Project Elijah

Flight Readiness Review

Cedarville Student Launch 2024-2025

Cedarville University
251 N. Main St.
Cedarville, OH 45314
March 17, 2025

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FRR Acronym References

Acronym	Full Name
AB	Airbrakes Subsystem
AGL	Above Ground Level
ANSI	American National Standards Institute
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
COTS	Commercial-Off-the-Shelf
CP	Center of Pressure
CSL	Cedarville Student Launch
CSO	Chief Safety Officer
DMM	Digital Multimeter
EPL	Engineering Project Laboratory
FAA	Federal Aviation Administration
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
FRR	Flight Readiness Review
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
OD	Outer Diameter
PCB	Printed Circuit Board
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
SDS	Safety Data Sheet
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
VDF	Vehicle Demonstration Flight
WBS	Work Breakdown Structure
WSR	Wright Stuff Rocketeers

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1. Summary of FRR Report

1.1. Team Summary

Team Info	Cedarville Student Launch Team (CSL) 251 North Main Street, Cedarville, OH 45314	**Final Launch Plan**	5995 Federal Road, Cedarville, OH 45314 WSR, NAR #703 Dave Combs, President April 26, 2025
Mentor Info	Dave Combs – #86830 – High HPR Level 2 Email: davecombs@earthlink.net Phone Number: (937) 248 – 9726	**Backup Launch Plan**	5995 Federal Road, Cedarville, OH 45314 WSR, NAR #703 Dave Combs, President April 27, 2025
NAR Section	NAR #703 Wright Stuff Rocketeers (WSR)	**FRR Hours**	**601.5**

1.2. Launch Vehicle Summary

Target Apogee	**4100 ft**
Competition Launch Motor	**Aerotech K1000T-P**
Fore Section Length / Weight	**30 in / 6.83 lb**
Avionics Bay Section Length / Weight	**27.25 in / 3.97 lb**
Aft Section Length / Weight	**56.95 in / 12.18 lb**
Dry Mass with / without Ballast	**21 lb**
Wet / Burnout / Landing Masses	**27.8 lb / 25.2 lb / 25.2 lb**
Recovery System	**15” Elliptical Drogue / 7ft Parabolic Main**
Rail Size	**1515/ 12ft Long**

1.3. Payload Summary

The primary payload is known as Elijah. Its mission is to safely hold four STEMnauts and to transmit flight and landing information to a receiver over radio after landing. The payload will transmit 5 objectives: the temperature of the landing site, the apogee reached, the orientation of the on-board STEMnauts, the time of landing, and a power status report. The payload will take in this data during flight and after landing and will transmit it to a receiver at the launch site via a radio transmission on the 2-meter band.

2. Changes Made Since CDR

2.1. Changes Made to Vehicle

Changes made to the launch vehicle criteria are given in Table 2.1.1 below. The effects of these summarized changes are also discussed in the Vehicle Criteria section (Section 3).

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

Subsystem	Change	Effects of Design Change
Nosecone	Reinforcing pins has been added to the nosecone system to strengthen it against failure due to shear stresses upon landing. The nosecone has also been separated into two pieces instead of four, to reduce failure points. Ballast was reduced from 1100 g to 500 g.	The nosecone has been strengthened against landing impacts from the side and has had its failure points reduced.
Airframe	The length of the airframe has been increased by 3 inches. The drogue bay was shortened, and aft section of the rocket lengthened. A coupler has been added to the aft section of the rocket to reinforce the airframe where airbrake slots have been cut.	The airframe surrounding the secondary payload has been reinforced.
Fins	The fin height was changed from 3.2 inches to 3.5 inches.	The dimensions of the fins have been adjusted to improve the launch vehicle's stability and reduce ballast.
Tail cone	The holes facilitating attachment of the tail cone to the motor centering rings have moved inwards, changing the fastener holes to be fastener slots.	The inward facing geometry of the tail cone has changed, but the cone has not lost any structural integrity.

2.2. Changes Made to Payload

2.2.1. Mechanical Changes

The primary payload mechanical structure changed since the CDR due to the addition of steel ballast to the tip of the nosecone. Due to concerns about the integrity of the radio signals being broadcast by the payload, the radio was turned upside down, causing the other components to be rearranged to accommodate it.

The airbrakes had six mechanical design modifications from the CDR to the FRR. The diameter of the airbrakes (AB) was reduced to fit inside a reinforced airframe, the electrical housing was modified to fit inside the airframe, the as built mass was less than the estimated mass, the distance between the mounting bolts was different than the CAD, and the electrical housing was slightly shorter than the CAD model.

2.2.2. Electrical Changes

The electrical system for APRS transmission for the primary payload has been simplified so that packets can be transmitted using only the Raspberry Pi Pico and several passive components. This removes the necessity of the analog decoder as described in the CDR. A speaker has also been added to both the primary and override PCBs so that the tone can be heard while the rocket is on the launch pad and status LEDs are not visible. All changes to the primary payload are discussed in more detail in Section 4.1.2.

The airbrakes had six electrical design changes made since the FRR. Some of these changes were due to a component failure prior to launch, which includes a higher RPM motor, no SD card, and 1 BMP sensor. A change in battery, substitution of a buck converter for a voltage regulator, and addition of an onboard speaker were due to practical design modifications. See these changes in Section 4.2.2 for more details.

2.3. Changes Made to Project Plan

Plans for CSL's final and backup competition launches have changed from April 12th and 19th to April 26th and 27th. This was done so that CSL could have the competition launch at a local NAR chapter launch day. The location for the backup launch has also been changed to the same location as the primary location.

The requirement verification system, as given in the Project Plan section (Section 7) has been fully updated to reflect the requirements CSL has defined for this project (as of 03/17/25). The system is of the same format as in the CDR but has expanded requirements and validations for the primary and secondary payload systems. As CSL has better understood and carried out the completion of NASA and internal requirements, some verification methods have been changed to suit specific requirements, such as a test validation being changed to a demonstration. Some tests that CSL originally planned to conduct, such as the wind tunnel test and tail cone drop test, have been removed from the project plan. All details for the validation of the project requirements are given in Section 7.

Launch checklists, FMEA sheets, and other safety related topics have also been updated to reflect the updated payload systems.

3. Vehicle Criteria

3.1. Mission Statement & Success Criteria

CSL's mission is to safely fly and recover the launch vehicle Chariot, containing the STEMnaut flight capsule Elijah, to a predicted apogee. After landing, Elijah will transmit capsule and landing site data to a designated receiver. The work that CSL accomplishes will adhere to NASA and internal requirements and will serve as a knowledge base for following years of CSL rocket teams.

Mission success involves validating the launch vehicle and payload design to all requirements and criterion outlined in the 2025 Student Launch Handbook and internal CSL requirements, and successfully performing a vehicle flight, recovery, and data transmission with flight survivability. To succeed in this mission, CSL's solution is a launch vehicle with a dual bay parachute deployment system, self-contained STEM craft for STEMnaut flight and data transmission, and a secondary payload airbrakes system to control vehicle apogee. This launch vehicle will be validated against the aforementioned NASA and CSL requirements, which are further discussed in the Project Plan section (Section 7).

CSL has continued to establish a knowledge base for future team members by recording advice, procedures, and other team information in handbooks on safety, STEM engagement, and general rocketry design. These knowledge bases contain rocketry information, as well as rules of thumb and other useful information for success in the NASA SL competition.

3.2. Launch Vehicle Overview

Chariot is a 108" long 4" diameter fiberglass rocket that flies on the Aerotech K1000T-P motor and aims to precisely hit CSL's target altitude of 4100 feet by utilizing airbrakes. It makes extensive use of 3D printed materials, featuring a high-efficiency Haak-series nosecone and a drag-reducing tail cone that doubles as motor retention. Throughout the design, minimal use of epoxy can be observed; each internal component of the rocket and some external components such as the rail buttons and fins are screwed in from the exterior of the fiberglass airframe, allowing for quick assembly and disassembly as well as rapid repair and iteration possibilities. The rocket has two non-in-flight separation points along its airframe and two in-flight separation points with a dual-bay dual deployment recovery system. Figure 3.2.1 shows the nature of the rocket's separation. The specifics of Chariot's recovery system and the rocket's expected flight performance are shown in Table 3.2.1.

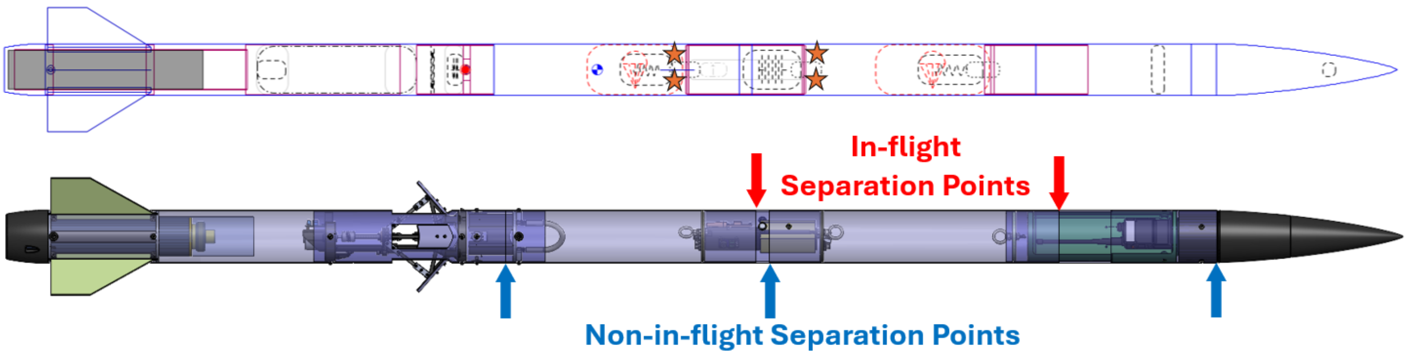


Figure 3.2.1* *(Top) *OpenRocket simulation schematic of Chariot (Stars denote the location of energetic materials);* ***(Bottom)*** *Full Solidworks CAD model of the final Chariot design with separation points labelled*

Table 3.2.1. *Chariot vehicle and performance summary. Performance metrics come from OpenRocket.*

Total Length	108"	**Apogee [ft]**	4716
Airframe Diameter	4.024"	**Velocity off Rail [ft/s]**	81.3
Airframe Material	G12 FG	**Max Velocity [ft/s]**	580
Motor	Aerotech K1000T-P	**Max Acceleration [ft/s^2]**	272
SSM	2.54 cal	**Flight Time [s]**	60.4

3.3. Subsystem Design

3.3.1. Nosecone

The nosecone subsystem is a critical component of the rocket whose main mission is to provide aerodynamic stability, structural rigidity, and to protect the main payload of the rocket.

The overall shape of the cone remains unchanged from the CDR report submitted in January. The fully assembled cone extends 14 inches beyond the airframe, has a 4-in diameter, and includes a 3-inch-long coupler tube. However, internal design modifications have been made to enhance the cone’s ability to withstand acute impact angles during recovery.

Previously, the design was assembled from four separate parts; this has been reduced to two parts to minimize stress concentration locations and potential separation points upon impact. Additionally, four 5-inch-long reinforcement bars have been added to strengthen the lower half of the cone against shear stress during landing. These design changes are further discussed in Sections 3.4 and 7.1.

A CAD drawing of the nose cone is shown in Figure 3.3.1 and a table of its important dimensions and characteristics are shown in Table 3.3.1.

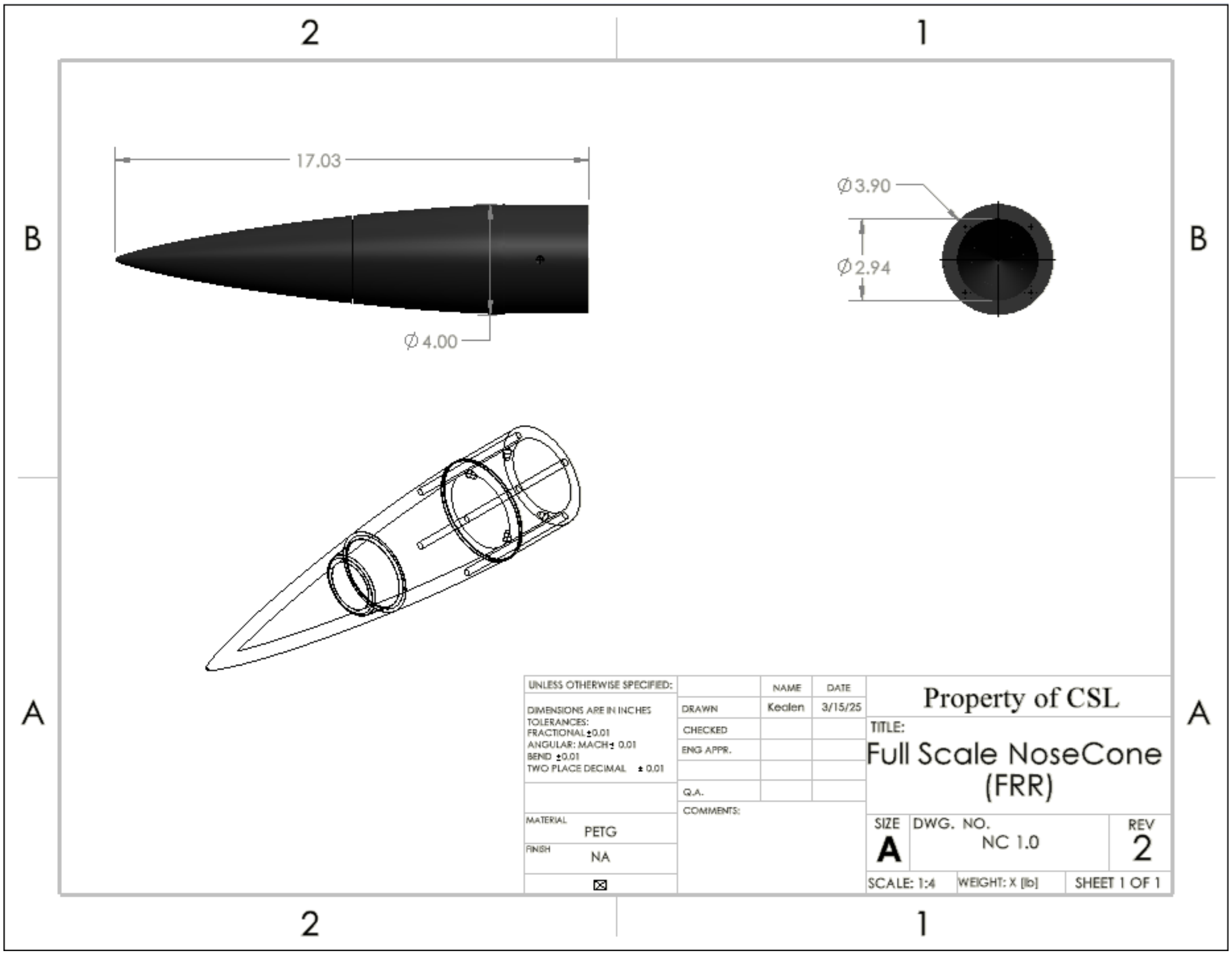


Figure 3.3.1. *Dimensioned SolidWorks drawing of the nosecone.*

Table 3.3.1. *Important dimensions and specifications for nosecone (as designed).*

System Specification	Value
Nosecone Length (in)	17.02
Nosecone OD | ID [At coupler tube] (in)	3.9 | 2.94
Nosecone Outer Geometry	Haak Series
Nosecone Tip Material | Infill % | Infill Pattern	PETG | 80% | Cubic
Nosecone Bottom Material | Infill % | Infill Pattern	PETG | 70% | Cubic
Nosecone Tip Mass (g)	315
Nosecone Botton Mass (g)	756
Fastener Type | Count	10/32 NF x 3/8 | 4

Fastener Mass (g)	1.75
Epoxy Mass (g)	12
System Total Mass (g)	1090

3.3.2. Airframe Sections & Couplers

Chariot's airframe is divided into three main sections: The aft section, the avionics section, and the forward section. The aft section houses the thrust structure, the motor retention system, and the airbrakes system, and features three equally spaced radial slots on one end through which the fins can slide during assembly. Strategically placed holes on airframe serve as screw points where internal components such as the centering rings in the thrust structure or the airbrakes can be mounted from the airframe exterior. To facilitate airbrake electronics access and maintenance, the aft section features a non-in-flight separation point just above the booster airframe where the aft section can be split, and the airbrake electronics canister can be accessed. The tubing section just above the booster airframe is the drogue parachute bay, which mounts just underneath the avionics bay.

The main parachute bay is bolted to the avionics bay via two radially spaced screws that penetrate the avionics bay coupler tube. Finally, the forward section is constructed in a more conventional manner, being the only airframe section that is bonded to its coupler with epoxy. This airframe section, of course, houses the primary payload, and features four equally spaced holes in the front by which the 3D printed nose cone can be mounted. Figures 3.3.2-4 show engineering drawings of each of the three airframe sections.

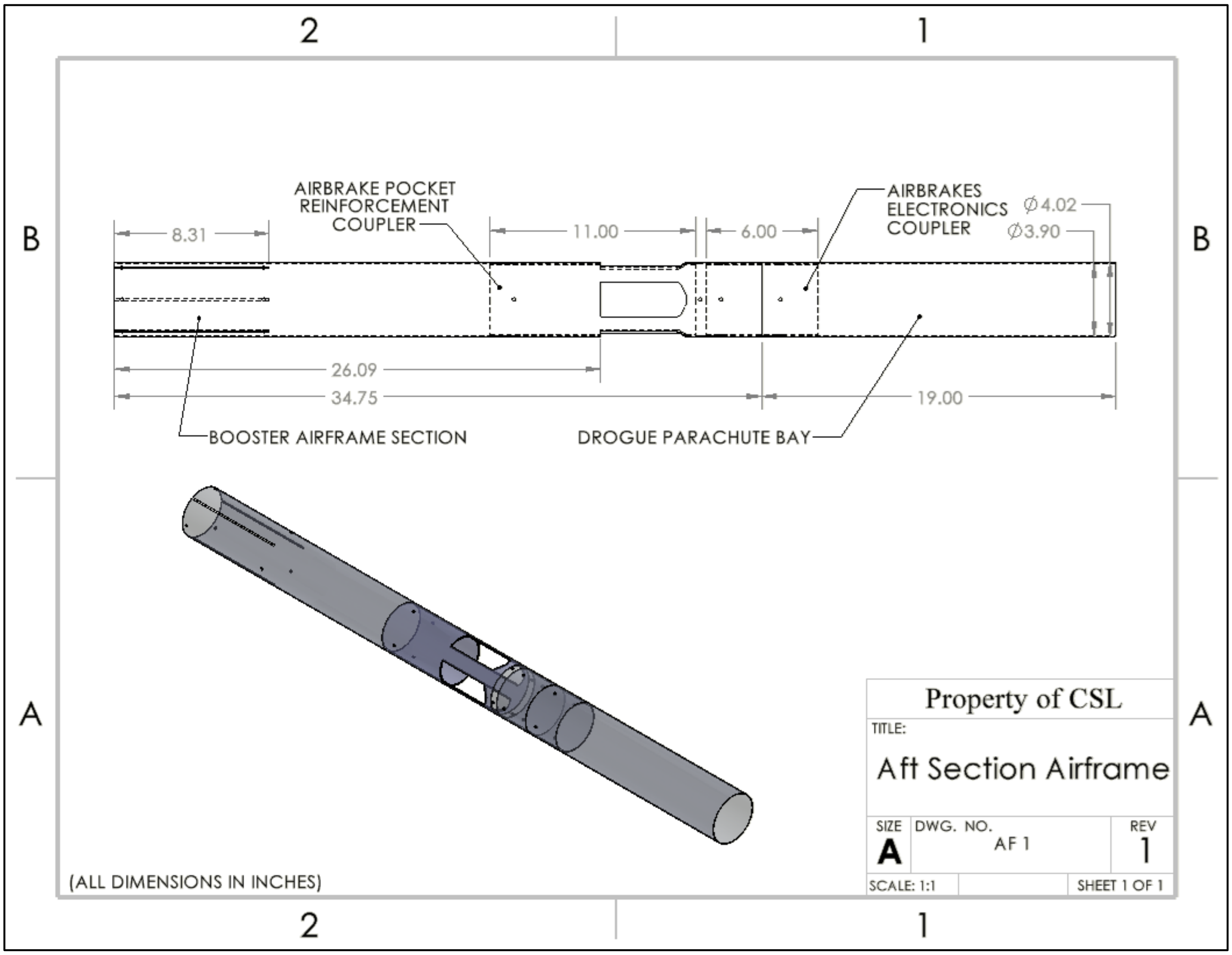


Figure 3.3.2. *Aft section airframe schematic.*

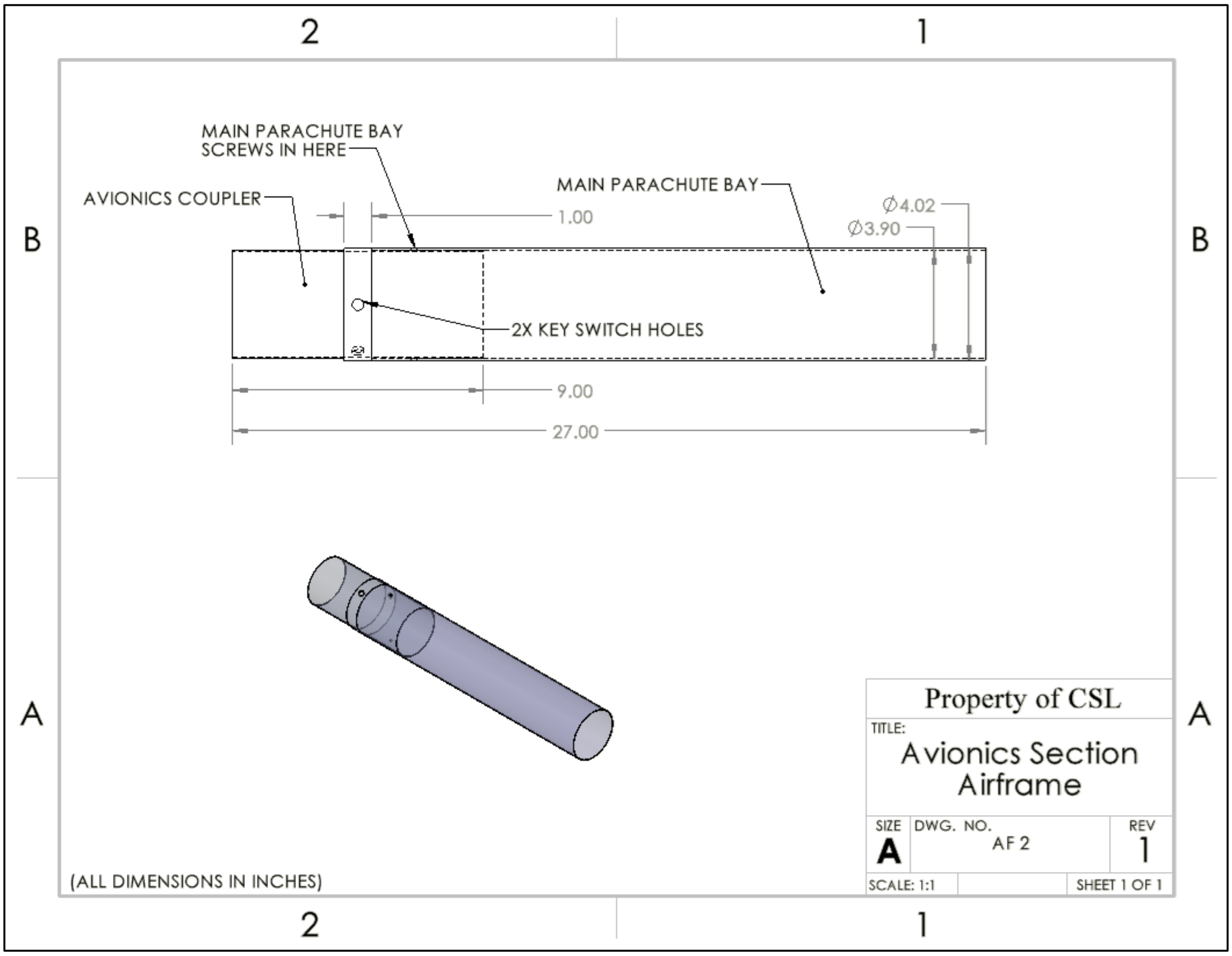


Figure 3.3.3. *Avionics section airframe schematic.*

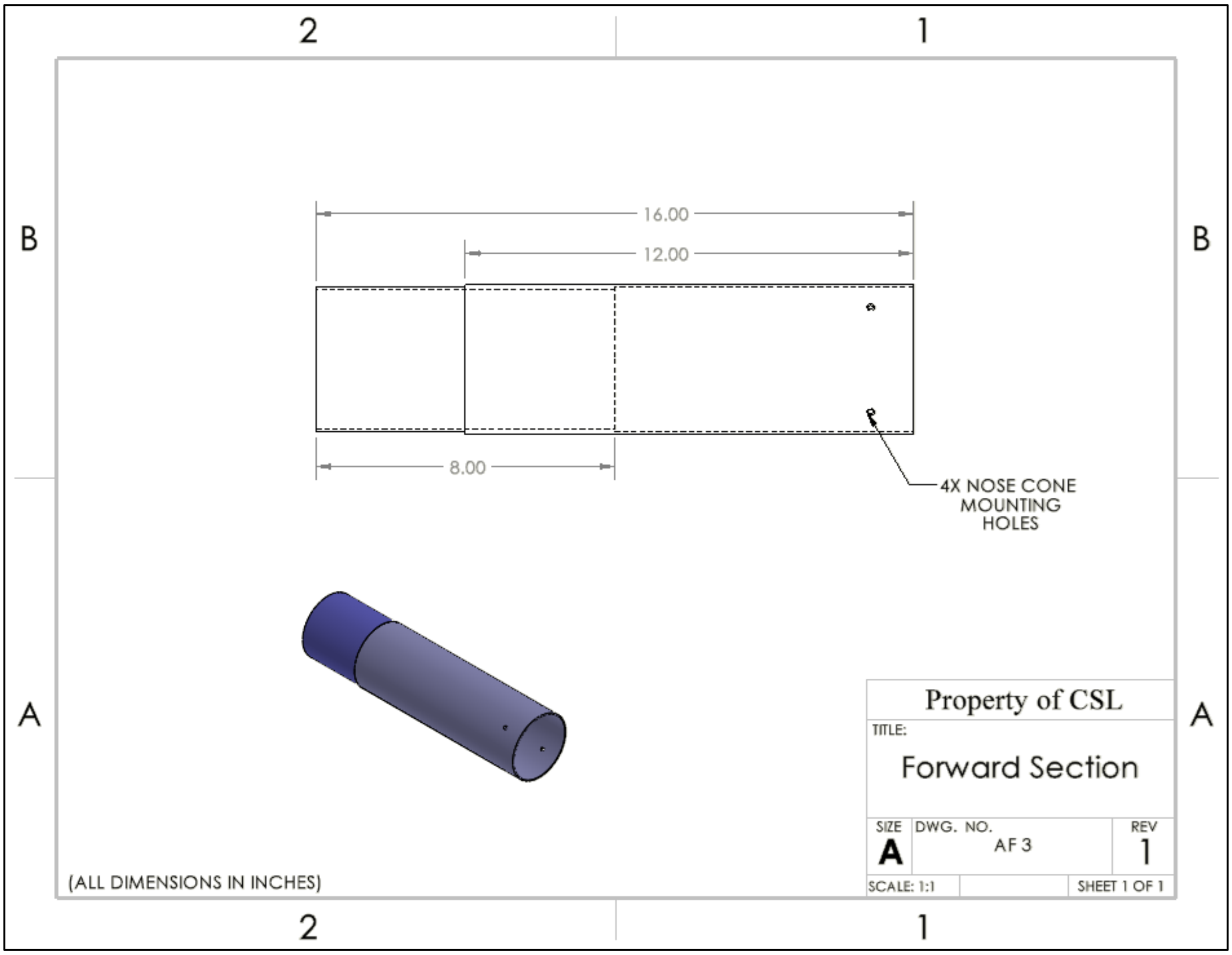


Figure 3.3.4. *Forward section airframe schematic.*

3.3.3. Avionics

There have been no major design changes made to the avionics since the CDR. 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. Figure 3.3.5 shows the final design of the avionics bay with relevant dimensions labeled. For more details on the mechanical and electrical design of the recovery avionics, refer to Section 3.4.3 and Section 3.5.4 respectively.

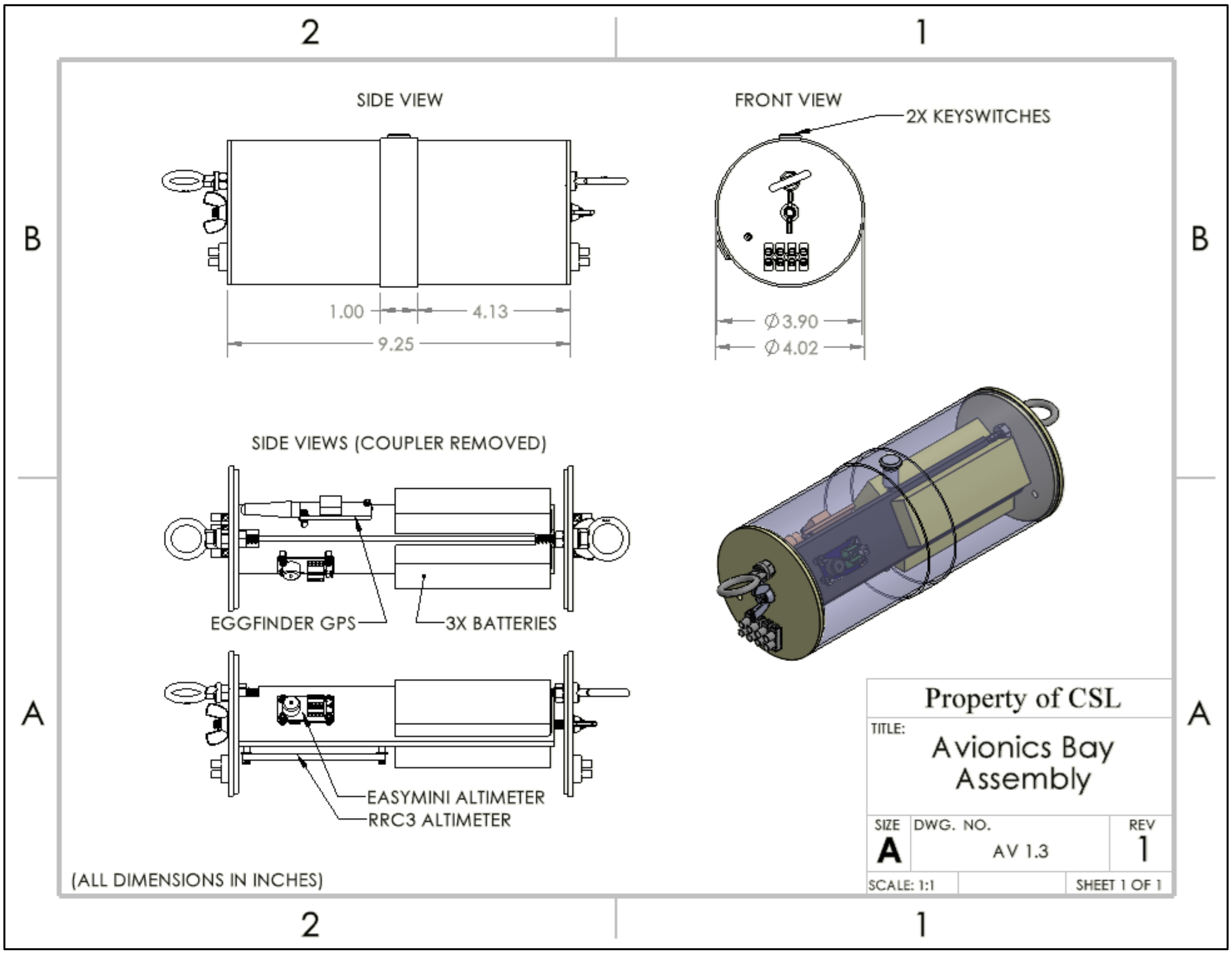


Figure 3.3.5. *SolidWorks drawing of the avionics bay final design.*

3.3.4. Camera Shroud

The camera was a subsystem that was used to validate the success or failure of the secondary payload during flight as well as provide video that can be posted on social media websites.

The camera shroud's design did not change substantially from the CDR report. CFD analysis tests verified that the overall shape of the shroud had negligible effect on the rocket's stability and can be viewed in Section 7.1. A detailed CAD drawing of the camera is provided in Figure 3.3.6 with a descriptive dimensions table provided in Table 3.3.2.

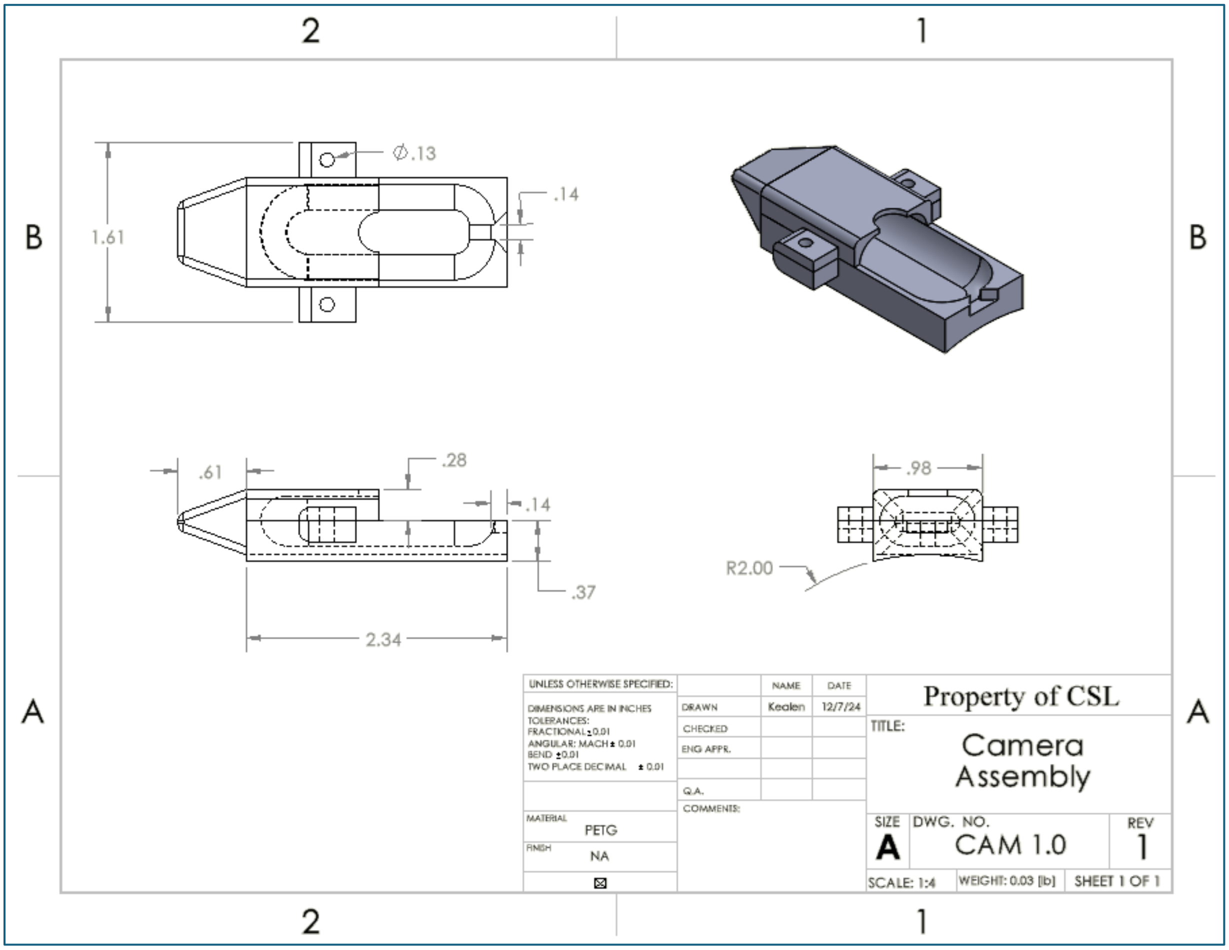


Figure 3.3.6. *Dimensioned SolidWorks drawing of the camera shroud.*

Table 3.3.2. Important specifications and dimensions for the camera shroud.

System Specification	Value
Length (in) | Width (in) | Height (in)	2.95 | 1.61 | 0.65
Material | Infill % | Infill Pattern	PETG | 25% | Cubic
Shroud Top Mass (g)	3
Shroud Botton Mass (g)	10
Fastener Type | Count	4-40 x 1/2 | 2
Individual Fastener Mass (g)	0.5
System Total Mass (g)	13

3.3.5. Shock Cord Mount

The shock cord mount is the subsystem that transfers the force from the recovery system and distributes it to the aft section of the rocket. It takes most of the force that the shock cords generate after the black powder charges ignite at apogee. When the drogue parachute deploys the rocket splits into two sections moving away from each other. The shock cords will fully extend and deflect a little bit but most of the energy from the black powder charge is released from the shock cords into the AV bay and the shock cord mount after they fully extend.

The mount itself is shown in Figure 3.3.7. Each dimension is shown in the drawing, along with the material and total mass. A summary table the important information can be found in Table 3.3.3.

Table 3.3.3. Important specifications and dimensions for the shock cord mount

System Specification	Value
Diameter (in)	3.74
Material	Aluminum
Total Weight (lb)	0.36

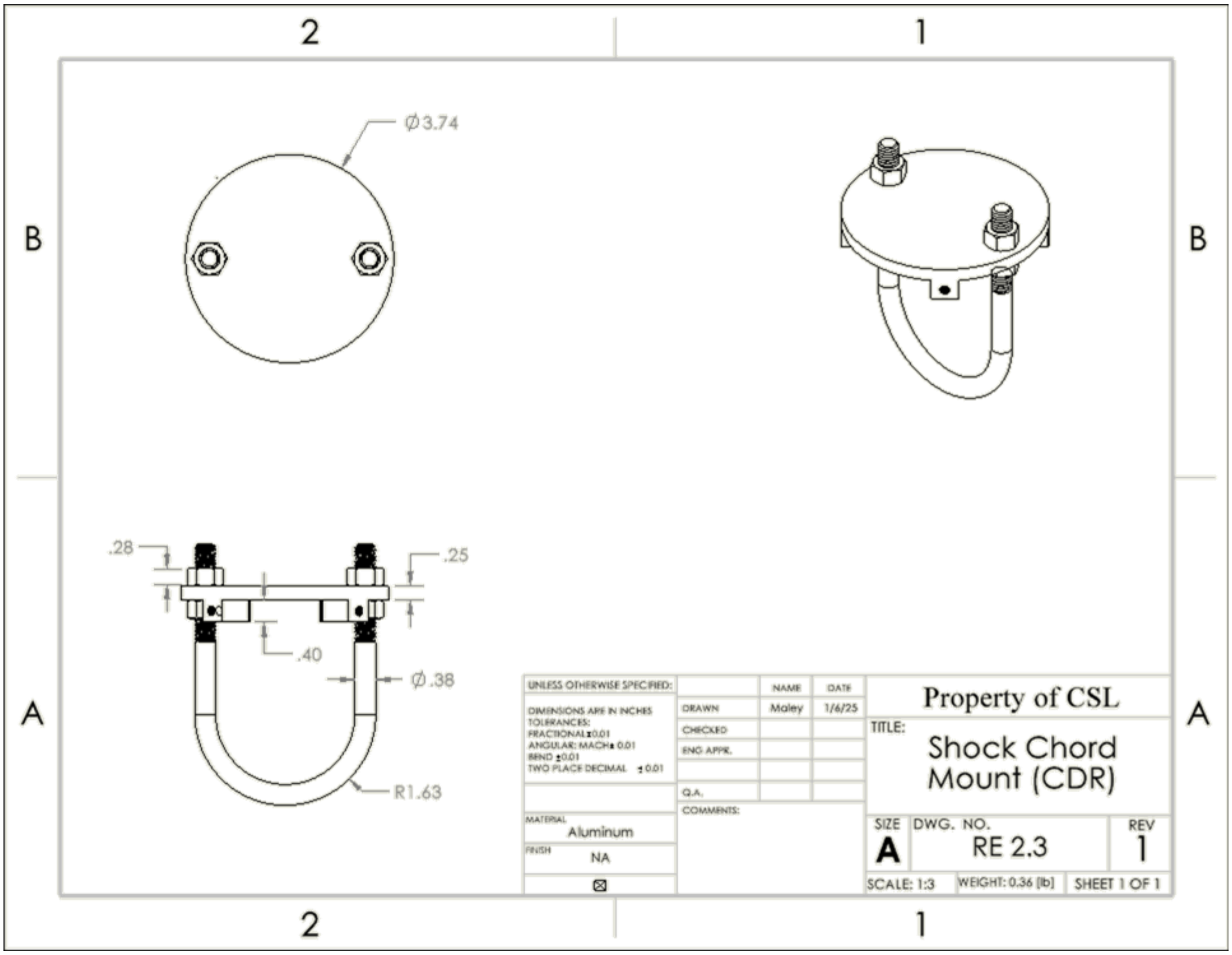


Figure 3.3.7. *Shock cord mount SOLIDWORKS Drawing.*

3.3.6. Bulkheads

Bulkheads exist in three locations on Chariot, as shown in Figure 3.3.8. Each one is designed to be composed of two pieces of 1/8” G10 fiberglass epoxied together to be 1/4” thick.

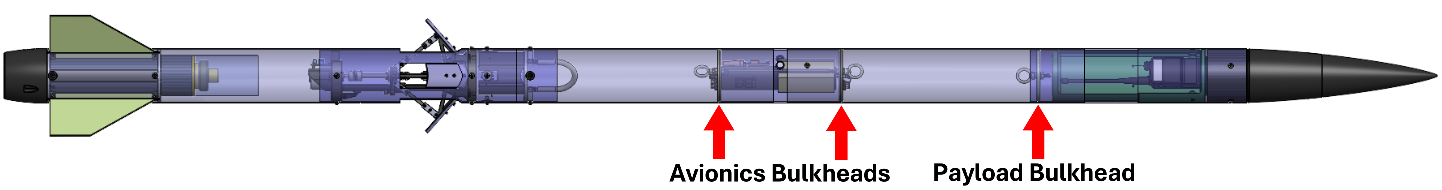


Figure 3.3.8. *Locations of bulkheads in Chariot.*

Each bulkhead in Chariot is an attachment point for the ends of a shock cord, so they feature one 1/4-20 forged eye bolt along with hex nuts and washers where appropriate. Figure 3.3.9 shows the design schematic for the payload bay bulkhead, and Figure 3.3.10 shows a schematic representative of both the avionics bay bulkheads.

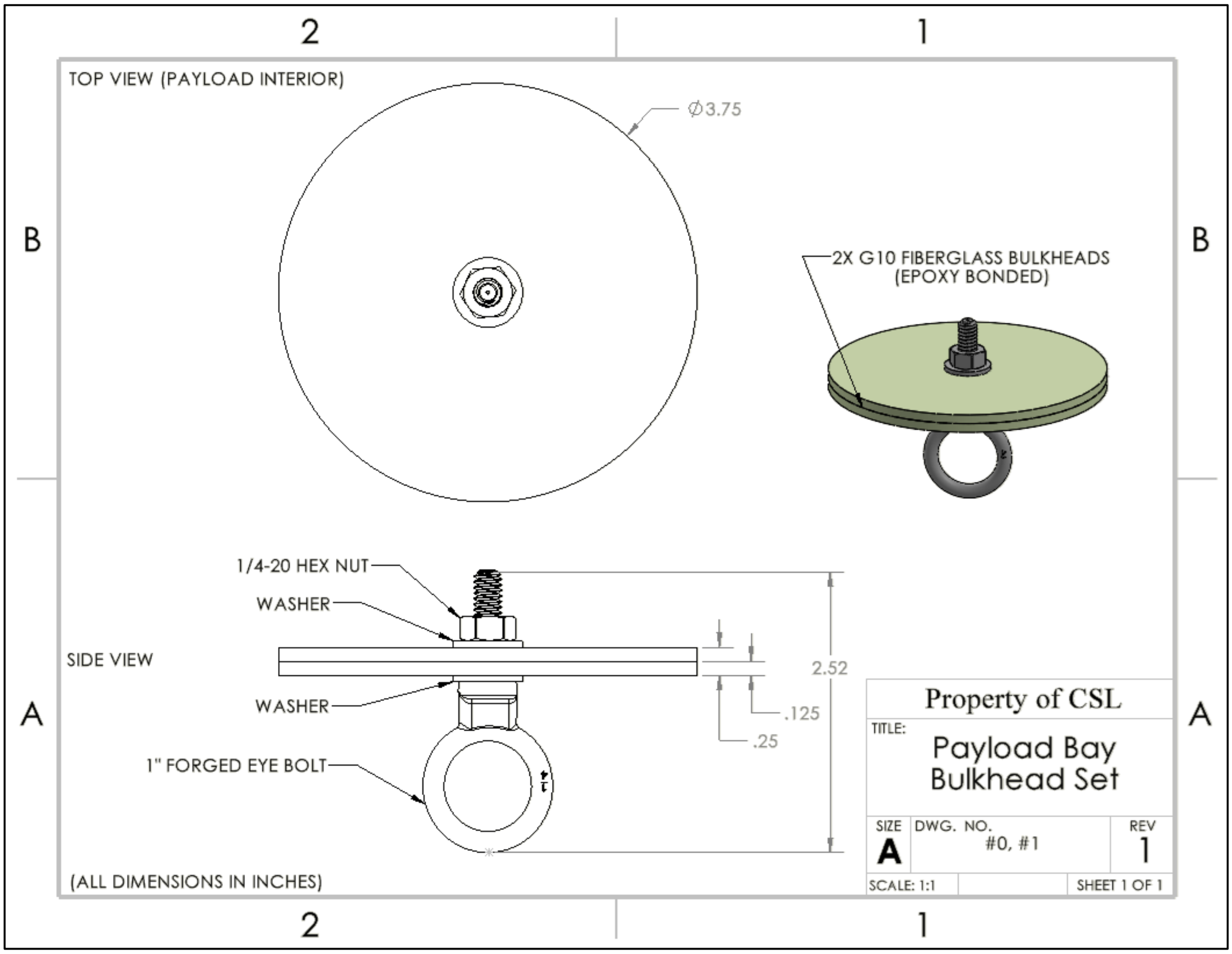


Figure 3.3.9. *Payload bay bulkhead schematic.*

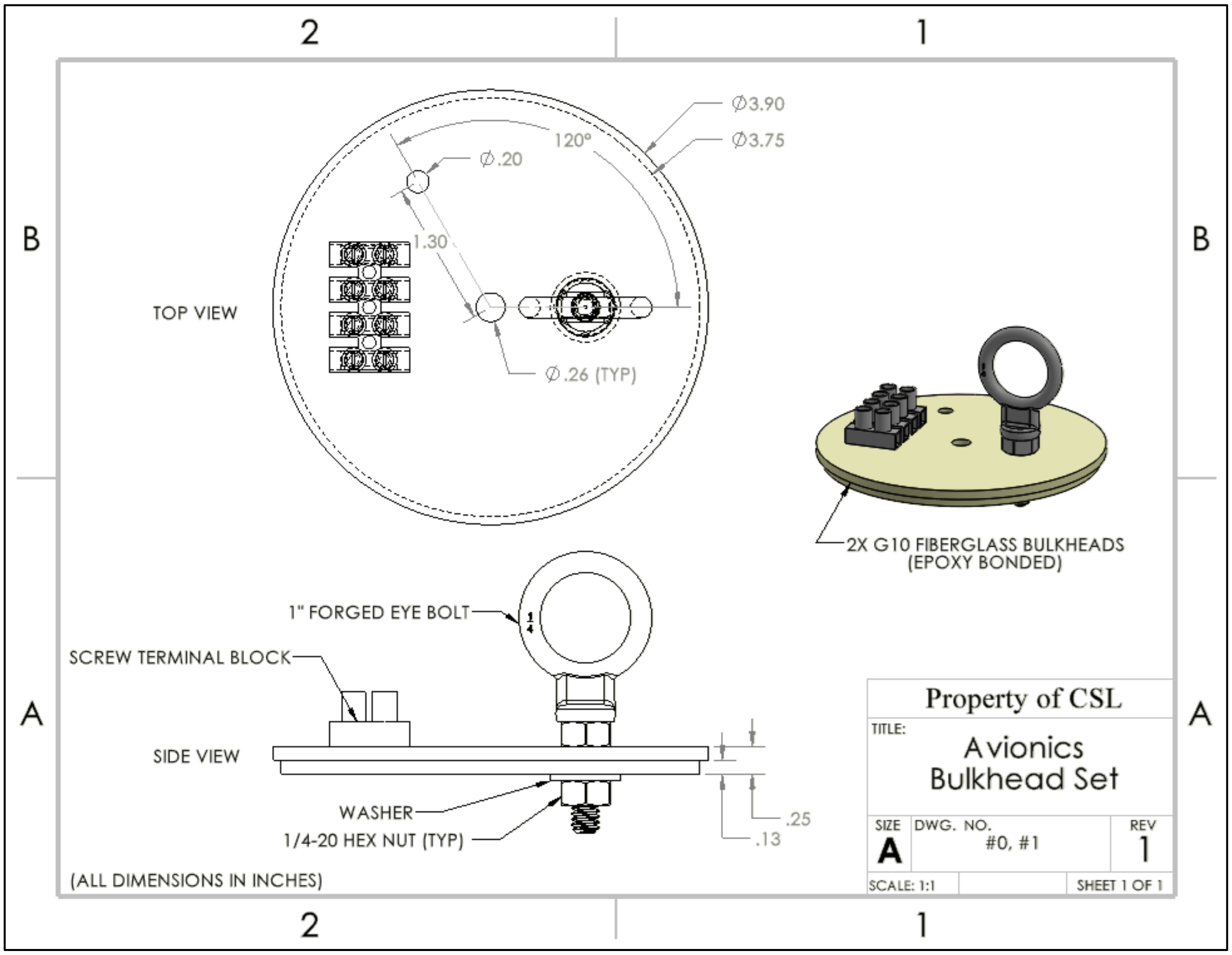


Figure 3.3.10. *Schematic of the avionics bulkhead assembly. Both avionics bulkheads are roughly identical.*

3.3.7. Centering Rings & Thrust Structure

CSL's launch vehicle uses custom designed centering rings to secure the motor tube and fins within the rocket's airframe. They ensure proper alignment inside the aft section, which is essential for stable flight. The ring is cut out in the center to fit around the motor tube and keep it secure. Slots were constructed on the face for the fins to be inserted and screwed in tightly. Holes facing outward were designed so the rings could be kept in place by being attached to the airframe. Three holes on the face of one of the centering rings were designed to ensure a connecting point for the tail cone. These centering rings were first modeled using SolidWorks and then manufactured out of aluminum.

The primary way CSL secures the motor tube in place is by using a 3D-printed flange designed to keep the motor centered within the aft section of the vehicle. The flange is glued to the motor retained using epoxy so that there is easy installation of the motor tube into the airframe. This also helps all the holes in the aft section to line up perfectly and effortlessly. The design of these flanges was modeled using SolidWorks and 3D printed using PETG.

During construction of the subscale, the CE noticed the tolerance of the center hole of the rings was incorrect. This caused the rings to not perfectly fit within the thrust structure and resulted in sanding down the pieces. CSL changed the tolerance for the full-scale by ± 0.005 inches. This affected alignment with the tail cone and resulted in a change of the hole locations on the tail cone. This change did not affect the performance of the centering rings, but it did change the geometry of the centering rings. CSL changed the dimensions slightly on the flanges so they would align more efficiently within the airframe. This resulted in shrinking the height of the piece by a fraction of an inch and squaring it so there would be a flat surface to lay on for 3D printing. This change did not affect the performance of the flanges but resulted in a much easier construction process for motor retention. A dimensioned SolidWorks drawing of the centering rings and motor retainment flanges is given in Figure 3.3.11 and Figure 3.3.12 respectively. Table 3.3.4 and Table 3.3.5 provide the specifications of the centering rings and flanges.

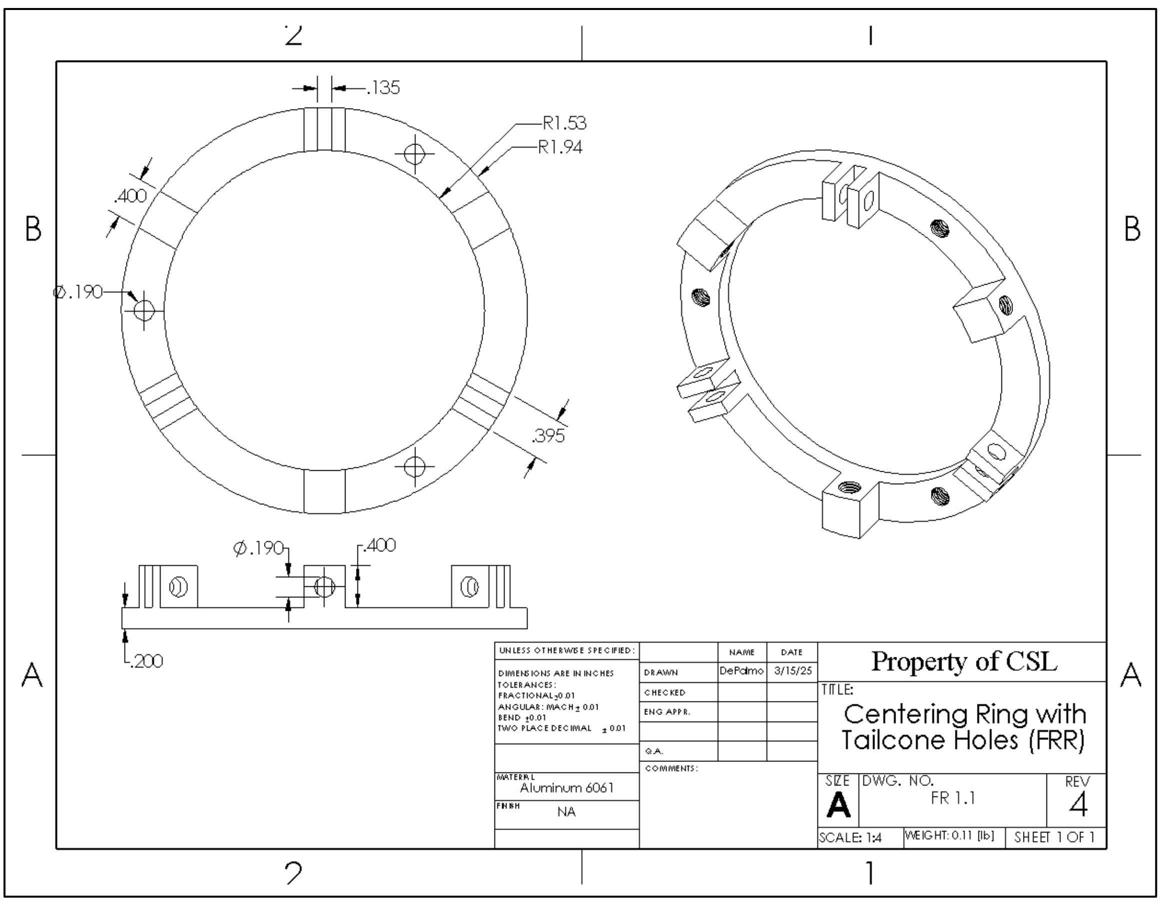


Figure 3.3.11. *Dimensioned SolidWorks drawing of centering rings with tapped tail cone holes.*

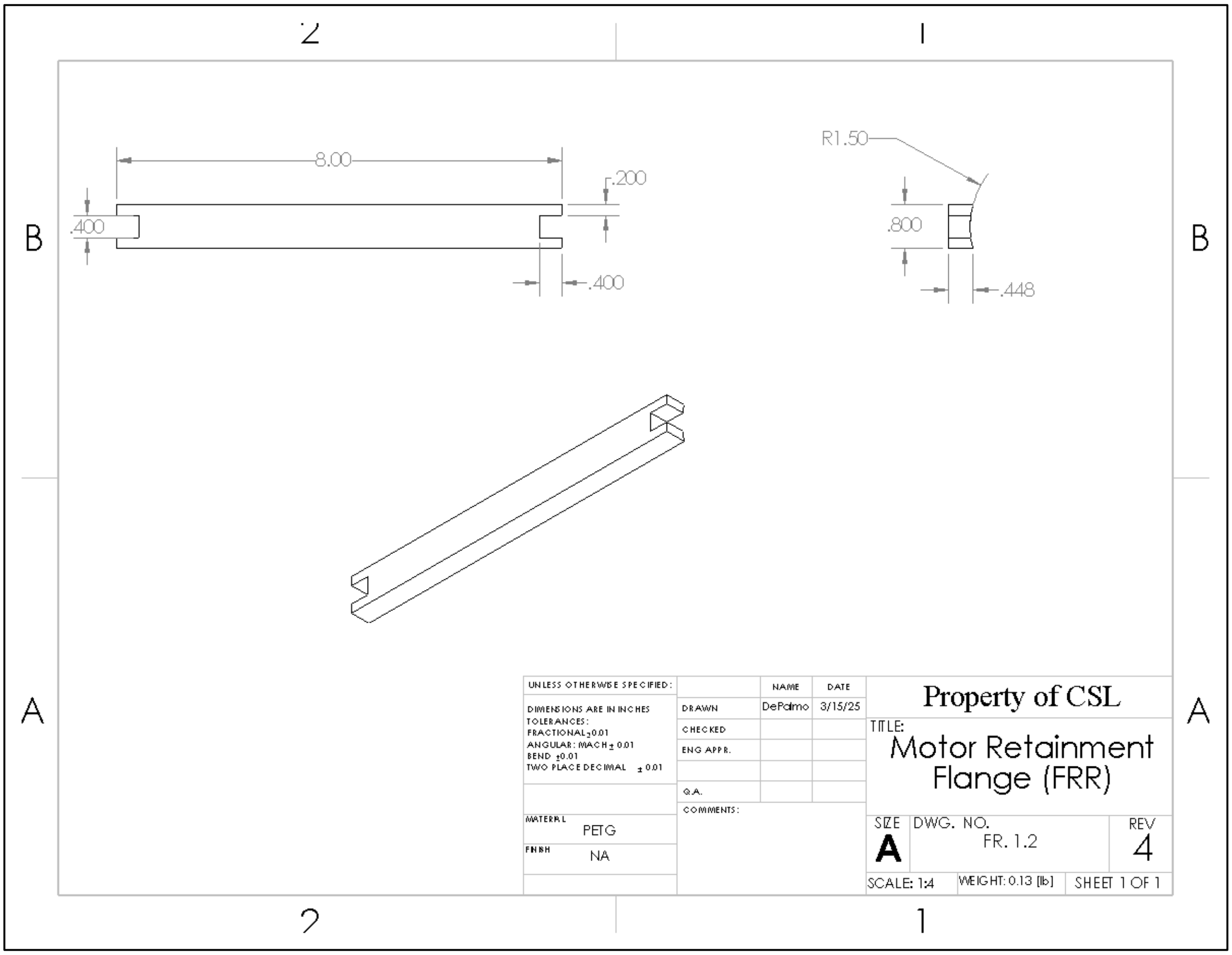


Figure 3.3.12. *Dimensioned SolidWorks drawing of the motor retainment flange.*

Table 3.3.4. *Centering ring design specifications.*

System Specification	Value
Centering Ring Material	Aluminum 6061
Centering Ring OD | ID (in)	3.87 | 3.05
Centering Ring Thickness (in)	0.200
Centering Ring Mass (lb | g)	0.11 | 49.8

Table 3.3.5. *Motor retainment flange design specifications.*

System Specification	Value
Flange Material | Infill % | Infill Pattern	PETG | 30% | Cubic
Flange Length (in)	8.00

Flange Width (in)	0.80
Flange Thickness (in)	0.50
Flange Mass (lb | g)	0.13 | 58.9

3.3.8. Fins

The fins of this rocket are clipped delta fins, and they are what allow for the rocket to maintain a steady flight throughout the launch. The fins went through some minor changes since the CDR. The span length had to be increased from 3.2 inches to 3.5 inches. The reason for this is because CSL desired to decrease the ballast in the nosecone to reduce stress at the nosecone shoulder and improve rocket ascent performance. This caused the center of gravity to move significantly. To maintain proper static stability margin, the height of the fins was then increased. The SOLIDWORKS drawing of the fins is shown in Figure 3.3.13.

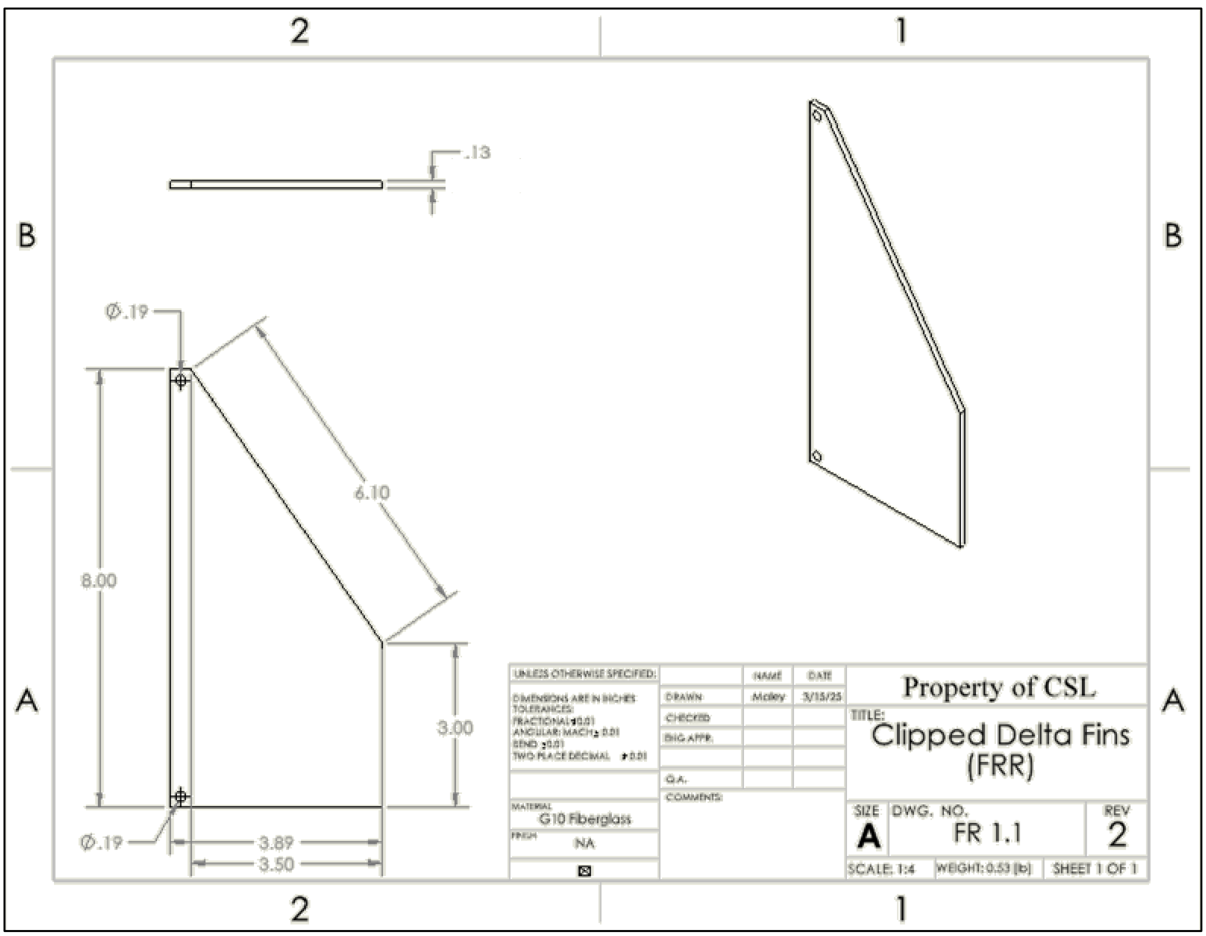


Figure 3.3.13. *SolidWorks fin drawing with important dimensions.*

3.3.9. Motor Retention

The launch vehicle utilizes a custom motor retention system in the form of a SolidWorks modeled PETG 3D printed tail cone and threaded fasteners. This system holds the motor casing in place, allowing safe retainment and removal of the motor post-flight. The tail cone was originally intended to reduce drag on the launch vehicle, but OpenRocket and Ansys analysis indicates it provides negligible benefits compared to a flat-bottomed vehicle. The system now proves CSL's capability to manufacture iterable, 3D printed motor retention systems that interface with the thrust structure's centering rings. The tail cone is also covered in lightweight polyester-based plastic body filler, also called Bondo, to fill gaps in the print to facilitate for painting of the rocket. As shown by the testing CSL requirement V.10, the system is strong enough for expected energies with its current infill but could be increased to adjust mass balance for proper CG placement. As shown by the VDF attempt flight, the tail cone can withstand heat damage for CSL requirement V.11.

Due to slight dimensional changes in the thrust structure's centering rings, the holes in the tail cone for fastening to the launch vehicle also shifted inward to the center of the cone. This shifting in hole locations has resulted in different internal geometry for the cone. This geometry does not affect flight performance and only changes the fastener holes to be fastener slots. As mentioned earlier, testing for CSL requirement V.10 has been conducted, showing that this small change does not reduce the structural integrity of the system. The tail cone used for the VDF is given in Figure 3.3.14. The system as assembled on the thrust structure is seen in Figure 3.3.15. The specifications of the motor retention system are given in Table 3.3.6.

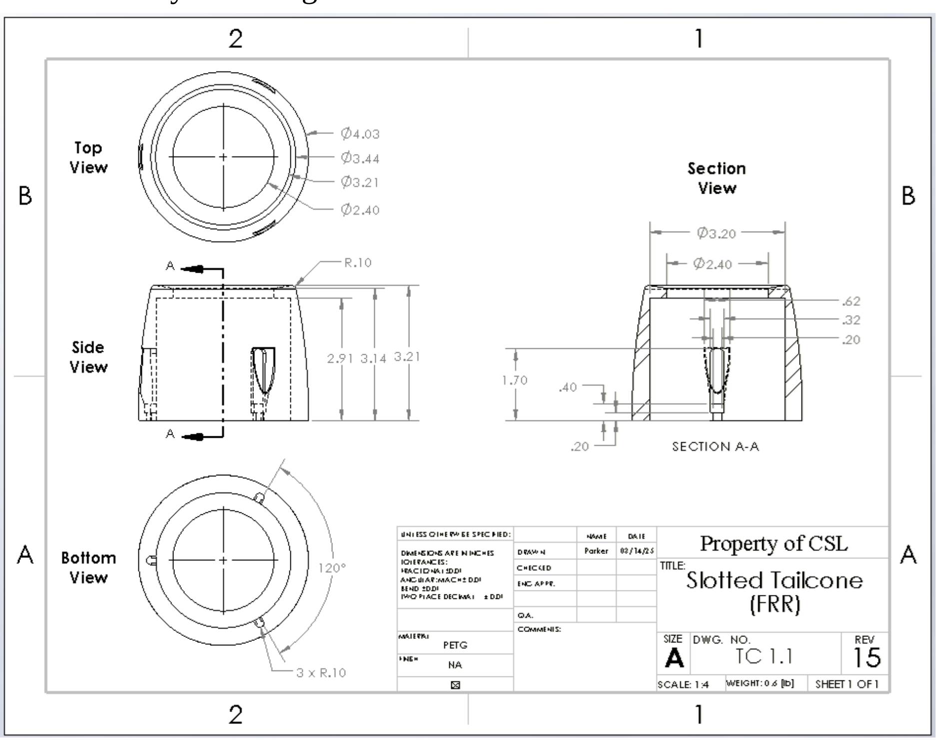


Figure 3.3.14. *Dimensioned SolidWorks drawing of the motor retention tail cone.*

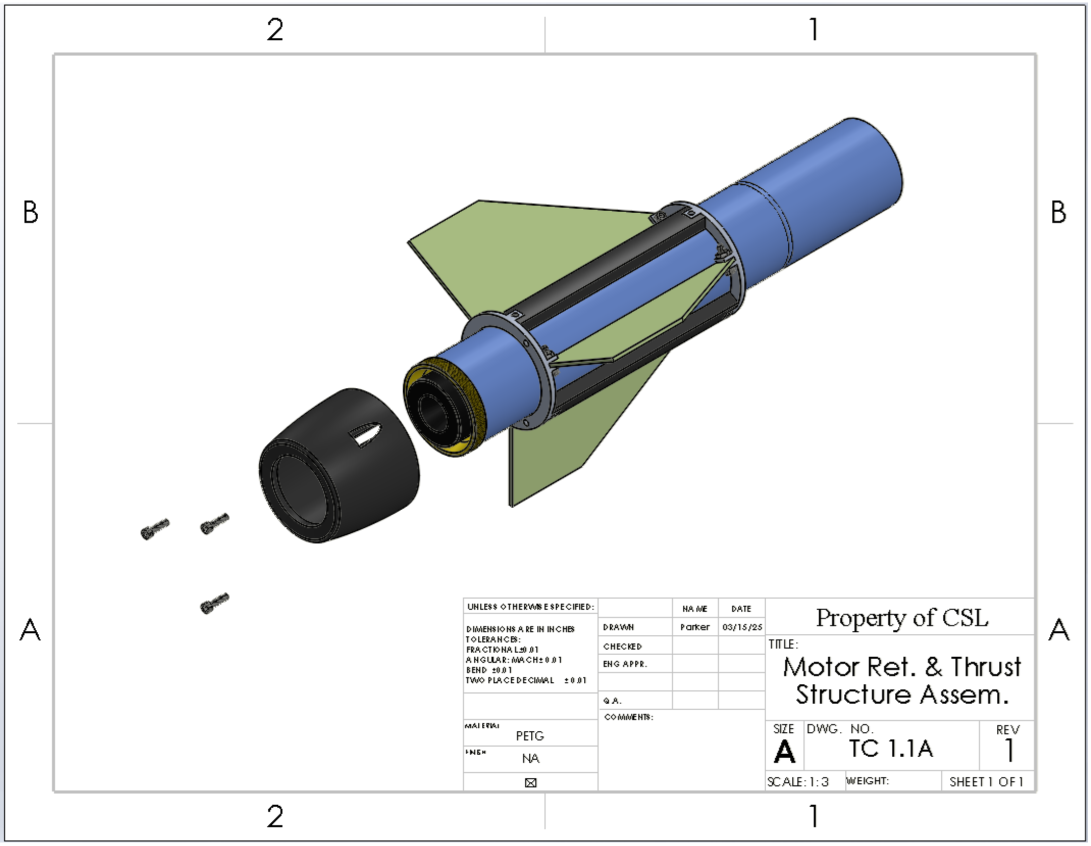


Figure 3.3.15. *SolidWorks drawing of the motor retention system as assembled on the vehicle thrust structure.*

Table 3.3.6. *Motor retention system as-designed system specifications.*

System Specification	As-Designed Value
Tailcone Length (in)	3.22
Tailcone OD | ID | Nozzle Diameter (in)	4.03 | 3.20 | 2.40
Tailcone Outer Geometry	Ogive
Tailcone Material | Infill % | Infill Pattern	PETG | 30% | Cubic
Tailcone Mass (lb | g)	0.29 | 132
Fastener Type | Count	3/16” 10-32 Hex Head (3/4”) | 3
3 Fastener Mass (lb | g)	0.02 | 9
System Total Mass (lb | g)	0.31 | 141

3.4. Subsystem Construction

3.4.1. Nosecone

The nosecone subsystem was constructed using 3D prints and assembled using epoxy to adhere components together. The following sections describe the process used to assemble the nose cone.

3.4.1.1. 3D CAD Preparation

The construction of the nose cone began with the creation of a 3D model in SolidWorks. The desired cone dimensions (length and height) were used in the Von Karman Haak Series Equation to produce an equation-driven curve in a sketch plane. A sketch of the cone along this plane was then created, as shown in Figure 3.4.1.

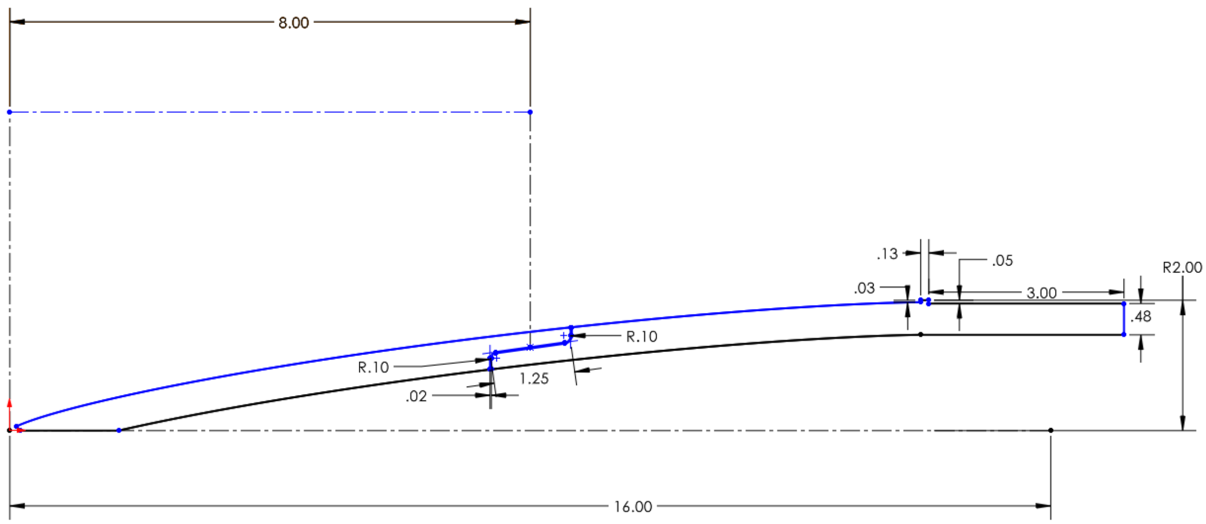


Figure 3.4.1. *SolidWorks sketch of nosecone with dimensions.*

Next, the SolidWorks Revolve feature was used to rotate the sketch around a central axis, forming the nosecone shape. Holes were then cut into the revolved cone body to accommodate fasteners in the coupler tube, as well as reinforcement pins.

Once the 3D model was complete, it was split into two different parts and saved as SDL files for 3D printing.

3.4.1.2. 3D Printing and Assembly

Both halves of the nosecone were printed using a Bamboo Lab A1 printer using PETG filament. Both halves of the cone were printed in a cubic pattern with an 80% infill for the upper half and a 70% infill for the lower half of the cone.

Once both halves of the cone were printed, they were adhered together using quick-dry epoxy and left to cure for an hour before handling. Once the epoxy had set, the cone was mounted to a lathe for even sanding and smoothing. Additional epoxy was then applied to further streamline the cone's surface and reinforce the structure.

To achieve this, the cone was secured in the lathe chuck and spun at 60 rpm while slow hardening epoxy was drizzled over its outer surface. A tarp was laid out underneath the cone to contain any drippage and minimize mess. To accelerate the drying process, a heater was used while the cone continued to spin for approximately for three hours while under supervision. Figure 3.4.2 shows the process of smoothening the nose cone on the lathe.

Figure 3.4.2. *Setup of nosecone lathe assembly.*

Throughout the assembly, proper safety precautions were followed. anytime that epoxy was used, safety glasses, latex gloves, and respirator masks were used in accordance with Safety rules C.1 and C.2.

After the cone is done on the lathe, it needs finalizing touches before being ready to launch. This includes adding the reinforcement pins and fasteners, adding in the necessary ballast and securing it with epoxy, and painting the cone. For the VDF attempt submitted with this document, the nosecone was filled with a ballast of 500 g of steel powder and was launched with two coats of primer on it. Figure 3.4.3 displays the completed cone used in our VDF attempt fully assembled and attached to the rocket ready for launch.

Figure 3.4.3. *Nosecone fully assembled and ready for launch.*

3.4.1.3. Differences compared to original Design

In the time between turning in the CDR report and the writing of this report, the nosecone underwent several internal design changes to address issues regarding its ability to survive acute angle impacts with the ground.

As mentioned in Section 3.3.1, the nosecone was initially designed to be printed in four smaller components as that made it a quicker and easier job for 3D printers to print the cone. However, through subscale test launches using this design, it became apparent that the sections where the individual cone components were joined together usually served as locations where stress concentrations occurred. These caused the 3D print to crack and break in these locations. As a result, the design was changed to what is shown in Figure 3.4.3 and used throughout the full-scale launches.

The second internal change made to the cone was the addition of reinforcement pins in the lower half of the cone. Results from the drop tests recorded in Section 7.1 showed that the cone design is more than capable of withstanding near perpendicular impacts with the ground. However, the cone design was unable to withstand impacts when it landed parallel to the ground. From the tests, it was observed that the cone tended to break right above where it was attached to the airframe due to the cone trying to take the full weight of the for section of the rocket acting at that specific location. To prevent the cone from breaking in such a way again, five-inch-long reinforcement pins were inserted into the lower half of the cone to provide structural support and take the brunt of the impact forces acting on that section.

There were minor physical differences between the finished cone and the planned design that arose during the construction process. Table 3.4.1 details the dimensional changes between the finalized cone and the planned design. As shown in the table, the actual cone ended up being a fraction of an inch shorter and approximately 30 grams lighter.

These differences arose primarily during the sanding period as the two 3D printed parts did not fit together perfectly and had to be sanded down to achieve a smooth, secure fit between the two parts. Additionally, weight reduction occurred due to the inherent limitations of 3D printing, as printed parts are not always produced with absolute precision.

Table 3.4.1. *Differences between planned nosecone and actual nosecone.*

System Specification	Planned	Actual
Nosecone Length (in)	17.02	16.875
Nosecone Tip Mass (g)	315	300
Nosecone Botton Mass (g)	756	745
Approximate Epoxy Mass (g)	15	18
System Total Mass (g)	1093	1063

3.4.2. Airframe Sections & Couplers

The airframe subsystem was constructed out of 4-inch and 3.9-inch G12 fiberglass tubing. The main sections of the airframe, along with their corresponding coupler tubes, were cut to their design lengths using a circular saw. These sections included the main and drogue chute bays, payload, and aft section. To ensure a precise fit, each component was sanded using a composite belt sander to achieve a smooth connection between the tubes.

Once all the tubing was cut and sanded, various holes were drilled to accommodate the mounting other subsystems. These included openings for the motor retention system, primary and secondary payloads, nosecone, and rail buttons. Additionally, a Dremel was used to cut out the slots for the fins in the aft section tube.

During the airframe construction, complications arose before the first full scale launch. A measurement error occurred when drilling holes for the secondary payload and using the CNC routing machine to cut out the holes for the brake flaps. As a result, the secondary payload did not fit within the aft section, as it collided with the motor tube as shown in Figure 3.4.4.

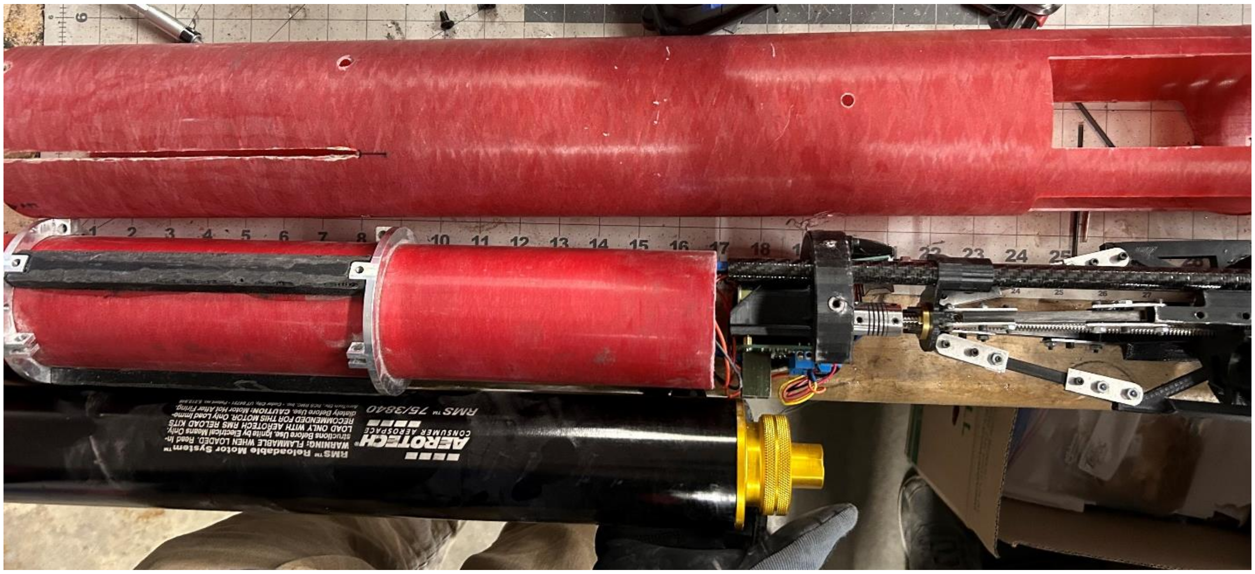


Figure 3.4.4. *Aft section of the rocket showing that the secondary payload and motor do not fit.*

To overcome this issue, the aft section was cut in half, and a 9-inch-long section of fiberglass coupler was inserted to create the necessary space for the air brakes. To compensate for this design adjustment and maintain the rocket's overall length, the drogue chute bay was shortened by 3 inches.

Additionally, due to a catastrophic buckling of the thin stringers defining the airbrake flap pockets in the aft section airframe, CSL deemed it necessary to glue a stiffening fiberglass coupler into the booster airframe to reinforce the weak area. The aft section airframe was rebuilt entirely in preparation for the second chariot launch attempt, only this time a coupler had been glued in the place of the airbrakes flaps with the pockets being cleared out afresh using the CNC router as shown in Figure 3.4.5. It proved difficult to evenly distribute epoxy around the reinforcing coupler and it became necessary to reglue parts of the coupler that freed themselves after the second flight, as well as grind down forward clearance for the air brake flaps to allow them to operate freely.

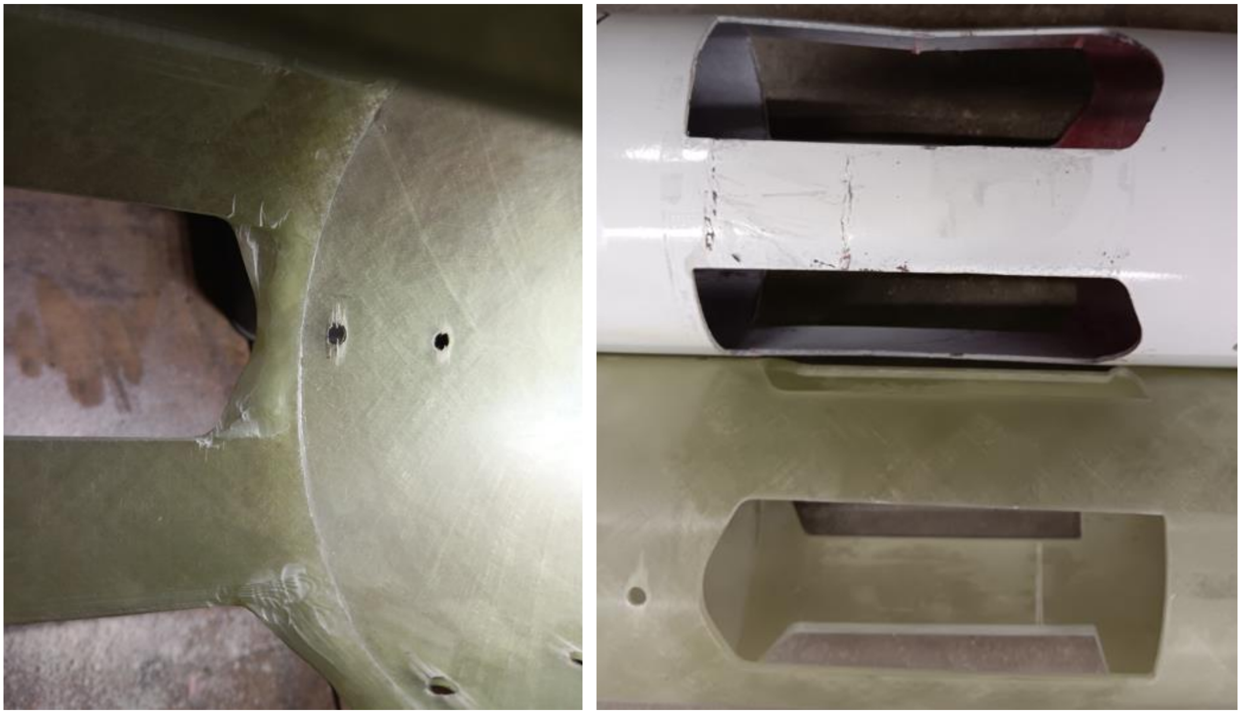


Figure 3.4.5. (Left) Interior view of the strengthening coupler added to the stringers; **(Right)** Comparison photo between the damaged airframe and the reinforced airframe.

Table 3.4.2. *Summary of fiberglass part conditions from design to manufacture*

Component Name	Critical Dimension	Design	Manufacture	Actual Mass [lb]	Actual Mass [g]
Airframe					
Booster Airframe	*Length [in]*	34.75	34.81	1.70	771.00
Drogue Parachute Bay	*Length [in]*	19.00	19.00	1.19	538.00
Avionics Ring	*Length [in]*	1.00	0.94	0.06	25.00
Main Parachute Bay	*Length [in]*	22.00	21.94	1.25	566.00
Payload Bay Airframe	*Length [in]*	14.00	13.94	0.79	360.00
Couplers					
Booster Reinforcement Coupler	*Length [in]*	12.00	12.50	0.68	310.00
Airbrake Electronics Can Coupler	*Length [in]*	6.00	6.13	0.39	175.00
Avionics Coupler	*Length [in]*	9.00	9.00	0.52	235.00
Payload Bay Coupler	*Length [in]*	8.00	8.00	0.46	209.00
Control Surfaces					
Fins	*Height [in]*	3.50	3.49	0.19	86.70
Airbrake Flaps	*Length [in]*	4.50	4.40	0.03	14.00
	Width [in]	1.72	1.60		

3.4.3. Avionics

The avionics sled was manufactured on an Ender 3 3D printer and the altimeters, GPS, and batteries were mounted onto it using heat set inserts and Velcro straps respectively. The halves of the bulkheads were epoxied together while using the appropriate PPE (safety glasses, mask, gloves), and the terminal blocks and eye bolts were then epoxied on to the bulkheads as done for the subscale rocket. Figure 3.4.6 shows the avionics bay as manufactured. The final as built mass of the avionics bay is 1225 g. This mass includes the coupler tube that the avionics sled is housed inside of. Because the avionics bay is completely housed inside a 9” coupler tube that is manufactured to very tight tolerances, no important dimensions of the avionics bay were different than the designed dimensions.

Figure 3.4.6. *Avionics bay as manufactured.*

3.4.4. Camera Shroud

The camera shroud was constructed using PETG 3D print and then it was mounted to the rocket using epoxy.

The camera shroud was constructed in SolidWorks by creating a 3D model that the Estes Astrocam could sit securely in. The model was made into two different sections, a lower section that the camera would sit in that would be adhered to the airframe of the rocket, and an upper section that would be fastened to the bottom section that would hold the camera in place during its flight. Figure 3.4.7. shows the lower portion of the camera being printed on an Ender 3 printer.

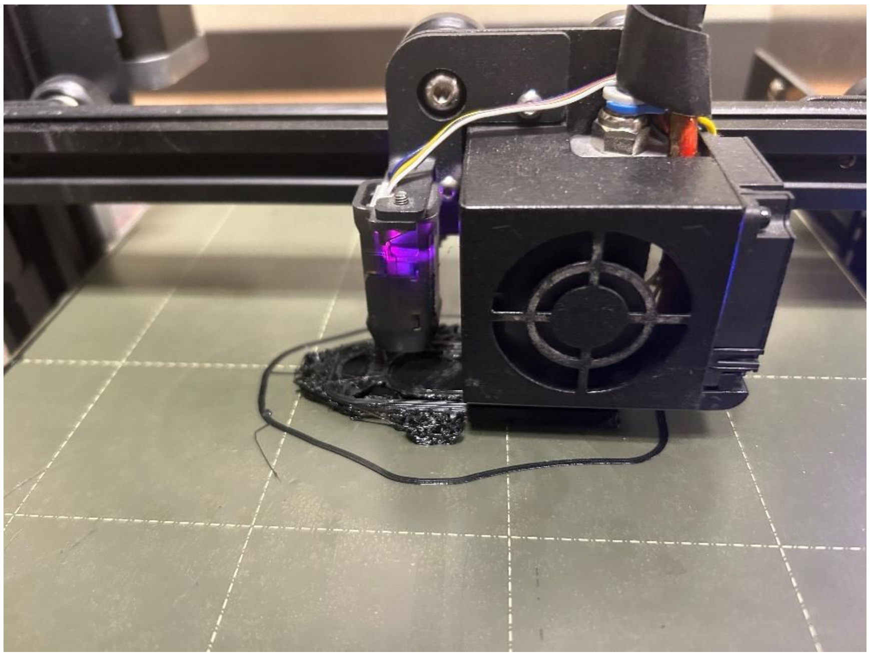


Figure 3.4.7. *The lower half of camera shroud being printed.*

Once both parts were printed, two small inserts were press-fitted into designated slots in the lower half of the shroud. These inserts provided secure attachment points for the fasteners that would hold the upper section in place. Figure 3.4.8 shows the full camera shroud after 3D printing.

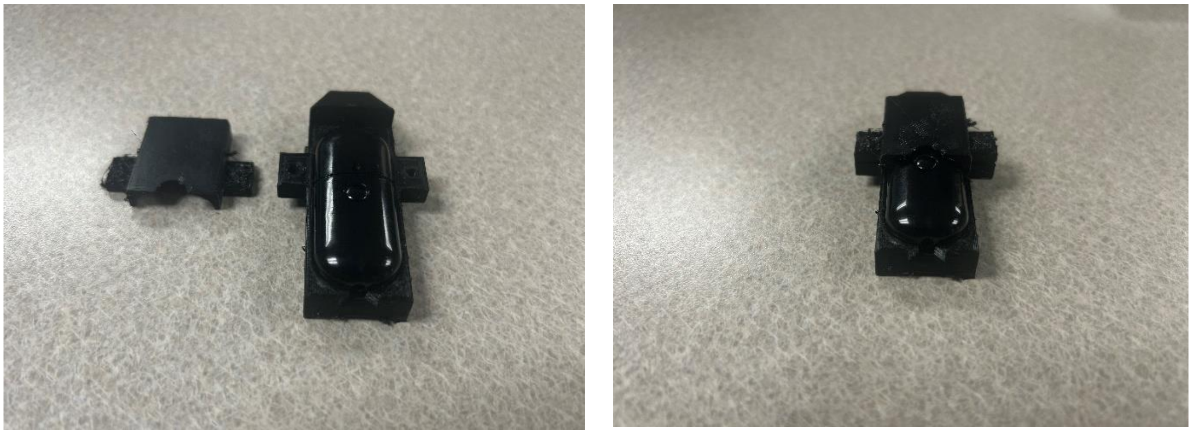


Figure 3.4.8. *Fully printed camera shroud and Estes camera.*

After assembling the lower section with the inserts, the Estes Astrocam was test-fitted to confirm a secure hold. The upper section of the shroud was then aligned and attached using small fasteners, ensuring that the camera remained stable but could still be removed if necessary. The two parts were then primed and painted so that they were the same color as the rest of the rocket.

To mount the camera shroud onto the rocket, the lower section was adhered to the airframe using a high-strength epoxy. The bonding surface was lightly sanded beforehand to promote better adhesion.

3.4.4.1. Differences Compared to Original Design

The fully assembled camera shroud had minimal differences compared to the original design, with the only notable change being an increase in mass from 13 g to 15 g.

However, during a full-scale practice launch, issues arose with the Estes Astrocam that pushed the team to seek a more durable camera and mounting solution. CSL's Estes Astrocam exhibited a tendency to stop recording after approximately 60 seconds in colder temperatures. Additionally, the shroud detached from the rocket during landing, presenting significant reliability concerns.

As a result, CSL replaced the Estes Astrocam with a more reliable RunCam. CFD simulations were conducted to compare the aerodynamic impact of the new camera with the existing camera shroud with the results being displayed in Section 7.2. As the CFD results show, the new camera had minimal effect on the rocket's stability and was similar to the existing shroud design. The effectiveness of the RunCam was demonstrated in the VDF flight attempt in which the camera operated successfully and was able to validate that the air brakes did not deploy. This combined with the RunCam's similar video recording characteristics and ability to be fastened directly to the airframe led CSL to adopting the new camera for all future full-scale flights. Figures 3.4.9 and Figure 3.4.10 show the RunCam and its mounting on the airframe.

Figure 3.4.9. *RunCam.*

Figure 3.4.10. *RunCam fixed to airframe.*

3.4.5. Shock Cord Mount

The shock cord mount was one of three parts that needed to be manufactured since they were custom parts made from aluminum. The shock cord mount consists of a custom-made mount, and a U-bolt that can withstand the pulling force of the shock cords. The mount was cut out in Cedarville University’s CNC mill. With help from the shop stewards, a tool path was made, and the mount was cut out successfully.

After the mount was cut, four other holes needed to be drilled and tapped so it can be screwed into the airframe. The team took the part and cut out the four holes using one of Cedarville University's mills. Then, the holes were manually tapped to make sure they could fit the 10-32 screws.

The team then realized that the diameter of the mount was a little too large to fit into the airframe, so they took the part to one of Cedarville’s lathes to reduce the mounts diameter by a small amount. The manufactured shock cord mount can be seen assembled in Figure 3.4.11.

Figure 3.4.11. *Finalized shock cord mount assembled.*

3.4.6. Bulkheads

To promote epoxy adhesion, an engraving bit on a rotary tool was used to roughen the interior faces of the bulkhead discs. Figure 3.4.12 shows the bulkheads during manufacturing, before roughing treatment, and after roughing treatment.

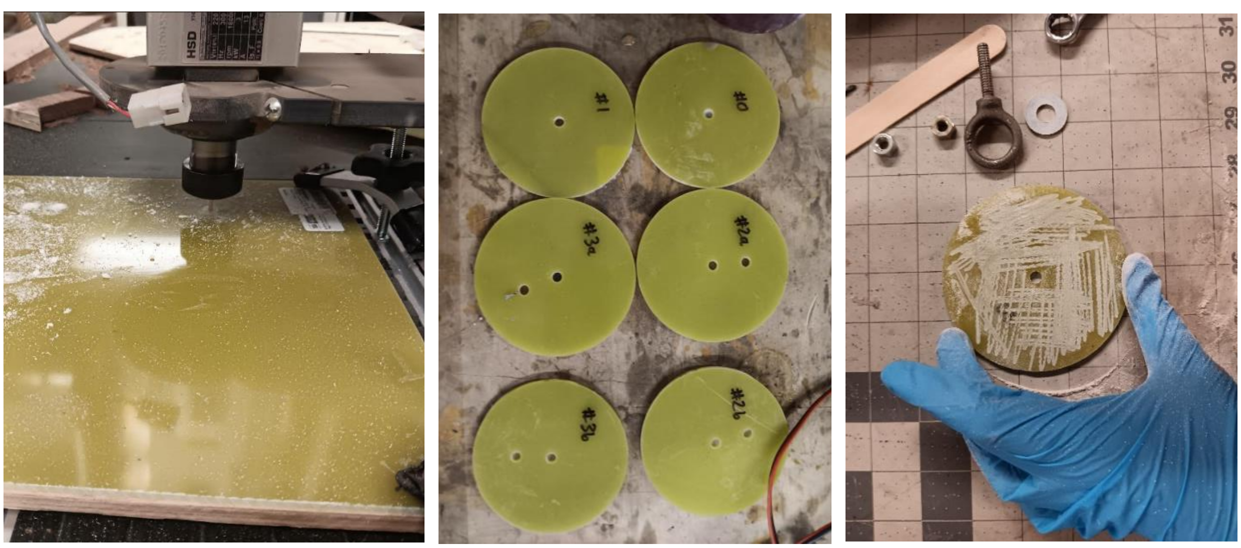


***Figure 3.4.12*. (Left)** CNC router manufacturing the bulkhead disks; **(Middle)** bulkhead disks sorted and ready for roughing; **(Right)** example of a roughed bulkhead disk prepped for epoxy.

Once the bulkheads were epoxied, the appropriate hardware was screwed in and locked into place with more epoxy. The avionics bulkheads were then attached to the avionics bay via butterfly nuts, and the payload bay bulkhead was glued 0.5” into the payload coupler and filleted on both sides with epoxy as shown in Figure 3.4.13.

Figure 3.4.13. View of the interior and exterior fillets on the payload bay bulkhead.

3.4.7. Centering Rings & Thrust Structure

For Project Elijah, the centering rings are one of the few machined parts. The centering rings were designed using SolidWorks and then manufactured in-house using Cedarville University’s machines and facilities. During the process, all proper PPE was used especially when using the machine shop mills and drills. CSL used proper techniques when applying epoxy to the motor retainment flanges.

The first step of manufacturing was to send the CAD file to the CNC mill. A tool path was made for the centering rings, and they were cut successfully. Next, the centering rings needed their holes drilled precisely with a mill. The holes were drilled and threaded for screws to attach the centering ring to the airframe. A light sanding was done on the parts to smooth out the aluminum and to prevent cuts during the assembling process. Figure 3.4.14 shows one of the centering rings mounted to be milled.

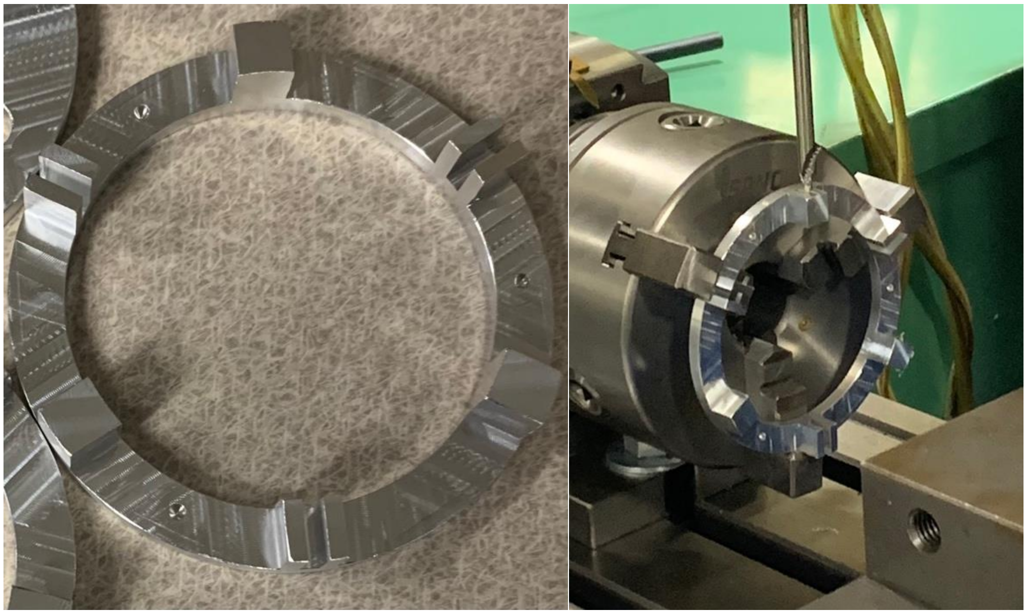


Figure 3.4.14. *Centering ring after the CNC and holes being drilled by the mill.*

Even though the CAD file altered some of the dimensions to increase tolerance, the centering rings needed to be sanded slightly to remove excess aluminum from the inner diameter. CSL couldn't fit the centering rings around the motor tube, so this change was necessary during assembly. Table 3.4.3 provides a comparison of design specifications for the CAD model, contrasted with the constructed model.

Table 3.4.3. *Centering ring comparing the design and as constructed.*

System Specification	As Designed	As Constructed
Centering Ring OD | ID (in)	3.87 | 3.05	3.87 | 3.09
Centering Ring Thickness (in)	0.200	0.205
Centering Ring Mass (lb | g)	0.11 | 49.8	0.10 | 45.3

The motor retainment flanges were constructed using PETG on a 3D printer. This was done using a program to slice the CAD file and upload it to an SD card to be placed in the 3D printer. Once these were printed, CSL measured out where they would be placed in the aft section and then were glued in place using epoxy. The slots slide right into the square inserts of the centering rings, making a seamless fit. Figure 3.4.15 provides an image of the motor retainment system where the centering rings and motor retainment flanges are in place within the aft section.

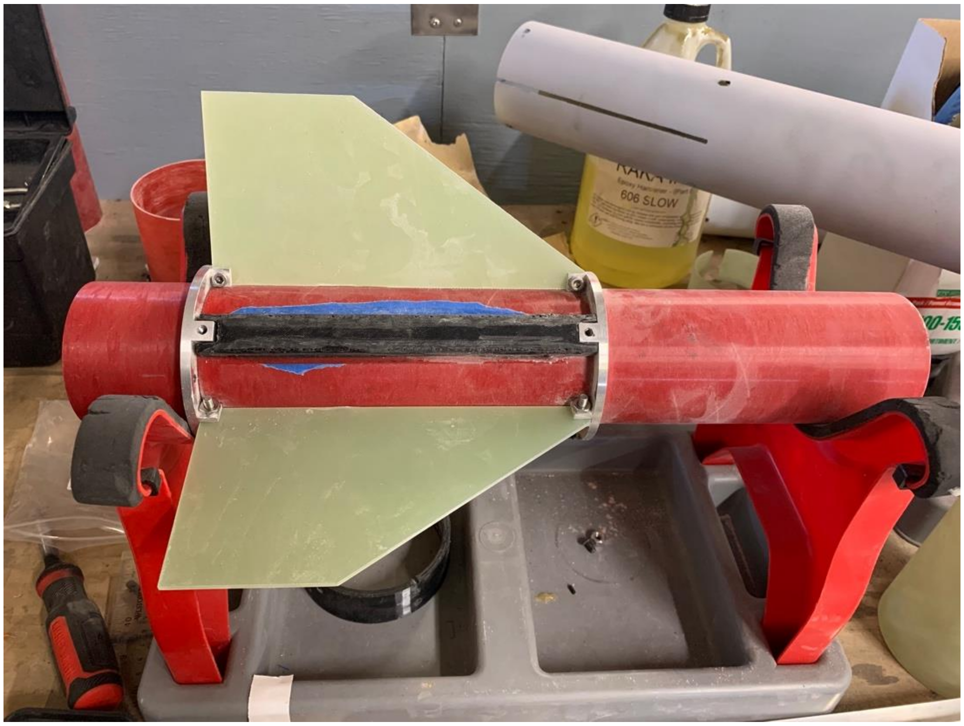


Figure 3.4.15. *Centering rings, flanges, and fins securely fastened within the motor retainment system.*

3.4.8. Fins

Construction of the fins was a fairly simple process. To get the most accurate dimensions, the team decided to use Cedarville University's CNC router. To get the machine to work properly, a toolpath was made to cut out the fins while not wasting fiberglass. A picture of the fiberglass after being cut can be seen in Figure 3.4.16. This process resulted in fins with little to no dimensional differences between the as-designed and as-constructed result.

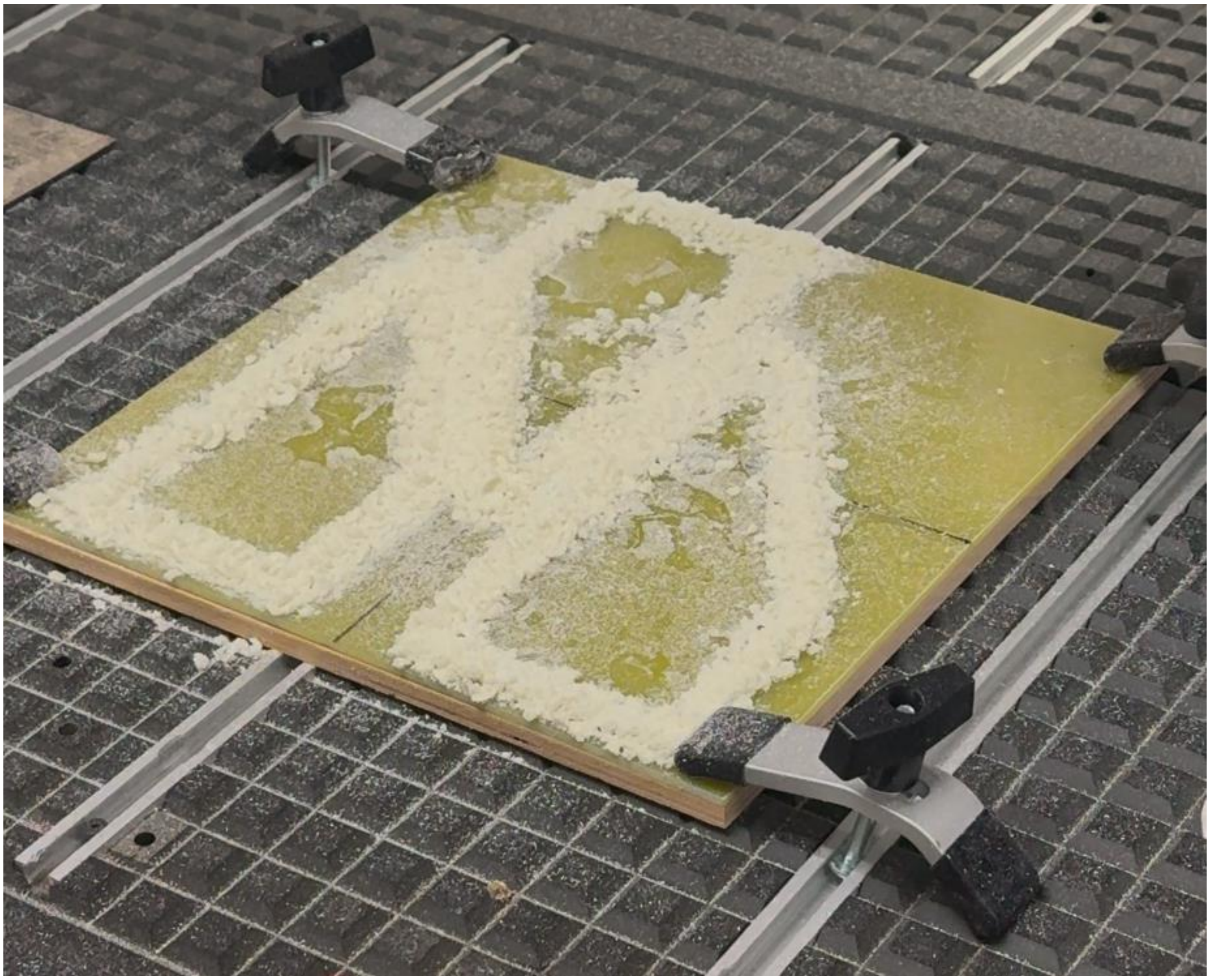


Figure 3.4.16. *Fin fiberglass cutting.*

3.4.9. Motor Retention

Construction of the motor retention system involved making the tail cone and acquiring the correct fasteners as listed in Section 3.3.9. Such fasteners were simple to acquire by order through McMaster-Carr. Constructing the tail cone itself required multiple steps.

First, CSL printed the tail cone from a SolidWorks model, as shown in Figure 3.4.17. After removing the print's support material, the cone was roughed with sandpaper. Bondo was applied to the tail cone and dried. After drying, the Bondo was sanded again to provide a smooth even surface. The tail cone was given two layers of primer coat, a coat of paint, and a layer of clear coat paint. Anytime Bondo or paint was applied, CSL members utilized safety glasses, gloves, and N95 masks for PPE as required by CSL safety requirements C.3 and C.10.

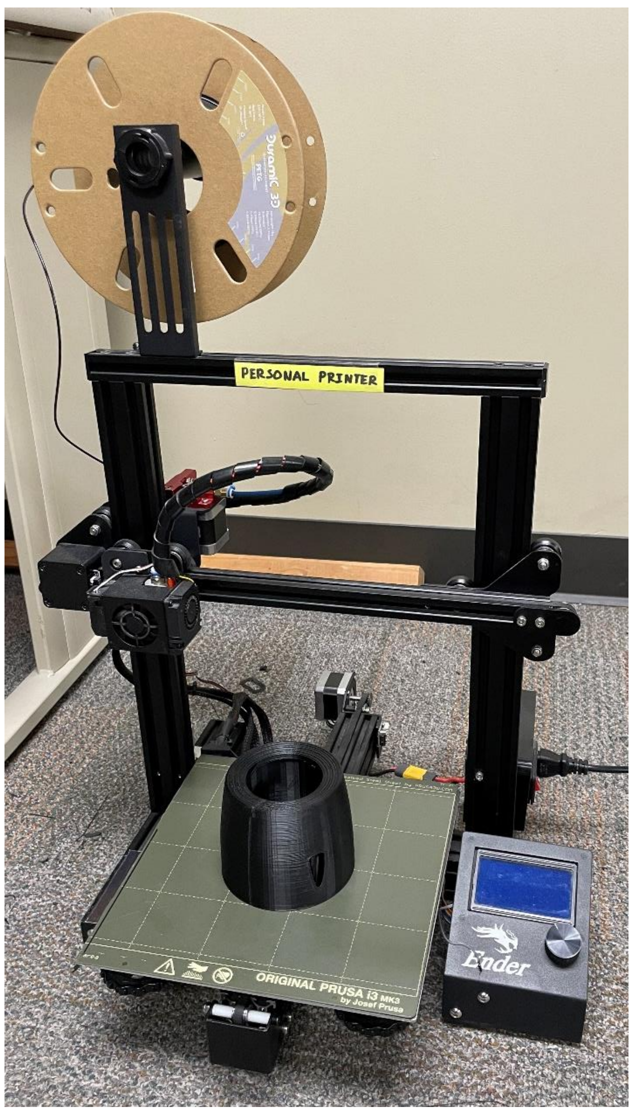


Figure 3.4.17. *Ender3 printer used to print PETG tail cone, with finished cone for scale.*

The as-constructed tail cone differed from the as-designed cone by dimensional measurements due to sanding, layers of Bondo and paint applied to its outer surface, and printing imperfections. These dimensions and differences are given in Table 3.4.4.

Table 3.4.4. *As-Designed vs As-Constructed system specifications.*

System Specification	As-Designed Value	As-Constructed Value
Tail cone Length (in)	3.22	3.24
Tail cone OD | ID | Nozzle Diameter (in)	4.03 | 3.20 | 2.40	4.02 | 3.16 | 2.29
Tail cone Mass (lb | g)	0.29 | 132	0.27 | 121
3 Fastener Mass (lb | g)	0.02 | 9	0.02 | 9
System Total Mass (lb | g)	0.31 | 141	0.29 | 130

The change in nozzle diameter is important to note, as during construction, CSL observed that the diameter was too small for the motor nozzle to fit through, which was surmised to be a printing issue. To address this, CSL reduced the nozzle diameter with an electric Dremel tool so that the motor nozzle could fit through. This tool is seen in Figure 3.4.18. While using this tool, CSL team members used long sleeves, gloves, safety glasses, and N95 masks for PPE as required by CSL safety requirements C.3 and C.10. To rectify this, the nozzle diameter of future prints of the tail cone will be checked before printing and before the Bondo and paint process begins.

Figure 3.4.18. *Electrical Dremel tool used to bore larger nozzle diameter*

3.5. Recovery Subsystem

3.5.1. Recovery Mission Statement and Success Criteria

For CSL's launch vehicle to have a successful recovery there were many different requirements that had to be met and considered when the subsystem was designed. In the NASA SL Handbook the requirements given for the rocket are listed below:

- The descent must be 90 [s] or less from apogee,
- The kinetic energy at landing for each section of the rocket must be below 75 [ft*lbs],
- There must be two deployment events, a drogue that deploys no more than 2 [s] after the rocket reaches apogee and a main that deploys above 500 [ft] AGL,
- The launch vehicle must not drift more than 2,500 [ft] from the launch pad with wind of 20 [MPH],
- Removable shear pins must be used for deployment bays,
- A successful ground ejection test for all electronically initiated recovery events must take place prior to the initial flights of the subscale and full-scale vehicles,
- The recovery system must contain altimeters that are redundant COTS,
- Each altimeter must have its own dedicated power supply made up of COTS batteries,
- Each altimeter must be armed with an accessible, exterior mechanical switch that cannot be disarmed due to flight forces,
- The recovery system's electronics must operate independently from any payload electronics and not be adversely affected by any other on-board devices,
- Any rocket section of payload component that lands untethered to the launch vehicle must contain its own GPS tracking device and parachute.

In the following sections the validation of the recovery subsystems design regarding these requirements are outlined.

3.5.2. Recovery Overview

Project Elijah utilizes a dual bay deployment with the drogue parachute in the aft section of the rocket and the main parachute in the fore. Between each bay is the avionics bay that holds the altimeters that set off the black powder charges for each bay at the altitudes programmed before the launch. The black powder charges are connected on each side of the avionics bay to utilize shorter wires and make connecting them easier. Each bay has two black powder charges, a primary along with a larger secondary to ensure the deployment of the parachutes. The charges are also controlled by separate altimeters in case one was to stop working. Calculating the amount of black powder used depends on the size of the bay, size of the parachute, and the amount of shear pins being used. From this information CSL was able to find the charge sizes shown in Table 3.5.1. For the descent of the launch vehicle the drogue bay's primary charge is set to go off at apogee with the second a few seconds behind. The main bay's primary charge is set for 600 [ft], and the secondary is 550 [ft] AGL The deployment steps can also be seen in Figure 3.5.1.

Table 3.5.1. *Black powder primary and secondary amounts for the Full-Scale launch vehicle's main and drogue bay along with an appropriate secondary amount.*

	Main Bay	Drogue Bay
Primary [g]	5.0	3.3
Secondary [g]	5.5	3.8

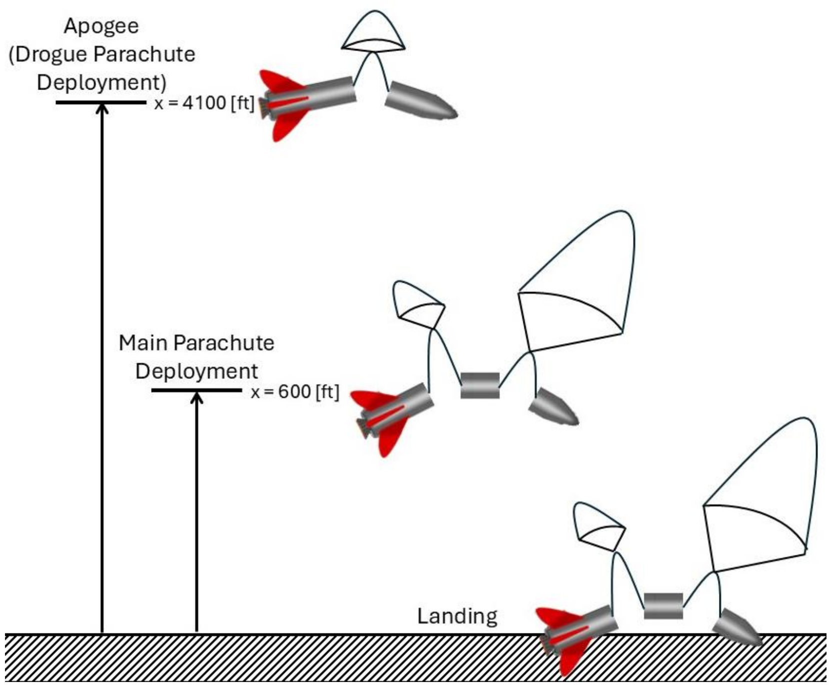


Figure 3.5.1. *Outline for the recovery steps showing the altitude for when the parachutes are deployed.*

The shear pins used are #4-40 nylon with a shear strength of approximately 10,500 [psi]. To hold the rocket together during its ascent and partially through the descent for the main bay three total shear pins are utilized at the separation points. The drogue bay has one shear pin and the other two are for the main bay. When preparing the recovery bays for launch the proper launch checklist will be completed, this will include the folding of the parachutes and the placement of the shock cords.

3.5.3. Shock Cords

For the full-scale launch vehicle CSL is using shock cords that are 30 [ft] in length for both parachutes, this is roughly 3.5 times the length of the rocket. The shock cords themselves are made from 9/16 [in] tubular nylon. The parachutes are connected to the shock cords with quick links attached at a quarter of the length. For the main's shock cord the longer end is attached to the avionic bulkhead, and the shorter end to the aft section's bulkhead. The drogue's shock cord has the longer end attached to the shock mount in the fore section and the shorter end to the other avionic bulkhead. To ensure the shock cord do not sustain major damage that cause for them to break in parachute deployment, new shock cords are cut and tied after each launch. The shock mount has been previously discussed in Section 3.3.5 and the bulkheads in 3.3.6. Another piece of the structural system for the recovery subsystem is the shear pins used for both the drogue and main bay; these pins are discussed in Section 3.5.2.

3.5.4. Electrical System

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 Figure 3.5.2 and Figure 3.5.3.

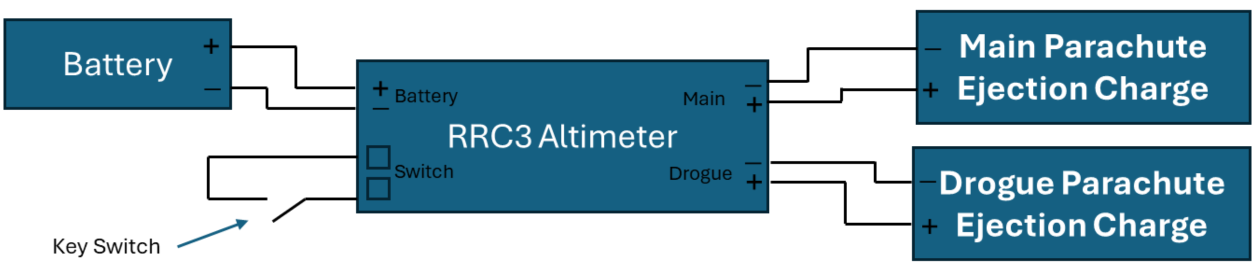


Figure 3.5.2. *RRC3 altimeter wiring diagram.*

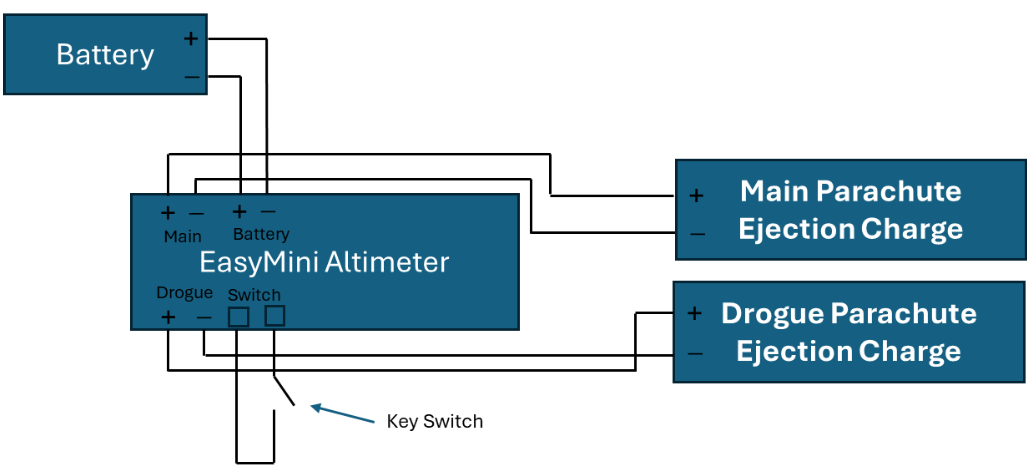


Figure 3.5.3. *Easymini altimeter wiring diagram.*

The final component inside the avionics bay is an Eggfinder Mini C4 GPS from Eggtimer. The transmitter is set to transmit on the 921.00 MHz frequency and will continuously send its location to the receiver when it is powered on and has gained satellite lock. 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.

3.5.5. Parachutes and Descent Rates

To be able to properly slow down the descent of the full-scale launch vehicle the proper parachute size and shape was needed. To keep our descent time short the drogue parachute chosen was a 12 [in] elliptical from Fruity Chutes made from Ripstop Nylon. This had a very high descent rate that allowed CSL to accomplish a large safety factor for the descent rate allowing more freedom in choosing the main parachute. The main parachute is a 7 [ft] parabolic from Rocketman Parachutes made from Ripstop Nylon which was rated to bring the descent rate to 25 [ft/s] for a rocket of 23 [lb] but for the two full-scale launches completed the descent rate was only brought down to between 40-50 [ft/s]. Table 3.5.2 contains additional data about the parachutes used.

Table 3.5.2. *Main and drogue parachute data used in simulations.*

	Main Parachute	Drogue Parachute
Type	Parabolic	Elliptical
Material (Parachute/Shroud Line)	Ripstop/Nylon	Ripstop/Nylon
Coefficient of Drag	0.9	1.75
Outer Diameter [in]	84	15
Inner Diameter [in]	NA	3.5
Packing Volume [in^3]	74.5	8.2
Mass [g]	232.00	47.00
Shroud Line Amount	4	8
Shock Cord Length [ft]	30	30
Shock Cord Material	Tubular Nylon	Tubular Nylon
Shock Cord Size [in]	9/16	9/16

One problem with this is the larger descent rate for the main parachute that does not lower the velocity of the launch vehicle enough to have a kinetic energy at landing below 75 [ft*lbs]. Due to this CSL plans to switch the main parachute from a parabolic to a toroidal due to the larger coefficient of drag. The new main parachute is a 7 [ft] toroidal from Fruity Chutes with a rated descent rate of 20 [ft/s] for 39 [lb]. Table 3.5.3 contains the additional data for this parachute. This new parachute will also require new black powder charges due to its larger packing volume; these new calculated values have not been tested yet but can be seen in Table 3.5.4.

Table 3.5.3. *New main parachute data to replace the original that can be used in simulations as well.*

	New Main Parachute
Type	Toroidal
Material (Parachute/Shroud Line)	Ripstop/Nylon
Coefficient of Drag	2.2
Outer Diameter [in]	84
Inner Diameter [in]	14.78
Packing Volume [in^3]	105.1
Mass [g]	486.19
Shroud Line Amount	12
Shock Cord Length [ft]	30
Shock Cord Material	Tubular Nylon
Shock Cord Size [in]	9/16

Table 3.5.4. *New primary and secondary black powder charges calculated for the main deployment bay with the new parachute data.*

	Main Bay
Primary [g]	3.5
Secondary [g]	4.0

3.6. Mission Performance Predictions

3.6.1. Ascent Predictions

To accurately predict Chariot's flight performance throughout the remainder of CSL's testing campaign, the rocket's coefficient of drag and mass distribution must be carefully simulated. Throughout the final construction process, the team kept a careful account of each subsystem's mass properties and updated the leading OpenRocket simulation to give the most accurate vehicle mass possible. The static stability margin and CG/CP locations resulting from this simulation are summarized below in Table 3.6.1. Note that, for marginally different locations of the recovery devices in the parachute bays, the CG location and SSM can vary slightly.

Table 3.6.1. *CG/CP location and SSM relationship derived from OpenRocket.*

Min Location CG From Tip [in]	62.53
Max Location CG From Tip [in]	61.99
CP Location From Tip [in]	72.05
Min SSM [cal]	2.37
Max SSM [cal]	2.50
Avg SSM [cal]	2.44

Currently, Chariot's Cd for subsequent launches is not precisely known, as the final paint scheme is not fully complete, and due to a minor dimensioning error, the airbrake flaps have not been built completely to specification yet. For this reason, CSL's ongoing OpenRocket simulation efforts use a "smooth paint" surface roughness approximation on all external components, which gives a total Cd of 0.574 for the entire rocket. Chariot's drag characteristics as estimated in OpenRocket are provided in Table 3.6.2. In subsequent flights, the accelerometer and pressure data from the main and backup PCBs onboard Chariot will allow CSL to improve these Cd estimates and override the overall Cd in OpenRocket to an experimental value.

Table 3.6.2. *Drag characteristic summary from OpenRocket while using a Mach number of 0.300.*

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Total (Rocket)	**0.142 (0%)**	**0.094 (0%)**	**0.338 (0%)**	**0.574 (1%)**
Nose Cone	0 (0%)	0 (0%)	0.027 (0%)	**0.027 (0%)**
Payload Bay	0 (0%)	0 (0%)	0.042 (0%)	**0.042 (0%)**
Main Parachute Bay	0 (0%)	0 (0%)	0.066 (0%)	**0.066 (0%)**
Avionics Body Tube	0 (0%)	0 (0%)	0.003 (0%)	**0.003 (0%)**
Drogue Parachute Bay	0 (0%)	0 (0%)	0.057 (0%)	**0.057 (0%)**
RunCam	0.098 (0%)	0 (0%)	0.002 (0%)	**0.1 (0%)**
Booster Airframe	0 (0%)	0 (0%)	0.104 (0%)	**0.104 (0%)**
Trapezoidal Fin Set	0.014 (0%)	0 (0%)	0.009 (0%)	**0.024 (0%)**
Rail Button	0.001 (0%)	0 (0%)	0 (0%)	**0.001 (0%)**
Rail Button	0 (0%)	0 (0%)	0 (0%)	**0 (0%)**
Tailcone	0 (0%)	0.094 (0%)	0.009 (0%)	**0.103 (0%)**

Reference length: 4.024 in   Reference area: 12.7 in²

Figure 3.6.1. shows the thrust profile of the K1000T-P motor that Chariot flies on. OpenRocket uses a similar dataset to simulate thrust over time. Figure 3.6.2 shows OpenRocket's predicted flight profile for vertical motion over time, and Table 3.6.3 summarizes specific flight metrics from this simulation.

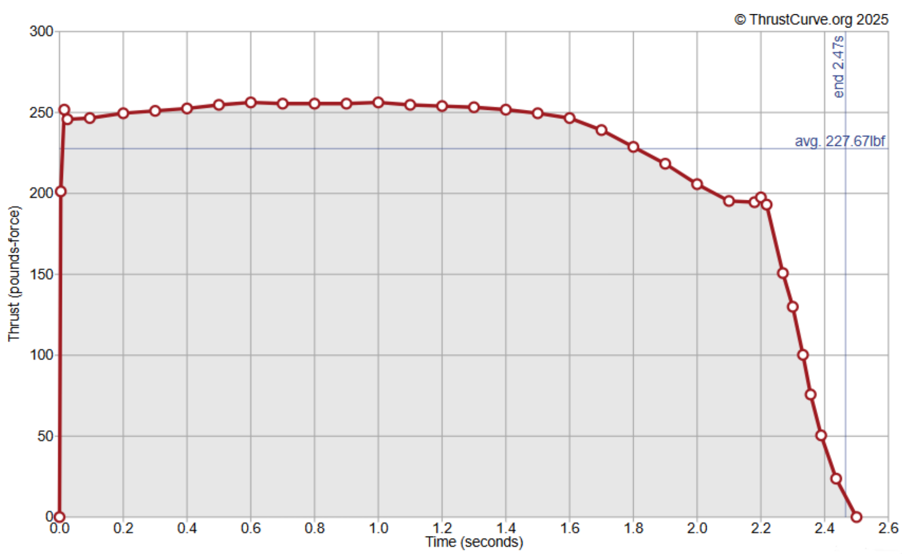


Figure 3.6.1. Thrust curve for the Aerotech K1000T-P motor used in both of our Chariot launches.

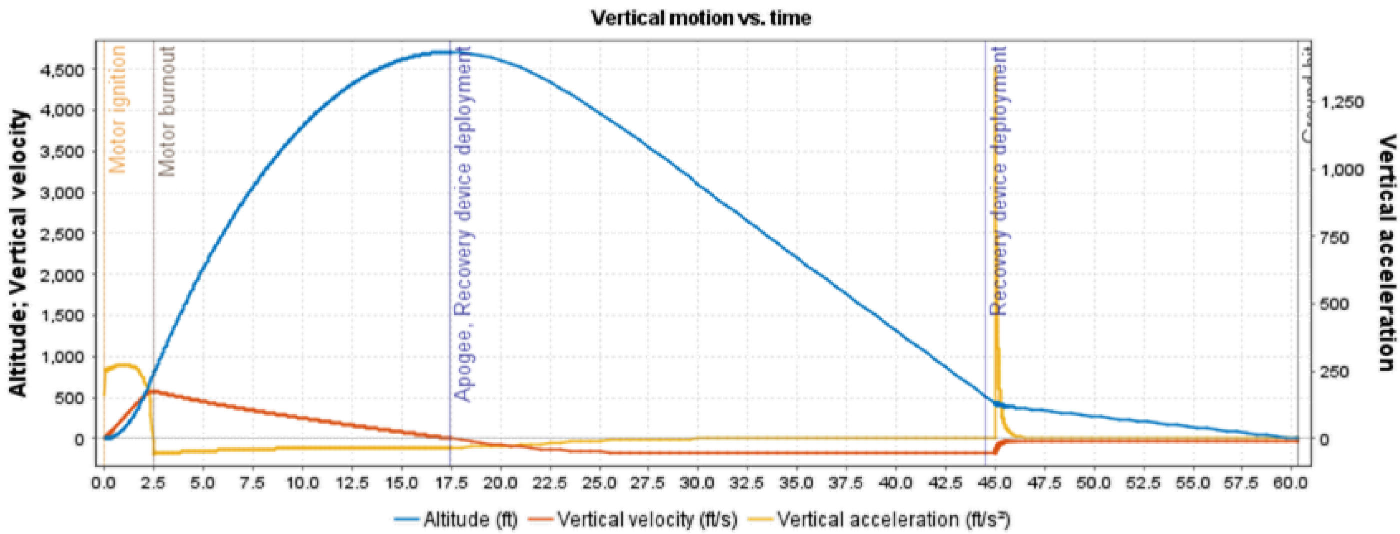


***Figure* 3.6.2.** *OpenRocket flight profile for Chariot, featuring the most updated mass estimates but without a specifically overridden Cd.*

Table 3.6.3. Summary of OpenRocket flight data for the K1000T-P motor, 0.574 Cd (automatic).

Apogee [ft]	4716
Max Velocity [ft/s]	580
Max Acceleration [ft/s^2]	272
Flight Time [s]	60.4

Since the rocket could encounter a variety of wind/launch angle conditions, CSL explored other methods of predicting rocket performance that excluded AOA, wind, restoring moments, and launch rail angle to understand the effect that these parameters have on the rocket's performance compared to the OpenRocket predictions. The team developed a python code (called ChariotSim hereafter) that ran a simple single-axis flight sim of the rocket given a Cd input and environmental information. ChariotSim used the actual thrust curve for the K1000T-P motor, and accounts for environmental aspects that change with altitude to produce the most precise single-axis simulation possible. Table 3.6.4 shows the flight summary produced by ChariotSim, and Figure 3.6.3 shows key flight parameters plotted versus time. The full ChariotSim code can be found in Appendix A. 3.

Table 3.6.4. *ChariotSim data summary. Note that the wind disturbances, AOA variation, and rail angle can lower Chariot's apogee by almost 100 ft compared to the OpenRocket results in Table 3.6.3.*

	Metric	Imperial
Apogee	1465.56	4808.19
Velocity Off Rail	24.24	79.54
Max Velocity	179.18	587.84
Max Acceleration	84.18	276.18
Time to Apogee	17.56	

	Parameter
Temperature [K]	288.7056
Wind Speed [m/s]	0
Wind Speed [ft/s]	0.0
Rail Angle [deg]	0
Cd	0.574

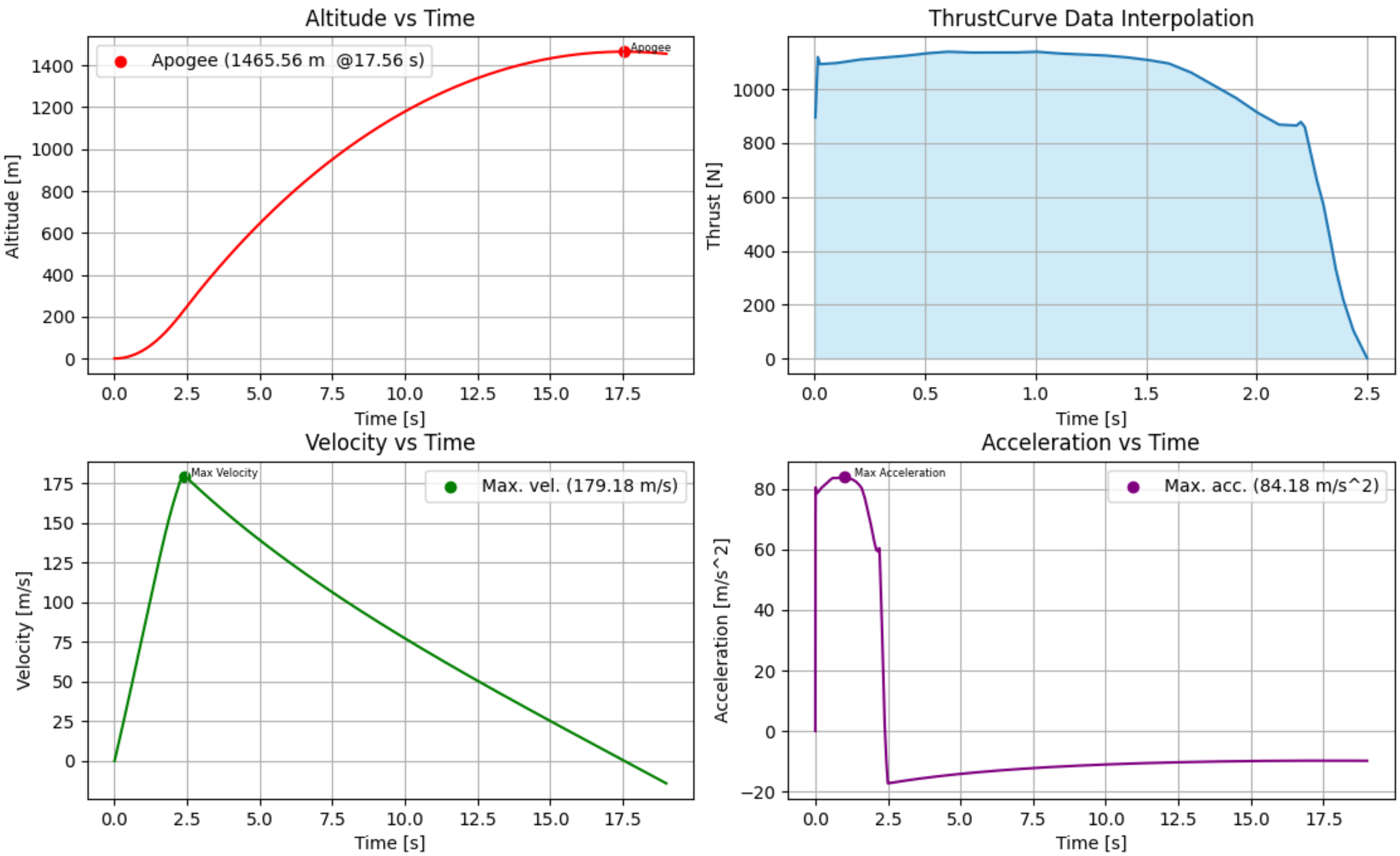


Figure 3.6.3. *Vertical motion parameters generated by ChariotSim.*

3.6.2. Descent Predictions

Using the data for the two parachutes used in the full-scale launch vehicle and a model of the forces in the descent theoretical values for the descent time, velocity, kinetic energy, and drift distance can be found. This is found through OpenRocket simulation (Table 3.6.5 and 3.6.6 for the original main parachute values) and a MATLAB code which is shown in A.1. Table 3.6.7 and 3.6.8 show the data from the old main parachute and Table 3.6.9 and 3.6.10 show the new. The kinetic energy is based on the masses for each section of the rocket after drogue and main deployment and the drift distance is based on wind speeds of 5, 10, 15, and 20 [MPH].

Table 3.6.5. *OpenRocket theoretical descent data. The theoretical descent time, velocity, and kinetic energy. This is from the data for the old main parachute.*

Descent Time [s]	45.4		
Velocity @ Landing [ft/s]	26.38		
Apogee [ft]	4717.85		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf]	131.7173	42.9512	73.9085

Table 3.6.6. *OpenRocket theoretical descent data. The theoretical drift distance for different wind speeds. This is from the data for the old main parachute.*

Wind Speed [MPH]	5	10	15	20
Drift Radius [ft]	332.9	665.9	998.8	1331.7

Table 3.6.7. *MATLAB theoretical descent data. The theoretical descent time, velocity, and kinetic energy. This is from the data for the old main parachute.*

Descent Time [s]	47.01		
Velocity @ Landing [ft/s]	30.6502		
Apogee [ft]	4100		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf]	177.8117	57.9820	99.7728

Table 3.6.8. *MATLAB theoretical descent data. The theoretical drift distance for different wind speeds. This is from the data for the old main parachute.*

Wind Speed [MPH]	5	10	15	20
Drift Radius [ft]	344.7	689.5	1034.2	1379.0

Table 3.6.9. *MATLAB theoretical descent data. The theoretical descent time, velocity, and kinetic energy. This is from the data for the new main parachute.*

Descent Time [s]	64.00		
Velocity @ Landing [ft/s]	16.3692		
Apogee [ft]	4100		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy [ft*lbf]	50.7162	16.5379	28.4576

Table 3.6.10. *MATLAB theoretical descent data. The theoretical drift distance for different wind speeds. This is from the data for the new main parachute.*

Wind Speed [MPH]	5	10	15	20
Drift Radius [ft]	469.3	938.7	1408.0	1877.3

Comparing the data for Tables 3.6.5-3.6.8 which contains the theoretical descent data from OpenRocket and MATLAB with the original main parachute it can be seen that there is very little difference between the two (Table 3.6.11 and 3.6.12). The changes that can be seen can be explained through the difference in apogee because MATLAB considers the apogee CSL is aiming to reach with the airbrakes while OpenRocket does not.

Table 3.6.11. *OpenRocket and MATLAB comparisons for theoretical descent data. The theoretical descent time, velocity, apogee, and kinetic energy are compared. This is from the data for the old main parachute.*

Descent Time Difference [%]	3.5		
Velocity Difference [%]	15.0		
Apogee Difference [%]	14.0		
	Aft Section	Avionics Bay	Fore Section
Kinetic Energy Difference [%]	29.8	29.8	29.8

Table 3.6.12. *OpenRocket and MATLAB comparisons for theoretical descent data. The theoretical drift distance is compared. This is from the data for the old main parachute.*

Wind Speed [MPH]	5	10	15	20
Drift Radius Difference [%]	3.5	3.5	3.5	3.5

4. Payload Criteria

4.1. Primary Payload Review: Elijah

4.1.1. Mission Statement and Success Criteria

The mission of the primary payload, as stated in the Student Launch Handbook Section 4.1, is to safely hold four STEMnauts and to transmit flight and landing information to a receiver over radio after landing. In order to do so successfully, the payload must take in data during flight and after landing; process, format, and encode that data; and transmit it via radio on the 2-meter band. It must also remain structurally intact to protect the STEMnauts within it.

The following success criteria provide testable and verifiable benchmarks for the overall mission. A fully successful payload flight will be one in which all of the following criteria as well as all of NASA's specific payload verifications are fulfilled.

P.1 Payload survives vehicle landing to be able to perform post-flight operations.
P.2 Payload has sufficient battery power for pre-flight, in-flight, and post-flight operations.
P.3 Payload sensors all deliver accurate data to the microcontroller.
P.4 Payload transmits APRS packets from the rocket's landing site to the launch site receiver.
P.5 Payload transmits decodable telemetry data using the standard APRS protocol.

4.1.2. Changes Since CDR

There have been two design changes made to the payload's electrical system since the CDR. First, testing has revealed that the TMUX1204 chip that the team proposed for creating waveforms for APRS encoding is unnecessary. Instead, a square wave is passed from the Raspberry Pi Pico through a voltage divider, lowpass filter, and capacitor, which sets the correct voltage level, smooths the signal, and removes its DC component. The resulting waveform matches decodable APRS waveforms when sent over radio. Second, small tone generators have been added to the printed circuit boards which make a beep sound when the payload is functioning properly. These allow the team to confirm that the payload is powered on and ready for launch when the rocket is sitting on the launchpad and LED indicators are not visible.

In addition to the changes made to the electrical layout of the primary payload since the time of the CDR, significant changes were made to its mechanical structure. The necessity of using ballast in the tip of the nosecone immediately required these changes because the original design would have had the radio antenna pointing up into the nosecone. The addition of steel ballast could have caused significant electromagnetic interference to the radio transmission as well as limiting the available space within the nosecone, so the entire transmitter was flipped upside down. This caused the rest of the payload to be restructured. Figure 4.1.1 shows the new payload design.

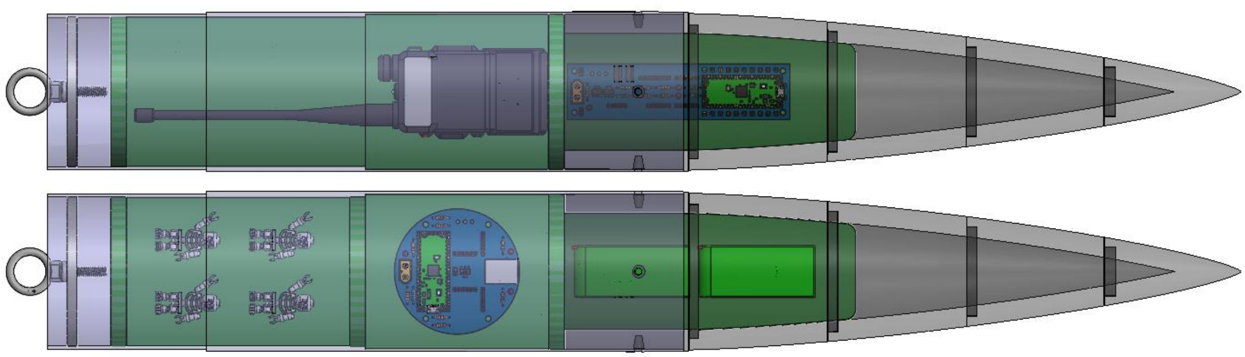


Figure 4.1.1. *Payload front and back views.*

The front of the payload houses the *Baofeng* UV-5R radio and the primary PCB, while the back of the payload holds the STEMnauts, the override PCB, and both batteries. The lower section, which includes the radio, STEMnauts, and override PCB, is contained by thin translucent shields, while the upper section that houses the primary PCB and batteries is surrounded by the nosecone. The payload is retained within the rocket by the bulkhead below and the nosecone above, and it is prevented from moving by both the two bolts in its sides and by the airframe overlap (which can be seen just below the override PCB section, where the payload's diameter becomes smaller to allow for the overlap).

4.1.3. Primary Payload Design

4.1.3.1. Electrical System Validation

The majority of the payload's electrical system consists of two independent circuits, each one on a custom printed circuit board. The reason for having a primary PCB and an override PCB is discussed in more detail below in Section 4.1.3.3, but the design of both printed circuit boards has remained unchanged since the CDR with the exception of the additional tone generator as described above. A picture of the completed primary PCB is shown below in Figure 4.1.2 and the completed override PCB is shown in Figure 4.1.3.

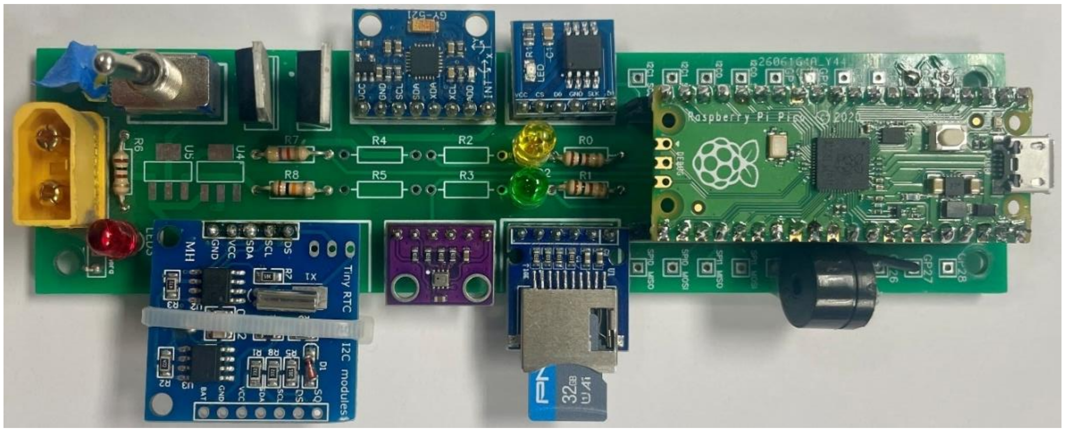


Figure 4.1.2. *Completed primary PCB.*

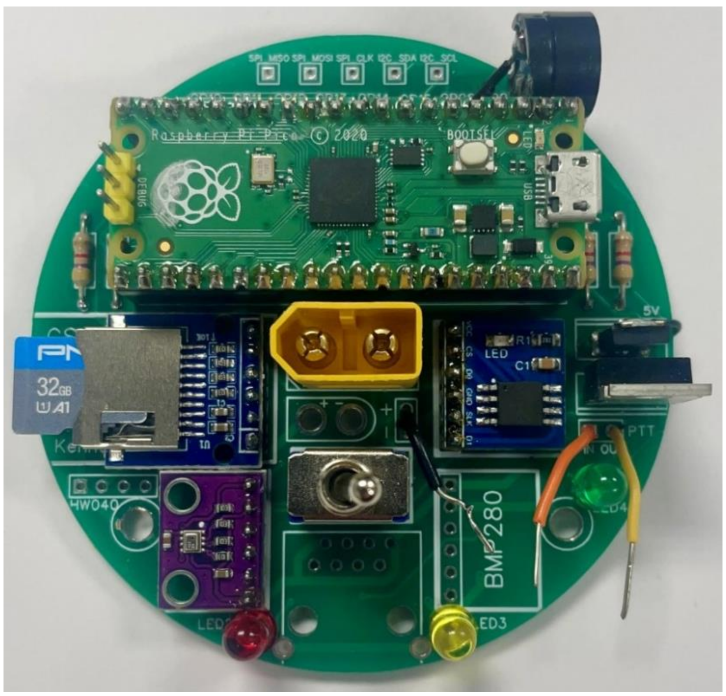


Figure 4.1.3. *Completed override PCB.*

Because having all the important circuitry on printed circuit boards eliminates nearly all risk of in-flight electrical failure, the main potential failure mode of the electrical system becomes the battery life. According to NASA requirement 2.6, all systems within the rocket must be capable of running for a minimum of three hours before launch. The payload team has specified this condition in CSL requirement P.2 and has verified the claim using analysis and testing. A summary of the results of the analysis and testing is shown below in Table 4.1.1.

Table 4.1.1. *Battery life analysis and testing results.*

Circuit	Estimated (mA)	Tested (mA)	Battery	Estimated (mAh)	Tested (mAh)	Estimated Battery Life (h)	Tested Battery Life (h)
Payload Primary	114.0	68.0	Ovonic	1000	930	8.8	13.7
Payload Secondary	97.1	110.0	Ovonic	1000	930	10.3	8.5
Airbrakes	112.5	212.0	Liperior	850	738	7.6	3.5
Minimum Battery Life						**7.6**	**3.5**

4.1.3.2. Software Performance

The calibration computer, when attached to either the primary or override PCB, will display all collected data from all sensors, as described in CSL requirement P.3. Before launch and after calibration, all PCBs should be rotated and moved to ensure that realistic data is being recorded by each sensor. The payload is also capable of detecting certain sensor faults, such as unresponsiveness. If such a fault is detected, the software will take appropriate steps to ensure faulty data does not result in a frozen state or a deadlock. Fault detection will be tested by manually disconnecting or disabling sensors to ensure that faults are both detected and handled properly. Because there is no accurate controlled environment for the physical electronics and sensors within the payload, most testing must be done by human observation of reasonable values and software functionality. Collected data on test flights can also be compared with simulations and altimeter data to ensure the collected data is reasonable throughout flight.

The software on both the primary and override PCBs operates on a five-phase flight model: preflight, launch, coast, descent, and landed. Phase transitions are tested by giving the rocket data from previous flights and ensuring that all states are reached at reasonable times by observation. Since the payload may perform differently in different states, during development, the active phase is transitioned through manually by temporarily implementing different transition conditions so that transitions can occur naturally (e.g. if the acceleration is greater than $20\frac{m}{s^2}$).

4.1.3.3. Transmitter Validation

The transmitter system takes the collected data, encodes it into data packets using the APRS protocol, and transmits them from the landed rocket to an APRS receiver at the launch site. There are numerous steps in this process that must be independently and collectively validated.

First, the transmitter must send data in a way that does not violate any FAA or FCC rules according to NASA requirement 4.1. The transmissions will not exceed 5W and will begin and end with a team member’s callsign, according to NASA requirement 4.2. The design of the transmitter system is such that by inspection and demonstration, the team can prove that the rules stated above have been followed. Additionally, the payload team has added an extra level of safety to ensure that no NASA or FCC regulations regarding radio transmissions are violated. This is accomplished by having a second PCB with a similar sensor array to the first. As discussed in the CDR, the design is such that both PCB circuits must independently permit radio transmissions to occur for the transmitter to be activated. The payload team has determined that should the two circuits disagree about whether transmissions should occur, it is preferable to forego data transmission than to risk transmitting in violation of NASA or FCC regulations.

Second, the transmitter inside the payload must be capable of transmitting up to 2500 feet in any conceivable landing orientation, as stated in CSL requirement P.4. This requirement aligns with NASA requirement 3.11 and assumes that the receiver will be placed near the launch site of the rocket. As seen in the test verification for CSL requirement P.4, transmitted packets can be very reliably decoded from 1000 feet regardless of orientation. At 2000 feet the consistency declines and becomes more dependent on the orientation of the landed payload. At 2500 feet or more, the consistency is much lower and highly dependent on landing orientation. There are two reasons why these test results are not concerning to the CSL team. First, previous launches have landed within 2000 feet of the launch site, meaning that it is likely that transmitting at the full range will be unnecessary. Second, the five-minute transmit window after rocket landing gives the payload the opportunity to send the required data via APRS packet multiple times. This means that the success rate does not need to be 100%; it can be lower depending on the number of times it is able to be transmitted in that time window.

Finally, the transmitter system must be able to send APRS-encoded data packets which can be decoded by any standard APRS receiver, as presented in CSL requirement P.5. The Raspberry Pi Pico generates these packets by sending a square wave into a circuit containing a voltage divider, a resistor-capacitor circuit for lowpass filtering, and a series capacitor for removing DC bias. The diagram for this circuit is shown below in Figure 4.1.4 and its implementation on the payload is shown in Figure 4.1.5. While CSL requirement P.5 has not yet been demonstrated either in a flight test or in the lab, the payload team has confirmed that the circuit can produce a waveform identical to that of a decodable APRS packet.

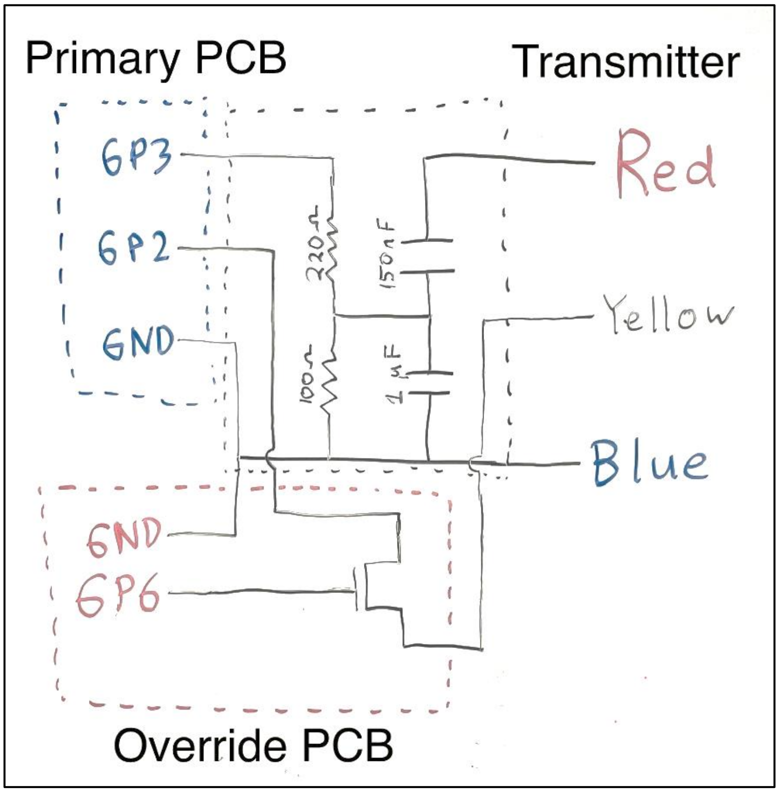


Figure 4.1.4. *Full transmitter circuit diagram.*

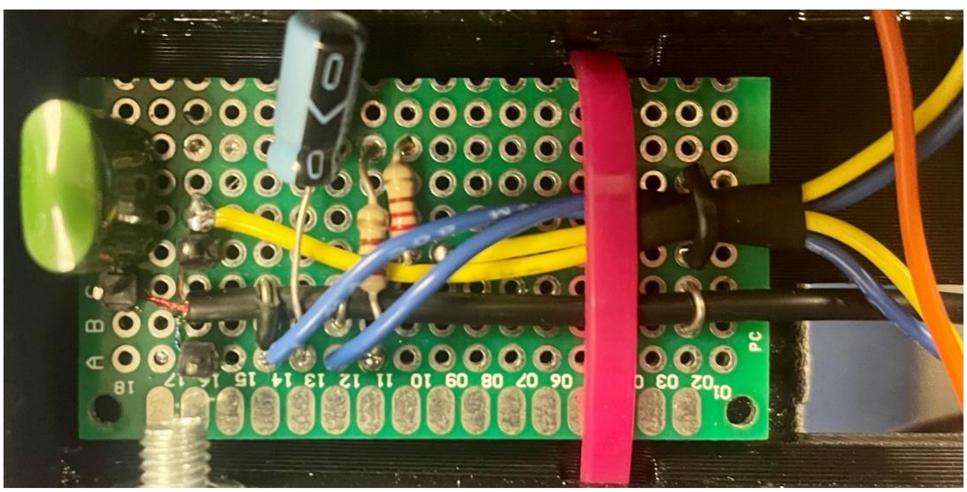


Figure 4.1.5. *Transmitter circuit implementation.*

4.1.3.4. Mechanical Construction

The 3D printed structure of the payload is 475 mm in height, so it was printed in two separate parts that were then bolted together. After printing and bolting the 3D printed parts, the first step in assembling the payload was to install the heat-set inserts for the two PCBs and the airframe attachment bolts. The *Baofeng* UV-5R radio was then attached using the screws in the back of the radio, with two zip ties for added security. The batteries were also secured in their notches with zip ties, after which both PCBs were screwed into the heat-set inserts. The STEMnauts were then secured by supergluing Lego shield components onto the payload in their individual holding bays and having the STEMnauts hold onto their handles. The last step in payload assembly was to slide in the translucent plastic barriers that seal off the payload. Once the payload was fully assembled, it was slid into the airframe and bolted in on both sides. The fully assembled payload is shown in Figure 4.1.6, while the constructed payload dimensions are shown in Table 4.1.2 below. The designed and constructed dimensions are nearly identical because the part was 3D printed. Notable features of the payload include the individual STEMnaut compartments, the slot for the translucent cover, and the extension into the nosecone to maximize the available space.

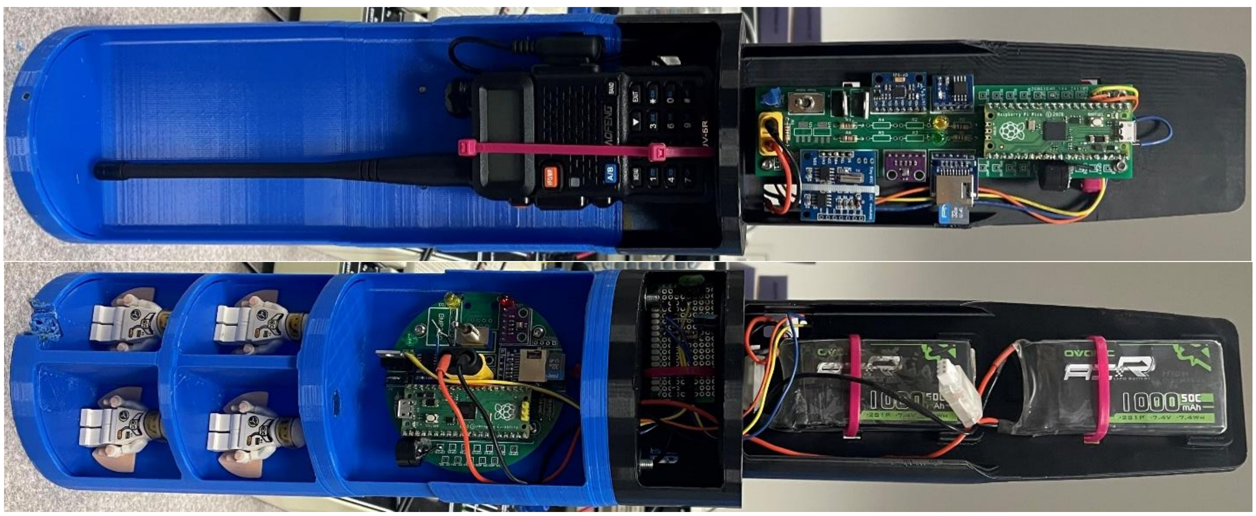


Figure 4.1.6. *Front and back of constructed payload.*

Table 4.1.2. *Constructed payload dimensions.*

System Specification	As Designed	As Constructed
Large Outer Diameter (mm)	98.044	98.1
Medium Outer Diameter (mm)	94.304	94.3
Small Outer Diameter (mm)	73.612	73.4
Total Height (mm)	475.22	475

The changes to the constructed payload as opposed to the earlier payload designs are mainly slight construction variations, but one intentional change was made after an earlier payload iteration was printed. The part of the payload that extends into the nosecone was moved back slightly (giving more room to the main PCB and less room to the batteries) because of the construction of the PCB. One of its components was slightly larger and farther off the board than expected, so more room was needed to allow it to still fit into the nosecone.

4.1.4. Flight Reliability

The payload team has not yet made a Payload Demonstration Flight attempt. CSL plans to conduct the Payload Demonstration Flight by April 5, 2025, or sooner. The primary task that still needs to be accomplished before the Payload Demonstration Flight is the encoding of APRS data packets by the Raspberry Pi Pico, CSL requirement P.5. All other payload requirements have been validated either in prior flights or in the lab setting.

In its current state, software bugs have caused inconsistencies in payload performance during previous flight tests, though new systems are being put in place to address these problems. As the payload team continues to optimize software development flow our probability of overall mission success increases.

The final criterium that makes a significant impact on probability of payload success is the distance that the transmitter is required to send APRS packets, CSL requirement P.4. This is completely dependent on where the launch vehicle lands, and therefore the payload team has attempted to quantify the probability of transmission success based on distance and orientation, as seen above in Section 4.1.3.3 and in the verification documentation for CSL requirement P.4.

4.2. Secondary Payload Review: Airbrakes Flight Control System

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.

4.2.1. Mission Statement and 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 were successful, the following criteria are shown below. (Note: **AB.S.8** was added to the list of success criteria in the FRR document.)

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.
AB.S.8 Flight data was recorded and retrieved.

4.2.2. Changes Since CDR

The changes made to the airbrakes mechanical system from the CDR to the FRR (AB; secondary payload) are outlined in Table 4.2.1, and the electrical system is outlined in Table 4.2.2. The "Component CDR" column is the components which was on the AB during the CDR. The "Component FRR" is the component which was on the AB for the FRR. The "Purpose" is the reason for the component being on the subsystem. The "Reason For Change" is the logic to make the switch.

Table 4.2.1. *Airbrakes mechanical changes.*

Component CDR	Component FRR	Purpose	Reason For Change
Diameter of AB 3.85 inches	Diameter of AB 3.822 inches	Mounting	Coupler added to airframe for support.
Electrical PCB housing covers no PCB	Electrical PCB housing covers PCB and changed form factor	Holds PCB and battery	The PCB would have been crushed while assembling.
No electrical breakout board	Electrical breakout board on the end stop button mount	Connects PCB to electronics on motor mount	The breakout board was planned to be placed there, but no CAD modeling was introduced for practical reasons.
1117.2 g overall weight estimated	1060 g practical	Full weight of AB	Theorical predications vs real weight
Distance between Mounting Bolts is 9.685 inches	Distance between Mounting Bolts is 9.875 inches	Mounting airbrakes into airframe	CAD versus as built
Electrical Housing height is 3.55 inches	Electrical Housing height is 3.3125 inches	Holding the electronics	CAD versus as built

Table 4.2.2. *Airbrakes electrical changes.*

Component CDR	Component FRR	Purpose	Reason For Change
Zeee 12V 1500mAh battery	Three 7.4V 850mAh batteries (24V nominally)	Provide power to AB	The motor was not strong enough during final testing, so light high voltage battery required 3 small batteries in series.
300RPM 12V motor	500RPM 12V motor	AB actuation	Higher voltage ∝ faster speed in this case, because of motor burnout during testing, this was the backup motor which was available.

Component CDR	Component FRR	Purpose	Reason For Change
3 BMP280's (Pressure sensor sensor)	1 BMP280	Measure altitude	Final confirmation testing proved fatal to the SPI bus on the PCB, thus an emergency pressure sensor was wired to an I^2C bus to have one functional altitude sensor for the launch. (Only one BMP will be used in the future on the SPI bus.)
1 SD card	0 SD cards	Collect data	Final confirmation testing proved fatal for the SPI bus on the PCB, thus there was no way to collect data due to the short turnaround time. (This will not be a future implementation.)
LM317 Voltage Regulator	LM2596 Buck Converter	Battery voltage to board voltage	The amount of power dissipated into heat energy from the small voltage regulator was too great for it to handle, so a buck converter had to be used, this also meant that the power remained the same and the amperage increased, rather than giving off residual heat.
No speaker	Speaker	Audible activation confirmation	Although the speaker was not working at the VDF, the hardware and software were present

4.2.3. Secondary Payload Design

The airbrakes consist of four main sections, the electrical housing, encoder mount, flap mounts, and motor mount. A picture of the as built system is shown in Figure 4.2.1. after the VDF. It does not have the flaps mounted because they are mounted on the system after it is inserted into the airframe. In this figure, the four sections are called out and will be discussed more in depth in the next subsection.

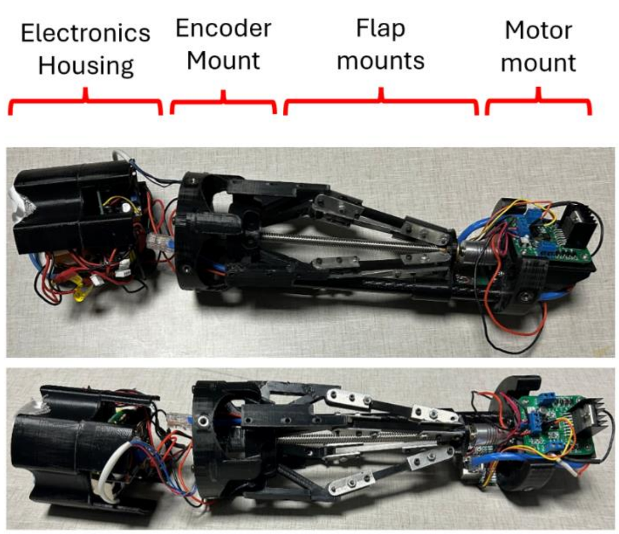
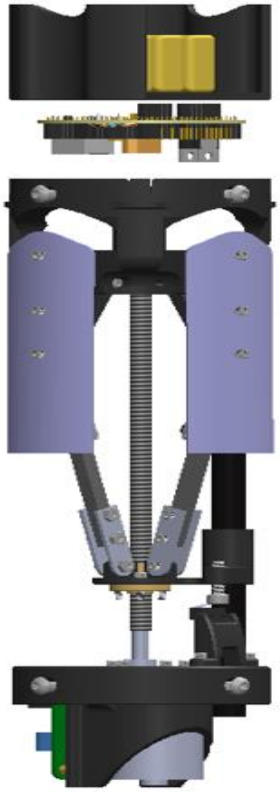


Figure 4.2.1. *Assembled airbrakes system after VDF.*



- As Built
- Rendered CAD

Figure 4.2.2. *CAD model of airbrakes system compared to Assembled airbrakes system after VDF.*

Figure 4.2.2 shows the CAD model of the AB system compared to the as built system; there are no major differences. The CAD did not include all hardware and wiring.

4.2.3.1. Mechanical Design

Figure 4.2.3 features the mechanical system with no electrical integration. The primary structure of the mechanical system consisted of the motor mount, carbon fiber structure tube, lead screw, and encoder mount. Both the motor and encoder mount are custom 3D prints, but the lead screw is a precision acme lead screw, and the structure tube is a 0.5-inch diameter hollow carbon fiber tube with 0.1-inch thickness. To keep the structure firm outside of the airframe, the structure tube has a set screw inside of the motor mount to keep the system from separating.

Figure 4.2.3. *As built mechanical structure.*

Going from the bottom to the top of the airbrakes system the motor mount is first. In Figure 4.2.4 through Figure 4.2.6 shows the motor mount in various configurations; this is the bottom half of the AB system. It features three heat set inserts (which are put in via a soldering iron as seen in Figure 4.2.7), which fasten the mount to the airframe; one set screw implant, which holds the structure tube in place; a mounting plate for the motor controller; a mounting hole for the motor, and a button/breakout board mount.

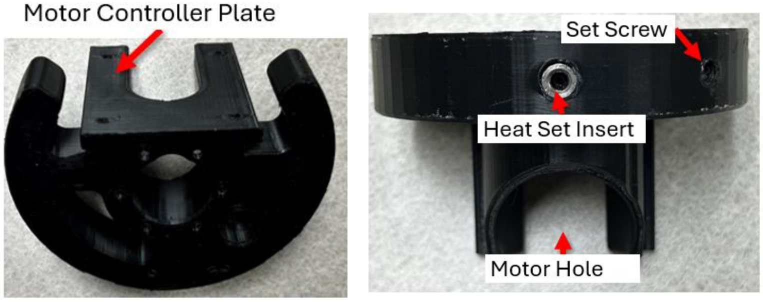


Figure 4.2.4. *As built motor mount with no electronics.*

To communicate with PCB electronics, the structure tube serves a double purpose as it carried the wires needed for communication and power, and it holds the system in place as seen in Figure 4.2.5. The logic and lower power go through an RJ45 cable through the structure tube, and the high amperage motor wires are run separately through a direct bus on the PCB.

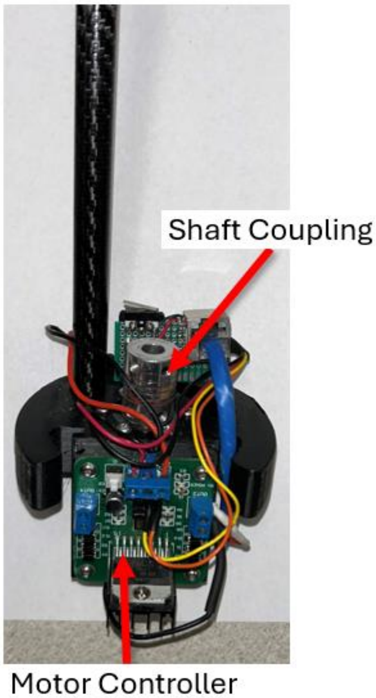


Figure 4.2.5. *As built motor mount with all hardware and electronics.*

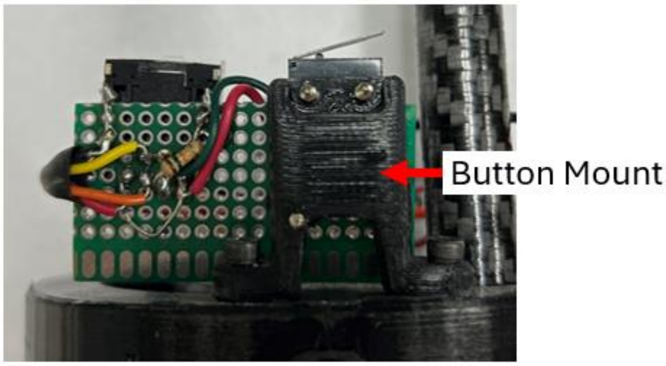


Figure 4.2.6. *As built magnification of the button/breakout board mount.*

Figure 4.2.7. *Process of inserting heat set inserts.*

Moving upward to the mechanical flap actuation system as seen in Figure 4.2.8, it consists of the force transmission system from the flap, which is made from G12 fiberglass tubing; the ternary link which was 3D printed out of PETG; the coupler which is seen in Figure 4.2.9; the slider anchor, which was 3D printed out of PETG; the lead screw; and the lead screw nut. The entire system was held together by a 4-40 x 5/8 Hex Socket Head Cap Screw fastener. To keep the nuts in place, thread locker is used on each fastener. The thread locker holds the screws on, but they can be removed easily by force.

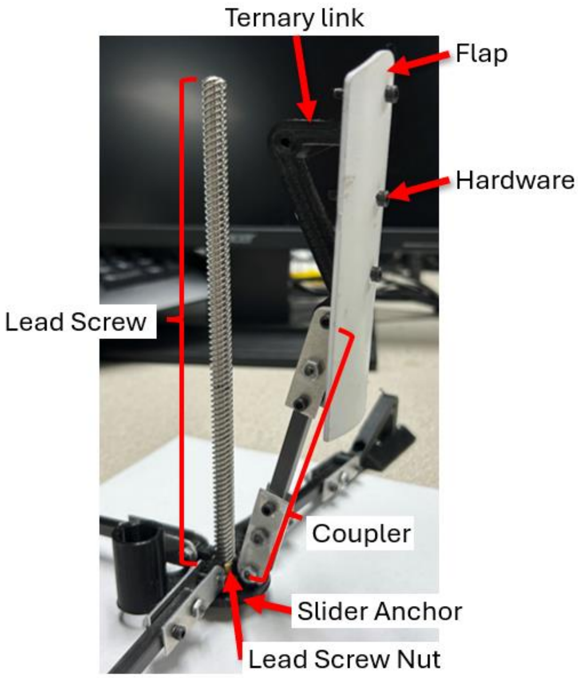


Figure 4.2.8. *Mechanical flap actuation system of AB.*

Figure 4.2.9 is the coupler in the force transmission system. It consists of the gusset plate which is fabricated from a 1/32" 6061 aluminum sheets; the spacer, which expands the size of the gusset plates to make room for the ternary link, is made of PETG; the hardware; and the carbon fiber pultruded rod, which transmits force.

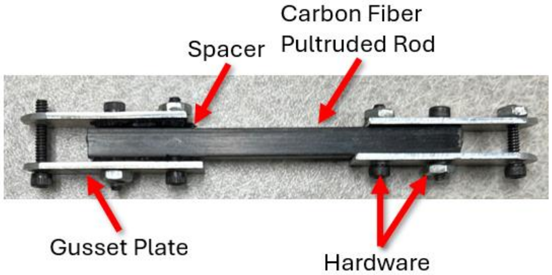


Figure 4.2.9. *Coupler of mechanical flap actuation system.*

Moving up from the force transmission system, the top of the mechanical system is the encoder mount as seen in Figure 4.2.10. It features four heat set insets to hold the system in the airframe; the structure tube hole, which is held in via friction fit; and a ball bearing in the center to allow for rotation along the threaded rod. On top of the encoder mount is the encoder web as seen in Figure 4.2.11. This web holds the rotary encoder and manages wires; and has four mounting points around the circumference of the encoder mount. The encoder mount, web, and coupler are printed out of PETG; the encoder coupler has two screws, one to tighten around the lead screw as the motor turns, and another as a set screw into the encoder itself.

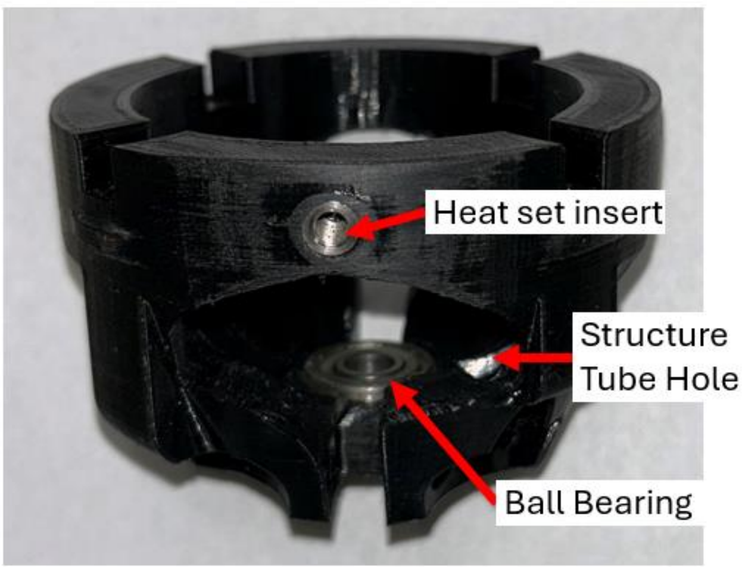


Figure 4.2.10. *As built encoder mount.*

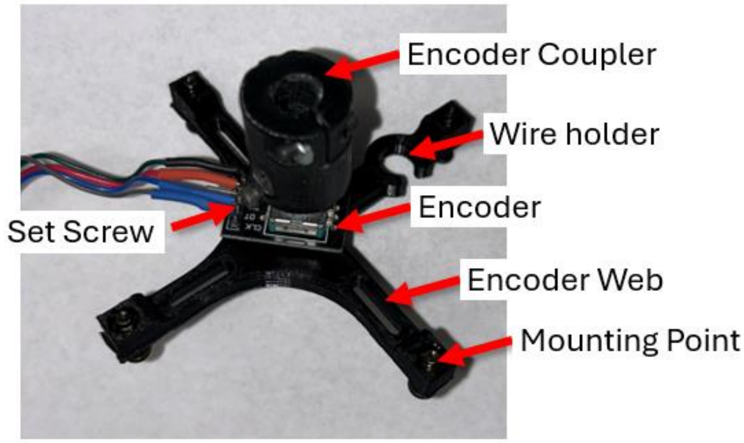
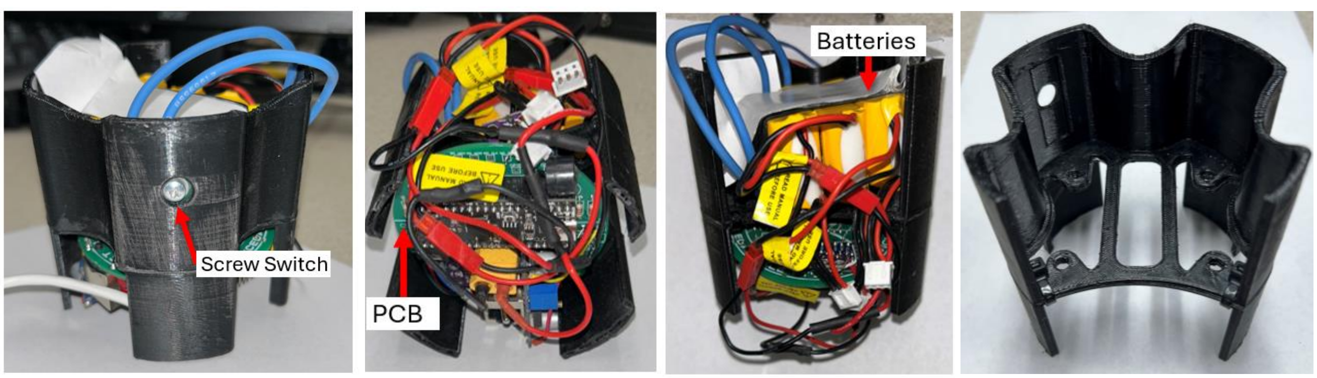


Figure 4.2.11. *As built encoder web.*

Atop the mechanical system sits the electrical housing as seen in Figures 4.2.12 a-d. The canister holds three vital components to the electrical system: the PCB, batteries, and screw switch. The screw switch was added onto the PCB because the manual toggle switch was not accessible since it is inside the rocket. Thus, if the system needed restarted for any reason the whole airbrakes system would need to be pulled out, but with the new screw switch added, it allowed for easy (de)activation.



- Electrical housing side view
- Electrical housing bottom view
- Electrical housing front view
- Electrical housing front view (no electronics)

Figure 4.2.12. *Electrical housing.*

4.2.3.2. Mechanical Manufacturing

The airbrakes were manufactured using multiple different methods. Table 4.2.3 visualizes the manufacturing methods, the materials selected, a brief description of the manufacturing process if applicable, and why this manufacturing method was chosen.

Table 4.2.3. *Airbrakes manufacturing.*

Selected Component	Selected Material	Manufacturing Tool	Manufacturing Process/Details	Manufacturing Method Rationalization
Electrical Housing	Polyethylene Terephthalate Glycol (PETG)	3D Printer	Ender3; printed in 2 parts and glued together with gorilla glue.	It is a structural part, which is light with complex geometry.
Encoder Mount/Web/Coupler	PETG	3D Printer	Ender3; printed with 85% infill.	It is a structural part, which is light with complex geometry.
Motor Mount	PETG	3D Printer	Ender3; printed with 85% infill.	It is a structural part, which is light with complex geometry.
Slider Anchor	PETG	3D Printer	Ender3; printed with 85% infill.	Analysis determined this material to withstand the loading expected; 3D printing is quick and repeatable.
Ternary Link	PETG	3D Printer	Ender3; printed with 85% infill.	Analysis determined this material to withstand the loading expected; 3D printing is quick and repeatable.
Button Mount	PETG	3D Printer	Ender3; printed with 85% infill.	It is a structural part, which is light with complex geometry.
Coupler Spacer	PETG	3D Printer	Ender3; printed with 100% infill.	It is a structural part, which is light.

Gusset Plate	Aluminum	Shear, End Mill, Drill press, Sander	Correctly sized rectangles are sheared off a 1/32" aluminum sheet. The sides are straightened with an end mill. The holes are drilled in a press. The fillet is created on a belt sander.	This design was created for ease of manufacturing, and the gusset plates were analyzed using double shear techniques.
Coupler Rod	Pultruded Carbon Fiber	Band saw, End mill	The correct length of rod is cut on the band saw. Holes are cut into one side of the hollow square rod at a time on the end mill using a center drill.	The rod was tested under load in the INSTRON machine, and it takes approximately one hour to make the four rods.
Flaps	G12 Fiberglass	CNC Machine	Set tool path, place coupler and airframe in place, and cut airframe for flap	This material was analyzed to stand up to wind forces, and it has similar surface roughness as the rocket airframe.

4.2.3.3. Mechanical Integration

Figure 4.2.13 demonstrates the flow of putting the airbrakes into the airframe and their final fitment. First the system went through a rigorous mechanical and electrical checklist (not shown). Once all systems were go for launch, then the electrical housing was connected to the mechanical structure. The housing was pushed up into the top coupler, and the structure was pushed down into the airframe below. The final fitment had a slight issue, so the holes had to be expanded before launch to expose the screw switch for the AB.

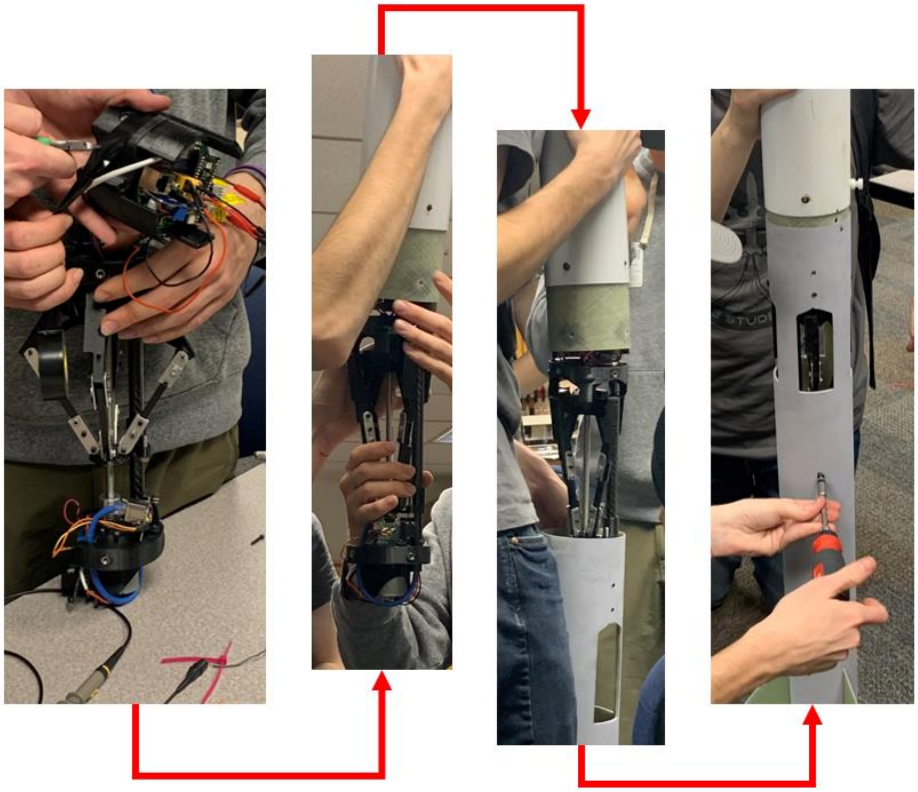


Figure 4.2.13. *Airbrakes integration process.*

4.2.3.4. Electrical Design

Printed Circuit Board (PCB)

Figure 4.2.14 shows the electrical PCB schematic for the airbrakes. There have been a couple of changes since the CDR. The RJ45 jack is present on the schematic, LEDs were added for functional testing and debugging, extra GPIO pins were added for unforeseen use cases, a battery voltage regulation system was incorporated, but the override NMOS is used on the override PCB not the airbrakes PCB. (Note: the override and AB PCB are the same, but have different components soldered onto the physical board.)

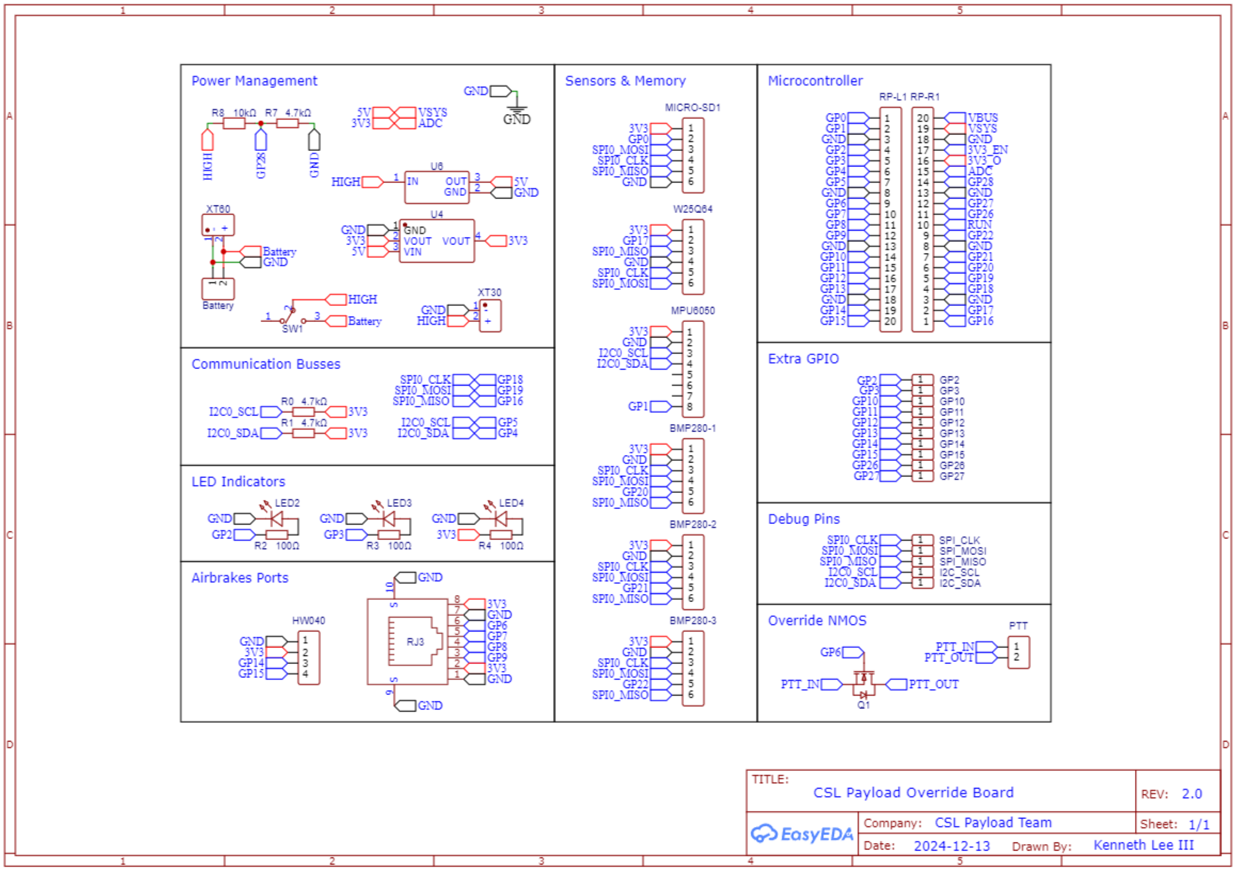


Figure 4.2.14. *Airbrakes PCB electrical schematic.*

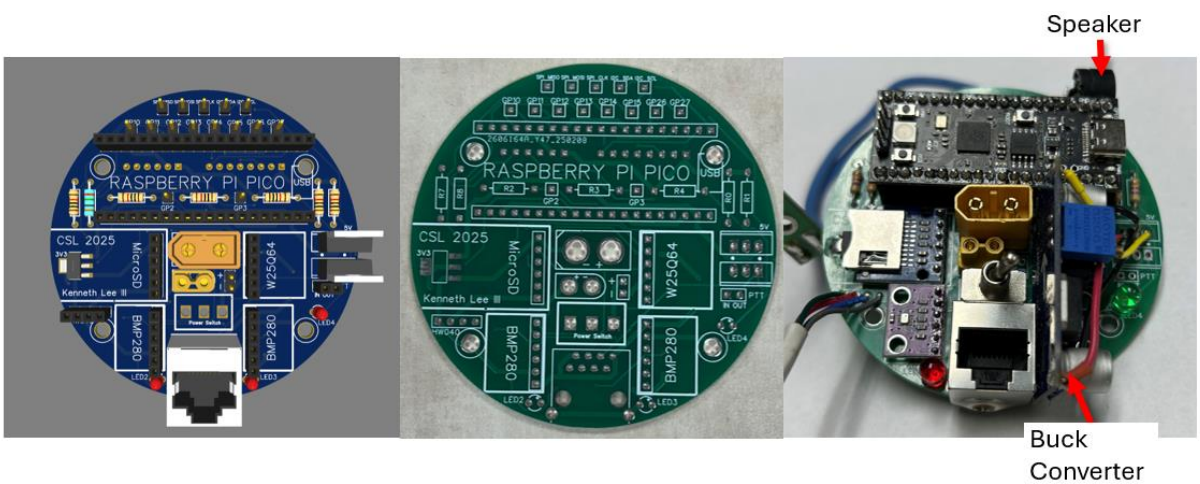


Figure 4.2.15. *Top of Airbrakes PCB from EasyEDA to non-soldered to soldered.*

The airbrakes PCB progression from CAD to non-soldered to soldered is shown in Figures 4.2.15 and 4.2.16. There are a couple notable remarks about these PCBs. First, they match the wiring diagram as shown above, including three BMP280 pressure sensors, one accelerometer, one SD card, one external flash memory, one Raspberry Pi Pico, and one 3.3V voltage regulator. There were some modifications to this board that will stay for future flights such as the speaker and buck converter. The speaker is added for audible confirmation while the rocket is on the launch pad, and the buck converter is used instead of a voltage regulator because stepping down from 24V to 5V releases a lot of heat, thus the buck converter will give extra amperage if needed, rather than releasing this power in heat.

On the bottom side of the PCB the components were present, but because the airbrakes could not be activated from the launch pad a screw switch was added. So, if either the screw switch or the toggle switch is activated, the PCB turns on. While commencing a final electrical test for the airbrakes system, the motor controller released a large quantity of unwanted power into the system via a short circuit due to failure to follow standard procedure during testing; because of this accident, the SPI bus on board was no longer active; therefore, one BMP280 was connected to the I^2C bus where the accelerometer was connected. This was not a planned addition and will not be followed for the next launch.

Figure 4.2.16. *Bottom of Airbrakes PCB from EasyEDA to non-soldered to soldered.*

Battery Selection

The battery selected for the electrical system was a Zeee 1500mAh 11.1V battery, but because of design changes with the motor the battery voltage had to be doubled to 24V, and this required three Liperior 850mAh 7.4V batteries in series to produce 22.2V nominally. Figure 4.2.17 shows the comparison of the original battery to the battery used in flight. The electrical system, while active in a standby mode, draws 212mA and the new battery pack has a tested capacity of 738mAh, which results in a final predicted battery life of 3.5 hours.

Figure 4.2.17. *Airbrakes battery selection.*

Motor

The motor which was to be used in the flight was burnt up in testing and the backup motor which was to be used in case of motor failure arrived with shipping damage, a backup motor was used with the same form factor, and voltage, but with a higher speed of approximately 600 RPM.

4.2.3.5. Software & Control Design

The software controlling the AB subsystem remained the same since CDR, as can be seen from Figure 4.2.18 and Table 4.2.4. The AB is regulated by a state machine which transitions between five phases: preflight, liftoff, burnout, apogee, landed. The airbrakes only initiate in the burnout (or coast phase). Launch is detected by a spike in acceleration and sufficient increase in altitude. The AB transitions to coast (or burnout) with a decrease in acceleration. After a decrease in altitude, the airbrakes are considered to have hit apogee, at which point they close to prevent being tangled with the shock cords. After apogee, a stable altitude is detected for the rocket to be considered landed. Phase transitions were tested using flight data from previous flights in place of collected sensor data. However, the AB failed to deploy during the VDF since testing was done with units of $\frac{m}{s^2}$, but sensor data was collected in g's therefore the spike in acceleration was not high enough to trigger the liftoff state.

The rocket continuously collects data at a frequency of 10Hz for most phases of flight, and 25Hz during the coast phase. The data is filtered, then given to a control algorithm to compute the optimal angle of the AB during its coast phase. The additional microcontroller core is used to continuously open or close the AB to move them to the optimal angle.

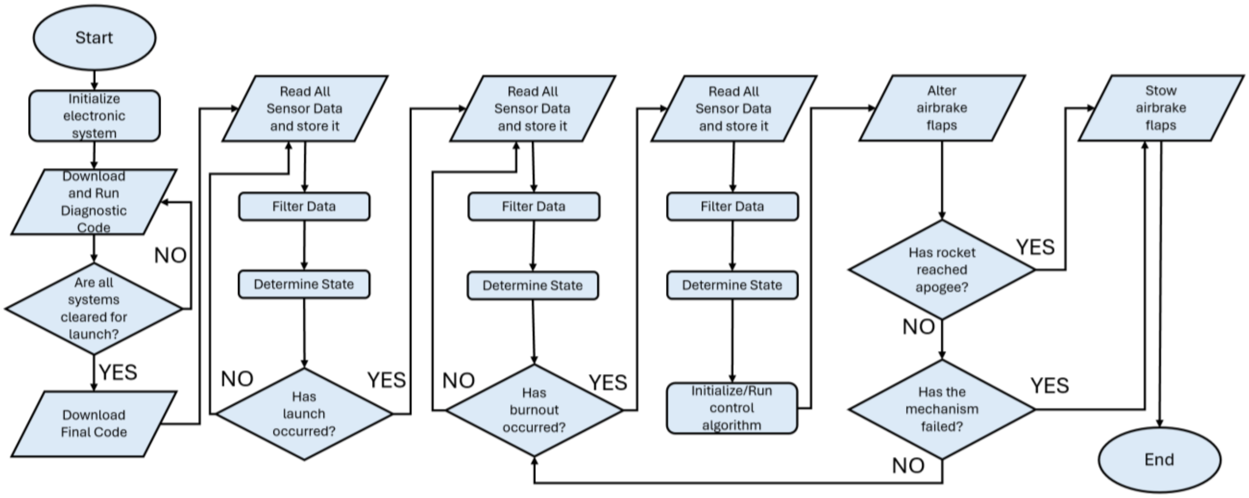


Figure 4.2.18. *Process flowchart of air brakes electromechanical decision logic.*

Table 4.2.4. *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	Stop data collection and transfers data from flash memory to the SD card.

When the control system is active, the control algorithm uses the pressure change to calculate the current velocity and compares that velocity to an "ideal velocity" at the current altitude. If there is a discrepancy between the ideal and current velocity, the controller calculates the desired deceleration and converts that to the appropriate angle to remedy that will achieve that desired deceleration. Every time the controller function is called it performs this calculation and outputs the best angle possible to achieve the ideal velocity at the current altitude. This method of control is advantageous because the ideal flight trajectory can be simulated using MATLAB on a much more powerful computer than the Raspberry Pi days or weeks before the flight. The control function requires very little processing power and thus is able to be called as many times as desired to achieve a quick response rate to changes in velocity and altitude. The ideal trajectory was found by simulating a slow deployment to 45 degrees and adjusting the deployment speed until 4100 ft is achieved in the simulation. 45 degrees was chosen to allow for further deployment if the temperature is warmer than when the ideal velocity was calculated, the ideal trajectory can still be achieved by deploying the airbrakes slightly further to make up for the reduced atmosphere density.

4.2.4. Testing & Demonstration Performance

The testing CSL has performed is to assess if the motor will be strong enough, the couplers won't break, the button stops the motor, the code transitions from state to state correctly, the controller gives out correct values in the C++ code when it was ported, the data can be taken correctly, and the BMP pressure data is very smooth so the system only requires one pressure sensor. Through the first test we figured out we need a new type of switch to avoid an electrical blackout.

From the second launch we found out that the mechanical system needs to change at the slider anchor because in mounting and under launch forces the coupler members will be in tension. The screw switch worked to avoid blackouts. There is no cause for brownouts because no large amps were being drawn. All tests on the airbrakes are described in section 7.1.

5. Demonstration Flights

5.1. Chariot Flight #1

5.1.1 Demonstration Flight Overview

The inaugural flight of Chariot was intended to test the data collection capabilities of both the primary and secondary payload and then use that data to estimate an accurate drag coefficient for the rocket. Due to the desire to find the drag coefficient of the rocket without the airbrakes deployed the mechanical system was inactive during this flight. The "measured" drag coefficient from the flight was then used with CFD analysis to estimate the drag coefficient with the airbrakes deployed at various angles. Due to a manufacturing error, the airbrake pockets were 0.71" too high on the airframe. This, as well as the airbrake system itself being longer than designed, caused the internal linkages to not line up with the pockets for the flaps. Because the airbrakes were not intended to deploy on this flight, and because CSL did not have any more fiberglass tubing on hand to manufacture another aft section, the airbrake flaps where taped onto the rocket using packing tape as shown in Figure 5.1.1. Chariot reached an apogee of 4632 ft measured by the primary RRC3 altimeter and landed 1603 ft from the launch rail. The landing exceeded the maximum allowable kinetic energy for all three independent sections. Table 5.1.1 contains an overview of the data from this inaugural flight and Figure 5.1.2 shows the launch and landing locations overlayed on an aerial view of the launch site.


Figure 5.1.1. *Chariot on loaded on launch rail for inaugural flight. Note the packing tape holding the airbrake flaps on from both the inside and outside of the airframe.*

Table 5.1.1. *Overview of Chariot Flight #1 data.*

Date and time of flight	March 2, 2025. 6:50 PM EST
Location of flight	WSR club launch site: 5995 Federal Rd, Cedarville, OH 45314
Launch conditions	Temperature: 33 F Wind: 5.75 mph, N Visibility: ≥ 10 miles Cloud Cover: clear Relative Humidity: 63%
Motor	Aerotech K1000T-P
Ballast flown	2.425 lb (1100 g)
Payload status	Collecting data. Transmitter inactive.
Air brake status	Collecting data. Motor inactive.

Official target altitude	4100 ft
Predicted altitude (no AB)	4714 ft
Measured altitude	4632 ft
Main descent rate	48 ft/s
Landing kinetic energy	Forward section: 292 ft*lb Avionics section: 142 ft*lb Aft section: 404 ft*lb
Descent time	62 s
Drift distance	1603 ft
Drogue deployment	Apogee & apogee +1 s
Main deployment	600 ft & 550 ft

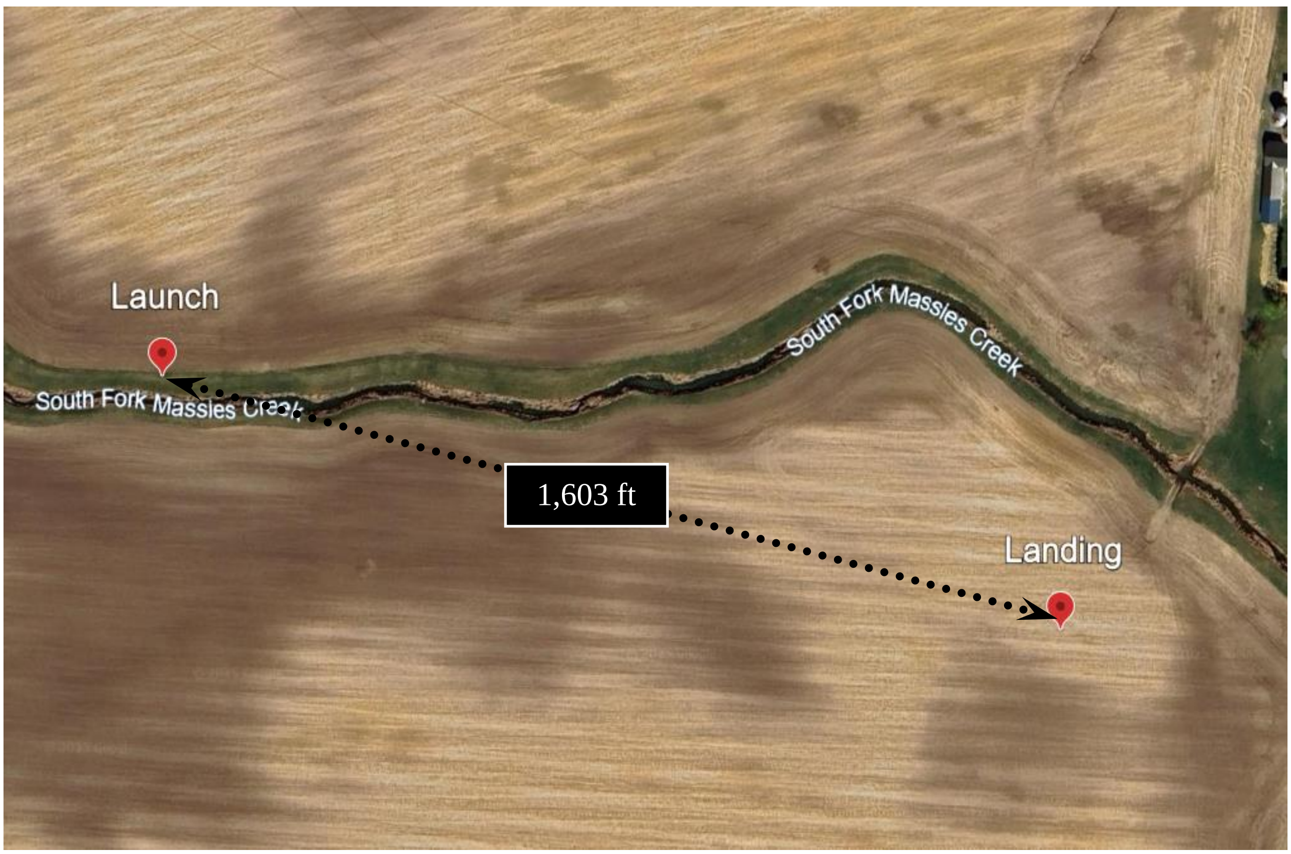


Figure 5.1.2. *Aerial view of launch site, showing launch and landing locations of Chariot flight #1.*

5.1.2. Flight Data

The electrical components for the recovery system performed almost flawlessly during this flight. Both the primary RRC3 altimeter and the secondary Easy Mini altimeter set off their ejection charges for both parachutes. The flight profile graphs generated by the primary and secondary altimeters are shown in Figure 5.1.3 and Figure 5.1.4 respectively. The secondary altimeter stopped recording data at drogue deployment but still fired all ejection charges as designed. Note the recorded descent rate is 2.5 times the desired descent rate causing an off nominal kinetic energy at landing.

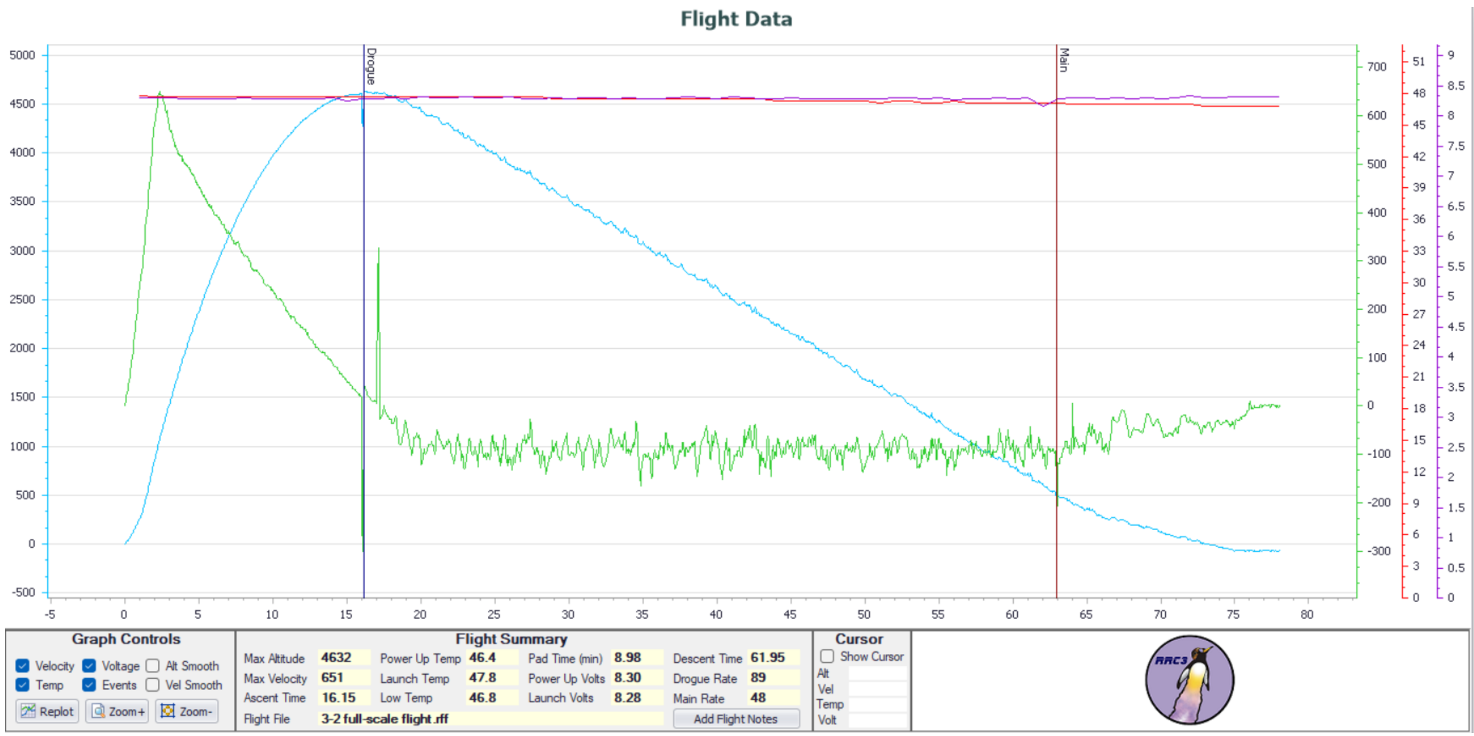


***Figure 5.1.3.** RRC3 flight profile graph for Chariot Flight #1.*

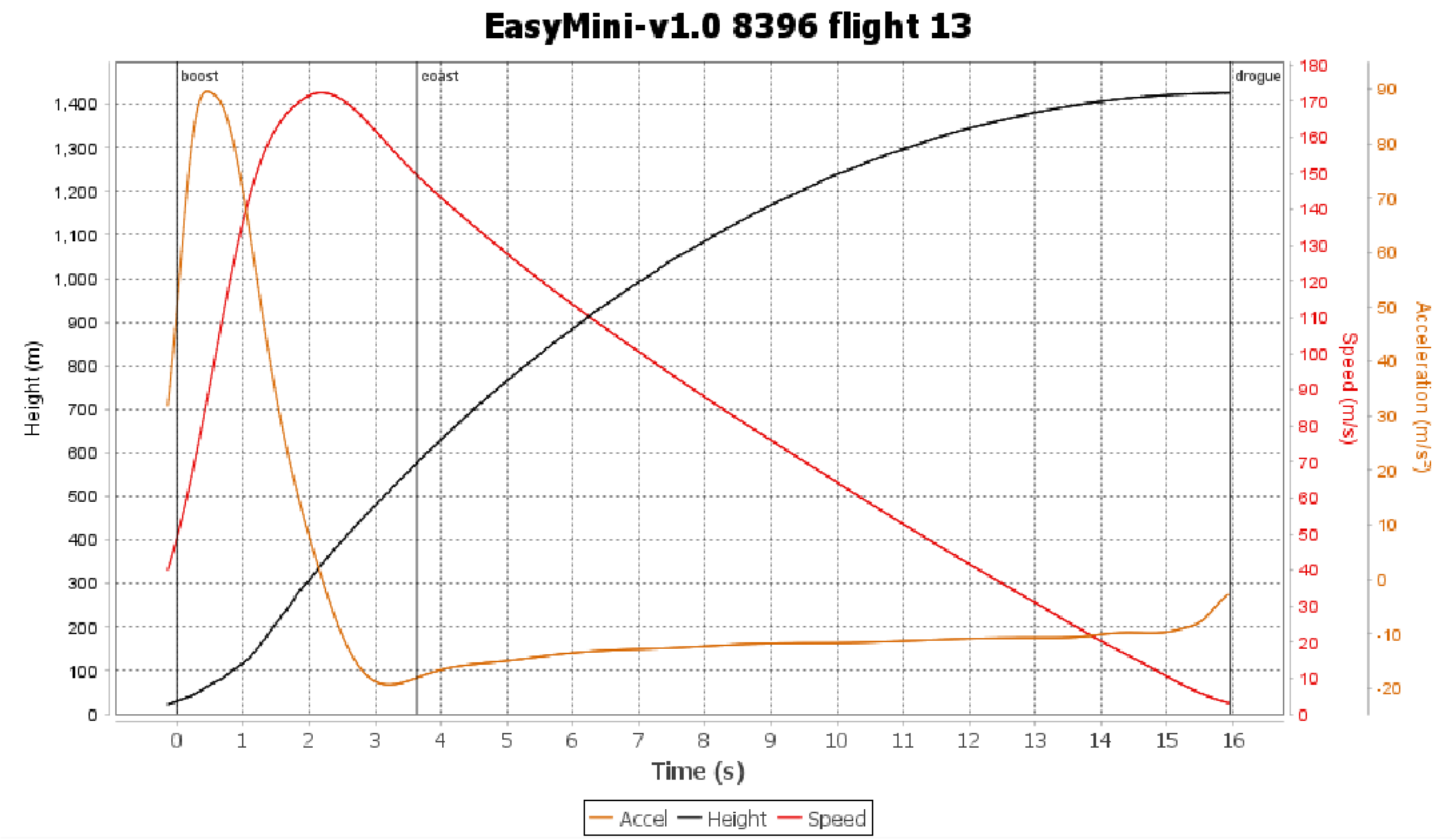


Figure 5.1.4. *Easy Mini flight profile graph for Chariot Flight #1. Note the altimeter stopped recording data upon drogue deployment, this issue did not stop any ejection charge from going off.*

5.1.3. Vehicle Recovery Discussion

The rocket recovery sequence operated perfectly as the main and secondary charges for both the drogue and main recovery event fired at the anticipated times. Both parachutes opened fully, but the launch vehicle suffered significant damage. Figure 5.1.5 contains the landing condition of each independent section of the rocket, and Figure 5.1.6 shows a close view of each piece of the rocket.

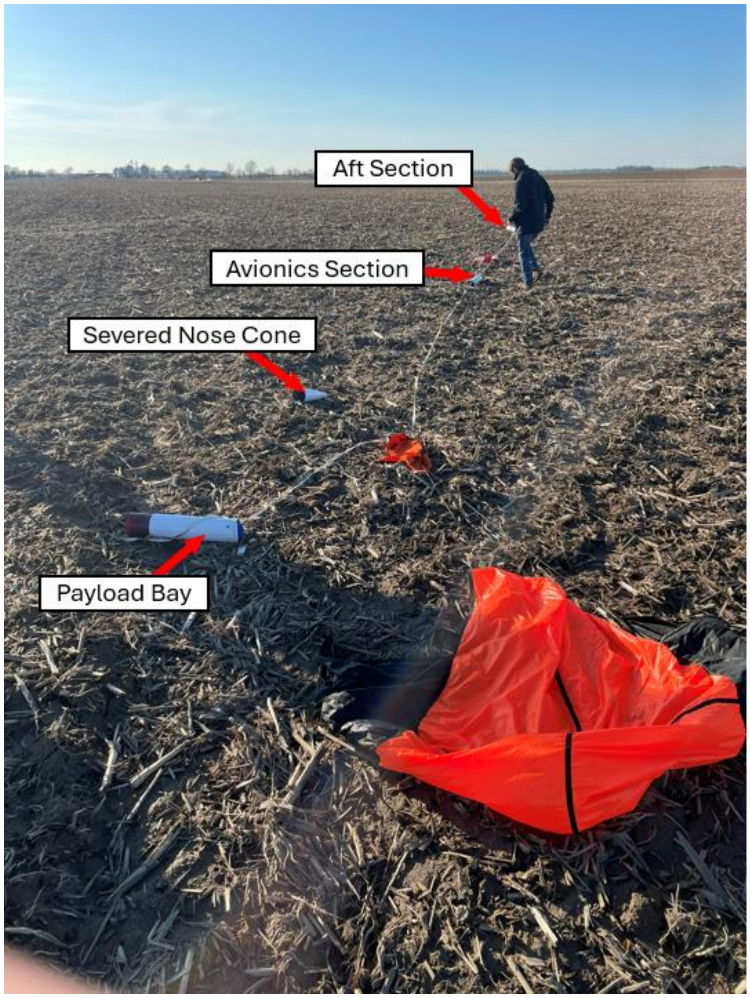


Figure 5.1.5. *Landing orientation of the three independent rocket sections and the broken rocket nose cones.*

Figure 5.1.6. *Close view of each of the free portions of the rocket after landing. Pictured are:* ***1)*** *the broken tip of the 3D printed nose cone,* ***2)*** *the payload bay,* ***3)*** *the avionics section, and* ***4)*** *the aft section of the rocket with the airbrake flaps detached and lying beside the rocket.*

The fins, thrust structure, tailcone, avionics bay, and recovery devices all survived landing. However, the impact force at landing was sufficient to fracture the nose cone just above the shoulder, crush the portion of the primary payload body contained in the nosecone, and dislodge both the airbrake flaps and camera mount. The portion of booster tube surrounding the airbrakes was the only airframe casualty, as shown in Figure 5.1.7. This airframe destruction also minorly damaged the main 3D printed pivot point inside the airbrakes.

Figure 5.1.7. (Right) *Damaged portion of the airframe after landing. All four of the stringers buckled to the point un-flightworthiness.* ***(Left)*** *Fissure in the airbrake encoder mount caused by the booster flexing upon landing. (Note: The rest of the damage to the part was a result of the airbrakes being broken out of the airframe and was not a result of the flight).*

Table 5.1.2 *Kinetic energy estimates for Chariot's first landing.*

Section:	Forward	Avionics	Aft
Landing velocity (ft/s)	48.0	48.0	48.0
Mass (slug)	0.25	0.12	0.35
Kinetic energy (ft*lb)	292.07	142.20	404.11

5.1.4. Payload Performance

5.1.4.1. Secondary Payload Performance

The mechanical system was not active during this flight, but the electrical system was active. The electrical system took data, but unfortunately it turned itself off during the flight because the on/off IO was a manual toggle switch. The electrical system was taken out of the rocket, and thinking it was still on, it was turned from off to on. This erased the data and no useful information was retrieved from the sensors.

Below are the success criteria; if the success criteria was met the box is green, if the criteria was not met, the box is red.

AB.S.1 Confirmation of AB deployment during launch. (Failed)
AB.S.2 AB were stowed within ±2 seconds of apogee. (Failed)
AB.S.3 Rocket apogee achieved within ±25 feet of target altitude. (Failed)
AB.S.4 Confirmation of drag flaps actuation in the onboard camera. (Failed)
AB.S.5 The drag flaps should be located no further than 2 inches behind the CP to ensure aerodynamic stability. (Passed)
AB.S.6 No components of the system shall experience mechanical failure during any stage of flight. (Passed)
AB.S.7 No electrical brownout or blackouts shall occur. (Failed)
AB.S.8 Flight data recorder and retrieved. (Failed)

The main mission of the AB on the rocket is to achieve **AB.S.3**. Since this was not achieved, this was a mission critical failure, and overall, there were six failures and two successes.

5.1.4.2. Mission Payload

All of the payload hardware was present on the flight except the STEMnauts. When the nosecone broke on landing, the top of the payload inside it also fractured. This meant that the payload's primary PCB experienced damage, including a broken microSD card, resulting in loss of all of the primary PCB's collected data. The override PCB collected data as expected with the exception of altitude, which failed because of a broken pressure sensor.

Below are the success criteria; if the success criteria was met the box is green, if the criteria was not met, the box is red.

P.1 Payload survives vehicle landing to be able to perform post-flight operations.
P.2 Payload has sufficient battery power for pre-flight, in-flight, and post-flight operations.
P.3 Payload sensors all deliver accurate data to the microcontroller.
P.4 Payload transmits APRS packets from the rocket's landing site to the launch site receiver.
P.5 Payload transmits decodable telemetry data using the standard APRS protocol.

5.1.5. Flight Analysis

Before the inaugural flight, a preliminary OpenRocket simulation was conducted using the as constructed rocket and standard weather conditions. This simulation predicted an apogee of 4732 ft using the estimation of smooth paint covering the entire rocket. This predicted apogee gives enough margin for varying weather conditions to lower the apogee while still overshooting the official target altitude of 4100 ft by enough for the AB to effectively slow down the rocket. Figure 5.1.8 shows the flight profile graph from this OpenRocket simulation.

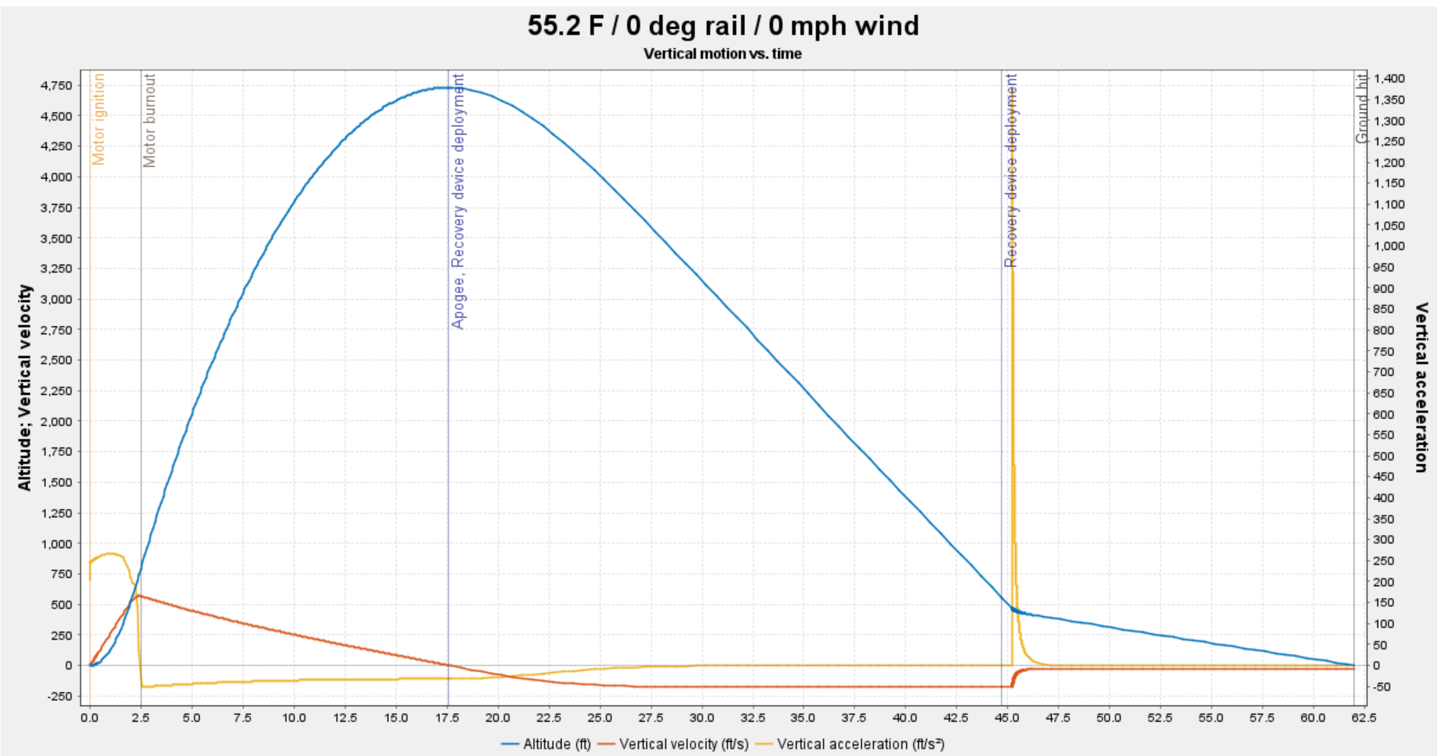


Figure 5.1.8. *Preliminary OpenRocket simulation of Chariot using standard weather conditions. This simulation predicted an apogee of 4732 ft using a Cd of 0.484 which corresponds to smooth paint.*

After conducting the inaugural flight of Chariot, the aforementioned OpenRocket sim was updated using the recorded weather data from the flight. This new simulation is shown in Figure 5.1.9 and predicted an apogee of 4683 ft.

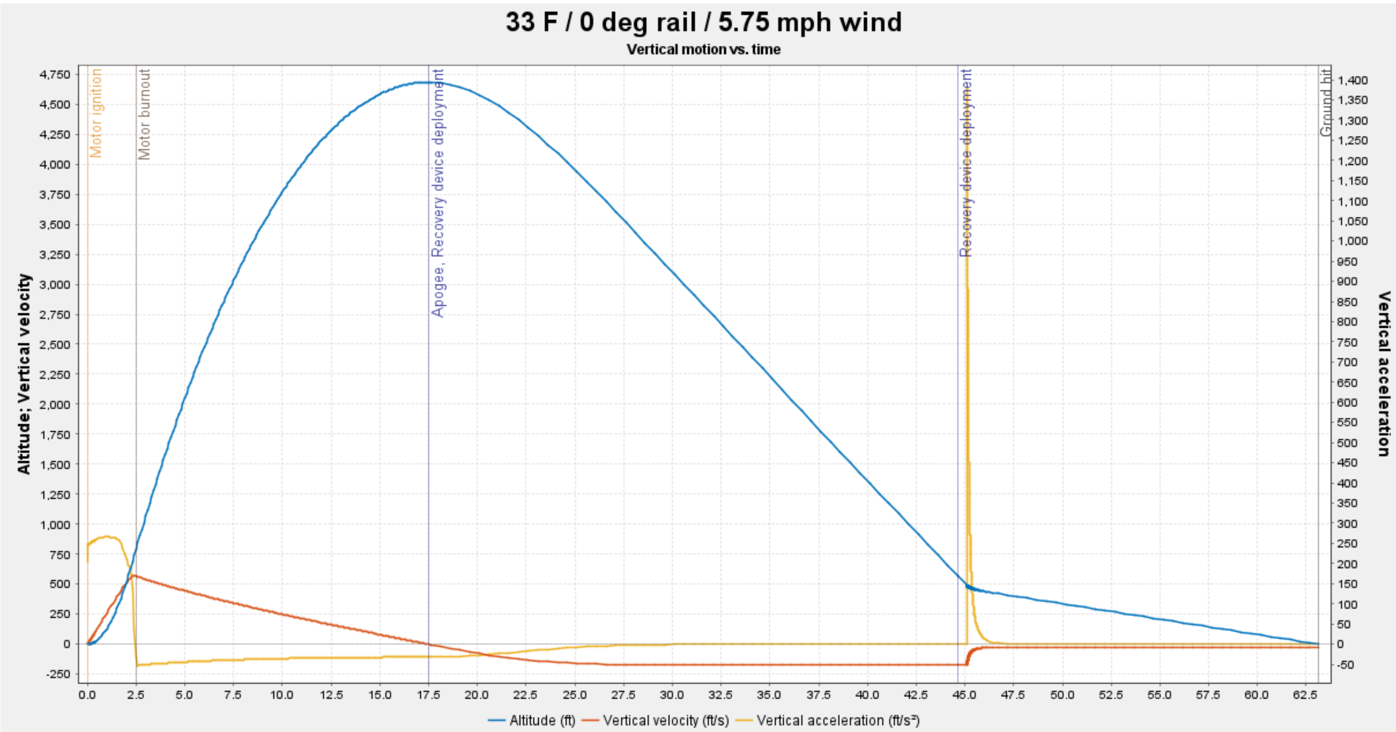


Figure 5.1.9. *Preliminary OpenRocket simulation of Chariot using launch day weather conditions. This simulation predicted an apogee of 4683 ft using a Cd of 0.484 which corresponds to smooth paint.*

Next, the drag coefficient of the rocket was estimated by plotting the total velocity vs the total acceleration recorded during the coast phase of flight and overlaying this plot onto similar graphs using the OpenRocket model to vary the drag coefficient from 0.5-0.9. The point of this plot, shown in Figure 5.1.10, was to find the drag coefficient for the curve that most closely matched the data collected data from the flight: this drag coefficient would be a reasonable estimate for the drag coefficient of the rocket. Unfortunately, there was some error in the velocity due to the main payload backup pcb not collecting pressure data due to a known error that could not be remedied in time for the flight. To estimate the velocity over time, the maximum recorded velocity from the primary RRC3 altimeter was used for an estimate of the starting velocity and the collected total acceleration was used in MATLAB to numerically integrate the velocity over time to form the below curve. There are two significant sources of error that are introduced by producing the curve this way: the first is the fact that the RRC3 was measuring vertical velocity and this calculation assumes that the total velocity was being measured, the second is that due to using data from two completely separate electrical systems both the time step between data points and the speed of reading and storing the data can vary. This could cause the altimeter data to reveal that the coast phase of the flight started at a different time than was evident from the acceleration data causing the wrong starting velocity to be used. To account for these two types of error, error bars of +- 30 ft/s were added to the y-axis of the recorded data. The estimate for the drag coefficient of the rocket was found by varying the drag coefficient in the most current OpenRocket simulation, shown in Figure 5.1.11, until the calculated apogee closely matched the measured apogee from the primary RRC3 altimeter. This number was detemiend to be reasonable because it is inside the error bars at the lower velocities on the velocity vs acceleration plot.

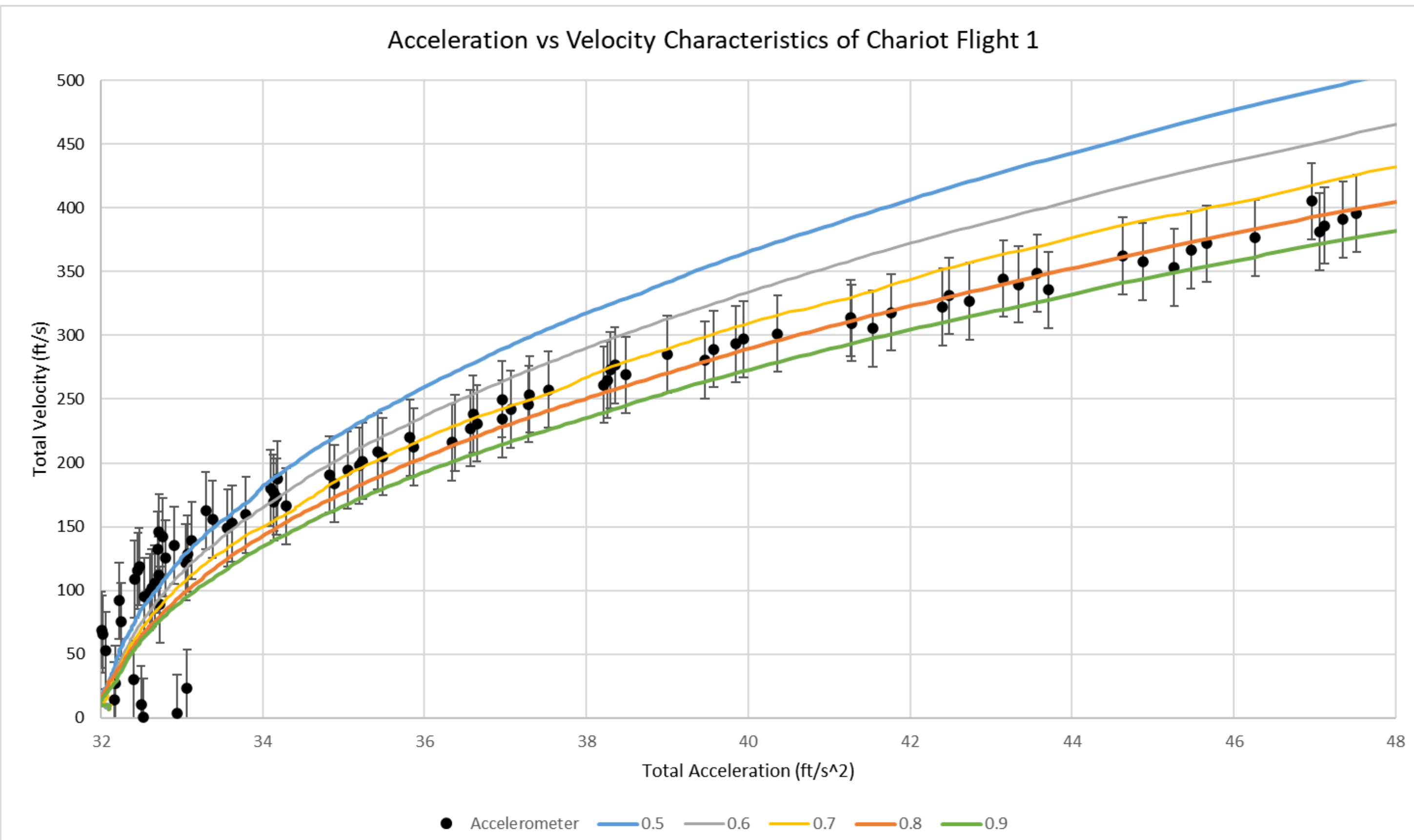


Figure 5.1.10. *Recorded velocity vs acceleration of Chariot overlayed on simulated velocity vs acceleration plots from OpenRocket simulations with varying Cd. Error bars of +- 30 ft/s velocity were used due to inadequate data collection from the payload forcing the primary RRC3 to provide the starting velocity. This plot shows that the Cd estimate of the rocket of 0.53 is a reasonable estimate.*

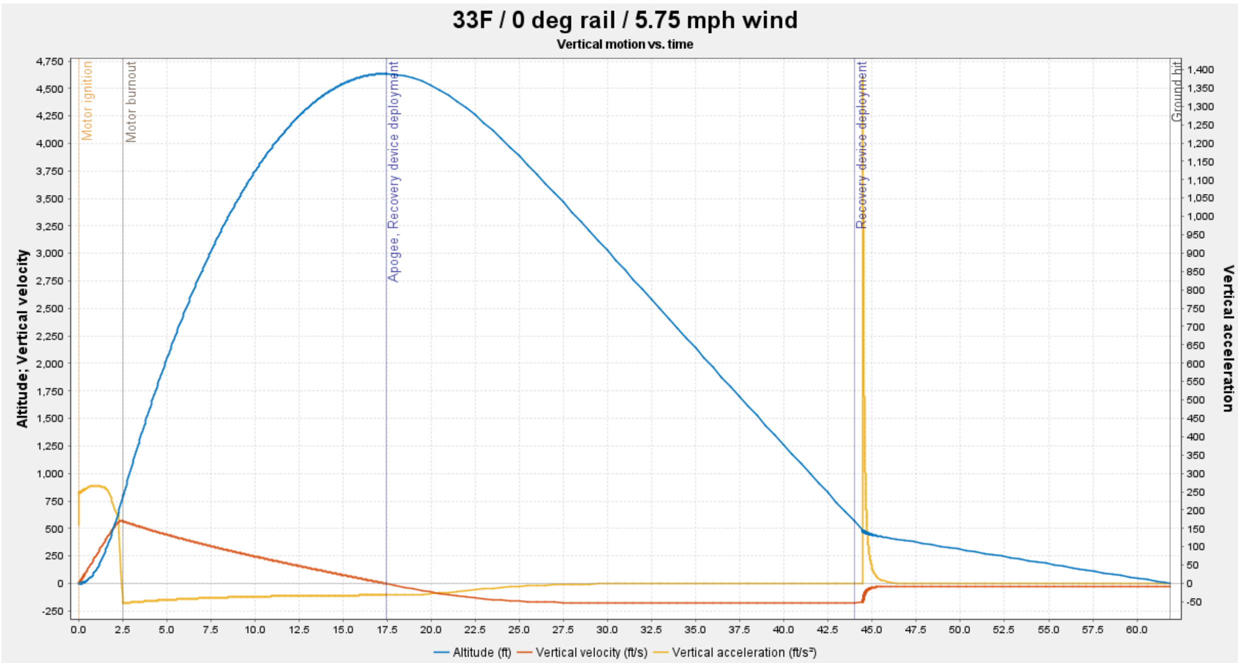


Figure 5.1.11. *Post-flight OpenRocket simulation using launch day conditions and calculated Cd of 0.53. This simulation produced a projected apogee of 4634 ft.*

Table 5.1.3 contains a summary of the various iterations of the OpenRocket simulations that were conducted before and after the inaugural full-scale flight. There are two notable discrepancies between the recorded flight data and any of the OpenRocket simulations. The maximum recorded velocity is almost 100 ft/s higher than any of the simulations and the landing velocity is almost double the simulated landing velocity. This issue with the simulated landing velocity caused Chariot to well exceed the kinetic energy limit on impact with the ground causing the nosecone to break in half destroying the top of the payload.

Table 5.1.3. *Summary table of OpenRocket simulations for Chariot flight #1.*

	Apogee	Cd	Max Velocity	Max Acceleration	Velocity at Landing	Total Flight Time
Preliminary 0 Wind	4732 ft	0.484	570 ft/s	267 ft/s^2	26.2 ft/s	61.9 s
Preliminary Launch Conditions	4683 ft	0.484	569 ft/s	267 ft/s^2	25.6 ft/s	63.1 s
Post Flight Calculated Cd	4634 ft	0.53	568 ft/s	266 ft/s^2	25.6 ft/s	62.9 s
Recorded Flight Data	4632 ft	0.53	651 ft/s	294 ft/s^2	48 ft/s	62 s

Chariot's inaugural flight revealed that the rocket's internal components and delicate instrumentation had to be implemented more robustly overall in future flights, both in terms of construction methods and software practices. Both the primary and secondary payloads suffered partial or complete data losses due to electronics being unable to withstand flight vibrations, improper coding protocols that allowed data to be easily erased, and, of course, catastrophic launch vehicle damage that destroyed sensitive internals.

CSL believes that three fundamental changes must be made in future to prevent similar flight outcomes. First, the main parachute must be swapped with a parachute featuring a higher coefficient of drag. As the altimeter data in Table 5.1.3 indicates, the rocket experienced an unacceptably fast descent rate that likely compounded the construction issues already present in the rocket, so the primary mitigation that CSL will pursue in the following months will be to purchase a parachute better rated for Chariot's burnout mass. Unfortunately, the parachute could not be changed for the VDF attempt due to time constraints, but the main recovery device will be upgraded in future launches.

Second, the amount of ballast must be reduced to produce a straighter ascent and reduce the stress experienced by the custom 3D printed nose cone. Chariot's first flight demonstrated that the launch vehicle could indeed perform a successful ascent while carrying the maximum amount of ballast allowed under competition rules, but, as CSL's three subscale flights demonstrated, the rocket tended to wobble on ascent and prevented the rocket from reaching its full potential altitude. Additionally, though the exact force at which a heavily ballasted cone breaks is not currently known, CSL believes that a 3D printed plastic nosecone containing 2.4 lb of steel powder cannot be reasonably expected to survive even a nominal landing. For this reason, subsequent Chariot flights will contain over 50% less ballast.

Third, the portion of the airframe with pockets cut out for the airbrakes must be significantly reinforced in subsequent launches. Again, the rocket airframe experienced a much higher descent rate than expected, but the threat of losing of the largest airframe section and the secondary payload was too great for CSL to proceed without reinforcing the airframe. For the VDF attempt, the booster airframe was reinforced with a tube coupler as was detailed in report Section 3.4.2. Table 5.1.4 contains a damage summary from the first Chariot launch attempt and the mitigations planned.

Table 5.1.4. *Damage report and mitigation summary for Chariot's inaugural flight.*

Damaged Hardware	Description	Mitigation
Booster Airframe	Booster airframe stringers buckled on landing impact.	Reinforce portion of airframe around airbrake pockets with a tube coupler; Correct descent rate with proper parachute.
Nosecone	3D printed noscone severed near shoulder.	Reduce ballast amount; Correct descent rate with proper parachute.
Airbrakes Encoder Mount	Major airbrake pivot point cracked due to the booster airframe buckling.	None. Booster airframe mitigation is expected to resolve this issue.
Primary Payload	Primary Payload body was destroyed due to the nosecone fracture.	None. Nosecone mitigation is expected to resolve this issue.
Camera Shroud	Camera shroud fell off airframe on impact.	Replace camera with screw-mounted Runcam solution.

5.2 Chariot Flight #2 (VDF Attempt)

5.2.1. Demonstration Flight Overview

Chariot's second flight was CSL's first attempt to fulfill the Vehicle Demonstration Flight requirement outlined in NASA requirement 2.19.1. The airbrake system was active but during testing the day of the flight the SPI bus was overloaded causing the pressure sensors and sd card to be overloaded. One pressure sensor was integrated onto the I^2C bus allowing for the AB system to function enough to fly but the SPI bus was no longer functional, and no data could be recorded. The decision was made to proceed with the VDF attempt due to the AB system functioning well enough to satisfy the requirements for a successful VDF. Table 5.2.1 contains an overview of the relevant data from this VDF attempt. Chariot reached an apogee of 4,234 ft and landed 1,015 ft from the launch rail as shown in Figure 5.2.1.

Table 5.2.1. *Overview of Chariot Flight #2 data. VDF attempt #1.*

Date of flight	March 13, 2025. 7:26 PM EST
Location of flight	WSR club launch site: 5995 Federal Rd, Cedarville, OH 45314
Launch conditions	Temperature: 70° Wind: 5 mph ENE Visibility: ≥10 miles Cloud cover: Few 8,500 ft Relative humidity: 34%

Motor	Aerotech K1000T-P
Ballast flown	1.102 lb (500 g)
Payload status	Collecting data, transmitter inactive
Air brake status	Active
Official target altitude	4100 ft
Predicted altitude	4100 ft
Measured altitude	4234 ft
Main descent rate	40 ft/s (from Easy Mini altimeter)
Landing kinetic energy	Forward section: 170 ft*lb Avionics section: 99 ft*lb Aft section: 303 ft*lb
Descent time	62 s
Drift distance	1,015 ft
Drogue deployment	Apogee & apogee +1 s
Main deployment	600 ft & 550 ft

Figure 5.2.1. *Aerial view of launch site, showing launch and landing locations of Chariot flight #2.*

5.2.2. Flight Data

Figures 5.2.2 and 5.2.3 contain the flight profile graphs collected by the primary RRC3 and secondary EasyMini altimeters respectively. The official apogee for the VDF attempt was 4234 ft recorded by the RRC3 altimeter with the EasyMini altimeter recording an apogee of 4281 ft. all four ejection charges were successfully ignited by the altimeters during the flight and both altimeters recorded complete flight profile graphs.

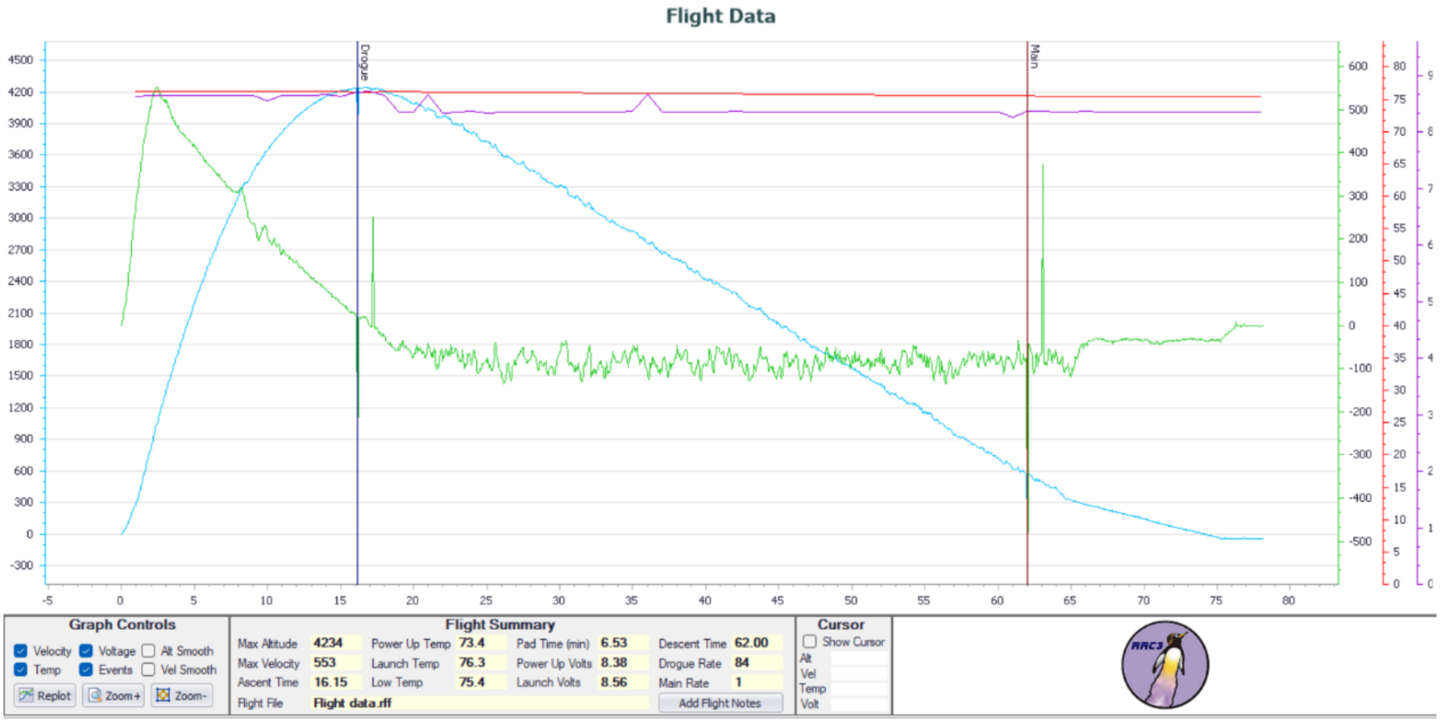


Figure 5.2.2. *Flight profile graph from primary RRC3 altimeter for Chariot flight #2. The recorded apogee was 4234 ft with a flight time of 62 seconds.*

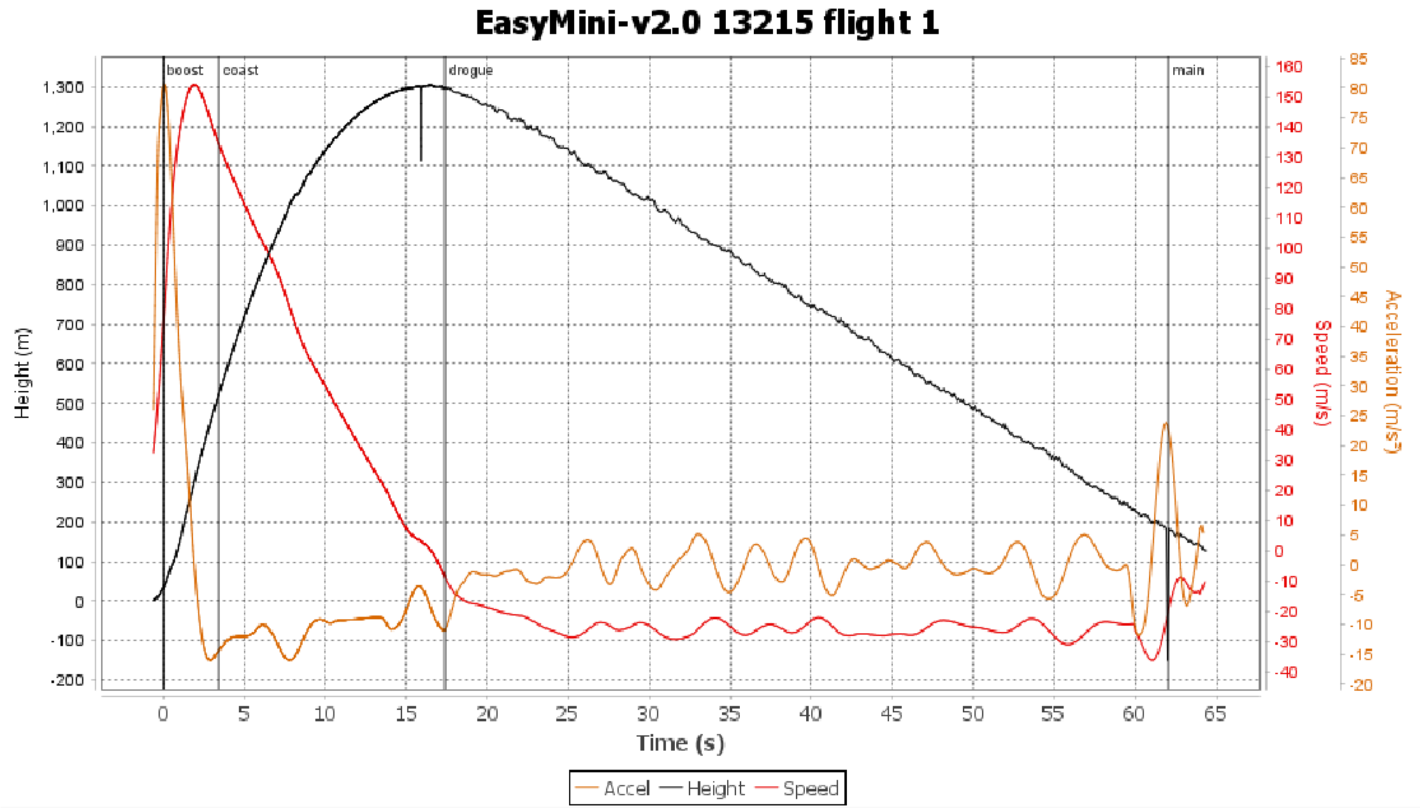


Figure 5.2.3. *Flight profile graph from secondary EasyMini altimeter for Chariot flight #2. The recorded apogee was 4281 ft with a flight time of 65.3 seconds.*

5.2.3. Vehicle Recovery Discussion

Chariot's second flight attempt ended without any major damage to the rocket, and as can be seen in Figure 5.2.4, both recovery events fired without issue. Both the primary and backup charges fired for the drogue and main, and all eye bolts, shock cords, and airframe sections remained secure and undamaged. The RunCam attached to the airframe detached from its mount during landing, but the camera itself was lying nearby under the main parachute. CSL was able to recover 4K camera footage for the entirety of the rocket's flight.

Table 5.2.2 contains kinetic energy calculation results for the second flight. Although the rocket landed at a considerable speed, the stringers on the booster airframe tube remained intact, though some thinly applied epoxy had released slightly from the reinforcing coupler placed in the airbrake area. Figure 5.2.5 contains a close view of the three independent sections of the rocket as they landed.

Table 5.2.2 *Kinetic energy estimates for Chariot's second landing. Note that the fast main parahcute descent time could not be corrected for this vehicle demonstration flight attempt because the proper parachute could not be sourced in time.*

Section:	Forward	Avionics	Aft
Landing velocity (ft/s)	40.0	40.0	40.0
Mass (slug)	0.21	0.12	0.38
Kinetic energy (ft*lb)	169.92	98.75	302.84

Figure 5.2.4 *Landing orientation of the second Chariot flight.*

Figure 5.2.5. (Left) *Close view of the payload bay and avionics section of the rocket;* ***(Right)*** *Aft section of the rocket. Note that the orange bracket that held on to the RunCam was empty upon landing.*

5.2.4. Payload Performance

5.2.4.1. Secondary Payload Performance

The airbrakes system went through a rigorous checklist system both before and after mounting into the airframe; all mechanical and electrical systems were ready for launch. Once inserted into the airframe the flaps were attached to the ternary links. Because of slight tolerancing issues, the flaps didn't line up with the airframe, and while tightening the bolts on the flaps, it caused the coupler to be in tension; thus, the sider anchor material experienced unwanted plastic deformation which allowed the coupler to come loose. The PCB was active and affirmed active before the launch, but the software was expecting acceleration in $\frac{m}{s^2}$, and the sensor was outputting units of gs, therefore the system never detected the launch because the measured acceleration was not high enough for the state detection software to detect the launch.

Below are the success criteria; if the success criteria was met the box is green, if the criteria was not met, the box is red.

AB.S.1 Confirmation of AB deployment during launch. (Failed)
AB.S.2 AB were stowed within ±2 seconds of apogee. (Failed)
AB.S.3 Rocket apogee achieved within ±25 feet of target altitude. (Failed)
AB.S.4 Confirmation of drag flaps actuation in the onboard camera. (Failed)
AB.S.5 The drag flaps should be located no further than 2 inches behind the CP to ensure aerodynamic stability. (Passed)
AB.S.6 No components of the system shall experience mechanical failure during any stage of flight. (Failed)
AB.S.7 No electrical brownout or blackouts shall occur. (Failed)
AB.S.8 Flight data recorder and retrieved. (Failed)

The main mission of the AB on the rocket is to achieve **AB.S.3**. Since this was not achieved, this was a mission critical failure, and overall, there were seven failures and one success.

5.2.4.2. Mission Payload Performance/Simulation

All the payload hardware was present on the flight and all electrical systems were in place as they are expected to be for the final flight. The payload incurred no physical damage. The software had not yet been completed to perform any of the following functions: use tone generator to give audio feedback of launch readiness, send APRS data packets, activate/allow transmitter PTT. Additionally, a software bug caused the override PCB to not save any of its collected data.

Below are the success criteria; if the success criteria was met the box is green, if the criteria was not met, the box is red.

P.1 Payload survives vehicle landing to be able to perform post-flight operations.
P.2 Payload has sufficient battery power for pre-flight, in-flight, and post-flight operations.
P.3 Payload sensors all deliver accurate data to the microcontroller.
P.4 Payload transmits APRS packets from the rocket's landing site to the launch site receiver.
P.5 Payload transmits decodable telemetry data using the standard APRS protocol.

5.2.5. Vehicle Demonstration Flight Attempt Analysis

Creating an accurate simulation of Chariot for the second flight was a challenging task. Due to the quick turnaround time required between flight #1 and the VDF attempt, there was not time to paint the repaired nosecone, the new aft section of Chariot, and the new fins. The nosecone and aft section had primer applied to them but no paint or clear coat. As a result the surface roughness was much higher for those sections than the rest of the rocket. An OpenRocket simulation was created that utilized OpenRocket's ability to individually discriminate the surface finish of each part to model the as constructed rocket as accurately as possible. Figure 5.2.6 contains the flight profile graph from this simulation using default weather conditions. This simulation was then updated using the recorded weather conditions of flight number 2 and the flight profile graph is shown in Figure 5.2.7.

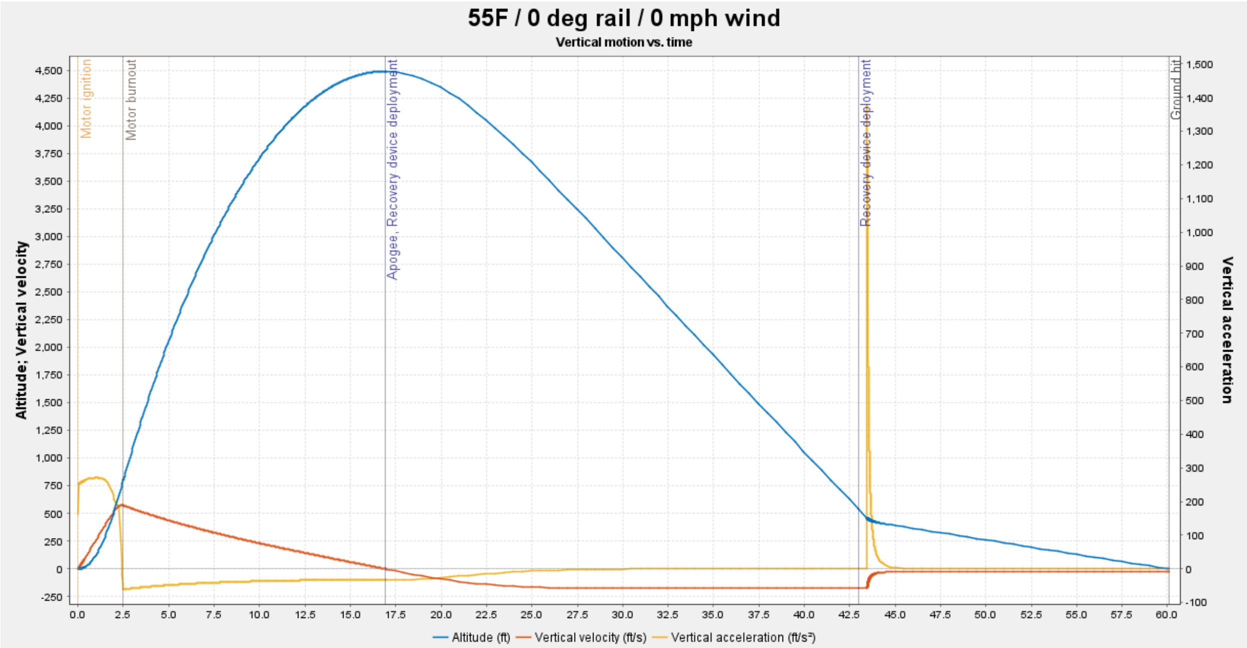


Figure 5.2.6. *Flight profile graph of preliminary OpenRocket model of Chariot in the same configuration as flight #2. This simulation outputs an apogee of 4490 ft with a drag coefficient of 0.675.*

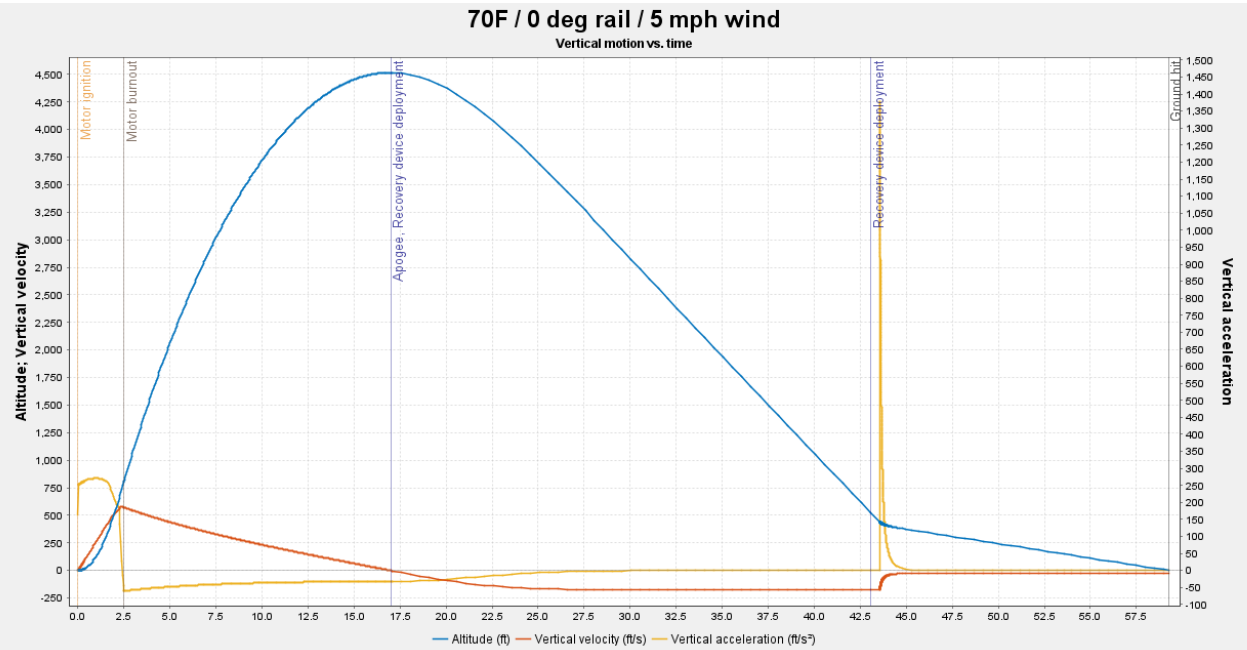


Figure 5.2.7. *Flight profile graph of preliminary OpenRocket simulation using the recorded launch weather conditions. Apogee of 4516 ft with a drag coefficient of 0.675.*

The predicted apogee from both of these simulations was 200-300 ft higher than the recorded apogee of 4234 ft from the primary RRC3 altimeter. One of the reasons for the rocket not going as high as predicted was the fact that during the ascent Chariot experienced rapid rolling, as seen in Figure 5.2.8, which increases the drag and the effective drag coefficient. Due to a minor manufacturing defect in the airbrake flaps, each flap overlapped with the bottom of airbrake flap pockets in the booster airframe. CSL attributes the sharply tilting ascent and violent roll behavior to these protruding airbrake flaps and expects that correcting the manufacturing issue with the flaps will aid in reducing the high roll rate in subsequent flights.

Figure 5.2.8. *Screenshot from onboard RunCam showing the motion blur from the rapid roll movement during ascent as well as the spiraling smoke trail.*

The effective drag coefficient of Chariot during the VDF attempt was estimated using the same method as for the first VDF attempt. Figure 5.2.9 shows the velocity vs generation curves from this method and demonstrates that an estimate of 0.9 for the effective drag coefficient of the rocket during the VDF attempt was 0.9. A final OpenRocket simulation was then created using this estimated drag coefficient to model the flight trajectory of Chariot during the VDF attempt. The flight profile for that simulation is shown in Figure 5.2.10.

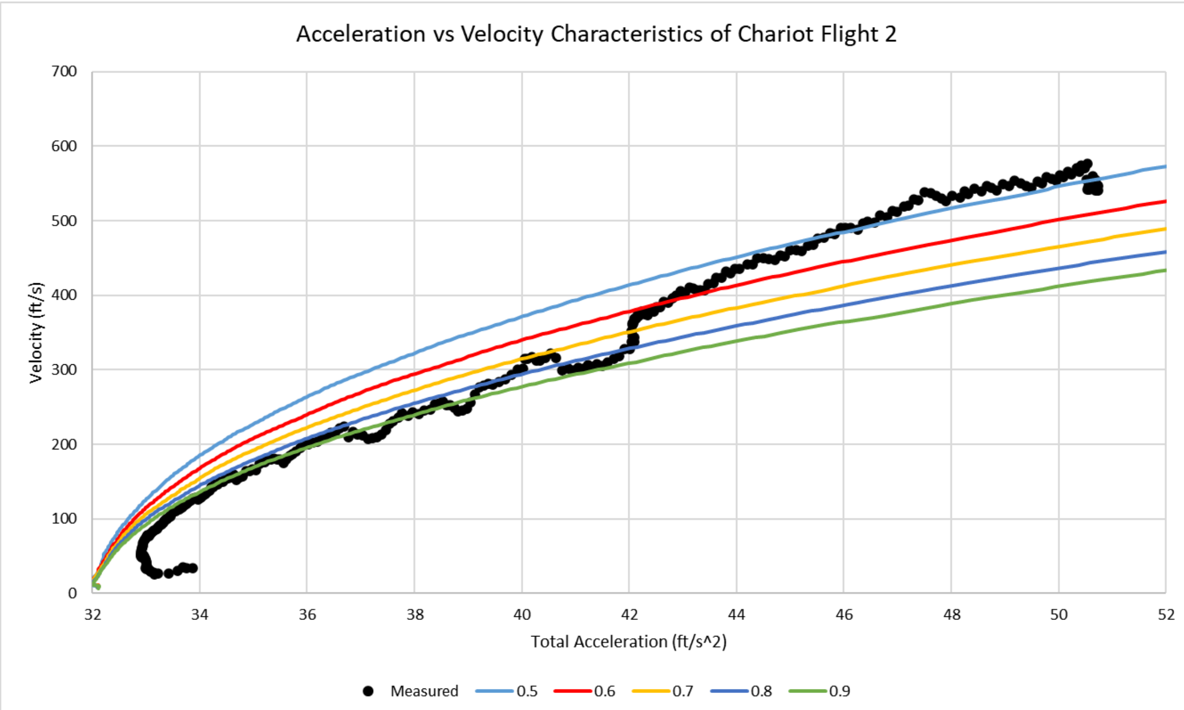


Figure 5.2.9. *Velocity vs acceleration recorded by the main payload primary pcb and run through a low pass filter to generate as smooth a curve as possible. For the lower velocities where there is less absolute error in either the measured velocity or acceleration, the curve matches with a drag coefficient of 0.9.*

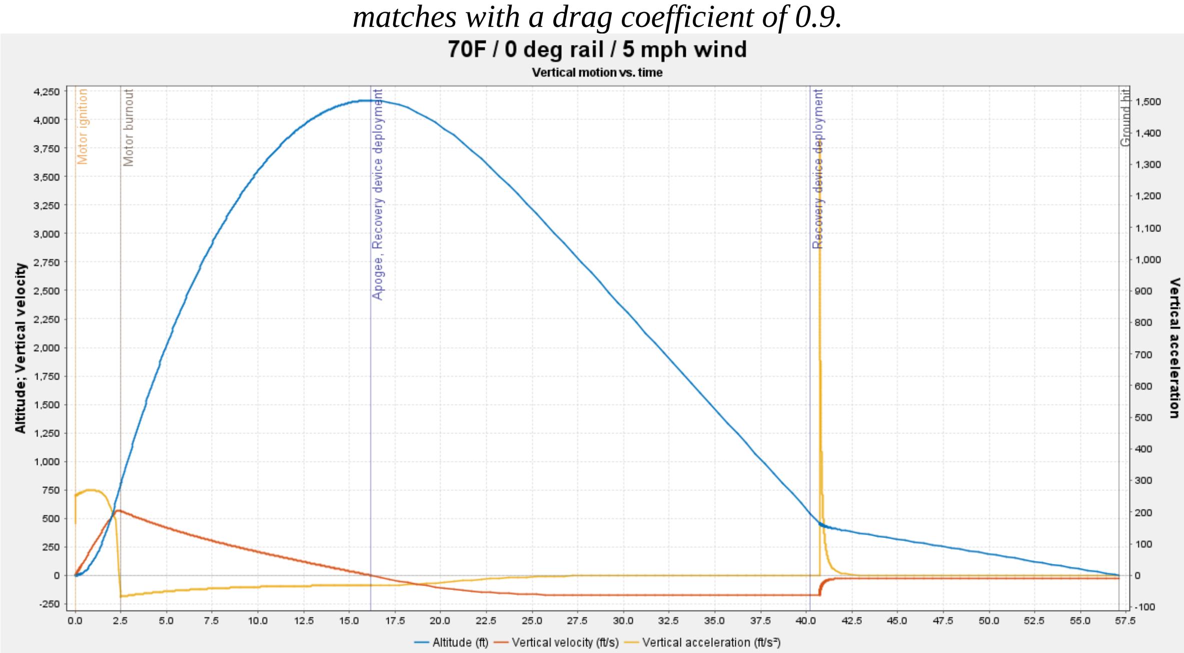


Figure 5.2.10. *Flight profile graph of final OpenRocket simulation of Chariot for the VDF attempt. This simulation predicts an apogee of 4169 ft using the calculated drag coefficient of 0.9.*

Table 5.2.3 contains a summary of the various OpenRocket simulations created for the VDF attempt and comparing them to the flight data that was collected. The discrepancies of the simulations when compared to the VDF attempt can be mostly attributed to the complexity of modeling both the non-uniform surface finish and the airbrake flaps not being perfectly flush with the airframe.

Table 5.2.3. *Summary of OpenRocket simulations and collected flight data for the VDF attempt.*

	Apogee	Cd	Max Velocity	Max Acceleration	Velocity at Landing	Total Flight Time
Preliminary 0 Wind	4490 ft	0.675	576 ft/s	271 ft/s^2	25.9 ft/s	60.1 s
Preliminary Launch Conditions	4516 ft	0.675	576 ft/s	271 ft/s^2	26.2 ft/s	59.2 s
Post Flight Calculated Cd	4169 ft	0.9	569 ft/s	269 ft/s^2	26.2 ft/s	57.1 s
Recorded Flight Data	4234 ft	0.9	553 ft/s	264 ft/s^2	40 ft/s	62 s

5.3. Future Flight Plans

As of the submission of the FRR deliverable, CSL plans to fly the launch vehicle again to satisfy the requirements of a successful VD re-flight and PDF for the FRR addendum at the beginning of April. CSL then plans to fly its competition flight mid to late April. Table 5.3 describes the locations, dates, and objectives of these launches and backup launches. Should CSL finish improvements to the launch vehicle early, or outside considerations such as weather impede CSL from adhering to the following launch dates, the team will be flexible in completing these launches in a similar timeframe. CSL may also complete additional launches if additional motors arrive in a timely fashion. All launches are planned to take place on the Federal Road Field, as given in Section 1.1.

Table 5.3.1. *CSL's future flight plans.*

Launch	Date	Location	Launch Objectives
VD Re-Flight and PDF	April 2, 2025	Federal Road Field	Fulfill NASA reqs 2.19 and 2.20
VD Re-Flight and PDF (Backup)	April 5/6, 2025	Federal Road Field	Fulfill NASA reqs 2.19 and 2.20
Competition Flight	April 26, 2025	Federal Road Field	Fulfill all NASA reqs for successful competition launch
Competition Flight (Backup)	April 27, 2025	Federal Road Field	Fulfill all NASA reqs for successful competition launch

6. Safety and Procedures

Cedarville Student Launch has elected Jesse DePalmo as Chief Safety Officer (CSO). In this role, the CSO is responsible for the safety of all team members, students, and the public participating in the team's activities. The CSO's duties include assessing and mitigating potential risks throughout the design, construction, and launch phases. Once CSL 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 are not limited to, the following:

- Promoting a strong safety-first culture across all team areas that promotes proper design.
- Creation of a Safety Handbook to equip team members to perform their roles effectively while maintaining safety standards.
- Collaborating with the Launch Officer to design and implement launch procedures.
- Ensuring compliance with local and federal safety regulations.
- Overseeing sub-scale and full-scale launches to ensure correct adherence to launch procedures.
- Enforcing general safety measures throughout the design process.
- Assessing failure modes and proposing mitigations using Failure Modes and Effects Analysis (FMEA) tables.
- Understanding the facilities, equipment, and regulations beyond the team's direct responsibilities.
- Serving as the primary contact for safety-related inquiries from team members.

6.1. Safety and Environment Considerations

6.1.1. 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. Table 6.1.1 outlines the criteria for determining probability levels, while Table 6.1.2 describes the severity of hazards. Table 6.1.3 presents the risk assessment table and associated codes, with color-coding cells representing varying risk levels. Table 6.1.4 explains how different risk values align with specific risk categories.

Table 6.1.1. *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 6.1.2. *Danger level definitions.*

Description	Value	Team Personnel	Physical Environment	Launch Vehicle	Mission Success
Negligible	1	Minor or No Injuries	No Damage	Insignificant	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 6.1.3. *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 6.1.4. *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.

6.1.2. Overall Risk Reduction

The CSO and team personnel researched and identified safety risks for all areas of this project. Table 6.1.5 provides the percentage for each risk distributed between probability and severity. Table 6.1.6 provides the percentage and quantity for low, medium, and high risks before mitigation. The total number of safety hazards identified is 137.

Table 6.1.5. *Risk assessment before mitigation.*

Probability	Severity			
	Negligible (1)	Minimal (2)	Major (3)	Catastrophic (4)
Rare (1)	0%	0%	1.45%	0.72%
Occasional (2)	0%	5.10%	13.13%	6.56%
Often (3)	0%	3.64%	26.27%	24.81%
Likely (4)	0%	1.45%	4.37%	11.67%
Frequent (5)	0.72%	0%	0%	0%

Table 6.1.6. *Risk classification before mitigation.*

Severity	Acceptance Level	Quantity	Percentage
Low Risk	Desired	10	3.15%
Medium Risk	Undesirable	71	51.82%
High Risk	Unacceptable	56	40.87%

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 6.1.7 reflects the risk assessment after mitigation, and Table 6.1.8 classifies the risk post-mitigation.

Table 6.1.7. *Risk assessment after mitigation.*

Probability	Severity			
	Negligible (1)	**Minimal (2)**	**Major (3)**	**Catastrophic (4)**
Rare (1)	0%	24.08%	36.49%	23.35%
Occasional (2)	2.18%	4.37%	5.83%	0%
Often (3)	0.72%	2.91%	0%	0%
Likely (4)	0%	0%	0%	0%
Frequent (5)	0%	0%	0%	0%

Table 6.1.8. *Risk classification after mitigation.*

Severity	Acceptance Level	Quantity	Percentage
Low Risk	Desired	125	91.24%
Medium Risk	Undesirable	12	8.75%
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 6.1.9 outlines each category of FMEA sheets that may contain significant specific hazards.

Table 6.1.9. *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.

6.1.3. Personnel Hazard Analysis

Table 6.1.10. *Hazards to personnel during construction of vehicle evaluated by the defined 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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 to 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.	**Inspection:** 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.	**Inspection:** 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 battery's will be disposed of.	**Inspection:** 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.	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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	**Inspection:** 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 6.1.11. *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.	**Inspection:** The RSO is 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	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** Team personnel will be briefed about 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	**Inspection:** Team personnel need to be aware of 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 are 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 recovery vehicle if it lands in power lines. Communication with the police and power company will be necessary.	**Inspection:** Team personnel need to be aware of 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.	**Inspection:** 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 weather is very warm.	**Inspection:** 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.	**Inspection:** 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 weather is very warm.	**Inspection:** 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 launch site. Team personnel is required to wear proper PPE during launch procedures.	**Inspection:** The CSL Launch Checklist states the RSO is 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.	**Inspection:** The CSO and Launch Officer will conduct a Launch Rehearsal warning team personnel of the weather and potential allergies present at 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.	**Inspection:** 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.	**Demonstration:** 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.	**Inspection:** 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.	**Inspection:** The CSL Launch Checklist states the NAR Team Mentor is 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.	**Inspection & Demonstration:** 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

6.1.4. Failure Modes and Effects Analysis

Table 6.1.12. *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.	**Analysis:** 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 force of impact. Multiple team members will be present during construction to ensure there are no extra holes drilled into airframe.	**Analysis:** 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.	**Analysis:** 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.	**Analysis & Testing:** 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.	**Analysis & Testing:** 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.	**Analysis & Testing:** 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 cord 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 cord mount subsystem will be thoroughly researched to make sure it will not fail during launch.	**Analysis & Testing:** The shock cord mount subsystem will be tested prior to launches 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 thust 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.	**Analysis & Testing:** 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.	**Analysis & Testing:** 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. 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.	**Analysis & Testing:** 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. 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	**Analysis:** The CE and Launch Officer will verify 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.	**Analysis & Inspection:** 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 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.	**Analysis & Inspection:** 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 6.1.13. *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.	**Inspection & Analysis:** 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.	**Inspection:** 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.	**Demonstration:** Ground testing will allow for the team to safely check 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.	**Inspection:** Packing job will be verified by the NAR Affiliated mentor. The CSL Launch Checklist ensures proper parachute folding techniques. This is verified by inspection and demonstration.	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.	**Inspection:** 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.	**Analysis & Inspection:** 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.	**Inspection:** 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.	**Inspection & Demonstration:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection & Demonstration:** The CSL Launch Checklist ensures proper assembly, testing, and inspection of the recovery subsystem.	1	4	4

Table 6.1.14. *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	Internal damage to components.	Lack of tightening nuts and bolts.	Faulty braking system which can hinder the recovery system if	3	3	9	The RSO will ensure all nuts and bolts are tightened down with a certain torque prior to launch.	**Inspection:** The tightening of nuts and bolts will be documented. The CSL Launch Checklist verifies final assembly and inspection prior to launch.	1	3	3

			brakes do not retract.								
AB.2	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	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.	**Inspection & Demonstration:** 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.3	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.	**Analysis & Demonstration:** 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.4	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.	**Analysis & Demonstration:** The design algorithm will run with correct sensor, and broken senor. The CSL Launch Checklist ensures the airbrake control system is properly tested and inspected prior to launch.	1	3	3

AB.5	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.	**Analysis:** 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.6	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.	**Inspection:** The CSL Launch Checklist requires final assembly, testing, and inspection procedures to ensure system is ready for launch.	1	3	3
AB.7	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.	**Inspection & Testing:** 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.8	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 un	4	4	16	Wires used for the system will be rated for high amperage to ensure proper function.	**Inspection & Testing:** 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

			unknown position.								
AB.9	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.	**Inspection & Testing:** 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
AB.10	Screw switch becomes undone during flight	Vibration from rocket	The system resets	3	4	12	Turn on the physical switch with the screw switch	**Inspection:** The CSL Launch Checklist ensures two team members are present while switches are activated.	1	4	4
AB.11	The system enters a state at the wrong time	Bad data processing	The airbrakes will fail to deploy	2	4	8	Testing of the state space model	**Testing:** Validation testing of the airbrake system ensures the timing of the system is correct.	1	4	4
AB.12	SD card breaks	Hard landing or vibrations	No data retrieval	3	4	12	Have the raspberry pi output to another external flash.	**Inspection & Testing:** The CSL Launch Checklist ensures testing of flash memory to determine if it will save data.	1	4	4

AB.13	Inserting airbrakes into airframe	Exposed hands to sharp fiberglass	Cut or wounded finger	3	2	6	Wear gloves and proper PPE	**Inspection:** The CSL Launch ensures proper PPE is worn during assembly.	1	2	2
AB.14	Dropping the airbrake system during assembly	Mishandle of airbrake system or carelessness	Broken component	2	4	8	Only verified personnel are allowed to handle the airbrake system.	**Inspection:** The CSL Launch Checklist ensures proper assembling techniques	1	4	4
AB.15	Water damage	Accidental spill or rain	Ruin electronics	3	4	12	Airbrakes will not be kept near open containers of liquid or outside if there is a chance of rain.	**Inspection:** The CSL Launch Checklist ensures that if the airbrakes appear wet, team personnel will NOT turn them on.	1	4	4

Table 6.1.15. *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 payload could damage other components or cause rocket instability.	2	3	6	The transmitter will be fastened to the payload housing with two screws and then reinforced with a zip tie.	**Inspection:** 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.	**Inspection & Testing:** 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.	**Inspection & Testing:** 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	Only LiPo batteries in good, working condition will be used and charging will only be done using the proper equipment.	**Inspection:** 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	Only LiPo batteries in good, working condition will be used and charging will only be done using the proper equipment.	**Inspection:** 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.	**Inspection & Testing:** 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.	**Inspection & Testing:** 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.	**Inspection & Testing:** 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 6.1.16. *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.	**Inspection:** 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 launch site stays at the minimum distance away per NAR regulations.	**Inspection:** 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.	**Inspection:** 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, disfunctional 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection & Demonstration:** 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 6.1.17. *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.	**Analysis & Demonstration:** 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.	**Analysis & Demonstration:** 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.	**Inspection:** 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.	**Analysis & Inspection:** The RSO, CSO, and Launch Officer will inspect the fin mounting method before launch. The Chief Engineer 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.	**Analysis & Inspection:** 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 rockets 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.	**Inspection:** 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

6.1.5. Environmental Hazard Analysis

Table 6.1.18. *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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** The CSL Launch Checklist requires team personnel to clean 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 area will be cleaned. Trash bags will be brought for any team personnel waste.	**Inspection:** The CSL Launch Checklist requires team personnel to clean 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.	**Inspection & Testing:** 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 breifed on situations where recovery system fails.	**Inspection:** The CSO, Launch Officer, and RSO will ensure team members and spectators are aware of NAR regulations at launch sites.	1	4	4

Table 6.1.19. *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.	**Inspection & Testing:** 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. This is verified by the CSL Launch Checklist.	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.	**Inspection & Testing:** 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 and outdoor tests. The team will follow NAR guidelines for launches.	**Inspection:** 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.	**Inspection:** 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 elctronic 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.	**Inspection:** 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.	**Inspection:** The CSO, LO, and RSO will monitor weather before launch 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 personel, 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.	**Inspection:** The CSO, LO, and RSO will do a final check and observe the conditions on the CSL Launch Checklist prior to launching. A fire extinguisher is required by the checklist.	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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** The CSO, LO, and RSO will use the CSL Launch Checklist and NAR HPRSC to ensure the safety of the launch site.	1	2	2

ER.12	Unstable Ground at Launch Site	Ground where launch pad is placed is unstable and 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.	**Inspection:** The NAR HPRSC and the CSL Launch Checklist require careful inspection and confirmation of the 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 at the launch site, the launch will be postponed until conditions are clear.	**Inspection:** 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

6.1.6. Project Risks Analysis

Table 6.1.20. *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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection & Analysis:** 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.	**Inspection:** The Launch Officer, CE, and PM will oversee the assembly of the launch vehicle and the communication surrounding the launch. The Lauch 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.	**Inspection & Analysis:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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.	**Inspection:** 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 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.	**Inspection:** 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.	**Inspection & Testing:** 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.	**Inspection:** 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	**Inspection:** 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

							effected by said changes.				
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.	**Inspection:** 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

6.1.7. Environmental Safety

A safe environment during the event of a rocket launch is one in which there is no serious injury, no property damage, and a reduced possibility of injury or death. The CSO and team members are responsible for minimizing the rocket's impact on the environment while checking for potential environmental factors that could affect the rocket's performance during launch. The launch site includes farmland and a creek supporting various plant and animal species. CSL ensures there is little to no impact to the environment at the launch site as the team follows federal and SDS guidelines when handling and disposing of hazardous materials. After a launch, every member of CSL is asked to contribute to keeping the natural environment clean by taking equipment and trash back to campus. Anything left behind at the launch site can be considered a safety hazard.

6.1.8. Safety Concerns Reporting

The CSO has encouraged team personnel to follow a precise safety plan throughout the design and construction process. Team personnel must fill out this form if a personnel or vehicle hazard has occurred. This form includes fields describing the hazard and the location where it occurred. Additionally, the form provides a section to propose methods for mitigating the hazard that has been identified. This form helps to identify safety hazards and helps to prevent them from occurring in the future. A summary of reported safety concerns is provided in Table 6.1.21.

Table 6.1.21. *Summary of the reported safety concerns.*

Date	Type of Hazard	Severity	Description	Mitigation
11/9/24	Personnel	Low	A team member was using a box cutter and cut the hand.	The team member will wear proper PPE when using a box cutter.
11/15/24	Personnel	Medium	Team member skin came into contact with epoxy.	The team member will wear PPE that fits and use a different technique to epoxy nosecone.
11/16/24	Personnel	Low	Team member cut cardboard towards the body, injuring finger.	The team member will cut material away from body and wear proper PPE.
11/18/24	Personnel, Launch	Medium	Team member carried subscale rocket to launch pad by themselves.	There will always be at least two people carrying the rocket towards the launch pad, as per the CSL Launch Checklist.
2/2/25	Personnel, Launch	Medium	Team member carried subscale rocket to	There will always be at least two people carrying the rocket

			launch pad by themselves.	towards the launch pad, as per the CSL Launch Checklist.
3/11/25	Personnel, Construction	Medium	Team member plugged pressurized air into the end of a die cutter while holding the trigger down. This resulted in a minor cut that went through the glove.	Team personnel will remember to keep both the trigger and the cutting head in sight when plugging in the air hose.
3/13/25	Personnel, Airbrakes	Medium	Faulty motor connection on airbrakes caused sparks to occur.	Proper PPE will be worn when working on electrical systems. A fire extinguisher is located in the Electrical Engineering Laboratory.

6.2. Launch Operations Procedures

6.2.1. 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

CSL will schedule a launch when every required team member is available. Each subsystem is essential to the overall success of CSL to have a safe and efficient launch sequence.

6.2.2. 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, Launch Officer, and Team Lead 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.

6.2.3. 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

• 10 x 32" screws		

Recovery Equipment

• Main Parachute	• 2 x Shock cords	• 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	• Radio Transmitter
• Charged RTC Battery	• 2 x Micro SD Cards	• Polycarbonate Shields

Airbrakes Equipment

• Battery	• RJ45 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 x Screws (PCB)	• 4 x Standoffs
• 4-40 Should Screws and Nuts (x32 for assembly)		

Electrical Equipment

• Charged Computer	• Multimeter	• Portable Soldering Iron
• Extra LiPo Batteries	• 2 x Radio Receivers	• Precision Screwdrivers
• Micro-USB and USB-C Cables	• APRS to Aux Adapter Cable	• Charged Android Phone

Team Mentor Equipment

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

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: ___________________________

6.2.4. 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: ___________________________

6.2.5. 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 that all CSL team personnel have followed the transportation procedures to the launch site.

Chief Safety Officer: _________________________

Team Lead: _________________________

6.2.6. 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 occur. 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 Lead: ________________________

6.3. Pre-Flight Assembly Procedures

6.3.1. Nosecone Pre-Flight Assembly

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

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: C.1, C.2, C.5, C.7, C.10, C.11, C.12, C.13, C.18, C.22, RS.5.

- The Chief Engineer will take the completed 3D model from SolidWorks and have it 3D printed using PETG.
- The 3D-printed components will then be assembled using 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.

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

6.3.2. Avionics Pre-Flight Assembly

Mandatory PPE: Safety Glasses

Required Personnel: Chief Engineer, 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: ___________________________

6.3.3. 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 positioned between the battery holding tabs and fastened securely.
- Radio transmitter settings set
    - Correct frequency
    - VOX off
- The radio transmitter is inserted correctly, and both set screws are tightened down.
- Screw in the antenna fully.
- Tighten the PCB screws for both PCBs.
- Ensure the STEMnauts are securely fastened.
- Ensure the polycarbonate shields are inserted and secured.
- Ensure proper calibration of the sea level pressure.
- Ensure 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: ________________________

6.3.4. 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, AB.10, AB.11, AB.14, AB.15, C.4, C.7, C.8, C.14.

- **Pre-launch**
    - Mechanical shakedown
        - Check by inspection
            - All screws have lock nuts on ☐
            - Encoder web has 4 screws on top holding it in. ☐ (If failed: Put new screw into encoder web.)
            - Encoder has two screws holding it in ☐ (If failed: take out encoder web and remount encoder.)
            - Encoder has 4 wires leaving it. ☐
            - Encoder coupler has a set screw onto the encoder. It must be screwed in all the way. ☐
            - The encoder coupler should have a screw holding it in place on the threaded rod. ☐ (If failed: replace screw and tighten.)
            - The threaded rod spins freely. ☐ (If failed: check the encoder, bearing, and motor coupler.)
            - The button stop screw is adjusted to stop at the bottom of the travel distance. ☐ (If failed: adjust screw.)
            - The ternary links have screws holding in on each lug mount. ☐ (If failed: replace screw.)
        - Check by manipulation
            - Screws cannot spin at the non-joint members. ☐ (If failed: Tighten nuts until tight, but DO NOT over tighten as this will destroy the coupler member.)
            - Screws can spin at the jointed members. ☐ (If failed: loosen screw and reapply screw stop.)
            - Wire holders are tightened down on the motor controller. ☐
            - The motor screws are tightened. ☐
            - The button screws are tightened. ☐

            - A screw can be threaded into the airframe screw implants. ☐ (If failed: replace and sand down.)
            - The carbon fiber structure tube set screw is present and tightened on the motor mount. ☐ (If failed: tighten.)
            - Pull the solder with <1lb of force to see if it pulls off on each exposed contact. ☐ (If failed: re-solder.)
    - Electrical shakedown
        - Check by inspection
            - PCB has 3 pressure sensors, 1 accelerometer, 1 buck converter, 1 raspberry pi, 1 flash memory, 1 SD card and reader, 1 speaker, 3 LED's, 1 toggle switch, 1 screw switch, and four wires headed to the rotary encoder which all appear with no mechanical damage. ☐ (If failed: replace part.)
            - The batteries have been charged ☐
            - The battery polarity is correct (red with red, black with black, and check XT60/XT30 connectors to ensure black is the triangle side as labeled.)
            - The ethernet cable is connected on both sides and has little tension. ☐ (If failed: connect and release tension.)
            - Button clicks and moves with no mechanical damage. ☐ (If failed: replace button.)
            - Button has good solder contact with two wires. ☐ (If failed: resolder.)
        - Check by manipulation: **NOTE: Every time connecting or disconnecting the Raspberry Pi or battery, turn the system off and wait 3 or more seconds.**
            - Connect batteries and tape or zip tie them together.
            - Connect the main battery and flip the toggle switch. The Raspberry Pi, accel, flash memory, motor controller, and power LED should light up. Leave steady state for 3 minutes while monitoring temperature using finger on each component. ☐
            - Flip the toggle switch off and turn the screw switch on. The Pi, accel, flash mem, motor controller, and power LED should light up. ☐
            - Pull out the SD card and wipe all data from the SD card. ☐
            - Connect the computer to the Pi and upload the airbrakes code. The motor should set itself by going down to the button and zeroing. ☐

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: ________________________

6.3.5. Motor Retention and Fins Pre-Flight Assembly

Mandatory PPE: Safety Glasses

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: 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 at the bottom of the airframe with 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.

Chief Engineer: ________________________

Chief Safety Officer: ________________________

6.3.6. Tail Cone Pre-Flight Assembly

Mandatory PPE: Safety Glasses

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: RS.3, RS.4, RS.8, RS.9, RS.10, C.15, C.16, C.20, C.22.

- The 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 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 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.

Chief Engineer: ________________________

Chief Safety Officer: ________________________

6.4. Launch Preparation

6.4.1. Recovery Preparation

6.4.1.1. Main Parachute Preparation

Mandatory PPE: N/A

Required Personnel: 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: 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 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 parachutes 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: ___________________________

Chief Safety Officer: ___________________________

6.4.1.2. Drogue Parachute Preparation

Mandatory PPE: N/A

Required Personnel: 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: 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 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 parachutes 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: ___________________________

Chief Safety Officer: ___________________________

6.4.1.3. 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: ___________________________

6.4.1.4. Pop Test

Mandatory PPE: Safety Glasses, Nitrile Gloves

Required Personnel: NAR Team Mentor, Recovery Lead, 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.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: ___________________________

Avionics Lead: ___________________________

Chief Safety Officer: ___________________________

6.4.1.5. 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.

Recovery Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

6.4.2. Avionics Preparation

6.4.2.1. 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 the 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.

Avionics Lead: ___________________________

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

6.4.3. Payload Preparation

6.4.3.1. 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, the main PCB, and the override PCB.
- Check that the radio power is on.
- Check power indicator LEDs on the main PCB and the override 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: ________________________

6.4.3.2. 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 them 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: ___________________________

6.4.4. Airbrakes Preparation

6.4.4.1. 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: ___________________________

6.4.4.2. 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 by 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: ________________________

6.4.5. Nosecone Preparation

6.4.5.1. Nosecone Inspection

Mandatory PPE: Safety Glasses

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: 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 needs 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.

Chief Engineer: ___________________________

Chief Safety Officer: ___________________________

6.4.6. Motor Systems Preparation

6.4.6.1. 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: ___________________________

6.4.6.2. Tail Cone Inspection

Mandatory PPE: Safety Glasses

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: 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 overtightened.

Troubleshooting Process

- If the tail cone has been damaged or deemed otherwise unworthy for flight, the Chief Engineer 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.

Chief Engineer: __________________________

Chief Safety Officer: __________________________

6.4.6.3. 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: ________________________

6.5. Launch Procedures

6.5.1. Launch Pad

6.5.1.1. 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: ________________________

6.5.1.2. 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: __________________________

6.5.1.3. 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: ___________________________

6.5.2. Launch Checklist

6.5.2.1. 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: ___________________________

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.2. 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: ___________________________

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.3. Payload Launch Checklist

Mandatory PPE: Safety Glasses

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.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: ___________________________

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.4. 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, AB.11, AB.12, AB.13, AB.14, AB.15.

- **Pre-launch (At site)**
  - Turn on the screw switch. While the airbrakes are opening and closing during zeroing the speaker will give one long tone. Then it has entered "pad mode," meaning that it is ready to launch, and this will be a repeated two beep chip followed by silence. ☐
  - Turn on the physical toggle switch by sticking in a screwdriver or Allen wrench. ☐

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

Airbrakes Lead: ___________________________

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.5. Fin Launch Checklist

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 fin retention system is cleared for launch.

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.6. Tail Cone Launch Checklist

Mandatory PPE: Safety Glasses

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: 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.

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.5.2.7. Flight Camera Checklist

Mandatory PPE: Safety Glasses

Required Personnel: Chief Engineer, Chief Safety Officer, Launch Officer

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.6, RS.11.

- Check to make sure that the camera is fully charged.
- Ensure that the camera's mount is affixed to the airframe of the rocket in the correct location.
- Secure the camera into the mount.

For recording in flight video, adhere to the following procedure:

- Press and hold the main button on the camera for a minimum of two seconds. A blue light should turn on and stay on. This means that the camera is on and is set to recording mode.
- After the camera is set to recording mode, press the button once starts recording. * Note that the camera has approximately 40 minutes of recording time. You can tell the camera is recording because the blue light will flash on and off repeatedly.
- To stop recording, press the button on the camera again. The blue light will go back to a constant blue color and stop flashing.
- To turn off the camera, hold the button until the blue light turns off.

Signature: My signature confirms that the flight camera is secure on airframe and ready for launch.

Chief Engineer: _________________________

Chief Safety Officer: _________________________

Launch Officer: _________________________

6.5.2.8. 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

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 the launch sequence.
- The 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: ___________________________

6.6. Post-Launch Procedures

6.6.1. Post-Flight Inspections

6.6.1.1. 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: ________________________

6.6.1.2. 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: ________________________

6.6.1.3. 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: ________________________

6.6.1.4. 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 the 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: ________________________

6.6.1.5. 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: ________________________

6.6.1.6. Fin Post-Flight Procedure

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

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: 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.

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.6.1.7. Tail Cone Post-Flight Procedure

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

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: 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.

Chief Engineer: ___________________________

Launch Officer: ___________________________

Chief Safety Officer: ___________________________

6.6.2. 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: ___________________________

6.6.3. Launch Confirmation

Signature: My signature confirms that all launch procedures were followed. Team personnel followed the direct command 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: ___________________________

7. Project Plan

7.1. Testing

All requirement validation carried out for both NASA and CSL internal requirements have been conducted and recorded in CSL's database. These requirements have been fulfilled with demonstration, analysis, inspection, and testing methods. The tests that CSL has conducted are summarized in Table 7.1.1 below, and documentation of these are tests are also given. A new test, related to CSL requirement P.20, has been marked "In Progress" as CSL wishes to conduct more testing on top of previous work after the results of the VDF attempt. This supplemental testing will be presented in the FRR addendum. In addition, the tail cone drop test has been dropped due to the sufficiency of system flight demonstrations. The requirement tables have been updated to reflect this.

Table 7.1.1. *Testing summary.*

Test Title	Requirement(s) Satisfied	Result
Black Powder Pop Test	3.2	**Complete**
Camera Durability Test	V.3	**Complete**
Nosecone Drop Test	V.7 (NC.S.4)	**Complete**
Tailcone Drop Test	V.10 (TC.S.3)	**Dropped**
Battery Life Test	P.2	**Complete**
APRS Transmission Test	P.4	**Complete**
Flap Static Electromechanical Mechanism Actuation Test	P.13 (AB.S.9)	**Complete**
Flap Dynamic Loading Test	P.14 (AB.S.10)	**Complete**
State Transition Test	P.16 (AB.S.12)	**Complete**
Data Filter Test	P.18 (AB.S.14)	**Complete**

Apogee Prediction Algorithm Test	P.19 (AB.S.15)	**Complete**
Control Algorithm Shakedown Demonstration	P.20 (AB.S.16)	**Complete**
Mechanical Coupler Failure Test	P.21 (AB.S.17)	**Complete**
Comprehensive Airbrake Bench Test	P.22 (AB.S.18)	**In Progress**

7.1.1. Black Powder Pop Test

Requirement Validated:

This test validates requirement 3.2.

This requirement necessitates that successful ground test must be completed for the black powder amounts calculated for the main and drogue bay to confirm that they work as intended. A successful test is when the black powder charges safely separate the launch vehicle at the specified separation points without damaging the rest of the rocket. The test to validate this requirement is titled a “Ground Test” or “Pop Test”.

Test Description:

Objective: The goal of the ground test is to confirm the calculations completed for the black powder amounts work correctly to separate the rocket. The test will verify that the pressure generated when the black powder is detonated, it breaks the shear pins, and separates the launch vehicle without breaking the airframe or bulkheads.

Materials and Equipment:

1. Assembled launch vehicle (to simulate realistic mass in launch and to separate appropriate sections).
    a. Parachutes, flame blankets, shock cords, and shear pins need to be placed in respective parachute bays to ensure realistic conditions.
2. Clear and relatively flat land to perform test.
3. Way to prop rocket to properly set off charges.
4. Remote e-match lighter and e-matches.
5. Black powder charges of the calculated masses.
6. Proper PPE.

Test Pass/Fail Criteria:

For the black powder amounts to pass the ground test, the rocket must separate at the separation points with enough force the parachutes are pushed out with no damage to the rocket body itself. However, if the rocket does not separate or damage is found then the black powder charges have failed and do not pass the test. The results of this test will be used to validate the separation of the rocket to deploy the parachutes in flight.

Variables to be Controlled and Their Values:
Independent Variables:

- Amount [g] of black powder used in each charge.

Dependent Variables:

- Damage to rocket.
- Separation of rocket (level of completion).

Controlled Variables:

- Type of black powder used (FFFFG).
- Parachutes, flame blankets, shear pins, and shock cords used.
- Launch vehicle set up
- Environmental Conditions

Test Procedure:

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

1. **Preparation**
    a. Measure and record the volume of each of the parachute bays including the volume retracted due to the recovery devices (parachute, shock cord, and flame blanket).
    b. Decide on the amount of shear pins used to hold the rocket together until deployment.
    c. Insert the volumes and shear pin amounts in the TK Solver code used to calculate the amount of black powder theoretically needed to separate the rocket.
    d. These amounts are to be used in the ground test.
2. **Test Setup**
    a. Set up the black powder charges in their respective bays for remote detonation.
    b. Put the rocket together similar to launch conditions.
3. **Perform the Drop Test**
    a. Prop the rocket against a ladder or on top of steady platform.
    b. Ensure everyone is safe distance away.
    c. Use the remote detonation to set off each charge one at a time (putting the rocket back together after the first charge).
4. **Data Collection**
    a. After each detonation check to see if good separation occurred and if any damage to the rocket happened.
5. **Repeat the Test**
    a. As changes are made to the recovery system a new ground test must be completed to confirm the new values are correct.

Results of Test:

A ground test performed on February 27th for the full-scale launch vehicle launched March 2nd and 13th was successful for both the drogue and main bays. Both calculated black powder charges were able to separate their respective recovery bays without damaging the rocket body.

7.1.2. Camera Durability Test

Requirement Validated:

This test validates requirement V.3

Test the reliability of the camera under different environmental conditions. Titled: Camera Reliability Test.

Test Description:

CSL wishes to use an Estes Astrocam to record in flight footage to validate the success or failure of the secondary payload during launches.

Objectives:

- Assess the reliability of the Estes Astrocam in different temperature environments
- Assess actual camera power supply
- Determine recording capabilities.

The purpose of this test is to validate the reliability of the Estes Astromcam and determine if it is suitable for use on the full-scale rocket.

Equipment:

- Estes Astrocam
- Stopwatch (Phone)
- Refrigerator
- Thermometer

Test Pass/Fail Criteria:

Pass Criteria

- The camera is capable of recording video for at least 30 minutes before shutting off as this is the maximum amount of time CSL is expecting the rocket to sit on the launch rail and landing.
- Camera successfully records footage under different environmental temperatures.

Fail Criteria

- Camera is unable to record data for the allotted 30 minutes
- Camera is unable to record data in temperature environments that CSL may be expected to launch in.

Test Procedure:

1. Charge the camera till the battery is full
2. Insert the fully charged camera into testing environment (Room temperature for normal weather conditions, refrigerator to simulate cold weather conditions)
    a. Use the thermometer to record the temperature in the testing environment
3. Hold the button on the camera and wait for a blue light to turn on. This means the camera is on.
4. Press the button on the camera again and see if the blue light is flashing on and off. The camera is now recording.
5. Start the stopwatch timer
6. Check on the camera every five minutes till the flashing light has gone off. This will indicate that the camera has shut down and is unable to record more footage in that session.
7. Once the blue light has shut off, stop the stopwatch timer and record the time value
8. Repeat the process at least three times to determine accurate results.

Variables to be Controlled and Their Values:

Variables:

- Recording time → Dependent Variable
- Environmental Conditions (Temperature) → Independent Variable

Results of Test:

Test #	Recording Time in 69°F	Recording Time in 38°F
Test 1	34:23 min	1:05 min
Test 2	31:47 min	0:59 min
Test 3	36:14 min	1:03 min
Avg	34:08 min	1:02 min

From the reliability test, it was observed that the camera was able to record for an average of 34:08 minutes in a temperature of 69°F and recorded an average of 1:02 minutes in at a temperature of 38°F. Based off these results, the camera is more than capable of recording footage in warmer weather. However, the camera suffers major problems in colder temperatures. Due to CSL's location in Ohio where the weather fluctuates frequently, it is difficult to justify the use of a camera that malfunctions at colder times. As such, CSL has concluded that the Estes Camera does not pass the camera reliability test.

7.1.3. Nosecone Drop Test

Requirement Validated:

V.6 (NC.S.1)

Validate that the nosecone can survive predicted impact kinetic energies during landing.

Name: Nosecone Drop Test.

Test Description:

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

- Fully assembled 3D printed nose cone
- Drop test stand (15 ft ladder or lift hoist)
- Scale to measure the mass of the nose cone
- Steel powder to be used as mass ballast
- MATLAB code from Appendix A.1 from the FRR to predict the impact of kinetic energy
- Camera to record impact for analysis (Phone camera)
- Proper PPE (safety glasses, closed-toed shoes, long sleeve clothing)
- Tape measurer and meter stick to precisely determine drop height

Test Pass/Fail Criteria:

Pass Criteria:

- Nosecone must withstand at bare minimum the impact kinetic energies predicted by the MATLAB code from Appendix A.1 with minimal damage and be reusable without jeopardizing subsystem's mission priorities
- Nosecone must be reusable over the course of at least 3 drop tests at different angles of attack. (approximately 90° and 0°)

Fail Criteria:

- If the cone is damaged at predicted impact kinetic energy values and 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.
- If the cone does not pass the test, reinforce the design so that the cone is able to survive the necessary kinetic impact energies.

Test Procedure:

1. **Preparation**
   a. 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.
   b. Insert the mass value into the descent performance prediction MATLAB code displayed in Appendix A.1 to calculate the predicted kinetic energy that the fore section will have when it impacts the ground from the rocket's descent.
   c. 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.

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

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

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

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

   e. 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**
   a. Insert ballast into the nose cone to correctly simulate the mass of the entire fore section of the rocket using the scale for accuracy.
   b. Set up the phone camera to record the test
3. **Perform the Drop Test**
   a. Raise the cone to the desired height and position it at the desired angle of attack if applicable.
   b. 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**
   a. After the cone hits the ground, observe the cone for cracks or damage.
   b. Record the impact of using the phone camera.
5. **Repeat the Test**

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

Variables to be Controlled and Their Values:

- **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

Results of Test:

The results used to validate this test were completed with a subscale version of the nosecone. There was no design difference between this cone and the full-scale cone. Everything was scaled down correctly. These tests were to be done with the predicted impact energy for test 1, a safety factor of 1.25 the predicted kinetic impact energy for test 2, and the maximum allowable kinetic impact energy for test 3.

Tests Performed dropping the cone straight down perpendicular to level dirt surface

Test 1	Drop Height (m)	Cone Mass (kg)	Impact KE (Nm)	Impact Velocity (m/s)
Drop 1	3.53	1.555	39.59	8.32
Drop 2	3.55	1.555	39.82	8.35
Drop 3	3.81	1.555	42.73	8.65

Test 2	Drop Height (m)	Cone Mass (kg)	Impact KE (Nm)	Impact Velocity (m/s)
Drop 1	4.44	1.555	49.8	9.33
Drop 2	4.5	1.555	50.48	9.39
Drop 3	4.49	1.555	50.37	9.38

Test 3	Drop Height (m)	Cone Mass (kg)	Impact KE (Nm)	Impact Velocity (m/s)
Drop 1	6.86	1.555	76.93	11.59
Drop 2	6.92	1.555	77.62	11.65
Drop 3	7.01	1.555	78.64	11.73

*See Figure 1 for test 3 drop height from lift hoist

Figure 7.1.1. *Drop test setup for maximum allowable kinetic energy at impact.*

<u>Tests Performed dropping the cone straight down parallel to level dirt surface</u>

Test 1	Drop Height (m)	Cone Mass (kg)	Impact KE (Nm)	Impact Velocity (m/s)
Drop 1	2.13	1.555	23.89	
Drop 2	NA	1.555	NA	NA
Drop 3	NA	1.555	NA	NA

<u>Conclusions and Updates:</u>

From the results, it was observed that the subscale nosecone was more than capable of surviving perpendicular impacts with the ground. The cone was able to survive the maximum kinetic impact energy that NASA allows for sections of the rocket to descend with as shown in Figure 7.1.1. However, when it was dropped parallel to the ground, the cone suffered damage and broke along the area where it fastens to the airframe. This damage can be seen in Figure 7.1.2.

Based on the damage that the cone received, four 2.5-inch-long reinforcement bars were inserted into the base of the cones design to strengthen the area and prevent further damage from occurring in that specific location.

A full-scale demonstration flight was then launched with the reinforced design. During the landing sequence of the flight, the fore section impacted at the ground causing the cone to break. The fracture and subsequent damage occurred right above where the reinforcement pins in the cone had stopped as shown in Figure 7.1.3. From the demonstration flight, it was inferred that while the reinforcement pins did indeed stop breaking inside coupler tube. However, the cone was now breaking right above where it connected to the airframe due to how the cone impacted the ground when at a parallel angle. As a result, the reinforcement pins were increased to a length of 5 inches as this would allow them to fully support the area of the cone most likely to be damaged while adding a minimum amount of weight.

As demonstrated by the VDF attempt launch, the new and improved nosecone design was capable successfully of withstanding 169.92 ft-lbs. of kinetic energy that the fore section had on impact.

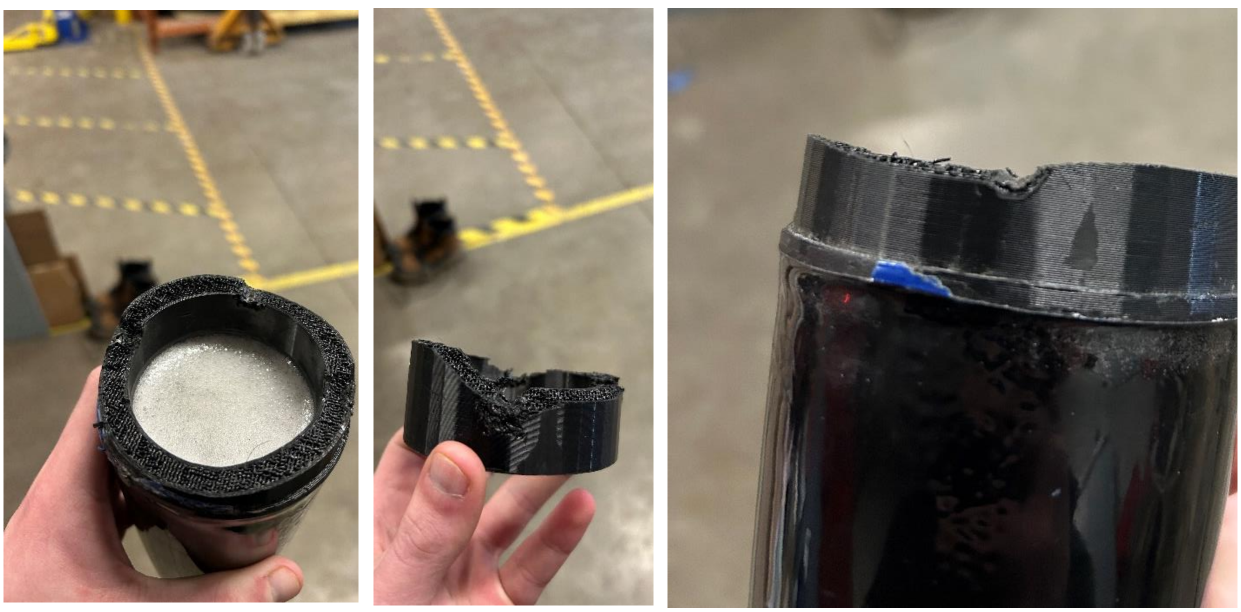


Figure 7.1.2. *Damage to subscale nosecone after parallel drop test.*

Figure 7.1.3. *Damage to full scale cone indicating break above reinforcement pins.*

7.1.4. Battery Life Test

Requirement Validated:

This test validates requirement P.2.

This requirement necessitates that the payload's batteries will be capable of providing enough power to power the payload while it is on the launch pad then perform all functions during and after the rocket's flight.

Test Description:

Objective: The goal of this test is to accurately predict the minimum battery life of each section of the payload's electrical system. This will allow the team to know how long after powering the payload on, the payload can still be expected to perform its functions. This test will be accomplished by measuring the current draw of the electronics and the capacity of the batteries.

Materials and Equipment:

- LiPo battery in good condition
- Each PCB running most current code
- LiPo battery tester
- Multimeter

Test Pass/Fail Criteria:

For the system to pass this test, the battery life of all systems should be greater than three hours, as calculated from a current draw test of the PCB circuits and a discharge test of the batteries.

Variables to be Controlled and Their Values:

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

Independent Variables:

- Battery
- Electrical circuit

Dependent Variables:

- Resulting battery life

Test Procedure:

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

1. **Preparation**
    a. Obtain all materials and equipment.

2. **Test Setup**
    a. Plug in LiPo battery to charger and charge it fully.
    b. Safely put multimeter in series with the selected PCB power source.
    c. Set multimeter to current draw mode.

3. **Perform the Test**
    a. Run the discharge cycle on the LiPo battery until complete.
    b. Power on the PCB.

4. **Data Collection**
    a. Record total current supplied by the LiPo battery until it was empty.
    b. Record the PCB's average current draw.

5. **Repeat the Test**
    a. Change LiPo battery.
    b. Change PCB.

Results of Test:

Circuit	Estimated (mA)	Tested (mA)	Battery	Estimated (mAh)	Tested (mAh)	Estimated Battery Life (h)	Tested Battery Life (h)
Payload Primary	114.0	68.0	Ovonic	1000	930.0	8.8	13.7
Payload Secondary	97.1	110.0	Ovonic	1000	930.0	10.3	8.5
Airbrakes	112.5	212.0	Liperior	850	738.0	7.6	3.5
Minimum Battery Life						**7.6**	**3.5**

The LiPo batteries produced lower capacity numbers than advertised, which is expected. The PCBs produced wildly different current draw numbers than what was predicted. The reason for this is unknown, but the results still suggest battery lives significantly longer than needed to pass this test.

7.1.5. APRS Transmission Test

Requirement Validated:

This test validates requirement P.4.

This requirement necessitates that the payload's transmitter, the Baofeng UV-5R, will be able transmit decodable APRS data from the landing site of the rocket to the receiver near the launch site.

Test Description:

Objective: The goal of this test is to assess whether the payload's transmitter will be able to reliably transmit APRS data from a distance of up to 2500 feet in any conceivable landing orientation using 5W of power.

Materials and Equipment:

- Three charged Baofeng UV-5R transceivers
- BTECH APRS-K2 adapter cable
- Charged Android phone with aux port running APRSdroid
- Male-to-male aux cord
- Charged device with aux port running PulseModem, APRSdroid, or Direwolf

Test Pass/Fail Criteria:

For the transmitter to pass this test, the receiver system must be able to reliably decode APRS packets sent from up to 2500 feet away from any transmitter orientation that would be expected based on how the vehicle lands. Because APRS packets will be sent multiple times in a row after the actual flight, not every single packet must be decoded, but most should be decoded. This test will be conducted using a standard APRS encoding application but should be verified using the payload's final APRS encoding setup once it is available.

Variables to be Controlled and Their Values:

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

Independent Variables:

- Distance between Transmitter and Receiver (d) measured in [ft]
- Angle between Antenna Direction and Receiver Direction (α) measured in [deg]
- Transmitter

Dependent Variables:

- Approximate Percentage of Messages Decoded

Controlled Variables:

- Software Settings
    - Callsign: KF8CDC
- Receiver Settings
    - Frequency: 145.530
    - Height: 5 feet
- Transmitter Settings
    - Frequency: 145.530
    - VOX: 5
    - TXP: HIGH

Test Procedure:

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

1. **Preparation**
    a. Charge all devices.
    b. Check settings on all devices.
2. **Test Setup**
    a. Power on receiver and check that its settings are correct, including that the receiver is placed at a height of approximately 5 feet.
    b. Listen on the chosen frequency to ensure that there is not already radio traffic occurring on that frequency in the area.
    c. Open APRSdroid on the Android phone and verify that its settings are correct; hit the "Start Tracking" button in APRSdroid.

d. Plug the APRS-K2 adapter into both the Android phone and receiver.
e. Power on both transmitters and set them to the correct settings.
f. Plug one transmitter into the APRS encoding device using the aux cable.
g. Send a test transmission and verify that it decodes correctly to ensure that all settings are correct throughout the system.

3. **Perform the Test**
   a. Take the transmitters to a location where there is relatively open terrain between transmitter and receiver and record the distance *d*.
   b. Set one transmitter off to the side, powered on.
   c. Set the other transceiver on the ground in the orientation α or standing straight up.
   d. Enter values of independent variables into the "comment" portion of the APRS packet to be sent.
   e. Send three good messages from both transmitters in each orientation. Verify that a message is "good" by listening to whether the audio played by the other transceiver sounds complete.
4. **Data Collection**
   a. After testing, return to the receiver and save the APRSdroid log of decoded APRS packets.
   b. While probably not all packets will be decoded, at least one from each group of three should be decoded.
5. **Repeat the Test**
   a. Change the location of the transmitters for the test, keeping all other variables constant.

Results of Test 1 on 3/4/25:

Radio 2 -> Radio 1	Orientation			
Distance (feet)	**Up**	**0**	**90**	**180**
2472	33%	67%	50%	67%
3456	33%	0%	0%	33%
6385	0%	0%	0%	0%

Radio 3 -> Radio 1	Orientation			
Distance (feet)	**Up**	**0**	**90**	**180**
2472	67%	67%	75%	33%
3456	67%	0%	0%	67%
6385	0%	0%	0%	0%

This test showed that the transmitter is incapable of transmitting at a range of over a mile. At 3400 feet, the data packets are only decoded when the transmitter is at particular orientations. At 2500 feet, the transmitter can reliably deliver APRS packets. Finally, the test indicates that there is very little difference in results when the transmitting radios are swapped.

Results of Test 2 on 3/14/25:

Radio 2 -> Radio 1	Orientation					
Distance (feet)	**Up**	**0**	**45**	**90**	**135**	**180**
1000	67%	100%	83%	50%	50%	67%
2000	67%	67%	50%	17%	50%	0%
2640	33%	0%	17%	17%	0%	0%

This test shows high consistency at a distance of 1000 feet and fairly good consistency at a distance of 2000 feet. Messages are delivered very inconsistently at a distance of one-half mile.

7.1.6. Flap Static Electromechanical Mechanism Actuation Test

Requirement Validated:

This test validates requirement P.13.

Flap Static Electromechanical Mechanism Actuation Test.

This requirement necessitates that the flaps can be actuated up and down with the electromechanical system with varying loads.

Test Description:

Objective: The mechanical system works with the electrical hardware planned to be used on the AB with 25% of the planned weight.

Materials and Equipment:

- Airbrakes prototype
- Electrical system
    - Motor controller
    - Motor
    - Microcontroller

    - Actuation button
    - Battery
- Additional weight

Test Pass/Fail Criteria:

Pass Criteria

- The mechanical system moves without entering a toggle position.
- The system actuated through the full range of motion with no jittering.
- The system lifts 25% of weight determined to be reasonable.

Fail Criteria

- The weight stalls the motor
- The mechanism does not work as intended.

Test Procedure:

1. **Preparation**
    a. Obtain all materials and equipment.
2. **Test Setup**
    a. Set up the electrical system with software to actuate the motor with a button on command.
    b. Hold the AB system up with a vice along the structure tube.
    c. Weigh out the mass with increasing wights.
    d. Prepare the AB model with mass mounting points at the center of pressure.
3. **Perform the Test**
    a. Load the mass onto the mounting point.
    b. Actuate the air brakes.
    c. As the AB are being actuated, measure the time from bottom to top.
4. **Data Collection**
    a. Write down time in a table.
5. **Repeat the Test**
    a. Charge the battery.
    b. Add weight as necessary.

An example of the test apparatus is shown below in Figure 7.1.5.

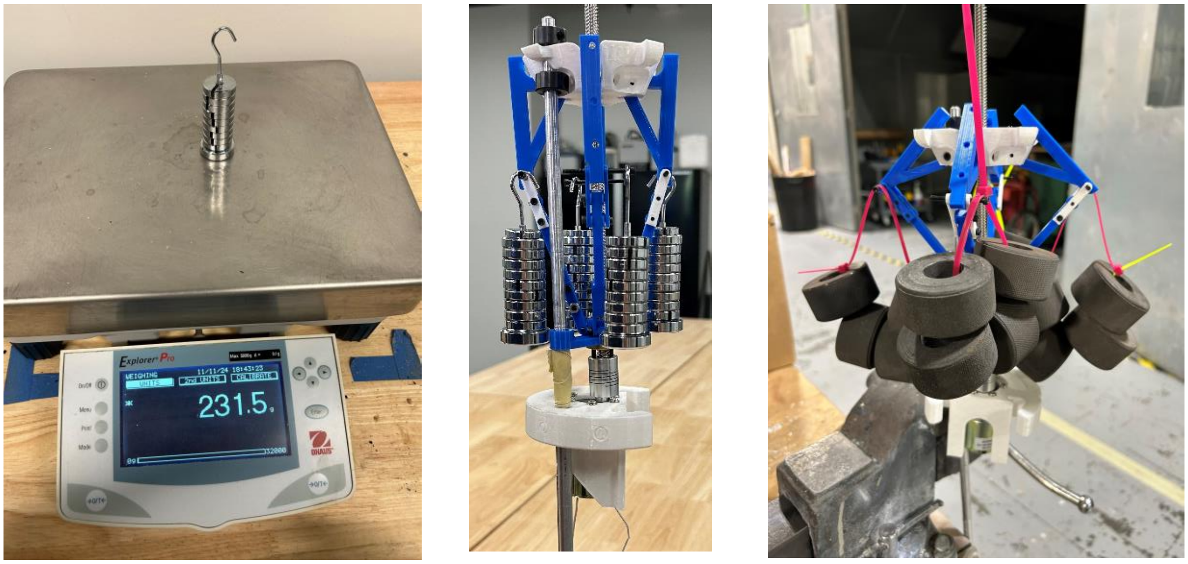


Figure 7.1.4. ***(a)*** *Mass measurement;* ***(b)*** *mass application;* ***(c)*** *larger mass application.*

Variables to be Controlled and Their Values:

Variables:

- Recording time → Dependent Variable
- Weight → Independent Variable

Results of Test:

Because, at the time of this test, the force on each flap is estimated to be 6.85lbs, and 25% of this is 1.7125. Thus, the airbrakes pass this test based on the weight and time.

Weight per flap (lb)	Time (s)
0.00	1.80
0.51	2.00
2.55	4.90

7.1.7. Flap Dynamic Loading Test

Requirement Validated:

This test validates requirement P.14.Flap Dynamic Loading Test.

This requirement necessitates that the flaps will be loaded at the load they are expected to withstand with an increasing force on the flaps.

Test Description:

Objective: As the flaps must be tested with a realistic loading condition, the motor will be tested to make sure it can lift its required realistic weight based on the most relevant CFD model. Thus, the airbrakes will sit on a test bench with increasing weight to determine if they can lift the CFD allotted amount of weight with a performance margin of 1-2.

Materials and Equipment:

- Airbrakes full scale model
- Electrical system.
  - Motor controller.
  - Motor.
  - Microcontroller.
  - Actuation button.
  - Batteries of varying voltages.
- Multi-meter.
- Weights with varying intensity on the system.
- Mounting apparatus for the mechanism.
- Gorilla tape.
- Thermocouple.
- IR thermometer.

Test Pass/Fail Criteria:

Pass Criteria

- The mechanical system moves without entering a toggle position.
- The system actuated through the full range of motion with no jittering.
- The motor can lift CFD allotted weight with a safety margin of >1 in both speed and weight.

Fail Criteria

- The weight stalls the motor.
- The mechanism does not work as intended.
- Motor is overheated (motor heats up more than 15 degree F).

Test Procedure:

1. **Preparation**
    a. Obtain all materials and equipment.
2. **Test Setup**
    a. Set up the electrical system with software to actuate the motor with a button on command.
    b. Hang the AB system up so it can pull up weight.
    c. Use two-liter bottles of water with string hanging the bottles in the air.
        i. Allow the string to be at different lengths to simulate more weight being added to the AB as the mechanism extends upward.
    d. Hook wires up to the appropriate locations ensuring no short or open circuits occur.
    e. Measure maximum flap angle which corresponds to the maximum height of the slider. Mark this point with tape.
    f. Place thermocouple on the shell of the motor.
3. **Perform the Test**
    a. Commence motor actuation while a video is taken of the process.
    b. Hold the IR thermometer over the shell of the motor.
4. **Data Collection**
    a. Record the amount of time it takes for travel up the threaded rod.
    b. Record the temperature of the motor casing.
5. **Repeat the Test**
    a. Charge the battery voltage as necessary.
    b. Add weight as necessary.

An example of the test setup is shown below. (a) shows the mass being measured, (b) shows the test setup, and (c) shows the thermocouple placement.

(a). Angle measurement. ***(b). Test setup*** ***TV-P14.1(b). (b). Thermocouple placement.***

Figure 7.1.5. **(a)** Angle measurement; **(b)** test setup; **(c)** thermocouple placement.

<u>**Variables to be Controlled and Their Values**</u>:

Variables:

- Recording time → Dependent Variable
- Recording temperature → Dependent Variable
- Weight → Independent Variable
- Battery Voltage → Independent Variable

<u>**Results of Test**</u>:

The time needed for the airbrakes to deploy under load is less than four seconds, and the weight needed for them to deploy under load is 3.606 pounds. As shown, the motor passed in Test No. 4. This test approximated the weight curve of the air onto the system, so although it passed this test, the results need to be confirmed by a flight.

Test No.	Battery Voltage	ΔT (°F)	Weight Per Flap (lb)	Average Time (s)
1	12	0	0	1.798
2	12	0	2.2	2.846
3	12	0	4.4	Failed
4	24	4.5	4.4	1.220

7.1.8. State Transition Test & Data Filter Test

Requirement Validated:

This test validates requirements P.16 and P.18.

P.16: State Transition Test

P.18: Data Filter Test

This requirement necessitates that the data filters must best predict the physical state of the system and that the state will change smoothly (at the right time) from the pad through landing.

Test Description:

Objective: Data from a flight will be run through the state machine, and if it changes state at the appropriate times (times are known because it is a real launch), then it passes because the filter gave an appropriate state space model.

Materials and Equipment:

- Pressure flight data.
- Acceleration flight data.
- Functional controller.
- Functional state machine.

Test Pass/Fail Criteria:

Pass Criteria

- The state transitions from one state to the next state.
- The state transitions happen within ± 0.75 seconds of when they are supposed to transition (except for apogee).

Fail Criteria

- The code does not detect a state transition.
- The filter estimates a state wrong so that

Test Procedure:

1. **Preparation**
    a. Code software to change the state and filter the data.
2. **Test Setup**
    a. Prepare data from the flight to enter the software.
3. **Perform the Test**
    a. Import the CSV file to the software.
4. **Data Collection**
    a. Record the state change.

5. **Repeat the Test**
   a. Change the filters and state tuning as necessary.

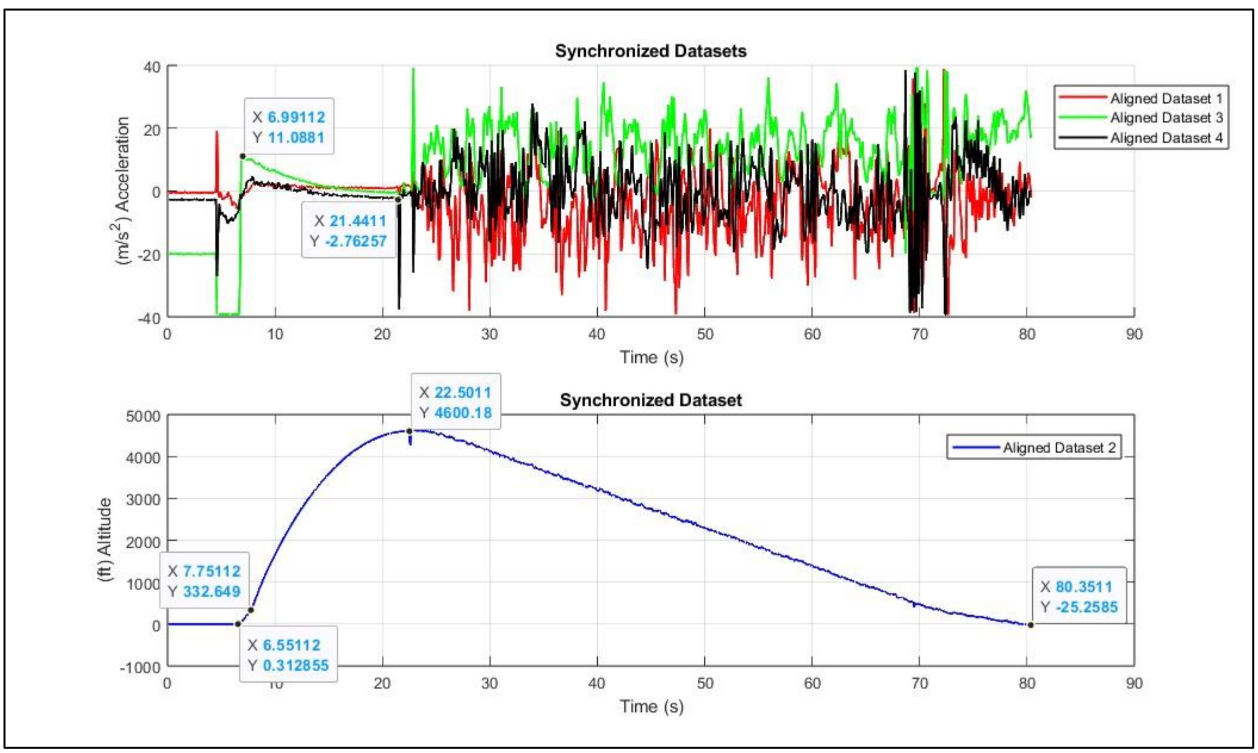
Variables to be Controlled and Their Values:

Variables:

- State change → Dependent Variable
- Altitude → Independent Variable
- Acceleration (x,y,z) → Independent Variable

Results of Test:

The data from avionics and the backup PCB were synchronized to share the same bit rate through a MATLAB script, see the figure below, using interpolation (see script in Appendix A.4), and the output of the state machine is seen the next figure. The flight starts with the spike of positive acceleration at about 6.99 seconds, and the code predicts 677 (conversion is 6.77 seconds). The next milestone is burnout once the rocket has reached a certain altitude at time 7.77 seconds (this is when the airbrakes will activate). The code then predicts apogee at 25.88 whereas the true apogee is more like 22.5 seconds, but this must be a loose tolerance because it takes many pressure readings to ensure the rocket has truly reached apogee and not stop the control algorithm prematurely. It then predicts landing 80.29 where is almost exact at 80.35.



```
03:16:17.469 -> liftoff detected 677
03:16:18.758 -> burnout 777
03:16:50.444 -> apogee 2588
03:18:02.506 -> landed 8029
```

Because the states changed at the appropriate times, the state space data filters and state machine are validated.

7.1.9. Apogee Prediction Algorithm Test

Requirement Validated:

This test validates requirement AB.S.15

This requirement necessitates that the control algorithm must output the best flap angle possible to cause the airbrakes to achieve the target apogee within 25 ft. This test is called the "Control Simulation Test".

Test Description:

Objective: The objective of this test is to validate that the control algorithm can cause the airbrakes to move in such a way that the desired apogee can be achieved. The purpose of this test is to prove that the airbrake control system will work.

Test Pass/Fail Criteria:

The control algorithm will pass this test if the simulated rocket reaches an apogee of 4100 +-5 ft for a wide range of starting simulation conditions.

Test Procedure:

Using starting conditions from OpenRocket simulations, run the MATLAB simulation and verify that the controller causes the apogee to be within the desired range.

Variables to be Controlled and Their Values:

Ground temperature – range of values from OpenRocket simulations

Ground pressure – range of values from OpenRocket simulations

Starting velocity – range of values from OpenRocket simulations

Starting altitude – range of values from OpenRocket simulations

Results of Test:

This test has validated the airbrake control system. If the airbrakes are physically capable of slowing the rocket down enough to reach the desired apogee, they will do so. Something that needs to be studied further is why, when the airbrakes are not capable of slowing the rocket enough, they fully deploy and then fully close and then fully deploy again.

7.1.10. Control Algorithm Shakedown Demonstration

Requirement Validated:

This test validates requirements P.20.

Control Algorithm Shakedown Demonstration.

This requirement necessitates that the control algorithm must not pose a problem when incorporated into the state machine and vice versa.

Test Description:

Objective: Random data will be input into the state machine with the controller in the system. If the output of the state machine is what the controller predicted, then it passes the test. If the outputs differ at all, then it fails.

Materials and Equipment:

- Functional controller.
- Functional state machine.

Test Pass/Fail Criteria:

Pass Criteria

- The expected value of the state machine with the controller matches with the output of the controller as built standalone within a tolerance of 1%.

Fail Criteria

- The state machine with the controller does not match the controller within 1% of accuracy and have 99.999% (6 sigma STD) precision.

Test Procedure:

1. **Preparation**
   a. Code controller software and state machine software.
2. **Test Setup**
   a. Prepare data from the flight to enter the software.
3. **Perform the Test**
   a. Import the CSV file of the pressure to the software.
4. **Data Collection**
   a. Record the output angle of the controller.
5. **Repeat the Test**
   a. Compare to the controller as built standalone and ensure they are the same within the tolerances.

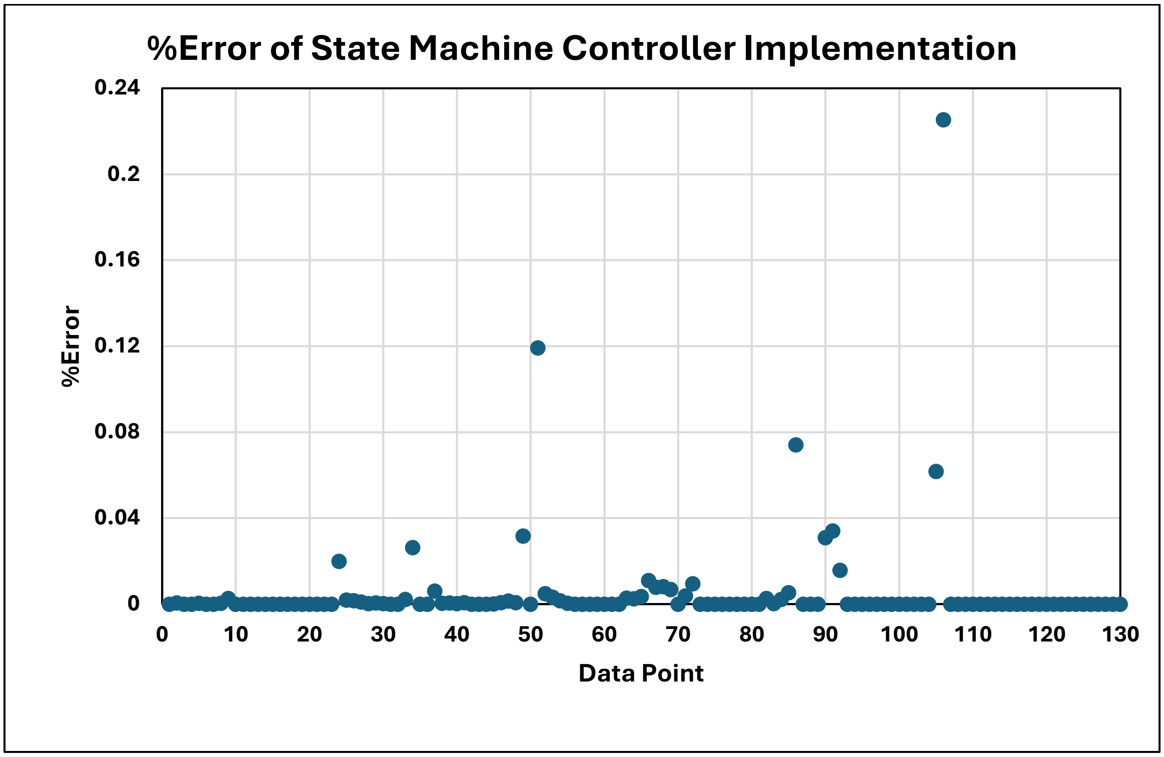
Variables to be Controlled and Their Values:

Variables:

- Output angle → Dependent Variable
- Pressure (altitude) → Independent Variable

Results of Test:

As seen in Appendix A.5, the data output by the controller versus the data output by the controller in the state machine. The %error is shown below, the %error never goes above 1%, and thus meets the criterium of having six sigma precision by less than 1% error.



7.1.11. Mechanical Coupler Failure Test

Requirement Validated:

This test validates requirements P.21.

Mechanical Coupler Failure Test. This requirement necessitates that the coupler must not break under load during the flight.

Test Description:

Objective: The coupler in the force transmission system will be tested under load to determine how much force can be exerted on it in the INSTRON machine.

Materials and Equipment:

- INSTRON machine.
- Coupler rod (pultruded carbon fiber rod).
- Gusset plates (aluminum).
- Hardware (screws 4-40 x 5/8; hex nuts).
- Machine mounding brackets.

Test Pass/Fail Criteria:

Pass Criteria

- The coupler withstands the force applied (expected) in compression and in tension with at least a safety factor of 1.5.

Fail Criteria

- The coupler fails with a safety factor less than 1.5.
- The coupler buckles with a safety factor less than 1.5.

Test Procedure:

1. **Preparation**
    a. Machine the mounting brackets.
2. **Test Setup**
    a. Insert the coupler into the mounting brackets.
    b. Insert the mounting bracket into the INSTRON machine.
3. **Perform the Test**
    a. Preform the tension or compression test. See Figure TV-P.22.1 of the coupler being tested in compression.
    b. Record a video as the machine conducts the test.
4. **Data Collection**
    a. Send the csv file to student email through the INSTRON account.
5. **Repeat the Test**
    a. Take the apparatus out of the INSTRON machine.

Variables to be Controlled and Their Values:

Variables:

- Failure force → Dependent Variable
- Force applied → Independent Variable

Results of Test:

At the time of this test, the force on the flaps is said to be 6.85 lbs. The test revealed that this part is overengineered and can withstand a force of 258 lbs. This does not fail the test, because there were no constraints on overengineering. Thus, the coupler passes this test.

7.1.12. Comprehensive Airbrake Bench Test

Requirement Validated:

This test validates requirements P.22.

Comprehensive Airbrake Bench Test. This requirement necessitates that the airbrakes work with realistic simulated conditions.

Test Description:

Objective: On the test bench, the airbrakes actuate under load, and in vibrational conditions with forces acting on the center of pressure according to the function of air force expected. The airbrakes will have the final software implemented onto the PCB to test the software

Materials and Equipment:

- Vibrational actuator.
- As built airbrakes mechanism.
- Functional state machine
  - Controller implemented
  - Filter implemented.
  - Physics based model feeding and receiving data to act as live feedback loop.
- CFD equivalent resistance for the flaps.
- Airframe to fit inside of.
- Mounting mechanism for airframe on.

<u>Test Pass/Fail Criteria</u>:

Pass Criteria

- The SD card does not break or become disconnected as to corrupt the data.
- The data filters clean the messy data to determine the correct state.
- The final state machine moves through the stages.
- The controller actuates the motor with realistic times (physically possible with the expected load).
- The motor does not overheat.
- The motor can keep up with the controller as needed.
- The vibrations of the system do not interfere with the test validity.

Fail Criteria

- The vibrations interrupt the test validity.
- The motor is impinged by the force of resistance as to not be able to affect the apogee to the degree required.
- The state space model skips or misses a state.
- The controller does not end at the right altitude.

<u>Test Procedure</u>:

1. **Preparation**
    a. Create physics-based function model which outputs altitude and acceleration and inputs flap angle (simulating the rocket in flight).
    b. Modify the physics-based model to output dirty data like the sensors would.
    c. Import this modified physics-based model into the state machine with sensor filters.
    d. Develop test apparatus.
        i. Calculate the highest force on the flaps as they start to open. Calculate a spring or rubber band that best matches this curve.
        ii. Create airframe for the airbrakes.
    e. Charge batteries.
2. **Test Setup**
    a. Download file to microcontroller.
    b. Set up apparatus
        i. Insert into airframe
        ii. Attach springs
        iii. Attach the apparatus to the vibrational machine.
3. **Perform the Test**
    a. Turn the AB and vibrational machine on.
    b. Let the system actuate.
4. **Data Collection**

   a. Turn the system off and pull the SD card out. Plug it into the computer and read the data.

5. **Repeat the Test**
   a. If any part of the test fails, troubleshoot and repeat as necessary.

Variables to be Controlled and Their Values:

Variables:

- Motor temperature → Dependent Variable
- Output angle → Dependent Variable
- Force applied to flaps → Independent Variable

Results of Test:

THIS TEST HAS NOT YET BEEN PREFORMED.

7.2. Requirements Compliance

The system that CSL uses to monitor requirement compliance has been summarized in Tables 7.2.1 and 7.2.2, which describes the NASA and CSL requirements respectively. In these tables, the requirement is described, given a general compliance plan, a verification method, a status, and a verification description. The location in FRR where these requirements are discussed is also given. All requirements are validated by demonstration, analysis, inspection, and testing as defined by the NASA SL Committee.

CSL requirements are classified as vehicle, payload, or other, and are named respectively using the letters V, P, and O (ex: V.1, for the first vehicle related requirement). Some requirements also contain other classification codes in parentheses for reference to specific mission success objectives (ex: AB.S.1, a criterion for specifically airbrakes success criteria). Some verifications under the payload classification are marked as in progress, but all test related to these verifications have been completed.

Table 7.2.1. *NASA requirement verification table.*

Req. #	Description of Requirement	Compliance	Verification Method	Status	Verification Description	Location (FRR)
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	Complete	The team mentor Dave Combs has handled all motor assembly and black powder charges. Students are responsible for and completing all other 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.	Inspection	Complete	The Team Lead, Chief Engineer, Chief Safety Officer, and STEM Engagement Officer have assembled all required project deliverables in a comprehensive and organized file system. These deliverables have been included in all NASA report deliverables.	Section 7
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 followed.	Inspection	Complete	The STEM Engagement Officer has created a plan for CSL to reach out and engage with schools in the areas surrounding the university. A count of engaged students will be closely followed by team leadership as milestones are approached.	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 is maintained.	Inspection	Complete	The team's social media activity is regularly checked by the Team Lead and social media coordinating engineering team member.	NA
1.6	Teams will submit all deliverables to NASA by the deadlines 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	Complete	CSL leading personnel have personally submitted all NASA deliverables 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.	Inspection	Complete	Team leaders have inspected all project deliverables before submission to ensure 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	Complete	In all of the submitted deliverables, CSL leadership and the team's Chief Editor have verified proper 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	Complete	In all of the submitted deliverables, the Chief Editor verifies proper documentation formatting and includes page numbers located at the bottem of the document.	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	Complete	CSL's team lead ensures that proper equipment and rooms are reserved 2 weeks before scheduled 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. Dave is member #86830 and member-elected president of NAR chapter #703 (the Wright Stuff Rocketeers).	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	Complete	CSL members have used Excel documents to keep track of individual's hours spent working on each milestone. The Team Lead will be in charge of maintaining this information.	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, Demonstration	Complete	CSL has used OpenRocket to simulate full scale launches with a predicted apogee goal of 4100 feet AGL. CSL's attempted VDF had an apogee of 4234 feet.	Section 5
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.	See CDR, Section 1.2
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. The attempted VDF flight has proved the launch vehicle is nearly reusable and recoverable with some adjustment.	Sections 3 & 4

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.	Section 3.2
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.	Demonstration	Complete	CSL has proven the team's ability to prepare the launch vehicle under 2 hours with their attempted VDF flight.	Section 6.2
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.	Analysis will be conducted to verify that the rocket and payload systems will maintain all functionality on the launchpad for at least 3 hours.	Analysis	Complete	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 by analyzing the power consumption and miliamp hours of the systems' batteries.	Section 7.1
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 / Demonstration	Complete	The Chief Engineer has inspected that the launch vehicle's ignitors are capable of being set off by a 12 -volt DC firing system, and this system has been verified as succesful with the VDF attempt.	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 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	Complete	CSL will only purchase and use commercially available e-matches or igniters, as approved by the team mentors.	NA

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	Complete	The vehicle designed by CSL utilizes an Aerotech K1000T-P approved by NAR/TRA and has declared this choice in the CDR.	Section 1.2
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 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.	Sections 1.2 & 3.6
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.	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.	See CDR & Section 5
2.15	The rocket's thrust to weight ratio will be at least 5.0:1.0	CSL will determine the weight of the rocket, and then, using OpenRocket and the motor thrust curve data, will ensure that the thrust to weight ratio exceeds 5:1.	Analysis	Complete	CSL will ensure the rocket's thrust to weight ratio exceeds 5.0:1.0 using the rocket weight and thrust data.	See CDR & Section 5

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 3.3.4
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.	Analysis / 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.	See CDR & Section 5
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 18, 2024. The was a separate new construction that included an altimeter. The proof of concept was included in the CDR.	NA
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	In Progress	CSL has completed an attempted Vehicle Demonstraiton flight and will attempt a Payload Demonstration Flight for the FRR Addendum.	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 for succesful completion of the VDF and PDF.	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 conditions. All LiPo batteries are brightly colored and clearly marked as fire hazards and distinguishable from other payload hardware	Section 3.5, 4.1, & 4.2
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.	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 1.2
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 4.1
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 & 3.4
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	Complete	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 3.5

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 7.1
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 analyzed 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].	Section 3.6
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	Complete	Two altimeters of different brands will be used for recovery. The team member in charge of avionics will ensure altimeter compliance.	Section 3.5
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	Complete	Each altimeter has a dedicated, commercially available battery as a power source.	Section 3.5
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	Complete	Key-switches or equivalent means will be used to arm the flight avionics.	Section 3.5
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	Complete	Key-switches or equivalent means will be used to arm the flight avionics.	Section 3.5
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 3.5
3.9	Drogue and main parachute sections will use removable shear pins.	Inspection will verify the construction and assembly of the recovery subsystem.	Inspection	Complete	The recovery lead will be responsible for the insertion and inspection of shear-pins prior to every launch.	Section 3.5

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	The Chief Engineer has supervised the design of the recovery system and ensured no eyebolts were utilized.	Section 3.5
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 demonstration shown in the VDF attempt verify the drift stays within a 2,500 [ft] radius.	Section 3.6
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 demonstration shown in the VDF attempt verifies descent time is below 90 seconds.	Section 3.6
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.	The GPS will be inspected to ensure the device is working properly. Inspection will verify the proper installation of the GPS in the avionics bay.	Inspection	In Progress	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. The system is being troubleshooted for the FRR addendum.	Section 3.5
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	Complete	Electronics will be shielded from interference. Insulation will be applied to electronics. The avionics bay will physically isolate it from all other electronics. Flight attempts show the recovery is unaffected by other transmitters.	Section 3.5
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. The PDF has not yet been attempted.	Section 4.1

4.2	The payload must transmit 3-8 pieces of the provided data to NASA. Transmissions may not exceed 5 [W] 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. The PDF has not yet been attempted.	Section 4.1
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	Complete	The payload will remain attached to the main body of the rocket and will not be jettisoned or deployed from the rocket's body, so it will not be classified as a UAS.	Section 4.1
5.1	The team will use a launch safety checklist that will be included the FRR and used during the LRR.	The Chief Safety Officer will create a safety check list.	Inspection	Complete	The Chief Safety Officer will be responsible for writing the Launch Operating procedures to be used on launch day.	Section 6.4
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 Chief Safety Officer.	Inspection	Complete	The team has assigned Jesse DePalmo as the 2024-2025 CSO.	Section 6
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	Complete	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 6
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	Complete	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 6

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	Complete	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 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	Complete	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 6
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	Complete	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 6
5.5	The team will abide by all FAA rules.	The SO will ensure that all FAA rules are followed.	Inspection	Complete	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 6
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.	NA
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

Table 7.2.2. *CSL requirement verification table.*

Req. #	Description of Requirement	Compliance	Verification Method	Status	Verification Description	Location (FRR)
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.	NA
O.2	CSL will utilize a Mass Growth Allowance Plan to manage system mass growth and ensure overall successful flight performance.	The Chief Engineer will track and manage mass changes across all subsystems and ensure mass changes do not negatively impact mission success.	Inspection / Analysis	Complete	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.	NA
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.	Analysis	Complete	The design for the CSL launch vehicle will be simulated in OpenRocket and the VDF attempt will demonstrate adequate performance of K class motors.	NA
V.2	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	Complete	Team members will attempt to keep all components modular, and will have designs approved and inspected by the Chief Engineer to achieve this unity.	Sections 3.2 & 3.3
V.3	CSL will implement an onboard camera system to capture flight footage and evaluate performance. This system must have minimal affect on the performance of the launch vehicle and be reusable.	CSL will evaluate the launch vehicle's performance with and without the integrated camera system, and will evaluate the reliability of the system.	Analysis / Test / Demonstration	Complete	CFD Analysis in Ansys will be conducted to understand the affect of the camera system on the launch vehicle's performance. The camera will be tested to determine if it can reliably capture flight footage.	Section 3.3.4 & 3.4.4
V.4 (NC.S.1)	The nosecone will reduce drag acting on the launch vehicle during flight.	The nosecone will be analyzed using fluid analysis methods, such as simulation.	Analysis	Complete	Variations of the nosecone design will be analyzed using OpenRocket for a design that reduces vehicle drag to improve launch vehicle performance.	Section 3.3
V.5 (NC.S.2)	The nosecone will improve flight stability.	The launch vehicle's stability will be simulated using simulation software tools.	Analysis	Complete	Variations of the nosecone design will be analyzed using OpenRocket for a design that improved stability for launch vehicle performance.	Section 3.3

V.6 (NC.S.3)	The nosecone will provide structural stability to the fore section of the rocket and provide protection to the primary mission payload.	Both the nosecone and the payload will be inspected after launch for damage. The payload is to be checked that it is still operable and in a successful working condition	Demonstration	Complete	The nosecone and the payload were inspected for damage after the VDF attempt submitted in the FRR report. Both subsystems survived the landing and the payload was still operable.	Section 3.3
V.7 (NC.S.4)	The nosecone will survive impact with the landing surface, remaining attached to the launch vehicle with minimal damage, and will be reusable for immediate reflights.	The nosecone's ability to survive landing forces with minor damage will be assessed with drop tests.	Test	Complete	Drop tests will be conducted on the nosecone system at various heights and mass configurations.	Section 7.1
V.8 (TC.S.1)	The tailcone will improve launch vehicle performance.	CSL will simulate the launch vehicle with and without the tailcone and assess flight performance characteristics.	Analysis	Requirement Failed	CSL will utilize the simulation software OpenRocket to analyze launch vehicle flight performance characteristics such as apogee and stability, with and without the tail cone.	Section 3.3.9
V.9 (TC.S.2)	The tailcone will remain attached to the aft centering ring and retain the motor tube during all stages of vehicle flight.	The tailcone will be inspected before and after all flights to ensure system integrity.	Demonstration	Complete	Before and after all flights, the tailcone system's attachment points, aft centering ring, and motor tube will be inspected for damage or retainment failure.	Section 3.3.9 & 3.4.9
V.10 (TC.S.3)	The tailcone will survive vehicle landing within expected descent energies and be reusable for future flights.	The tailcone will be inspected before and after all flights to ensure system integrity.	Demonstration	Complete	Before and after all flights, the tailcone system's attachment points, aft centering ring, and motor tube will be inspected for damage or retainment failure.	Section 3.3.9
V.11 (TC.S.4)	The tailcone will survive heat from vehicle launch with minor/no damage and be reusable for future flights.	The tailcone will be inspected after all test launches and flights to ensure that no damage from motor firing heat will affect system performance.	Demonstration	Complete	The tailcone will be inspected before after all test launches and flights for damage related to motor burn, including weakened material, propogations of damage due to heat, or created stress concentrations.	Section 7.1
P.1	The payload will survive vehicle landing within expected descent energies and be able to perform post-flight operations.	Durability testing will be conducted by way of drop testing to quantify overall payload housing durability.	Demonstration	Complete	The payload will be demonstrated to be fully capable of surviving the full-scale rocket launch and return unharmed.	Section 4.1 & 7.1

P.2	The batteries will be capable of providing enough power to power the payload while it is on the launch pad then perform all functions during and after the rocket's flight.	All batteries will have enough power to operate the payload for three hours on standby mode then for the duration of the flight and post-flight operations.	Analysis / Test / Demonstration	In Progress	Analysis and testing will be done to measure power consumption of the circuits versus battery power provided and then payload flight demonstrations will confirm battery longevity.	Section 7.1
P.3	All payload sensors will be capable of delivering accurate data to the microcontroller.	Payload sensor data will be compared to known or expected data to ensure accuracy in data acquisition.	Demonstration	In Progress	The payload will be demonstrated to be collecting proper data, during development and before each flight.	Section 4.1
P.4	The payload's transmitter, the Baofeng UV-5R, will be able transmit decodable APRS data from the landing site of the rocket to the receiver near the launch site.	The payload's transmitter will be able to reliably transmit APRS data from a distance of up to 2500 feet in any conceivable landing orientation using 5W of power.	Test / Demonstration	In Progress	Tests will be completed at varying distances and orientations which determine our transmission distance capabilities, and this will be also be demonstrated by rocket flights where the rocket lands within 2500 feet of the launch site.	Section 7.1
P.5	The payload will transmit data using the APRS protocol. These APRS data packages will be decodable by any standard APRS receiver.	APRS packages created by the payload's primary microcontroller will be sent by the transmitter then decoded using a standard APRS receiver.	Inspection	Incomplete	Transmissions sent by the payload will be decoded by a standard APRS decoding setup.	Section 4.1
P.6 (AB.S.1)	The airbrakes will successfully deploy during ascent of the launch vehicle.	The launch vehicle's onboard camera will confirm the airbrakes actuation during launch.	Demonstration	Incomplete	Camera footage will be reviewed post-flight and compared to airbrakes control data to demonstrate intentional flap deployment.	Section 3.3.4 & 4.2
P.7 (AB.S.2)	The airbrakes will be fully stowed within ±2 seconds of the launch vehicle reaching apogee.	The launch vehicle's onboard camera will observe the actuation of the airbrakes system during launch, and can time the stowing of the airbrakes.	Demonstration	Incomplete	Camera footage will be reviewed post-flight and compared with altimeter data to show that airbrake flaps stow within the allotted timeframe.	Section 4.2
P.8 (AB.S.3)	The airbrakes system will increase drag acting on the launch vehicle such that the rocket apogee is within ±25 feet of the target altitude.	CSL will design and manufacture an airbrakes system that will accurately control flight performance, and thus apogee.	Demonstration	Incomplete	During flight, the airbrakes will demostrate, via data analysis, that the apogee was indeed reached within a range of ±25 feet.	Section 4.2

P.9 (AB.S.4)	The drag flaps of the airbrakes system will be located no further than 2 inches behind the center of pressure (Cp) to ensure aerodynamic stability.	The airbrakes engineering lead will coordinate with CSL's chief engineer to ensure the airbrakes drag flaps will be located in a position compliant to this requirement.	Inspection	Complete	Using OpenRocket and practical methods, the center of pressure will be calculated and compared to the location of the drag flaps.	Section 4.2
P.10 (AB.S.5)	No components of the airbrakes system will experience mechanical failure during any stage of flight.	The airbrakes engineering lead and chief engineer will determine the capabilitiy of the airbrakes mechanical system using multiple destructive/loading tests and demonstrations.	Inspection	Incomplete	After the flight, each component will be checked in there is any mechanical damage, if there is, then it failes.	Section 4.2
P.11 (AB.S.6)	The airbrakes system will be manufactured such that no electrical brownouts or blackouts will occur.	CSL will monitor the airbrakes electrical system voltage and monitor for readings outside of acceptable constraints.	Inspection	Incomplete	While the rocket is in the air, the battery voltage must stay consistent in a range reasonable for its amperage draw such that the system does not restart.	Section 4.2
P.12 (AB.S.8)	Flight data recorder and retrieved.	When the airbrakes are retreived from the rocket, the data they collected can be aquired and veiwed on a computer.	Inspection	Incomplete	When the rocket is flown, the data must be aquired and downloaded onto a computer for data analysis and showcase.	Section 4.2
P.13 (AB.S.9)	Flap Static Electromechanical Mechanism Actuation Test	The flaps can be actuated up and down with the electromechanical system with varying loads.	Test	Complete	The flaps must work to move along the arc of operation, thus if the motor can move the flaps along this arc with 25% of the weight, then the test is a pass.	Section 7.1
P.14 (AB.S.10)	Flap Dynmaic Loading Test	The flaps will be loaded at the load they are expected to withstand with an increasing force on the flaps.	Test	Complete	As the flaps must be tested with a realistic loading condition, the motor will be tested to make sure it can lift its required realistic weight baAs the flaps must be tested with a realistic loading condition, the motor will be tested to make sure it can lift its required realistic weight based on the most relevant CFD model. Thus, the airbrakes will sit on a test bench with increasing weight, and if they can lift the CFD allotted amount of weight with a performance margin of 1-2, the test is a pass.	Section 7.1
P.15 (AB.S.11)	Data Aqusition Demonstration	The airbrakes PCB will be tested to see if it can take data under simi-realistic conditions.	Demonstration	Complete	The PCB will be set up in a bottle rocket, and if the data continues to be taken with little interuption, no betteries come disconected, and the data can be aquired onto a computer, then the system passes.	Section 4.2

P.16 (AB.S.12)	State Transition Test	The state machine will be tested to determine if it changes state from Pad through landing.	Test	Complete	Either theoretical or real data will be entered into the state machine to see if the states transition at the proper time.	Section 7.1
P.17 (AB.S.13)	Solder Join Reliability Inspection	No soldered join may fail during launch.	Inspection	Complete	Each major joint on the final AB system will be inspected to ensure there is a liberal amount of solder.	Section 4.2
P.18 (AB.S.14)	Data Filter Test	The data filters must best prdict the state of the system.	Test	Complete	Data from a flight will be run through the state machine, and if it changes state at the appropriate times (times are known because it is a real launches), then it passes because the filter gave an appropriate state space model.	Section 7.1
P.19 (AB.S.15)	Apogee Prediciton Algorithm Test	The control algorithm must give the best prdiction of what the flaps must do to achieve the desired apogee.	Test	Complete	A MATLAB simulation will be used to simulate the rocket during the coast phase of flight. If the control algorithm casues the apogee to be within +-5 feet of 4100 ft in the simulation, then it passes the test.	Section 7.1
P.20 (AB.S.16)	Control Algorithm Shakedown Demostration	The control algorithm must not pose a problem when incorporated into the state machine.	Test	Complete	Random data will be input into the state machine with the controller in the system. If the output of the state machine is what the controler predicted, then it passes the test. If the outputs differ at all, then it fails.	Section 7.1

P.21 (AB.S.17)	Mechanical Coupler Failure Test	The coupler must not break under load during the flight.	Test	Complete	The coupler in the force transmission system will be tested under load to determine how much force can be exerted on it in the INSTRON machine.	Section 7.1
P.22 (AB.S.18)	Comprehensive Airbrake Bench Test	The airbrakes work with realistic simulated conditons.	Test	In Progress	On the test bench, the airbrakes actuate under load, and in vibrational condtions with force acting on the center of pressure according to the function of air force expected. The airbrakes will have the final software implimented onto the PCB to test the software.	Section 7.1

7.3. Budgeting and Funding Summary

The budget for the CSL team was established at the beginning of the school year when the CSL team turned in the proposal for this project. It was estimated that between 6000 to 6500 dollars would be needed to complete this project. As of 3/17/2025, the CSL team is projected to be under budget, which is at 5765.50 dollars. The line-by-line breakdown of the budget can be seen in Table 7.3.1. .

Table 7.3.1. *Budgeting sheet for CSL NASA project*

Overall Budget for NASA Project									
System	**Qty**	**Item Name**	**Item Description**	**Actual Price**	**Allocated Price**	**Total**	**Allocated Total**	**Source**	**Purchased?**
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
	1	G12 Fiberglass Tube (Madcow Rocketry)	4ft length, 4 in diameter	$ 182.00	$ 182.00	$ 182.00	$ 182.00	-	X
	1	G12 Coupler (madcow rocketry)	9 in length, 4 in diameter	$ 37.00	$ 37.00	$ 37.00	$ 37.00	-	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					**$ 279.02**	**$ 582.52**		
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
	1	BTECH APRS-K2	APRS encoder/decoder	$ 22.49	$ -	$ 22.49	$ -	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	$ -	$ 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	$ -	$ 14.99	$ -	$ 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
	1	Micro SD-Card 32GB (5-pack)	removable memory	$ 19.20	$ 29.94	$ 19.20	$ 29.94		X
	2	PCB Manufacturing per Version	printed circuit board	$ 21.50	$ 40.00	$ 43.00	$ 80.00	Link	X
	4	LEGO STEMnauts	minifigure	$ 5.00	$ 5.00	$ 20.00	$ 20.00	Link	
	Total					**$ 297.43**	**$ 427.64**		
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
	2	J540R-L Motors	54 mm	$ 135.99	$ 135.99	$ 271.98	$ 271.98	Link	X
	6	Stainless Steel Powder	for mass control	$ 16.98	$ 16.98	$ 101.88	$ 101.88	Link	X
	2	Checkered Contact Paper	17.7 x 118 in, for velocity blanket	$ 6.99	$ 6.99	$ 13.98	$ 13.98	Link	X
	Total					**$ 915.10**	**$ 915.10**		

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)	5	Chloroplast corrugated cardboard	construction materials	$ 26.74	$ 26.74	$ 133.70	$ 133.70	Link	X
	4	Foam Footballs	construction materials	$ 19.99	$ 19.99	$ 79.96	$ 79.96	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	Straws (380 pack)	construction materials	$ 18.99	$ 18.99	$ 18.99	$ 18.99	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
	2	Scotch Tape	construction materials	$ 9.99	$ 9.99	$ 19.98	$ 19.98	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
	2	Metal bb and Pebbles	construction materials	$ 8.99	$ 8.99	$ 17.98	$ 17.98	Link	X
	Total					$ 838.39	$ 949.97		
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
	200	Shock Cords	9/16 in width, 1500 lbs tensile strength	$ 1.50	$ 1.50	$ 300.00	$ 300.00	Link	X
	2	Fasteners	(50 ct) 18-8 Stainless Steel Button Head	$ 7.56	$ 7.56	$ 15.12	$ 15.12	Link	X
	6	PETG plastic	Plastic for 3D printing, 1 kg spool	$ 13.00	$ 20.00	$ 78.00	$ 120.00	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
	2	15 Min Epoxy	212 epoxy, 13 combined oz	$ 24.99	$ 29.99	$ 49.98	$ 59.98	Link	X
	10	Male-Female Threaded Hex Standoff	for secondary payload	$ 2.38	$ 2.38	$ 23.80	$ 23.80	Link	X
	Total					$ 889.90	$ 1,101.90		
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		

Appendix

A.1. MATLAB Code for Full-Scale Descent 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 = 0.0023;
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 = (1.66 + 23.6/2)/(in.g*16); m_main = (17.15 + 23.6/2)/(in.g*16);
m_parachutes = m_drogue + m_main;
in.m = [0.37855 0.12344 0.21241];
in.W = in.g*(sum(in.m, "all") + m_parachutes);

% Drogue Parachute Values
D_od = 1;
D_id = 3.5/12;
Ad = (pi/4)*(D_od^2 - D_id^2);
C_Dd = 1.6;
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 = 5e-4;
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-8;
    else
        A1 = A1 + 1E-6;
    end

    if A1 <= 0
        A1 = 1E-12;
    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 = 64.00;
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])
% To best compare the theoretical drift with the actual launch data
% wind speed closest to the actual may be changed accordingly
V_wind = 5:5:20;
% V_wind(#) = #;
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.2. MATLAB Code for the CP/CG Calculation

```
%% Approximate Center of Pressure for the full-scale launch vehicle (w/o
Airbrakes Deployed)
% Cross-Sectional area of each section
% multiplied by its individual center of pressure
% divided by the total cross-sectional area

% Approximate Projected Areas [in^2]
Nosecone = 36;
```

```
Airframe = 356;
Tailcone = 12.5;
Fins = 38;

TotalA = 420;

% Individual Center of Pressure [in]
CN = 14/2;
CA = 14 + 89/2;
CF = 89 - (4.5*(7.75 + 2*3.25)/(3*(7.75 + 3.25)) + (1/6)*(7.75 + 3.25 -
(7.75*3.25)/(7.75 + 3.25)));
CT = 103 + (3.75/3)*(1 + (1 - (4/3.5)/(1 - (4/3.5)^2)));

% Approximate Center of Pressure from the Nose Cone [in]
cp = (Nosecone*CN + Airframe*CA + Fins*CF + Tailcone*CT)/TotalA

%% Approximate Center of Gravity for the full-scale launch vehicle (w/o Airbrakes
Deployed)
% Individual center of gravity for each section
% multiplied by their respective weights
% divided by the total weight of the launch vehicle

% Approximate Individual Center of Gravity [in]
CN = 14*3/14;
CA = 14 + 89/2;
CF = 89 - (5/3)*(3.25 + 2*7.75)/(3.25 + 7.75);
CT = 103 - 3.5*2/3;

% Weights of each section [N]
Nm = (1385)*0.0098;
Am = (9279)*0.0098;
Fm = (301)*0.0098;
Tm = (160)*0.0098;

TotalW = 110;

% Approximate Center of Gravity from the Nose Cone [in]
cg = (CN*Nm + CA*Am + CF*Fm + CT*Tm)/TotalW

%% Stability (w/o Airbrakes Deployed)

stability = (cp - cg)/4
```

A.3. ChariotSim Flight Simulation Python Code

```python
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
from matplotlib.widgets import Button, TextBox
import matplotlib.pyplot as plt

# Constants
g0 = 9.81  # Gravity (m/s^2)
rho0 = 1.225  # Air density (kg/m^3)

Cd0 = 0.574  # Drag coefficient
plot = True

SM = 2.29  # Static stability margin (cal)
A = 0.0082  # Cross-sectional area (m^2)
F_T0 = 1674  # Initial thrust (N) only used if thrust_method = 1
m0 = 12.4  # Initial mass (kg)
mb = 11.22  # Burnout mass (kg)
burn_time = 2.5  # Engine burn time (seconds)
mass_flow_rate = (m0 - mb) / burn_time  # Mass flow rate (kg/s)
thrust_method = 2  # 1: standard equation; 2: experimental thrustcurve
implementation

RAIL_ANGLE = 0  # (deg)
T0 = 288.7056  # Initial temp (K) 60F
WIND_SPEED = 0  # (m/s)

# Time step
dt = 0.001  # Time step (seconds)
total_time = 19  # Total simulation time (seconds)

# K1000T-P Original thrustcurve data (time, value)
thrustC_time = np.array(
    [
        0.004, 0.015, 0.025, 0.095, 0.200, 0.300, 0.400, 0.500, 0.600,
        0.700, 0.800, 0.900, 1.000, 1.100, 1.200, 1.300, 1.400, 1.500,
        1.600, 1.700, 1.800, 1.900, 2.000, 2.100, 2.180, 2.200, 2.218,
        2.269, 2.300, 2.332, 2.356, 2.389, 2.436, 2.500
    ]
)

thrustC = np.array(
```

```
    [
        895.149, 1119.762, 1093.337, 1096.64, 1109.853, 1116.459, 1123.065,
        1132.975, 1139.581, 1136.278, 1136.278, 1136.278,  1139.581, 1132.975,
        1129.672, 1126.369, 1119.762, 1109.853, 1096.64, 1063.609, 1017.365,
        971.121, 914.968, 868.724, 865.421, 878.634, 858.815, 670.536, 578.048,
        445.923, 336.92, 224.613, 105.7, 0
    ]
)


# Create new time values from the first to the last time, based on the defined
interval
new_time = np.arange(thrustC_time[0], thrustC_time[-1], dt)
burnout_ind = len(new_time)

# Interpolate the values at the new time points
interpolated_thrust = np.interp(new_time, thrustC_time, thrustC)

# Initialize variables
t = 0  # Time (seconds)
v = 0  # Initial velocity (m/s)
y = 0  # Initial altitude (m)
a = 0  # Initial acceleration (m/s^2)
m = m0  # Initial mass (kg)
rail_angle_rad = RAIL_ANGLE * (2 * np.pi) / 180

## AIR DENSITY INFORMATION
L = 0.0065  # Temp lapse rate K/m
M = 0.029  # Molar mass of air (kg/mol)
R = 8.314  # Universal gas constant (J/(mol*K))
alpha = -0.01  # Constant that accounts for the rate by which Cd varies with
velocity

time = [t]
altitude = [y]
velocity = [v]
acceleration = [a]
ind = 0  # Thrust index (iff thrust_method = 2)


def run_simulation(total_time, dt, burn_time, thrust_method, m0, mb,
    mass_flow_rate, F_T0, T0, WIND_SPEED, RAIL_ANGLE, Cd0):
    # Initialize variables
    t = 0  # Time (seconds)
```

```
v = 0  # Initial velocity (m/s)
y = 0  # Initial altitude (m)
a = 0  # Initial acceleration (m/s^2)
m = m0  # Initial mass (kg)
rail_angle_rad = RAIL_ANGLE * (2 * np.pi) / 180

## AIR DENSITY INFORMATION
L = 0.0065  # Temp lapse rate K/m
M = 0.029  # Molar mass of air (kg/mol)
R = 8.314  # Universal gas constant (J/(mol*K))
alpha = (
    -0.01
)  # Constant that accounts for the rate by which Cd varies with velocity

time = [t]
altitude = [y]
velocity = [v]
acceleration = [a]
ind = 0  # Thrust index (iff thrust_method = 2)

# Numerical integration (Euler's method)
while t < total_time:
    # Calculate forces
    if t < burn_time:
        if thrust_method == 1:
            F_T = F_T0 * (1 - t / burn_time)  # Thrust decreases over time
        elif thrust_method == 2:
            if ind < len(interpolated_thrust):  # Ensure ind is within bounds
                F_T = interpolated_thrust[ind]
                ind += 1
                m -= mass_flow_rate * dt
            else:
                F_T = 0  # No thrust after the thrust curve ends
                m = mb
    else:
        F_T = 0  # No thrust after burn out

    ## PHYSICAL QUANTITIES THAT CHANGE WITH ALTITUDE
    T = T0 - (L * y)  # Temperature
    g = g0 * (1 - (2 * y / 6.371e6))  # Gravity
    rho = rho0 * pow(
        (1 - (L * y) / T), ((g * M) / (R * L))
    )  # Calculate air density
```

```
        vsafe = max(v, 1e-3)  # log safe velocity value
        Cd = Cd0 * (1 + alpha * np.log(vsafe))

        # Force calculations
        F_g = m * g  # Gravitational force
        F_D = 0.5 * Cd * rho * A * v**2  # Drag force
        F_net = F_T - F_g - F_D  # Net force

        # Calculate acceleration, velocity, and position
        a = F_net / m
        v += a * dt
        y += v * dt

        # Store values
        t += dt
        time.append(t)
        altitude.append(y)
        velocity.append(v)
        acceleration.append(a)

    return time, altitude, velocity, acceleration


# Button callback functions
def export_full(event):
    data_to_export = {
        "Time [s]": time,
        "Altitude [m]": altitude,
        "Velocity [m/s]": velocity,
        "Acceleration [m/s^2]": acceleration,
    }
    df = pd.DataFrame(data_to_export)
    filename = f"FULL_{np.round(Cd0, 3)}.csv"
    folder_path = "C:/Users/Daniel Hogsed/OneDrive - Cedarville University/NASA
Rocket/2024-2025 NASA Student Launch/Rocket Design/Simulations/ChariotSim/output"
    file_path = f"{folder_path}\\{filename}"
    df.to_csv(file_path, index=False)
    print(f"Exported full dataset as {filename}")


def export_coast(event):
    print(str(int(np.round(apogee_index, 3) / dt)))
    apogee_loc = int(np.round(apogee_index, 3) / dt)
    data_to_export = {
```

```
        "Time [s]": time[burnout_ind:apogee_loc],
        "Altitude [m]": altitude[burnout_ind:apogee_loc],
        "Velocity [m/s]": velocity[burnout_ind:apogee_loc],
        "Acceleration [m/s^2]": acceleration[burnout_ind:apogee_loc],
    }
    df = pd.DataFrame(data_to_export)
    filename = f"COAST_{np.round(Cd0, 3)}.csv"
    folder_path = "C:/Users/Daniel Hogsed/OneDrive - Cedarville University/NASA
Rocket/2024-2025 NASA Student Launch/Rocket Design/Simulations/ChariotSim/output"
    file_path = f"{folder_path}\\{filename}"
    df.to_csv(file_path, index=False)
    print(f"Exported coast dataset as {filename}")


def cd_submit(text):
    time, altitude, velocity, acceleration = run_simulation(
        total_time,
        dt,
        burn_time,
        thrust_method,
        m0,
        mb,
        mass_flow_rate,
        F_T0,
        T0,
        WIND_SPEED,
        RAIL_ANGLE,
        float(text),
    )


time, altitude, velocity, acceleration = run_simulation(
    total_time,
    dt,
    burn_time,
    thrust_method,
    m0,
    mb,
    mass_flow_rate,
    F_T0,
    T0,
    WIND_SPEED,
    RAIL_ANGLE,
    Cd0,
```

```
)

# Data Summary
npalt = np.array(altitude)
max_vel_index = time[np.argmax(velocity)]
max_vel = np.max(velocity)
ind_off_rail = np.argmax(npalt > 3.6576)
vel_off_rail = velocity[ind_off_rail]
max_acc_index = time[np.argmax(acceleration)]
max_acc = np.max(acceleration)
apogee_index = time[np.argmax(altitude)]
apogee_value = np.max(altitude)


# for i in range(11):
# time, altitude, velocity, acceleration = run_simulation(total_time, dt,
burn_time, thrust_method, m0, mb, mass_flow_rate, F_T0, T0, WIND_SPEED,
RAIL_ANGLE, Cd0)
# export_coast(True)
# Cd0 += 0.02

summary_data = [
    [np.round(apogee_value, 2), np.round(apogee_value * 3.2808, 2)],
    [np.round(vel_off_rail, 2), np.round(vel_off_rail * 3.2808, 2)],
    [np.round(max_vel, 2), np.round(max_vel * 3.2808, 2)],
    [np.round(max_acc, 2), np.round(max_acc * 3.2808, 2)],
    [np.round(apogee_index, 2), ""],
]
columns = ["Metric", "Imperial"]
rows = [
    "Apogee",
    "Velocity Off Rail",
    "Max Velocity",
    "Max Acceleration",
    "Time to Apogee",
]

plt.figure(figsize=(8, 4))
plt.subplot(1, 2, 1)
plt.subplots_adjust(wspace=0.99, hspace=0.6, left=0.25, top=0.99, bottom=0.01)
# plt.title("Simulation Summary", loc='left')
plt.table(
    cellText=summary_data,
    colLabels=columns,
```

```
    rowLabels=rows,
    loc="center",
    cellLoc="left",
)
plt.axis("tight")
plt.axis("off")

summary_data = [
    [T0],
    [WIND_SPEED],
    [np.round(WIND_SPEED * 3.2808)],
    [RAIL_ANGLE],
    [Cd0],
]
columns = ["Parameter"]
rows = [
    "Temperature [K]",
    "Wind Speed [m/s]",
    "Wind Speed [ft/s]",
    "Rail Angle [deg]",
    "Cd",
]
plt.subplot(1, 2, 2)
# plt.title("Simulation Conditions", loc='left')
plt.table(
    cellText=summary_data,
    colLabels=columns,
    rowLabels=rows,
    loc="center",
    cellLoc="left",
)
plt.axis("tight")
plt.axis("off")

exp_button_full = plt.axes(
    [0.012, 0.02, 0.35, 0.1]
)  # Position: [left, bottom, width, height]
button1 = Button(exp_button_full, "Export Full Performance to .csv")
button1.on_clicked(export_full)

exp_button_coast = plt.axes(
    [0.4, 0.02, 0.35, 0.1]
)  # Position: [left, bottom, width, height]
```

```
button2 = Button(exp_button_coast, "Export Coast Performance to .csv")
button2.on_clicked(export_coast)

# cd_ask = plt.axes([0.1, 0.15, 0.25, 0.04])  # Position: [left, bottom, width,
height]
# txtbox = TextBox(cd_ask, 'Enter Cd: ', initial=str(Cd0) )
# txtbox.on_submit(cd_submit)

if plot == True:
    # Plot the results
    apogee_index = time[np.argmax(altitude)]
    apogee_value = np.max(altitude)
    plt.figure(figsize=(12, 8), num="ChariotSim V1.1")
    plt.subplot(2, 2, 1)

    plt.plot(time, altitude, color="red")
    plt.scatter(
        apogee_index,
        apogee_value,
        color="red",
        label=f"Apogee ({np.round(apogee_value, 2)} m  @{np.round(apogee_index,
2)} s)",
    )
    plt.text(apogee_index, apogee_value, "  Apogee", fontsize=6, color="black")
    plt.title("Altitude vs Time")
    plt.xlabel("Time [s]")
    plt.ylabel("Altitude [m]")
    plt.grid(True)
    plt.legend()

    plt.subplot(2, 2, 2)
    plt.plot(new_time, interpolated_thrust)
    plt.fill_between(new_time, interpolated_thrust, color="skyblue", alpha=0.4)
    plt.title("ThrustCurve Data Interpolation")
    plt.xlabel("Time [s]")
    plt.ylabel("Thrust [N]")
    plt.grid(True)

    # Velocity Off Rail, Max Velocity
    npalt = np.array(altitude)
    max_vel_index = time[np.argmax(velocity)]
    max_vel = np.max(velocity)
    ind_off_rail = np.argmax(npalt > 3.6576)
```

```
    vel_off_rail = velocity[ind_off_rail]

    plt.subplot(2, 2, 3)
    plt.plot(time, velocity, color="green")
    plt.scatter(
        max_vel_index,
        max_vel,
        color="green",
        label=f"Max. vel. ({np.round(max_vel, 2)} m/s)",
    )
    plt.text(max_vel_index, max_vel, "  Max Velocity", fontsize=6, color="black")
    plt.title("Velocity vs Time")
    plt.xlabel("Time [s]")
    plt.ylabel("Velocity [m/s]")
    plt.grid(True)
    plt.legend()

    max_acc_index = time[np.argmax(acceleration)]
    max_acc = np.max(acceleration)
    plt.subplot(2, 2, 4)
    plt.subplots_adjust(wspace=0.3, hspace=0.6)
    plt.plot(time, acceleration, color="purple")
    plt.scatter(
        max_acc_index,
        max_acc,
        color="purple",
        label=f"Max. acc. ({np.round(max_acc, 2)} m/s^2)",
    )
    plt.text(max_acc_index, max_acc, "   Max Acceleration", fontsize=6,
color="black")
    plt.title("Acceleration vs Time")
    plt.xlabel("Time [s]")
    plt.ylabel("Acceleration [m/s^2]")
    plt.grid(True)
    plt.legend()
    plt.subplots_adjust(bottom=0.14, top=0.9)

plt.tight_layout()
plt.show()
```

A.4. MATLAB Code for State Transition Test & Data Filter Test

```
clc; clear;

fileName1 = "Accel2.xlsx"; %name file for accel
dataTable = readtable(fileName1); %import file
accelTime = dataTable.(2); % Change '2' to the column name for better readability
accelBlue = dataTable.(3);
accelOrange = dataTable.(4);
accelGreen = dataTable.(5);
fileName2 = "Pressure2.xlsx";
dataTable2 = readtable(fileName2); %import file
pressureTime = dataTable2.(1);
altitude = dataTable2.(2);
pressure = dataTable2.(3);
% time vectors for two datasets
time1 = accelTime; % Time for dataset 1
time2 = pressureTime; % Time for dataset 2
% data
data1 = accelBlue; % Replace with  dataset 1 values
data2 = altitude; % Replace with  dataset 2 values
data3 = accelOrange;
data4 = accelGreen;
% --- Step 1: Handle Duplicate Time Points ---
[time1, idx1] = unique(time1, 'stable'); % Remove duplicates, retain order
data1 = data1(idx1);
data3 = data3(idx1);
data4 = data4(idx1);
[time2, idx2] = unique(time2, 'stable');
data2 = data2(idx2);
% --- Step 2: Remove NaN or Invalid Data Points ---
valid_idx1 = ~isnan(time1) & ~isnan(data1) & ~isnan(data3) & ~isnan(data4);
time1 = time1(valid_idx1);
data1 = data1(valid_idx1);
data3 = data3(valid_idx1);
data4 = data4(valid_idx1);
valid_idx2 = ~isnan(time2) & ~isnan(data2);
time2 = time2(valid_idx2);
data2 = data2(valid_idx2);
% --- Step 3: Define a Common Time Step and Time Vector ---
% Use the overlapping range of both time vectors
start_time = max(min(time1), min(time2)); % Earliest common start time
end_time = min(max(time1), max(time2));   % Latest common end time
```

```
common_step = 0.01;                        % Define a step size
common_time = start_time:common_step:end_time; % Common time vector
% --- Step 4: Interpolate Datasets ---
aligned_data1 = interp1(time1, data1, common_time, 'linear', 'extrap');
aligned_data2 = interp1(time2, data2, common_time, 'linear', 'extrap');
aligned_data3 = interp1(time1, data3, common_time, 'linear', 'extrap');
aligned_data4 = interp1(time1, data4, common_time, 'linear', 'extrap');
% --- Step 5: Plot and Verify Results ---
figure;
subplot(2,1,1);
hold on;
plot(common_time, aligned_data1, '-r', 'LineWidth', 1.5, 'DisplayName', 'Aligned
Dataset 1');
plot(common_time, aligned_data3, '-g', 'LineWidth', 1.5, 'DisplayName', 'Aligned
Dataset 3');
plot(common_time, aligned_data4, '-k', 'LineWidth', 1.5, 'DisplayName', 'Aligned
Dataset 4');
xlabel('Time (s)');
ylabel('Data');
legend('show');
title('Synchronized Datasets');
grid on;
hold off;
subplot(2,1,2);
plot(common_time, aligned_data2, '-b', 'LineWidth', 1.5, 'DisplayName', 'Aligned
Dataset 2');
xlabel('Time (s)');
ylabel('Data');
legend('show');
title('Synchronized Datasets');
grid on;
% --- Step 6: Output Aligned Data (Optional) ---
aligned_data = table(common_time', aligned_data1', aligned_data2',
aligned_data3', aligned_data4', ...
    'VariableNames', {'Time', 'AccelBlue', 'Altitude', 'AccelOrange',
'AccelGreen'});
disp(aligned_data); % Display aligned data in a table format
% Save to Excel file
writetable(aligned_data, 'aligned_data.xlsx');
disp('Data saved to aligned_data.xlsx');
```

A.5. State Machine Output for Control Algorithm Shakedown Demonstration

Table TV-P.21.1. *State machine output compared to the expected controller value with %error for accuracy.*

curr_press	prev_press	ground_pressure	out	expect	%Error
95096	95296.5	98180	0	0	0
94895.6	95096	98180	52.2772	52.2769	0.000574
94697.6	94895.6	98180	55	55	0
94502.2	94697.6	98180	55	55	0
94309.5	94502.2	98180	52.0531	52.0529	0.000384
94119.5	94309.5	98180	45.4242	45.4242	0
93932.3	94119.5	98180	36.6536	36.6536	0
93748.1	93932.3	98180	26.0513	26.0512	0.000384
93566.9	93748.1	98180	11.0306	11.0303	0.00272
93388.9	93566.9	98180	0	0	0
93213.8	93388.9	98180	0	0	0
93041.4	93213.8	98180	0	0	0
92871.5	93041.4	98180	0	0	0
92704	92871.5	98180	0	0	0
92538.7	92704	98180	0	0	0
92375.5	92538.7	98180	0	0	0
92214.3	92375.5	98180	0	0	0
92055.2	92214.3	98180	0	0	0
91898	92055.2	98180	0	0	0
91742.8	91898	98180	0	0	0
91589.5	91742.8	98180	0	0	0
91438.1	91589.5	98180	0	0	0
91288.6	91438.1	98180	0	0	0
91141	91288.6	98180	4.1232	4.12238	0.019891
90995.2	91141	98180	16.2071	16.2074	0.001851
90851.3	90995.2	98180	24.2907	24.2903	0.001647
90709.3	90851.3	98180	30.5876	30.5873	0.000981
90569.2	90709.3	98180	35.1479	35.1478	0.000285
90431.2	90569.2	98180	37.3195	37.3193	0.000536
90295.3	90431.2	98180	36.3654	36.3655	0.000275
90161.5	90295.3	98180	32.1111	32.1111	0
90029.8	90161.5	98180	24.7388	24.7388	0
89900.4	90029.8	98180	13.1903	13.19	0.002274
89773.2	89900.4	98180	2.91644	2.91567	0.026409
89647.9	89773.2	98180	0	0	0

89524.5	89647.9	98180	0	0	0
89402.9	89524.5	98180	9.41603	9.41545	0.00616
89283	89402.9	98180	20.1244	20.1243	0.000497
89164.8	89283	98180	31.4198	31.4196	0.000637
89048.3	89164.8	98180	41.8894	41.8895	0.000239
88933.5	89048.3	98180	52.3444	52.344	0.000764
88820.5	88933.5	98180	55	55	0
88709.4	88820.5	98180	55	55	0
88600.1	88709.4	98180	55	55	0
88492.7	88600.1	98180	49.3267	49.3268	0.000203
88387.2	88492.7	98180	37.9388	37.9391	0.000791
88283.7	88387.2	98180	25.9207	25.9203	0.001543
88182	88283.7	98180	14.7851	14.7852	0.000676
88082.1	88182	98180	4.98022	4.97864	0.031736
87984	88082.1	98180	0	0	0
87887.6	87984	98180	0.821044	0.820066	0.119259
87792.7	87887.6	98180	10.128	10.1285	0.004937
87699.4	87792.7	98180	21.4772	21.4765	0.003259
87607.6	87699.4	98180	36.2419	36.2413	0.001656
87517.3	87607.6	98180	53.0784	53.0786	0.000377
87428.5	87517.3	98180	55	55	0
87341.2	87428.5	98180	55	55	0
87255.5	87341.2	98180	55	55	0
87171.4	87255.5	98180	55	55	0
87088.9	87171.4	98180	55	55	0
87008	87088.9	98180	55	55	0
86928.7	87008	98180	55	55	0
86850.9	86928.7	98180	46.6371	46.6358	0.002788
86774.8	86850.9	98180	32.2156	32.2148	0.002483
86700.3	86774.8	98180	22.3781	22.3789	0.003575
86627.2	86700.3	98180	14.6047	14.6031	0.010957
86555.6	86627.2	98180	9.06099	9.06028	0.007836
86485.5	86555.6	98180	7.65679	7.65616	0.008229
86416.7	86485.5	98180	11.6728	11.672	0.006854
86349.3	86416.7	98180	19.7868	19.7868	0
86283.3	86349.3	98180	31.2102	31.209	0.003845
86218.5	86283.3	98180	51.2566	51.2517	0.009561
86155	86218.5	98180	55	55	0
86092.8	86155	98180	55	55	0
86032	86092.8	98180	55	55	0

85972.4	86032	98180	55	55	0
85914.2	85972.4	98180	55	55	0
85857.3	85914.2	98180	55	55	0
85801.7	85857.3	98180	55	55	0
85747.4	85801.7	98180	55	55	0
85694.5	85747.4	98180	55	55	0
85642.8	85694.5	98180	45.6748	45.6736	0.002627
85592.4	85642.8	98180	32.2153	32.2152	0.00031
85543.2	85592.4	98180	22.1547	22.1542	0.002257
85495.3	85543.2	98180	12.9289	12.9282	0.005415
85448.6	85495.3	98180	3.1246	3.12692	0.074194
85403.1	85448.6	98180	0	0	0
85358.7	85403.1	98180	0	0	0
85315.6	85358.7	98180	0	0	0
85273.6	85315.6	98180	6.85932	6.86144	0.030897
85232.7	85273.6	98180	19.0659	19.0594	0.034104
85192.9	85232.7	98180	33.6352	33.6299	0.01576
85154.2	85192.9	98180	55	55	0
85116.7	85154.2	98180	55	55	0
85080.2	85116.7	98180	55	55	0
85044.9	85080.2	98180	55	55	0
85010.6	85044.9	98180	55	55	0
84977.5	85010.6	98180	55	55	0
84945.5	84977.5	98180	55	55	0
84914.6	84945.5	98180	55	55	0
84884.8	84914.6	98180	55	55	0
84856	84884.8	98180	55	55	0
84828.4	84856	98180	55	55	0
84801.9	84828.4	98180	55	55	0
84776.4	84801.9	98180	35.939	35.9168	0.06181
84752	84776.4	98180	11.8715	11.8448	0.225415
84728.7	84752	98180	0	0	0
84706.5	84728.7	98180	0	0	0
84685.3	84706.5	98180	0	0	0
84665.1	84685.3	98180	0	0	0
84646	84665.1	98180	0	0	0
84628	84646	98180	0	0	0
84610.9	84628	98180	0	0	0
84594.9	84610.9	98180	0	0	0
84580	84594.9	98180	0	0	0

84566	84580	98180	0	0	0
84553.1	84566	98180	0	0	0
84541.2	84553.1	98180	0	0	0
84530.3	84541.2	98180	0	0	0
84520.4	84530.3	98180	0	0	0
84511.6	84520.4	98180	0	0	0
84503.8	84511.6	98180	0	0	0
84496.9	84503.8	98180	0	0	0
84491.1	84496.9	98180	0	0	0
84486.3	84491.1	98180	0	0	0
84482.5	84486.3	98180	0	0	0
84479.8	84482.5	98180	0	0	0
84478	84479.8	98180	0	0	0
84477.3	84478	98180	0	0	0
84477.3	84477.3	98180	0	0	0