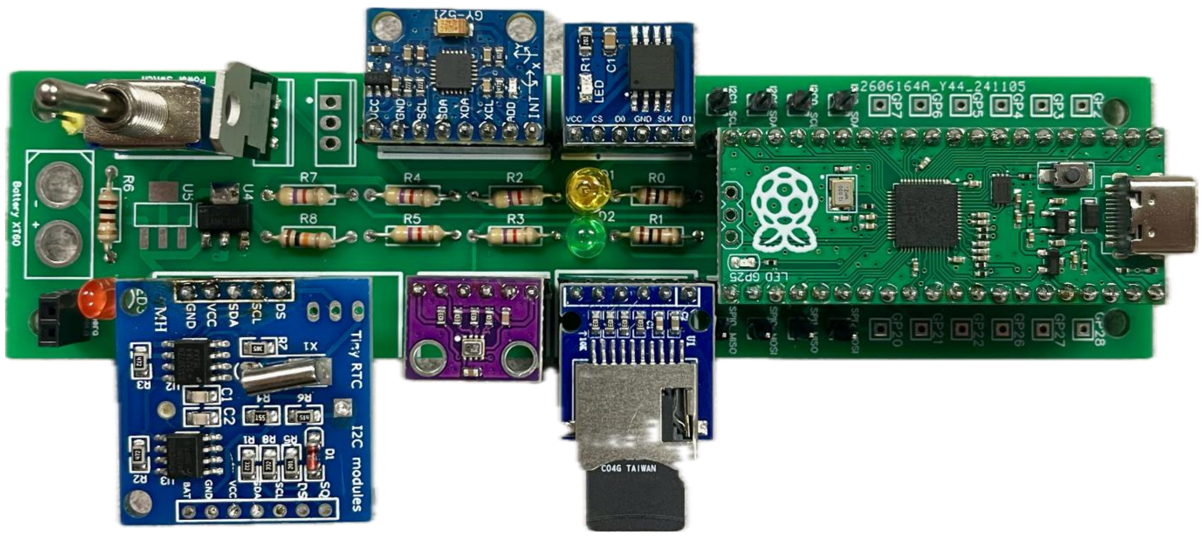

Figure 4.3.4. Primary PCB Device.

The secondary PCB is also a daughterboard for the Raspberry Pi but has a slightly reduced array of sensors and memory modules. The role of the secondary PCB is to override the push-to-talk (PTT) signal that is sent from primary circuit to the radio transmitter. The design and implementation of the override circuit is shown in Figure 4.3.5. The three-dimensional render for the primary PCB is shown below in Figure 4.3.6.

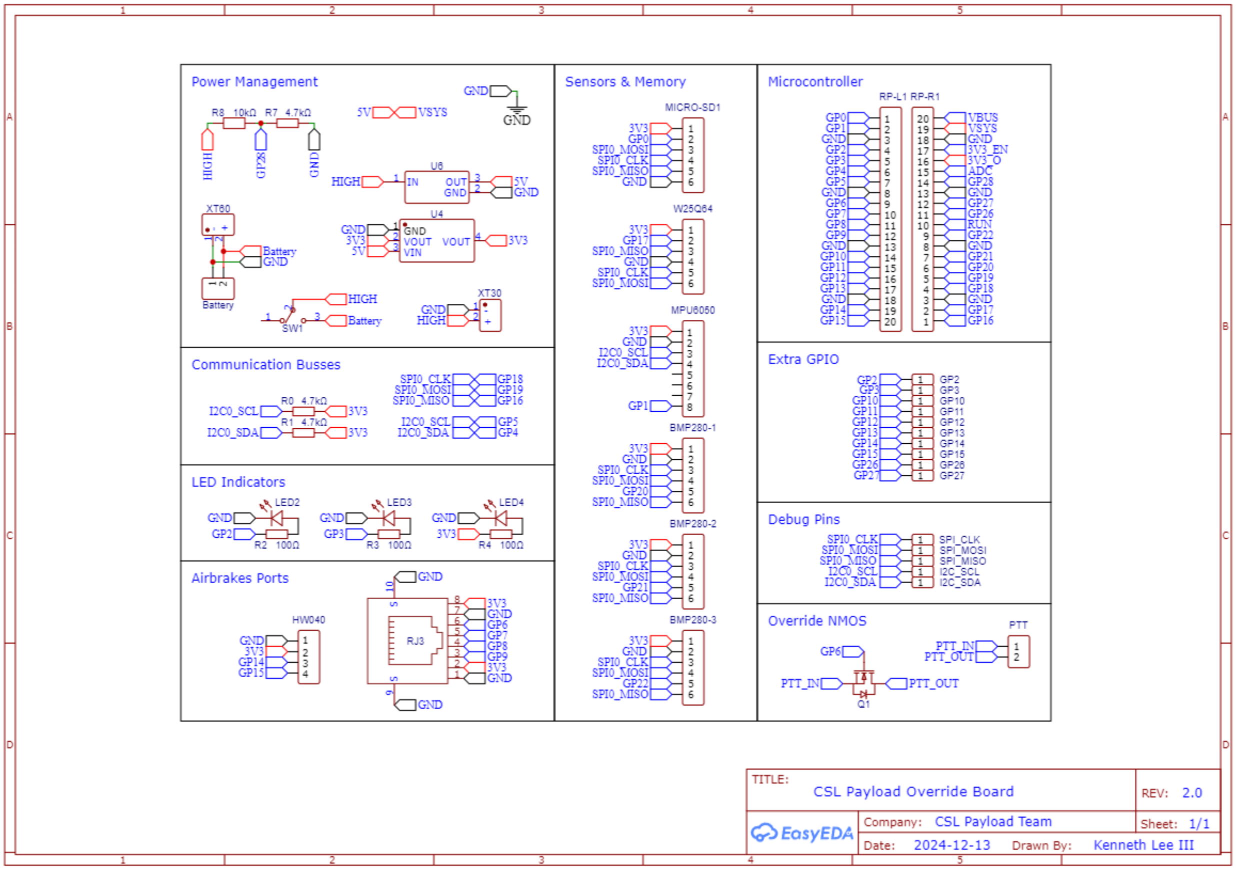

Figure 4.3.5. *Override PCB Electrical Schematic.*

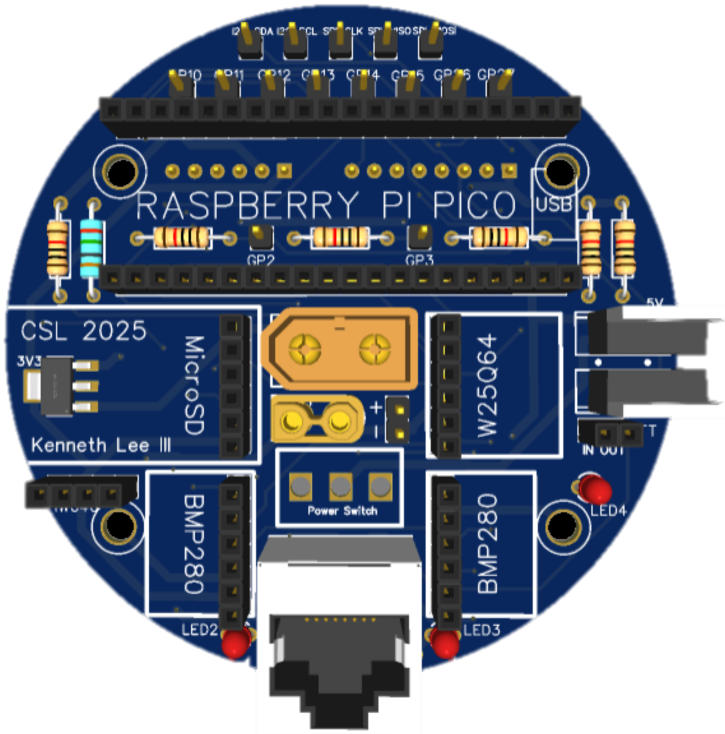

Figure 4.3.6. *Override PCB Render.*

Both the primary and secondary circuits on their respective PCBs are powered by Ovonic 2S LiPo batteries, each with 1000mAh capacities. The payload team chose LiPo batteries because they are smaller than comparable Ni-Cd batteries and because the Ovonic LiPo batteries with the chargers are already available to the payload team.

The current draw for the primary circuit based on the components' specifications is shown below in Table 4.3.1. Based on the average current draw, the 1000mAh LiPo battery should provide an expected battery life of over eight hours; based on the worst-case current draw, it should provide over four hours of battery life. The current draw for the override circuit based on the components' specifications is shown below in Table 4.3.2. Based on the worst-case current draw, the 1000mAh LiPo battery should provide an expected battery life of over ten hours for the secondary circuit.

Table 4.3.1. *Current Draw of Primary Circuit Components.*

Quantity	Name/Description	Average Current (mA)	Maximum Current (mA)
1	DS1307 Real Time Clock	1.5	1.5
1	BMP280 Barometer & Thermometer	0.00274	0.00416
1	MPU6050 Gyroscope & Accelerometer	3.6	3.9
1	W25Q64 Flash Memory Module	15	25
1	Micro SD-Card Reader	0.4	100
1	Raspberry Pi Pico	93.5	95.6
Total		**114.0**	**226.0**

Table 4.3.2. *Current Draw of Override Circuit Components.*

Quantity	Name/Description	Average Current (mA)	Maximum Current (mA)
0	DS1307 Real Time Clock	1.5	1.5
1	BMP280 Barometer & Thermometer	0.00274	0.00416
1	MPU6050 Gyroscope & Accelerometer	3.6	3.9
0	W25Q64 Flash Memory Module	15	25
0	Micro SD-Card Reader	0.4	100
1	Raspberry Pi Pico	93.5	95.6
Total		**97.1**	**99.5**

4.3.2. Software Design

The payload's code is written using C++ and the official Pico software development kit (SDK). The SDK was chosen over an alternate approach (such as Micropython or Arduino) for faster processing and fine-tuned memory management. It operates using two cores: one for data collection (Core 0) and one for data writing (Core 1). Launch will be detected by the software; once it is detected, the payload will start collecting data with Core 0. The data will then be sent to Core 1, which will write the data to external flash memory. This will occur continuously until the payload detects landing. After landing, Core 0 will transmit the data to the Baofeng UV-5R radio transmitter, while Core 1 will pull the data from external flash memory and write it to the MicroSD card.

The system is calibrated using an external computer, which sends the current air pressure and time to the payload before launch. This data is stored within the DS1307's persistent memory and will be loaded upon the payload receiving power. The external computer will also send debugging information (logging statements, sensor status, sensor calibration, etc.), which will be useful for debugging. This computer is represented in Figure 4.3.1 by the trapezoid labeled "Calibration Computer." It is detached from the payload before rocket assembly.

4.3.3. Transmitter Design

The transmitter circuitry for the payload consists of the radio transmitter itself, the APRS encoder, and the microcontroller. The microcontroller takes the data collected by the sensors and formats it into APRS packets, which it then sends to the APRS encoder. The encoder is a voltage divider followed by the TMUX1204 analog multiplexer chip; the voltage divider provides four voltages to choose from and the analog multiplexer allows one of these voltages through at a time (see the OUT pin in Figure 4.3.7). The two select pins (see the S0 and S1 pins in Figure 4.3.7) are controlled by the microcontroller, which will control the multiplexer such that it makes the voltage step up and down along a rough sine wave. The shape and frequency of this sine wave will be controlled by the microcontroller to create the correct APRS tones. Once this rough sine wave is created, it can be low-pass filtered to be a much better approximation of a true sine wave; however, it is likely that an additional low-pass filter will not be needed, as the parts and transmitter themselves may provide enough filtering to make the tones decipherable. This sine wave will then be sent to the *Baofeng* UV-5R radio transmitter for transmission to the receiver at the launch site. The radio will transmit on the 2-meter band and can transmit up to 5 watts, which is the power limit for the payload transmitter (Amazon: *Baofeng*, 2025). The team intends to use the antenna that the radio came with but will complete thorough testing of the payload to ensure that the transmission can be received from various angles and distances. The landing orientation of the rocket is highly variable, so the payload must be able to complete its mission successfully regardless of how the rocket lands.

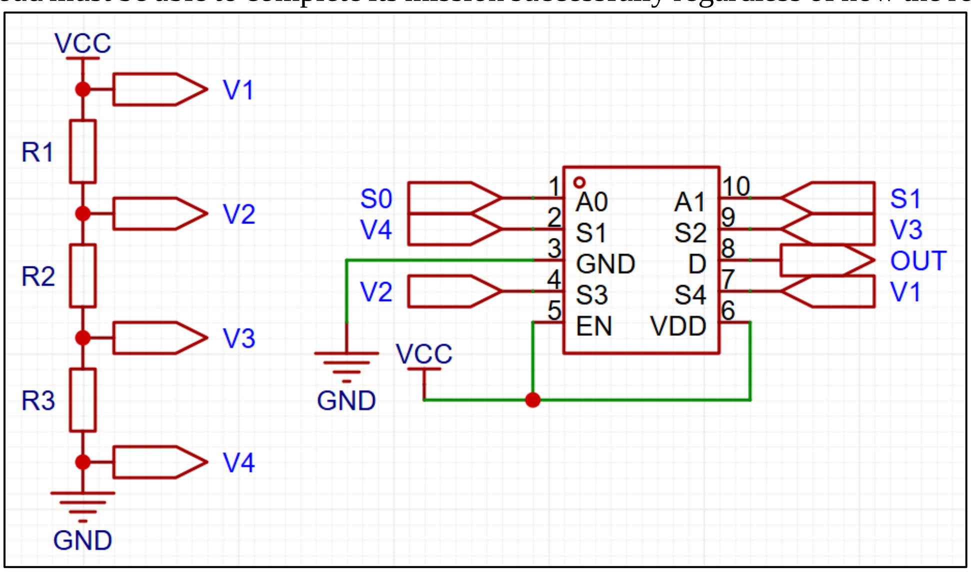

Figure 4.3.7. *Electrical Schematic for Voltage Divider and Analog Multiplexer.*

4.3.4. Mechanical Design

Details of the mechanical design of the payload have been refined since the Preliminary Design Review. The SolidWorks assembly of the payload can be seen in Figure 4.3.9 with key components identified. The payload is shown in context in Figure 4.3.8 where the bulkhead sits below the payload and the nose cone is attached above the payload, which is contained inside the rocket's airframe.

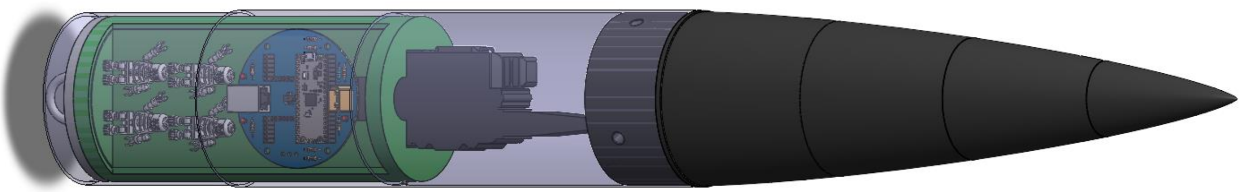

Figure 4.3.8. *Payload Context View.*

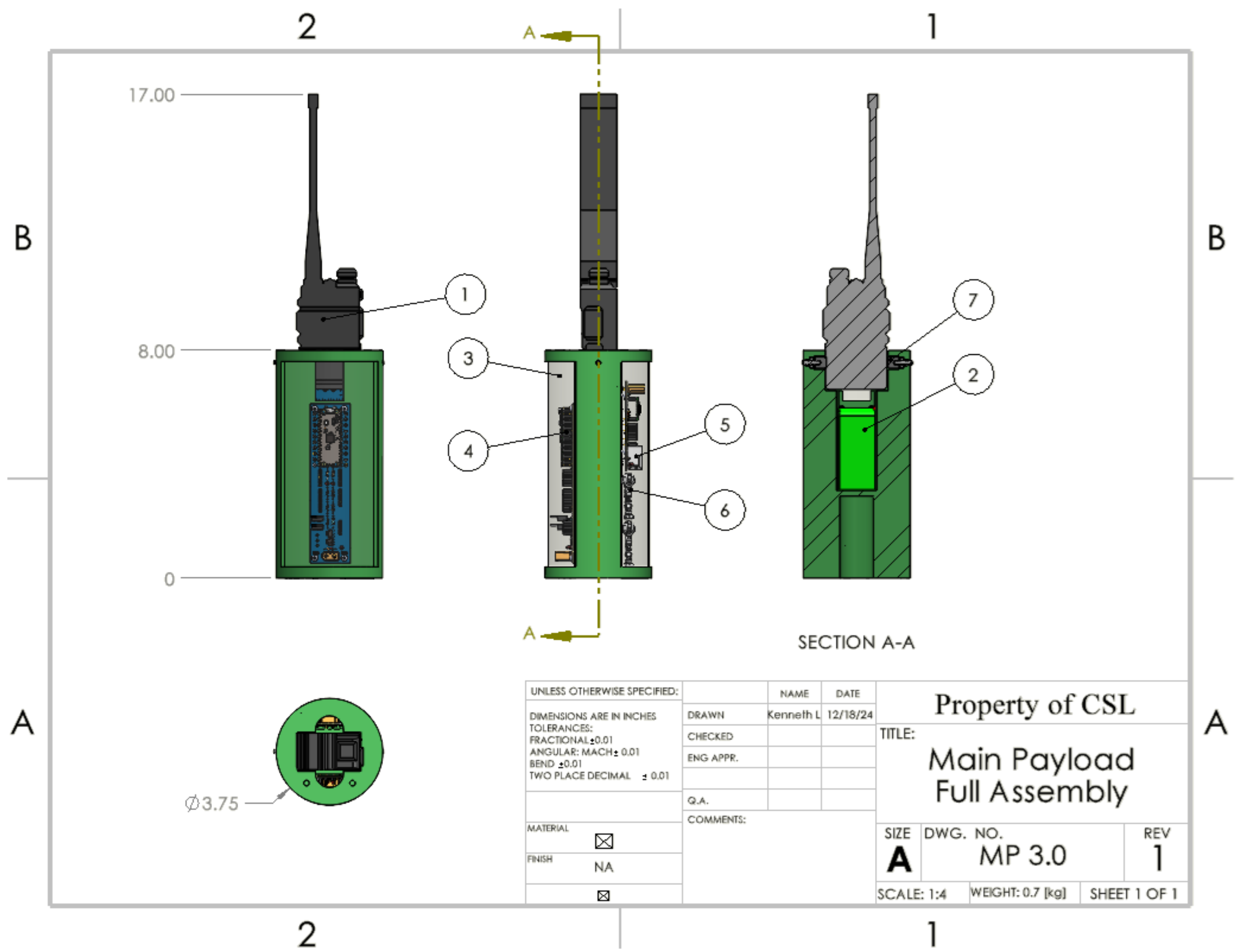

Figure 4.3.9. *Payload Full Assembly Drawing.*

The main body of the payload will be a 3D printed part. Additive manufacturing processes such as 3D printing allow for rapid prototyping, which is a necessity for a part such as this one with numerous distinct interfaces. PLA+ was chosen as the material because of its combination of strength and ease of printing (Tyson, 2023). The part will be printed at 12% infill with three exterior walls to achieve a unit weight of 180 grams. As shown in the SolidWorks drawing in Figure 4.3.10, the basic shape of the part will be an 8-inch-tall cylinder with a 3.75-inch diameter. Because nearly all measurements reported for small electronics are given in millimeters, all other dimensions in Figure 4.3.10 are metric. This 3D printed part will be manufactured multiple times so that all tolerances can be refined.

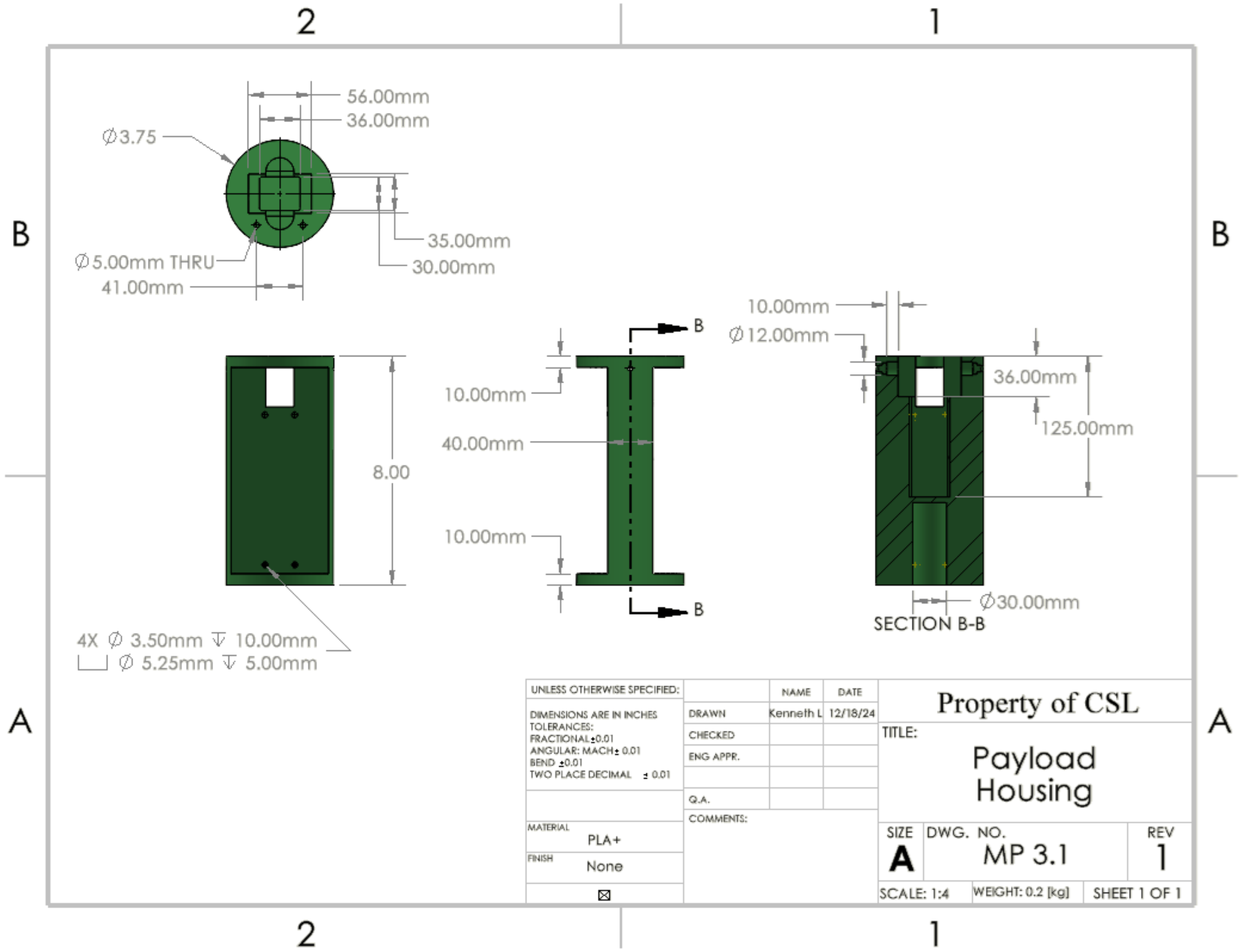

Figure 4.3.10. *Payload Housing Drawing.*

The UV-5R radio transmitter, which is marked as "1" in Figure 4.3.9, will be secured at the top of the payload with its antenna extending into the nose cone. When the payload is viewed from the front, as in Figure 4.3.13, the information shown on the transmitter's display will be clearly visible. This will allow for quick troubleshooting both for payload testing and on launch day.

The UV-5R transmitter will be secured in place by two anti-vibration rubber feet, which are marked as "7" in Figure 4.3.9. These rubber feet have a female thread into which a set screw will be tightened. This set screw will be held in place by a T-nut embedded in the 3D print. This subassembly can be seen more clearly in a section view such as Figure 4.3.11. More testing will be completed to ensure that this system can hold the radio transmitter firmly in place during the entire duration of the rocket's flight.

Two LiPo batteries, marked as "2" in Figure 4.3.9, will be contained in a cavity in the center of the payload. As seen in Figure 4.3.11, the batteries will be set down into a cavity in the 3D printed part and the transmitter placed on top of it will prevent them from moving during flight. This specific placement of the batteries provides at least two additional benefits. First, the wires coming from the batteries can easily be draped over the edge of the battery cavity to each PCB's power input port. This allows for clean cable management and efficient battery troubleshooting. Second, housing the relatively dense batteries at the center of the payload keeps the center of gravity of the payload very near its radial center.

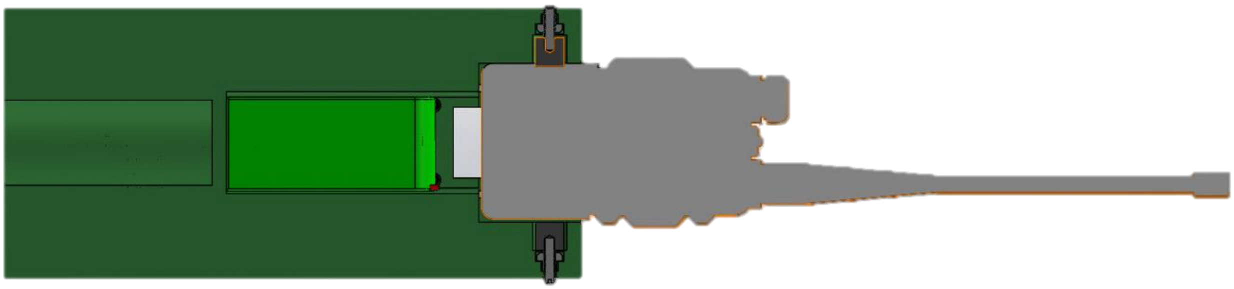

Figure 4.3.11. *Payload Section View.*

Two translucent shields, which are marked as "3" in Figure 4.3.9, will surround the STEMnauts and printed circuit boards. This can be seen in Figure 4.3.12, where the shields provide a boundary which contains all electronic components other than the transmitter. These shields are not meant to provide structural protection but are intended to isolate the internal components from the airframe while still allowing for the indicator lights to be visible when the payload is fully assembled.

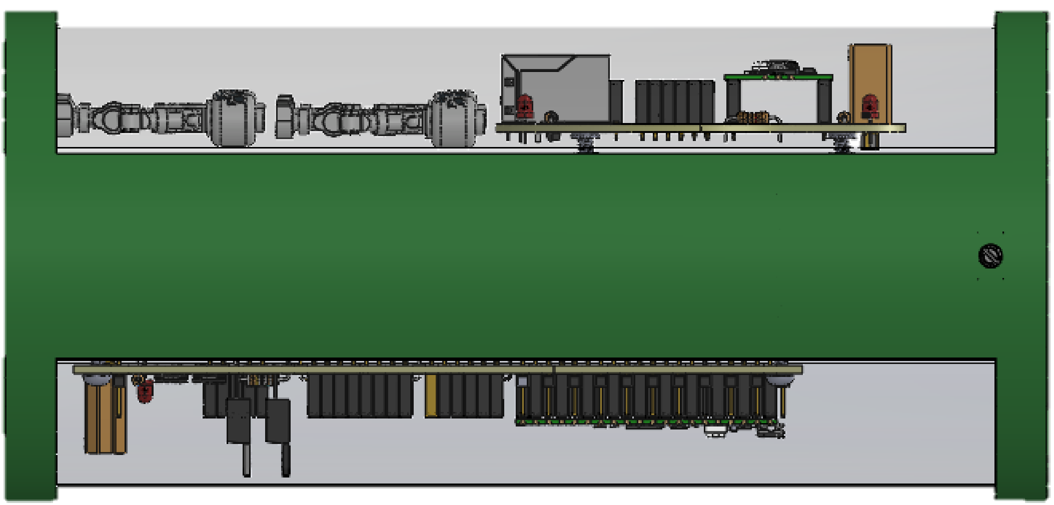

Figure 4.3.12. *Payload Side View.*

The primary and secondary PCBs, marked as "4" and "5" in Figure 4.3.9, reside on opposite sides of the payload. This is appropriate because very few wires are required to run from one PCB to the other. As shown in Figure 4.3.13 and Figure 4.3.14, M3 bolts run through the mounting holes on the PCB and tighten into M3 heat-set brass inserts which are inserted into the 3D printed part

(*Using Heat Set Inserts*, n.d.). These brass inserts provide a sturdy yet easy way to keep the PCBs from moving around inside the payload.

The four STEMnauts, indicated by a "6" in Figure 4.3.9, will be secured below the secondary PCB. These STEMnauts will be LEGO minifigures and will be able to look out of the capsule through the translucent shielding.

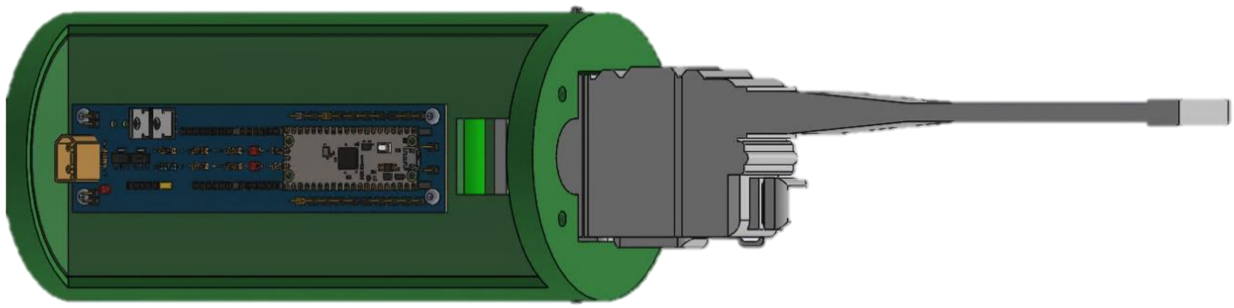

Figure 4.3.13. *Payload Front View.*

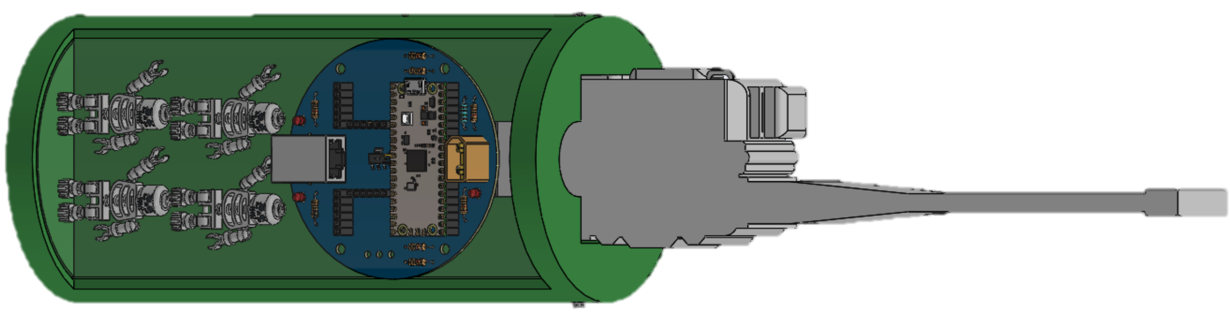

Figure 4.3.14. *Payload Back View.*

5. Safety

Cedarville Student Launch has elected Jesse DePalmo as Chief Safety Officer (CSO). The CSO is responsible for the safety of all team members, students, and the public participating in the team's activities. This role is responsible for evaluating and mitigating failure modes that can occur throughout the design, construction, and launch processes. The CSO is required to promote a strong safety culture across all team areas. Once the team sets a procedure or plan, the CSO has the right to amend team activities to maintain a high level of safety. The general responsibilities and duties of the CSO are, but not limited to, the following:

- Creation of a Safety Handbook to equip team members to perform roles effectively while maintaining safety standards.
- Designing and coordinating launch procedures with the Launch Officer.
- Ensuring compliance with local and federal safety regulations.
- Ensuring all team members comply with NAR and university safety regulations.

- Promoting a safety-first culture that prioritizes proper design.
- Attending sub-scale and full-scale launches to ensure correct adherence to procedures.
- Enforcing general safety practices throughout the design process.
- Assessing failure modes and proposing mitigations using Failure Modes and Effects Analysis (FMEA) tables.
- Understanding of the facilities, equipment, and regulations that exist beyond the team's direct responsibilities.
- Acting as a point of reference for safety-related inquiries from team members.

5.1. Launch Concerns and Operating Procedures

5.1.1. Introduction

Launch procedures and checklists are essential components for ensuring the safety of all team members contributing to a successful launch. Launches are the climax of this competition, and each procedure must be followed precisely to maximize efficiency during launch day. The comprehensive launch procedures provided enhance overall safety, discipline, reliability, and contribute to the overall success of the launch. These checklists are in accordance with NAR/TRA regulations, and they must be followed by both team members and Team Mentor Dave Combs.

CSL personnel required for any launch to occur include the following:

NAR/TRA Level 2 Certified Team Mentor: Dave Combs

Chief Safety Officer: Jesse DePalmo

Launch Officer: Jack Kealen

Team Lead: Grant Parker

Chief Engineer: Daniel Hogsed

Recovery Lead: Elisa Schmitt

Payload Lead: Kenneth Lee III

Avionics Lead: Joseph Copeland

Airbrakes Lead: Seth Mitchell

If a required team member is not available to be present for the launch, it will be rescheduled. Each subsystem lead is essential to the overall success of CSL to have a safe and efficient launch sequence.

5.1.2. Launch Rehearsal

Mandatory PPE: N/A

Required Personnel: All Team Members

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: ER.1, ER.2, ER.3, ER.4, ER.8, P.14, P.15, P.16.

The CSO and the Launch Officer will give a briefing about preparations for each scheduled launch. Each briefing will consist of reviewing the equipment needed for the launch, transportation to the launch site, and launch operating procedures. Team members will be reminded what clothes to wear as the weather may be chilly. A reminder will be given that Team Mentor Dave Combs is the only person who will be handling motors or other explosives at the launch site. Team members will be encouraged to review launch procedures to ensure they know every detail during launch day. Team members who attend the launch must have signed the team Safety Agreement to follow all rules and regulations in place. All team members are expected to attend these briefings. If a team member cannot attend a briefing, the CSO or the Launch Officer will provide the necessary details using the team's communication program.

5.1.3. Equipment Needed for Launch Operations

The comprehensive list provided below indicates the necessary equipment to be transported to the launch site. Team members will be briefed about the equipment needed to be packed during the launch rehearsal. Personnel required to attend the launch must confirm that the essential equipment is loaded into vehicles before departure.

General Equipment

• Trash Bags	• Ladder	• Fire Extinguisher
• Burn Kit	• Sunscreen (if applicable)	• Water Bottles

Personal Protective Equipment

• Nitrile Gloves	• Long Sleeves	• Safety Glasses
• Closed Toed Shoes	• First Aid Kit	• Heat Resistant Gloves

Tools

• Screwdrivers	• Allen Wrenches	• Tape Measure
• Electrical Tape	• Rubber Hammer	• Weight Scale
• Pliers	• Drill / Bits	• Voltmeter
• Shear Pins	• Wire Strippers	• Masking Tape

Recovery Equipment

• Main Parachute	• 2 x Shock Chords	• 2 x Flame Blankets
• Drogue Parachute	• 6 x Quick Links	• 3 x 4-40 Shear Pins
• Black Powder*	•	•

* 4FG Supplied by Team Mentor

Avionics Equipment

• Electronics Sled	• 2 x RRC3 Altimeter	• 2 x Easy Mini Altimeter
• Eggfinder Mini C4 GPS	• 3 x Batteries	• Extra Wire
• Velcro Straps	• Zip Ties	•

Payload Equipment

• 2 x Charged LiPo Batteries	• Primary and override PCBs	• Charged Radio Transmitter
• Charged RTC Battery	• 2 x Micro SC Cards	• Polycarbonate Shields

Airbrakes Equipment

• Battery	• Ethernet Cable	• Raspberry Pi Pico
• Puck PCB	• External Cache	• Rotary Encoder
• SD Card Reader	• SD Card	• 3 x BMP280
• GY-521	• Motor Controller	•

• Airframe Fastener	• Shaft Helical Coupler	• 4-40 Should Screws and Nuts (x 32 for whole assembly)
• 4 x Standoffs	• 4 x Screws (PCB)	•

Electrical Equipment

• Charged Computer	• Handheld Multimeter	• Portable Soldering Iron
• Extra LiPo Batteries	• Radio Receiver	• Precision Screwdriver
• Micro-USB and USB-C cables	• APRS to USB-C adapter cable	•

Team Mentor Equipment

• Launch Rail	• Launch Pad	• Igniter
• Black power	• Weight Scale	•

Signature: My signature confirms the following equipment essential for a successful launch is packed and loaded in vehicles for transportation. Only the NAR Team Mentor is allowed to pack and transport motors and other energetics to the launch site.

Chief Safety Officer: ________________________

Launch Officer: ________________________

Team Lead: ________________________

Chief Engineer: ________________________

Recovery Lead: ________________________

Avionics Lead: ________________________

Payload Lead: ________________________

Airbrakes Lead: ________________________

5.1.4. Stability Test (CG)

Mandatory PPE: N/A

Required Personnel: Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: FD.1, FD.2.

- Before arriving at the launch site, weigh the unloaded rocket on the mass scale, verifying that its dry weight compares well to the dry weight predicted by the OpenRocket simulations.
- Measure and mark the center of gravity on the rocket according to the location predicted by OpenRocket.
- Balance the rocket in hand; if the rocket balances on the mark made in the previous step, the simulation's stability prediction is deemed accurate assuming the rocket is geometrically identical to the OpenRocket model.
- Ensure that the OpenRocket simulation predicts a stability margin of no less than 2.0 calibers.

Troubleshooting Process

- If the dry weight of the rocket does not compare well to the dry weight predicted by the OpenRocket simulation, the simulation must be audited for mass consistency with the specific components used for constructing the rocket. The mass of the rocket itself should NOT be modified to make it more like the simulation.
- Verify that all major internal components of the rocket, including shock cords, parachutes, and quick links, are all represented in the OpenRocket simulations.

Signature: My signature confirms the rocket is stable enough to be launched and the OpenRocket simulation predicts a stability margin of no less than 2.0 calibers.

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.1.5. Transportation to Launch Site

Mandatory PPE: N/A

Required Personnel: Chief Safety Officer, Launch Officer, Team Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: P.7, P.8, RS.1, RS.5.

- The weather forecast for a potential launch day will be monitored throughout the week.
- CSL will notify Team Mentor Dave Combs of when the team would like to launch within a given time window.
- On the day of launch, all team members will be notified of the time and place of a rendezvous point to pack and load essential equipment.
- All equipment needed for launch will be packed carefully into the vehicle while ensuring nothing will be dropped or scratched during transportation.
- Only team members or team mentors with a valid driver's license will be allowed to drive to the launch site.
- The Team Lead is responsible for communication with drivers on directions to where the launch site is located.
- The Team Lead is responsible for notifying Team Mentor Dave Combs when CSL is leaving campus on the way to the launch site.
- Team members riding in vehicles will wear seatbelts while the vehicle is in motion. The driver of the vehicle must follow the rules and laws of the road.

Signature: My signature confirms the transportation procedures to the launch site have been followed by all CSL team personnel.

Chief Safety Officer: ________________________

Team Lead: ________________________

5.1.6. Arrival at Launch Site

Mandatory PPE: Safety Glasses, Closed-toed Shoes, Long Sleeves, Long Pants

Required Personnel: Chief Safety Officer, Launch Officer, Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA

Failure ID include, but are not limited to: P.5, P.14, ER.1, ER.2, ER.3, ER.4, ER.5, ER.6, ER.7, ER.8, ER.9, ER.11, LP.7, LP.8, LP.10, LP.12, LP.13, LP.17.

- Vehicles arriving will park in an appropriate location not blocking the road to leave the launch site.
- The CSO and Launch Officer will examine the launch site and make sure there are minimal trees present, stable ground for a launch pad to set up, and far enough away from the road in case the rocket drifts during flight.
- The CSO and Launch Officer will meet with NAR/TRA Level 2 Certified Team Mentor Dave Combs to ensure the launch can still take place. This will involve checking the weather forecast to ensure no winds greater than 20 mph, no storms, no precipitation, no extreme temperatures, low humidity, no fog, no fire threat, and no potential animals that could interfere with launch operations.
- If the Team Mentor confirms a launch can take place, team members are allowed to begin setting up the launch pad and launch rail on stable ground at a distance following NAR regulations away from cars, team personnel, and any spectators.
- The CSO and Launch Officer will ensure team personnel are always wearing the appropriate PPE during launch preparation.

Signature: My signature confirms that the launch site arrival procedures have been followed by all CSL team personnel.

Chief Safety Officer: _________________________

Launch Officer: _________________________

Team Mentor: _________________________

5.2. Pre-Flight Assembly Procedures

5.2.1. Nosecone Pre-Flight Assembly

Mandatory PPE: Safety Glasses, Nitrile Gloves, Long Sleeves, Closed-toed Shoes

Required Personnel: Nose Cone Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: C.1, C.2, C.5, C.7, C.10, C.11, C.12, C.13, C.18, C.22, RS.5.

- The Nose Cone Lead or the Chief Engineer will take the completed 3D model from SolidWorks and have it 3D printed using PETG.
- The Nose Cone lead will then assemble the 3D-printed components and apply a layer of epoxy to hold the parts together.

- Once the epoxy has hardened and the cone is one solid piece, it will be mounted and centered on a lathe in the Engineering Project Lab. Plastic tarping will be laid over the rest of the machine to protect it from epoxy. The lathe will then be operated at a speed of no greater than 50 rpm. The cone should be rotating at the same rpm. Epoxy will then be drizzled over the cone and smoothened out with a gloved hand or a similar object. This should give the cone a hardened outer shell and provide an overall smooth and aerodynamic finish.

Signature: My signature confirms that the nosecone is manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing techniques lead to FMEA personnel hazards.

Nosecone Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.2.2. Avionics Pre-Flight Assembly

Mandatory PPE: Safety Glasses

Required Personnel: Avionics Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.1, R.2, R.7, R.8, C.4, C.7, C.8, C.14.

- Mount altimeters and GPS on avionics sled using 4-40 Allen head screws with 3D printed electrical insulating standoffs between the electronic components and the sled.
- Charge batteries and mount them to the sled using zip ties and/or Velcro cable ties.
- Wire altimeters to batteries, key switches, and terminal blocks following the wiring diagram for altimeters in manual.
- Care must be taken to ensure enough wire is left from altimeters to key switches for the avionics sled to be fully removed from the coupler tube without detaching wires.
- Plug wire holes in bulkheads with hot glue or putty to seal the avionics bay from parachute bays.
- Connect each altimeter to the computer and program for desired deployment modes.
- Ensure both altimeters and GPS function properly and detect continuity if a wire is used to complete the circuit on the terminal blocks.
- Ensure properly sized vent holes are drilled in the coupler tube and not blocked by anything assembled inside.

Troubleshooting Process:

- If an altimeter or GPS does not turn on, check all connections and make sure they are secure. If the component still will not power on, bring it to the avionics lead for further troubleshooting and replacement.
- If the altimeters do not detect continuity, use the multimeter to check for continuity in the circuit. If the multimeter does not detect continuity check all wire connections to ensure proper connection. If the multimeter detects continuity use a wire between terminals on the altimeter to figure out if the problem is with the altimeter, if it is, replace the altimeter and follow the troubleshooting steps in the manual.

Signature: My signature confirms that the avionics bay is manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Avionics Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

5.2.3. Payload Pre-Flight Assembly

Mandatory PPE: Safety Glasses

Required Personnel: Payload Team

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: PS.1, PS.3, PS.5, PS.6, PS.8, C.4, C.7, C.8, C.14, C.15.

- Batteries are inserted into the battery cavity and fastened securely.
- Extra mass is inserted into the corresponding cavity (if applicable).
- Radio transmitter settings set
  - Correct frequency
  - VOX off
- The radio transmitter is inserted correctly, and both set screws are tightened down.
- The antenna is fully screwed in.
- PCB screws tightened.
- STEMnauts fastened securely.
- Polycarbonate shields are inserted and secured.
- Sea level pressure calibrated.
- The current time is set.

Troubleshooting Process

- Check for cracks in PLA+ or missing hardware if the transmitter is not secure.
- If the chosen frequency is unavailable or in use, switch both radios to a secondary frequency.
- If any battery has physical damage, is swollen, has exposed wires, begins overheating, or has other potential issues, replace it with a new battery.
- Any issues of loose wires should be fixed as solidly as possible using a soldering iron or electrical tape.

Signature: My signature confirms that the payload is manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Payload Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

5.2.4. Airbrakes Pre-Flight Assembly

Mandatory PPE: Safety Glasses, Anti-static Grounding Strap

Required Personnel: Airbrakes Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: AB.8, AB.9, C.4, C.7, C.8, C.14.

- Mechanical
    - Linkage
        - Take the parts from the kit and assemble them as shown in the CDR. The ternary link connects to the encoder mount. Then the coupler connects to it via two gusset plates and two spacers. Ensure shoulder screws are used, not conventional screws. From there, the coupler attaches to the slider anchor via two gusset plates. The slider anchor attaches to the lead screw nut via four screws. Ensure the slider anchor has the hole lined up for the carbon fiber rod with the encoder mount. At the top, in the encoder mount, place the roller skate bearing on the inside of the groove.
        - Once the linkage is together, install the motor into the motor mount, and then attach the helical coupler to both the motor and the lead screw. Thread the lead screw through the nut and the roller skate bearing. To hold it together thread the carbon fiber rod through the hold in the corner. This is held via snap rings and shaft collars.
        - Install the flaps using the screws provided.

        - Install the motor controller, button, and rotary encoder.
        - Put the electronics canister on the top of the whole system and move onto the electronics to continue.
- Electronics
    - Pre-Assembly
        - To assemble the electronics, take each sensor and solder it onto the PCB in the location shown. Don't forget the backside.
    - Sensors
        - Check each sensor component for continuity to make sure none of them have a short. This can be done with a DMM.
        - Once each sensor has been cleared for continuity, the PCB can be turned on by flipping the small switch. A light will appear that indicates the PCB is getting power. The GY-521 (accelerometer) and the W25Q64FV (flash memory) should both have red lights. The rest of them will not.
    - SD Card
        - Take the SD card and ensure there is no data on the card.
            - If there is, then delete it
        - Install the SD card after ensuring it has no data on the card.
    - Communication Protocol
        - To make sure each component is talking with the Pico correctly, run the test programs on the Arduino IDE. This will only test the components currently connected so an additional mechanical/electrical test is needed.
            - To interpret the results, pull out the SD card and read it. The SD card has information if the systems are okay and if the PCB has communications within itself.
    - Battery
        - Test the battery charge level in the battery charger. See below for instructions.
        - Inset it into the electronics canister.
    - Post-assembly
        - Connect the ethernet cable to the PCB and the bottom adapter.
        - Ensure the battery is connected to the PCB. This will avoid unwanted drains or electronic accidents.
        - Carefully place the PCB into the electronics canister and fasten it into place.
        - Connect the wires, protruding from the encoder into the electronics canister, to the PCB header labeled HW-040.
- Final Testing Procedure
    - All components should be assembled at this time.

- Connect the Pico to the Arduino IDE and the battery to the PCB to run the final test program. This will ensure all hardware is speaking to one another. Once it has run, take the SD card out, read it, and it should have output that all systems are a go.
- Turn off the PCB and disconnect the battery.

Troubleshooting Process

- Ensure the sensors are getting power by taking a voltmeter and testing across the power and ground pins for each troublesome sensor.
- If sensors are not communicating with the Pico, but have power, hold an o-scope to the clock pin of each sensor to make sure each of them looks like a clock line.
- If the battery is lower than 95%, make sure it is charged before launching.

Signature: My signature confirms that the airbrakes are manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Airbrakes Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

5.2.5. Motor Retention and Fins Pre-Flight Assembly

Mandatory PPE: Safety Glasses

Required Personnel: Fin Design Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, C.3, C.5, C.6, C.10, C.15, C.17, C.19, C.20, C.21, C.22.

- Manufacture centering rings using a CNC machine.
- Use the 3D printer to manufacture the motor retention flanges. Using epoxy, glue the flanges to the outside of the motor tube.
- Insert centering rings into the airframe.
- Align the centering rings in the bottom of the airframe with the holes in the airframe.
- Attach fins to centering rings to line up the holes of the fins with the holes of the centering rings.
- Screw fins onto the centering rings. Ensure screws are tight enough to negate all erratic movement.
- Screw the motor retention system into the airframe.

Signature: My signature confirms that the motor and fin retention system is manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Fin Design Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.2.6. Tail Cone Pre-Flight Assembly

Mandatory PPE: Safety Glasses

Required Personnel: Tail Cone Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.8, RS.9, RS.10, C.15, C.16, C.20, C.22.

- The Tail Cone Lead or Chief Engineer should assemble this portion of the launch vehicle.
- Line up the PETG 3D printed tail cone with the three through-holes of the aft centering ring. Then, begin threading each of the three fasteners, ensuring the tail cone remains evenly attached to the aft centering ring.
- Finish screwing in each fastener until they are firmly tightened against the ring. Do not overtighten the assembly.

Troubleshooting Process

- If the tail cone is damaged or does not properly fasten to the aft centering ring, the Chief Engineer and Tail Cone lead will discuss if the component is salvageable (for example: sanding down the cone so that it adheres evenly to the ring), or if it is unsalvageable.
  - If the tail cone is salvageable, then make necessary repairs.
  - In the case the tail cone is unsalvageable, the Tail Cone Lead or Chief Engineer will replace the tail cone with a replacement component. There will be multiple tail cones on standby should the primary tail cone have unforeseen issues.

Signature: My signature confirms that the tail cone is manufactured and assembled correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Tail Cone Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3. Launch Preparation

5.3.1. Recovery Preparation

5.3.1.1. Main Parachute Preparation

Mandatory PPE: N/A

Required Personnel: Recovery Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.4, RS.5, R.4, R.5, R.6, R.9, R.11, R.12.

- Shock Cords
  - Prepare a new length of shock cord according to the dimensions specified by the CE and approved by the NAR Team mentor.
  - Attach three approved quick links to the shock cord in the following manner: one attached to the free end with a buntline hitch, another mounted 1/4 the cord length down from that end using an overhand knot, and another quick link mounted to the long end of the cord with a buntline knot.
  - Attach the larger of the two flame blankets to the shock cord where the middle quick link is tied. The flame blanket must be slid onto the long end of the shock cord all the way up to the middle knot so that the blanket cannot slip onto the shroud lines and reef the main parachute. The quick link on the long end of the shock cord may need to be temporarily removed to accomplish this.
  - Pass the long end of the shock cord through the main parachute bay tube.
  - Attach the long end of the shock cord to the forward eye ring in the avionics bay and the other end to the eye ring in the payload bay.
- Parachute
  - Affix the main parachute bay into place on the forward end of the avionics bay using two 4-40 shear pins.
  - Unpack and unfurl the main parachute, untangling its shroud lines.
  - Pulling the middle of the parachute and shroud lines tight, gather the shroud lines into a single loop at the end, loop them through the middle quick link, and pull the parachute through the loop.
  - Fold the parachute into thirds lengthwise, then pack the parachute into thirds horizontally.
  - Loosely wrap the shroud lines around the parachute bundle and burrito-fold the flame blanket around the parachute bundle. Ensure that the flame blanket covers the parachute canopy and shroud lines completely.

Troubleshooting Process

- Ensure that the personnel folding the parachute are trained in the proper parachute folding techniques.
- Double-check the parachute fold with one of the other personnel listed.
- Remove and re-fold the parachute bundle if the fit is too tight. The fit of all components of the recovery system must be approved by the NAR Team mentor.

Signature: My signature confirms that the main parachute is assembled and folded correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Recovery Lead: ___________________________

Chief Engineer: ___________________________

NAR Team Mentor: ___________________________

Chief Safety Officer: ___________________________

5.3.1.2. Drogue Parachute Preparation

Mandatory PPE: N/A

Required Personnel: Recovery Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.4, RS.5, R.4, R.5, R.6, R.10, R.11, R.12.

- Shock Cords
  - Prepare a new length of shock cord according to the dimensions specified by the CE and approved by the NAR Team mentor.
  - Attach three approved quick links to the shock cord in the following manner: one attached to the free end with a buntline hitch, another mounted 1/4 the cord length down from that end using an overhand knot, and another quick link mounted to the long end of the cord with a buntline knot.
  - Attach the smaller of the two flame blankets to the shock cord where the middle quick link is tied. The flame blanket must be slid onto the long end of the shock cord all the way up to the middle knot so that the blanket cannot slip onto the shroud lines and reef the main parachute. The quick link on the long end of the shock cord may need to be temporarily removed to accomplish this.
  - Attach the short end of the shock cord to the aft eye ring in the avionics bay and the other end to the shock cord mount inside of the booster tube.
- Parachute
  - Unpack and unfurl the main parachute, untangling its shroud lines.

  - Pulling the middle of the parachute and shroud lines tight, gather the shroud lines into a single loop at the end, loop them through the middle quick link, and pull the parachute through the loop.
  - Fold the parachute into thirds lengthwise, then pack the parachute into thirds horizontally.
  - Loosely wrap the shroud lines around the parachute bundle and burrito-fold the flame blanket around the parachute bundle. Ensure that the flame blanket covers the parachute canopy and shroud lines completely.

Troubleshooting Process

- Ensure that the personnel folding the parachute are trained in the proper parachute folding techniques.
- Double-check the parachute fold with one of the other personnel listed.
- Remove and re-fold the parachute bundle if the fit is too tight. The fit of all components of the recovery system must be approved by the NAR Team mentor.

Signature: My signature confirms that the drogue parachute is assembled and folded correctly for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

Recovery Lead: ___________________________

Chief Engineer: ___________________________

NAR Team Mentor: ___________________________

Chief Safety Officer: ___________________________

5.3.1.3. Black Powder Separation Charges

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.1, R.2, R.3, R.4, R.5, R.8, R.12, L.3, L.4.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- Calculate the black powder charges based on the volume of the parachute bays as well as the amount and type of shear pins used.
- Test ignitor batch with a ground (or pop) test, hooking an ignitor to the launch system and firing it at a safe distance.
- For redundancy place a second, slightly larger black powder charge in each parachute bay for launch to combust after the first one.

- Affix the main parachute bay into place on the forward end of the avionics bay using fasteners.
- Drop the main parachute bundle into place, orienting the flame blanket over the charges and loosely piling the shock cord on top of the parachute bundle. As much as possible, the flame blanket should seal the shock cord from the ejection charges.
- Affix the primary payload bay to the main parachute bay using two shear pins in the appropriate holes.

Troubleshooting Process

- If the tubes are fitting too tightly, apply baby powder to the coupler surfaces or sand the interfaces until the Team Mentor approves the fit.
- If the rocket does not separate energetically enough or at all, the Team Mentor must increase the charge size as necessary and perform additional pop tests.

Signature: My signature confirms that the black powder separation charges were calculated, measured, and tested accurately for launch. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

NAR Team Mentor: ___________________________

Recovery Lead: ___________________________

Chief Safety Officer: ___________________________

5.3.1.4. Pop Test

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.1, R.2, R.3, R.4, R.5, R.8, R.9, R.10, R.12.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- Place black powder charges into the parachute bays and set the rocket up to safely separate with the black powder charges. Do not just place it on the ground, brace one end or ensure the ends that can move are not facing towards any person or vehicle at the launch site.
- Install shear pins into the parachute bay being pop-tested.
- Remotely ignite the ejection charge once everyone is a safe distance away and the rocket is set up correctly.
- Repeat the process for pop testing the other parachute bay.

Signature: My signature confirms that the pop test, completed by the NAR Team Mentor, was successful. Team personnel must fill out the Safety Violation Form if any manufacturing or assembling techniques lead to FMEA personnel hazards.

NAR Team Mentor: ___________________________

Recovery Lead: ___________________________

Chief Safety Officer: ___________________________

5.3.1.5. Recovery Inspection

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor, Recovery Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.1, R.2, R.3, R.4, R.5, R.8, R.9, R.10, R.12.

- Check and make sure parachutes are accurately folded and the lines are placed correctly within the recovery bay.
- Ensure all recovery laundry can easily leave the body tubes during the recovery sequence.

Signature: My signature confirms that the recovery subsystem has been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling techniques lead to FMEA personnel hazards.

NAR Team Mentor: ___________________________

Recovery Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

5.3.2. Avionics Preparation

5.3.2.1. Avionics Inspection

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor, Avionics Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.2, R.7, R.8.

- Perform a pull test on every wire and ensure every connection is secure.

- Power on each altimeter and ensure altimeter beeps continuity for both main and drogue chutes when jumper wires are attached to terminal blocks to complete the circuit.
- Power on the GPS and ensure the location is being transmitted accurately to the handheld receiver.
- Power off altimeters and slide the avionics sled into the avionics bay. Ensure the avionics bay is properly sealed from parachute bays.
- Wire black powder charges to terminal blocks and insert the avionics bay into the rocket.
- Ensure the avionics bay slides easily into the airframe with a good amount of friction to ensure proper separation.

Troubleshooting Process

- If the GPS is not functioning properly, follow the troubleshooting steps in the manual.
- If the altimeters do not detect continuity use a multimeter to check for continuity in the circuit. If the multimeter does not detect continuity check all wire connections to ensure proper connection. If the multimeter detects continuity use a wire between terminals on the altimeter to figure out if the problem is with the altimeter, if it is, replace the altimeter on the sled.

Signature: My signature confirms that the avionics bay has been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

NAR Team Mentor: ___________________________

Avionics Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

5.3.3. Payload Preparation

5.3.3.1. Payload Power Check

Mandatory PPE: N/A

Required Personnel: Payload Team

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: PS.5, PS.7.

- Use a voltmeter to check the battery status of the radio and the main PCB. Override the PCB.
- Check that the radio power is on.
- Check power indicator LEDs on the main PCB and override the PCB.

Troubleshooting Process

- Use extra batteries if needed.
- Charge all batteries the day/night before launches.

Signature: My signature confirms that the payload power check has been completed. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Payload Lead: ___________________________

Chief Safety Officer: ___________________________

5.3.3.2. Payload Inspection

Mandatory PPE: N/A

Required Personnel: Payload Team, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: PS.1, PS.2, PS.3, PS.5, PS.7, PS.8.

- Check that the radio transmitter is secure by jostling it gently.
- Check that both PCBs indicate that they are powered on and launch ready.
- Check that the radio transmitter is powered on and set to the correct frequency.
- Check that the PTT wire is routed through the override PCB.
- Check that all battery connections are secure by gently pulling against the connectors.
- Check for exposed wires which could potentially cause an electrical shortage.
- Check that all other wire connections (soldered or screw terminal) are secure.
- Check that sensors with indicator LEDs are on.
- Attach payload to calibration computer and verify all sensors are detected and reasonable data points are being collected.

Troubleshooting Process

- If the transmitter is not secure, check for cracks in PLA+ or missing hardware.
- If the chosen frequency is unavailable or in use, switch both radios to a secondary frequency.
- Any issues of loose wires should be fixed as solidly as possible using a soldering iron or electrical tape.
- Any sensor regarded as faulty should have soldering points and/or other connections inspected and fixed as solidly as possible using a soldering iron.
- Optional test: short PTT to GND on primary PCB and make sure radio does not activate; then short PTT_OUT to GND on override PCB and make sure radio does activate.

Signature: My signature confirms that the payload has been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Payload Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3.4. Airbrakes Preparation

5.3.4.1. Airbrakes Power Check

Mandatory PPE: Safety Glasses, Anti-static Grounding Strap

Required Personnel: Airbrakes Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: AB.3, AB.8, AB.10, AB.11.

- Visually inspect that power is on via the power LED, and that the battery is plugged in firmly.
- Test to make sure each sensor has power by visually inspecting the flash memory and the accelerometer. Use a multimeter to test the other sensor.

Signature: My signature confirms that the airbrakes power check has been completed. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Airbrakes Lead: ________________________

Chief Safety Officer: ________________________

5.3.4.2. Airbrakes Inspection

Mandatory PPE: Safety Glasses, Anti-static Grounding Strap

Required Personnel: Airbrakes Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: AB.6, AB.10.

- To make sure everything is functioning properly, download the day-of-launch safety code to the Pico and let it run its course. This program should run through a list of checks to ensure every piece of hardware is working properly.

  - Not only does this program run a list of checks, but it will also take data that would be used in flight, and then run it through its decision-making logic. Review the results of the altitude, temperature, and acceleration to see if they are consistent.
- It is vital to make sure the right program is connected to the Pico before launch. Connect the Pico to a computer that has the Arduino IDE and the most recent version of the AIRBRAKES code. Download this code to Pico so it will be ready to activate during launch.

Troubleshooting Process

- If the values from the sensors look incorrect, alter the values in the code denoted for changing prelaunch. Re-run the code and test the values to see if they are consistent.

Signature: My signature confirms that the airbrakes have been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Airbrakes Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3.5. Nosecone Preparation

5.3.5.1. Nosecone Camera Integration

Mandatory PPE: Safety Glasses

Required Personnel: Nosecone Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.12.

- The camera assembly will be 3D printed and mounted onto the airframe of the rocket using hardware.
- The camera will then be inserted into the housing assembly and secured for launch.
- Before the rocket is to be launched, the camera will be turned on and set to record video feed.
- The video feed will then be retrieved and observed from the camera after the rocket's recovery.

Troubleshooting Process

- The assembly will be checked for damage or crack propagation by the Chief Engineer and Nosecone Lead. If any is found, the parts will be assessed for survivability.
  - If the damage is deemed negligible, then the assembly would be used during launch.

  - If the damage is deemed severe, the assembly will not be used on that specific launch. A new assembly would be 3D printed and mounted for the next launch.
  - This is because the camera is not a mission priority. Its failure will not impede rocket launches.
- The camera will be checked to see if it is on and has a charged battery.
  - If the camera is not turned on or will not turn on correctly, check the battery and swap in an extra charged battery.
  - If the camera refuses to work remove it and see if the problem can be solved. If not, the camera will not be used during the present launch.

Signature: My signature confirms that the flight camera has been integrated into the nosecone and is working properly. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Nosecone Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3.5.2. Nosecone Inspection

Mandatory PPE: Safety Glasses

Required Personnel: Nosecone Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: C.10, C.11, C.13, RS.5.

- Check for any cracks or damage to either the 3D print material or the epoxy coating.
- Make sure the cone is inserted into the airframe and properly secured into place using the correct hardware screws.

Troubleshooting Process

- If the cone is not properly mounted onto the airframe, take the cone off and insert it in the correct position.
- If damage is discovered in either the 3D printed material or the epoxy coating, the Chief Engineer and Nosecone Lead need to assess the effects of this damage on the overall performance of the rocket.
  - If the damage can be repaired in a manner that a launch can still occur, then do so.
  - If the damage cannot be repaired but is not deemed to be detrimental to the rocket's success, continue the launch.
  - If the damage is severe and will impede the rocket's launch, either replace the cone with a spare (if available) or postpone the launch.

Signature: My signature confirms that the nosecone has been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Nosecone Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3.6. Motor Systems Preparation

5.3.6.1. Fin Inspection

Mandatory PPE: Safety Glasses

Required Personnel: Fin Design Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.12, RS.13.

- Check for any scratches or potential damage to the fins. If damage is found, the Team Mentor needs to be alerted and questioned if the rocket will still be able to launch.
- Attempt to wiggle fins to make sure they are securely attached to the airframe. Tighten the screws if wiggling is noticeable.

Signature: My signature confirms that the fins have been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Fin Design Lead: ________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.3.6.2. Tail Cone Inspection

Mandatory PPE: Safety Glasses

Required Personnel: Tail Cone Lead, Chief Engineer

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.8, RS.9, RS.10.

- Inspect the tail cone for surface damage, thermal scoring, or propagated cracks that might have occurred during previous flights or mishandling during transportation.

- After the motor reload is inserted and the tail cone has been reattached to the launch vehicle, ensure by visual and hand inspection that the tail cone is evenly seated on the aft centering ring and each fastener is not over tightened.

Troubleshooting Process

- If the tail cone has been damaged or deemed otherwise unworthy for flight, the Chief Engineer and Tail Cone Lead will discuss whether the component is salvageable or unsalvageable.
  - If the tail cone is salvageable, then repair the tail cone.
  - If the tail cone is unsalvageable, it will be swapped with a replacement component.
- If the component has sufficient structural integrity and is properly fastened to the tail cone, then proceed with the launch.

Signature: My signature confirms that the tail cone has been thoroughly inspected. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

Tail Cone Lead: _________________________

Chief Engineer: _________________________

Chief Safety Officer: _________________________

5.3.6.3. Motor Integration

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: L.1, P.8, RS.3, RS.4, RS.8, RS.9, LP.11, LP.16.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- The Team Mentor must assemble the motor reload kit.
- The Team Mentor must ensure that no ejection charge was installed in the motor build.
- Insert the motor into the motor tube.
- Place the tail cone over the aft closure of the motor and screw it into the aft centering ring.
- Twist and pull the tail cone repeatedly to ensure that the motor retention is sufficient. This step is performed at the discretion of the Range Safety Officer.

Signature: My signature confirms that the motor has been properly assembled and integrated into the rocket. Team personnel must fill out the Safety Violation Form if any assembling or troubleshooting techniques lead to FMEA personnel hazards.

NAR Team Mentor: _________________________

Chief Engineer: ________________________

Chief Safety Officer: ________________________

5.4 Launch Procedures

CSL developed a set of launch and pre-launch procedures to improve safety, efficiency, and success during launch operations. These procedures are listed in sections 5.4.1 and 5.4.2.

5.4.1. Launch Pad

5.4.1.1. Launch Equipment Setup

Mandatory PPE: Safety Glasses

Required Personnel: Chief Safety Officer, Launch Officer, Team Lead, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: L.4, L.6, C.4, C.10, LP.1, LP.2, LP.5, LP.17, ER.12.

- Unpack the ladder, launch pad, and launch rail from vehicles.
- Have team members inspect the launch site for even ground and have them carry the launch equipment to this site. If the area chosen for the launch pad is not even or firm, another area that satisfies launch requirements will need to be selected.
- Unfold the legs of the launch pad. Place the rail inside the hole of the launch and tighten the screws to secure the assembly.
- Multiple team members will help carry the assembled rocket to the launch pad. They need to be careful not to trip or fall in the launch field due to the uneven ground. This could cause team members to accidentally drop and damage the rocket.

Signature: My signature confirms that the rocket has been properly assembled and transported to the launch pad. Team personnel must fill out the Safety Violation Form if any FMEA personnel hazards occur.

Launch Officer: ________________________

Chief Safety Officer: ________________________

Team Lead: ________________________

NAR Team Mentor: ________________________

5.4.1.2. Launch Rail

Mandatory PPE: Safety Glasses

Required Personnel: Chief Safety Officer, Launch Officer, Team Lead, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: L.4, L.6, C.4, C.10, FD.3, LP.1, LP.2, LP.5, LP.17, ER.12.

- The launch rail needs to be lowered to be parallel with the ground.
- The Team Mentor will ensure there are no live wires at the launch pad.
- Team members carrying the assembled rocket need to align the rail buttons on the airframe with the launch rail and slide the rocket onto the rail. This is to be done carefully to ensure the rocket is not dropped or damaged.
- The Team Mentor should inspect if the rocket is on the launch rail.
- The Team Mentor will make sure the launch rail is at the appropriate launch angle.
- Put a standoff of some kind in place to protect the bottom of the rocket from burning. This step is to be performed at the discretion of the Team Mentor.

Signature: My signature confirms that the assembled rocket is aligned on the launch rail and inspected to ensure an appropriate launch angle. Team personnel must fill out the Safety Violation Form if any FMEA personnel hazards occur.

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

Team Lead: ___________________________

NAR Team Mentor: ___________________________

5.4.1.3. Ignitor Installation

Mandatory PPE: Safety Glasses

Required Personnel: NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: L.4, L.6, C.4, FD.3, LP.3, LP.11, LP.16, LP.17.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- Once the rocket is upright on the pad, strip the igniter wires enough that the launcher clips can be reliably attached.
- Inspect the pyrogen on the tip of the igniter for any signs of cracks or moisture damage.
- Insert the igniter into the motor.
- Tape the igniter in place on the nozzle and arrange the wires so that they cannot be short. Alternatively, the nozzle cap supplied with the motor reload can be used to fix the igniter into place.

Signature: My signature confirms that the ignitors have been properly installed on the launch pad. Team personnel must fill out the Safety Violation Form if any FMEA personnel hazards occur.

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.4.2. Launch Checklist

5.4.2.1. Recovery Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Recovery Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.2, R.3, R.4, R.5, R.6, R.7, R.8, R.9, R.10, R.11, R.12.

- Check parachutes and lines again. Repeatedly checking parachutes and lines can help ensure that the parachutes deploy correctly.
- Attach black powder charges.
- Confirm the avionics bay and the altimeters are correctly set up before connecting black powder charges to better ensure they only combust when they are supposed to.

Signature: My signature confirms that the recovery system is cleared for launch.

Recovery Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.4.2.2. Avionics Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Avionics Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.2, R.7, R.8.

- Once the rocket is on the pad, power on each altimeter one at a time ensuring each altimeter powers on correctly and is beeping continuity on both parachutes.
- Ensure GPS is still transmitting location to the receiver.

Troubleshooting Process

- If anything is not working properly, turn off key switches and remove the rocket from the launch rail. Revert to the avionics inspection procedure.

Signature: My signature confirms that the avionics system is cleared for launch.

Avionics Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.4.2.3. Payload Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Payload Team, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: PS.1, PS.2, PS.6, PS.7.

- Check that nothing moves or breaks when the entire payload is jostled.
- Check that all LED indicators show the correct status.
- Check that the radio frequency is still available using the radio receiver.

Troubleshooting Process

- Use assembly and inspection troubleshooting procedures as needed.

Signature: My signature confirms that the payload system is cleared for launch.

Payload Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.4.2.4. Airbrakes Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Airbrakes Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: AB.1, AB.2, AB.3, AB.4, AB.5, AB.6, AB.7, AB.8, AB.9, AB.10.

- Visually inspect that no hardware is missing. Check each bolt to make sure it is all tightened down and there are no loose ends.
- Make sure all electrical connections are soldered or have good connections.

Troubleshooting Process

- ✦ If the connections are loose, run a continuity check through the component. If it is loose, then fix it by resoldering the connection.
- ✦ If a bolt is loose, then tighten it.

Signature: My signature confirms that the airbrake system is cleared for launch.

Airbrakes Lead: ________________________

Launch Officer: ________________________

Chief Safety Officer: ________________________

NAR Team Mentor: ________________________

5.4.2.5. Nosecone Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Airbrakes Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: C10, C.11, C.13, RS.5, RS.12.

- Check to make sure that the nosecone is mounted properly to the airframe and four securing screws and tightened.
- Turn on the camera and make sure it is recording.

Troubleshooting Process

- If the nosecone is not mounted correctly, fix this issue by mounting it correctly before launch.
- If the camera becomes inoperable before launch, remove the camera and check the wiring between itself and the battery resupply.
- Turn the camera on and off again.
- Reset the camera and reinsert the command code via the SD card.

Signature: My signature confirms that the nosecone and flight camera are cleared for launch.

Nosecone Lead: _________________________

Launch Officer: _________________________

Chief Safety Officer: _________________________

NAR Team Mentor: ________________________

5.4.2.6. Fin Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Fin Design Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.12, RS.13.

- Check for any scratches or potential damage to the fins. If damage is found, the Team Mentor needs to be alerted and questioned if the rocket will still be able to launch.
- Attempt to wiggle fins to make sure they are securely attached to the airframe. Tighten the screws if wiggling is noticeable.

Signature: My signature confirms that the fin retention system is cleared for launch.

Fin Design Lead: _________________________

Chief Engineer: _________________________

Chief Safety Officer: _________________________

NAR Team Mentor: _________________________

5.4.2.7. Tail Cone Launch Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Tail Cone Lead, Chief Engineer, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.8, RS.9, RS.10, RS.12.

- Ensure that the tail cone is properly and evenly attached to the aft centering ring by all three fasteners.
- Ensure there is minimal to no gap between the tail cone and the airframe.

Troubleshooting Process

- If the tail cone is not properly attached, reattach the tail cone.
- If there is a gap between the tail cone and the airframe, check to see if an alternate cone fits more evenly.

Signature: My signature confirms that the tail cone system is cleared for launch.

Tail Cone Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.4.2.8. Rocket in Flight

Mandatory PPE: Safety Glasses, Nitrile Gloves, Long Sleeves, Closed-toed Shoes

Required Personnel: Chief Safety Officer, Launch Officer, Chief Engineer, Team Lead, NAR Team Mentor, Recovery Lead, Avionics Lead, Airbrakes Lead, Payload Lead, Nosecone Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: L.1, L.4, L.5, L.6, FD.1, FD.2, FD.3, FD.4, FD.5, RE.7, RE.8, LP.1, LP.2, LP.3, LP.4, LP.11, LP.14, LP.16, LP.17.

- The NAR Team Mentor reminds team members that the ignition wires are hot, and the rocket is ready for launch sequence.
- CSO and Launch Officer will remind team personnel to wear safety glasses and to back away at least 100 feet from the launch pad.
- The NAR Team Mentor counts down from 5 with the launch button in his hand. He presses the ignition button for launch as the count ends at 1.
- Team members will observe that the rocket has ignited and that it will leave the launch rail.
- Team members will observe the trajectory of the rocket in the air as it descends toward the ground.
- Warnings will be sounded if the rocket descends towards spectators or team members. These warnings will be instructions to move out of the potential path the rocket takes as it descends.
- If the recovery system does not deploy, team members need to be aware and make appropriate warnings to those around them. Team members and the public at the launch site need to be removed from the rocket's potential path. Failure to do so may result in injury or possibly death.

Troubleshooting Process

- If the ignitor does not start the launch sequence when intended, the NAR Team Mentor, wearing safety glasses and nitrile gloves, will travel to the launch pad to perform an inspection after waiting sixty seconds with the launch key disengaged.
- The NAR Team Mentor will ensure the live wires are disconnected without flowing current.
- The NAR Team Mentor will carefully remove the igniter from the motor and install a new one.
- Once a new igniter is installed, launch procedures can be repeated.
- If the ignitor still does not start the launch sequence, then the NAR Team Mentor will need to inspect the motor and ensure there are no defects.
- The NAR Team Mentor will reinstall the motor and prepare for launch if no defects are found.
- If the motor still does not ignite, the Range Safety Officer will provide instructions on how to proceed.

Signature: My signature confirms that the launch sequence was a success. Team personnel wore proper PPE and avoided potential hazards.

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.5. Post-Launch Procedures

5.5.1. Post-Flight Inspections

5.5.1.1. Recovery Post-Flight Procedure

Mandatory PPE: Safety Glasses, Nitrile Gloves, Long Sleeves, Closed-toed Shoes

Required Personnel: Recovery Lead, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.1, R.2, R.3, R.4, R.5, R.6, LP.3, LP.4, LP.6, LP.9, LP.15, LP.16.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- Team members or bystanders must not attempt to catch the rocket, even if the main parachute is deployed. This may result in injury or possibly even death.
- The Range Safety Officer will give the signal to retrieve the rocket. Team members must wear appropriate clothing and footwear to be able to retrieve the rocket no matter the terrain.

- A phone camera must be used to document how the rocket landed. Team members are NOT allowed to touch any part of the rocket until pictures have been taken.
- Turn off the avionics key switches.
- Inspect the avionics bay for unexploded charges.
- Carry the rocket back to the staging area while maintaining control of the parachutes so that they do not tangle unnecessarily.
- Inspect the drogue and main parachutes for burnt-through areas.
- Inspect the parachute shroud lines for melting/breakage.
- Inspect the shock cords for melting/breakage.
- The NAR Team Mentor is the only person that is allowed to take the motor out of the rocket. He must wear nitrile gloves to avoid contamination and burns to the skin.

Signature: My signature confirms that post-launch recovery procedures were followed and only the NAR Team Mentor handled any energetics involved.

Recovery Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

NAR Team Mentor: ___________________________

5.5.1.2. Avionics Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Avionics Lead, NAR Team Mentor

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: R.7, R.8.

Note: Only NAR Team Mentor Dave Combs is qualified to handle energetics.

- Approach the rocket carefully and listen for the altimeter beeping apogee and status.
- Power off the altimeters using the exterior key switches to prevent delayed activation of black powder ejection charges.
- Inspect exterior bulkheads for intact ejection charges.
- Disassemble the avionics bay and connect altimeters to the computer to extract collected flight data.

Troubleshooting Process

- If a black powder charge has not been ignited, maintain a safe distance from the rocket, and the NAR Team Mentor shall carefully disarm altimeters and remove the live charge from the rocket.

Signature: My signature confirms that post-launch avionics procedures were followed and only the NAR Team Mentor handled any energetics involved.

Avionics Lead: ________________________

Launch Officer: ________________________

Chief Safety Officer: ________________________

NAR Team Mentor: ________________________

5.5.1.3. Payload Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Payload Team

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: PS.8.

- Save record of APRS transmissions received.
- After transmissions end, power down the radio receiver.
- Take a picture of the payload in the landed configuration.
- Power down the radio transmitter.
- Power down PCBs.
- Remove and securely store micro-SD cards.

Signature: My signature confirms that post-launch payload procedures were followed. Transmissions of the APRS were saved.

Payload Lead: ________________________

Launch Officer: ________________________

Chief Safety Officer: ________________________

5.5.1.4. Airbrakes Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Airbrakes Lead, Payload Team

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: AB.11.

- Take out SD card and upload data to a laptop. This data should display that the airbrakes deployed, the airbrakes were stowed within ± 2 seconds of apogee, and if the rocket apogee was achieved within ± 25 feet of the target altitude. If data was not recorded, then the launch was a mission failure.

Troubleshooting Process

- If the data is not on the SD card, then try and pull the data off the flash memory.

Signature: My signature confirms that post-launch airbrake procedures were followed. Airbrake data from the launch was recorded and recovered.

Airbrakes Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

5.5.1.5. Nosecone Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Nosecone Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: C.3, C.4, C.10, C.13, RS.5, RS.6.

- Check to see if the flight camera is still recording before leaving the launch site. If so, turn off the camera and remove the memory chip to analyze the video.
- Once back at the barn, remove the nosecone from the rocket and assess if there is any damage.
- Take the rest of the camera system out of the cone to make sure that none of its components have received any damage.
- Analyze the areas where the cone failed and determine if the failure was caused by a design flaw or something that could not be accounted for.

Signature: My signature confirms that post-launch nosecone procedures were followed.

Nosecone Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

5.5.1.6. Fin Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Fin Design Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4.

- Inspect the fins to see if there is any damage or scratches. If any fins disconnected during launch and became a projectile, analyze where the failure took place and determine if the failure was caused by a design flaw or something that could not be accounted for.

Signature: My signature confirms that post-launch fin procedures were followed.

Fin Design Lead: ________________________

Launch Officer: ________________________

Chief Safety Officer: ________________________

5.5.1.7. Tail Cone Post-Flight Procedure

Mandatory PPE: Safety Glasses, Long Sleeves, Closed-toed Shoes

Required Personnel: Tail Cone Lead

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RS.3, RS.4, RS.8, RS.9, RS.10.

- If the tail cone is not attached to the launch vehicle during recovery, or only partially attached, recover all component pieces.
- Once back in the Barn, inspect the tail cone for surface damage, surface scoring, or cracks that occurred during the launch. Take the tail cone off the launch vehicle and inspect portions of the components that were covered when assembled.
- If the tail cone suffers damage, analyze the failure modes that created the damage, and identify design choices or manufacturing methods that initiated the failure mechanism.

Signature: My signature confirms that post-launch tail cone procedures were followed.

Tail Cone Lead: ________________________

Launch Officer: ________________________

Chief Safety Officer: ________________________

5.5.2. Pack up Launch Site

Mandatory PPE: N/A

Required Personnel: Chief Safety Officer, Launch Officer, Team Lead, NAR Team Mentor, Chief Engineer, Recovery Lead, Avionics Lead, Airbrakes Lead, Payload Team

Warning: Failure to comply with the prescribed launch procedures creates significant safety hazards that can lead to catastrophic mission failure. These hazards, classified by the FMEA Failure ID include, but are not limited to: RE.1, RE.2, RE.3, RE.6, RE.7.

- Team members are required to help clean up the launch pad and launch area, ensuring no trash or equipment is left at the launch site.
- All explosives and motor components must be taken with the NAR Team Mentor and are not to be handled by team members.
- Batteries must be disconnected and inspected to ensure there are no acid leakages.
- If an impact landing occurs, team members must clean up the crash and ensure nothing is left behind. This could cause environmental and wildlife damage.
- Everything brought to the launch site is to be packed back into the vehicles.
- After returning to campus, all launch materials, equipment, and tools are to be placed back in their appropriate location inside the Barn.
- Any waste collected from the launch site should be placed in the dumpster outside the Barn.

Signature: My signature confirms that the team followed clean-up procedures after launch, and nothing was left behind at the launch site.

Team Lead: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

5.5.3. Launch Confirmation

Signature: My signature confirms that all launch procedures were followed. Team personnel followed the direct commands of the NAR Team Mentor, Range Safety Officer, Launch Officer, and Chief Safety Officer. The NAR Team Mentor was the only qualified person to handle energetics. Whether a mission success or failure, team personnel left the launch site, clearing any debris or waste, ensuring the protection of the environment and any wildlife in the area.

NAR Team Mentor: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

Team Lead: ___________________________

Chief Engineer: ___________________________

Recovery Lead: ___________________________

Avionics Lead: ___________________________

Payload Lead: ___________________________

Airbrakes Lead: ___________________________

5.6. Risk Assessment Method

Implementing safety risk management is an effective approach to identifying potential hazards affecting the team, the public, and the environment. Hazards will be assessed using consistent scales for severity and probability. Each identified safety risk will be documented by the CSO, including its cause, effect, and mitigation strategy. Hazards will receive a score based on severity and probability. A high score indicates a significant safety risk that demands immediate mitigation. Table 5.6.1 outlines the criteria for determining probability levels, while Table 5.6.2 describes the severity of hazards. Table 5.6.3 presents the risk assessment table and associated codes, with color-coding cells representing varying risk levels. Table 5.6.4 explains how different risk values align with specific risk categories.

Table 5.6.1. *Probability Value Criteria.*

Description	Value	Description of Occurrence	Probability of Occurrence
Rare	1	Very Unlikely	Less than 5%
Occasional	2	Event Occurs Occasionally	Between 5% and 25%
Often	3	Event Occurs Often	Between 25% and 50%
Likely	4	Highly Likely Event Will Occur	Between 50% and 75%
Frequent	5	Event Expected	Above 75%

Table 5.6.2. *Danger Level Definitions.*

Description	Value	Team Personnel	Physical Environment	Launch Vehicle	Mission Success
Negligible	1		No Damage	Insignificant	

		Minor or No Injuries			Complete Mission Success
Minimal	2	Minor Injuries	Minor and Reversible Damage	Mild Damage	Near Complete Mission Success
Major	3	Moderate Injuries	Moderate Reversible Damage or Minor Irreversible Damage	Major Damage	Partial Mission Failure
Catastrophic	4	Life-threatening Injuries	Major Irreversible damage	Irrevocable Damage	Complete Failure

Table 5.6.3. *Risk Assessment Table and Codes.*

Probability	Severity			
	Negligible (1)	Minimal (2)	Major (3)	Catastrophic (4)
Rare (1)	1	2	3	4
Occasional (2)	2	4	6	8
Often (3)	3	6	9	12
Likely (4)	4	8	12	16
Frequent (5)	5	10	15	20

Table 5.6.4. *Risk and Acceptance Level Definitions.*

Severity	Range	Acceptance Level	Approval Authority
Low Risk	Less than 5	Desired	CSO approval recommended, but not required.
Medium Risk	5 to 9	Undesirable	Mitigation must occur. Document approval from CSO.
High Risk	Greater than 10	Unacceptable	Mitigation must occur before proceeding.

5.7. Overall Risk Reduction

The CSO and team personnel researched and identified safety risks for all areas of this project. Table 5.7.1 provides the percentage for each risk distributed between probability and severity. Table 5.7.2 provides the percentage and quantity for low, medium, and high risks before mitigation. The total number of safety hazards identified is 134.

Table 5.7.1. *Risk Assessment Before Mitigation.*

Probability	**Severity**			
	Negligible (1)	**Minimal (2)**	**Major (3)**	**Catastrophic (4)**
Rare (1)	0%	0%	1.49%	0.74%
Occasional (2)	0%	5.22%	13.43%	5.97%
Often (3)	0%	2.98%	26.86%	23.13%
Likely (4)	0%	2.23%	4.47%	12.68%
Frequent (5)	0.74%	0%	0%	0%

Table 5.7.2. *Risk Classification Before Mitigation.*

Severity	**Acceptance Level**	**Quantity**	**Percentage**
Low Risk	Desired	10	7.5%
Medium Risk	Undesirable	70	52.2%
High Risk	Unacceptable	54	40.3%

CSL has developed a safety plan to reduce the probability and severity of each hazard in all areas of this project. A low risk is acceptable with light documentation and approval from the CSO. A high risk is extremely dangerous and unacceptable. If any high-risk hazard occurs, extensive documentation and mitigation must occur.

The CSO and team personnel explored mitigation and verification strategies to minimize the risks related to the student launch. After establishing a mitigation plan, the CSO verified it is effective in reducing the risk. The hazard was then reassessed to give a new risk value. Table 5.7.3 reflects the risk assessment after mitigation, and Table 5.7.4 classifies the risk post-mitigation.

Table 5.7.3. *Risk Assessment After Mitigation.*

Probability	**Severity**			
	Negligible (1)	**Minimal (2)**	**Major (3)**	**Catastrophic (4)**
Rare (1)	0%	23.88%	36.56%	22.38%
Occasional (2)	2.23%	4.47%	5.97%	0%
Often (3)	1.49%	2.98%	0%	0%
Likely (4)	0%	0%	0%	0%
Frequent (5)	0%	0%	0%	0%

Table 5.7.4. *Risk Classification After Mitigation.*

Severity	**Acceptance Level**	**Quantity**	**Percentage**
Low Risk	Desired	122	91.04%
Medium Risk	Undesirable	12	8.95%

High Risk	Unacceptable	0	0%

Failure Modes and Effect Analysis (FMEA) sheets are utilized to identify all safety risks related to the project. The CSO and team personnel categorized these sheets based on the hazards associated with the rocket's various subsystems and team members' roles. Table 5.7.5 outlines each category of FMEA sheets that may contain significant specific hazards.

Table 5.7.5. *Identification for FMEA Tables.*

ID	Category	Description of FMEA
C	Personnel	The hazards of construction to personnel.
LP	Personnel	The hazards of launch operations to personnel.
RS	Rocket Structure	The hazards of the structure of the rocket.
R	Recovery	The hazards of the rocket during the recovery stage.
AB	Airbrakes	The hazards involving the airbrakes.
PS	Payload	The hazards of the payload electronics and control systems.
L	Launch	The hazards of launch operations.
FD	Flight Dynamics	The hazards of the rocket during flight.
RE	Rocket Risks to Environment	The hazards the rocket can have on the environment.
ER	Environment Risks to Rocket	The hazards the environment can have on the rocket.
P	Project Risks	The hazards of completion of the project.

5.8. Personnel Hazards

Table 5.8.1. *Hazards to Personnel during Construction of Vehicle Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
C.1	Contact with Hazardous Chemicals	Chemical spills, mishandling of chemicals	Burns, skin irritation, erosion of vehicle	3	3	9	Wear appropriate PPE, especially gloves and eye protection, in conjunction with clothing that covers the whole body, and workspace will have a protective layer of material.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	2	2	4
C.2	Inhalation of Toxic Fumes	Inhalation of toxic fumes while handling chemicals, especially in confined areas	Pain, sickness, lung damage	3	3	9	Respirators will be used when handling chemicals that have toxic fumes. These chemicals will only be used in well-ventilated areas.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	2	2

C.3	Contact and Inhalation of Dust or Debris	Contact with dust and debris	Pain, lung damage, skin irritation	2	3	6	Team members will wear appropriate PPE, including gloves, eye protection, respirator, and clothing that covers the whole body.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3
C.4	Electrocution	Contacting electrical terminals, inadequate caution	Pain, burns, physical harm, death	4	3	12	Clearly label high voltage equipment and provide a briefing on the proper handling of electronics.	Regular inspection of electronics will be performed. Students will confirm with CSO that they have had appropriate training prior to using labeled equipment. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	1	4	4
C.5	Abrasion from Powered Equipment	Mishandling of machinery	Pain, burns, abrasion, cuts, physical injury, death	3	4	12	Safety training on the proper use of equipment will be required for those using construction. A 10 ft radius will be observed when machinery is in use. Proper PPE will be used.	When power tools are in use the CSO or another team member will be present to supervise and ensure that proper procedure is being observed. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	2	2	4

C.6	Hearing Damage	Loud machinery, explosions, chemical reactions	Temporary or long-term hearing damage	3	3	9	Ear plugs or earmuffs will be worn while using machinery and at launches and testing of black powder, as well as for all other activities above 90 dB.	Ear protection will be part of pre-flight and pre-test check lists. The CSO will ensure that proper ear protection is used, and the CSO will ensure use with machinery. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	3	1	3
C.7	Electronics Catch on Fire	Overloading of electrical circuits	Burns, destruction of electronics	2	4	8	A chemical-based water extinguisher will be kept near electronics. Team members are required to know how to escape a laboratory for fire emergencies.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. Inspections of electronics will regularly take place. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	1	3	3
C.8	Lithium Polymer (LiPo) Battery Explosion.	LiPo gone bad, or LiPo puncture	Burns, physical harm from fire	4	4	16	The batteries will be stored in a cool, dry environment to prevent heating, over-charging, and puncturing. Any damaged or potentially damaged batteries will be disposed of.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. Battery inspections will be performed to ensure battery health. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	1	4	4

C.9	Tripping	Untidy work area	Scrapes, cuts, concussion	3	3	9	Workspace will be kept clean; cables will be routed through proper cable covers and marked accordingly	The CSO will ensure that the work area is clean and make all members aware of any potential tripping hazard. The safety violation form will be filled out and verified by the CSO. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	3	1	3
C.10	Eye Injury or Irritation	Lack of eye protection.	Damage to eyes, could cause blindness.	3	4	12	Understanding workshop procedures, wearing appropriate eyewear during construction	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3
C.11	Explosion or fire in the EPL	Failure of a machine or tool, not following proper laboratory procedures	Fire, major injury, damage to rocket and machinery	3	4	12	Understanding and following safe construction procedures, understanding fire code and the emergency exit system in laboratories and workshops	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	1	4	4

C.12	Roughhousing in the EPL, the Barn, or Advanced Manufacturing Laboratory	Not following laboratory procedures, distracted team members	Major injury, damage to rocket and machinery	3	3	9	Understanding construction procedures, knowledge of the universities laboratories, wearing appropriate PPE	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The safety violation form will be filled out and verified by the CSO. The First Aid Kit in the Barn and EPL are stocked with medical equipment.	1	3	3
C.13	Epoxy Contact	Not following laboratory procedures, not wearing appropriate PPE	Itchiness, burns to exposed area	2	4	8	Understanding construction procedures, wearing appropriate PPE, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	2	2
C.14	Soldering Iron Injury	Not following laboratory procedures, not wearing appropriate PPE, distracted team members	Serious burns to exposed areas	4	3	12	Understanding construction procedures, wearing appropriate PPE such as eye protection and gloves, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3

C.15	Pinch Points	Not wearing appropriate PPE when handling machinery or vehicle, distracted team members	Pinching or cutting of skin, bruises, bleeding possible	3	4	12	Understanding construction procedures, wearing appropriate PPE eye protection, gloves, long pants, and closed-toed shoes, knowledge of the universities laboratories.	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	2	2
C.16	Personnel getting caught in machinery	Jewelry, loose fitted clothing, long hair not being tied back properly	Serious injury, pinching or cutting of skin, bleeding possible	3	4	12	Understanding construction procedures, wearing appropriate PPE eye protection, gloves, long pants, and closed-toed shoes, knowledge of the universities laboratories and construction procedures	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3
C.17	Falling tools in EPL and Barn	Tools are not properly stored after use	Moderate to serious injury, bruises, bleeding possible	3	3	9	Understanding construction procedures, wearing appropriate PPE eye protection, gloves, long pants, and closed-toed shoes, knowledge of the universities laboratories and construction procedures	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3

C.18	Fiberglass Inhalation	Team personnel breathe in fiberglass particles during construction of airframe or fins	Difficulty breathing, dizziness, headache	4	2	8	Understanding construction procedures, wearing appropriate PPE such as dust masks, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	2	2
C.19	Metal Chips Contact	Touching sharp metal chips with bare hands while using machinery	Hand lacerations, bruises, bleeding likely	3	3	9	Understanding construction procedures, wearing appropriate PPE such as safety glasses and gloves, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3
C.20	Cordless Drill Contact	Hand too close to drill bit, not wearing proper PPE	Hand lacerations, bruises, bleeding likely	3	4	12	Understanding construction procedures, wearing appropriate PPE such as safety glasses and gloves, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	4	4

C.21	Spray Paint Inhalation	Team personnel breathe in paint aerosols	Difficulty breathing, dizziness, headache	3	3	9	Understanding construction procedures, wearing appropriate PPE such as dust mask, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	3	3
C.22	Contact of Fiberglass Debris	Touching sharp edges of fiberglass tubing during construction of airframe	Hand lacerations, bruises, bleeding likely	3	2	6	Understanding construction procedures, wearing appropriate PPE such as safety glasses and gloves, knowledge of the universities laboratories	Team members are required to sign the team safety agreement to follow all safety rules and regulations set in place. The First Aid Kit in the Barn and EPL are stocked with medical equipment. The Safety Handbook provides information on construction and operating procedures.	1	2	2

Table 5.8.2. Hazards to Personnel during Launch Operations Evaluated by the Defined Risk Assessment Code.

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
LP.1	Accidental Black Powder Explosion	Exposure to high temperatures, accidental connection to a voltage source	Burns, destruction of rocket components, flying debris	4	4	16	Black powder will be stored in an explosive's chest. It will only be handled by the team mentor or CSO after they have reviewed proper handling procedure. Avionics and electric matches will only be armed directly before launch.	The RSO is the only person qualified to handle motor and other energetics. Powder will be handled carefully and cautiously at the launch site. The correct amount of black powder needed will be calculated and checked by the recovery lead and RSO.	1	4	4
LP.2	Launch Pad Fire	Not following Launch Checklists, not wearing appropriate PPE	Burns, serious injury	3	4	12	Understanding launch procedures, wearing appropriate PPE, NAR Team Mentor is only qualified person to handle motors and other energetics	Team personnel will be briefed about launch day and the launch checklists will be available for everyone to read and understand. A fire extinguisher is required by the CSL Launch Checklist.	1	3	3
LP.3	Injury from Projectiles Launched by Rocket Blast	Debris from launch pad harming team members due to motor blast	Injury, destruction of launch pad or rail, flying debris	3	4	12	The launch pad will be cleaned before use. Team members will wear proper PPE during launch and will be at a safe distance away from launch pad.	The CSL Launch Checklist requires the CSO, RSO, and Launch Officer to confirm the launch pad setup and launch pad is cleared prior to launch.	1	4	4

LP.4	Physical Contact with Hot Materials during Recovery of Vehicle during Launch	Lack of awareness, not wearing appropriate PPE	Serious injury, burns	4	3	12	Understanding launch procedures, wearing appropriate PPE, always watching vehicle during flight. The NAR Team Mentor is only person qualified to remove motor from vehicle.	Team personnel will be briefed about the launch day and the CSL Launch Checklists will be available for everyone to read and understand. Appropriate PPE will be worn when recovering the rocket.	1	3	3
LP.5	Rocket Is Dropped When Carried to Launch Pad	Uneven ground, not enough team members holding rocket	Head injuries, feet injuries, hand injuries	3	3	9	Understanding launch procedures, wearing appropriate PPE including closed-toed shoes and long pants, always watching vehicle during transportation to launch pad	Team personnel need to be aware of their surroundings. Appropriate PPE will be worn during transportation of the rocket. The CSL Launch Checklist will verify transportation and assembly procedures.	1	2	2
LP.6	Downed Power Lines	Rocket lands where there is an excess of downed power lines	Electrocution, death	3	4	12	The launch site needs to be in accordance with NAR regulations. Team personnel will not attempt to recover vehicle if it lands in power lines. Communication with the police and power company will be necessary.	Team personnel need to be aware of the surroundings especially when recovering the vehicle. The RSO will allow recovery if it is safe to do so. The CSL Launch Checklist verifies recovery procedures.	1	4	4

LP.7	Hypothermia	Body temperature drops very low during extended time outside in low temperatures	Shivering, drowsiness, weakness, possible hospitalization	2	4	8	Team personnel will wear appropriate PPE such as long pants, long sleeves, closed-toed shoes, hats, gloves, and a winter coat if cold temperature at launch site.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel of the weather for launch day and what to bring. This is verified by the CSL Launch Checklist.	1	4	4
LP.8	Heatstroke	Body overheats during extended times outside in hot temperatures	Brain dysfunction, dizziness, headache, nausea, weakness	2	3	6	Team personnel will be reminded to bring plenty of water during launch operations, especially if the weather is very warm.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel of the weather for launch day and what to bring. This is verified by the CSL Launch Checklist.	1	3	3
LP.9	Injury from Navigating Terrain	Large divots or rocks in ground, poison ivy	Irritation, rash, ankle injury, tripping, falling	4	2	8	Understanding launch procedures, wearing appropriate PPE including closed-toed shoes and long pants.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel of the terrain of the launch site and what to wear. This is required by the CSL Launch Checklist.	1	2	2
LP.10	Dehydration	Not drinking enough water during launch	Dizziness, headache, exhaustion, hospitalization	4	2	8	Team personnel will be reminded to bring plenty of water during launch operations, especially if the weather is very warm.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel of the weather for launch day and what to bring. This is	1	2	2

								required for the CSL Launch Checklist.			
LP.11	Premature Ignition	Improper installation of motor, not following launch procedures	Serious injury, burns, damage to rocket and team personnel	3	4	12	The RSO is the only person qualified to handle motors and energetics at the launch site. Team personnel is required to wear proper PPE during launch procedures.	The CSL Launch Checklist states the RSO is the only person qualified to handle energetics and is responsible for installing the motor. Proper PPE will be worn and will be a safe distance away from launch pad.	1	3	3
LP.12	Allergies Present at Launch Site	Seasonal allergies to pollen or grass	Severe allergic reactions, watery eyes, blowing nose, sneezing	2	2	4	Team personnel will be reminded that the launch site is outdoors, and allergic reactions may occur. If a team member has an allergy, the Team Lead and CSO must be aware.	The CSO and Launch Officer will conduct a Launch Rehearsal warning team personnel of the weather and potential allergies present at the launch site. This is required for the CSL Launch Checklist.	1	2	2

LP.13	Bite/Sting from Insect	Exposure to wildlife in launch field	Rash, itchiness, burns	2	2	4	Team personnel will be reminded that the launch site is outdoors, and allergic reactions may occur. If a team member has an allergy, the Team Lead and CSO must be aware.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel of the weather, potential allergies, and wildlife present at launch site. This is required for the CSL Launch Checklist.	1	2	2
LP.14	Contact with Shrapnel during Launch	Falling debris from rocket harming team personnel during flight	Serious head and appendage injuries, possible hospitalization	4	4	16	Appropriate PPE must be worn during launch sequences including eye protection, nitrile gloves, closed-toed shoes, and long pants. Team personnel must be aware of surroundings during launch.	The CSL Launch Checklist ensures team personnel will wear appropriate PPE, stay at a safe distance from launch pad, and wait until RSO says it's safe to recover vehicle.	1	4	4
LP.15	Excessive Amount of Walking to Recover Vehicle	Rocket lands far away from launch site	Leg pain, shin splints, twisted ankles	5	1	5	The rocket is equipped with GPS and team personnel are required to wear proper PPE such as comfortable closed-toed shoes and long pants during launches.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel to wear proper PPE for recovery of the vehicle. This is required by the CSL Launch Checklist.	2	1	2
LP.16	Live Wire Contact	Improper assembly and handling of payload, avionics bay,	Burns, skin irritation, electrocution	3	4	12	Appropriate PPE must be worn during launch sequences including eye protection, nitrile gloves, closed-toed shoes, and long pants.	The CSL Launch Checklist states the NAR Team Mentor is the only person qualified to handle energetics and is responsible for setting up	1	4	4

		or recovery systems						the ignitors. Proper PPE will be worn.			
LP.17	Team members are distracted during launch sequence	Lack of awareness, not following launch checklist	Personnel not in correct places during launch, miscommunications	3	3	9	Team personnel have signed a safety contract ensuring to follow all safety rules during launch from the CSO, Launch Officer, and RSO.	The CSO and Launch Officer will conduct Launch Rehearsal warning team personnel to wear proper PPE and the high risk-high reward of high-power rocketry.	1	3	3

5.9. Failure Modes and Effect Analysis

Table 5.9.1. *Hazards of the Rocket Structure Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
RS.1	Airframe failure during launch	Rocket is dropped, harsh impact during landing sequence	Damage to rocket airframe and potentially internal electronics inside	1	3	3	The airframe material will be thoroughly researched to make sure it is of high quality to withstand force of impact.	The airframe will be bought from a trusted vendor to ensure good quality. Analysis of the airframe will be conducted to ensure it will withstand force applied.	1	2	2

RS.2	Airframe failure during construction	Team personnel drills too many holes into tube, airframe cracks under an increase in pressure	Damage to rocket airframe which results in an increase in budget	2	2	4	The airframe material will be thoroughly researched to make sure it is of high quality to withstand the force of impact. Multiple team members will be present during construction to ensure there are no extra holes drilled into airframe.	The airframe will be bought from a trusted vendor to ensure good quality. Analysis of the airframe will be conducted to ensure it will withstand force applied.	1	2	2
RS.3	Centering ring failure	Misalignment between fins and airframe, improper manufacturing technique	Motor is not aligned inside the motor tube, mass imbalance, loss of stability, flight path is not controlled	3	3	9	The centering rings will be manufactured using a high strength material to ensure cracking and failure will not occur. Stress analysis will ensure the design can withstand the stress of the launch.	The centering rings will be installed correctly to ensure alignment of the motor tube and other components. FEA analysis will ensure that the centering ring will be able to withstand the maximum thrust of the motor.	1	4	4
RS.4	Motor retention failure	Excessive stress within motor retention attachment points or threads	Motor ejection, mass imbalance, loss of stability	4	4	16	The motor retention assembly will be designed to withstand the stress of the launch with a reasonable factor of safety.	The motor retention will be inspected by the CSO, LO, and RSO prior to each flight. Analysis of the motor retention subsystem will ensure it will be able to withstand the maximum thrust of the motor.	2	3	6

RS.5	Nose Cone failure assembly	The 3D portions of the nose cone my break due to rough handling or dropping	Affects the structural integrity of the nose cone and may potentially affect the rocket's aerodynamics	2	3	6	The nose cone will be designed with a fiberglass outer shell to take the brunt of the stresses acting on it and add rigidity to the design.	The nose cone will be inspected before and after each launch to check for crack propagation to determine its safety for reuse. Analysis of the nose cone will ensure it won't fail upon impact.	1	2	2
RS.6	Nose Cone failure during launch	The rocket lands so that the nose cone takes a large amount of force on landing causing it to break.	Damage to the forward section of the rocket and possible damage to the payload.	3	3	9	The nose cone assembly will be made to withstand potential hard landing forces.	The nose cone assembly will have mechanical design analysis performed on the selected design to verify it can withstand forces applied.	1	3	3
RS.7	Shock Chord mount failure during launch	The blast from the black powder charges causes the shock cord mount to fail	The nosecone detaches from the body of the rocket and the rocket does not land safely	3	3	9	The shock chord mount subsystem will be thoroughly researched to make sure it will not fail during launch.	The shock chord mount subsystem will be tested prior to launch to make sure it does not fail during launch. Analysis of the shock cord mount will verify it can withstand forces of black powder charges.	1	3	3

RS.8	Tail cone is deformed	The tail cone could be warped or deformed by heat from motor burn.	Poor thrust generation during launch, and non-uniform drag around the rocket body.	2	3	6	Before and after test and competition launches, the tail cone will be inspected for proper geometry and any warping.	The CE and Launch Officer will verify integrity of the tail cone and its attachment before and after all flights, ensuring proper action is taken if necessary.	1	3	3
RS.9	Tail cone retention fails.	Stripped threads, fractured fasteners, or damaged tail cone fastening points.	Uncertain flight or to the tail cone and motor reload falling from the airframe.	3	4	12	Before and after test and competition launches, tail cone fasteners and attachment points will be inspected for cracks or deformation.	The CE and Launch Officer will verify the integrity of the tail cone and its attachment before and after all flights, ensuring proper action is taken if necessary. Analysis will be performed to verify tail cone can withstand maximum thrust of the motor.	1	4	4
RS.10	Tail cone damaged during flight or test flights.	Tail cone could be cracked, deformed, or otherwise damaged during landing impact.	A damaged tail cone could affect future launch performance or cause future damage if unmanaged.	3	3	9	Before and after test and competition launches, the tail cone will be inspected for cracks or deformation.	The CE and Launch Officer will verify the integrity of the tail cone and its attachment before and after all flights, ensuring proper action is taken if necessary. Analysis will be performed to verify tail cone can withstand maximum thrust of the motor.	2	2	4

RS.11	Camera mount is damaged	The camera mount is cracked or damaged during flight	Mass imbalance, loss of stability, flight path is not controlled, components falling out of airframe	3	2	6	Before and after test and competition launches, the camera mount will be inspected for cracks or other damages	The CE and Launch Officer will verify the integrity of the camera assembly before and after all flights, ensuring proper action is taken if necessary. Analysis will be performed to verify if design can withstand forces during flight.	1	2	2
RS.12	Screw is loose connecting components to airframe	Screws used to secure the airframe, shock cord mount, fins, centering rings, and tail cone becomes loose	Mass imbalance, loss of stability, flight path is not controlled, components falling out of airframe	4	4	16	Prior to launch, each component of the rocket will be inspected to ensure tight connection of the screws. If a screw is loose, team personnel will ensure it is tightened.	The CSL Launch Checklist verifies final assembly as well as inspection and testing procedures. Analysis will be performed to verify the screws holding subsystems in place can withstand forces applied.	1	3	3
RS.13	Fins Incorrectly Oriented	Misalignment between fins and airframe, improper manufacturing technique	Fins are not aligned, mass imbalance, loss of stability, flight path is is not controlled	3	4	12	The CE and Fin Design Lead will ensure the fins and slots on centering rings are correctly oriented using proper manufacturing techniques.	The CSL Launch Checklist verifies final assembly as well as inspection and testing procedures. Analysis will be performed to verify the fins can withstand the forces applied during flight.	1	3	3

Table 5.9.2. Hazards involving Recovery Systems Evaluated by the Defined Risk Assessment Code.

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
R.1	The wrong altitude is read by the altimeter.	Pressure difference between outside and inside of rocket	Late or early drogue and main parachute deployment. Possibility of injury or death to bystanders.	3	4	12	The avionics section will be designed with properly sized vent hole large enough to equalize the pressure inside the rocket with atmospheric pressure.	Calculations and actual measurements for vent hole sizes will be checked by a second person to ensure accuracy. The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	2	3	6
R.2	Ejection charges fail to ignite.	Altimeter loses power due to loose connections. The deployment signal is not sent to ignitor.	Parachutes fail to deploy and rocket nosedives into the ground. Possible injury or death to bystanders.	4	4	16	Redundant altimeters with redundant batteries will be used. Pull tests will be conducted on all wires before every launch.	Continuity will be verified on both altimeters by audio cue after the rocket is placed on the launch rail. The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	3	2	6

R.3	Ejection charge fails to separate rocket.	Not enough black powder in ejection charge.	Parachutes fail to deploy and rocket nosedives into the ground. Possible injury or death to bystanders.	4	4	16	Ground testing and having the NAR Affiliated mentor double check the amount of black powder calculated to be needed.	Ground testing will allow for safely checks so that the black powder charges will behave as expected. The CSL Launch Checklist ensures a pop test will take place to test the amount of black powder.	3	2	6
R.4	Parachute or shock cords become damaged	Parachute is burnt or torn from deployment or packing. Shock Cords snap in deployment.	Coefficient of drag decreases. Parachute cannot deploy correctly. Rocket falls faster than anticipated.	3	4	12	Parachute and Shock cords will be checked before packing into the rocket and a flame blanket will be used to protect them from the black powder charges.	Packing job will be verified by the NAR Affiliated mentor. The CSL Launch Checklist ensures proper parachute folding techniques.	1	4	4
R.5	Shock Cords tangle in deployment	Parachute is not properly folded and stored in the rocket.	Parachute is unable to open correctly.	4	3	12	The team member in charge of folding the parachute will be properly taught how to do it by the NAR Team Mentor and through the CSL Launch Checklist.	Packing job will be verified by the NAR Affiliated mentor. The CSL Launch Checklist ensures proper parachute folding techniques.	1	3	3

R.6	Zippering	Shock cords tear at airframe in deployment due to the force when the lines become taut.	Main rocket body is damaged. Damage can range from superficial to crucial.	3	3	9	Airframe will be properly reinforced, and the shock cords will be designed to help diminish some of the force at lines taut.	Calculations will be performed to find the risk factor and show how it is decreased due to mitigation effort. The CSL Launch Checklist ensures inspections for parachutes and shock cords.	1	3	3
R.7	GPS does not transmit location to handheld receiver after landing	Power lost to GPS or improperly configured GPS.	Possible significant delay in locating rocket after landing.	3	3	9	Launch procedures will be followed which ensures wire pull tests and proper GPS configuration.	Proper function of GPS will be verified before launch. The CSL Launch Checklist ensures proper assembly, testing, and assembly of the avionics and recovery subsystem.	1	3	3
R.8	Black powder ejection charge fails to ignite during flight.	Loose wire connection in avionics bay during flight.	Live charge in rocket after landing which can explode during recovery procedures. Injury or death.	4	4	16	Pull tests will be conducted on wires during avionics assembly to ensure proper electrical connections.	Verification of continuity on all ejection events will be verified through beeping of altimeters while on launch rail. The CSL Launch Checklist ensures the inspection of the recovery subsystem.	1	4	4
R.9	Main Parachute fails to deploy	Improper main parachute installation	Uncontrolled rocket descent, becomes a projectile, injury or death	4	4	16	The main parachute will be folded accurately and correctly according to the CSL Launch Checklist. The NAR Team Mentor will inspect parachutes prior to launch.	The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	1	3	3

R.10	Drogue Parachute fails to deploy	Improper drogue parachute installation	Uncontrolled rocket descent, becomes a projectile, injury or death	4	4	16	The drogue parachute will be folded accurately and correctly according to the CSL Launch Checklist. The NAR Team Mentor will inspect parachutes prior to launch.	The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	1	3	3
R.11	Rocket Surpasses Calculated Drift Radius	Parachutes are installed incorrectly, calculation error	Longer recovery time, potential for rocket to land	3	3	9	The NAR Team Mentor will inspect parachutes prior to launch. Calculations for drift radius will be checked and confirmed.	The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	1	2	2
R.12	Shear pin failure	Ejection of recovery system fails incorrect number of shear pins	No airframe separation or separation too soon, vehicle falls at high speed	3	4	12	Testing of the recovery system will ensure the vehicle has the correct amount of shear pins.	The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	1	4	4

Table 5.9.3. *Hazards involving the Airbrake System Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk

AB.1	Top motor retainer system fails.	Design or manufacturing defect.	Rogue launch and/or motor ejection.	3	4	12	Ensure structural integrity of the components before launch in addition to preforming calculations to minimize design overlooks.	Analysis will be documented in engineering project reports, and the physical system will be inspected by the RSO as required by the CSL Launch Checklist.	1	4	4
AB.2	Airbrakes fail to retract.	Mechanical or electrical design or manufacturing defect.	The recovery system becomes entangled, and the rocket becomes ballistic.	4	4	16	A redundant system will be built in the system to ensure the brakes will be retracted after apogee. This system will be powered by an extra battery and on a separate PCB.	Analysis will be documented in engineering project reports. Faculty advisors, team leader, CE, CSO will ensure no missteps are taken during development of this system.	1	4	4
AB.3	Internal damage to components.	Lack of tightening nuts and bolts.	Faulty braking system which can hinder the recovery system if brakes do not retract.	3	3	9	The RSO will ensure all nuts and bolts are tightened down with a certain torque prior to launch.	The tightening of these nuts and bolts will be documented. The CSL Launch Checklist verifies final assembly and inspection prior to launch.	1	3	3
AB.4	Airbrake control system cannot properly augment the rocket's altitude	Undiagnosed sensor issues, hardware limitations, or software errors	Rocket cannot actively affect its altitude.	3	3	9	The control system will be demonstrated and improved over the course of two flights before the competition launch. If the airbrakes must be abandoned, a mass equivalent will be used.	The CE and Team Lead will evaluate the progress of the airbrake control solution and monitor the system's behavior during launches.	1	3	3

AB.5	Failure of mechanical component	Failure to properly predict/model loads	The system breaks and less than desirable drag is achieved.	2	4	8	CSL will use proper load testing, practical testing, and modeling to test and analyze failure of mechanical components.	The first test flight will prove successful where the airbrakes were fully deployed and did not fail. Proper analysis will be used to verify model loads.	1	4	4
AB.6	Sensor breaks	Poor mounting or blunt force	Bad data is taken into the decision logic, and the wrong apogee is predicted.	3	3	9	A design algorithm will be developed that can detect a sensor fault. This will be properly integrated into the airbrake control system.	The design algorithm will run with correct sensor, and broken sensor. The CSL Launch Checklist ensures the airbrake control system is properly tested and inspected prior to launch.	1	3	3
AB.7	Flow separates past the airbrakes	Poor modeling of flow during design phase	Fins cannot affect the stability of the rocket for better or worse.	3	4	12	Flaps will be designed smaller to ensure enough air is flowing to create a resting force.	Thorough analysis through CFD and practical testing is required to ensure modeling of airbrake system is correct. The CSL Launch Checklist requires proper testing and inspection prior to launch.	1	4	4
AB.8	Motor wire connection comes loose	Rocket induced vibrations	The airbrakes do not actuate	3	4	12	The solder connections for the airbrake motor control system will be checked to make sure they are solid and working correctly. Wires will be pulled slightly after soldering.	The CSL Launch Checklist requires final assembly, testing, and inspection procedures to ensure system is ready for launch.	1	3	3

AB.9	Airbrakes stall	Electrical brown out	Overcurrent to the system and mechanical system breaks itself	4	4	16	Wires used for the system will be rated for high amperage to ensure proper function.	Testing to see if high amperage will blow the system is required. The CSL Launch Checklist requires testing and inspection procedures prior to launch.	1	4	4
AB.10	Electrical Brown out	Overload of current in system	The system will restart all data will be lost in this event. The rotary encoder will be an unknown position.	4	4	16	Wires used for the system will be rated for high amperage to ensure proper function.	Testing to see if high amperage will blow the system is required. The CSL Launch Checklist requires testing and inspection procedures prior to launch.	1	4	4
AB.11	No data retrieved from rocket after launch.	Data from launch is lost	Loose pin connections	3	3	9	Solid connections will be used, and an external flash memory chip will be added to the system to ensure data is saved.	Testing the system to simulate failure and ensure the data is retrieved from launch is required. The CSL Launch Checklist requires testing and inspection procedures prior to launch.	1	3	3

Table 5.9.4. *Hazards involving the Payload System Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
PS.1	Radio transmitter comes loose during flight.	Improperly installed or excessive vibration.	Large unsecured mass in the nose of the rocket could damage other components or cause rocket instability.	2	3	6	Testing will be performed to ensure that the transmitter will not rattle loose.	During assembly, the transmitter will be double checked so that it is fastened securely to the payload. The CSL Launch Checklist ensures proper inspection and testing of the payload.	1	3	3

PS.2	Radio transmitter transmits at the wrong time.	Radio transmitter equipment malfunction.	Violates FCC and NASA guidelines and could interfere with another rocket's transmissions or other 2m radio traffic.	2	3	6	The transmitters will be tested rigorously in many conditions which will reveal any equipment issues.	Any errors discovered during testing will be recorded and the equipment will be inspected. The CSL Launch Checklist ensures proper inspection and testing of the payload.	1	3	3
PS.3	Radio transmitter transmits at the wrong frequency.	Radio transmitter equipment malfunction.	Violates FCC guidelines and could interfere with important 2m radio traffic.	2	3	6	The transmitters will be tested rigorously in many conditions which will reveal any equipment issues.	Any errors discovered during testing will be recorded and the equipment will be inspected. The CSL Launch Checklist ensures proper inspection and testing of the payload.	1	2	2
PS.4	Battery explosion during lab or field testing.	Battery lifespan, improper charging, short circuiting, overheating, and excessive vibration all contribute to battery failure.	Varying levels of damage to humans and property.	3	4	12	NiCd batteries will be used instead of LiPo for increased safety and only batteries in good condition will be used.	Batteries will be verified to not be old, damaged, or likely to overheat. The CSL Launch Checklist ensures battery checks and inspections prior to launch.	1	3	3

PS.5	Battery explosion during rocket flight.	Battery lifespan, improper charging, short circuiting, overheating, and excessive vibration all contribute to battery failure.	Major damage to rocket could include damage to many other components and cause major rocket instability.	3	4	12	NiCd batteries will be used instead of LiPo for increased safety and only batteries in good condition will be used.	Batteries will be verified to not be old, damaged, or likely to overheat prior to assembly and flight. The CSL Launch Checklist ensures battery checks and inspections prior to launch.	1	3	3
PS.6	Wires or soldering joints come loose during flight.	Excessive in-flight vibration.	Possible payload failure, resulting in transmission of incorrect data or no transmission at all.	3	3	9	Testing will be performed to find weak points ahead of time.	Connections will be verified to be intact before final payload assembly. The CSL Launch Checklist ensures the payload will be inspected and tested prior to launch.	1	3	3
PS.7	Sensor failure or memory storage failure.	Malfunction due to vibration or factory defect.	Possible payload failure, resulting in transmission of incorrect data or no transmission at all.	2	3	6	Testing will be performed to find device defects or durability issues ahead of time.	Only devices that have been tested before will be used for the final flight. The CSL Launch Checklist ensures the payload will be inspected and tested prior to launch.	1	3	3

PS.8	Radio transmits for too long.	Software fails to stop transmission.	Violates FCC and NASA guidelines and could interfere with another rocket's transmissions or other 2m radio traffic.	3	3	9	Isolated transmitter override system will stop transmissions from occurring after a pre-set time duration. Software will be tested rigorously.	Intentional failure of the main transmission system and ensure that the override system is functional. The CSL Launch Checklist ensures the payload will be inspected and tested prior to launch.	1	3	3

Table 5.9.5. *Hazards of Launch Operations Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
L.1	Incorrect motor installation	Disobedience of the safety launch checklist and TRA procedures	Damage to rocket, motor failure during launch, injury to team personnel	4	4	16	Team members will follow the safety launch checklist. All ignition related hardware will be handled by a licensed professional.	NAR Team Mentor Dave Combs will be responsible for the handling and installation of motors and other energetics. Team personnel will follow the NAR guidelines and the CSL Launch Checklist.	2	3	6

L.2	Team personnel or bystanders coming too close to launch pad	Disobedience of the safety launch checklist and NAR safety parameters	Serious injury, burns, possible death	3	4	12	The CSO, LO, and RSO will make sure everyone at the launch site stays at the minimum distance away per NAR regulations.	The RSO will have the final say to determine a safe and successful launch. Team personnel will follow NAR guidelines and CSL Launch Checklist.	1	4	4
L.3	Improper black powder handling	Disobedience of the safety launch checklist and TRA procedures	Can cause recovery system to not deploy	3	4	12	Team members will follow the safety launch checklist. All ignition related hardware will be handled by a licensed professional.	NAR Team Mentor Dave Combs will be responsible for the handling and installation of motors and other energetics. Team personnel will follow NAR guidelines and the CSL Launch Checklist.	1	4	4
L.4	Ignition failure	Improper ignition placement, dysfunctional igniter.	Failure to launch.	4	4	16	All ignition related hardware will be handled by a licensed professional. The pad will not be approached for five minutes after an ignition failure.	NAR Team Mentor Dave Combs will be responsible for the handling and installation of motors and other energetics. Team personnel will follow NAR guidelines and the CSL Launch Checklist.	2	3	6
L.5	Rocket is lost after launch	Wind creates parachute to have a high drift, visibility is low	Loss of rocket and hindrance in the completion of the project	3	3	9	The team will follow NAR guidelines to not launch rocket if wind speeds are greater than 20 mph. If rocket crashes, team members will clean up the area and not leave any debris behind.	Team mentor Dave Combs and the CSO will be held responsible for making sure the weather is clear for launch. Team personnel will follow the NAR guidelines and the CSL Launch Checklist.	1	3	3

L.6	Rocket does not exit launch rail	Launch rail is not clean enough to allow the rocket to escape the pad. Rocket may be too heavy.	Motor burns in place, possibly damaging launch equipment and aft rocket assembly.	3	3	9	Clean rail with scotch Brite pad before loading the rocket. Remove unnecessary ballast.	The Launch Officer will verify that the rail is clean before launch. The thrust-to-weight ratio will be verified by simulation. Team personnel will follow the NAR guidelines and the CSL Launch Checklist.	1	3	3

Table 5.9.6. *Hazards of the Rocket during Flight Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk

FD.1	Weathercocking	Static stability margin is too large.	Rocket does not recover vertical flight, causing the recovery device to deploy at high speed or not at all.	3	4	12	Stability simulation will be conducted alongside hand calculations.	CG will be verified by balancing the launch vehicle once assembled, CG location estimated by simulations will be checked. CP estimation reliability will be evaluated based on this perceived simulation integrity.	2	3	6
FD.2	Rocket uncontrollability	Static stability margin may be too small. Airbrake flap may be stuck or broken.	Rocket loops, oscillates wildly, and may not return to a vertical flight path.	4	4	16	Stability simulation will be conducted alongside hand calculations. Ballast will be added as needed. Airbrakes will be inspected before each launch.	CG will be verified by balancing the launch vehicle once assembled, CG location estimated by simulations will be checked. CP estimation reliability will be evaluated based on this perceived simulation integrity.	3	2	6
FD.3	Rocket pulls toward onlookers upon rail exit.	Launch rail may be too far from vertical. Rail buttons may have fallen off or degraded.	Rocket leaves the launch pad in an unsafe direction, endangering personnel, vehicles, and equipment.	4	4	16	Rail buttons will be glued in place. Launch rail will be pointed within 15 degrees of vertical, with consideration given to the direction and strength of the wind.	The RSO will inspect both the attachment of the rail buttons and the angle of the launch rail. The CSL Launch Checklist ensures proper inspection and setup of the launch pad.	2	3	6

FD.4	Fin flutter	High aerodynamic forces coupled with poor fin construction can cause fin flutter.	Rocket oscillates uncontrollably, airbrake control system is ineffective, and the apogee will be negatively impacted.	3	4	12	Hand calculations will be conducted to ensure that the velocity at which the fin flutter occurs will be higher than the maximum simulated launch velocity.	The RSO, CSO, and Launch Officer will inspect the fin mounting method before launch. The Fin Design Lead will verify the fin flutter velocity.	1	4	4
FD.5	Drag separation	High aerodynamic forces focused on the aft end of the rocket that bend the airframe.	Forces cause vibrations and flexure in the airframe, possibly separating the rocket prematurely in its flight.	2	4	8	Launch angle will be set within 15 degrees of vertical to reduce unexpected pressure drag early in the flight, and the mitigations applied to ensuring the stability of the rocket will continue to be informative in this area.	The RSO will inspect the launch rail angle. The Launch Officer and CE will inspect the separation points on the rocket before launch. The CSL Launch Checklist requires inspection of the launch pad setup.	1	3	3
FD.6	Flight Path Interference	Path of rocket during flight is obstructed by wildlife, aircraft, or manmade objects	Change in the rocket's trajectory potentially harming team personnel and bystanders	3	4	12	The launch site will be an empty corn field with no manmade objects present. The RSO will use an aircraft radar to observe any potential aircraft in the area.	The RSO, CSO, and Launch Officer will inspect the launch site and ensure that no manmade objects, aircraft, or wildlife is in the area as required by the CSL Launch Checklist.	1	4	4

5.10. Environmental Risks

Table 5.10.1. *Hazards of how the Rocket can Affect the Environment Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
RE.1	Waste pollution	Improper disposal of trash and excessive amounts of unorganized material.	Uncleanliness, damage to environment	2	2	4	Team members will be briefed on proper waste disposal practices, and bins for specific product disposal will be placed in the work area.	Individual team leads will ensure that their teams are properly disposing of materials. The CSL Launch Checklist ensures proper disposal of waste during launches.	1	2	2
RE.2	Propellant pollution	Pollution caused by the combustion of the rocket propellant.	Hazardous emissions and fumes	2	3	6	Motors will be properly ignited and only when necessary for tests and launches.	The CSO will understand ignition procedures and will collaborate with the RSO and NAR Team Mentor to ensure safe ignition.	1	2	2
RE.3	Battery acid leakage	Puncture and damage to batteries and casings.	Hazardous chemical exposure, risk of fire, and damage to surrounding vehicle airframe.	3	3	9	Batteries will be properly stored and routinely checked before and after launches.	The CSO, Launch Officer, and RSO will complete battery inspections before and after launch. The CSL Launch Checklist requires proper inspection prior and after launch.	2	2	4

RE.4	Paint and adhesives	Use of paint and adhesives in the construction of the rocket. Improper use, application, and storage of these elements.	Hazardous chemical exposure from spills, hazardous fumes	4	3	12	Paint and adhesives will be stored properly. Proper PPE will be worn, and careful application techniques will be utilized.	The CSO will ensure team personnel understand proper PPE use and adhesive application. The team Safety Handbook will be available to all team members.	2	3	6
RE.5	Noise pollution	Use of power equipment, motor ignition at launches	Hearing damage or loss	2	3	6	Proper PPE will be worn while using power equipment. Equipment will only be used when needed.	The team will understand proper PPE use when operating equipment or conducting launches. The CSO will verify proper PPE use at launches.	1	2	2
RE.6	Wildlife habitat damage	Rocket launches and testing near areas with significant amounts of wildlife.	Damage to rocket airframe and animals. Littering of rocket pieces. Impact of airframe with wildlife and habitats.	2	3	6	Sites will be surveyed prior to launch and points of concern will be identified. All components will be firmly attached to the body.	The CSL Launch Checklist requires team personnel to clean the launch site after launch. Team members will report any wildlife or environmental related issues to the CSO, Launch Officer, and RSO.	2	1	2

RE.7	Wildlife Ingestion of Trash	Litter left from launch site is eaten by wildlife in the area	Damage to wildlife population, infection, poisoning, choking	2	4	8	Anything brought to the launch site will be picked up and the area will be cleaned. Trash bags will be brought for any team personnel waste.	The CSL Launch Checklist requires team personnel to clean the launch site after launch. Team members will report any wildlife or environmental related issues to the CSO, Launch Officer, and RSO.	1	3	3
RE.8	Impact landing	Recovery system fails	Damage to soil, vegetation, wildlife habitat	2	3	6	The recovery lead along with the CSO, Launch Officer, and RSO will ensure recovery system is working and will deploy during launch sequence.	The CSO, Launch Officer, and RSO will ensure recovery system deploys correctly prior to launch. The CSL Launch Checklist ensures proper inspection of the recovery system.	1	3	3
RE.9	Rocket hits spectators or a general crowd	Recovery system fails, spectators not aware of surroundings	Serious injury, death	3	4	12	The CSO, Launch Officer, and RSO will make sure everyone at the launch site stays at the minimum distance away per NAR regulations. All team members will be briefed on situations where recovery system fails.	The CSO, Launch Officer, and RSO will ensure team members and spectators are aware of NAR regulations at launch sites.	1	4	4

Table 5.10.2. *Hazards of how the Environment can Affect the Rocket Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk

ER.1	Extreme Temperatures	Heat wave or cold front	Damage to electrical equipment leading to reduced performance or functionality	2	2	4	Weather conditions will be monitored prior to flights and outdoor tests. Electronics will be stored in shaded or cooled areas and will only be installed just before launch.	The recovery lead and payload team will ensure electronics remain functional during high/low temperature conditions and will halt launch activities if any failures occur.	2	1	2
ER.2	Humidity	Moisture infusing into water sensitive components	Damage to sensitive electronics, motor propellants, adhesives, and surface treatments	2	2	4	The weather will be monitored before flights and outdoor tests. The team will ensure storage areas have reasonable humidity levels.	The CSO will coordinate with the faculty advisors to ensure that the motor propellant is undamaged. Performance tests will be performed to ensure electronics are working properly.	1	2	2
ER.3	Wind	High winds during descent	Larger drift distances, erratic flight path, instability	3	3	9	Weather conditions will be monitored prior to flights and outdoor tests. The team will follow NAR guidelines for launches.	The CSO, LO, and RSO will monitor weather before launches. Team members will have severe weather alert systems on their phones to warn if any threat will impede launch operations according to NAR HPRSC.	2	3	6

ER.4	Fog	Poor weather conditions	Low visibility, difficult retrieval of vehicle, and potential danger of vehicle impacting observers	2	3	6	Weather conditions will be monitored before launches. In any case where there is a risk for fog, there will be a delay until fog risk has decreased.	The CSO, LO, and RSO will monitor weather before launches. Team members will have severe weather alert systems on their phones to warn if any threat will impede launch operations according to NAR HPRSC.	2	2	4
ER.5	Rain, Hail, & Storms	Water damage to rocket, hail damage, lightning	Damage to vehicle airframe, onboard electronic systems	3	3	9	Team members will use weather apps to monitor and receive alerts for severe weather. All outdoor activities will be postponed accordingly.	The CSO, LO, and RSO will monitor weather before launches. Team members will have severe weather alert systems on their phones to warn if any threat will impede launch operations according to NAR HPRSC.	1	2	2
ER.6	Tornadoes	Seasonal weather patterns	Extreme risk to team members, extreme damage to buildings and the rocket itself	3	4	12	Team members will use weather apps to monitor and receive alerts for severe weather. All outdoor activities will be postponed accordingly. The team will follow the university's emergency plan for tornado warnings.	The CSO, LO, and RSO will monitor weather before launches and team activities. Team members will have severe weather alert systems on their phones to warn if any threat will impede launch operations according to NAR HPRSC.	2	2	4

ER.7	Fire	Dry grass, improper motor use	Burns to team personnel, damage to the airframe and electronics, potential for small brush fires to escalate into major wildfires	3	3	9	Prior to launches, the surrounding area will be inspected for dry grass and brush. Heat sources will be kept clear of the launch zone before flights.	The CSO, LO, and RSO will do a final check and observe the conditions on the CSL Launch Checklist prior to launching.	1	2	2
ER.8	Terrain	Launch site selection, bodies of water, uneven ground	Difficult to retrieve rocket, tripping and falling hazards, potential for airframe or water damage	2	2	4	Prior to launches, the surrounding area will be assessed for challenging terrain and cleared of major obstacles. The launch site and direction will be adjusted as needed.	The RSO will make sure team members are aware of the surrounding terrain prior to launch. The CSO will ensure team members have the appropriate attire and PPE for the recovery of the rocket.	1	2	2
ER.9	Tall structures	Trees, buildings, powerlines, and other man-made structures	Damage to the airframe upon impact and potential challenges in recovery	3	3	9	Prior to launch, the surrounding area will be assessed for tall structures and obstacles. Adjustments to the launch site and direction will be made if needed.	The RSO and CSO will make sure team members are aware of the surrounding structures and obstacles prior to launch. The CSL Launch Checklist and NAR HPRSC requires the launch site to be free of such structures.	1	3	3

ER.10	UV Light	Excessive exposure to sunlight	Skin damage, sunburns	1	3	3	The UV index will be checked prior to outdoor activities. Sunscreen will be applied to team members.	The Launch Officer will ensure that sunscreen is brought to launch and other team activities if it is deemed necessary.	1	2	2
ER.11	Wildlife Interference	Animals interfere with launch operations	Incorrect launch trajectory, flight interference	2	3	6	The launch area and air space will be carefully inspected prior to launch by the CSO, Launch Officer, and the RSO.	The CSO, LO, and RSO will use the CSL Launch Checklist and NAR HPRSC to ensure of the safety of the launch site.	1	2	2
ER.12	Unstable Ground at Launch Site	Ground where launch pad is placed is unstable or too wet	Incorrect launch trajectory, unpredictable launch angle	3	3	9	The launch site will be carefully inspected prior to launch by the CSO, Launch Officer, and the RSO ensure a proper launch can take place.	The NAR HPRSC and the CSL Launch Checklist require careful inspection and confirmation of launch site and air space.	1	3	3
ER.13	Snow	Cold weather conditions bring snow to launch site	Low visibility, difficult retrieval of vehicle, and potential danger of vehicle impacting observers	3	3	9	If hazardous weather conditions arrive to launch site, the launch will be postponed until conditions are clear.	The NAR HPRSC prohibits launch in low visibility and hazardous weather conditions. The RSO will halt launch operations if there are poor weather conditions.	1	3	3

5.11. Project Risks Analysis

Table 5.11.1. *Hazards that could Affect the Completion of the Project Evaluated by the Defined Risk Assessment Code.*

ID	Hazard	Cause	Effect	Probability	Severity	Risk	Mitigation	Verification	Probability	Severity	Risk
P.1	Motor order shipping is delayed	Poor inventory practices on Aerotech's part and late ordering on CSL's behalf	Fewer to no full-scale flights can be conducted, abbreviated testing schedule.	4	3	12	Motors will be ordered well in advance of project milestones to accommodate long lead times.	A motor order invoice will be sufficient to prove that the order has been placed. Communication with the motor manufacture is required to ensure proper arrival time.	3	2	6
P.2	Launch vehicle mass does not agree with MGA figures	Faulty mass figure bookkeeping	Simulation integrity would be low, contributing to unpredictable flight performance.	3	4	12	Subsystem designers will tabulate the real mass of each element in their system. The CE will conduct a mass properties audit of each subsystem and its associated records.	The CE will ensure that all subsystem MGA tables are updated after auditing. Communication with team personnel will verify if each subsystem mass property is updated.	1	4	4
P.3	Machined parts have poor tolerances	Poor machining practices and invalid SOLIDWORKS designs	Time and material will be lost turning parts down to the proper tolerance.	3	3	9	Detailed engineering drawings and material information will be provided to the machinists.	The CE will verify the integrability of each machined part before manufacturing begins.	1	2	2

P.4	Subscale rocket does not perform successfully	Recovery system failure, airframe failure, improper assembly, and faulty mass distribution	New motor for a second subscale launch must be sourced, repairs or complete redesign may be needed to redistribute mass in the vehicle.	2	3	6	Careful simulation and construction methods will be employed to ensure that the mass distribution will result in stable flight and that the rocket is manufactured in a sound manner.	The CE will verify that the subscale rocket is designed competently and manufactured to specifications. Team personnel will perform analysis to ensure each component is properly designed.	1	3	3
P.5	Rocket takes longer to assemble than the time allotted for launch.	Poor equipment organization, missing crew members, inclement weather, missing equipment, and unclear communication.	Testing and evaluation timeline is pushed back, possibly resulting in cutting a vital test launch.	3	2	6	The rocket and its subsystems will be assembled as completely as possible to make sure the time spent on field is minimal. All launch equipment will be organized by the launch officer.	The Launch Officer, CE, and PM will oversee the assembly of the launch vehicle and the communication surrounding the launch. The Launch Officer will direct on-field operations using the CSL Launch Checklist.	1	2	2

P.6	Subsystems do not fit in the airframe or with each other.	Dimension miscommunication, SOLIDWORKS design errors, and imprecise manufacturing methods	Testing and evaluation timeline is pushed back. Materials may need to be reordered. 3D printing time will increase.	3	3	9	Components fit and finish will be continuously tested using all parts on hand throughout the design process.	CE will verify the fit of each subsystem in the final assembly. The CSL Launch Checklist ensures final assembly procedures.	1	3	3
P.7	Rocket or its subsystems are dropped during transport or storage.	Carelessness and unsafe shop conditions	Rocket airframe and/or subsystems can be damaged, introducing extensive manufacture or repair times.	2	3	6	CSL members will be properly trained in handling the launch vehicle and its components, as well as maintaining a clean, obstruction-free work area.	The CSO will enforce safety regulations. The CSL Launch Checklist ensures that the vehicle is transported carefully to the launch site.	1	2	2

P.8	An assembled motor or motor reload is dropped or otherwise damaged.	Carelessness and unsafe shop conditions	Motor is unfit for launching if fissures are present in the propellant grain. Launch schedule is affected for motor lead times.	3	4	12	The NAR Team Mentor is properly trained and is certified to handle rocket motors.	The NAR Team Mentor will oversee the assembly and storage of the rocket motors. The CSO and Launch Officer will ensure that the motors are handled responsibly in every space.	1	4	4
P.9	Amount of ballast needed in nose cone exceeds space available.	Major design changes or discrepancies in the mass properties figures would necessitate adding more ballast.	Not enough room for the STEMnaut capsule or antenna. The cone would have to be redesigned and re-printed.	3	3	9	Extensive simulation and mass properties planning will indicate the amount of ballast needed and therefore the amount of space needed in the nose cone.	The CE will ensure that the simulations reflect the current nose cone and payload design and will continuously reevaluate the mass growth of the design.	1	3	3
P.10	The CNC machines available to CSL may be out of order.	Machine misuse on the CNC mill, router, or the 3D printers.	Some parts may need to be outsourced or redesigned for a different manufacturing process.	2	3	6	Personal 3D printers will supplement the university 3D print farm as necessary. The CNC machines will only be operated by trained lab technicians to reduce instances of misuse.	The status and availability of all necessary machines will be monitored in advance of any manufacturing undertakings.	1	3	3

P.11	Vital flight computers are damaged.	Improper wiring, catastrophic launch events, or careless storage and handling can damage flight computers.	Parts of the avionics, payload, and recovery systems will not be operable until new computers are sourced.	3	3	9	CSL will store all flight computers safely and will borrow replacement computers as needed from the local WSR club members.	The Launch Officer will oversee the handling of all flight computer hardware. The CSL Launch Checklist ensures proper inspection and handling of avionics, payload, and airbrakes flight computers.	1	2	2
P.12	Team fails to submit any project deliverable before due date.	Improper time management, and inability to understand deliverable requirements could affect ability to submit items.	Team could be penalized or disqualified from the NASA USLI Challenge.	2	4	8	CSL will implement artificial deadlines on deliverables and deliverable items to ensure completion and review before submission to NASA.	Discussions will be held with all relevant CSL personnel when setting/changing artificial deadlines, and a schedule will be created. If these deadlines are not met, the PM and CE will meet to discuss issue delaying deliverable.	1	3	3
P.13	Purchasing exceeds proposed budget limit.	Design changes, improper use of materials, or failing to properly quantify proper materials.	CSL will require additional funding/donations to acquire materials needed to finish the project.	3	2	6	CSL will keep close track of all purchasing requests and inform the team accountant and team leadership if item prices change.	Team accountant will regularly update team records of all purchased materials, giving reports if CSL is over or under budget.	1	2	2

P.14	Inability to follow launch test plan.	Improper time management or failure to adequately prepare for tests.	Proper testing is not conducted and CSL does not have data-verified confidence in their rocket systems.	3	4	12	Create test specifications clearly outlining test safety and performance requirements and have Launch Officer and CSO involved in the planning process.	CE and PM will ensure tests occur as planned and will verify if the results of each test meet validation requirements. The CSL Launch Checklist requires confirmation signatures to move on to the next procedure.	1	4	4
P.15	Miscommunication on project requirements/rules occurs between CSL and NASA.	Improper interpretation of NASA USLI rules, improper monitoring of communication channels, or failing to ask questions.	Team could be penalized for failing to meet requirements or disqualified from the NASA USLI Challenge.	2	4	8	Verify rules that could have multiple interpretations with NASA USLI personnel and team mentor and create deliverable requirement lists.	Keep records of all communication between NASA and CSL, verify deliverable requirements are completed as defined by the 2025 NASA USLI Handbook.	1	3	3
P.16	CSL personnel are unable to attend regular team meetings and miss important information.	Individual CSL member failure to manage time or miscommunication on team meeting expectations.	Team members do not have pertinent information and are restricted from doing satisfactory work.	1	4	4	If a CSL member is unable to attend team meetings, share meeting notes and team updates with them. If any changes to schedule, plans, or design occur, also notify relevant personal effected by said changes.	Keep records of weekly team meetings and system updates and ensure they are available to all team members. Have all team members update the Mass Growth Allowance plan per project deliverable.	1	2	2

P.17	CSL personnel are unable to continue working on NASA USLI competition.	Personal injury, sickness, or other life events.	Rocket subsystem(s) could be left without a dedicated team member, and manpower decreases.	2	3	6	Ensure proper documentation of rocket subsystems and cross team interaction such that no subsystem is understood solely by one person.	Have all subsystem information, including documentation and models, available to all CSL team members. Follow safety measures put in place by the CSO. Ensure team members have proper rest and resources.	1	2	2

6. Project Plan

6.1 Changes from PDR Project Plan

The Mass Control Plan, Work Breakdown Structure, and Test Launch plan as described in the PDR have not been changed and can be referenced in the PDR. The GANTT chart that CSL uses to track project deliverables is given below and has been updated to match team progress.

Cedarville University NASA Student Launch 2024-25 Plan

CSL: Project *ELIJAH* PROJECT NAME — **8/14/2023** START DATE — **05/03/2024** END DATE

Task	Start Date	End Date	Progress	8/12/2024	8/19/2024	8/26/2024	9/2/2024	9/9/2024	9/16/2024	9/23/2024	9/30/2024	10/7/2024	10/14/2024	10/21/2024	10/28/2024	11/4/2024	11/11/2024	11/18/2024	11/25/2024	12/2/2024	12/9/2024	12/16/2024	12/23/2024	12/30/2024	1/6/2025	1/13/2025	1/20/2025	1/27/2025	2/3/2025	2/10/2025	2/17/2025	2/24/2025	3/3/2025	3/10/2025	3/17/2025	3/24/2025	3/31/2025	4/7/2025	4/14/2025	4/21/2025	4/28/2025	5/5/2025	5/12/2025
NASA Deliverables																																											
Student Launch Proposal	8/14/2024	9/11/2024	100%																																								
Preliminary Design Review (PDR)	10/3/2024	10/28/2024	100%																																								
PDR Teleconferences	11/4/2024	11/26/2024	100%																																								
Gateway Registration	11/26/2024	11/29/2024	100%																																								
Huntsville Roster (for in person teams)	11/30/2024	12/16/2024	N/A																																								
Critical Design Review (CDR)	11/30/2024	1/8/2025	100%																																								
Subscale Flight	10/7/2024	1/8/2025	100%																																								
CDR Teleconferences	1/15/2025	2/6/2025	--																																								
Team Photos	2/6/2025	2/10/2025	--																																								
Flight Readiness Review (FRR)	2/6/2025	3/17/2025	--																																								
Vehicle Demonstration Flight	1/8/2025	3/17/2025	--																																								
Payload Demonstration Flight	3/17/2025	4/14/2025	--																																								
FRR Teleconferences	3/24/2025	4/11/2025	--																																								
Launch Window	4/5/2025	5/4/2025	--																																								
Post-Launch Assessment Review (PLAR)	4/5/2025	5/18/2025	--																																								
Test Launch Plan																																											
Subscale Launch #1	10/28/2024	11/28/2024	100%																																								
Launch #1 (Inactive Payload & Airbrakes)	2/26/2025	3/12/2025	--																																								
Launch #2 (Inactive Payload & Airbrakes)	3/5/2025	3/19/2025	--																																								
Launch #3 (VDF)	3/12/2025	3/26/2025	--																																								
Launch #4 (Simple Airbrake Actuation)	3/19/2025	4/2/2025	--																																								
Launch #5 (Active Airbrakes)	3/26/2025	4/9/2025	--																																								
Launch #6 (PDF)	4/2/2025	4/16/2025	--																																								
Launch #7 (Competition Launch)	4/9/2025	4/23/2025	--																																								
Cedarville University Course Deliverables																																											
Background Research	8/17/2024	9/6/2024	100%																																								
Senior Design Proposal Rough Draft	9/6/2024	9/16/2024	100%																																								
Senior Design Final Proposal	9/16/2024	9/30/2024	100%																																								
Oral Committee Design Review	11/18/2024	11/22/2024	100%																																								
End of Semester Report (Fall)	11/22/2024	12/6/2024	100%																																								
Final Report (Draft)	1/7/2025	4/11/2025	--																																								
Final Presentations (Oral)	4/11/2025	4/15/2025	--																																								

6.2 Tests

All requirements that cannot be fully verified by inspection, demonstration, or analysis must be tested. CSL team members must adhere to the following guidelines when conducting tests:

Test Guidelines

1) All tests must have a **description** containing an overall count of the test and its objectives. This description describes the purpose of the test and how it validates the tested design
2) All tests must have a **procedure**, a set of step-by-step actions on how to perform the test. Procedures can include variations on the base procedure should multiple iterations be required.
3) All tests must have clearly defined **variables**: independent, dependent and controlled variables that can be easily measured and have an impact on the performance of the test.
4) All tests must have **pass and fail criteria**, which are often determined from requirements or other performance expectations.

At the current stage in the design process, the following tests have been identified in proving the integrity of the design:

- Black powder pop tests
- Subscale flight test
- Nosecone and tail cone drop tests
- Airbrakes material tests
- Wind tunnel testing

Each of these tests, as they are mentioned and developed throughout the Vehicle and Payload Criterion sections of the CDR, present objectives, success criteria, testing variables, and methodologies. Each test also justifies its importance in validating the design of the launch vehicle and payload.

As tests have been and will continue to be performed, members of CSL will continue to iterate on the chosen rocket designs with slight modifications to improve and fully validate the launch vehicle and payload performance. Results of completed tests are presented in their relevant sections.

6.3 Requirements Compliance

To ensure all NASA and CSL requirements are held to for vehicle criterion as well as project management goals, CSL have created requirement verification compliance tables for all project requirements. In these tables, the requirement is described, identified as a requirement verified by testing, analysis, demonstration, or inspection, and each verification method has a description for further detail.

The first table, given in Table 6.3.1, describes NASA requirement compliance. The second table, given in Table 6.3.2, describes CSL requirement compliance. CSL requirements are classified as Vehicle, Recovery, Payload, or Other, and are named respectively (ex: V.1 for the first vehicle related requirement). Both tables have been updated and will be utilized as tools to track project success moving forward.

Table 6.3.1. *NASA Requirement Verification Table.*

Req. #	Description of Requirement	Compliance	Verification Method	Status	Verification Description	Location
1.1	Students on the team will do 100% of the project. The team will submit new and original work.	The team will ensure they do all project reports, designs, construction, and testing.	Inspection	In Progress	The team mentor Dave Combs has handled all motor assembly and black powder charges. Students are responsible for and completing all components of the project. Eccessive use of outside resources included past teams' work is prohibited	Section 2.3
1.2	The team will create and maintain a project plan for project milestones, budgets, community support, checklists, personnel assignments, STEM engagement, and risks and mitigations.	In addition to the project plans outlined in this proposal, the team will maintain the high and low level project plan using project management tools such as Notion.	Inspection	In Progress	The Team Lead (Grant Parker) and Chief Engineer (Daniel Hogsead) have been responsible for providing and maintaining a project plan, which includes a milestones timeline, goals and a budget. STEM engagement has been lead by	Section 6.0
1.4	The team will engage at least 250 participants in hands-on STEM activities. This must be completed between moment of project acceptance and the Flight Readiness Review (FRR) addendum due date.	The team will designate a STEM engagement lead and supporting team members. A multi-stage engagement plan will be created and is outlined in Section 5 of this report.	Inspection / Demonstration	In Progress	The STEM engagement officer (Seth Mitchell) has created a plan for CSL to reach out and engage with schools in the areas surrounding the university. As of right now, CSL has engaged with 145 students from October 5th to November 19th	NA

1.5	The team will create a social media presence to inform the public about team activities.	A social media lead outside of the engineering division will be utilized, and an engineering team member will meet regularly with her to ensure an active social media page	Inspection	In Progress	Social media lead Andrea Rucci has been posting updates for CSL on social media platforms.	NA
1.6	Teams will email all deliverables to NASA by the deadline specified in the handbook. Late submissions of milestone documents will not be accepted	A NASA deliverables checklist will be created to ensure all reports are properly formatted and submitted, and designated editors will be appointed specifically for reviewing the deliverables.	Inspection	In Progress	CSL has successfully submitted all NASA deliverables up until this point by the specified due dates listed in the handbook.	NA
1.8	All deliverables will be in PDF format.	A NASA deliverables checklist will be created to ensure all reports are properly formatted and submitted, and designated editors will be appointed specifically for reviewing the deliverables.	Inspeciton	In Progress	CSL has successfully submitted all NASA deliverables in the desired PDF format.	NA
1.9	In every report, teams will provide a table of contents, including major sections and their respective sub-sections.	The team has created a pre-formatted document that all new reports will be based on.	Inspection	In Progress	In all of the submitted deliverables, CSL has followed laid out documentation formatting and included table of contents, major sections, and their respective sub-sections.	See Table of Contents
1.10	In every report, the team will include the page number at the bottom of the page.	The team has created a pre-formatted document that all new reports will be based upon.	Inspection	In Progress	In all of the submitted deliverables, CSL has followed laid out documentation formatting and included page numbers located at the bottom of each page	See Document
1.11	The team will provide all computer equipment for video teleconferences with the review panel.	Acquisition of proper rooms, audio equipment, and video equipment will be ensured before every teleconference.	Inspection	In Progress	CSL meets in a reserved conference room with the appropriate equipment needed for successful teleconferences	NA

1.13	The team will identify a mentor prior to the PDR. The mentor will be an adult, and they will be certified through the NAR or TRA for the motor impulse of the launch vehicle.	The team has identified a local rocketry club (WSR) and has identified a mentor whose contact info is in Section 1.1 of this document.	Inspection	Complete	CSL indentified Dave Combs as the mentor for the 2024-2025 Cedarville Univiersity Rocket Team.	Section 1.1
1.14	The team will track the hours it spent working on each milestone.	Per Cedarville University Engineering senior design rules, each team member will keep a logbook that tracks weekly progress and hours worked. Hours will also be logged by spreadsheet.	Inspection	In Progress	CSL members have used Excel to keep track of their individuals hours that they have put into working on each milestone	Section 1.1
2.1	The vehicle will deliver the payload to an apogee between 4,000 and 6,000 feet AGL.	The team will design the rocket so that simulations and test launches ensure that the rocket reaches an apogee between 4,000 and 6,000 feet with and without functioning airbrakes.	Analysis	Complete	CSL has used OpenRocket to simulate full scale launches with a predicted apogee goal of 4100 feet AGL.	Section 1.2, 3.7.1
2.2	Teams shall declare their target altitude goal at the CDR milestone. The declared target altitude shall be used to determine the team's altitude score.	The team will identify reliable means of simulating the flight path and predicting the altitude so that a target will be determined by CDR.	Inspection	Complete	CSL has stated in the CDR that their target apogee goal of 4100 ft.	Section 1.2, 3.7.1
2.3	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The vehicle and recovery design will ensure the rocket safely lands. The propulsion system will be designed so that the rocket is reusable.	Inspection	In Progress	CSL members have designed their subsystems with recoverability at the forfront of their designs. These designs have stressed reusability and are being analyzed to determine that all subsystems can be successfully recovered and relaunched.	Sections 2-3

2.4	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the vehicle. Coupler/airframe shoulders which are located at in-flight separation points shall be at least two airframe diameters in length.	The chief engineer will ensure when creating the high-level design that the number of independent sections in the launch vehicle complies with the rules. The chief engineer is responsible for verifying that the engineering contributions of each team member follow the specific construction guidelines provided.	Inspection	Complete	The vehicle designed by the CSL team has a total of 3 independent sections. These sections include the fore section, avionics section, and the aft section of the rocket. All of the coupler airframes and shoulders are at least 8 inches in length, which is double the airframe's diameter.	See Section 3
2.5	The rocket will be able to be prepared for flight at the launch site within 2 hours of the time the FAA flight waiver opens.	The team will conduct launch preparation practices to ensure that they can prepare the rocket comfortably under 2 hours.	Test	In Progress	CSL will practice assemblying and preparing the launch vehicle and payload with a timer to ensure the rocket can be readied within 2 hours.	Section 5.4.1 , 5.4.2
2.6	The launch vehicle and payload shall be capable of remaining in launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical on-board components.	Tests will be conducted to verify that the rocket and payload systems will maintain all functionality on the launchpad for at least 3 hours.	Test	In Progress	CSL members have taken steps to ensure that the launch vehicle and payload are capable of remaining launch ready on the pad for a minimum of 3 hours. One of the practice full scale launches will be used to test the endurance of the vehicles equipment.	Section 3.7, 3.10, 4.3
2.7	The rocket will be capable of being launched by a 12-volt DC firing system.	The chief engineer will ensure that the launch protocol will only employ commercially available igniters rated for a 12-volt DC firing system.	Inspection	In Progress	CSL will inspect to make sure that the vehicle's ignitors are capable of being set off by a 12 -volt DC firing system	Section 3.2
2.8	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The chief engineer will ensure that all electronic subsystems will function in an entirely self-contained manner.	Inspection	Complete	CSL designed the launch vehicle to be fully functional with no external support during launches. The motor is to be ignited by a 12-volt firing system.	Section 1.2, 3.1, 3.2

2.9	Each team shall use commercially available e-matches or igniters. Hand-dipped igniters shall not be permitted.	The chief engineer will ensure that the launch protocol will only employ commercially available igniters rated for a 12-volt DC firing system.	Inspection	In Progress	CSL will only purchase and use commercially available e-matches or igniters, as approved by the team mentors.	Section 6.3
2.10	The rocket will use a NAR/TRA approved solid motor using ammonium perchlorate composite propellant (APCP). Final motor choices will be outlined by CDR.	The rocket will use an approved solid motor using APCP, this motor will be purchased from a licensed vendor and will follow all competition guidelines.	Inspection	In Progress	The vehicle designed by CSL utilizes an Aerotech K1000T-P approved by NAR/TRA and has declared this choice in the CDR.	Section 3.2
2.11	The rocket will be limited to a single stage.	The chief engineer will ensure that the vehicle is a single-stage rocket.	Inspection	Complete	The vehicle designed by CSL is capable of only single stage launches	Section 1.2 , 3.2
2.12	The impulse for the launch vehicle will be no more than 5,120 Newton-seconds (L-class).	We will be using a L-class motor that does not exceed 5,120 Newton-sconds as informed by the Motor Data Sheet.	Inspection	Complete	The vehicle designed by CSL utilizes an Aerotech K1000T-P operates at a lower impulse than L-class motors	Section 1.2
2.13	Pressure vessels on the rocket will be approved by the RSO, have a safety factor of at least 4:1, and will have detailed documentation included in all milestone reviews.	Pressure vessels on the rocket will be approved by the RSO have a safety factor of at least 4:1, and have detailed documentation that will be stored with all other safety documents.	Inspection	Complete	The vehicle designed by CSL does not utilize any pressure vessels.	NA
2.14	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Using OpenRocket and possibly other calculation methods, the team will ensure that the static stability margin will be at least 2.0 at rail exit.	Inspection / Analysis	Complete	CSL will use OpenRocket and other calculation methods to find the static stability margin at the point of rail exit, ensuring it is over the minimum value of 2.0.	Section 3.11

2.15	The rocket's thrust to weight ratio will be at least 5.0:1.0	We will determine the weight of the rocket, and then, using OpenRocket and the motor thrust curve data, we will ensure that the thrust to weight ratio exceeds 5:1.	Inspection / Analysis	Complete	CSL will ensure the rocket's thrust to weight ratio exceeds 5.0:1.0 using the rocket weight and thrust data.	Section 3.11
2.16	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.	Burnout CG will be calculated using a testing rig and multiple other methods. Camera housings will be simulated to determine compliance.	Inspection /Analysis	Complete	CSL will ensure all structural protuberances on the rocket are aft of the burnout center of gravity by calculating the burnout center of gravity and comparing this location to all structurable protuberances (camera housing, fins, airbrake flaps).	Section 3.3, 3.11
2.17	The rocket will have a minimum velocity of 52 fps at rail exit.	Theoretical analysis will be performed on the rocket using OpenRocket, and practical experimentation will be performed to ensure that the rocket has a minimum velocity of 52 fps at rail exit.	Inspection / Demonstration	Complete	Using OpenRocket, real physical data, and simple calculations, CSL will calculate and verify the rocket exit velocity, and ensure that it is above 52 fps.	Section 3.11
2.18	The team will successfully launch and recover a subscale rocket before CDR. The subscale must be a separate, newly constructed rocket and must have an altimeter. Proof of flight is required in the CDR.	The team will construct, launch, and recover a subscale rocket for testing and qualification purposes. This will be done with the help of a local rocketry club and will be completed by CDR.	Inspection	Complete	CSL has successfully launched and recovered a subscale rocket on November 18th, 2024. The was a separate new construction that included an altimerer. The proof of concept was included in the CDR.	Section 3.9
2.19	The team will complete both the Vehicle Demonstration Flight and the Payload Demonstration Flight as outlined by the SL Handbook.	The team lead will ensure that the Vehicle and Payload Demonstration Flights are performed as outlined by the SL Handbook, and prior to any deadlines. They will also submit the results to NASA as necessary.	Inspection	Incomplete	CSL has not completed the Vehicle Demonstraiton flight and the payload demonstration flight	NA

2.20	The team will create an FRR Addendum for any Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR.	The team will write an FRR addendum for all necessary changes needed after the submission of the FRR.	Inspection	Incomplete	The team will write an FRR addendum for all necessary changes needed after the submission of the FRR.	NA
2.21	The team will place the team name and Launch Day contact information on the rocket airframe and all untethered sections of the rocket.	The team lead will ensure that their name and launch day contact information are on the airframe and untethered sections.	Inspection	Incomplete	On the day of launch, the CSL rocket will be sufficiently decorated so that the team name and Launch Day contact infromation is visable on the rocket and all untethered sections of the rocket.	NA
2.22	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.	The safety officer will ensure that lithium polymer batteries will be stored in a fireproof LiPo bag. Stickers will denote that they are a fire hazard.	Inspection	Complete	All LiPo batteries are sufficiently protected from the ground under normal landing contions. All LiPo batteries are brightly colored and clearly marked as fire hazards and distinguishable from other payload hardware	NA
2.23.1-5	The rocket will not use forward firing, hybrid, cluster, or friction-fitted motors.	The team will use a single commercial motor that will be anchored using a motor retainer system.	Inspection	Complete	The vehicle designed by CSL utilizes an Aerotech K1000T-P which is not a forward firing, hybrid, cluster, or friction fitted motor.	Section 1.2
2.23.6-7	The launch vehicle will not exceed Mach 1 or contain excessive ballast.	Theoretical analysis will be performed on the rocket using OpenRocket, and practical experimentation will be performed to ensure that the rocket does not exceed Mach 1. Ballast use will be reasonable.	Inspection / Analysis / Demonstration	Complete	Based off OpenRocket simulations and the motor used by the rocket, the vehicle designed by CSL will not exceed a speed of Mach 0.55, which is well below the Mach 1. The vehicle design also avoids containing an excess amount of ballast.	Section 3.4.4

2.23.8-9	Transmissions from the vehicle will not exceed 250 [mW] of power per transmitter and will use unique frequencies and other methods to reduce interference.	Inspection of the transmitters used on the vehicle will confirm they are below the limit of power.	Inspection	Complete	The appropriate transmitters will be purchased such that they do not exceed the 250 mW power limit. Research into appropriate frequencies and techniques will be performed.	Section 4.3
2.23.10	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.	Inspection of the vehicle during construction and assembly will verify the use of light weight materials.	Inspection	Complete	The team will not use dense metals for structural components, only aluminum will be utilized in moderation where metal parts are necessary.	Section 3.3, 5.2
3.1	The rocket will deploy a drogue parachute at apogee with a delay of 2 seconds or less. A main parachute will be deployed no lower than 500 feet. Both deployments will not utilize motor ejection.	To deploy drogue with a delay of 2 seconds or less is verified using demonstration.	Demonstration, Inspection	In Progress	The recovery and avionics lead will ensure that altimeters will trigger black powder charges at apogee and at an altitude no lower than 500 feet in order to deploy the parachutes.	Section 3.10, 5.3
3.2	The team will conduct successful ground tests for parachute ejection before the subscale and full-scale flights.	A ground/pop test will verify successful parachute ejection prior to launch.	Testing	In Progress	The recovery team will trigger the altimeters so that the black powder charges are fired in a controlled and safe environment for ground testing.	Section 3.10, 5.3
3.3	Each separate section of the rocket will have a landing energy that does not exceed 75 [ft-lbf].lbs.	The landing energy of the vehicle will be analysed using software and by using hand calculation. This will be demonstrated during the full-scale launch.	Analysis, Demonstration	Complete	Theoretical analysis will be performed on the rocket using OpenRocket and hand calculations to ensure that the rocket's landing energy does not exceed 75 [ft-lbf].lbs.	Section 3.10

3.4	The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events.	Inspection confirms that the recovery system will contain redundant altimeters for rocketry recovery events.	Inspection	In Progress	Two altimeters of different brands will be used for recovery. The team member in charge of avionics will ensure altimeter compliance.	Section 3.10
3.5	Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.	Inspection confirms that each altimeter has a power supply. All recovery electronics are going to be powered by commercially available batteries.	Inspection	In Progress	Each altimeter will have a dedicated, commercially available battery as a power source.	Section 3.10
3.6	Each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection validates that each altimeter will be armed by a dedicated mechanical arming switch. This switch will be accessible from the exterior of the rocket airframe.	Inspection	In Progress	Key-switches or equivalent means will be used to arm the flight avionics.	Section 3.10
3.7	Every arming switch will be able to be locked in the ON position.	Inspection will verify that the arming switch will be able to be locked in the ON position.	Inspection	In Progress	Key-switches or equivalent means will be used to arm the flight avionics.	Section 3.10
3.8	The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.	Inspection will verify the construction and assembly of the recovery and avionics subsystem.	Inspection	Complete	Recovery system and payload circuits will be placed in isolated electronics bays within the rocket.	Section 3.10
3.9	Drogue and main parachute sections will use removable shear pins.	Inspection will verify the construction and assembly of the recovery subsystem.	Inspection	In Progress	The recovery lead will be responsible for the insertion and inspection of shear-pins prior to every launch.	Section 3.10
3.10	Bent eyebolts shall not be permitted in the recovery subsystem.	Inspection will verify the construction and assembly of the recovery subsystem.	Inspection	Complete	Forged eyebolts will be used where required.	Section 3.10
3.11	The recovery area will be within a 2,500 [ft]. radius from the launch pads.	Analysis using simulations and calculations with also a launch flight will verify that the recovery area will be within a 2,500 [ft] radius.	Analysis, Demonstration	Complete	Simulations will be performed on the rocket using OpenRocket and Systems Toolkit, MATLAB, and practical experimentation will be performed to ensure that the drift stays within a 2,500 [ft] radius.	Section 3.10

3.12	The vehicle descent time will be a maximum of 90 seconds.	Analysis using simulations and calculations with also a launch flight will verify that the vehicle descends faster than 90 seconds.	Analysis, Demonstration	Complete	Simulations will be performed on the rocket using OpenRocket and Systems Toolkit, and practical experimentation will be performed to ensure that the descent time is below 90 seconds.	Section 3.10
3.13	The launch vehicle will contain a GPS device that transmits the position of the vehicle or any independent section to a ground receiver.	Testing of the GPS will ensure the device is working properly. Inspection will verify the proper installation of the GPS in the avionics bay.	Testing, Inspection	Complete	A GPS will be purchased and tested by the avionics lead, the appropriate tracking software and ground station set up to receive signals will be taken care of by the recovery lead.	Section 3.10
3.14	The recovery system electronics will be carefully protected and separate from other transmitters in the launch vehicle.	The recovery system will be inspected to ensure electronics are separate from other transmissions.	Demonstration, Inspection	In Progress	Electronics will be shielded from interference. Insulation will be applied to electronics. The avionics bay will physically isolate it from all other electronics.	Section 3.10
4.1	Design, build, and fly a STEMnaut flight capsule capable of safely retaining four STEMnauts and transmitting, via radio frequency, relevant rocket and STEMnaut landing site data to a NASA-owned receiver located at the launch site. The methods and designs must be safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	The STEMnaut flight capsule will be inspected to verify that all designs follow requirements. A demonstration of the full-scale launch will provide verification of the payload.	Demonstration, Inspection	In Progress	The designs and prototypes of the payload will be reviewed and tested for safety, reliability, and conformity to FAA, FCC, and legal requirements.	Section 4.1
4.2	The payload must transmit 3-8 pieces of the provided data to NASA. Transmissions may not exceed 5 [W],5W, and transmissions should start and end with a team member's callsign. The data to be transmitted must be submitted by March 17.	Inspection and demonstration will verify that the transmissions will be provided to NASA during launch.	Demonstration, Inspection	In Progress	The team will purchase the same radio NASA will use at the competition, and through extensive testing, ensure the data received fulfills these requirements in replications of the final launch.	Section 4.3

4.3	The payload will abide by FAA and NAR rules and regulations, and will abide by additional rules if the payload is deployed during descent, especially if classified as an unmanned aircraft system (UAS).	Inspection will verify that the payload follows the FAA and NAR rules and regulations.	Inspection	In Progress	The payload will remain attached to the main body of the rocket and will not be jettisoned or deployed from the rocket's body.	Section 4.3
5.1	The team will use a launch safety checklist that will be included the FRR and used during the LRR.	The SO will create a safety check list.	Inspection	In Progress	The Chief Safety Officer will be responsible for writing the Launch Operating procedures to be used on launch day.	Section 5.0
5.2	The team will select a safety officer that is responsible for the items in section 5.3.	Inspection will verify if the team has assigned a safety officer.	Inspection	Complete	The team has assigned Jesse DePalmo as the 2024-2025 CSO.	Section 5.0
5.3.1	The safety officer will monitor the safety of the following: ▪ Design of vehicle and payload ▪ Construction methods ▪ Assembly methods ▪ Ground testing, ▪ Subscale and Full-scale launch test(s),) ▪ Competition Launch ▪ Recovery, activities, ▪ STEM Engagement Activities	The SO will write FMEA, RPN sheets, safety sheets, verification sheets, and procedure sheets. He will also monitor and observe all events to ensure that rules and regulations are being followed.	Inspection	In Progress	The Chief Safety Officer will be responsible for creating failure modes to mitigate hazards identified. They will also be responsible for writing a team Safety Handbook to ensure safe construction and assembly procedures are followed.	Section 5.0
5.3.2	The SO will create safety procedures for construction, assembly, launch, and recovery activities.	The SO will write FMEA, RPN sheets, safety sheets, verification sheets, and procedure sheets.	Inspection	In Progress	The Chief Safety Officer will be responsible for creating failure modes to mitigate hazards identified. They will also be responsible for writing a team Safety Handbook to ensure safe construction and assembly procedures are followed.	Section 5.1

5.3.3	The SO will maintain revisions of the team's hazard analyses, failure modes analyses, procedures, and Material Safety Data Sheet (MSDS) information.	The SO will write FMEA, RPN sheets, safety sheets, verification sheets, and procedure sheets.	Inspection	In Progress	The Chief Safety Officer will be responsible for creating failure modes to mitigate hazards identified. They will also be responsible for writing a team Safety Handbook to ensure safe construction and assembly procedures are followed.	Section 5.6
5.3.4	The SO will help develop the team's hazard analyses, failure modes analyses, and procedures.	The SO will write FMEA, RPN sheets, safety sheets, verification sheets, and procedure sheets.	Inspection	In Progress	The Chief Safety Officer will be responsible for creating failure modes to mitigate hazards identified. They will also be responsible for writing a team Safety Handbook to ensure safe construction and assembly procedures are followed.	Section 5.6 - 5.11
5.4	The team will abide by the rules and guidance of the local RSO during test flights.	The SO will ensure that all FAA rules are followed and will collaborate with the RSO to ensure proper test flight safety.	Inspection	In Progress	CSL will only launch with verification from the NRA/TRA Team Mentor and RSO. The RSO will have the final say whether a launch can occur.	Section 5.4, 5.9, 5.10
5.5	The team will abide by all FAA rules.	The SO will ensure that all FAA rules are followed.	Inspection	In Progress	CSL will only launch with permission from the NRA/TRA Team Mentor and the RSO. The RSO will have the final say whether a launch can occur.	Section 5.4, 5.9, 5.10
6.1	The team will pass the LRR during Launch Week. The team's mentor shall be at Launch Week and will oversee rocket preparation and procedures. The team will only launch once at competition.	Inspection will verify that the Team Lead will coordinate to ensure that each part of the rocket is prepared for launch.	Inspection	Incomplete	Both the Team Lead and Engineering Lead will coordinate and oversee completion of assembly preparations and ensure that all requirements are met.	Section 5.1, 5.2, 5.3, 5.4

6.2	If the team does not attend Launch Week, it will launch at a NAR or TRA sanctioned launch. The team will closely collaborate with the RSO, team mentor, and the Launch Control Officer, ensuring that all NASA procedures are followed.	If the team does not attend Launch Week, the team leader will organize and schedule proper launching times and delegate responsibilities to ensure that procedures are followed.	Inspection	In Progress	CSL will coordinate with the NRA/TRA Team Mentor to schedule a launch at an approved launch site. The RSO will ensure that an official launch can occur and that all Launch Operations are followed.	Section 1.1, 5.1

Table 6.3.2. *CSL Requirement Verification Table.*

Req. #	Description of Requirement	Compliance	Verification Method	Status	Verification Description
V.1	The full scale launch vehicle will be able to be sufficiently powered by K class motors	The launch vehicle must be designed to have reduced mass and compressed systems to fly on this motor size.	Test / Analysis	In Progress	The design for the CSL launch vehicle will be simulated and practically tested with K class motors to ensure adequate performance.
V.2	The motor retension system (tailcone) will be completely reusable and heat and impact resistant without need for replacement save for unexpected loads.	The tailcone will be analyzed and tested to prove can be a reusable and durable form of motor retension.	Analysis / Test / Demonstration	In Progress	The tailcone system will be analyzed, tested, and demonstrate success in full scale launch vehicle tests to show mission success in creating a reusable motor retension system.
P.1	The launch vehicle will hit a targeted apgoee with an accuracy of plus or minus 25 feet with an airbrakes secondary payload.	CSL will design and manufacture an airbrakes system that will accurately control flight performance, and thus apogee.	Analysis / Test / Demonstration	Incomplete	The airbrakes system will be CFD analyzed, simulated, wind tunnel tested, and practically tested to ensure they properly affect the launch vehicle's flight performance.

O.1	CSL will create knowledge bases for future team members for their success in the NASA SL competition.	CSL team members will gather and format useful project and engineering knowledge relevant to the SL competition for future members.	Inspection	In Progress	CSL team members will create handbooks on STEM engagement, safety, general rocket design, and project management. Once these handbooks have been completed, the requirement will have been fulfilled.
V.3	CSL will create an iterable and customizable launch vehicle with modular airframe sections and modular overall design.	The launch vehicle and payloads will be designed with identical fasteners whenever possible, and will be able to assemble and disassemble with simple tools.	Inspection	In Progress	Team members will attempt to keep all components modular, and will have designs approved and inspected by the Chief Engineer to achieve this unity.
V.4	The launch vehicle will utilize a 3D printed nosecone to reduce cost and allow for design flexibility.	The nosecone will be analyzed, tested, and iterated to prove it is a structurally sound and aerodynamically beneficial component.	Test / Analysis	In Progress	The nosecone will be analyzed, tested, and iterated to prove it is a structurally sound and aerodynamically beneficial component. When the tailcone proves its durability and performance, the requirement will be fulfilled.
O.2	CSL will utilize a Mass Growth Allowance Plan to manage system mass growth and ensure overall successful flight perforamnce.	The Chief Engineer will track and manage mass changes across all subsystems and ensure mass changes do not negatively impact mission success.	Inspection / Analysis	In Progress	The Chief Engineer will regularly check and track subsystem mass with milestones, and analyze the mass growth and its predicted growth to predict the trajectory and limits of the system.
V.3	CSL will conduct wind tunnel testing to provide valuable data in analyzing the airbrakes secondary payload system.	The CSL airbrakes team members will plan, approve, and carry out controlled wind tunnel tests to gather data for airbrake control.	Test / Analysis	Incomplete	stick airbrakes in, see how similar CFD analysis is with wind tunnel

6.4 Budgeting and Timeline

The format of the budgeting sheet has changed slightly since the PDR. These changes include separating the STEM Engagement consumables from the one-time purchases. This makes it easier to add to the budget when needed so no time is wasted trying to find a given item. Other changes include new items that are now needed for the project that were not on the budget previously. The final change is the allocated price and total sections of the budget sheet. Those prices were there as a guess price for an item if the team did not know exactly what to get at the time. The difference between the allocated total and the actual total is the surplus the team has because of finding better deals for the items the team needs. The taxes and shipping and handling fees are included in the actual total section of the budget table. The breakdown of the budget is shown in Table 6.4.1.

Table 6.4.1. *Budget Sheet for NASA Project.*

Overall Budget for NASA Project									
System	Qty	Item Name	Item Description	Actual Price	Allocated Price	Total	Allocated Total	Source	Purchsed?
Airframe	2	G12 Fiberglass Tubes	4 ft length, 4 in diameter	$ 80.00	$ 80.00	$ 160.00	$ 160.00	Link	X
	2	Body Coupler	9 in length, 4 in diameter	$ 24.00	$ 24.00	$ 48.00	$ 48.00	Link	X
	1	G12 Body Goupler	8 in length, 4 in diameter	$ 33.00	$ 33.00	$ 33.00	$ 33.00		
	1	G12 Fiberglass Motor Tube	22 in length, 75 mm diameter	$ 55.00	$ 55.00	$ 55.00	$ 55.00	Link	X
	2	G12 Fiberglass Motor Tube	18 in length, 54 mm diameter	$ 41.00	$ 41.00	$ 82.00	$ 82.00	Link	X
	Total					$ 378.00	$ 378.00		
Recovery/Avionics	1	Black Powder Charges	1 lb (already owned)	$ -	$ 50.00	$ -	$ 50.00	Link	X
	1	Main Parachute - Full-scale	Flat Nylon, 7 ft diameter	$ -	$ 225.00	$ -	$ 225.00	Link	
	100	1yd of Shock Cord	9/16 in Tubular White	$ 1.50	$ 150.00	$ 150.00	$ 150.00	Link	X
	2	Stainless Steel Tapered Heat-Set Insert	18-8, 4-40, 0.135' installed length, pack of 10	$ 6.01	$ 6.01	$ 12.02	$ 12.02	Link	X
	1	Black -Oxide Alloy Steel Socket Head Screw	4-40 Thread Size, 5/8" long, pack of 100	$ 11.65	$ 11.65	$ 11.65	$ 11.65	Link	X
	1	Atlus Metrum Easymini Altimeter	dual deploy altimeter with Logging	$ 80.00	$ 80.00	$ 80.00	$ 80.00	Link	X
	1	Drogue Parachute	Flat Nylon, 1 ft diameter	$ -	$ 28.50	$ -	$ 28.50	Link	
	3	Cabel Straps and Ties	8"-12"-18", adjustable, 20 pack	$ 8.45	$ 8.45	$ 25.35	$ 25.35	Link	X
	Total					$ 253.67	$ 557.17		
Electronics/Payload	2	FCC Ham Radio License	radio license	$ 35.00	$ 35.00	$ 70.00	$ 70.00	Link	X
	1	BTECH APRS-K1 PRO	APRS encoder/decoder	$ 34.49	$ 34.49	$ 34.49	$ 34.49	Link	X
	2	UV-5R Ham Radio Transceiver	radio transmitter	$ 31.69	$ 31.69	$ 63.38	$ 63.38	Link	X
	3	RH707 Diamond Dual-Band Antenna	dual-band antenna	$ 29.99	$ 29.99	$ 89.97	$ 89.97	Link	
	1	BMP280 Barometer & Thermometer (10-pack)	barometer/thermometer	$ 7.99	$ 7.99	$ 7.99	$ 7.99	Link	X
	1	1000mAh 2S Li-Po Battery (2-pack)	Li-Po battery	$ 22.99	$ 14.99	$ 22.99	$ 14.99	Link	
	1	W25Q64 Flash Memory Module (5-pack)	flash memory	$ 7.99	$ 7.99	$ 7.99	$ 7.99	Link	X
	1	Micro SD-Card Reader (10-pack)	removable memory	$ 8.89	$ 8.89	$ 8.89	$ 8.89	Link	X
	2	PCB Manufacturing per Version	printed circuit board	$ 25.00	$ 40.00	$ 50.00	$ 80.00	Link	X
	4	LEGO STEMnauts	minifigure	$ 5.00	$ 5.00	$ 20.00	$ 20.00	Link	
	Total					$ 375.70	$ 397.70		
Subscale	1	G12 Fiberglass	5 ft length, 3 in diameter, for Airframe	$ 98.00	$ 98.00	$ 98.00	$ 98.00	Link	X
	4	PETG plastic	1.75 mm, black filiment, for 3D printing	$ 20.00	$ 20.00	$ 80.00	$ 80.00	Link	X
	2	Coupler Tubes	9 in length, 3 in diameter G12 Fiberglass	$ 22.00	$ 22.00	$ 44.00	$ 44.00	Link	X
	1	Main Parachute - Subscale	Flat Nylon, 4 ft diameter	$ 115.00	$ 115.00	$ 115.00	$ 115.00	Link	X
	1	U-Bolts	8880T957	$ 1.98	$ 1.98	$ 1.98	$ 1.98	Link	X
	6	G10 Fiberglass	1/8 thickness, 1 ft x 1 ft, for fins	$ 31.38	$ 31.38	$ 188.28	$ 188.28	Link	X
	Total					$ 527.26	$ 527.26		
General Construction	2	Epoxy	Quart of epoxy for parts that need it	$ -	$ 80.00	$ -	$ 160.00		
	1	Alumninum Roundstock	4 inch diameter, 6 inch length	$ 82.73	$ 82.73	$ 82.73	$ 82.73	Link	X
	2	Hardener	Quart of hardener for parts that need it	$ 80.00	$ 80.00	$ 160.00	$ 160.00		
	10	Threaded eye bolts	1/4" X 20" 1"	$ 7.00	$ 7.00	$ 70.00	$ 70.00	Link	X
	2	Rail Buttons	10/10 ERX 9075C	$ 3.00	$ 3.00	$ 6.00	$ 6.00	Link	X
	2	Shock Cords	9/16 in width, 1500 lbs tensile strength	$ 50.00	$ 50.00	$ 100.00	$ 100.00	Link	X
	2	Fasteners	(50 ct) 18-8 Stainless Steel Button Head	$ 7.56	$ 7.56	$ 15.12	$ 15.12	Link	X
	4	PETG plastic	Plastic for 3D printing, 1 kg spool	$ 20.00	$ 20.00	$ 80.00	$ 80.00	Link	X
	3	Smooth T-Slotted Almuminum Extrusion	36 in length	$ 8.42	$ 8.42	$ 25.26	$ 25.26	Link	X
	6	Smooth T-Slotted Almuminum Extrusion	9.5 in length	$ 2.48	$ 2.48	$ 14.88	$ 14.88	Link	X
	2	Threaded Rods	1/4-20, for the avionics bay	$ 7.47	$ 7.47	$ 14.94	$ 14.94	Link	X
	1	Micro Balloons		$ 22.00	$ 22.00	$ 22.00	$ 22.00		
	1	Carbon Fiber Square Rods	6mm x 6mm	$ 50.99	$ 50.99	$ 50.99	$ 50.99	Link	X
	Total					$ 590.93	$ 801.92		
Flight Consumables	7	Motor reload kit	Motors for full scale launches	$ 202.99	$ 250.00	$ 1,420.93	$ 1,750.00	Link	X
	1	Shear Pins (100 ct)	for the mainframe recovery system	$ 5.50	$ 5.50	$ 5.50	$ 5.50	Link	X
	Total					$ 1,426.43	$ 1,755.50		

Stem Engagement (One Time Purchases)	4	Model rockets	Demonstration Materials	$ 7.00	$ 7.00	$ 28.00	$ 28.00	Link	X
	1	Table Cloth	construction materials	$ 9.99	$ 9.99	$ 9.99	$ 9.99	Link	X
	1	Dish Set	construction materials	$ 13.49	$ 13.49	$ 13.49	$ 13.49	Link	X
	1	Toy Cars	Demonstration Materials	$ 7.60	$ 7.60	$ 7.60	$ 7.60	Link	X
	1	Wood	construction materials	$ 4.42	$ 4.42	$ 4.42	$ 4.42	Link	X
	1	Tennis Balls	Demonstration Materials	$ 3.94	$ 3.94	$ 3.94	$ 3.94	Link	X
	1	Stuffed Toy	Demonstration Materials	$ 9.99	$ 9.99	$ 9.99	$ 9.99	Link	X
	1	Balloons	Demonstration Materials	$ 5.99	$ 5.99	$ 5.99	$ 5.99	Link	X
	1	Compressed Air	Demonstration Materials	$ 12.00	$ 12.00	$ 12.00	$ 12.00	Link	X
	1	Glasses	Demonstration Materials	$ 3.99	$ 3.99	$ 3.99	$ 3.99	Link	X
	1	Forks	Demonstration Materials	$ 5.99	$ 5.99	$ 5.99	$ 5.99	Link	X
	1	Baseball Bat	Demonstration Materials	$ 10.99	$ 10.99	$ 10.99	$ 10.99	Link	X
	1	Fan	Demonstration Materials	$ 30.99	$ 30.99	$ 30.99	$ 30.99	Link	X
	1	Ruler	construction materials	$ 6.99	$ 6.99	$ 6.99	$ 6.99	Link	X
	1	Markers	construction materials	$ 13.75	$ 13.75	$ 13.75	$ 13.75	Link	X
	1	Hot Glue Gun	construction materials	$ 9.99	$ 9.99	$ 9.99	$ 9.99	Link	X
	2	Scissors	construction materials	$ 13.99	$ 13.99	$ 27.98	$ 27.98	Link	X
	1	Scale	construction materials	$ 9.98	$ 9.98	$ 9.98	$ 9.98	Link	X
	1	Measuring Cups	construction materials	$ 7.99	$ 7.99	$ 7.99	$ 7.99	Link	X
	1	Launching Material	(already owned)	$ -	$ 100.00	$ -	$ 100.00	N/A	X
Stem Engagement (Consumables)	4	Chloroplast corrugated cardboard	construction materials	$ 125.00	$ 125.00	$ 500.00	$ 500.00	Link	X
	3	Foam Footballs	construction materials	$ 19.99	$ 19.99	$ 59.97	$ 59.97	Link	X
	1	Toothpicks	Demonstration Materials	$ 3.99	$ 3.99	$ 3.99	$ 3.99	Link	X
	1	Corugated Card Board	construction materials	$ 26.74	$ 26.74	$ 26.74	$ 26.74	Link	X
	3	Pencil	construction materials	$ 16.99	$ 16.99	$ 50.97	$ 50.97	Link	X
	80	2 Liter Bottles	construction materials	$ 1.00	$ 1.00	$ 80.00	$ 80.00	Link	X
	1	Corrugated cardboard	construction materials	$ 9.88	$ 9.88	$ 9.88	$ 9.88	Link	X
	1	Gravel	construction materials	$ 5.59	$ 5.59	$ 5.59	$ 5.59	Link	X
	2	Plastic Cups	construction materials	$ 5.06	$ 5.06	$ 10.12	$ 10.12	Link	X
	1	Straws	construction materials	$ 5.98	$ 5.98	$ 5.98	$ 5.98	Link	X
	1	Rubber Bands	construction materials	$ 6.80	$ 6.80	$ 6.80	$ 6.80	Link	X
	1	Tissue Paper	construction materials	$ 5.99	$ 5.99	$ 5.99	$ 5.99	Link	X
	1	String	construction materials	$ 4.99	$ 4.99	$ 4.99	$ 4.99	Link	X
	2	Popsicle Sticks	construction materials	$ 4.99	$ 4.99	$ 9.98	$ 9.98	Link	X
	1	Construction Paper	construction materials	$ 5.99	$ 5.99	$ 5.99	$ 5.99	Link	X
	1	Tape	construction materials	$ 23.39	$ 23.39	$ 23.39	$ 23.39	Link	X
	1	Name Tags	Identification	$ 5.53	$ 7.99	$ 5.53	$ 7.99	Link	X
	1	Stickers	construction materials	$ 5.99	$ 5.99	$ 5.99	$ 5.99	Link	X
	1	Bracelets	construction materials	$ 9.99	$ 9.99	$ 9.99	$ 9.99	Link	X
	2	Tape	construction materials	$ 23.39	$ 27.95	$ 46.78	$ 55.90	Link	X
	1	Boxes	construction materials	$ 25.02	$ 25.02	$ 25.02	$ 25.02	Link	X
	1	Metal bb and Pebbles	construction materials	$ 8.99	$ 8.99	$ 8.99	$ 8.99	Link	X
	Total					$ 1,136.74	$ 1,248.32		
Grand Total						$4,688.73	$5,665.87		
Surplus/Deficit							$977.14		

Bibliography

Aerospace, A. (2024). *ASM Material Data Sheet*. Asm.matweb.com. https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6

AeroTech K1000T Thrust Curve. 18 Mar. 2010, www.thrustcurve.org/motors/AeroTech/K1000T/thrustcurve.svg?unit=N. Accessed 7 Jan. 2025.

Amazon.com. (2025). *Baofeng UV-5R Ham Radio*. https://a.co/d/6f8Vv9G

Amazon.com. (2025). *OVONIC 2s Lipo Battery*. https://a.co/d/31gIlZ3

Bosch. (2015). *BMP280: Data sheet Document revision 1.14*. https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf

Budynas, R. G., & Nisbett, K. (2015). *Shingley´s mechanical engineering design*. Mc Graw Hill.

Engineers Edge. (2019). *Coefficient of Friction Equation and Table Chart*. Engineers Edge. https://www.engineersedge.com/coeffients_of_friction.htm

Gilmore, N., Timchenko, V., & Menictas, C. (2018). Microchannel cooling of concentrator photovoltaics: A review. *Renewable and Sustainable Energy Reviews*, *90*, 1041–1059. https://doi.org/10.1016/j.rser.2018.04.010

Handson Technology . (n.d.). *Handson Technology Data Specs Rotary Encoder for Arduino/Raspberry*. https://www.handsontec.com/dataspecs/module/Rotary%20Encoder.pdf

InvenSense. (2012). *MPU-6000 and MPU-6050 Product Specification Revision 3.3 MPU-6000/MPU-6050 Product Specification*. https://www.haoyuelectronics.com/Attachment/GY-521/mpu6050.pdf

Iyer, A. R., & Pant, A. (2020, August 8). *A review on nose cone designs for different ...* A REVIEW ON NOSE CONE DESIGNS FOR DIFFERENT FLIGHT REGIMES. https://www.irjet.net/archives/V7/i8/IRJET-V7I8605.pdf

Laminated Plastics. (2017). *Laminated Plastics - Technical Data Sheet G-10*. Laminatedplastics.com. https://laminatedplastics.com/g-10.pdf

Maxim Integrated Products. (2015). *DS1307: 64 x 8, Serial, I2C Real-Time Clock*. https://www.analog.com/media/en/technical-documentation/data-sheets/DS1307.pdf

McMaster-Carr. (2019). Mcmaster.com. https://www.mcmaster.com/91251A108/

Norton, R. L. (2020). *Machine design : an integrated approach*. Prentice Hall.

Raspberry Pi. (2024). *Raspberry Pi Pico Datasheet An RP2040-Based microcontroller board* . https://datasheets.raspberrypi.com/pico/pico-datasheet.pdf

S v, L. S., A, K., & C, D. (2024). Evaluation of mechanical properties of 3D printed PETG and Polyamide (6) polymers. *Chemical Physics Impact*, *8*, 100491. https://doi.org/10.1016/j.chphi.2024.100491

Schön, J. (2004). Coefficient of friction and wear of a carbon fiber epoxy matrix composite. *Wear*, *257*(3-4), 395–407. https://doi.org/10.1016/j.wear.2004.01.008

TDK. (n.d.). *Product Specifications: SD Card / Micro SD Card*. Mouser.com. https://www.mouser.com/catalog/specsheets/tdk_07292019_mmrd4_murd4_.pdf

Tyson, M. (2023, January 16). What is PLA+? 3D Printing Solutions. https://www.3dprintingsolutions.com.au/News/Australia/what-is-pla-plus

Using Heat Set Inserts. (n.d.). Markforged.com. https://markforged.com/resources/blog/heat-set-inserts

White, F. M. (2008). *Fluid mechanics*. Mcgraw-Hill Higher Education.

Winbond. (2024). *W25Q64FV*. Winbond.com. https://www.winbond.com/hq/product/code-storage-flash-memory/serial-nor-flash/?__locale=en&partNo=W25Q64FV

Winbond Electronics Corporation. (2013). *W25Q64FV*. https://www.pjrc.com/store/w25q64fv.pdf

Wisnom, M. R. (2012). The role of delamination in failure of fibre-reinforced composites. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *370*(1965), 1850–1870. https://doi.org/10.1098/rsta.2011.0441

Zou, R., Xia, Y., Liu, S., Hu, P., Hou, W., Hu, Q., & Shan, C. (2016). Isotropic and anisotropic elasticity and yielding of 3D printed material. *Composites Part B: Engineering*, *99*, 506–513. https://doi.org/10.1016/j.compositesb.2016.06.009

Appendix

A.1. Airbrakes MATLAB Code

A.1.1. Mechanical Design

```
clc; clear; close all;

%% Static Force Analysis
% The first step is to determine the forces acting at each pin. This is
% first done using equilibrium euqtions. The wind force was chosen
% arbitarrily to be placed at the point it is at. This will change when CFD
% analysis if finished to find the true

SF =2;

% Sum of forces in the x-axis.
% 0 = Fx + Asin(alpha)
% Sum of forces in the y-axis.
% 0 = Fy - w - Acos(alpah)
% Sum of moments about point.
% 0 = FyDx0 - FxDy0 + WDx1

% Define Terms
alpha = atand(2.4/2.56); %degrees
Dy0 = 0.68; %in
Dx0 = 1.95; %in
Dy1 = 0; %in
Dx1 = 0.23; %in
W = 6.85; %lbs


syms Fx Fy A
eqn1 = Fx + A*sind(alpha) == 0 ;
eqn2 = Fy - W - A*cosd(alpha) == 0 ;
eqn3 = Fy*Dx0 - Fx*Dy0 + W*Dx1 == 0 ;

[C,B] = equationsToMatrix([eqn1,eqn2,eqn3],[Fx Fy A]);

X = linsolve(C,B);

X = vpa(X); X = double(X);Fx = X(1); Fy1= X(2); F = X(3);

%% Gusset Plate Internal Forces

INCREASE = 3; % This is the correction factor which allows me to change
% the height of the gusset plate if any of the tests fail

%Now that the forces are known on the whole system, we will move into
%finding the internal stresses of each element in the assembly. First will
%be the gusset plate. For referance, I used assumption that this system
%acted like a double plate in tension and compression. This was from page
```

```
%350 of the Russel and Hibbler Statics and Mechanics of Materials Book.
%According the NASA, we will use a safety factor of 1.5 in this analysis.
%Additionally, using the rule of thumb Dr. Norman gave with his idea of
%2D+0.03 for the rounded edges for a material.

%% Plate Fails in pure Tension
D = 0.12; %in, diameter of the hole
sigma_a_allow = 40 * 10^3; % psi
B = D+0.03; %in this is the horizontal dimention from hole to end

h = INCREASE * abs(F) * (1.5/2) / (B*sigma_a_allow); % the height of the gusset plate

fprintf(['The smallest gusset plate height is %f, \n' ...
    'and nominal thickness around the hole should be %f.\n\n'],h, B)

%% Failure of shearing in the screw.

V_s = abs(F)/2; D_s = 0.112; A_s = pi*D_s^2/4; Tau_s = V_s / A_s;

Tau_s_safe = Tau_s * SF;

%Find the allowable shear stress
sigma_s = 170*10^3; %psi
F_s_allowable = 117; %(Lbs) Please see excel for this calculation.
Tau_s_allowable = F_s_allowable / A_s; %psi

if Tau_s_safe < Tau_s_allowable
    fprintf('The gusset plate does not fail in shear by the screw.\n\n');
end


%% Plate failing in bearing

%Taking the values we got from the previous analysis, we will determine how
%much force it will take to make the plate fail in bearing. If this force
%is less than the amount of force we apply then we are fine.

sigma_b_allow = 56 * 10^3; % psi
N_b_actual = sigma_b_allow * D * h; % lbs; this is the force force which
% would cause bearing stress

N_b_safe = N_b_actual / SF; % the safe amount of force which would be
% acting on the gusset plate;

% Now we compare the amount of force applied to the amount of force it
% would take to fail in bearing.

if abs(F) > N_b_safe
    fprintf('Recalculate failure by bearing! \n\n');

elseif abs(F) < N_b_safe
    fprintf('Plate does not fail by bearing stress\n\n');
end
```

```
%% Plate failing in shear

tau_p_allow = 30*10^3; % Psi, the amount of shear stress the plate has.

z = D + B; %intermediate variable

tau_p_actual = abs(F)/2 / (z * h); % psi, the amount of stress in the plate
% at current loading

tau_p_safe = tau_p_actual * SF; % safety factor applied

if tau_p_safe > tau_p_allow
    fprintf('Recalcualte shear failure in the plate! \n\n');
else
    fprintf('The plate does not fail by shear. \n\n');
end

% if tau_p_safe < tau_p_allow && abs(F) < N_b_safe && Tau_s_safe < Tau_s_allowable
%     fprintf(['The final dimentions for the gusset plate are\n ' ...
%         'diameter thickenss = %f inches & height = %f inches \n\n'], B, h);
% else
%     fprintf('Keep itterating\n');
% end
```

A.1.2. Kinematic Friction Design

```
clc; clear; close all;

a = 01;
r = 0.27;
l = 0.99+r;

syms F1 f2 f3 N2 N3 mu
e1 = -F1 +f2 + f3 == 0
e2 = N2 - N3 == 0
e3 = 0 == (l-r) * F1 -N3*a + f3*(2*r)
e4 = f2 == mu*N2
e5 = f3 == mu*N3

eqns = [e1 e2 e3 e4 e5]
S = solve(eqns)

% Check the hand calculations
mu1 = a/(2*l);
mu = double(S.mu);
disp(mu);
disp(mu1);
```

A.2. Airbrakes INSTRON Test Data

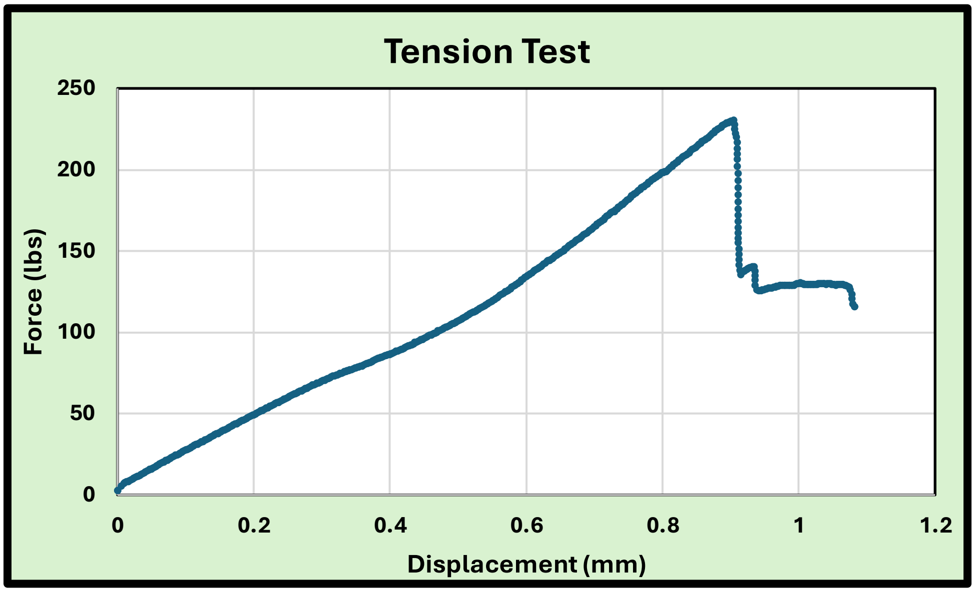

Figure A.2.1. *Tension test resulting data.*

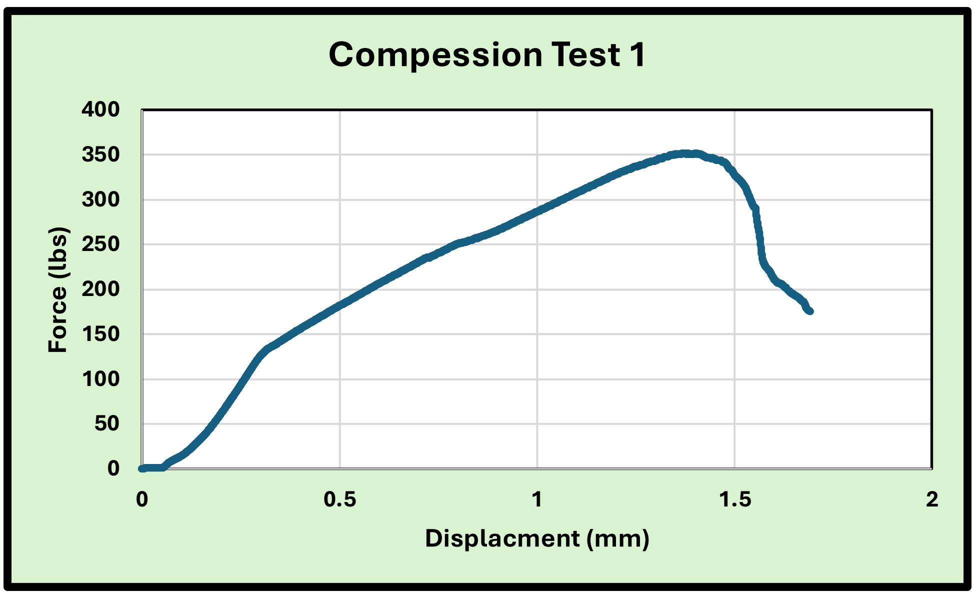

Figure A.2.2. *Compression test 1 resulting data.*

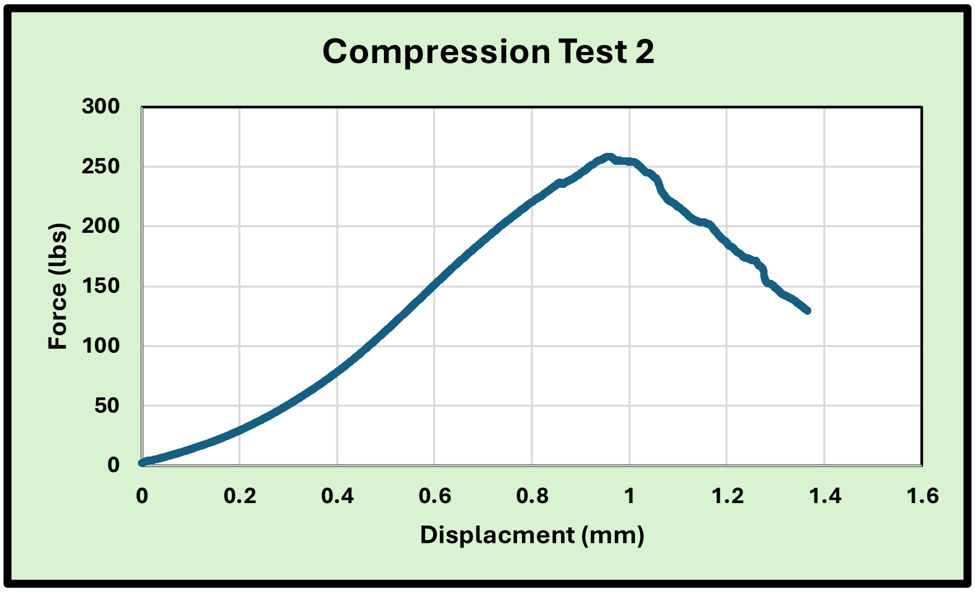

Figure A.2.3. *Compression test 2 resulting data.*

A.3. MATLAB Code used for Descent Performance Predictions

```
% Corrected Equations to find the descent time and drift for Full-Scale
% Assumption that acceleration continues to occur at state 1 (not terminal)
% While function will be used to iterate until a v1 is found
% V1 must give correct (or approximate) s1 (= apogee - main deployment)
% Will give descent time of rocket from state 0 > 1 and initial condition for state 2
% 'ode45' used to find the velocity, time, and position of state 2
% Total descent time adjusted so fall position is equal to apogee
% Total descent time is used to find the drift of the rocket at wind speeds
% Units are ft, s, lbm, lbf unless stated otherwise

% Constants
mainDeploy = 600;
apogee = 4100;
in.g = 32.174;
density = 0.00210722;
t0 = 0;

% Rocket Constants
% Including total weight and individual masses for each section
% Sections from aft > middle > fore
% oz > lbf (/16) oz > lbm (/(16*in.g))
m_drogue = (1 + 1.058 + 10)/(in.g*16); m_main = (15.3 + 1.587 + 10)/(in.g*16);
m_parachutes = m_drogue + m_main;
in.m = [9.92/in.g 4.45/in.g 7.89/in.g];
in.W = in.g*(sum(in.m, "all") + m_parachutes);

% Drogue Parachute Values
Dd = 1;
Ad = (pi/4)*Dd^2;
C_Dd = 0.97;
```

```
in.B1 = (1/2)*density*C_Dd*Ad

% Main Parachute Values
D_om = 7;
D_im = 14.78/12;
Am = (pi/4)*(D_om^2 - D_im^2);
C_Dm = 2.2;
in.B2 = (1/2)*density*(C_Dd*Ad + C_Dm*Am)

A1 = 1e-2;
err1 = 10;

% Inital Position Conditions
in.x0 = 0;
in.x1 = apogee - mainDeploy;
s1 = 0;
in.x2 = apogee;

% Finding Drogue Interval (0 -> 1)
while abs(err1) > 0.1
    V1 = sqrt((in.W - (in.W/in.g)*A1)/(in.B1));

    in.t1 = (in.W/in.g)/sqrt(in.B1*in.W)*atanh(V1*sqrt(in.B1/in.W));

    s0 = s1;

    s1 = (in.W/in.g)*(-log(abs(in.W - in.B1*V1^2)/in.W)/(2*in.B1));

    err0 = in.x1 - s0;
    err1 = in.x1 - s1;

    if abs(err1) < abs(err0)
        A1 = A1 + 1E-9;
    elseif abs(err1) > abs(err0)
        A1 = A1 - 1E-7;
    else
        A1 = A1 + 1E-6;
    end
    if A1 <= 0
        A1 = 1E-13;
    end
end

V1t = sqrt(in.W/in.B1)
Vt = sqrt(in.W/in.B2)

% Initial Velocity Conditions
in.x0dot = 0;
in.x1dot = V1t;
in.x2dot = Vt;

% Initial Acceleration Conditions
in.x0dot2 = in.g;
```

```
in.x1dot2 = A1;
in.x2dot2 = 0;

% Time Values
t0 = t0;
t1 = in.t1;
t2 = 58.5;
tstep = 0.01;
tspan = t1:tstep:t2;
t_tot = t2

% Solving second differential equation (1 -> 2)
[T2,X2] = ode45(@(t,x) odefcn2(t,x,in), tspan, [in.x1, in.x1dot]);

% Kinetic Energy at Touchdown
KE = (1/2)*in.m*Vt^2
KE_fail = (1/2)*[in.m(1), (in.m(2)+in.m(3))]*V1t^2

% Drift Due to wind (MPH -> ft/s)
V_wind = 5:5:20;
Drift = t2*V_wind*(5280/3600)

% Function to solve second-order differential (1 -> 2)
function dxdt = odefcn2(t,x,in)
    dxdt = [x(2); in.x0dot2 - (in.B2*in.g/in.W)*(x(2).^2)];
end
```

A.4. MGA Percentages for the Design Sequence

Design Maturity	MGA [%]															
	Nose Cone			Payload			Avionics			Airbrakes			Thrust Structure			
	Cone	Camera System	Airframe	Body	Electronics	Recovery Devices	Body	Electronics	Shock Cord Mount	Frame	Brakes	Electronics	Fin Retention	Fins	Tail Cone	Motor
Conceptual	30%	20%	20%	20%	15%	30%	20%	10%	20%	25%	20%	15%	15%	20%	20%	20%
PDR	20%	10%	15%	15%	8%	20%	15%	7%	15%	18%	18%	13%	8%	15%	10%	20%
CDR	10%	8%	10%	10%	3%	10%	2%	2%	5%	7%	10%	5%	5%	5%	5%	2%
Final	3%	3%	2%	2%	2%	1%	1%	1%	1%	4%	3%	1%	1%	1%	1%	2%