University of Massachusetts Lowell

Project: Peregrine Explorer

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NASA USLI Critical Design Review

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Acronyms

AGL = Above Ground Level

ACS = Altitude Control System

APCP = Ammonium Perchlorate Composite Propellant

ARCS = Avionics & Recovery Control System

CDR = Critical Design Review

CFR = Code of Federal Regulations

CG = Center of Gravity

CMASS = Central Massachusetts Spacemodeling Society

COTS = Commercial Off the Shelf

CP = Center of Pressure

DDIR = Dual Dissimilar Independent Redundancy

DOT = Department of Transportation

FAA = Federal Aviation Administration

FFF = Fused Filament Fabrication

FMEA = Failure Modes and Analysis

FN = Foreign National

FOV = Field of View

FRR = Flight Readiness Review

GPS = Global Positioning System

HPR = High Power Rocket

LCO = Launch Control Officer

LMS = Lawrence Lin Makerspace

LRR = Launch Readiness Review

MSDS = Material Safety Data Sheet

MSFC = Marshall Space Flight Center

MSL = Mean Sea Level

NAR = National Association of Rocketry

NFPA = National Fire Prevention Agency

PCB = Printed Circuit Board

PDF = Portable Document Format

PDR = Preliminary Design Review

PERR-C = Passive Electronic Recovery Reporter Capsule

PEP = Payload Electronics Package

PLAR = Post Launch Assessment Review

PPE = Personal Protective Equipment

PTT = Push To Talk

RF = Radio Frequency

RFP = Request for Proposal

RSO = Range Safety Officer

SL = Student Launch

SLA = Stereolithography

SME = Subject Matter Expert

SOW = Statement of Work

STEM = Science Technology Engineering & Math

TRA = Tripoli Rocket Association

TTS = Text to Speech

UML = University of Massachusetts Lowell

UMLRC = University of Massachusetts Lowell Rocketry Club

USLI = University Student Launch Initiative

VDF = Vehicle Demonstration Flight

1 Summary

University of Massachusetts Lowell Rocketry
Mailing Address: 220 Pawtucket Street, Suite #220. Lowell, MA. 01854 ATTN: UML Rocketry Club

Mentor: Howard Greenblatt, NAR#: 84058 Level 2 Certification
Email: h.greenblatt@comcast.net Phone: 617-797-1426

Final Launch Date: May 4th. Huntsville, Alabama.
Hours Spent on CDR: 1500

Social Media Site	Handle
Instagram	@RiverhawkRocketry
Twitter / X	@rhrocketry
YouTube	@UMLRocketry
Website	Umlrocketry.org

1.1 "Peregrine Explorer" Vehicle Summary

Target Altitude	5000 ft AGL
Motor Selection	Cesaroni Pro54-5G K780 Blue Streak Aerotech RMS 54/2560 K1275 Redline (Backup)
Outer Diameter	4.02 in (10.2 cm)
Independent Sections and masses	3 (PERR-C 2.01 lbs, Upper Section 5.44 lbs, Lower Section 8.74 lbs)
Predicted Launch Mass	Primary: 16.7lbs (7556g). Backup: 17.4lbs (7890g).
Total Length	83.625in (212.41 cm)
CG / CP Location from Nose Cone	Primary: 51.03 / 60.246 in Backup: 51.51 / 60.246 in
Recovery System Style and Computers	Dual-Sep, Dual-Deploy. Telemetrum and Blue Raven
Parachute Sizing	Main: 72 in. Drogue: 18 in.

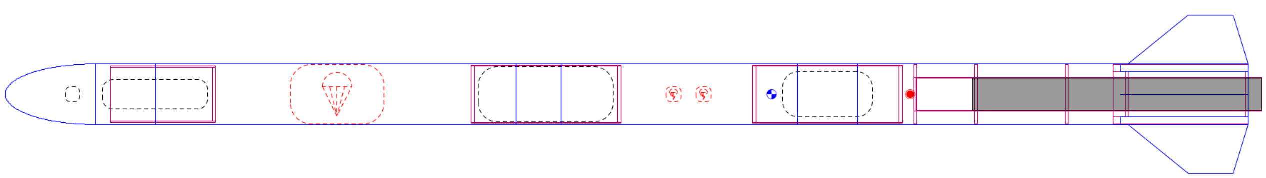


Figure 1.1.1: Open Rocket Diagram of Peregrine Explorer at the PDR Milestone

1.2 Payload Summary

UMLRC's 2024-2025 Payload experiment is divided into two systems, the Passive Electronic Recovery Reporting – Capsule (PERR-C) and the Altitude Control System (ACS). The nosecone of the vehicle will serve as the capsule's primary structural element. The system comprises of a custom sensor package and computer system PERR-C, fitted within the nosecone below the STEMNauts flight deck. Upon landing, the PERR-C system will transmit the data gathered by the custom sensor package via 2-M Radio back to NASA at the flight line. The ACS will assist the vehicle in hitting our target altitude.

2 Changes made since Preliminary Design Review

2.1 Vehicle Design Modifications

We have made refinements to the Motor and Fin Assembly to make manufacturing the system easier. The recovery system remains largely unchanged from the proposal.

2.2 Payload Design Modifications

2.2.1 Primary Payload

The changes to PERR-C include adding a 2nd radio on the 900mhz band to facilitate communication to the primary payload to send commands to stop transmissions.

2.2.2 Secondary Payload

The changes to ACS include design modifications to improve payload function and the removal of the 900mhz radio transceiver that was moved to PERR-C.

2.3 Project Plan Modifications

2.3.1 Project Timeline

Since the proposal, minimal changes have been made to the project timeline. Work on the CDR was moved to start earlier than planned. Final vehicle design was shortened to ensure vehicle construction was completed by the end of December and testing was completed in early January. This was done to ensure that there would be sufficient opportunities to perform a test flight before March.

3 Vehicle Criteria Design and Verification of Launch Vehicle

3.1 Mission Statement and Success Criteria

3.1.1 Mission Statement

The goal of the "Peregrine Explorer" project is to design, construct, and launch a reusable high-power rocket capable of achieving a target altitude of 5000 feet above ground level (AGL). The vehicle will employ a dual-separation, dual-deployment recovery system with precision tracking and telemetry provided by Telemetrum and Blue Raven systems. This project aims to provide team members with practical experience in advanced rocketry, recovery system design, and flight data analysis, fostering a deeper understanding of aerospace engineering principles.

3.1.2 Success Criteria

The vehicle maintains aerodynamic stability throughout the flight.
The vehicle achieves the target altitude of 5000 feet AGL within a ±5% margin.
The recovery systems (drogue and main parachutes) deploy safely and at the correct altitudes.
The vehicle lands with kinetic energy below the maximum allowable threshold to ensure safe recovery.
The vehicle remains structurally intact and reusable without requiring major repairs or alterations after flight.
The CG and CP locations remain within stable margins throughout the flight to ensure stability.
The onboard telemetry systems (Telemetrum and Blue Raven) successfully record and transmit flight data, including altitude, velocity, and system status.
All team members adhere to established engineering standards, safety protocols, and quality control practices during the design, construction, and launch phases.
The rocket utilizes either the Cesaroni Pro54-5G K780 motor or the Aerotech RMS 54/2560 K1275 motor, ensuring successful propulsion and meeting launch requirements.
The team demonstrates readiness through pre-launch testing, including mass verification, CG/CP balance checks, and recovery system testing.

3.2 Vehicle Design

3.2.1 Chosen Design

The Peregrine Explorer is designed to be a high-performance rocket that can reach a target altitude of 5500 feet. It uses the Cesaroni Pro54-5G K780 Blue Streak motor as its main motor, with the Aerotech RMS 54/2560 K1275 Redline as a backup. The rocket is 4.02 inches in diameter and 81.5 inches long, giving it a sleek shape to reduce air resistance and make assembly easier.

The rocket has two main systems: the Passive Electronic Recovery Reporting – Capsule (PERR-C) and the Altitude Control System (ACS). The PERR-C is inside the nosecone and has sensors that send important flight data back to the ground after landing. The ACS uses airbrakes to help control the rocket's altitude, ensuring it reaches the target height. The rocket also includes an avionics system, which has two computers (Telemetrum V4 and Blue Raven) for tracking the flight and making sure the rocket lands safely. These computers are mounted on a triangular sled inside the ARCS (Avionics and Recovery Control System) module, which keeps them secure and easy to adjust.

The fins can be attached in two ways: using a keyway and locking cap or a bolt-through design. Both methods ensure the fins stay secure during flight. The fins have an airfoil shape, which helps the rocket fly higher and more smoothly. The motor mount and other internal parts are reinforced with epoxy for strength.

The nosecone, made of PLA and PETG, is strong enough to hold the sensors in the PERR-C but can also be easily accessed for maintenance. After the motor burns out, the ACS adjusts the airbrakes to keep the rocket at the correct altitude. All these features work together to make the Peregrine Explorer a reliable and efficient rocket that meets the goals set by NASA for this project.

3.2.2 Justification for Chosen Design

The Peregrine Explorer was designed to balance good performance, reliability, and flexibility. The 4.02-inch diameter and 83.5-inch length make the rocket aerodynamic, which reduces drag and helps it reach the target altitude. The Cesaroni Pro54-5G K780 Blue Streak motor was chosen because it provides the power needed to reach 5500 feet, and the Aerotech RMS 54/2560 K1275 Redline serves as a backup to make sure the mission can still succeed if something goes wrong with the main motor.

The PERR-C and ACS systems were included to meet important mission goals. The PERR-C sends flight data back to the ground after landing, which is a key part of NASA's requirements. The ACS helps control the rocket's altitude during flight, making sure it stays as close as possible to the target. To make the rocket more reliable, the avionics system has two separate computers, so even if one fails, the other can still track the flight and handle recovery.

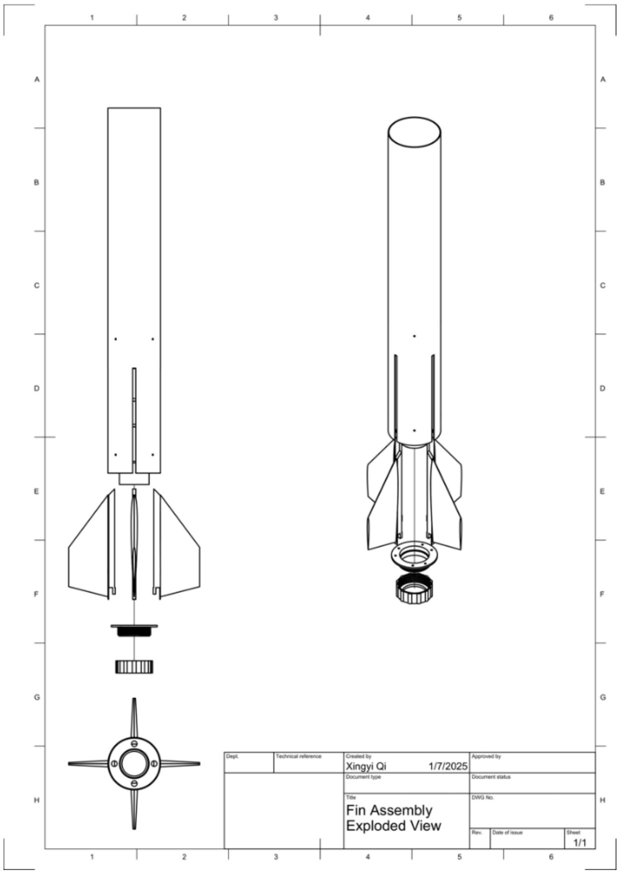
The fins were designed to be both strong and easy to work with. The airfoil shape was picked because it helps the rocket fly more efficiently. The option to attach the fins using either a keyway or bolt-through method gives flexibility during assembly and ensures the fins stay firmly in place.

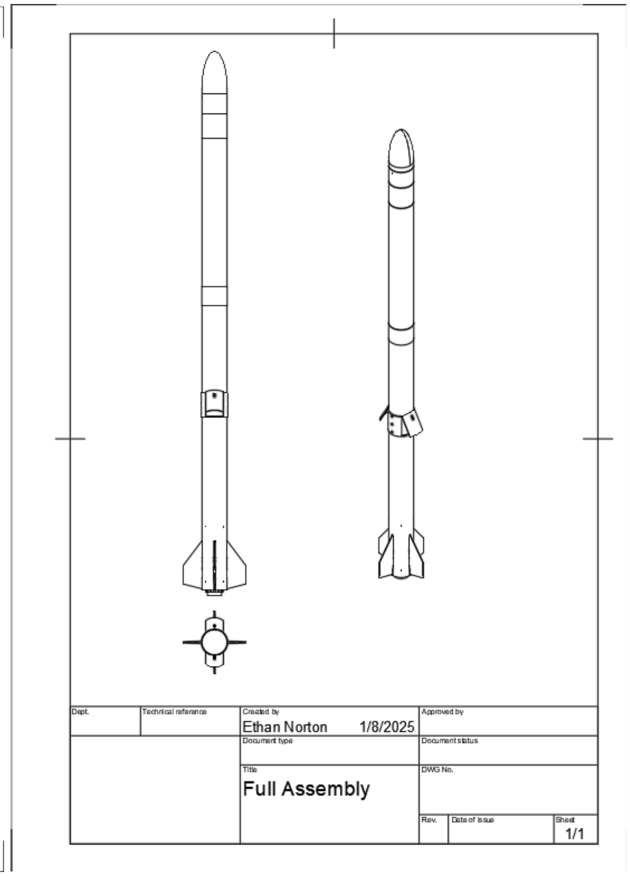
The nosecone materials, PLA and PETG, were chosen because they are both durable and easy to work with. The ACS airbrakes are essential for keeping the rocket at the correct height after the motor burns out, ensuring precise altitude control.

Lastly, the ARCS module was designed to keep all the avionics systems safe and functional. Features like the triangular sled, arming pins, and USB-C connectors make it simple to access and adjust the system as needed. These design choices make the Peregrine Explorer a great choice for achieving the mission goals while being reliable and student-friendly to build and operate.

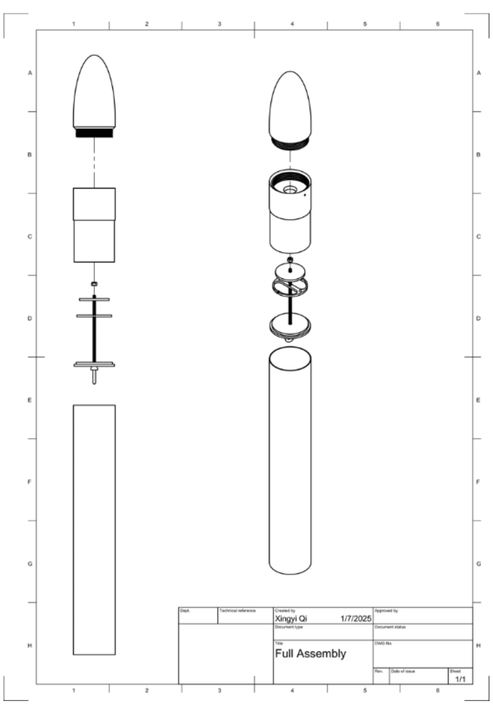
3.3 Computer Aided Design Drawings

3.3.1 Drawings





The four aerofoil profile fins are secured to the booster assembly through a keyed design in the retaining hub around the motor tube. This is then capped off with a threaded cap that hooks onto the rear of each fin keeping them bundled together and right against the motor tube. A small airgap does exist between the motor tube and the 3D printed retaining hub to prevent thermal deformation of the retainer.



3.3.2 Manufacturing Readiness

The designs for the "Peregrine Explorer" high-power rocket are finalized and ready for manufacturing, supported by a detailed bill of materials (BOM) and a clear production plan. The BOM includes all the components, with part numbers, quantities, materials, and sources like McMasterCarr, Wildman, Amazon, Adafruit, and Polymaker, along with associated costs and taxes. Parts like the nosecone are made using PLA and PETG at our campus makerspace, while structural components like the fiberglass body tubes and couplers were purchased from Wildman. We also sourced electronic components such as GPS chips, gyroscopes, and transceivers from Adafruit to ensure the rocket's systems are reliable and functional. The recovery system uses strong materials like stainless steel threaded studs and zinc-plated steel nuts to handle the high stresses during flight and landing.

To keep costs low and ensure everything can be manufactured efficiently, we've been using resources from our makerspace. We also will fabricate the fins in-house using polycarbonate to maintain accuracy and consistency.

We've already purchased stock materials from suppliers like McMaster Carr, and the team has set up a timeline to prioritize manufacturing of the more complex components, like the motor retainer and thrust plate flange. These parts require careful machining setups to ensure everything fits together properly. Overall, with the parts sourced, materials selected, and machining processes planned, we're confident that the designs are complete and ready to be manufactured.

3.4 Subscale Demonstration Flight

3.4.1 Design Criteria

The subscale vehicle was designed and built to maintain a ¾ scale factor on all flight-interfacing components. This means things critical to the full-scale structure, such as in-flight and non-in-flight coupler shoulder sizes, vehicle height, nosecone shape, fin geometry, and vehicle COM and COP were maintained. However, non-crucial internals of the vehicle, such as recovery electronics configurations, motor mounting hardware, airframe material, and payload electronics, were not scaled or designed to match the full scale. Items such as thickness were not scaled due to the minimum thickness of material needed to complete a safe flight. Scaling the non-crucial internals does not affect the flight, as these elements do not impact the flight data that is collected by the on-board recovery computer, therefore not necessitating a consideration in the subscale flight.

3.4.2 Flight Results

Image 3.4.2.1: Peregrine Explorer accelerating off the rail

Image 3.4.2.2: Peregrine Explorer Landed in the Range

Image 3.4.2.3: Lower Section of Subscale with Camera Housing visible - Landed

Image 3.4.2.4: Upper Section of Subscale with drogue parachute - Landed

Image 3.4.2.5: Nose Cone (PERR-C) of Subscale with Main Parachute - Landed

Year	Month	Day	Time	Flight_Tim	Sync	Temperatu	Baro_Pres	Baro_Altitu	Baro_Altitude_AGL_(feet)	Batt_Volts	Apo_Volts	Main_Volts	3rd_Volts	4th_Volts	Velocity_Up	Velocity_DR	Velocity_CR
2024	10	19	22:55.4	-1.92	207	89.4	1.0132	-364.4	0	3.831	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.4	-1.9	227	89.4	1.0132	-364.4	0	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.4	-1.88	247	89.4	1.0131	-361.7	2.8	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.4	-1.86	17	89.4	1.0131	-361.7	2.8	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.5	-1.84	37	89.4	1.0132	-364.4	0	3.832	3.84	3.74	0.01	0.01	0	0	-1
2024	10	19	22:55.5	-1.82	57	89.4	1.0132	-364.4	0	3.833	3.85	3.74	0.01	0.01	0	0	-1
2024	10	19	22:55.5	-1.8	77	89.4	1.0133	-365.5	-1	3.832	3.84	3.74	0.01	0.01	0	0	-1
2024	10	19	22:55.5	-1.78	97	89.4	1.0133	-365.5	-1	3.832	3.85	3.74	0.01	0.01	0	0	-1
2024	10	19	22:55.5	-1.76	117	89.4	1.0132	-364.4	0	3.833	3.85	3.74	0.01	0.01	0	0	-2
2024	10	19	22:55.6	-1.74	137	89.4	1.0132	-364.4	0	3.832	3.85	3.74	0.01	0.01	0	0	-2
2024	10	19	22:55.6	-1.72	157	89.4	1.0132	-362.8	1.7	3.832	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:55.6	-1.7	177	89.4	1.0132	-363.3	1.1	3.831	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:55.6	-1.68	197	89.4	1.0132	-363.3	1.1	3.831	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:55.6	-1.66	217	89.4	1.0132	-362.8	1.7	3.83	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:55.7	-1.64	237	89.4	1.0134	-368.3	-3.8	3.831	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:55.7	-1.62	7	89.4	1.0134	-368.3	-3.8	3.831	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:55.7	-1.6	27	89.4	1.0133	-365.5	-1	3.831	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:55.7	-1.58	47	89.4	1.0133	-366.1	-1.6	3.831	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:55.7	-1.56	67	89.4	1.0133	-366.1	-1.6	3.832	3.84	3.74	0.01	0.01	0	0	-4
2024	10	19	22:55.8	-1.54	87	89.4	1.0133	-365.5	-1	3.831	3.84	3.74	0.01	0.01	0	0	-4
2024	10	19	22:55.8	-1.52	107	89.4	1.0132	-362.8	1.7	3.832	3.84	3.74	0.01	0.01	0	0	-4
2024	10	19	22:55.8	-1.5	127	89.4	1.0132	-362.8	1.7	3.831	3.84	3.73	0.01	0.01	0	0	-4
2024	10	19	22:55.8	-1.48	147	89.4	1.0133	-365.5	-1	3.832	3.84	3.74	0.01	0.01	0	0	-4
2024	10	19	22:55.8	-1.46	167	89.4	1.0133	-365.5	-1	3.832	3.84	3.74	0.01	0.01	0	0	-5
2024	10	19	22:55.9	-1.44	187	89.4	1.0132	-364.4	0	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.9	-1.42	207	89.4	1.0132	-364.4	0	3.831	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.9	-1.4	227	89.4	1.0133	-366.1	-1.6	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.9	-1.38	247	89.4	1.0133	-365.5	-1	3.832	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:55.9	-1.36	17	89.4	1.0132	-364.4	0	3.831	3.84	3.74	0.01	0.01	0	0	0
2024	10	19	22:56.0	-1.34	37	89.4	1.0132	-363.9	0.6	3.832	3.84	3.74	0.01	0.01	0	0	-1
2024	10	19	22:56.0	-1.32	57	89.4	1.0132	-363.9	0.6	3.831	3.84	3.74	0.01	0.01	0	0	-1
2024	10	19	22:56.0	-1.3	77	89.4	1.0132	-363.9	0.6	3.833	3.85	3.74	0.01	0.01	0	0	-1
2024	10	19	22:56.0	-1.28	97	89.4	1.0131	-361.1	3.3	3.833	3.85	3.74	0.01	0.01	0	0	-1
2024	10	19	22:56.0	-1.26	117	89.4	1.0131	-361.1	3.3	3.832	3.85	3.74	0.01	0.01	0	0	-1
2024	10	19	22:56.1	-1.24	137	89.4	1.0132	-363.9	0.6	3.832	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:56.1	-1.22	157	89.4	1.0132	-364.4	0	3.832	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:56.1	-1.2	177	89.4	1.0134	-368.3	-3.8	3.831	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:56.1	-1.18	197	89.4	1.0134	-368.8	-4.3	3.831	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:56.1	-1.16	217	89.4	1.0132	-363.3	1.1	3.832	3.84	3.74	0.01	0.01	0	0	-2
2024	10	19	22:56.2	-1.14	237	89.4	1.0132	-362.8	1.7	3.832	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:56.2	-1.12	7	89.4	1.0132	-363.9	0.6	3.832	3.84	3.74	0.01	0.01	0	0	-3
2024	10	19	22:56.2	-1.1	27	89.4	1.0132	-363.9	0.6	3.832	3.85	3.74	0.01	0.01	0	0	-3
2024	10	19	22:56.2	-1.08	47	89.4	1.0132	-362.8	1.7	3.832	3.85	3.74	0.01	0.01	0	0	-3

Image 3.4.2.1: Excel Data from Featherweight Altimeters Blue Raven Altimeter

This data was recorded through the Featherweight Altimeters Blue Raven Altimeter. Sadly, our data cable for our PerfectFlite StratoLogger CF was damaged and we were unable to attain a replacement before recovering the full data from the StratoLogger for this report. Despite this, we successfully retrieved the following key metrics from Blue Raven:

- Apogee: 897.1 ft or 273.4 m.
- Time to Apogee: 7.78 seconds.
- Descent Time: ~60 seconds.
- Descent Performance: Recovery system successfully deployed with a controlled descent.

The recorded flight profile is shown in Figure 3.4.2.1 which depicts the actual altitude over time. This data will be compared to simulation data in Figure 3.4.2.2.

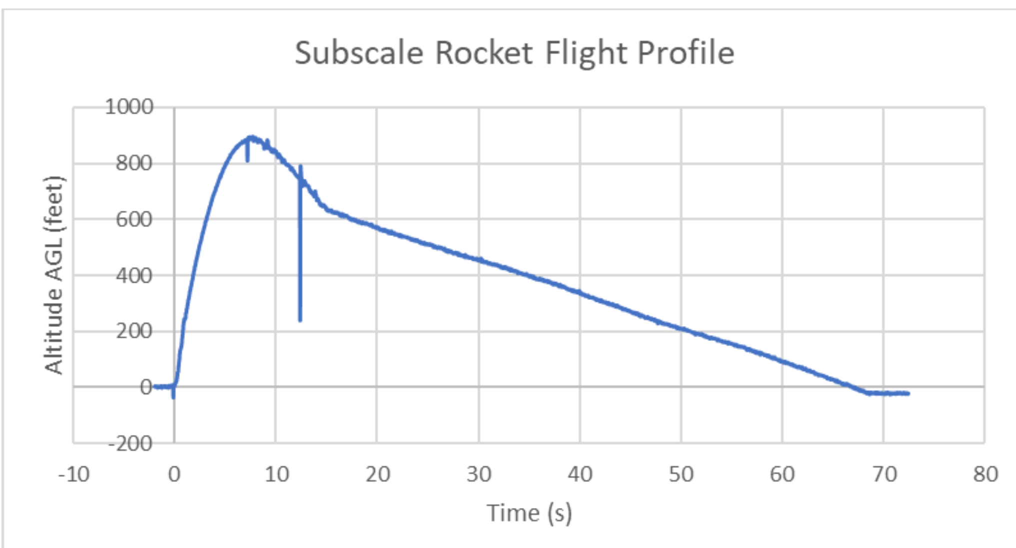


Figure 3.4.2.1: Time vs Altitude AGL from Blue Raven Altimeter

The subscale rocket was built to a 75% scale to the full-sized rocket. During this scaling process, the outer diameter and length of the rocket were held constant to ensure aerodynamic similarity and to maintain the overall shape. The center of gravity and center of pressure were also held constant to replicate the stability margin during ascent and recovery. The fin thickness of the rocket was not scaled and kept at 5 mm while the rocket components were adjusted to have a surface roughness of 150 microns in the simulation on open rocket as the vehicle had a rough, unsanded paint finish.

The subscale rocket was launched on October 19th, 2024, with the wind recorded at 9 mph coming from the 220-degree South-West direction. The ambient temperature at the time of launch was 65°F and the ambient pressure was 1.0132 atm. The launch rail was angled at 7 degrees with an azimuth direction of 160 degrees (South-South East).

An OpenRocket simulation with these conditions produced the following graph and metrics:

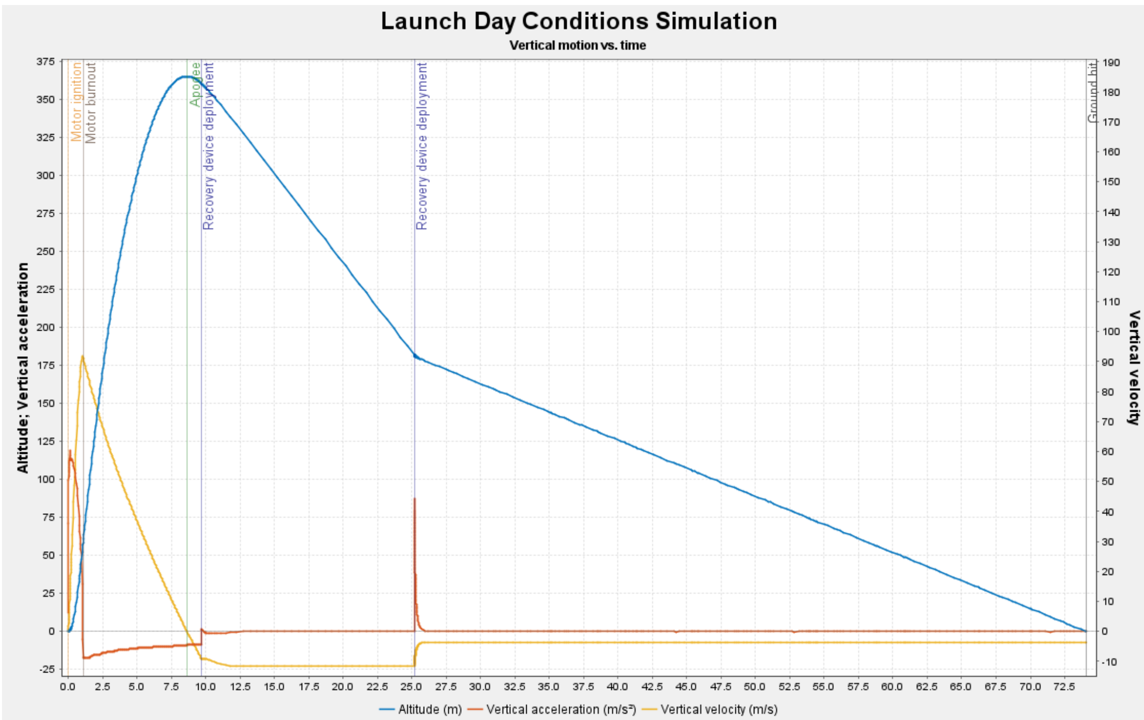


Figure 3.4.2.2: OpenRocket Simulation of Subscale Rocket using Launch Day Conditions

- Simulated Apogee: 1197.51 ft or 365 m
- Simulated Time to Apogee: 8.63 seconds
- Flight Time: 74 seconds
- Maximum Acceleration: 120 m/s^2

The simulated apogee was higher than the actual apogee, with a difference of 91.6 m. This discrepancy is likely due to the idealized assumptions made by the simulation, e.g. the drag coefficient, which was calculated to be 0.66 based on the subscale data, as opposed to the simulated value of 0.58 in OpenRocket. The actual rocket's roughness and high gusts of wind would introduce a pitch on the vehicle due to the high stability, and motor underperformance all contribute to the difference in simulation compared to the demonstration flight.

The coefficient of drag on the full-scale vehicle will likely be smaller, due to the full-scale rocket being larger in size, due to the 75% size reduction of the subscale, with the larger size allowing for flow stabilization across the body. However, the full-scale rocket will be moving at higher speeds, due to the more powerful motor. The drag coefficient was determined by using hand calculations, as well as verification through OpenRocket simulation overrides to take an iterative walk-back approach to computing an effective drag coefficient.

The subscale demonstration flight can be viewed here, this video contains all of the camera angles with the mission elapsed time in the corner.

3.4.3 Ejection Charge Testing and Decision to Forgo a Retest

The decision to push for flight on October 19th was made later than planned and was a reversal of a previous decision to focus on the PDR. This choice did pay off, as this was the last launch opportunity in the NE area for until Late December due to no rain falling for over a month, causing a long period of Red Flag Warnings. The vehicle was constructed over the course of 5 days leading up to launch, the vehicle was finished on Thursday 10/17 and was painted on 10/18.

Image 3.4.3.1: Frame from main parachute ejection ground test

Image 3.4.3.2: Subscale Vehicle After Apogee Ejection Charge

On Launch Day, the team planned to test the parachute ejection. Main parachute ejection went without issue; however, the Apogee (Drogue Parachute) charge was slightly undersized. The vehicle almost deployed, however it only cleared ~ 75% of the coupler shoulder. After a discussion between the Safety Officer, Team Lead, Avionics Lead, and Team mentor, the decision was made to use the backup apogee ejection charge as the primary and to quickly manufacture a new redundant apogee charge at the launch site.

	Apogee Primary	Apogee Redundant	Main Primary	Main Redundant
Initial ejection charge sizes	0.27g	0.35g	0.35g	0.45g
Ejection charges used on Demo	0.36g	0.41g	0.36g	0.45g

Table 3.4.3.1: Black Powder Ejection Charge sizing for testing and Subscale Demonstration Flight

	Apogee Primary	Apogee Redundant	Main Primary	Main Redundant
Initial ejection charge sizes	11 PSI	14 PSI	8 PSI	10 PSI
Ejection charges used on Demo	14 PSI	16.5 PSI	8 PSI	10 PSI

Table 3.4.3.2: Ejection charge calculated pressure on bulkhead for testing and Subscale Demonstration Flight

The choice to just size up the ejection charge for the Apogee charge has several reasons behind it. The first topic discussed between the leads and mentor was the fact that the vehicle could have been bent so that the coupler was binding on the airframe, which would not be as big of an issue in flight as the vehicle wouldn't be resting on a vehicle holder. It was also discussed that the original ejection charge could be sufficient and that the one in testing could have been improperly assembled, with the black power not being packed enough to create the proper reaction. In the end, the team decided to use the redundant charge as the primary, and increase the size of the redundant charge. The ultimate deciding factor was the adage from hobby rocketry of "Blow it out or Blow It up" which is the strategy of oversizing the ejection charges to ensure the vehicle will come down in a non-ballistic state. Ejection charges worked flawlessly during the flight, and both parachutes deployed from the primary charge.

3.4.4 Recovery Deployment Anomaly, Investigation, and Corrective Actions

During the flight, multiple comments were made by team members raising concerns over an early deployment of the main parachute. Team members were concerned that the bay opened early since it was not secured using shear pins or tape, but rather by friction alone. Initial inspection on the ground showed that all 4 ejection charges did deploy.
The team continued with launch efforts that day and 3 more members gained their certifications.

The data from the flight computer was not downloaded until the following Monday (10/21). However, the onboard camera's SD card was recovered that day (10/19), as we were eager to get our first on-board video and all initial observations pointed towards a successful flight.

3.4.4.1 Observations using Onboard Video

Using Davinci Resolve, video from the forward-facing on-board camera (UPCAM) was used to look at the parachute deployments to determine the nature of the main parachute deployment. The video was shot at 2704 x 1520 and 60 Frames per second. For analysis, the video was synced with first motion, which was a slight shift in a lens flare.

Image 3.4.4.1: Nose Cone separation at 12.58 s after lift-off

Image 3.4.4.2: Parachute Deployment at T+12.72s

Using the time scale from the video editor we saw that the nose cone separated at 12.58s, Followed by parachute deployment 0.14s later. Using the rough timeline from simulations for this motor, parachute deployment should have happened at T+21 seconds. It was here that other team members were notified that an anomaly has happened with parachute deployment and conversations between Safety Officer Josh Barosin, Team Lead Ethan Norton, and Lead Avionics Engineer Andrew Bonczek picked up. Initial guesses were that the friction fit of the nose cone failed and the nose cone deployed early not being commanded by on-board flight computers, a severe underperformance by the motor leading to a lower-than-expected altitude, or a malfunctioning or improperly programmed Flight Computer.

Image 3.4.4.3: Smoke from Ejection Charge seen venting from Main Parachute Bay at T+13.28s

Image 3.4.4.4: Second frame confirming smoke venting from Main Parachute Bay at T+14.40s

Further Analysis of the video shows smoke venting from the Main Parachute Bay shortly after parachute deployment and during the inflation of the main parachute. These frames confirmed that a flight computer had commanded the deployment and that the physical vehicle was not the issue. This still leaves a few different options for causation, the two leading ideas now are motor underperformance or improperly programmed flight computer.

A few seconds later smoke stops venting from the vehicle as confirmed in image 3.4.4.5. Some earlier frames had indicated that this may have happened sooner than T+29.05s but no decisive visuals could be gained until T+29.05s

Image 3.4.4.5: Confirmation of smoke no longer venting from Main Parachute Bay at T+29.05s

The second ejection charge, presumed to be the backup charge from the StratoLogger CF, can be heard at T+30.35s, followed by a puff of smoke 0.11s later. Strangely there is a period where no smoke is observed venting from the main parachute bay for approximately 2 seconds (Images 3.4.4.8 and 3.4.4.9).

Image 3.4.4.6: Screen Capture from Davini Resolve Showing Audio Spike at T+30.35s

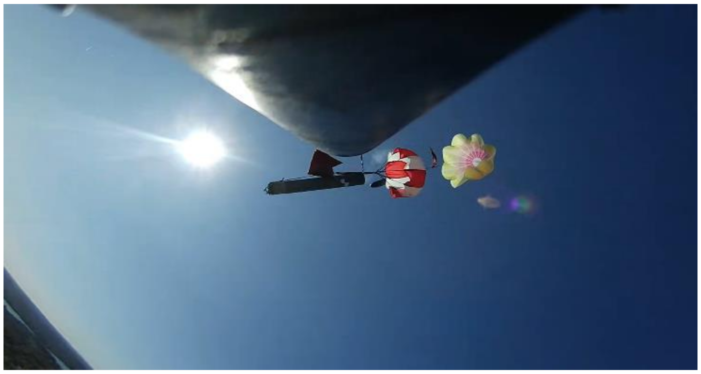


Image 3.4.4.7: Smoke Ejected from Ejection Charge at T+30.46s

Image 3.4.4.8: No venting from Main Parachute Bay at T+30.96s

We believe this is due to the initial pressure spike from the ejection charge, pushing out a puff of smoke followed by a period of low pressure due to rapid cooling after the hot gasses of ejection leave the system, trapping smoke inside the tube. This is then seen venting in image 3.4.4.8, most likely due to the venturi effect.

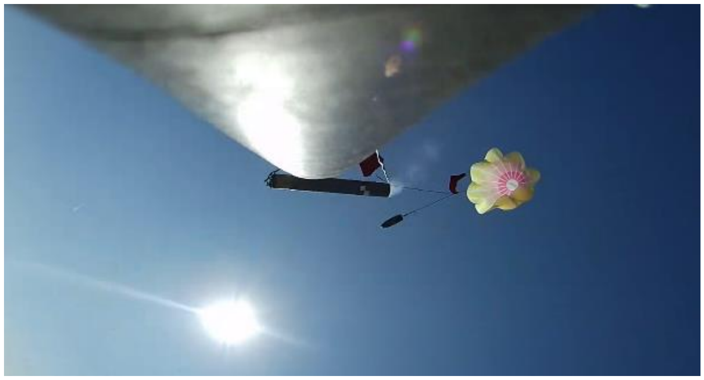


Image 3.4.4.9: Smoke Venting from Main Parachute Bay at T+32.88s

3.4.4.2 Blue Raven Data Analysis and Anomaly Determination

Once the data was recovered from the Blue Raven Altimeter using the Featherweight Altimeters App and Bluetooth connection, analysis was quickly done using the graphing function in the app, the graphs have been recreated in Excel for this report.

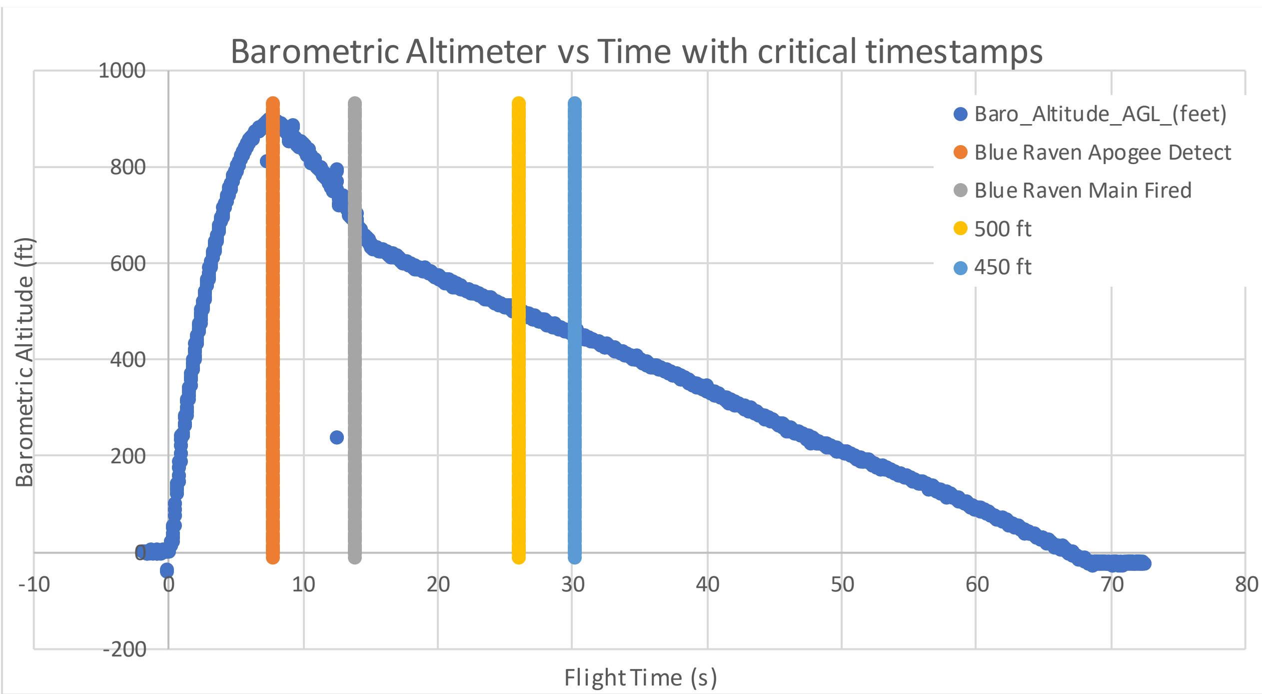


Figure 3.4.4.10: Altitude Data from Blue Raven with time markers of when relevant events happen

The Data from Blue Raven Clearly showed that the Main Parachute was commanded by Blue Raven at an altitude of 701 ft AGL and a flight time of 13.92s. This is confirmed by the onboard video, the time discrepancy is due because the video and Blue Raven used different T+0 times.

Other Flight events, like StratoLogger CF's Main Parachute ejection were also confirmed with Blue Raven Data and flight video. With Raven Barometric altitude passing through 450ft at ~30.2s and the Ejection Charge deploying at 30.35s on the onboard video. Without StratoLogger CF data we are unable to determine if that computer had deployed early or late, but it is within an acceptable range where no further inquiry is needed into that computer.

3.4.4.3 Anomaly Causation and Corrective Actions

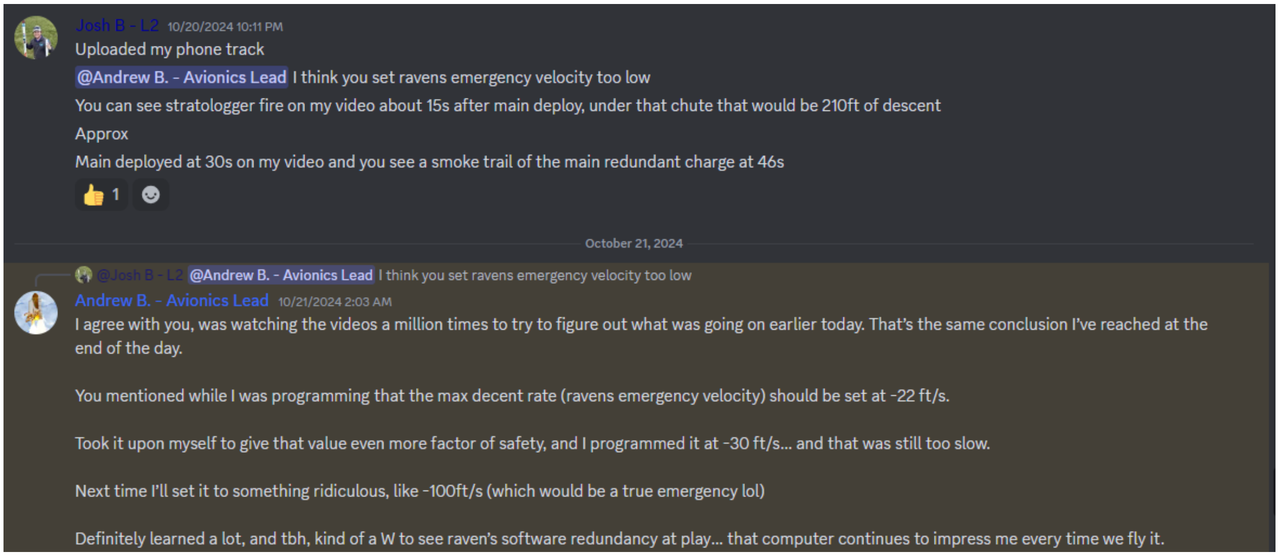


Image 3.4.4.11: Discord Chat log between Safety Officer Josh Barosin and Avionics Lead Andrew Bonczek Confirming Improper Programming

During Launch Day, Josh was also on the certification committees for members flying L1 Certifications. The Split in focus cause him to misunderstand Andrews question at the time and gave Andrew the expected drogue descent rate and didn't confer with Andrew about what a reasonable and safe emergency deployment velocity would be. Blue Raven features an emergency mode where if the vehicle exceeds a certain descent rate it will eject the main parachute as it assumes the drogue has failed. This velocity was set too low, and the vehicle exceeded the value set as the drogue descent velocity was higher than simulated. Thankfully the vehicle was on a low flight profile and the premature deployment didn't cause excessive drift or drift into a tree.

UMass Lowell has adopted a secondary flight card to those used at the field, which is used as a quick reference to prepare vehicles for launch. This flight card documents the motor used, expected altitude, velocity, and acceleration, the simulated stability, and gives the flyer a chance to outline the goals of the flight. For dual deployment it only documents the ejection charge size, which computer deployment line the charge is connected to, and what the deployment logic is. The flight card does not document additional data that might be useful for more advanced flight computers like Blue Raven. The UML Flight card for the subscale demonstration can be viewed in Appendix A. A revision to the current flight card or an additional sheet that will convey flight computer settings for computers like Blue Raven will be drafted for our team to use going forward.

3.5 Recovery System

3.5.1 Recovery System Mission Statement and Success Criteria

The Avionics and Recovery Control System (ARCS) is responsible for controlling all recovery events on the vehicle, providing a safe, controlled, and predictable decent profile for the vehicle. ARCS has two, redundant computers that operate separately to make logic and data-based parachute ejection decisions. The parachutes used on the vehicle are chosen to achieve safe decent conditions, balanced with decent rates that can score the team points.

3.5.1.1 Mission Statement

The Recovery System's mission is to successfully recover the vehicle after launch via an ejection of both the drogue parachute and the main parachute, while offering several physical and software redundancies to recover the vehicle if faced with possible failure modes.

3.5.1.2 Success Criteria

ARCS has criteria that determine if the system has performed successfully:

Criteria Number	Operation / Success Criteria
1	Primary Main Parachute Charge Detonated.
2	Redundant Main Parachute Charge Detonated.
3	Primary Drogue Parachute Charge Detonated.
4	Redundant Drogue Parachute Charge Detonated.
5	Main Parachute Opened and Achieves Controlled Descent.
6	Drogue Parachute Opened and Achieves Controlled Descent.
7	Main Parachute Deployed on time and at Programmed Altitude.
8	Drogue Parachute deployed at apogee by Primary Charge.
9	No Tangles in parachute lines inhibiting stable decent.

All success criteria must be met in order for the Recovery System (and therefore ARCS) to have a flight and recovery designated a "Complete Success".

3.5.2 Recovery System Final Design

Several ARCS designs and parachute configurations were explored to determine the safest and most capable recovery system. The final configuration, therefore, can be broken into a final ARCS design and a final Parachute Configuration, that together form the final, chosen design.

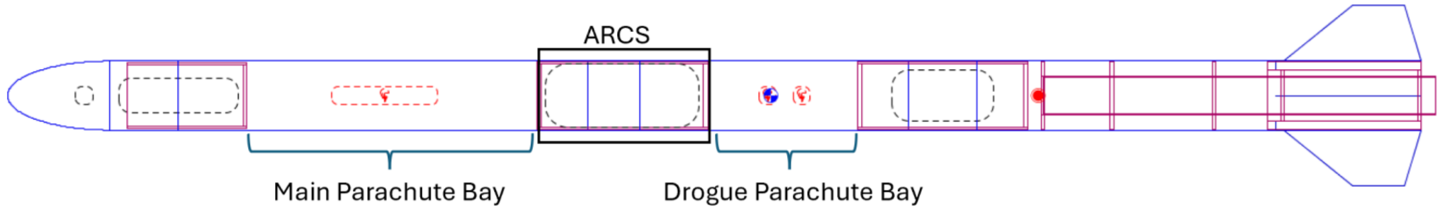


Figure 3.5.2A: ARCS and parachute locations, in full-scale vehicle, per the OpenRocket model.

The team used the rocketry software OpenRocket to conduct simulations of the full-scale vehicle's flight, recovery, and wind drift. In Figure 3.5.2A above, the main parachute and drogue parachutes can be seen in their respective bays. It is important to note, however, that the simulations were run with an additional parachute in the drogue bay that is simulated to mimic the drag the vehicle will experience from tumbling upon drogue and main parachute deployment. This secondary parachute is necessary, as OpenRocket does not account for the drag of a tumbling vehicle natively. As such, it is common to use an analog like an additional parachute in the simulations to account for this tumbling. To be clear, this additional parachute will not be present on the actual vehicle but will instead be replaced by the actual tumbling drag that the vehicle will experience during recovery. The vehicle will only utilize one main parachute and one drogue parachute when it is launched.

3.5.2.1 Final Avionics and Recovery Control System (ARCS) Design

The final ARCS design is 1450 grams, and utilizes a triangular configuration of three, rectangular laser-cut plywood sleds. Each sled houses a different system that is separate from the others. The first sled houses the primary flight computer and a strut to support its integrated antenna. The second sled houses the secondary flight computer and a "junction box" that allows for external access to arming hardware from the outside of the coupler tube. The third sled houses the service cameras and their respective computers.

The final design utilizes three separate batteries to power all on-board electronics:

Battery Number	Provides Power to:	Battery Type	Number of Cells	Capacity (mAh)
1	Primary Computer – Telemetrum V4	Lithium Polymer (LiPo)	1	450
2	Secondary / Redundant Computer – Blue Raven	Lithium Polymer (LiPo)	1	850
3	Service Cameras – Regulated to 5 volts	Lithium Polymer (LiPo)	2	450

Figure 3.5.2.1A: ARCS Battery Assignments, Capacities, Type, and Cell number.

The batteries are secured to two small sleds located under the service camera sled and secondary computer sleds. They are secured in all directions in such a manner that prevents them from being ejected from flight forces. These batteries are considered energetics inside the vehicle, and are indicated as such.

The structure of the Final ARCS design utilizes three, twelve-inch 316 stainless steel threaded rods to support all flight hardware and framework. All internal sleds and framework are made out of laser-cut, pure bond plywood, utilizing galvanized steel 4-40 screws and accompanying 316-stainless square nuts to secure all computers and flight componentry to the sleds. Additionally, 316 stainless steel hex nuts and galvanized steel nylon lock nuts are used to secure all framework and bulkheads in place on the ARCS structure. This type of framework has been used in past UMLRC 4-inch diameter high-power flights, and as such, was used to mitigate as much risk as possible.

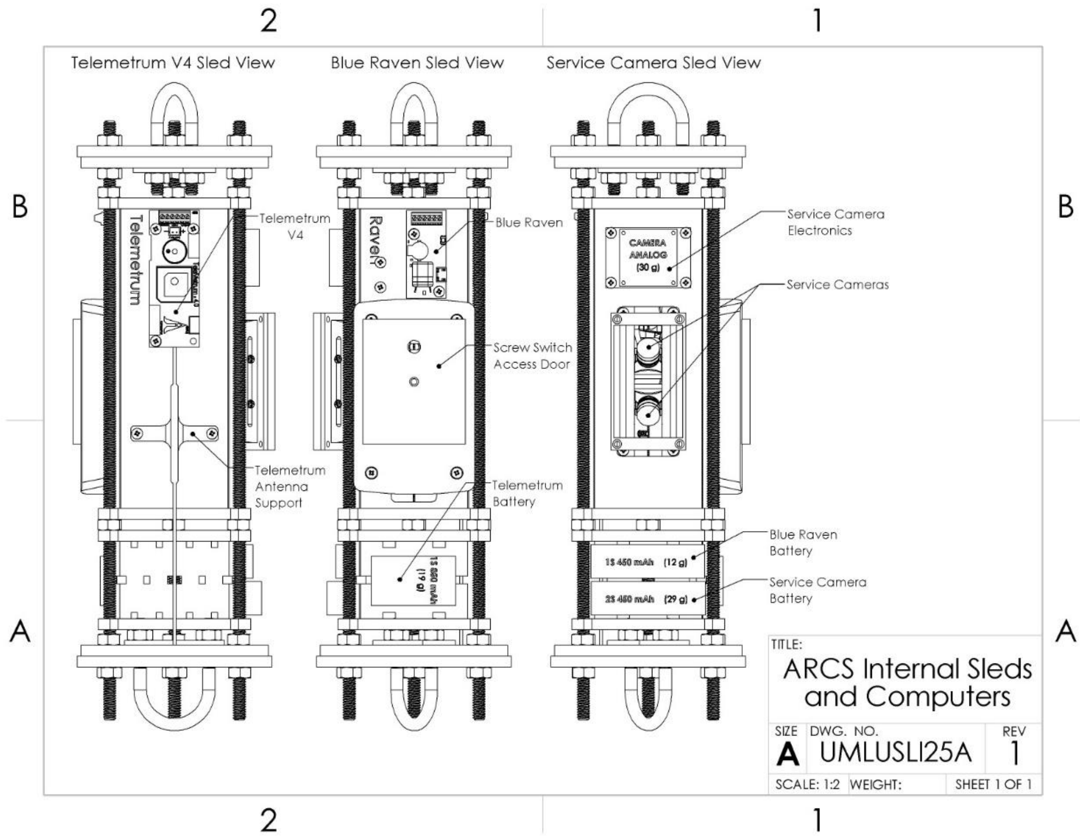


Figure 3.5.2.1A: Drawing of ARCS without the coupler tube.

ARCS uses plywood-epoxy composite bulkheads secured to the ARCS frame with galvanized steel lock nuts on the aft side (referred to as the “fixed end”), and 316 stainless steel nuts on the fore side (referred to as the “service end”). This plywood-epoxy composite material has been used in several past UMLRC 4-inch diameter high-power flights, and as such, were selected for their high strength, low risk, and flight experience, mitigating risk.

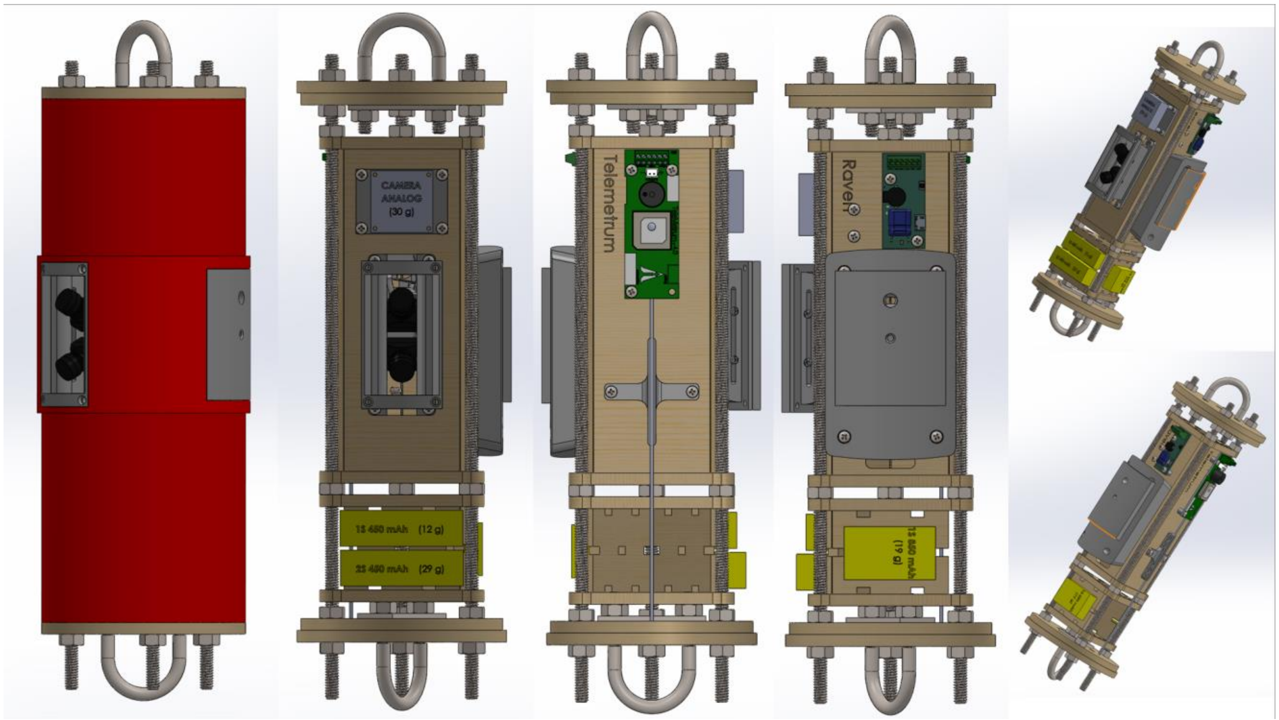


Figure 3.5.2.1B: Final design of ARCS with views of each internal sled, and the coupler tube.

ARCS will operate using a Telemetrum V4 as its primary flight computer, and a Blue Raven as its secondary / redundant flight computer. These recovery computers have been used on past flights and operated successfully. Additionally, the primary and redundant ejection charge wires from Telemetrum V4 and Blue Raven share a common positive (Blue Raven) and a common negative (Telemetrum V4). As such, a physical arming pin, equipped with two limit switch connections (one for each computer's common polarity) has been selected over ARCS configurations without such system.

ARCS will also utilize two, internally mounted service cameras that will monitor the main parachute ejection event (upwards facing) and the drogue parachute ejection event (downwards facing). The service cameras are mounted internally, and peer outwards from a rectangular hole in the switch band, protected with a thin polycarbonate film from aerodynamic forces. These cameras are not necessary, and act as another means of analyzing the flight after recovery. As such, they are actuated non-intrusively via an auxiliary charge from the redundant flight computer (Blue Raven). If the service cameras fail to initiate after liftoff, and the flight is otherwise a complete success, the flight remains a complete success.

The coupler that houses ARCS is 10-inches from the interior side of the bulkheads. The overall height of the system is 12-inches, as dictated by the threaded rods in its structure. The fore side of the coupler integrates into the main parachute airframe using rigid hardware, therefore designating it a "non-in-flight" connection point. The aft side of the coupler integrates into the drogue parachute airframe using 4, 45-pound shear pins mounted radially in 90-degree increments about the airframe, therefore designating it an "in-flight" connection point. The coupler tube is arranged such that the non-in-flight connection point is 100% of the body diameter, and the in-flight connection point is 75% of the body diameter, per the specification in the rulebook. A three-inch switch band was required for the cameras to see clearly.

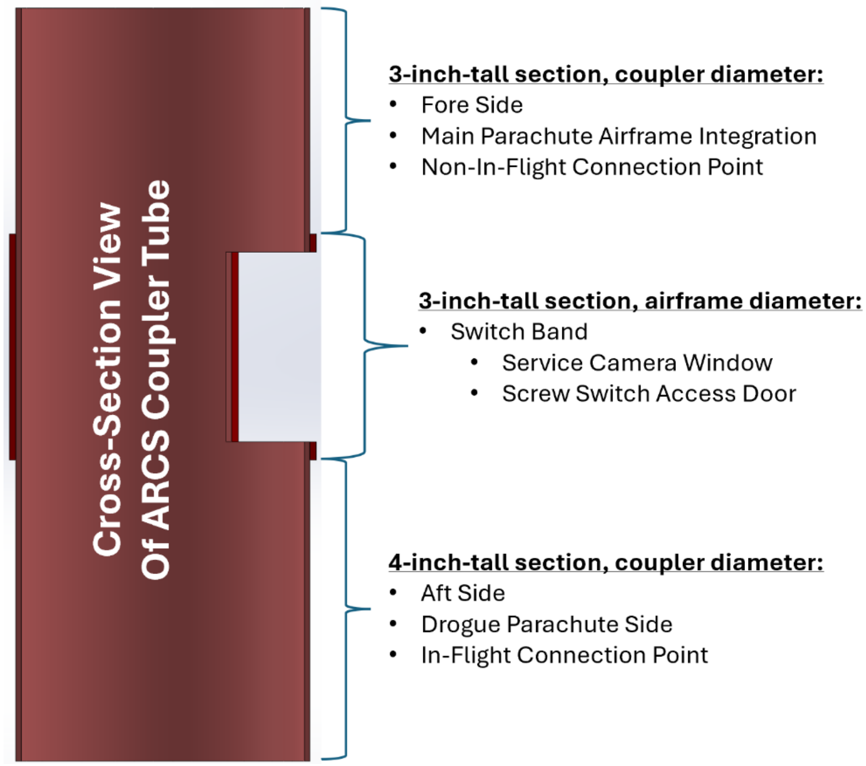


Figure 3.5.2.1C: Breakdown of ARCS coupler tube dimensions and classifications.

Additionally, a junction box (also referred to as the "Screw Switch Access Door") will allow for arming of ARCS' flight computers from outside the vehicle, through the switch band. This is important for when the vehicle is integrated and on the pad being prepped for launch. The junction box and its door are made of 3D-Printed PLA and integrated using 4-40 screws. The junction box houses two screw switches: one to arm Telemetrum, and one to arm Blue Raven. Although the junction box is rigidly mounted to ARCS' frame, the door is secured by tolerancing, the arming pin through hole, and a single 4-40 screw. The junction box door matches the exterior dimension of the body tube, and can be removed with or without first removing the arming pin. Disassembly of ARCS requires both the arming pin and junction box door to be removed, whereas arming the flight computers only requires the junction box door to be removed, as seen in Figure 3.5.2.2A below.

3.5.2.2 Final Avionics and Recovery System (ARCS) Design Justification

Compared to the presented designs in the Preliminary design review, the stated configuration was chosen for several reasons. Firstly, all major structural materials and layouts (which are crucial to system survivability and performance) have flight experience in different, but inertially similar, high-power flights. The bulkheads' structure, internal sleds material, structural hardware, nuts, and flight electronics are the items with past flight experience. As such, using them in the final design is justified, as they will perform the same as they have in the past on this vehicle.

The use of an arming pin was selected to ensure a physical means of disarming the vehicle during assembly and recovery. This was justified as our subscale experienced a recovery anomaly that left the recovery team unsure of potential unexploded ordinance on-board. To address this same failure mode in a potential full scale flight, adding a physical arming pin to disarm all ejection charges was justified. While developing the arming pin, however, it became apparent that high G-forces may cause the aft switch to depress during the boost phase, potentially damaging the computer's ability to properly conduct ejection charge firing. The team tested this using the weight of the switch's roller and the actuation force. Doing so revealed that under the flight G-force induced, the roller does not apply enough force on the actuator to depress the switch. Additional flight simulations were run on the flight computers, which revealed that even in the event of a momentary loss of continuity during flight, they will still send ejection signals to their respective charges on time. As a final means of precaution, small neodymium magnets will be used to secure the switch arms in place when not depressed by the arming pin. As a result, this safety system was justified and included in the final ARCS design.

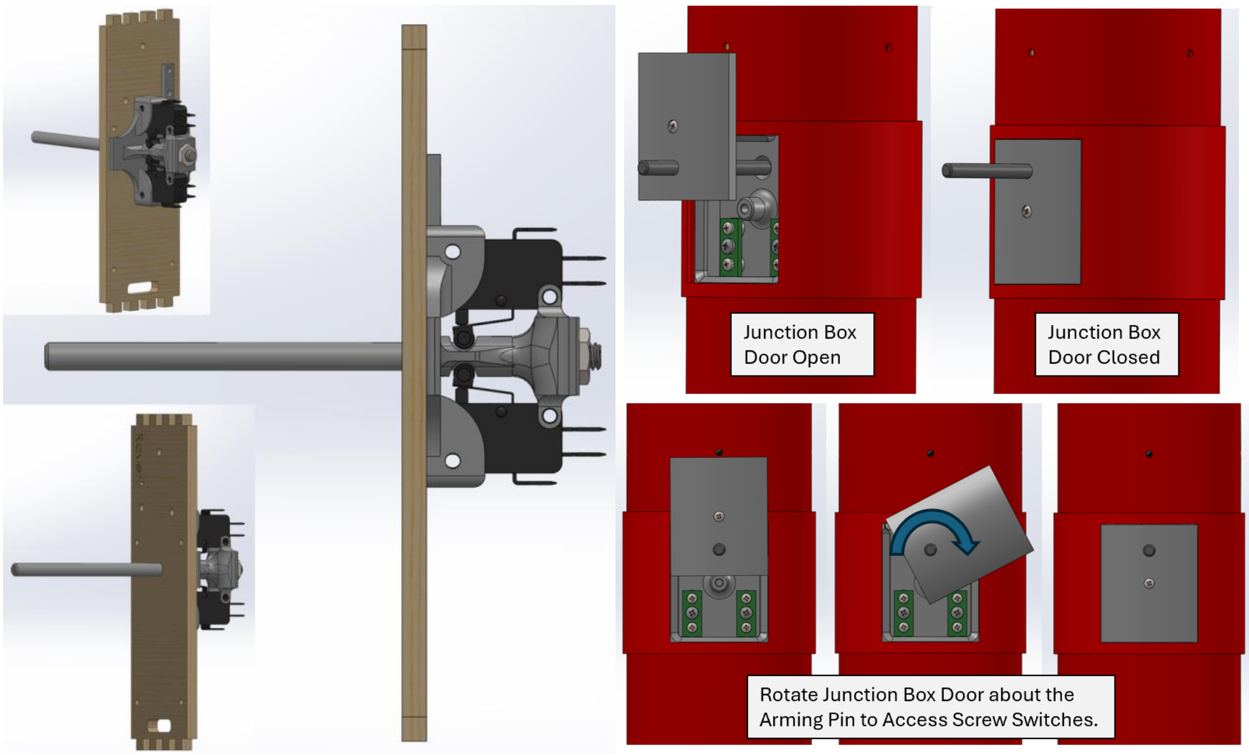


Figure 3.5.2.2A: Arming pin assembly on redundant sled, and junction box mating to coupler.

Additionally, the chosen configuration has the ability to be rapidly serviced as the sleds can easily be removed and inspected. The ability to have such flexibility built into the system is advantageous, as all systems are hot-swappable. For example, if the redundant computer is not functioning, the entire sled can be swapped out with one that is tested and works. This allows for the team to bring backup hardware already assembled to the launch site, mitigating the risk of computer damage, miswiring, or having to scrub a launch from a failed recovery system.

Telemetrum V4 was chosen as the primary flight computer because of its extensive, successful background in past UMLRC high-power flights. Additionally, it was chosen because of its integrated telemetry capabilities, having the capability of locating itself using GPS and transmitting telemetry to a ground station in case the vehicle travels out of sight. Overall, Telemetrum is a very capable computer, and the value of having live telemetry in addition to a visual justifies its position as the primary computer.

Telemetrum V4 has an integrated ¼ whip antenna to transmit its telemetry to the team's ground station. Originally, the team had intent to alter the integrated antenna and swap it out for a 1/8 whip for the sake of space, early in ARCS development. However, based on antenna simulations run in a MATLAB program and an excess of space allotted for it, the ¼ whip antenna was selected. The ¼ whip offers a gain capability and pattern that maximizes the likelihood of the vehicle flying in an acceptable orientation relative to the individual manning the antenna (T2 & T-DRO), such that the only two dead zones are aligned with the central axis of the vehicle. As such, the ¼ whip antenna was justified for the final design of ARCS.

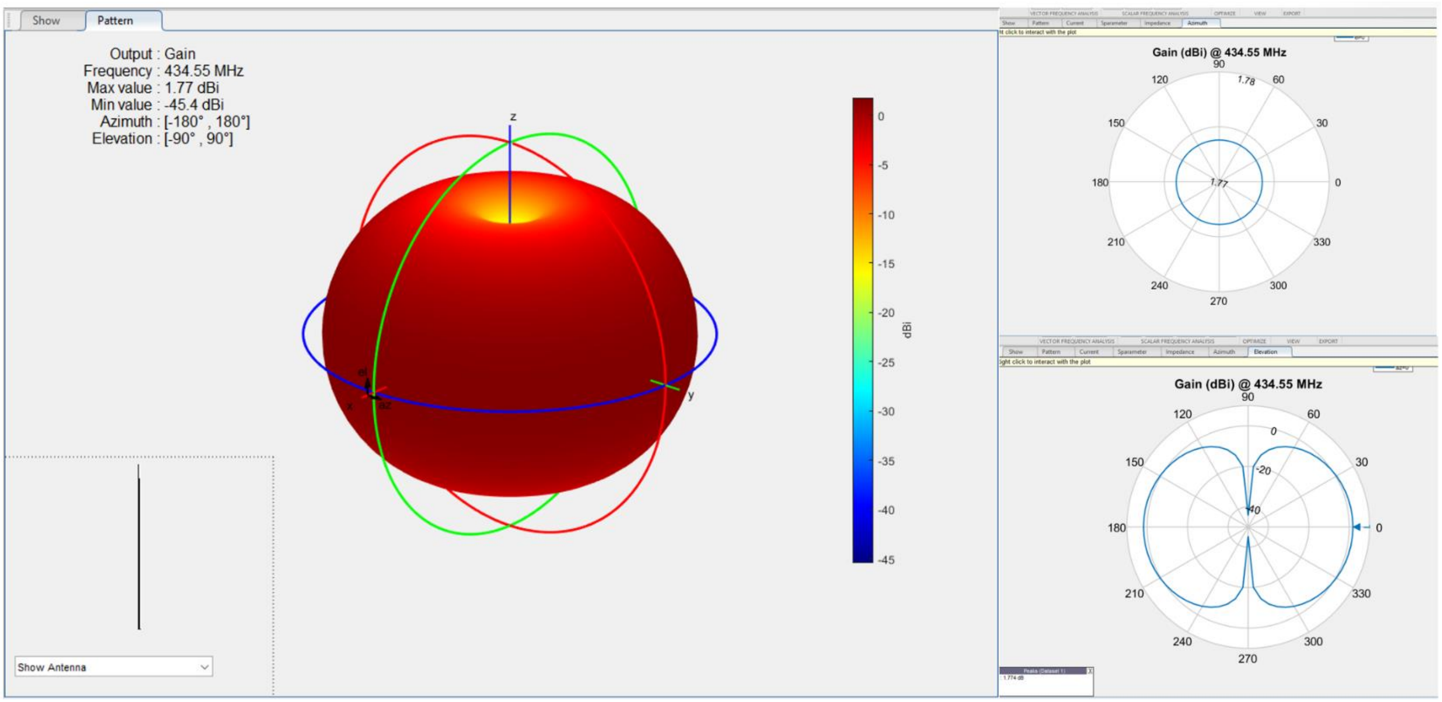


Figure 3.5.2.2B: Telemetrum V4 ¼ Whip Antenna Gain Pattern in MATLAB Simulator.

Blue Raven was chosen as the redundant flight computer because of its extensive, successful background in past UMLRC high-power flights. Additionally, it was chosen because of its diverse array of sensors, complete data redundancy to the primary computer, and its additional internal software redundancy / safety measures. For example, if the drogue parachute gets jammed and fails to deploy, a nominal drogue descent rate can be programmed pre-flight, such that if exceeded, Blue Raven will fire the main parachute automatically in attempts to save the vehicle from a ballistic failure. Overall, Blue Raven is capable of recovering the vehicle in the event of several failure modes, including a primary computer failure and a drogue ejection failure, and therefore is justified as the secondary computer.

3.5.2.3 Final Parachute Configuration and Justifications

Several configurations of parachutes, shear pins, and ejection charges were compared before choosing the final configuration for the recovery system.

The final parachute configuration consists of a 72-inch main parachute from Fruity Chutes, and an 18-inch drogue parachute from Fruity Chutes. Both of these chutes have flown in the past on a similar Level 2 high power flight and demonstrated attractive flight dynamics and sustained no damage. As such, selecting these chutes means we assume less risk, as the team has existing strategies to pack, protect, and wrap these parachutes in a 4-inch airframe.

The main parachute will reside in the fore airframe of ARCS (between Payload and ARCS), and the drogue will reside in the aft airframe of ARCS (between ARCS and ACS). Additionally, the shock cord lengths are designed in such a way that there is no interference between vehicle sections while suspended under either the drogue or main parachutes, as seen in table 3.5.2.3A. The shock cords will be ¼-Inch nylon strapping, and parachutes will exist in bites on the rope sections, as seen in Figure 3.5.2.3A. All cords will be anchored to the ARCS bay using 316 Stainless Steel hardware, and Galvanized Steel hardware, attached to Plywood-Epoxy composite bulkheads. For more information on the strength of mounting hardware, see the paragraph in Section 3.5.2.1, under figure 3.5.2.1A.

Shock Cord Section	Length (ft)
Main Parachute to Payload	8
Main Parachute to ARCS	16
Drogue Parachute to ARCS	8
Drogue Parachute to ACS	16

Table 3.5.2.3A: Shock Cord Lengths

Additionally, these parachutes perform well for the decent rate and kinetic energy specifications posed in the USLI 2025 handbook, as seen in Section 3.6.3. The parachute decent rates from 0-20 mph in increments of 5 mph are tabulated in Table 3.6.3B. The drogue parachute is deployed for 61.28 seconds, and the main is deployed for 28.61 seconds, for a total recovery duration of 89.89 seconds.

To protect the parachutes from the heat of ejection charges, the team decided to use a Nomex blanket to protect the charge-side of the parachute. Following the submission of the Preliminary Flight Review, the team considered the use of a deployment bag as an all-in-one means of both protecting and controlling the deployment of the parachutes. However, as this method has not been flown on a past vehicle and does not have any legacy with the team, it was ruled out due to its complexity and inherent risk as a new technology for the team.

To eject the Main and Drogue parachutes, four charges will be present on the vehicle: A primary main parachute charge, a secondary/redundant main parachute charge, a primary drogue parachute charge, and a secondary/redundant drogue parachute charge. As each parachute airframe section is a different volume, the masses of black powder used for each charge are selected based on both the volume of the parachute bay, and the urgency of the event. Meaning, if a primary charge fires but fails to separate the reframe section, the redundant charge must be nominally oversized such that it has the best odds of forcing a separation. The black powder values were derived using the equations seen in Figure 3.5.2.3B below.

$$Pressure(psi) = \frac{Force(lbs)}{Area(inch^2)}$$

$$volume(inches^3) = \frac{\pi \times (diameter(inches))^2 \times Length(inches)}{4}$$

$$Grams(BP) = \frac{454grams}{1lbf} \times \frac{Pressure(psi) \times Volume(inches^3)}{266\frac{inches \bullet lbf}{lbm} \times 3307 \circ R}$$

Figure 3.5.2.3A: Formulas used to calculate black powder ejection charge masses.

As such, the respective vehicle/parachute bay parameters, airframe ejection pressures, bulkhead forces, and ejection charge masses were measured and calculated, respectively. These values are the final values chosen.

Parachute Bay	Inside Diameter (in)	Internal length (in)	Volume (in^3)
Main Parachute Bay	3.9	16	98.01
Drogue Parachute Bay	3.9	7	42.88

Table 3.5.2.3B: Vehicle/Parachute Bay Parameters

Charge line	Pressure (PSI)	Force on Bulkhead (lbs)	Black Powder (g)
Main Primary	15.4	183.9	1.55
Main Redundant	20	238.7	1.95
Drogue Primary	15.4	183.9	0.68
Drogue Redundant	20	238.7	0.85

Table 3.5.2.3C: Ejection Charge Masses, Bulkhead Forces, and Airframe Ejection Pressures

3.5.3 Concept of Operations (CONOPS)

The recovery system has several potential scenarios it is prepared to operate within. In other words, ARCS and the parachute ejection charges are designed to recover the vehicle despite a potential failure modes. These failure modes are categorized by a letter, corresponding to the severity of the failure. Failure modes that result in vehicle disassembly or ballistic return are not categorized, as they are non-recoverable.

Phase Letter / Title	Failure Mode
A-Phase	Full Success / No Failure
B-Phase	Telemetrum V4 / Primary Computer Failure
C-Phase	Blue Raven / Redundant Computer Failure
D-Phase	Motor Underperformance / Failure
E-Phase	Drogue Parachute Failure

Table 3.5.3A: Horizontal Wind Drift Calculations from Apogee Directly Above Launch Rail

Each phase letter has its own concept of operation describing how the system operates under the respective failure mode. The Phase-A concept of operation highlights the standard, intended operation of ARCS and the parachutes, as seen in Figure 3.5.3A.

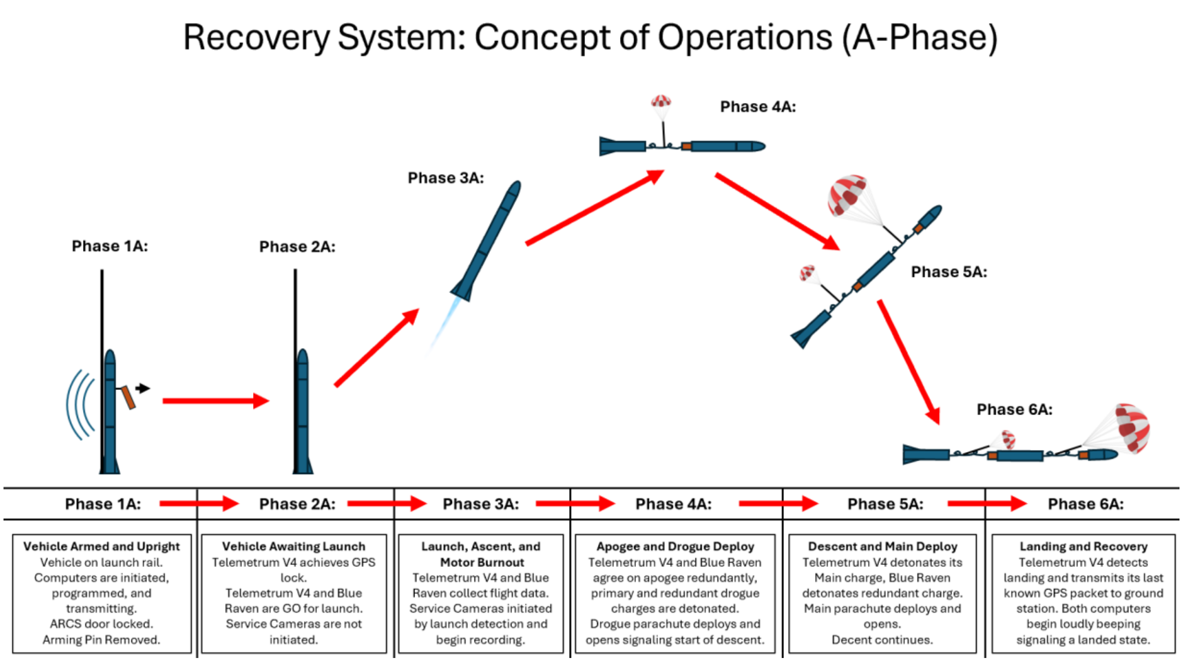


Figure 3.5.3A: Recovery System CONOPS, A-Phase (complete success).

3.6 Mission Performance Predictions

3.6.1 Flight Profile Predictions

Flight simulations to calculate the flight profile were performed in OpenRocket and RASAero II. In OpenRocket and RASAero II, all flight simulations assumed a launch from sea level, and a 5-degree launch angle, the minimum launch angle set by NASA, as well as a wind speed of 0 MPH. The simulation gathered data for the rocket's altitude, vertical velocity, and vertical acceleration using the Ceseroni K780 motor.

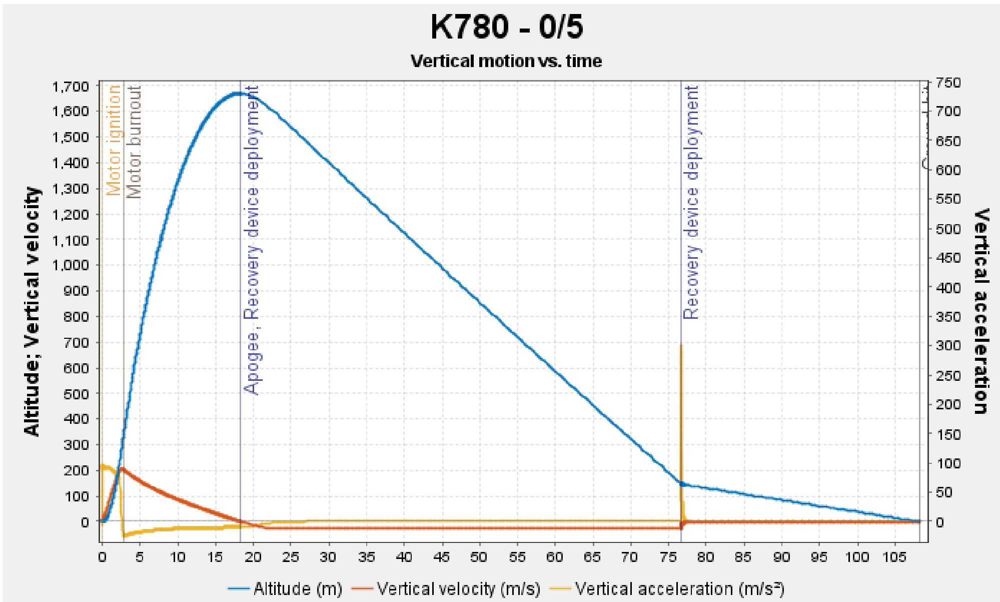


Figure 3.5.1A: OpenRocket flight profile simulation for the Cesaroni K780 motor with altitude, vertical velocity, and vertical acceleration over time

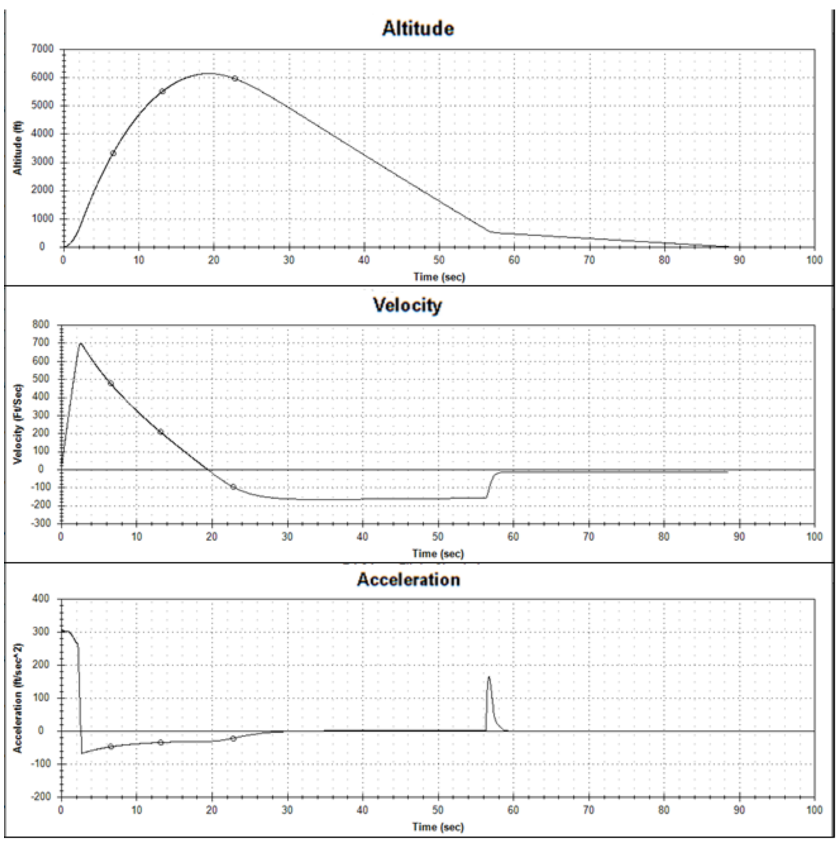


Figure 3.5.1B: RASAero II flight profile simulation for the Cesaroni K780 motor with altitude, vertical velocity, and vertical acceleration over time

Using the Ceseroni K780 motor in OpenRocket, the apogee was 5482 ft (1671 m), the maximum velocity was 682 ft/s (208 m/s), and the maximum acceleration was 320 ft/s^2 (97.5 m/s^2). Using RASAero II, the apogee was 6135 ft (1870 m), the maximum velocity was 696 ft/s (212 m/s), and the maximum acceleration was 330 ft/s^2 (101 m/s^2). While the data gathered using the two different software were similar, the RASAero II simulation data was observed to be consistently higher than the simulated data from OpenRocket. The difference is likely due to how OpenRocket handles transonic flight calculations, as well as differences in how each software is set up and how they calculate data.

3.6.2 Stability Margin

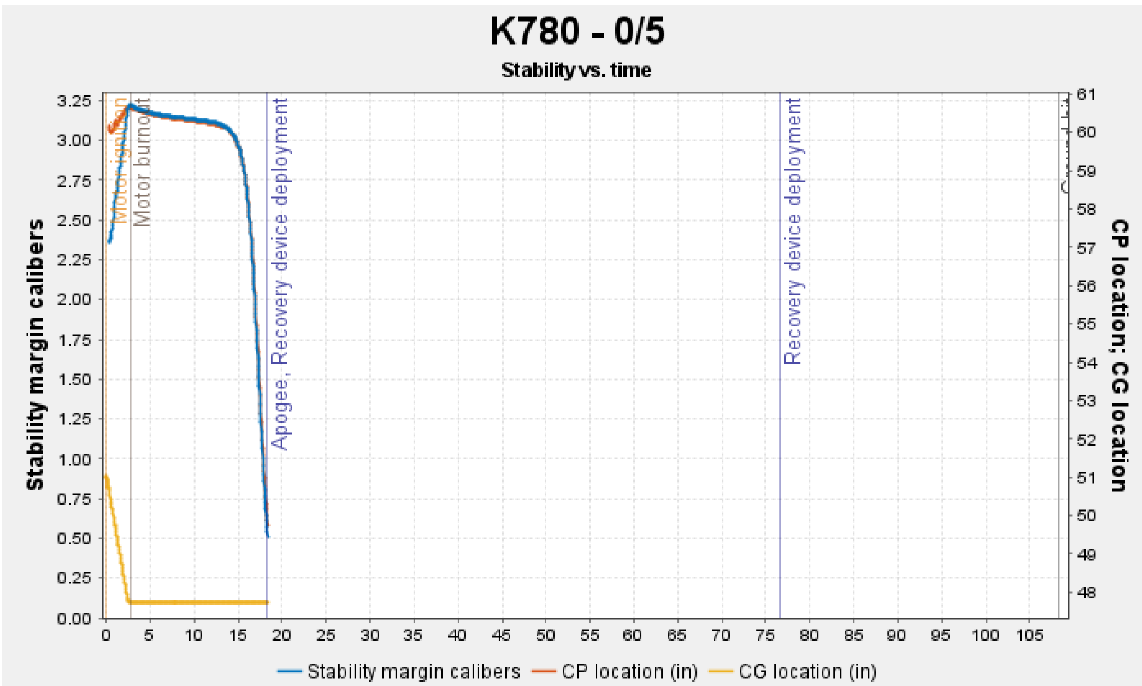


Figure 3.6.2A: OpenRocket stability margin, center of pressure location, and center of gravity location over time

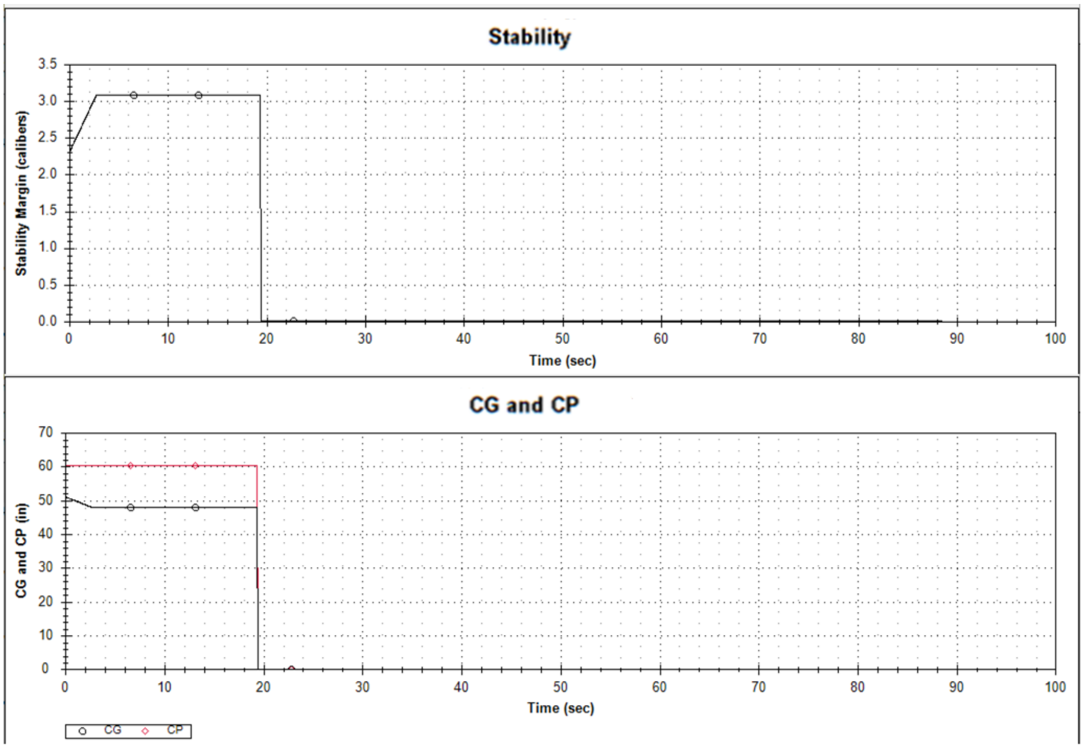


Figure 3.6.2B: RASAero II stability margin, center of pressure location, and center of gravity location over time

On the pad with no ballast, the vehicle has a static stability of 2.32 calibers, and at rail exit has a stability of 3.20 calibers. The center of gravity is located at 51.03 in from the tip of the nosecone, which is in the upper position of the ACS. The center of pressure is located 60.34 in from the tip of the nosecone, which is just below the ACS and camera bay.

3.6.3 Kinetic Energy at Landing

The worst-case scenario ground hit velocity is 15.29 ft/s (4.66 m/s) and is assumed for the following calculations. After all deployments, the launch vehicle will be in 3 sections. From fore to aft, the masses of each section, including parachutes, are: PERR-C at 2.01 lb, Upper-Section (Main Chute bay, ARCS) at 5.44 lb, and Lower-Section (drogue chute bay, ACS, Motor Mount, Spent Motor) at 8.74 lb with the K780 motor. With the worst-case scenario ground hit velocity, at ground hit, these segments will have kinetic energies of 7.30 lbf*ft, 19.76 lbf*ft, and 31.75 lbf*ft, respectively.

3.6.4 Drift Calculations

Wind Speed (Miles per Hour)	Drift Distance (Feet)
0 MPH	0 ft
5 MPH	712.29 ft
10 MPH	1424.59 ft
15 MPH	2136.88 ft
20 MPH	2849.17 ft

Table 3.6.3A: Drift calculations based on RASAero II descent times

Wind Speed (Miles per Hour)	Drift Distance (Feet)
0 MPH	0 ft
5 MPH	657.95 ft
10 MPH	1315.90 ft
15 MPH	1973.85 ft
20 MPH	2631.80 ft

Table 3.6.3B: Drift calculations based on OpenRocket descent times

Drift calculations were completed by hand using data from OpenRocket and RASAero II. The calculations were done under the assumption that apogee is reached directly above the launch site, and a constant wind speed is applied to the rocket. The calculations were completed by finding the product of the descent time, measured by taking the time apogee is reached to when the rocket touches the ground, and the wind speeds at different points during descent. The OpenRocket calculations used a calculated descent time of 97.11 seconds, and the RASAero II calculations used a calculated descent time of 89.70 seconds. Overall, the drift distances were observed to be similar between the two methods, with the greatest difference occurring at wind speeds of 20 MPH, resulting in a difference of roughly 7%. The differences between the calculations are likely due to how RASAero II handles parachute deployment, resulting in the drogue parachutes' surface areas having to be approximated as a single parachute.

4 Payload Design

The 2M radio system, along with its sensors and the sled it is mounted on, is collectively referred to as the Payload Electronics Package (PEP). The PEP is housed within the Payload Electronics Recovery Reporting Capsule (PERR-C), which also includes the nose cone and the body tube section. The Altitude Control System (ACS) is mounted further down the rocket and uses the same custom PCB as used in PEP, but without the 2M radio and related audio equipment. Instead, it includes a motor driver.

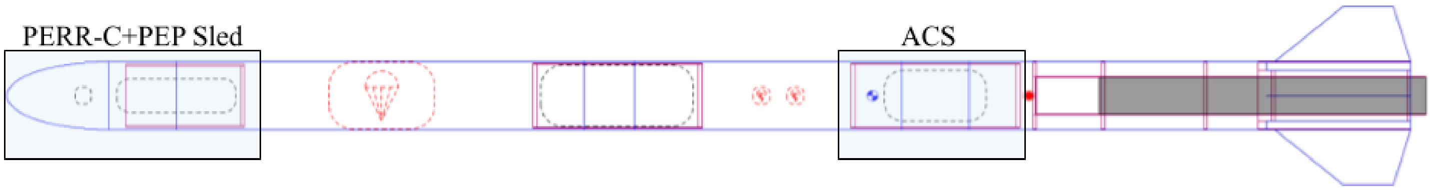


Figure 4.0.1: Wireframe with locations of PERR-C and ACS payload systems

4.1 Payload Criteria

As per the 2025 Student Launch Handbook we are required to provide space for STEMnauts, and a transmitter capable of transmitting on the 2M band. With the 2M transmitter our team intends to transmit all 8 data points listed under Payload Experiment Requirements 4.2.1

- Temperature of landing site
- Apogee reached
- Battery check/power status
- Orientation of on-board STEMnauts
- Time of landing
- Maximum velocity
- Landing velocity, G-forces sustained
- Calculated STEMnaut crew survivability

It is the intent of our team that our payload system will not only meet the payload experiment requirements outlined in the 2025 Student Launch Handbook but also ensure reliable data transmission, and STEMnaut safety.

In addition to transmission and STEMnaut safety the payload also includes an airbraking system that as per 2.2 of NASA Student Launch Handbook intends to get our actual altitude as close to our declared altitude as possible.

4.1.1 Mission Statement

Our mission when creating our payload design is to meet and exceed the requirements of the 2025 Student Launch Handbook, providing a safe and reliable environment for our STEMnaut and transmitter payload. Through collaborative design and testing, we aim to ensure the success of our payload experiment.

The mission of the Airbrake Control System (ACS) is to enhance the team's apogee score by improving the precision and accuracy of the launch vehicle's altitude performance. The ACS will utilize high-rate sensor data combined with sensor fusion to predict apogee deviations during the coast phase. Using this data the airbrake will do a "suicide burn" opening to a hard-set deployment angle limit at the precise moment calculated to correct the vehicles apogee. Since ACS will be operating in a high-speed aerodynamic environment, the ACS will be meticulously engineered with robust mechanical design, optimal material selection, and stability assurance. To ensure reliability, the system will incorporate fail-safes that deactivate the airbrakes in the event of control authority loss, safeguarding the integrity of the vehicle and its mission objectives.

4.1.2 Mission Success Criteria

A successful mission in the context of the payload systems, would require the following criteria to be met:

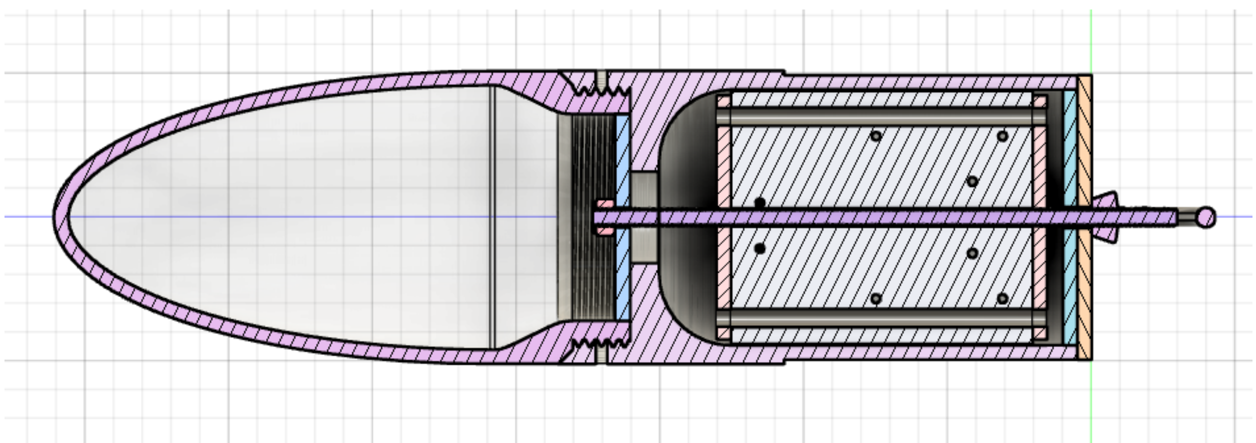
1. ACS operates successfully, bringing the vehicle to within 150 ft margin of the target selected altitude of 5000 ft AGL
2. After successfully landing the PEP system must transmit all eight required data points over the 2M band to NASA

For both the primary and secondary payload to be considered a success, the vehicle must complete these objectives without experiencing any structural, electronic, or software failures.

4.2 Passive Electronic Recovery Reporting Capsule

4.2.1 PERR-C Subsystem Design

The design of the PERR-C payload is a two-section nosecone that has an "upper deck"(flight deck) for the STEMNauts that are 2' mini figures with a Rowdy the RiverHawk head, and a "lower deck"(electronics bay) for the PEP systems sled that holds all electronics related to PERR-C, allowing communication between PERR-C, our custom Gound station, and NASA's ground station.



The upper deck and electronics bay are separated by a bulkhead that sits on the bottom of the flight deck within the threaded portion of the top section in the nosecone. This bulkhead is secured by an I bolt that runs through the electronics bay and is fastened by a nylon locknut on both sides of the electronics bay. This is then sealed off by another bulkhead on the aft section of the lower deck, fastened by another nylon locknut. The thinner walled portion of the bottom section is the shoulder of the nosecone, which will be the shoulder of the nosecone and will be push fit into the main body of the rocket. On the aft of the electronics bay, the lip that helped hold the PEP system in place was removed to allow for a wider sled to fit, and a bulkhead has been put in its place to aid in supporting the PEP sled.

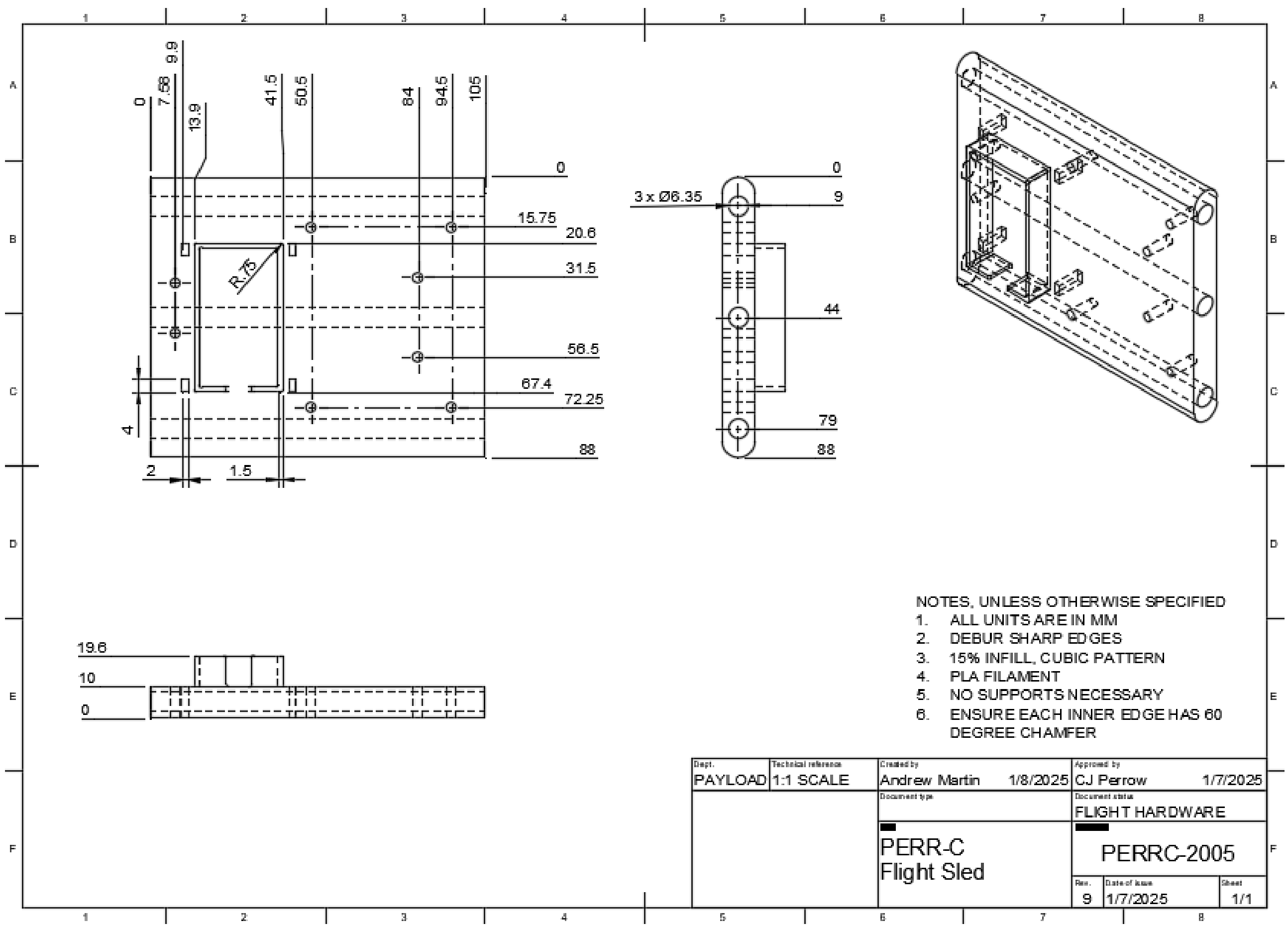
4.2.2 PERR-C Analysis

Due to the availability, ease of cost, and ease of manufacturing, both sections of the nosecone are 3D printed using Fused Deposition Modeling (FDM) printers, with the top section being printed in Polyethylene Terephthalate Glycol (PETG), and the bottom section being printed in Polylactic Acid (PLA). This will allow the top section of the nosecone, which experiences more force than the bottom section, to have a higher strength profile due to the type of plastic used, and the PETG for the top section will be clear to provide the STEMNauts with visibility of the landing site. Both are cheap on cost, and the UMASS Lowell campus has Ulti-maker printers readily available for us to use within the UMASS Lowell Lawrence Lynn Makerspace. Regarding all three bulkheads within the primary payload system, they will all be made from pure bond plywood due to ease of cost/manufacturability due to both the laser cutters and the material being available for free in the UMASS Lowell Lawrence Lynn Makerspace.

4.2.3 PEP Subsystem design overview

PEP is the system that will directly communicate with NASA over the 2M band after landing. To achieve this PEP has sensors used to read aspects of the environment including orientation, altitude, temperature, velocity, and battery power. It also includes an off-the-shelf HAM radio which is interfaced with our custom PCB to provide autonomous data transmission.

4.2.3.1 PEP Mechanical



Regarding the PEP flight sled, this has been changed to a two-sided sled instead of a three-sided to accommodate fitting a HAM radio within the lower deck without dissembling most of the radio. This is due to complications from testing the radio after it had been disassembled, with the radio not transmitting when being tested. This allows us to mount the HAM radio directly to the sled, which will be printed out of PLA. The sled will be mounted by the center threaded rod, as well as two threaded rods on opposite ends of the sled.

4.2.3.2 PEP Electrical

The physical portion of the PEP system is entirely subservient to its needs as a digital and mechanical device. That is to say, the physical considerations regarding the PCB design are entirely dependent upon the software and mechanical portions of the system, with much of the electrical design simply being determining methods through which to bind the constituent components of the system into a coherent piece of hardware, as well as some occasional concerns regarding signal integrity between the various endpoints within the PCB. Three main goals are in mind regarding how the system is designed, structural stability, power efficiency, and simplicity.

1. Structural Stability:
    a. Our device is composed of an integrated PCB acting as a “hat” to an ESP32 Feather board, utilizing as few “breakout” devices as possible, unlike the previous non-competition system which used perfboard to connect their various components.
    b. Five integrated, grounded stand-off points are integrated into the design to prevent any possible jostling/in-housing collisions during launch. This also ensures maximal “info” transfer to our selected accelerometer, as per the datasheet recommendations.
    c. Our chosen solution is relatively simple, with the only component dense sections being the DAC (digital to analog converter) and orientation sensor. Therefore, we opted for a four-layer PCB. This leaves us three layers for routing, and the bottom layer as a ground plane to reduce inductance.
2. Power Efficiency
    a. Our chosen Li-Po battery has an 850 mAh capacity. The goal of our component selection was to minimize any possible power draw, with the goal being a 3-hour maximum battery life in optimal conditions.
    b. Using the ratings for the provided power regulator in the Feather S3 and the estimated current draw in ideal conditions for each selected component, the lifespan of the system from power on to depletion should be roughly 4 to 5 hours if all extraneous communication methods (WiFi, Bluetooth) are disabled correctly.
    c. If the regulator is operating at near peak load conditions, or the unneeded portions of the feather are not disabled, then the lifespan of the system decreases to around one hour. Significant extensions to the efficiency of the system can be achieved via software alterations, such as disengaging the transmission mode of the 900 MHz band when possible.
3. Simplicity
    a. Minimal communication standards should be employed.
    b. Minimal additional breakouts/daughter boards should be utilized. This also ties into the structural stability of the device.
    c. The device must cost as little as possible to be manufactured.
    d. All relevant device features should be utilized, and all subsequent additions should be constructive to the existing feature set, not redundant.

Component Selection

	Chosen Component
Orientation Sensor	Bosch BNO055
Barometer	Bosch BMP390
Accelerometer	Analog Devices ADXL375
900 MHz Trans.	HopeRF RFM69HCW
144 MHz Trans.	Baofeng UV5-R (TBD)
Processing Hub	Adafruit/Espressif ESP32 Feather S3

- Orientation Sensor Overview:

	Bosch BNO055
Connection Type	I2C, UART
Peak Est. Current Draw	~12.3 mA
Operable Voltage Range	Sensors: 2.4 < V < 3.6 Digital I/O: 1.7 < V < 3.6
Output Info	Abs. orientation, Angular Vel., Acceleration, M.Field Info

- Barometer Overview:

	Bosch BMP390/288
Connection Type	I2C, SPI
Peak Est. Current Draw	~0.73 mA
Operable Voltage Range	Sensors: -0.3 < V < 3.6 Digital I/O: -0.3 < V < 3.6
Pressure resolution	Max - 0.085 Pa Min - 2.64 Pa

- Accelerometer Overview:

[redacted]	Analog Devices ADXL375
Connection Type	I2C, SPI
Peak Est. Current Draw	~0.145 mA
Operable Voltage Range	Sensors: 2.0 < V < 3.6 Digital I/O: 1.7 < V < V_s (Sensor voltage)
Max Measurable Acceleration	±200g

- 900 MHz Radio Overview:

[redacted]	HopeRF RFM69HCW
Connection Type	SPI, Proprietary
Peak Est. Current Draw	~130 mA
Operable Voltage Range	1.8 < V < 3.6
Est. Transmission Distance (Omnidirectional)	~500m

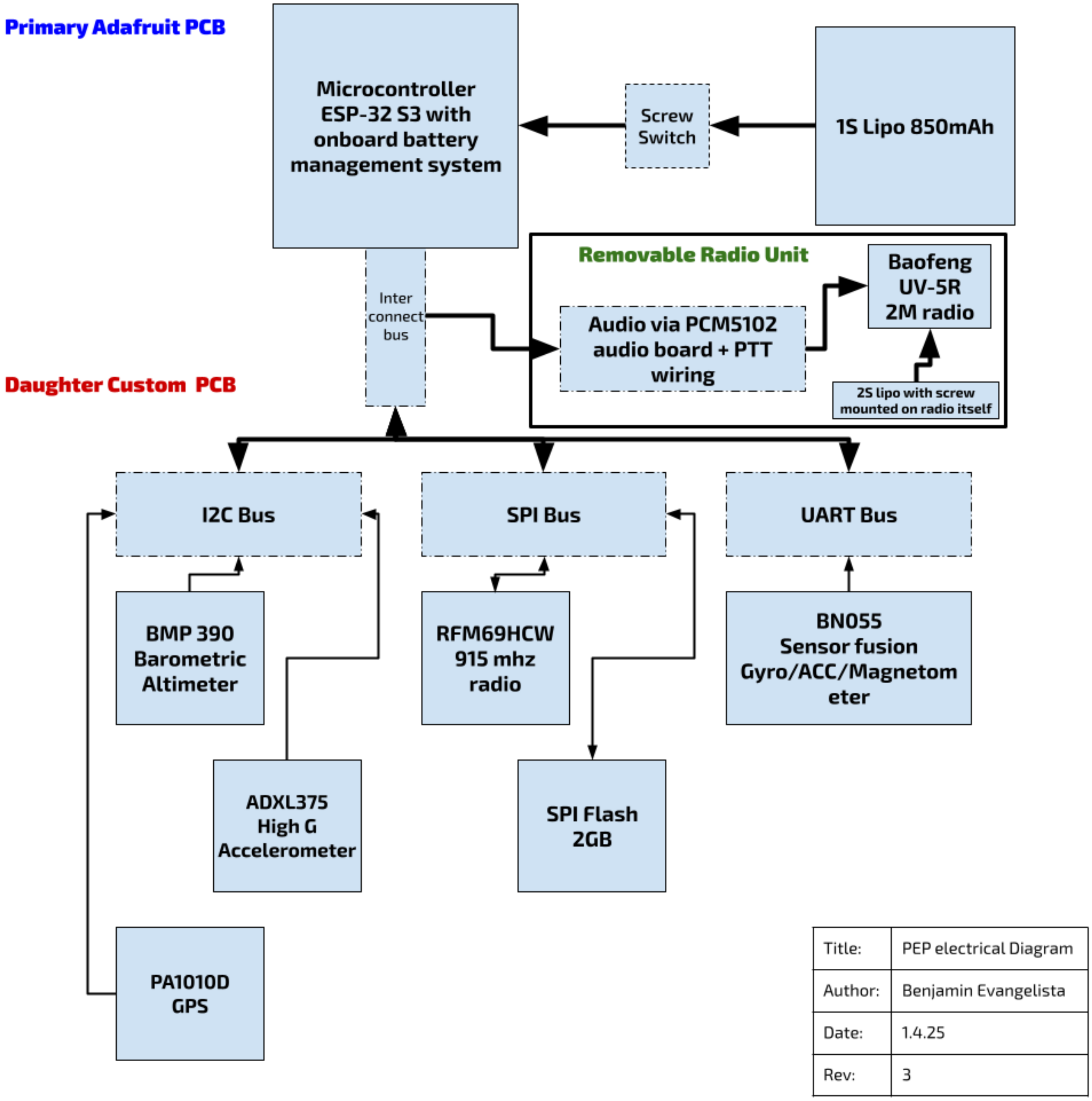
- Processor Overview:

[redacted]	Espressif ESP32 Feather S3
Clock Rate	240 MHz
Connectivity	Wi-Fi, USB C, I2C, SPI, Analog Out, UART, Serial
Core Count	Dual Core
Integrated Memory	8 MB

- 2M Radio Module Overview:

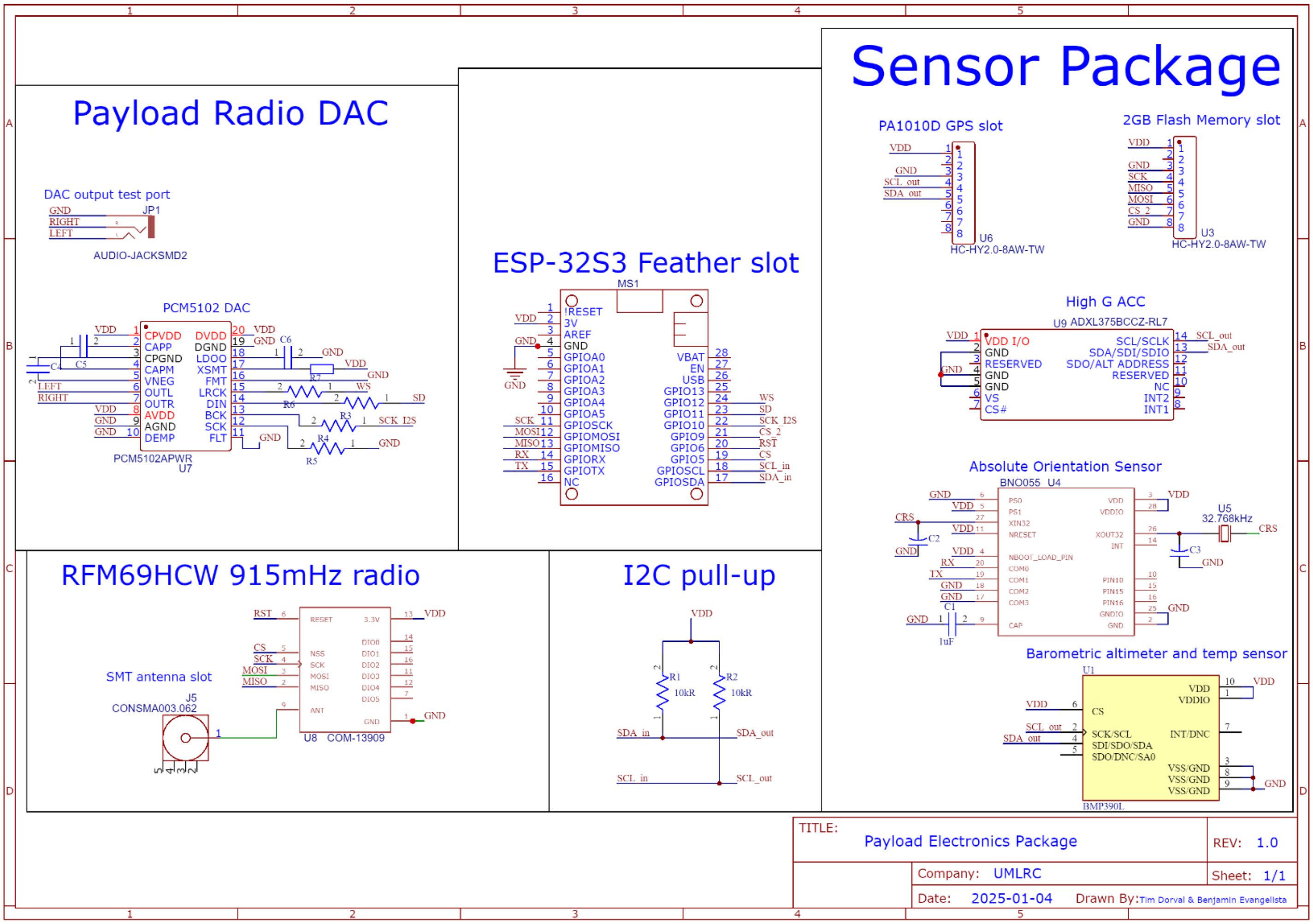
[redacted]	Baofeng UV5-R
Connection Type	Proprietary
Peak Est. Current Draw	N/A, external module
Operable Voltage Range	N/A
Est. Transmission Distance	~2 to 5 km

System Flow Chart:

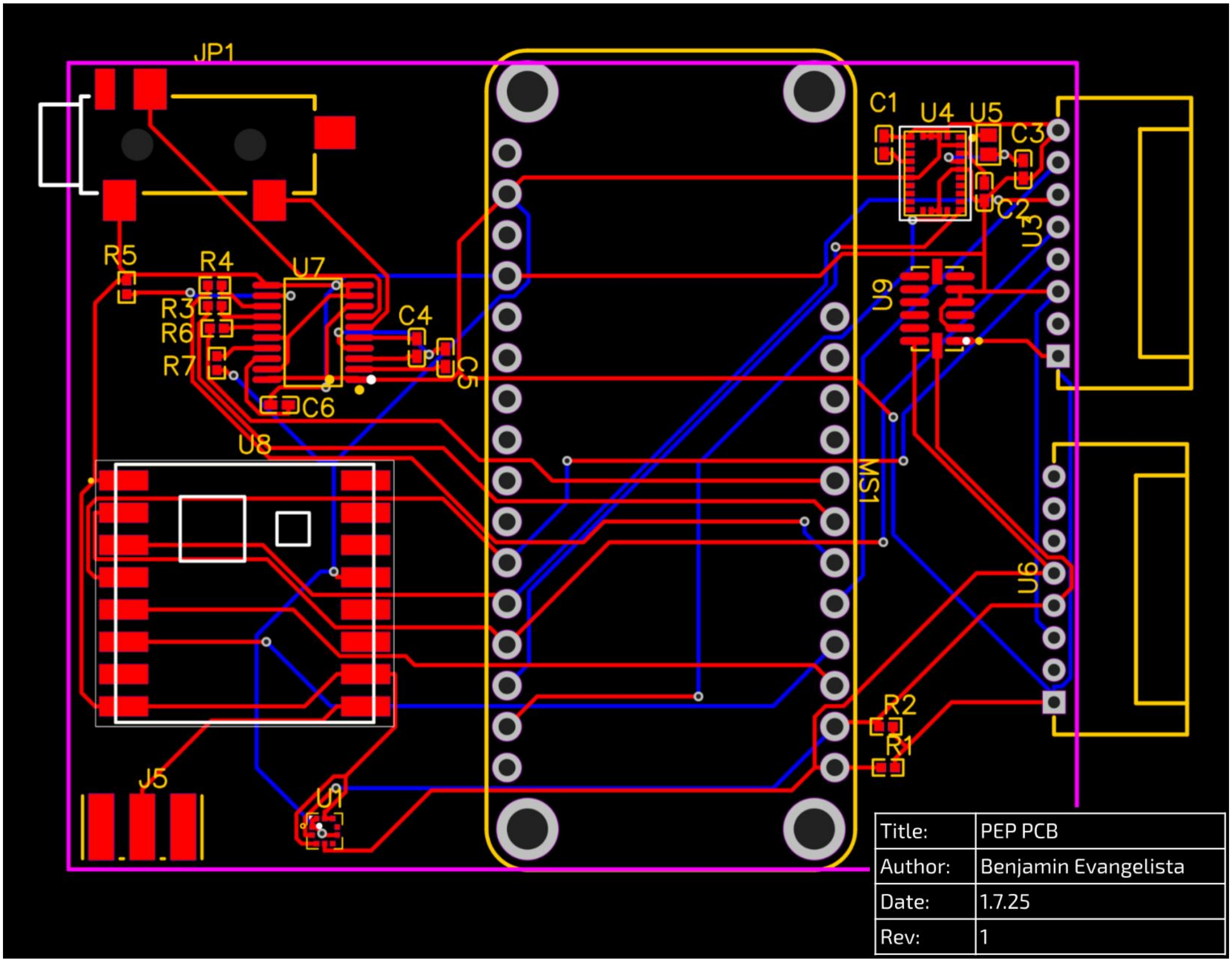


Title:	PEP electrical Diagram
Author:	Benjamin Evangelista
Date:	1.4.25
Rev:	3

Current Revison Schematic:



Current Revision PCB Layout (Not Final):



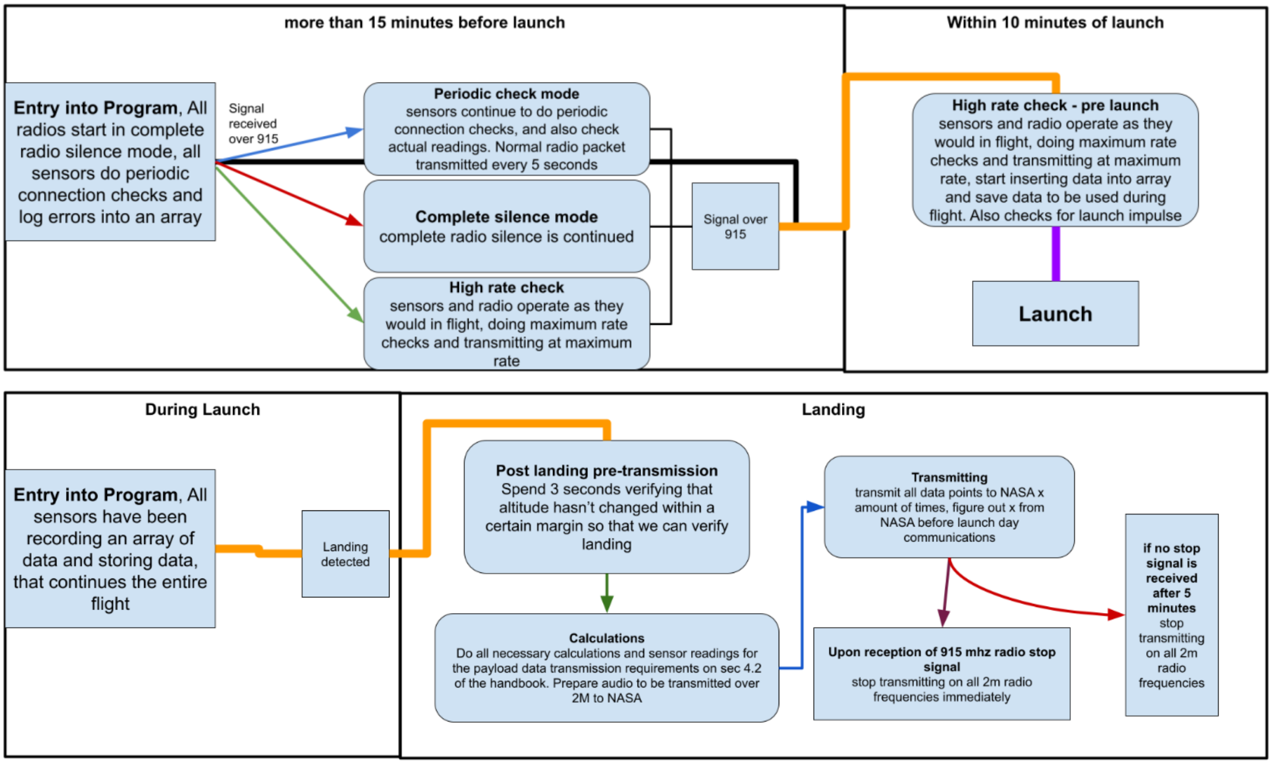
4.2.3.3 PEP Code

The Payload codebase will be entirely written within CircuitPython which is maintained by Adafruit, it'll include open-source libraries written by them which can be found on their website. Coding will generally follow so called "Power of 10" rules for reliable software from NASA/JPL.

For the payload there were a few primary goals with the code to achieve

1. Bidirectional data link over 915 MHz radio with club made ground station for telemetry, data logging, and commanding of a stop signal to the 2M radio after completion of 2M radio broadcast
2. Record and calculate all necessary data to send NASA the payload datapoints
3. Interfacing with an off-the-shelf 2M radio produced by Baofeng, the UV-5R
    a. Activation of the Push to Talk (PTT) autonomously after landing is detected
    b. Transmission of an automatically generated Text to Speech (TTS) message containing all 8 data points

To achieve these 3 goals a finite state machine is outlined below



Goal 1 bidirectional radio link 915mhz

<u>Commanding the vehicle</u>

Since we want to be able to command certain aspects of data transmission on launch day, we have included a set of commands we can send to the vehicle, some of which are shown on the state machine graph.

All commands will be rejected during flight except for the 2M radio stop signal as the rocket will automatically enter high-rate check mode during flight.

Description	Data Packet Sent
Periodic Check Mode	"PDC"
Radio Silence Mode	"RSM"
High-Rate Check Mode	"HRCM"
Change Node Address (Once new node address is programmed even in radio silence mode it'll send one message to the new Address to confirm it changed nodes, so we don't lose telemetry due to an error)	"CNA"+New Node Address (0,255)
2M Payload Radio Stop (Post landing)	"2MRS"
Update clock	"CLK" + Current time in Unix Epoch

Update Ground Level (Tells the computer onboard that the altitude its currently at should be considered ground level)	"UGL"
Update orientation (Computer gets a reading of current orientation and that tells it what is considered 0 pitch 0 roll 0 yaw	"UO"

Vehicle Telemetry

The vehicle will transmit to us using the 915 MHz frequency, using an open-source library made by Adafruit which is compatible with the commonly used RadioHead library. There is an automatic header which is applied, the important parts of the header are the broadcast address, which is the destination of the message, and the from address which is the address of the broadcaster. As above we will be able to change the destination address, with the destination being our ground station. The message packet itself has a length of 60 bytes available which will be broken out as follows

Gyro X Angle(3 bytes), Gyro Y Angle(3 bytes), Gyro Z Angle(3 bytes), Altitude(4 bytes), Airbrake deployment percentage(3 bytes), Main chute deployed(1 bytes), GPS Lat (10 bytes), GPS Lon(10 bytes)=37 bytes total+8 separator bytes = 45 bytes total

We aren't yet using the 60 bytes permitted which will leave room for the future if we need to add anything else to the packet of data that the vehicle is sending.

Goal 2 data collection and calculation

As per the state-machine graph the rocket will enter high-rate data collection mode during flight, creating an array of all datapoints at the highest rate possible. To collect and process data for each 8 points:

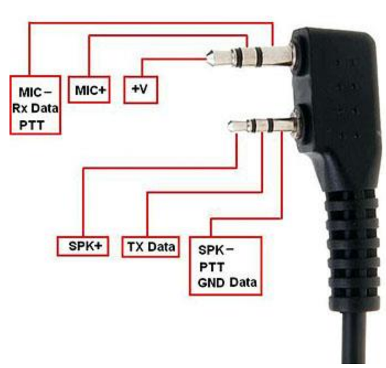
1. temperature which is being probed by our BMP390 altimeter which has an onboard temperature sensor. We are strategically placing this sensor away from heat generating components and near an opening in PERR-C so that accurate data can be collected
2. Our PA1010D GPS can get an accurate current date reading, but if no satellites can be reached for whatever reason, we have also included a command to send the current time from our 915 MHz ground station to the vehicle so that it can update its internal Real Time Clock (RTC) which is built into the ESP32-S3
3. Apogee is being recorded by our BMP390 down to a 0.25-meter accuracy, if we have a satellite lock the GPS can also provide fallback altitude readings. We have also included a command to tell the rocket what its ground level is currently at if it can't automatically determine that for whatever reason.
4. Maximum velocity is being recorded by our ADXL375 high G accelerometer, as a fallback the BN055 also includes an accelerometer.
5. Battery status is being recorded by a sensor that comes onboard our commercial Adafruit ESP32 S3 Board, we can query it for battery voltage/charge percentage at any time over the I2C bus

6. Landing velocity/G force sustained will be calculated at time of landing based on recordings made using the ADXL375 or BN055 fallback
7. Orientation of STEMnauts is being recorded with the BNO055 sensor fusion board which has a co-processor that calculates absolute orientation angles using a magnetometer, accelerometer and gyroscope
8. Calculated StEMnaut survivability will be calculated based on G forces sustained during launch, flight, and landing. A final percentage number will be output which will be the percentage chance that the STEMnauts have survived the flight. Only non-rotational g forces will be used for calculations. It will be calculated as such, a survivability score of 100 will be given at launch. As g force readings come in during the flight the survivability score will be subtracted from.
    a. G force readings over 9G's for more than 0.5 second, every additional half second will reduce the score by 10 points
    b. 15G for more than 0.5 seconds will result in a 35-point reduction
    c. 25G and above will be considered critical. If sustained for more than 0.5 seconds, the survivability score will be reduced by 75 points
    d. During landing, if the G-force exceeds 50G for even a moment, the score will be immediately reduced to 10, as it represents the threshold at which injury or death is almost certain.
    e. The score reduction is based on the highest load faced for a period of time (i.e if the Capsule encounters 25G on landing the reduction of 75 points wouldn't include the reduction for 15G and 9G readings on landing, but 9G on ascent would still face a reduction)

Goal 3 Interfacing with 2M radio and transmitting data points via TTS

The Baofeng UV-5R pictured below is an off the shelf 2M capable HAM radio. It is often used for its cheap price and small size.

On the right side of the radio (relative to the photo) is a Kenwood two pin connector which is used to interface with other audio equipment such as a headset, external PTT, or UART programming cable.



The only labels we are concerned with are MIC-/PTT, Mic+, PTT. Mic- and Mic+ are what will be connected to our microcontroller to send the audio signal itself to the radio to be transmitted. In this way our microcontroller would be acting as an external audio device. To allow for autonomous control of the PTT function we connect PTT (top lead) to PTT (bottom lead) and the radio will start transmitting, once this connection is broken the radio stops transmitting. So, by wiring these to our microcontroller we will have control over what the radio transmits and when it transmits, which can be programmed to be fully autonomous.

To form our TTS system, we will record a series of entries into the PEP computer; by combining these audio entries we can form a text to speech system. As stated above in Goal 2 the vehicle will have calculated and recorded all necessary data in text form.

Available audio entries

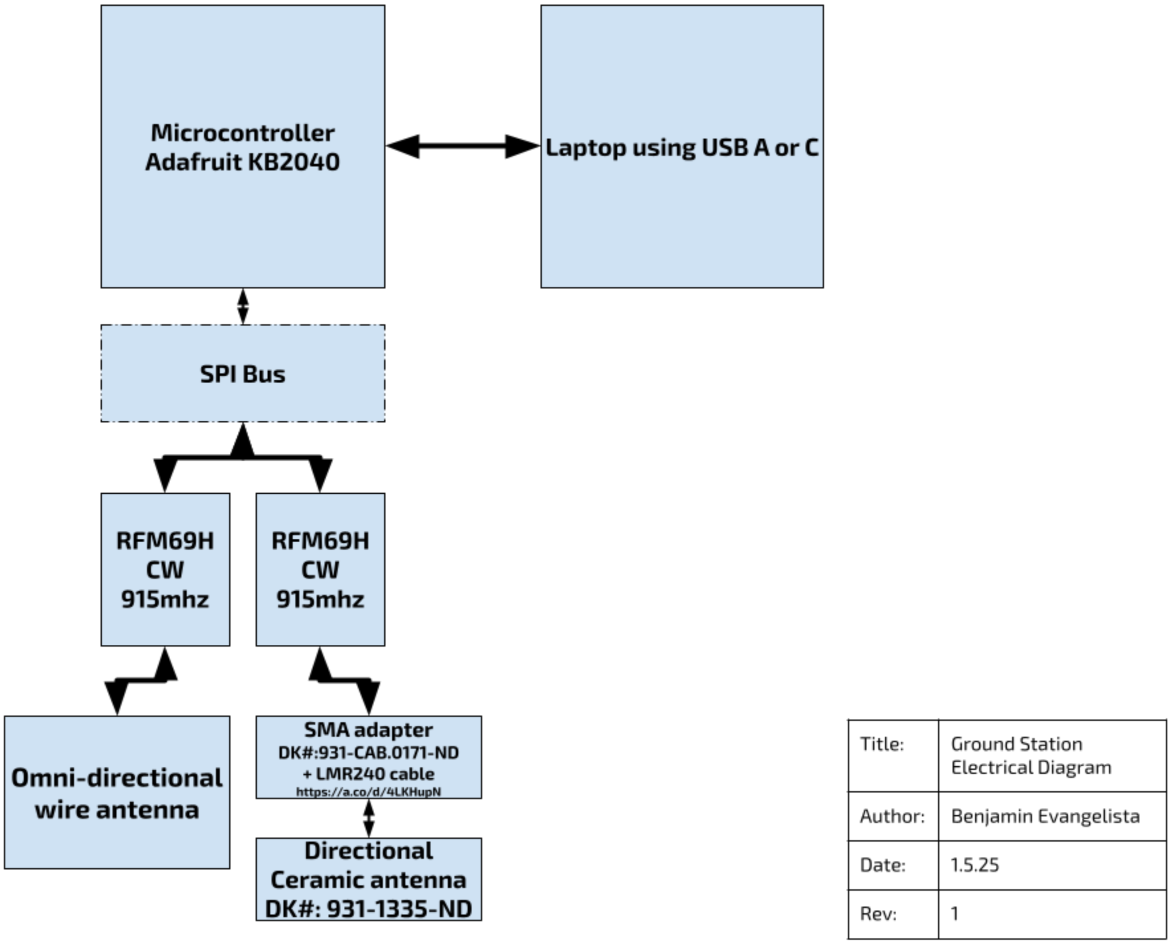
Temperature	Apogee	Time
Maximum	Battery Voltage	Battery
Orientation	Landing	Survivability
STEMnaut	Crew	Percent
Celsius	PM	AM
Degree	Velocity	G Force
Pitch	Yaw	Roll
Numbers 0-9	Phonetic alphabet	Normal pronunciation of each letter

By using a combination of these audio entries, the TTS system can form any message that would be transmitted over 2M radio for the 8 datapoints.

4.2.3.4 Custom Ground Station

Hardware+Embedded Code

The ground station is comprised of just a few components outlined below:



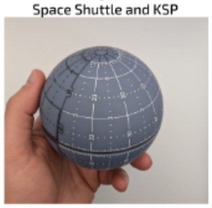
The ground station will utilize two separate radios, this will allow for directional and omnidirectional reception of signal packets. The Microcontroller will be responsible for preferring whichever radio has the highest Received Signal Strength Indicator (RSSI). Though there will be a manual override available in the ground station desktop software that'll allow the operator to choose which radio to prefer.

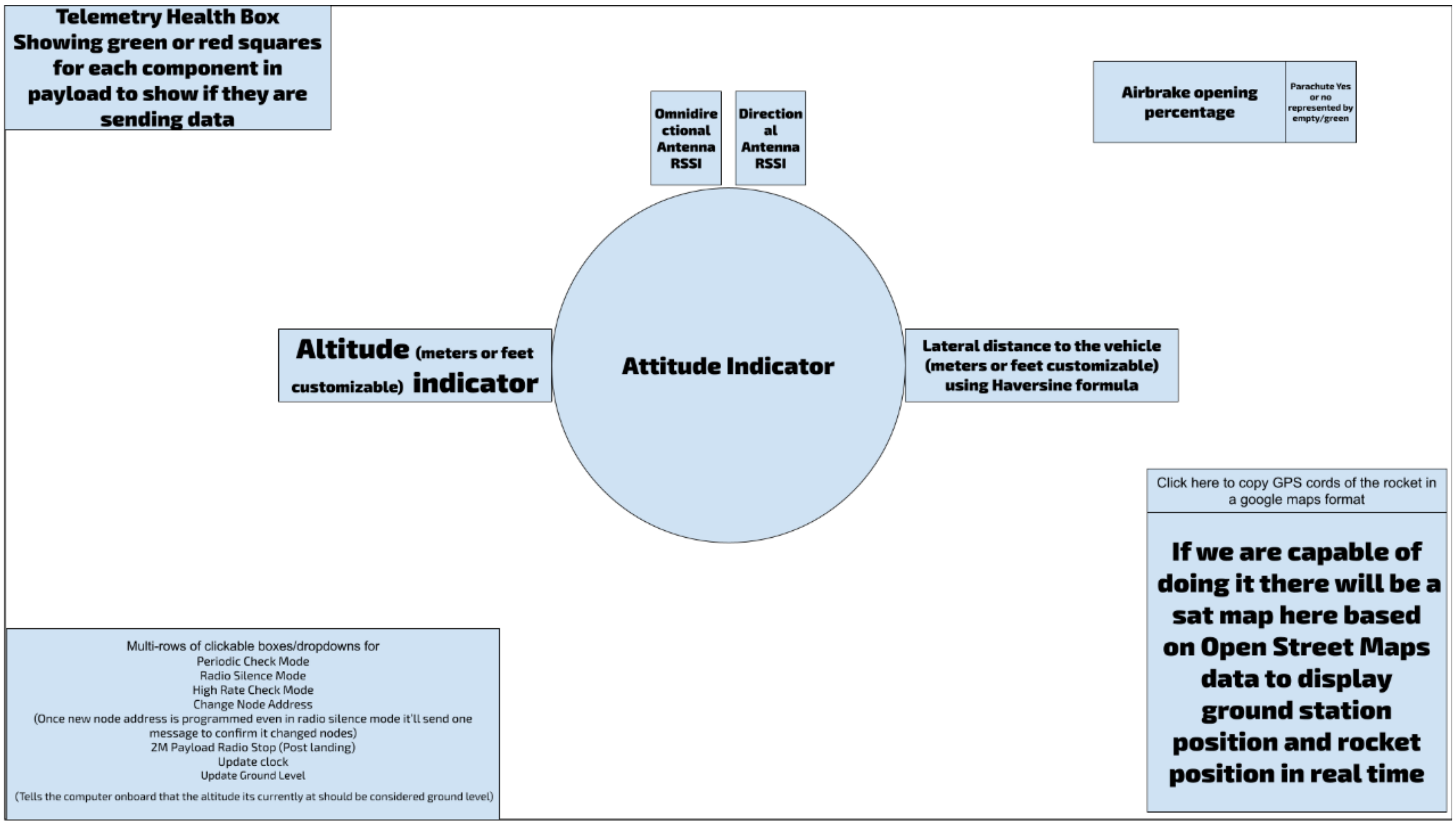
Desktop Software

Custom desktop software is being developed in Processing, which is capable of reading and sending serial data over the USB COM port.

Telemetry Health box inspiration taken from Nebulous Fleet command

Attitude indicator in a 3 dimensional style to that of the Space Shuttle and KSP





Title	Author	Date	Rev
Ground Station UI Outline	Benjamin Evangelista	1.5.25	1

4.2.4 PEP Analysis with PERR-C

- **900MHz/Packet Radio Broadcast Range**
  - While the listed range for the digital radio is significantly less than the distance our craft will travel on launch, this estimate is utilizing the omnidirectional antenna configuration, of which only the craft-side portion of our overall solution will be utilized. For the ground station, a directional antenna will be used to focus the range of the radio towards the rocket, giving it a longer overall distance along which info can be received from the craft. Testing regarding the selection of an antenna will begin upon the first test launch conducted by the team, posing a minimal revision that will occur to our system, consisting only of de-soldering and swapping the selected antenna type.
- **2M/144MHz Radio Selection**
  - The choice to outsource our 144MHz broadcast to the commercial Baofeng unit was a notable point of failure for our sub-team, but a necessary one given the state of the project relative to the time at which the choice was made. Several potential options were found to satisfy the need for transmission on this frequency, many of which could have been integrated into our central PCB. The reason these components were not selected was due to the lack of development board availability for them, meaning that our test bed could not be integrated with the device in a quick and efficient fashion, and by extension the necessary commands through which these ICs would be controlled via the processor could not be tested for implementation. The Baofeng and DAC combination is a reliable and quick way through which broadcast can be achieved, preventing us from needing to crunch the development timeline prior to the required deadlines.
- **BNO055 Selection**
  - The choice to utilize the BNO055 over other comparable options contradicts the goal of cost minimization outlined at the beginning of the subsection overview, but not without reason. Alongside the software development team, several competing chips were tested over the previous months to data acquisition rate relative to the needed response speed of our system. What we uncovered was that the majority of competing chips had issues quickly generating relevant data for transmission, oftentimes taking a whole second to output information, especially in the case of chips that required software-side translation calculations to occur in order for relevant position info to be found. The rate at which the craft is traveling dictates that the BNO055 is the best option for our system, even if utilizing such an IC raises the overall cost of manufacturing by some margin.
- **Final Revision PCB Layer Count**
  - The PCB presented within the subsection outline is a work-in-progress revision of our system, designed to reflect the physical positioning and composition of the device. As a team, we plan on making the swap to a four-layer design before ordering our PCB. The increased layer count was determined due to the need for a singular grounding plane to reduce potential inductances within our system, alongside the hardware development team’s desire for an additional power plane to keep the traces more organized. While the layout of the PCB is unlikely to change, trace alterations will be made before the first test launch of our team’s craft.
- **DAC Selection**
  - Our choice of DAC also runs counterintuitive to our original set of goals, increasing the overall complexity of the device through the addition of an I2S bus. The choice to use this specific IC

came at the request of the software engineering team, as the software-side implementation of this chip was significantly more applicable to our purposes than the other I2C enabled alternatives we initially proposed. Beyond this, the addition of the I2S bus is minimally complex, being only three wires and requiring no chip select pins or other similar additional connections. The swap to an increased layer-count PCB was done to alleviate some of the complexities that may be encountered through the introduction of this device.

- **BMP390/380 and ADXL375 Selection**
  - Neither of these chips are particularly spectacular in any way. In terms of what the team requires from these sensors, they both satisfy the resolution and power consumption needs of our device. Our justification in their selection instead is sourced from our familiarity with them, as both chips had been used in a previous, non-competition-related flight computer that the team was able to inspect during the early months of development. Familiarity in this case aligns itself with our declared goal of simplicity, as a greater breadth of knowledge on behalf of the team means that there are fewer overall roadblocks that could be encountered on our path to completion, thereby making our device "simpler."

4.3 Altitude Control System

The Altitude Control System (ACS) is an active airbrake system designed to regulate the vehicle's ascent by modulating drag, thereby ensuring precise apogee control. This system was developed to reach an altitude of 5500ft, compensating for propulsion inconsistencies, aerodynamic variability, and environmental factors.

The ACS was a ground-up development, evolving through iterative testing and performance characterization. The initial design from the Preliminary Design Review (PDR) featured a split-clamshell airbrake system, which was later revised due to structural risks and excessive drag force that could cause rapid unscheduled disassembly (RUD).

Key changes since PDR:

- Braking surface constraints – Reduced to ¼ of the rocket diameter to mitigate aerodynamic instability.
- Actuation angle limits – Deployment restricted to 30° to maintain structural integrity.
- Actuation mechanism redesign – Transitioned from a lead screw-based actuation to a rack-and-pinion system for compactness, efficiency, and responsiveness.
- These changes optimized performance, reduced risks, and improved reliability in real-flight conditions.

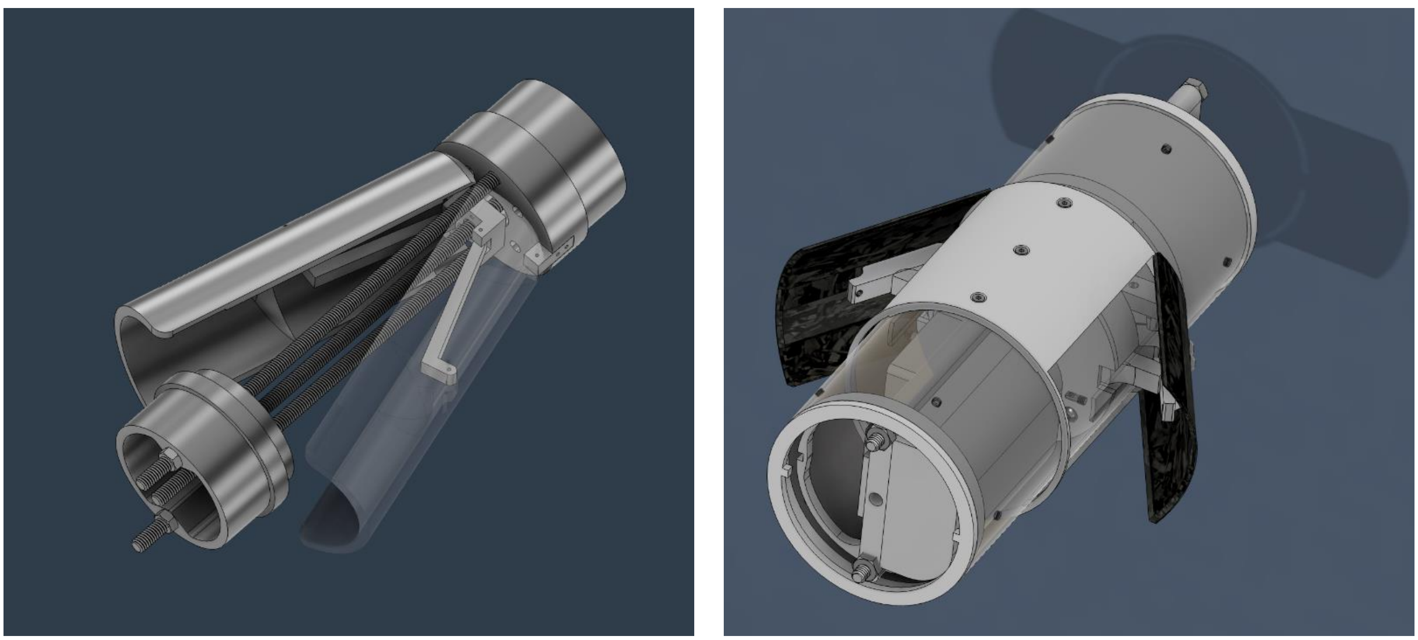


Figure 4.1: ACS Design Evolution Old – New

4.3.1 ACS Subsystem Design

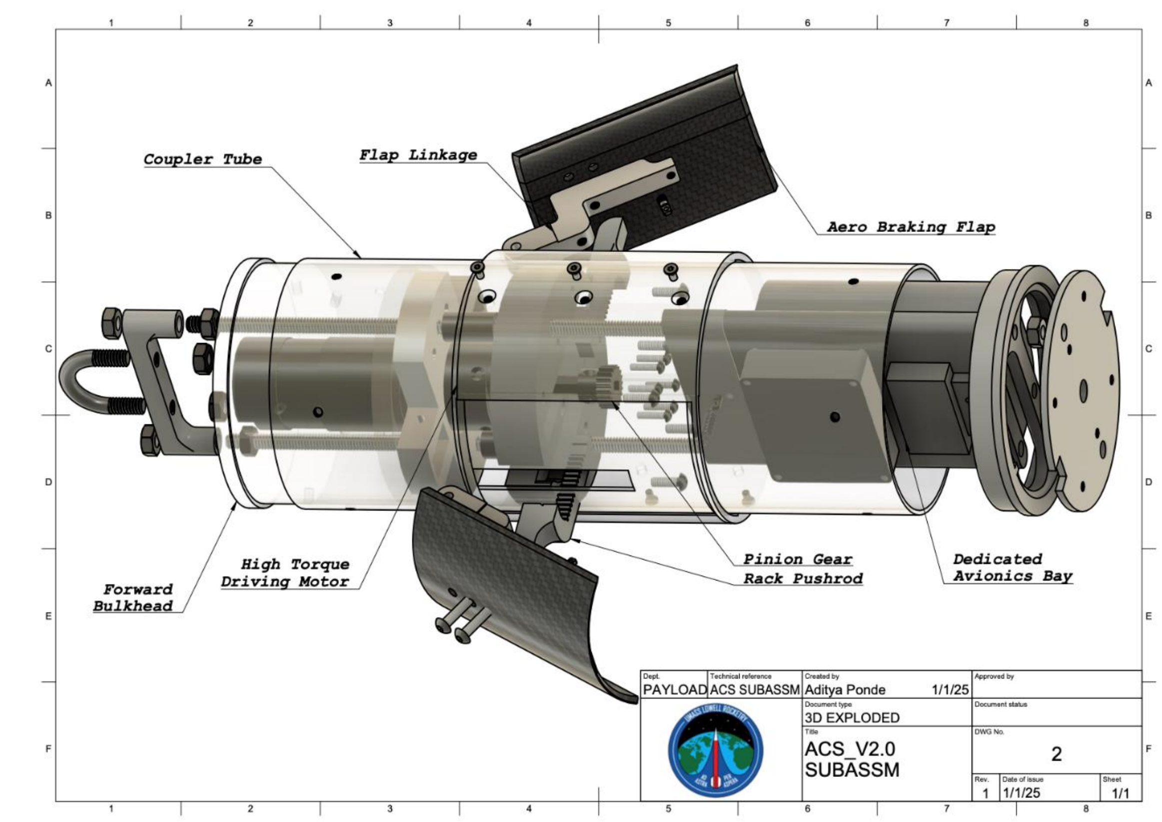
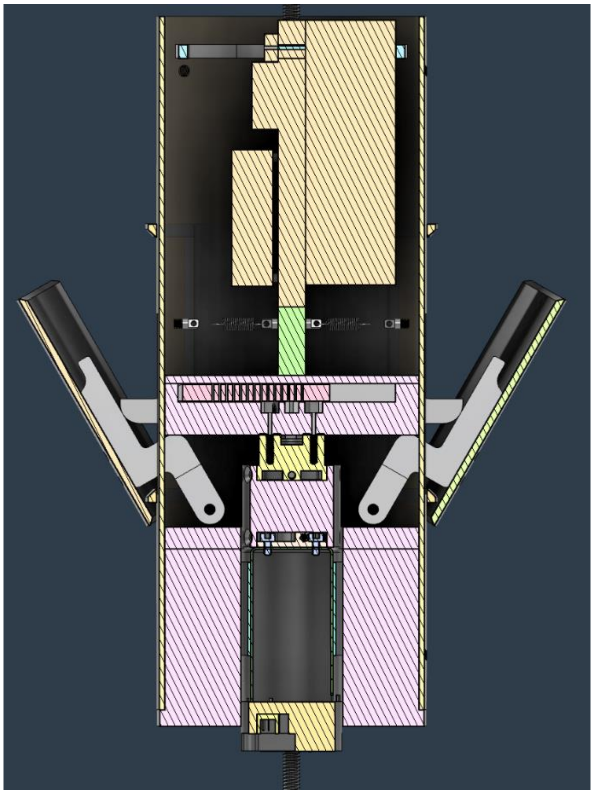
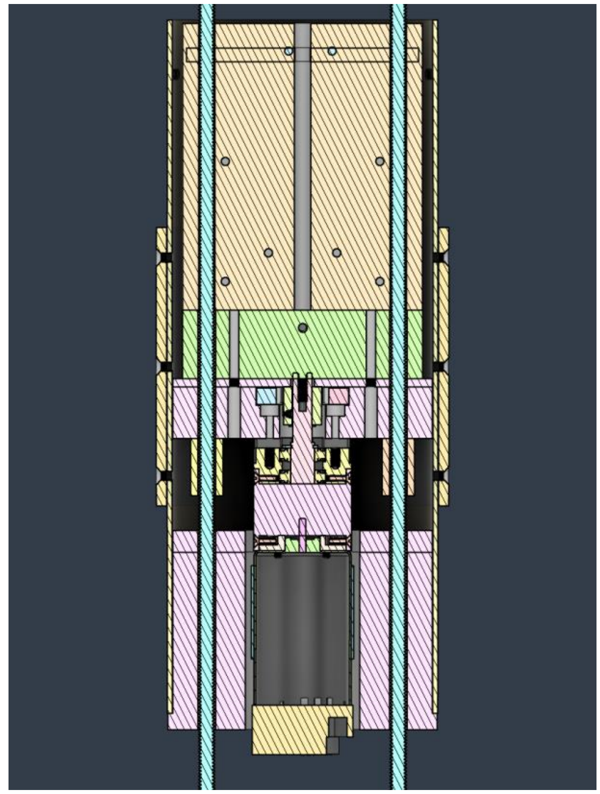


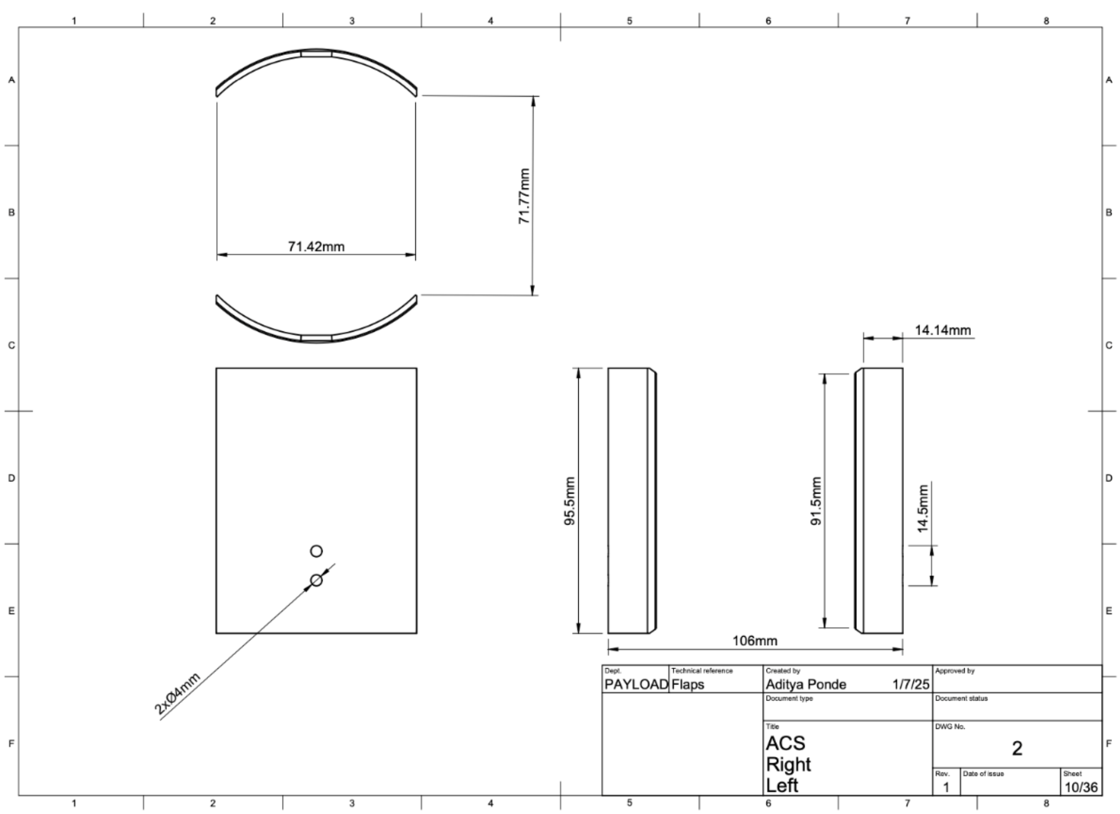
Figure 4.2: ACS Subsystem Assembly Exploded view

The design of this payload allows it to be fully independent in terms of power and computing required to record and process telemetry. It features a dedicated avionics bay powered by a **3S LiPo battery**, which supplies power during both flight and standby. This battery also drives the **motor**, which controls a **rack and pinion actuator** to deploy the flaps. The entire system is enclosed within a **3x coupler-length tube**, which is integrated between the **main body** and **booster sections** of the rocket. To ensure structural stability and functionality, key dimensional constraints were implemented:

- Braking flap circumference limited to ¼ of its circumference.
- Flap length restricted to span the length of the switch band.
- Structural integrity maintained by keeping ≥25% of coupler area intact.

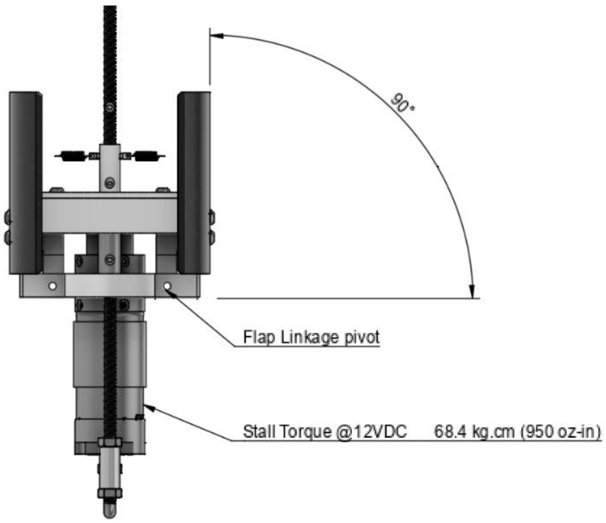


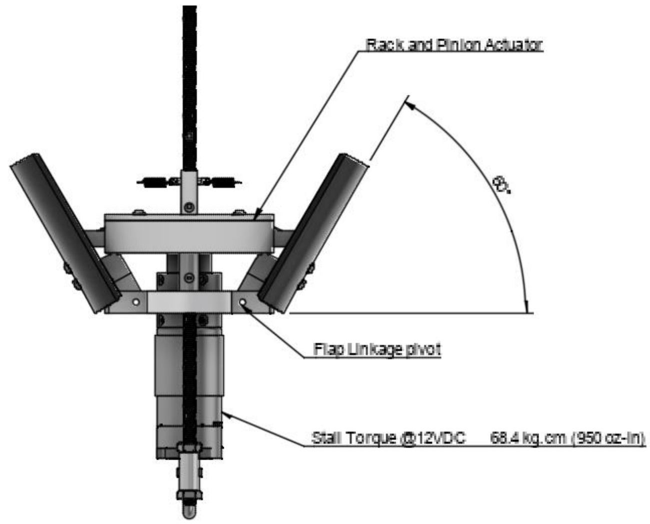


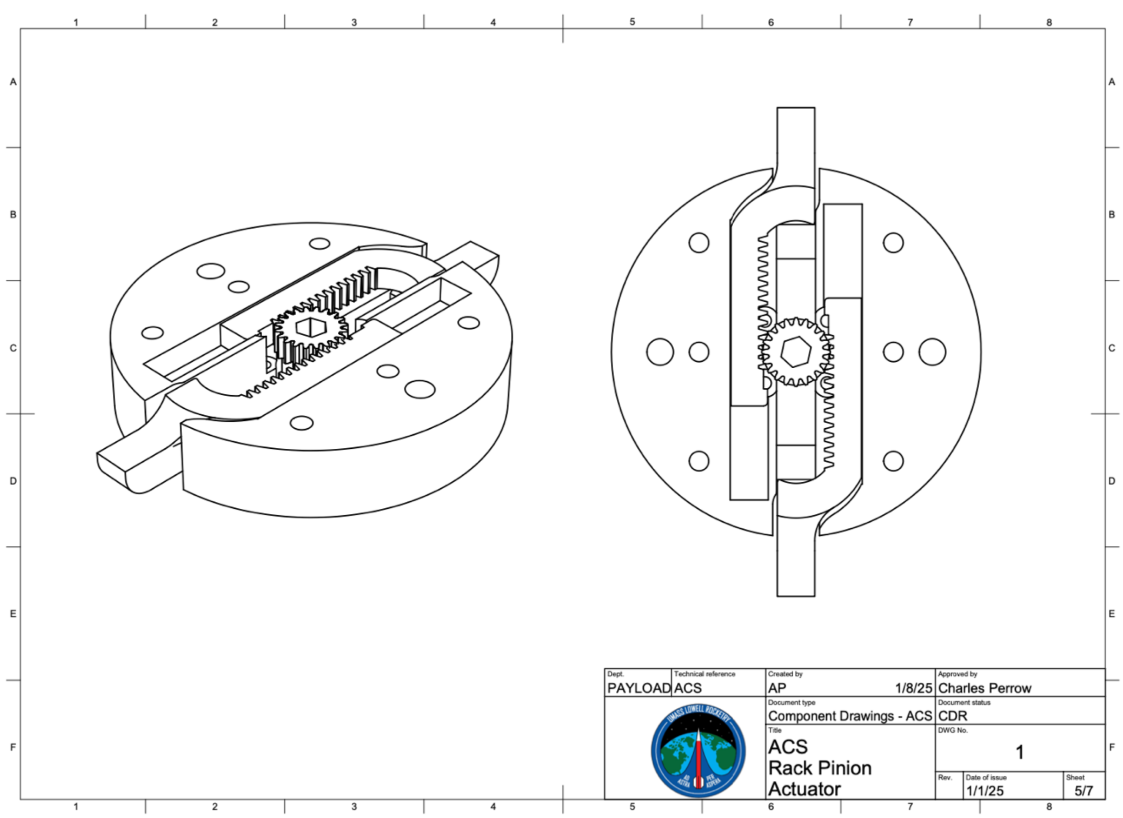

71.42mm
71.77mm
14.14mm
95.5mm
91.5mm
14.5mm
106mm
2xØ4mm
Dept.
PAYLOAD
Technical reference
Flaps
Created by
Aditya Ponde
1/7/25
Approved by
Document type
Document status
Title
ACS
Right
Left
DWG No.
2
Rev.
1
Date of issue
Sheet
10/36

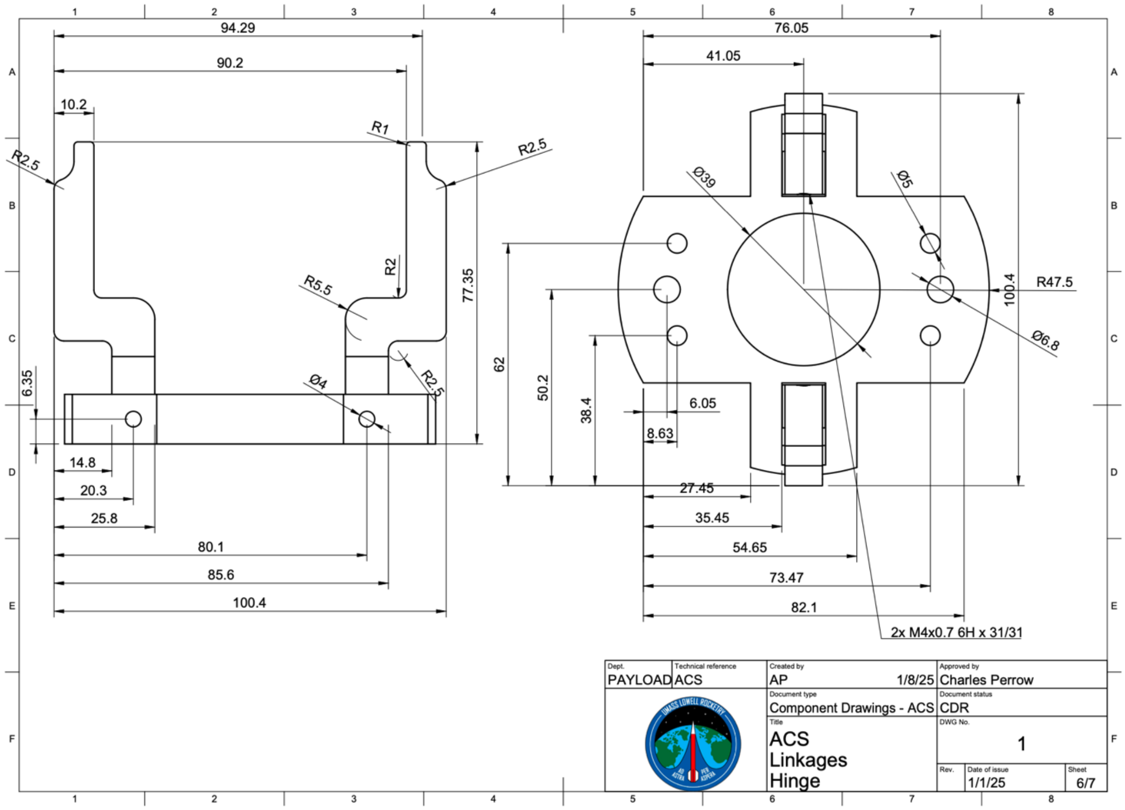
4.3.1.1 ACS Mechanical

The ACS mechanical system consists of a high torque motor that drives a rack and pinion actuator. The rack acts as a pushrod to deflect hinged linkages that the flaps mount. The linkage arms are hooked to an extension spring that is responsible for keeping the flaps in their closed position passively. This removes the reliance motor to keep the ACS inactive and improves safety.









4.3.1.2 ACS Electrical

Keeping in line with PEP's goal of simplicity, ACS is also dictated primarily by the software and mechanical portions of this subsection, although in this case more priority is given to the mechanical portions of the design. Due to the similarity in means of accomplishing the tasks needed by ACS, the majority of the system for this section of the craft is a duplication of the PEP system. For the sake of condensing the length of this report, the electrical subsection will cover primarily the differences between the two systems, rather than re-stating the majority of the previous section. To start, a new set of goals were outlined upon the introduction of this system, being safety, accuracy, and responsiveness.

1. Safety
    a. The nature of this portion of the craft means that a failure in any singular part of our design has the potential to escalate significantly, with airbrake damage potentially steering our rocket off-course and risking damage to nearby structures or individuals.
    b. Paramount in our considerations for component selection should be both the reliability and harm potential for any given option. Reliability in this case means that any component related to the driving of the motor should have recorded widespread application in similar situations, from which the team can draw from in relation to any issues encountered in development. Similarly, harm potential refers to the component's ability to cause harm towards either the craft or it's surroundings, either through accidental discharge of the high voltages necessary to drive the mechanical team's selected motor, or via critical failure during flight time.

2. Accuracy
    a. Moving aerodynamic parts are inherently sensitive to deviation, a factor that only escalates as the speed through which the device in question moves. For our purposes, accuracy should refer to not only the resolution at which a component can be adjusted, but also how precise its motion is. An exact level of actuation must be reached by the system to prevent unaccounted for behaviors from occurring.
3. Responsiveness
    a. Responsiveness is the simplest of the three requirements, simply denoting that the solution should be able to begin and end actuation at the proper time and place relative to the inputs to the system. These two descriptors refer to both the place of the craft and the place of the system in its localized motion. The selected components should not have the ability to break ACS, either through their inherent nature or through safeguards implemented within the system.

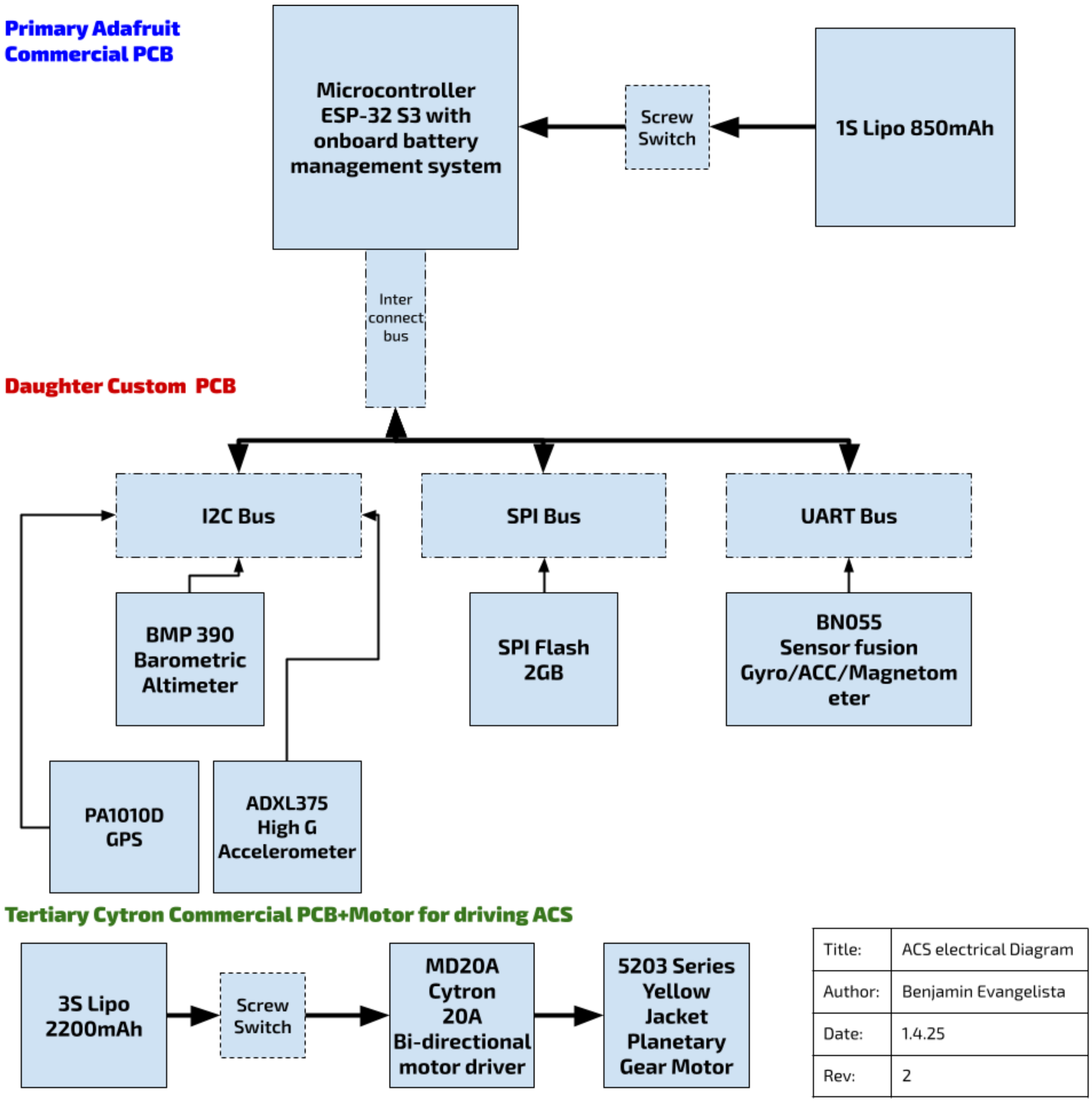
Component Deviations

	Chosen Component
Motor Driver	Cytron 20A Driver
DAC	Removed
2M Radio	Removed

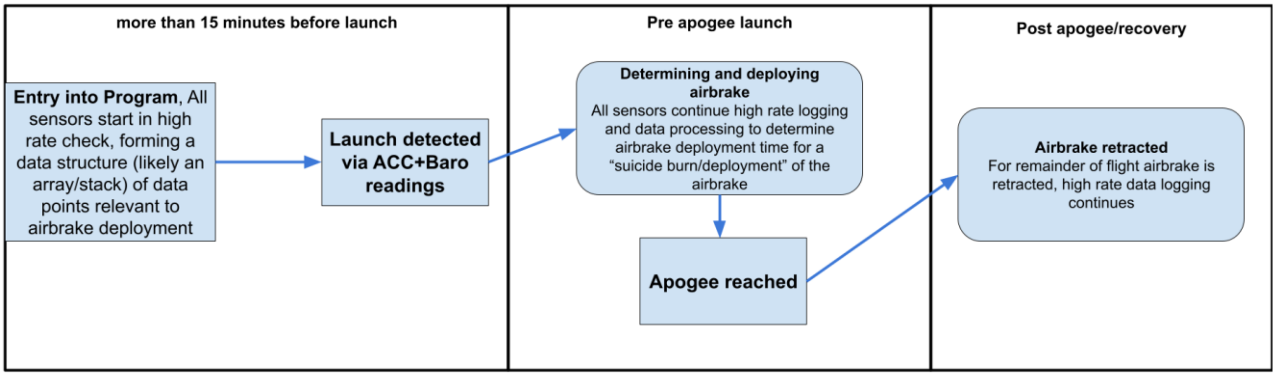
- Motor Driver Overview

	Cytron 20 Amp Driver
Connection Type	Standard PWM Control
Typical Output Current	20A Continuous, 60A Max
Operable Voltage Range	Digital Int.: 1.8 < V < 12 Motor: 6 < V < 30

System Control Flow Graph:



4.3.1.3 ACS Code



- **PCB Alterations**
  - Rather than create a separate PCB for the ACS system, the same PCB utilized in PEP will be used, with the irrelevant/removed component slots sitting vacant. This is being done primarily as a cost saving measure, but also due to the fact that interfacing with the driver board is merely a matter of wiring three connections between the ESP32 and the control inputs and providing a clock and relevant logic signals for each pin. No alterations of the PCB are needed, nor can they be justified in any context.
- **Power Considerations**
  - The operating voltage and current levels of the DC motor used to drive ACS is significantly more than what is present in, or can be generated by, the PEP system. Therefore, a separate 3S lipo will be added to the electronics bay for the purpose of powering the driver board. Decoupling the power sources for both boards has the benefit of completely disjointing any negative impacts that may occur in one system. Separating batteries prevent any voltage ripples that may occur in ACS from affecting the operation of the PEP duplicate.
- **Cytron Driver Justification**
  - A separate driver board was opted for both at the recommendation of the mechanical team, and the professors overseeing our project. While no component exists within the Cytron system that we could not reasonably implement ourselves, doing so is disadvantageous to the team relative to our time constraints, and relatively unsafe. Utilizing a mass-produced and consumer tested driver board assures that there is a lower chance of failure, and of harm being done to the craft or our development team, fulfilling one of the requirements set out at the onset of the section overview.
- **Component Removals**
  - As no transmissions on the two-meter band need to be carried out by ACS, the components related to completing said task can be left vacant on the PCB. This acts as a cost reduction and weight saving method as well. The 900MHz transmission hardware remains in the craft as to allow the software team to monitor the behavior of the airbrake throughout the rocket's flight if desired.

4.3.2 ACS System Analysis

4.3.2.1 Load Analysis

The purpose of the load test is to evaluate the structural integrity, durability, and performance of the ACS under expected aerodynamic and mechanical loads encountered during flight. This ensures the system can withstand operational stress while maintaining reliability and safety.

Methodology

1. Structural Load Testing

- A Fusion 360 static stress study was performed to analyze the stress distribution on the ACS flap under expected aerodynamic loads.
- A 400 N force was applied at a 60-degree offset from the flap surface to simulate maximum aerodynamic pressure.
- The selected material was forged carbon fiber composite, chosen for its high strength-to-weight ratio and ease of manufacturability.

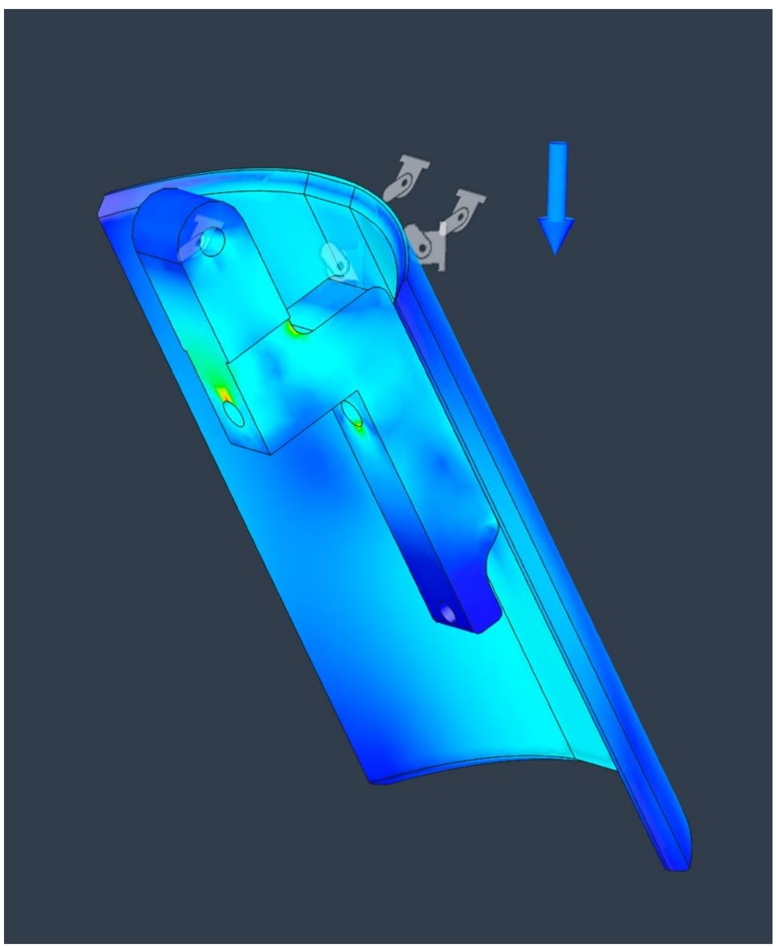


Figure: ACS Flap and linkage stress concentration image

Findings and Results

- **Structural Analysis:** The stress simulation indicated that the ACS flap maintains structural integrity well beyond the expected flight conditions.
- **Load Distribution:** The highest stress concentrations were observed near the actuator mount points, which were reinforced to mitigate failure risks.
- **Actuator Performance:** The motor was determined to have sufficient torque to overcome aerodynamic drag and extend the flaps under flight conditions.
- **System Reliability:** The overall ACS design was deemed reliable, with **no significant deformation** or structural failure under peak loading conditions.

Conclusion and Recommendations

The load testing confirmed that the ACS meets the structural and actuation force requirements necessary for successful operation. We do, however, must test practically with a built prototype in the future.

4.3.2.2 Performance Analysis

4.3.2.2.1 Aero Analysis

The primary objective of this analysis is to evaluate the effectiveness of the ACS in limiting the vehicle's apogee to the target altitude of 5,500 ft. This requires a comprehensive assessment of the aerodynamic forces introduced by the airbrakes and their impact on the vehicle's flight performance.

CFD Methodology

To achieve a high-fidelity drag profile that accurately reflects the real-world operation of the ACS, we employ a multi-step computational approach integrating Computational Fluid Dynamics (CFD) and 6-DOF flight environment built in python. OpenRocket alone cannot simulate protrusions such as airbrakes; therefore, we augment its body drag calculations with externally derived aerodynamic coefficients.

CFD 3D model development

A parametric CAD model of the rocket was developed in Fusion 360, incorporating the ACS in various deployment states. Five discrete configurations were modeled:

1. 0° Deflection – No deployment (control case for comparison and validation)
2. 5° Deflection – Initial deployment phase, transitioning from passive to active states
3. 15° Deflection – Intermediate deployment state during modulation
4. 25° Deflection – Advanced deployment phase nearing full extension
5. 30° Deflection – Full extension representing maximum braking force

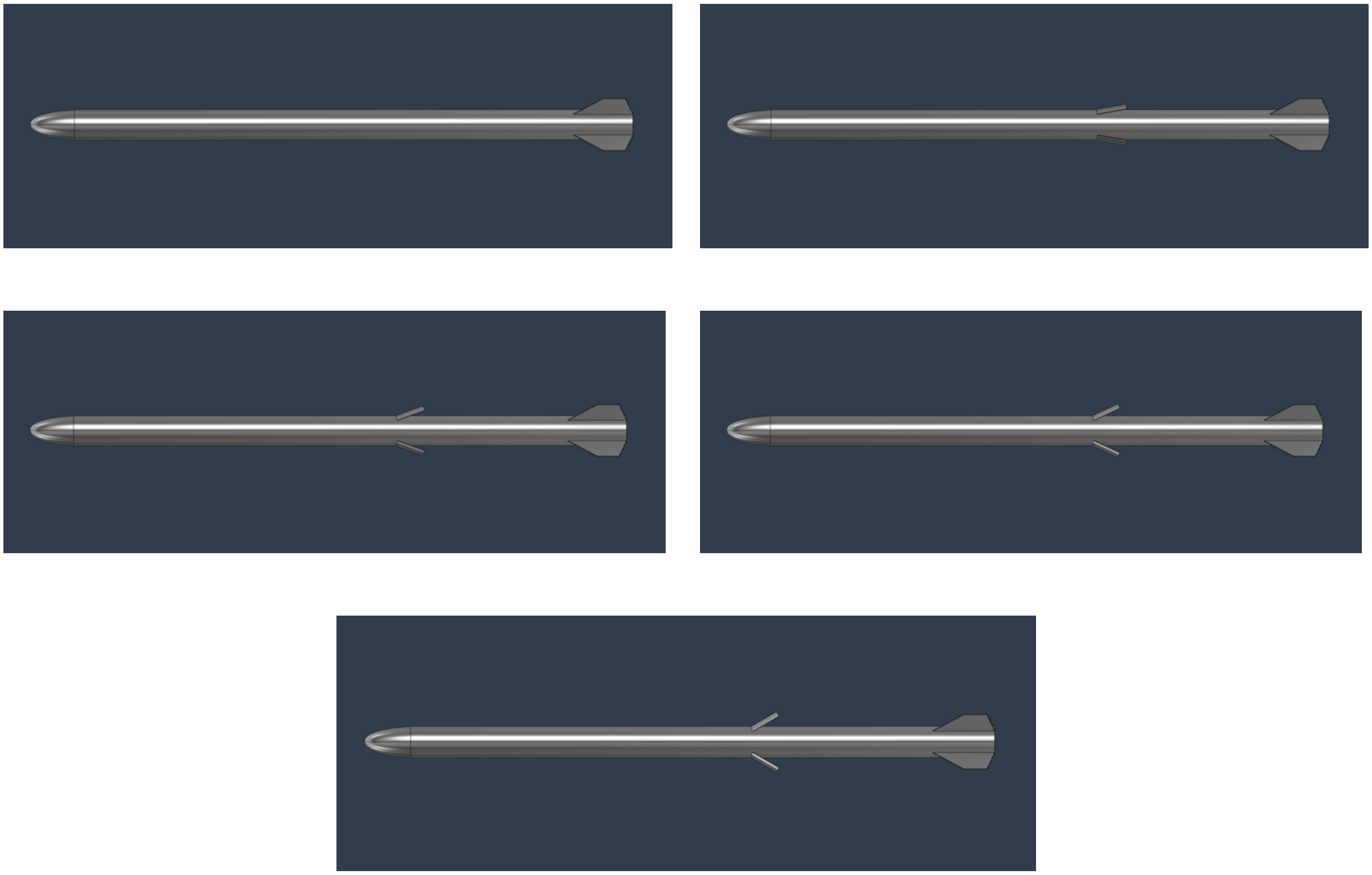


Figure:0,5,15,25,30 Deg deployment models

To ensure consistency, the CAD models were dimensionally matched to OpenRocket's representation of the rocket.

CFD Simulations

Once the CAD models were finalized, they were imported into Autodesk CFD Ultimate for aerodynamics characterization. CFD provides a detailed understanding of the pressure distribution, flow separation, and turbulent effects introduced by the ACS.

The 0° deflection case serves as a validation benchmark, comparing CFD-derived drag coefficients against OpenRocket simulations. Any significant deviation would indicate the need for environmental adjustments.

Simulation Setup

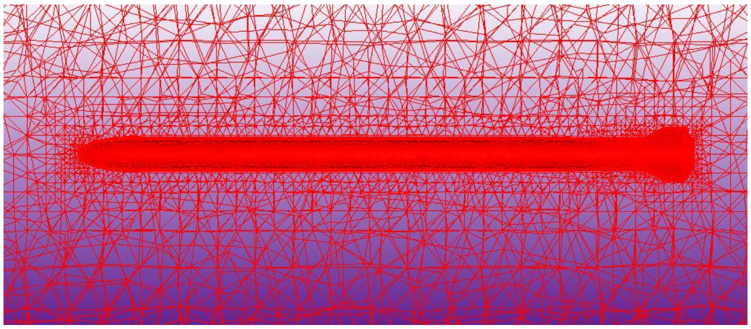
The simulation setup was very important as we wanted it to reflect the drag of the vehicle in realistic conditions which were carefully considered:

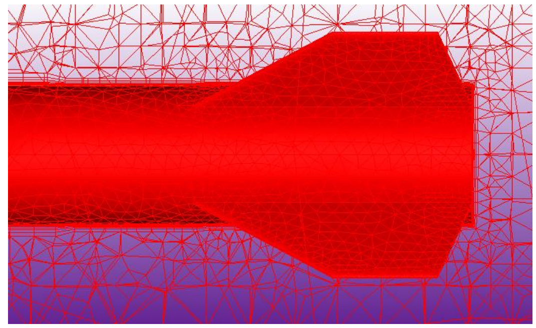
Setup Variable	Condition	Reason
Fluid Domain	Air	Vehicle is airborne
Model Material	Aluminium	Reasonable assumption with adjustment to surface texture for frictional losses
Pressure	998 mbar	Reasonable based on assumed operation altitude of the vehicle
Temperature	13.55C	Reasonable based on assumed operation altitude of the vehicle
Inlet Boundary (nosecone side)	Velocity Normal: (10-300)m/s	Reasonable based on assumed operation velocity of the vehicle
Outlet Boundary	Pressure: Static pressure drop to 0	Required to encourage fluid to behave like freestream air in simulation
Sidewalls (flow field)	Slip condition	Required to limit fluid interaction to 3D model and not the flow field

Meshing Strategy

A meshing strategy was also developed to study the effects of the boundary layer properly. The strategies used were:

- Fine mesh refinement near the rocket's surface to accurately capture boundary layer effects
- Higher element density around the airbrakes to resolve turbulent wake structures
- Overall mesh size constraint: Limited to 200,000 elements for computational efficiency





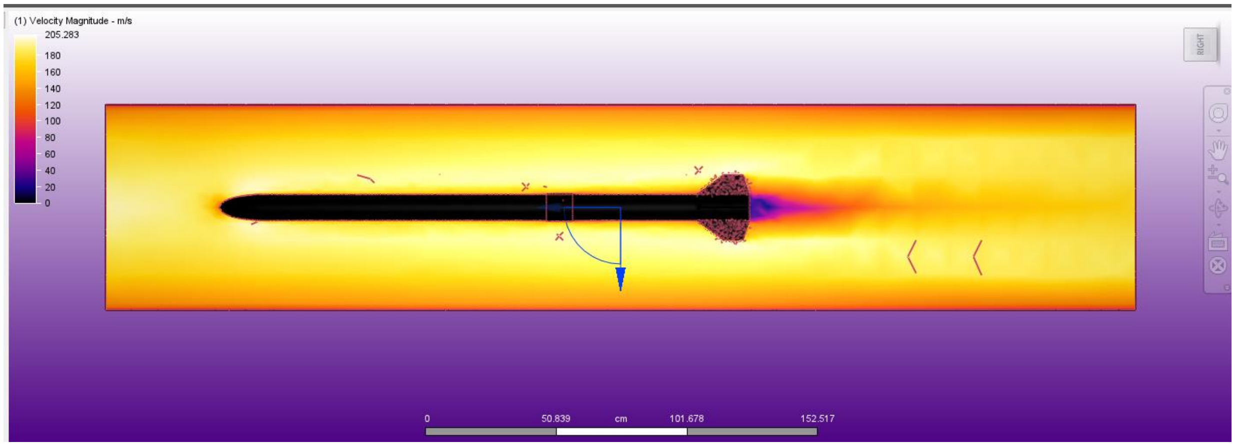
Solver

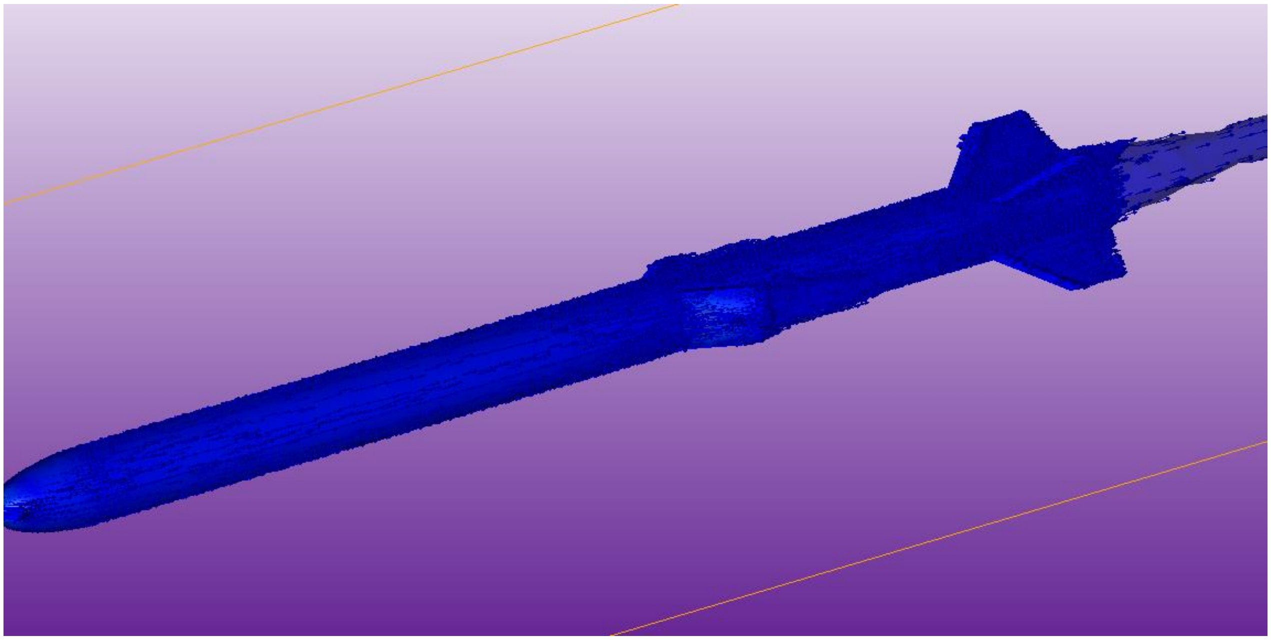
The solver used was SST-K Omega which is optimized for fluid flow near boundaries and the simulations were run in batches of 4 in parallel which allowed for a very high resolution drag profile of the vehicle.

Results

The specific results extracted from the simulations were:

- Drag Coefficient Matrix for each deflection state over a range of velocities
- Visualizations of flow separation and turbulent eddies
- Comparison against OpenRocket baseline data to ensure validity





Integration with Flight Simulations

Following CFD validation, drag coefficients (Cd) at various speeds and deployment angles were compiled into a matrix for integration into a python based 6-DOF flight simulator. This simulation accounts for:

- Variable mass effects as propellant burns
- Aerodynamic instabilities such as roll and tumble
- Parachute deployment sequences

To ensure simulation accuracy, the CFD-derived body drag (without ACS deployment) was compared against OpenRocket simulations. This was accomplished through a Python-based error-checking script, cross-referencing results across various flight velocities.

Reference simulation results (No ACS):

Maximum Speed: 257.591 m/s at 1.79 s
Maximum Mach Number: 0.746 Mach at 1.79 s
Maximum Reynolds Number: 1.650e+06 at 1.79 s
Maximum Dynamic Pressure: 3.826e+04 Pa at 1.79 s
Maximum Acceleration During Motor Burn: 188.444 m/s² at 0.13 s
Maximum Gs During Motor Burn: 19.216 g at 0.13 s
Maximum Acceleration After Motor Burn: 3.643 m/s² at 36.23 s
Maximum Gs After Motor Burn: 0.371 Gs at 36.23 s
Maximum Stability Margin: 4.110 c at 1.86 s
Apogee Time: 18.578 s
Apogee Altitude: 1935.822 m (ASL) | 1935.763 m (AGL)
Apogee Freestream Speed: 19.502 m/s

ACS Deployment and Control Analysis

With validated drag profiles, dynamic ACS behavior was implemented as a function within the simulator, incorporating:

- Actuation delay modeling
- Real-time drag modulation
- Deployment constraints based on structural integrity limits

An extreme case scenario was tested where the flaps were fully deployed ("suicide deploy") at 450 ft AGL, with altitude data analyzed to determine how effectively the system capped the apogee.

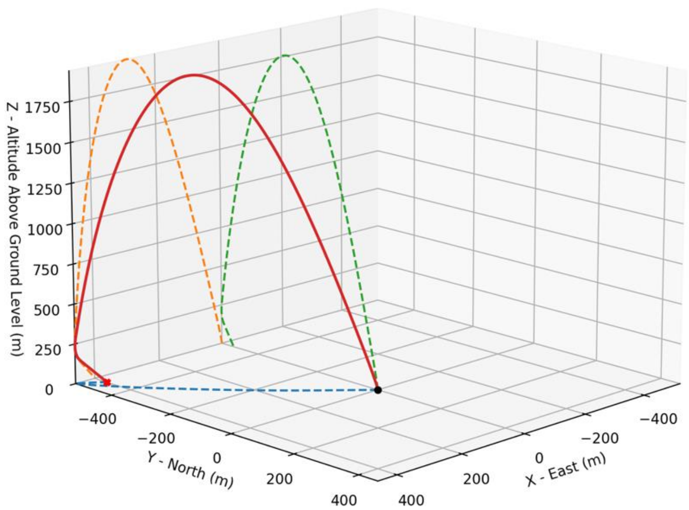
Performance Evaluation Metrics

1. Target altitude accuracy – Did the ACS achieve a controlled apogee within the design limits?

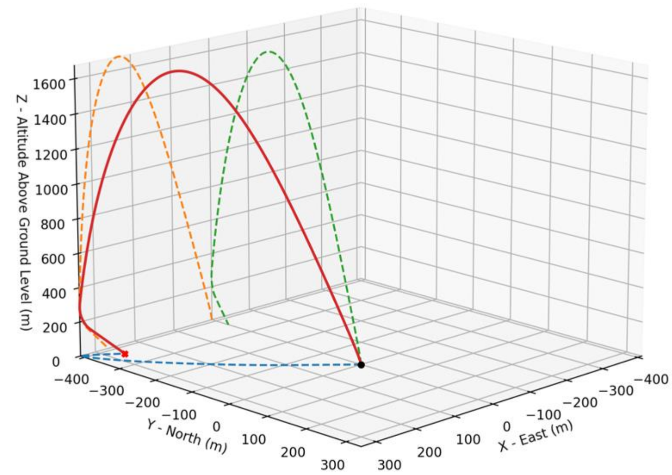
3. Aerodynamic stability – Did the deployment introduce excessive oscillations or instability?

Simulation results with ACS active:

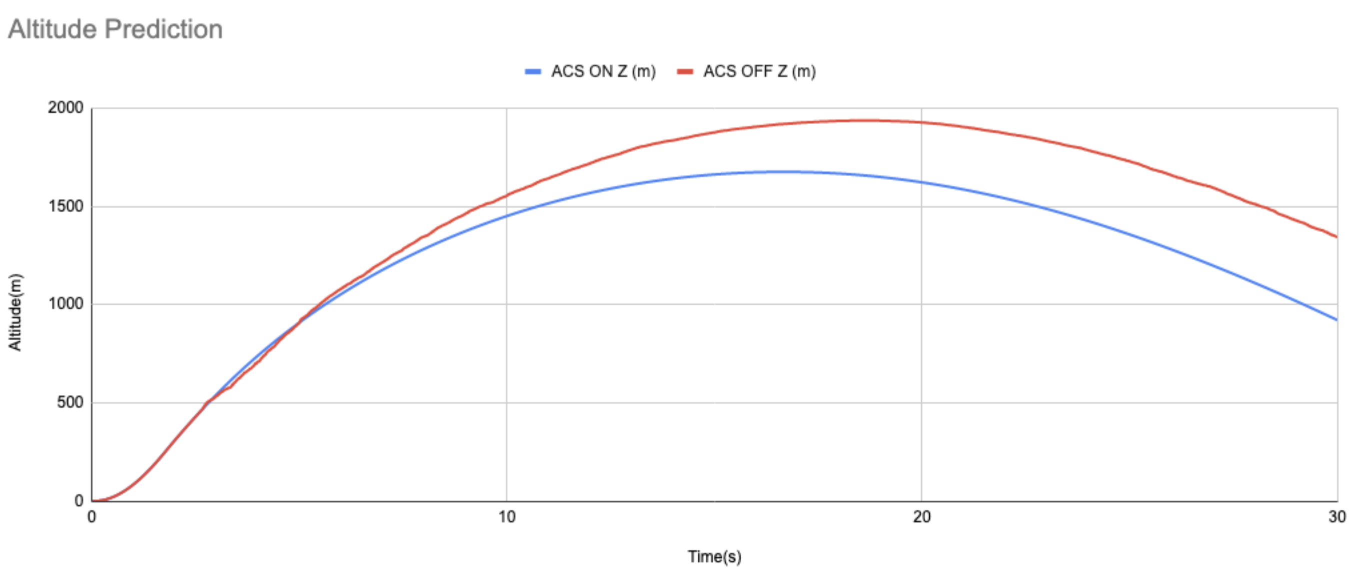
Maximum Speed: 257.591 m/s at 1.79 s
Maximum Mach Number: 0.746 Mach at 1.79 s
Maximum Reynolds Number: 1.650e+06 at 1.79 s
Maximum Dynamic Pressure: 3.826e+04 Pa at 1.79 s
Maximum Acceleration During Motor Burn: 188.444 m/s² at 0.13 s
Maximum Gs During Motor Burn: 19.216 g at 0.13 s
Maximum Acceleration After Motor Burn: 2.829 m/s² at 32.67 s
Maximum Gs After Motor Burn: 0.289 Gs at 32.67 s
Maximum Stability Margin: 4.110 c at 1.86 s
Apogee Time: 16.658 s
Apogee Altitude: 1674.805 m (ASL) | 1674.745 m (AGL)
Apogee Freestream Speed: 16.194 m/s
Apogee X position: 229.771 m
Apogee Y position: -239.479 m



ACS Off



ACS On



This analysis serves as a proof of concept, demonstrating that ACS will perform as expected.

4.4 Payload Safety

4.4.1 ACS Subsystem Safety

ACS has a few factors that need to be accounted for in safety, the airbrake itself is movable and may catch on someone, and the system contains both a 1 cell lipo for powering the computer, and a 3 cell lipo for powering the motor. Both batteries have the potential of overvoltage, electrical short, or puncture which would cause a class B/D fire. The 1 cell lipo has integrated electrical protection from a battery management system located on the ESP-32 S3 Feather Adafruit board. The 3-cell battery is protected from overvoltage via the Cytron MD20A motor driver board. We have added a 30-amp fuse to account for the possibility of a short circuit in the 3-cell lipo battery. Structurally, the fins need to be able to handle the forces seen from flight once they are open. To do this, we self-imposed a 30-degree opening limit on the ACS, on top of our minimum 3.0 factor of safety.

4.4.2 PEP Subsystem Safety

Payload has only one notable safety concern that being the 1 cell 850mAh battery for the payload computer, and the 2 cell Baofeng UV-5R battery pack. Both battery packs pose the risk of a lipo battery fire if they are overvolted, shorted, or punctured. To mitigate electrical related risks both the 1 cell and 2 cell batteries have battery management systems. The 1 cell has integrated overvolt, and short circuit protection provided to it by the ESP-32 S3 Feather Adafruit board. The 2 cell batteries are in the form of a battery pack which slots directly into the UV-5R, and thus already have integrated battery management.

4.5 Payload testing

4.5.1 PEP testing

1. Test 915 MHz range with omnidirectional antennas and directional antennas
2. Test HAM radio automation integration with PEP electronic payload
3. Test datalogging and data exfiltration from the board
4. Test full integrated payload
5. Test for 915 MHz radio dropout if it occurs with airbrake deployment, as the airbrakes are carbon fiber
6. Test 915 MHz and 2m band radios for issues with deployment charges
7. Test all commands to payload outlined in 4.2.3.3

4.5.2 ACS testing

ACS PEP testing needs:

1. Test ESPNow radio communications between ACS and Payload to transmit airbrake opening percentage
2. Test ESPNow for issues with deployment charges
3. Test ACS motor and motor driver board integration, making sure the system can drive the airbrake
4. Test full integration of all electronic components and the airbrake

ACS mechanical testing needs:

1. Test fins in UML wind tunnel to gain more accurate drag coefficient

5 Safety and Procedures

Safety, in all situations, is a paramount team priority. Failure could cause deadline insecurity, pose financial difficulty, and most importantly, severely hurt someone. As such, ensuring that all equipment, environments, properties, and people around the vehicle and launch area are safe is critical. Therefore, writing procedures according to the known danger of any situation is the best way to keep everyone safe at the team's scale.

5.1 T – 3 Hour Pre-Launch Procedure

List of Team Members and Responsibilities

Team Lead "Flight"	Moves team through procedure, Signs off on Critical items for Payload Systems.
Safety Officer "VSO"	Ensures safety gear is being worn, Signs off on critical items from Recovery and Structural Systems.
Operations Time Controller "OPS"	Responsible for managing time on launch day, letting the team know how long they spent on a task. Calls out time after lift-off the launch.
Payload Experiment Systems Officer "EXO"	In charge of all payload (PERR-C / ACS) systems on the rocket
Payload Antenna Operator "PAO"	Operator of the 915mhz high-gain antenna that communicates with PERR-C
Capsule Communication "CAPCOM"	In charge of communicating to PERR-C via its ground station
Structural Systems Officer "Booster"	In charge of assembly of the vehicle and inspection of the aerostructural components
Recovery Systems Officer "RECO"	In charge of recovery systems and tracking systems team. Assembles the ARCS bay.
Telemetrum Tracking Operator "T2"	Operator for the 433mhz High-gain antenna connected to Telemetrum
Telemetrum Data Relay Officer "T-DRO"	Member in charge of using the Telemetrum ground station and calling out vehicle location
RED TEAM	Group of 5 members that brings rocket to pad and prepares the vehicle for flight. Members include the safety officer, team mentor, and a member of the recovery, payload, and structures teams.

5.1.1 Hazards

Section 5.1.3 Steps 1-4 requires Eye Protection during testing and integration of Ejection Charges
Section 5.1.6 deals with motor assembly and integration, Flames and live batteries should be kept away during this section to prevent accidental ignition. Igniters should never be installed while the rocket is stored. Disconnect ignitors if the rocket is to be stored. Shunt must be placed on igniter until rocket reaches the pad. If said shunt is missing, twist exposed igniter cables together multiple times.

5.1.2 ARCS Integration

1. Remove the service camera shield, arming pin, junction box door, and fore bulkhead from the ARCS frame.
2. Ensure that the screw switches within the ARCS junction box are disconnected/unscrewed.
3. Orient the service cameras such that they are stowed within the interior curve of their mount.

4. Slide the coupler tube upwards and off the ARCS frame. The aft bulkhead should remain fixed to the ARCS frame.
5. Perform a visual inspection of the ARCS frame and bulkheads. Ensure there are no cracks in structural pieces, disconnected or frayed wires, and/or visual damage to any on-board computers and componentry. Ensure ARCS passes the visual inspection before proceeding.
6. Disconnect and check all battery voltages using a LiPo tester, ensure a nominal voltage on all LiPos in accordance with the peak voltage.
    a. If battery voltage is below the stated peak voltage, swap the battery out for a fully charged one of the same type and resecure it to the frame.
7. Reconnect all batteries to their respective connectors on the ARCS frame.
8. Close Blue Raven's screw switch in the ARCS junction box and ensure the computer reacts with a startup twill. Once a reaction is seen, disconnect the screw switch.
9. Close Telemetrum's screw switch in the ARCS junction box and ensure the computer reacts with a startup twill. Once a reaction is seen, disconnect the screw switch.
10. Slide the coupler tube down over the ARCS frame and align it using the visual indicators and clocking on the aft bulkhead and coupler tube.
11. Secure the XT30 parachute connectors from ARCS internals to their respective connectors on the bulkheads using the visual indicators on the connectors. Stow the excess wiring in the region above the topmost triangular frame bracket.
12. Attach the fore bulkhead to the coupler tube making sure to align the clocking before sliding the bulkhead onto the structural threaded rods.
13. Manually orient the service cameras such that they point outwards in their service configuration using the camera alignment tool.
14. Reattach the service camera shield, junction box door, and arming pin by securing them using their respective hardware.
15. When all checks are passed, ARCS Preparation is complete.

5.1.3 Ejection Charge Installation and Upper Section Integration

1. All team members within a 15ft radius of the ARCS section of the vehicle need to put on eye protection
2. The ejection charges will then be removed from their protective case and tested for continuity using a multimeter
    a. Nominal ejection charge resistance of the Wildman WM-02 ejection charge ignitors is 1.5 – 2.5 Ohms
3. The Team Mentor will then attach the respective ejection charges into their respective WAGO connectors on the outer surfaces of both the fore and aft bulkheads using the etched labels as a guide:
    a. Fore bulkhead: Primary and Redundant Main parachute charges as indicated.
    b. Aft Bulkhead: Primary and Redundant Drogue parachute charges as indicated.
4. With the Ejection Charges attached, ARCS should not be powered up to avoid accidentally energizing the ejection charges
5. Attach the quick link with the main parachute shock cord onto the fore bulkhead's U-bolt and tighten it down.
    a. Ensure that the quick link and attached shock chord pass through the upper fuselage, going in the fuselage's fore side and out its aft side.
6. Tighten the quick link shut and pull on the shock cord to make sure it has good connection with ARCS' fore bulkhead U-bolt.

7. Insert the fore side of ARCS into the aft side of the upper fuselage. Ensure that the parachute cord does not get pinched between the ARCS coupler tube and the upper fuselage when inserting.
8. Using the clocking on the ARCS coupler switch band and upper fuselage, align the two sections by rotating them inside one another.
9. Secure the two sections together by inserting and tightening screws into all the now-aligned holes in the upper fuselage.
10. Once all screws are inserted, tighten them down once more.
11. Once all screws are tight, Upper Section integration is now complete.

5.1.5 Booster Assembly

1. Taking the booster airframe, insert the internal fin brace into the airframe and secure it using #4 screws
2. On the nadir side (rail side) of the vehicle, remove the 2 screws between the fins and replace them with #4-40 x 5/8in screws, using them to secure the 2 aft rail buttons
3. Insert the 4 fins into the fin brace and hold them in place with the fin retention ring
4. Using #6 bolts, secure the fin retention ring to the airframe
5. Inspect the booster following the guide on Vehicle Integration Inspection Sheet B

5.1.6 Lower Section Integration

1. Starting with the ACS, take the Drogue parachute riser and secure it to the forward U-bolt on the ACS
2. Take the drogue parachute bay and pass the drogue riser through the bay
3. Using the clocking on the ACS and drogue parachute bay, rotate the ACS until it lines up
4. Secure the Drogue parachute bay to ACS using #4 screws
5. Once the booster has been fully assembled

5.1.7 PERR-C Programming and Inspection

1. Unscrew the set screw from the nosecone forward section and unscrew the nosecone
2. Remove the flight deck and Crew.
3. Un-install the nut on the forward closure nut and remove the contents of the Service Module
4. Turn on the Baofeng UV-5R and set the channel to the designated channel by NASA Staff
5. Replace the Service Module Frame and secure the system with the nut on the forward bulkhead
6. Replace the Flight Deck and Crew
7. Close the Nose cone until its hand tight and secure it using the set screw(s)

5.1.8 Vehicle Integration

Main Parachute Packing and PERR-C – Upper Section Integration

1. Take the Main Parachute riser out of the main parachute bay
2. Connect the main parachute to the riser using a quick link
3. Pack the parachute using standard tri-fold method, wrap the parachute in the parachute protector (18 or 24 in)
4. Connect the main parachute riser to the eye-nut on the aft end of PERR-C
5. Grabbing the middle of the section of riser between the main parachute and ARCS, wrap the cord around itself until you have a flat circle with the majority of the riser
6. Using a piece of blue painters tape, wrap a single layer around the riser to secure it

7. The packed main parachute and riser can be put into the main parachute bay, and the bay can be closed by PERR-C

Drogue Parachute Packing

1. Take the drogue riser out of the drogue parachute bay
2. Connect the drogue parachute to the riser using a quick link
3. Roll drogue parachute into a small cylinder and wrap with parachute protector (9 or 12 inches)
4. Connect the Drogue riser to the aft U-bolt of ARCS using a quick link
5. Grabbing the middle of the section of riser between the drogue parachute and ACS, wrap the cord around itself until you have a flat circle with the majority of the riser
6. Using a piece of blue painters tape, wrap a single layer around the riser to secure it
7. The packed drogue and riser can be put into the drogue parachute bay and the Upper Section and Lower Section can be mated

Confirm that all sections of the Vehicle Integration Inspection Sheets have been filled, except for final signoffs in the Final Integration section and Motor Integration Section

Final Integration

1. Secure PERR-C to main parachute bay using 4 #2-56 Nylon shear pins
2. Secure Upper Section to Lower Section using 4 #2-56 Nylon Shear Pins
3. Using Speed Tape, take small sections of tape and cover the heads of the shear pins
4. Take Small strips and wrap all non-in-flight separation points with speed tape

The vehicle is now fully assembled

5.1.9 Motor Preparation and Integration

CTI Motor Assembly

1. Inspect casing of motor for damage. If the casing is damaged, replace and discard. Modifications to casing can cause potential personal or property injury.
2. Leave protective cap on until prompted to remove.
3. Reloads mainly use one O-ring per closure but potentially may use two if required. Check forward and rear closures for properly installed O-rings. DO NOT PROCEED IF O-Rings ARE DAMAGED, instead contact Pro54 Dealer.
4. Apply a light film of silicone to the O-rings to the inside edge of casing. This is where the load casing is inserted.
5. To the forward end, insert the delay/ejection module. A small gap is present between the forward end and the shoulder is normal.
6. Remove the Forward end from the reload
7. Using a hobby knife, remove the white cap from the ejection charge well
8. Pour the 4F black powder into a container for use in vehicle ejection charges
9. Seal ejection charge well from the delay grain by using epoxy, Thick CA glue and paper, or a screw and O-ring
10. Re-seat the Forward closure onto the reload

11. Insert the reload kit into casing. The forward closure is first. Some resistance to O-rings will be present, ease this by placing the nozzle against the smooth surface and pushing carefully until completely inserted. Be careful not to damage the nozzle.
12. The nozzle should be plush. If not, remove the motor kit and investigate.
13. Begin to remove the nozzle cap. Screw retaining ring onto rear of motor casing until feeling tightness on the casing. It should be snug against rear closure. Do not overtighten, hand use is fine. Cap will rotate 3-¾ urns to full seat against case and 3 turns to engage. Reinstall cap of nozzle.
14. The motor is now ready to be installed. **Do not install igniter until on the launch pad.**

Integration into the vehicle

1. Remove the motor retention ring from the vehicle
2. Insert the motor into the motor mount tube
3. Check to see if the thrust ring on the casing sits flush against the motor retainer
4. Re-install the motor retaining ring on the vehicle

5.2 Vehicle Arming Procedure

5.2.1 Hazards

Starting in Section 5.2.4 Anyone on the Pad must wear protective eyewear until they are at least 50 ft away.

5.2.2 Installation on Launch Rail and Going Vertical

1. Set Launch Rail to horizontal position and lock (if available) in position
2. Slide Vehicle onto rail ensuring all rail buttons, slide vehicle down to launch stool (typically a rod or angle bracket that the rocket will sit on)
3. Remove all protective coverings (if Necessary) **DO NOT REMOVE ARCS ARMING PIN.**
4. Unlock launch rail and raise to vertical position
5. Secure Rail and remove any protective coverings from vehicle

5.2.3 Vehicle Power Up and Telemetry Check

1. **CAPCOM:** ensure that PERR-C Ground station is on and set to right channel and settings
2. **PAO:** Aim Antenna at vehicle and confirm antenna is connected to PERR-C Ground Station
3. **RED TEAM:** Turn on Screw Switch for PERR-C, wait for confirmation from vehicle and CAPCOM.
4. **T-DRO:** Ensure that "altOS" is on for both the low-gain and high-gain antenna computers. Check frequencies and callsigns to verify that the ground stations will connect to ARCS.
5. **T2:** Aim antenna at Vehicle and confirm antenna is connected to Computer running AltOS.
6. **RED TEAM**: Open "FeatherWeight Altimeters" app on phone.
7. Open ARCS Junction box by removing the single outer screw and sliding the door along the arming pin. **DO NOT REMOVE THE ARMING PIN AT THIS TIME**. Rotate the junction box door about the arming pin to expose the screw switches.
8. Turn on Screw Switch for Blue Raven, wait for Blue Raven's startup twill and continuity beeping.
9. Using "FeatherWeight Altimeters" app, verify that Blue Raven has all the correct settings programmed in accordance with the Flight Sheet.
10. In the junction box, power Telemetrum on using the Telemetrum screw switch, wait for Telemetrum's startup twill and continuity beeping.

11. Using team GMRS radio, contact T-DRO to confirm telemetrum radio connection to the team ground station.
12. In this state: both telemetrum and Blue Raven Should Report **NO EJECTION CHARGES CONNECTED**, confirm before moving on to next step.
13. Tighten down all screw switches once more. Slide the junction box door back into place on the junction box and press until it clicks into place.
14. Secure the junction box door in place by tightening down the single outer screw.

5.2.4 Parachute Arming Procedure

1. With Vehicle confirmed on and connected. Don Protective eyewear.
2. Unscrew the Arming pin to unlock it from the vehicle.
3. Remove the Arming Pin. All parachute ejection charges are now physically connected to the computers.
4. Both Computers should beep continuity checks.
    a. Blue Raven
        i. Continuity check order is APO, MAIN, 3rd, 4th
        ii. High Beep Voltage > 3.80V, Low Beep Voltage < 3.80V
    b. Telemetrum
        i. No ignitors: ½ second tone
        ii. Apogee Only: 1 beep
        iii. Main Only: 2 beeps
        iv. Both: 3 beeps
5. Using the featherweight app, check if Blue Raven is showing continuity on “APO” and “MAIN” lines.
6. Using team GMRS Radio, contact T-DRO to check if Telemetrum is transmitting telemetry.
7. Using team GMRS Radio, contact T-DRO to check if Telemetrum is showing continuity on “APO” and “MAIN” lines.
8. If continuity checks (step 4-7) are good, the vehicle’s recovery system is now armed and ready for flight.
9. If there is an issue with continuity checks move to section 5.5.3

5.2.5 Motor Arming Procedure

1. **ONLY PROCEDE IF THE VEHICLE RECOVERY SYSTEM (ARCS) IS ARMED AND A FINAL GO / NO-GO POLL HAS BEEN CONDUCTED.**
2. Unfurl the motor ignitor.
3. Strip the end of the ignitor lead and twist leads together, this prevents any static electricity from traveling up the wire to the ignitor.
4. Take ~18in of ignitor lead and begin to feed ignitor into the center bore of the motor grains. Feed until resistance is felt.
5. Secure Lead into motor, either by the motor cap (Cessaroni Motors), a piece of blue tape lightly placed on the bottom of the nozzle, or wrapped around a standoff on the launch pad
6. Take Launch Controller leads, tap the alligator clips together to check for residual current. Residual Current will result in small sparks being produced when the clips are touched together.
    a. If residual current is noticed **YELL STOP**, Proceed to 5.5.8

7. Untwist ignitor leads, take an alligator clip and clip one lead of the ignitor, wrap any remaining wire around the clip to increase contact area. Repeat for 2nd Lead.
8. The vehicle is now fully armed and ready for flight, RED TEAM retreats from Pad.

5.3 Flight and Recovery Procedure

5.3.1 Hazards

In this section, the vehicle will be in flight, this is truly the time where anything that could go wrong, will go wrong, team members should have reviewed the emergency procedures prior to launch as most scenarios are time-sensitive to the point where procedures are no longer able to be followed, and instead must be memorized.

5.3.2 Final Checks Before Launch

Before launch the team should monitor weather conditions (i.e. using pivotal weather to check weather soundings in the area for wind conditions at altitude) and continuing to monitor Telemetrum and PERR-C for periodic health checks to ensure vehicle remains ready for flight.

5.3.3 Roles During Flight

As boost and ascent only last 20 seconds, roles must be kept simple, and they are. There are 2 general roles: Callers and Trackers.

Callers are CAPCOM, T-DRO, and OPS. As stated in their roles they say their respective data out loud.

OPS: Calls the time after launch every 10 seconds
CAPCOM: Calls any data imperative to the success of the mission
T-DRO: Calls the altitude on Ascent, Apogee, then Altitude and Azimuth during descent for T2 and PAO

Trackers are everyone else. It is recommended that trackers pair up in 2s and 3s so that in the event of a break-up, groups can track individual sections according to emergency procedure 5.52B.

5.3.4 Landing and Payload Mission Procedure

Landing Determination:

1. Visual / Telemetry confirmation that the vehicle has landed or
2. Reasonable time has passed since loss of signal on descent or
3. 5.5 minutes since launch if loss of signal occurs on descent or at apogee with no confirmation of drogue deployment (Ascent time + Main Parachute Deployment at max apogee)

Payload Mission Procedure

1. According to NASA's rules, the team may take no action to activate the data transmission from the STEMCraft
2. The payload has a 2-minute timer after which transmissions will automatically cease
    a. In the event that transmissions do not stop or NASA requests it be stopped early, the stop command will be sent VIA ground station by CAPCOM (section 5.5.2)

5.3.5 Recovery Procedure

Approaching the vehicle (If location is unknown, follow search procedures in section 5.5.10

1. **REDTEAM:** Walk to within 30ft of the vehicle and then don protective eyewear
2. Using AltOS phone app and Featherweight Altimeters app, connect to both computers to determine state of ejection charge continuity on all 4 charges
    a. If a charge is still connected proceed to section 5.5.9 to isolate live charge
3. Reinsert arming pin into ARCS to isolate the ejection charges.
4. Open the junction box on ARCS to turn off both flight computers

5.4 Post-Flight Procedure

5.4.1 Initial Motor Disassembly

1. Unscrew motor retainer from the motor mount and remove casing from rocket
2. Unscrew aft retaining kit from casing. Push forward closure with plastic or wooden piece to eject reload assembly from casing. Be careful not to dent/scratch/damage the casing. DO NOT USE METAL TOOLS.
3. Minimal post clean-up is required by casing. If casing is to be reused within a close time frame, check for residue and remove it if needed. Store motor casing in original packaging when not in use.
4. To prevent damage, it is recommended that the ring is fitted to casing during storage. This is to protect threads.

5.4.2 Quick Cleaning of Vehicle From Combustion Byproducts

1. To clean the vehicle members should be wearing eye-protection and nitrile gloves
2. Using IPA wipes and rags, clean the hardware that has been exposed to the ejection charges
3. Using a small screw driver, the broken shear pins should be removed from the vehicle and discarded

5.5 Troubleshooting Procedures

5.5.1 PERR-C GPS Fails To Lock

1. If the GPS on PERR-C fails to lock after 60s a clock update may be required
2. **CAPCOM:** using PERR-C ground station, send command “CLK” + the current time in Unix Epoch to reset onboard Real Time Clock for the GPS

5.5.2 PERR-C 2M Radio Transmission Fails To Stop

1. After 2 minutes the 2M radio transmission for the mission goal should automatically stop
2. In the event that it doesn’t the **Flight, VSO, EXO, and CAPCOM** will work to determine if the vehicle is in a loop, or other cause of failure
3. The command “2MRS” will be sent VIA ground station to halt transmissions

5.5.3 ARCS Computer Fails To Detect Ejection Charge After Arming Pin Removal

1. Check FeatherWeight Altimeters app to see if Blue Raven Beeps are disabled or if the voltages on the APO and Main Lines are above 3.8V
    a. If Bluetooth is not able to connect, check the screw switch to make sure the switch is closed and tight
    b. If voltage is below 3.8V but above 3V the ejection charge is likely a dud, move to step 3, if issue does not resolve remove vehicle and replace ejection charge at flight line.

2. **REDTEAM:** Call T-DRO to verify that the RSSI and packet age are both nominal values for on the pad for telemetrum
    a. If telemetry does not connect, check the screw switch to make sure it is closed and tight
    b. If telemetry is connected on AltOS software go to table tab and look a the bottom of the first column pair to check voltages, if voltages are good but continuity is not beeping, move on to step 3
3. ARCS Restart without arming pin
    a. With arming pin removed, open the faulty computers screw switch and wait 10 seconds
    b. Close screw switch and wait for it to run through start-up self-test
    c. If the issue resolves, add note to flight log and continue to flight
    d. If the issue persists:
        i. Continuity is detected but voltage is low (i.e Batt volt 4.2V, Line volt 3.85V)
            1. The decision to fly can be made by the team only if the faulty charge is on the Main Primary Charge
        ii. All other scenarios
            1. Safe the vehicle and remove from the pad to replace offending charge and check internal wiring

5.5.4 Safeing Vehicle On Pad After Failed Launch Attempt

1. Approach the vehicle with eye-protection
2. Carefully disconnect the motor ignitor from launch controller and twist the leads
3. Insert arming pin into ARCS and twist to lock
4. Remove the motor ignitor from the rocket motor carefully
5. The vehicle is now safe and can be worked on or removed from pad

5.6 Emergency Procedures

As these procedures are extremely time-sensitive, members should review these procedures before any activity that involves testing the vehicle. Many of these require PPE and all present hazards to personnel.

5.6.1 Launch Misfire

1. When a misfire is identified yell “MISFIRE”.
2. If continuity is still maintained on the ignitor the LCO may attempt the launch again, holding the command for 3-6 seconds.
3. The team will remain in awaiting launch conditions since the motor could still ignite and the vehicle could launch
4. After a second launch attempt, or if continuity is lost, the range will wait for 60 seconds to wait out any slow burning propellant.
5. The team will then recover the vehicle from the pad and proceed to section 5.4.x to safe the vehicle on the pad, then reverse the procedure of motor arming to disarm and replace the ignitor.

5.6.2A Catastrophe After Take-Off With No Vehicle Breakup

1. Depending on the severity of the failure, a “heads-up” callout may be needed, if debris could fall near the flight line
2. The team should continue to track the vehicle and monitor for recovery system deployment
3. In the event of vehicle break up move to section 5.6.2B or 5.6.3, after landing proceed to section 5.6.6

5.6.2B Catastrophe After Take-Off Vehicle Causing Major Vehicle Break-Up

1. Team members should try to point at different sections of the vehicle. At most the vehicle should break up into 5 sections that can be considered harmful. Shrapnel and small debris produced from a violent break up will likely not be visible at that distance.
2. In the event that sections of the vehicle are heading to the flight line, yell "Heads Up!" and point to the debris poising the hazard.
3. If the debris is heading towards you, take action to avoid the debris, ideally by moving left or right.

5.6.3 Vehicle section separation

1. Team members should be pointing at the main vehicle, if separated, pairs of team members should communicate to start tracking all sections of the vehicle.
2. In the event that sections of the vehicle are heading to the flight line, yell "Heads Up!" and point to the debris poising the hazard.
3. If the debris is heading towards you, take action to avoid the debris, ideally by moving left or right.

5.6.4 Ballistic Return

1. Team members should maintain a visual and pointing towards the vehicle so that others may find it.
2. A ballistic return is when the apogee deployment does not deploy, and will be called if an event is not noticed within 24s of launch.
3. In the event that sections of the vehicle are heading to the flight line, yell "Heads Up!" and point to the debris poising the hazard.
4. If the debris is heading towards you, take action to avoid the debris, ideally by moving left or right.
5. If the emergency deployment from blue raven occurs, continue to track the vehicle and move to 5.6.9
6. On confirmed impact with the ground or time exceeds 90s since launch, move to section 5.6.10 to locate vehicle
7. Approach vehicle with fire suppression equipment. Follow Sections 5.6.6, 5.6.9, and 5.6.14 when approaching the vehicle

5.6.5 Recovery system failure (non-ballistic)

1. If the drogue parachute shreds, or main parachute fails to open call it out and point to the vehicle so others can locate it.
2. If the main parachute fails to deploy, or is destroyed, the vehicle will land hard and will likely be damaged.
3. The team will watch the vehicle intently looking for signs of fire or other distress from the vehicle
    a. If the vehicle catches fire alert the RSO and move to 5.6.6.
    b. When the RSO Opens the range for recovery approach the vehicle with caution and follow 5.6.9 if a parachute bay is closed.

5.6.6 Fire in the Launch Range

1. If a fire is noticed, immediately alert the Safety Officer and Team lead. If a fire is confirmed they will contact the RSO
2. In this scenario, the common fire is a grass fire. All HPR launches are required to have Fire Suppression gear on hand, these are commonly pump-sprayers, rakes, brooms coated in in fire retardant, and fire extinguishers.

3. When combatting a grass fire, conditions can change quickly, members should keep their head on a swivel and look for any embers starting secondary fires.
4. Members can use shoes to stomp out fire, however this is not recommended if they are wearing running shoes.
5. At any point, if the fire is not contained within 10 minutes or if the water supply is running low, the RSO or Safety Officer should Call 911 to report a grass fire.
6. If the vehicle is involved, Follow the steps in 5.6.7B

5.6.7A Personnel Near Vehicle on Fire

1. Personnel Should Immediately clear a distance of at least 100ft, do not help any injured parties at this time, self-extrication is the priority.
2. Wait at least 30 seconds before attempting to approach the vehicle. Work with RSO and other range personnel to determine when to approach
3. Extricating of personnel from the pad
    a. If personnel are withing 30ft of the fire, approach the fire from upwind, the smoke and combustion products are hazardous to breathe in, get low to reduce contact with smoke.
    b. Drag injured or unconscious personnel directly away from fire, provide the best medical care possible and call 911
4. After Personnel are extracted, move to section 5.6.7B

5.6.7B Vehicle on Fire

1. Wait sufficient time as to let hazardous materials burn off, at least 30 seconds
2. Approach vehicle cautiously, as the chance for hazardous material may still be present
3. Combating fire
    a. APCP, Black Powder, and Lithium Battery[1] Fires cannot be extinguished and produce toxic byproducts[2]. **DO NOT ENGAGE FIRE.**
    b. Wait until any Hazardous Material fire burn out before approaching with Fire Suppression Equipment. CO2 Extinguishers are preferred, followed by Foam, Water, then Dry Chemical[3]
    c. By the time you can approach the vehicle it is likely a total loss, fire suppression is to prevent spread, do not try to save the vehicle.
    d. Let the vehicle burn-out. Only approach once the vehicle has cooled. Use Fire suppressant to prevent fire spread through the grass.
    e. Avoid using water on the vehicle as corrosive byproducts from the combustion are produced.

5.6.8 Launch Controller has residual current

1. Yell "STOP”.
2. Twist motor ignitor leads together to safe the ignitor and secure the ignitor to the rocket with tape, using tape to cover the leads.
3. Hail the LCO to check the launch controller.

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[1] Lithium Fires can be extinguished, however, they require full body PPE and copious amounts of fire retardant.
[2] Common combustion byproducts are LiOH, HCl, SO_x, and NO_x compounds which become corrosive when in contact with water (i.e in lungs or eyes).
[3] Dry Chemical Extinguishers are effective; however they are lung irritants and could be harmful to plant life, contributing to lower priority.

4. Resume motor arming once issue has been resolved.

5.6.9 Live Ejection Charge

1. Upon approaching landing zone, the red team will hold off at 30 ft from the vehicle. And all members will don eye protection.
2. The team mentor and Safety Officer will approach the vehicle and quickly insert the arming pin into the ARCS system.
3. The Safety Officer and Team mentor will then unscrew the radial bolts or shear pins that close the parachute bays on either side of the ARCS bay.
4. Once the bulkhead is exposed and the ejection charges are in-sight, they are inspected to determine if they are still live.
    a. If the charges are spent, then the team can continue on normally in recovering the vehicle.
5. The Team Mentor will do a pull test on the ejection charge leads to determine if they are still connected to the flight computer leads
6. The live ejection charge will then be removed from the bulkhead
7. The leads to the ejection charge are then twisted together, and taped to protect the leads
8. The team can now proceed to the next procedure.

5.6.10 Searching for vehicle after LOS

Downwind Distance from time remaining and windspeed				
Est. remaining descent time	5 MPH	10 MPH	15 MPH	20 MPH
25s	185	365	550	735
35s	255	515	770	1025
45s	330	660	990	1320
55s	405	805	1210	1615
65s	475	955	1430	1905
75s	550	1100	1650	2200
85s	625	1245	1870	2495

Table 5.6.1: Drift table to determine search grid in emergency scenarios

Drawing of the Search Grid

1. From the last Known GPS Location, Draw a line along the wind vector. Use the drift table.
2. At the last known GPS Location, draw a circle with a radius of 150ft or 15% of the drift distance, whichever is greater
3. At the end of the downwind vector, draw a circle with a radius of 300ft or 30% of the drift distance
4. This should create a cone that the vehicle is likely to land in
5. To search for the vehicle, all team members should create a line, with members starting at 20-30 ft apart, while walking down the grid, team members should spread out to no further than 50ft
    a. If the vehicle or section, came in ballistic or in separate sections, it is recommended that the search gird is tighter as the vehicle will have a smaller visual profile.
6. **T2:** Using the AltOS app, connect to the TeleBT receiver for Telemetrum to bring the low-gain 433mhz antenna to the search grid to aid in locating the vehicle.

433mhz Antenna is a line-of-sight frequency, if terrain is blocking a direct line between the receiver and vehicle data packets will not be received or the signal strength will be greatly diminished.

5.6.12 Vehicle Drifts Outside of LZ

1. If the vehicle is believed to drift outside the LZ, contact the RSO and ask for their steps on how to recover the vehicle
2. Common steps are going to the house the property is believed to be on and asking to enter their property to recover the vehicle.

5.6.13 The vehicle lands on a power line

1. If the vehicle lands in a power line, do not attempt to recover the vehicle
2. Contact the local electrical service to request a team of linesman to recover the vehicle

5.6.14 Lithium Battery Fire on flight line before vehicle integration

1. If the battery has rapidly puffed but not ignited yet, attempt to quickly release battery from vehicle
2. If the battery is not attached to a section of vehicle toss it quickly away and **YELL FIRE**, try to toss it away from people and not at people
3. If an appropriate extinguisher (Class D) is available you can attempt to extinguish the battery
4. If you are not able to remove the battery quickly and it catches fire immediately back away from the system and let it burn

5.7 Vehicle Inspection and Sign Off / Accountability Sheets

The following pages have the inspection guide sheets for the vehicle at different stages of assembly, integration, arming, and recovery. There will be 3 two-sided sheets for each launch. Vehicle Integration Inspection Sheets A and B run through Sections 5.1.2 to 5.1.7 Which is the majority of vehicle integration. Each Sheet splits responsibility and allows for parallel assembly to occur with the vehicle, the Safety Officer and Team Lead will oversee one half of the assembly. The Vehicle Launch and Recovery Inspection Sheet covers Sections 5.1.8, all of 5.2, 5.3.5, and 5.3.6, which is the final integration checklist, and both pre and post-flight inspections. The Sheets feature a location for a member to sign off and write down the time of completion

5.7.1 Vehicle Integration Inspection Sheet A – Payload Systems

PEP Inspection

Are all wires connected and secured to the frame		
Are the Batteries secured to the frame?		
Are the Batteries full (4.2V, 8.4V or 12.6V)?		
Are the batteries healthy, showing no signs of puffiness?		
Is the 2M Radio set to frequency: ____________		
Is the 915MHz Radio set to frequency: _____________		
Has the system connected to the ground station and reported healthy Prior to integration?		
EXO Sign-Off		
Safety Officer / Team Lead Sign-Off		

PERR-C Inspection

Are both bulkheads structurally sound, showing no signs of fatigue?		
Is the eye-nut and jam-nut on the aft end tightened down and threadlocked?		
Is the service module frame (sled) secured to the rail?		
Is the forward bulkhead secured with a locknut?		
Is the Fight deck secured to the System, are the crew strapped in?		
Does the 3D printed airframe show any signs of fatigue?		
Are the set screws installed and tight?		
EXO Sign-Off		
Safety Officer / Team Lead Sign-Off		

ACS Integration

Does the structural elements of the air braking system appear intact and show no signs of fatigue?		
Are all screws and nuts on the deployment system snug?		
Are the Aerodynamic surfaces intact and show no cracks?		
Are the electrical systems secure, connected soundly, and tied down?		
Does the airframe section pass a visual inspection? Are the forward and aft mounting holes intact and showing no sign of damage?		
Are the bulkheads intact, showing no signs of fatigue?		
Is the forward U-bolt intact, showing no signs of fatigue? Are all retaining nuts on the U-Bolt?		
Are all nuts closing the bulkheads present and tight?		
EXO Sign-Off		
Safety Officer / Team Lead Sign-Off		
Team Mentor Sign-Off		

Payload Systems Final Inspection

Has PERR-C passed pre-flight start up testing?		
Has PERR-C passed pre-flight inspection?		
Is the 2M radio set to frequency:_______________		
Is the 915MHz radio set to frequency:_____________		
Has ACS passed pre-flight start up testing?		
Has ACS passed flap actuation test?		
CAPCOM Sign-Off		
EXO Sign-Off		
Safety Officer / Team Lead Sign-Off		
Team Mentor Sign-Off		

5.7.2 Vehicle Integration Inspection Sheet B – Vehicle Structures and Recovery Systems

Booster Inspection

Using a flashlight, inspect the visible sections of epoxy on the motor mount for any cracks or other signs of fatigue?		
Are the rail buttons present, secured using #4 screws, and showing no signs of damage?		
Are the edges of the fins intact, is there any sign of damage to the fins?		
Has the Fin Retention Ring been attached, is it hand-tight?		
Can all 12 fasteners for the fin can installed and secured?		
Are the fins securely installed in the vehicle? (Do they wobble when pushed?)		
Are the holes for the forward attachment points intact and showing no signs of fatigue?		
Booster Section Leader Sign-off		
Safety Officer / Team Lead Sign-Off		

ARCS Inspection and Integration

Are all internal wires to the computers secured in their terminals, connectors, and tie-downs?		
Have the Service Cameras been Adjusted into flight position and been secured?		
Are flight batteries charged and in healthy condition (4.2V or 8.4V)?		
Is Blue Ravens Battery Secure, does the computer power on and report healthy?		
Is Telemetrum's battery secure, does the computer power on and report healthy?		
Are the bulkheads showing signs of structural fatigue, are both nuts present on the back of the U-Bolt?		
Does the airframe section show any signs of fatigue?		
Are the forward and aft bulkhead rails secured by nuts, are they torqued down?		
Recovery Section Leader Sign-Off		
Safety Officer / Team Lead Sign-Off		

Motor Assembly and Integration

Motor Date Code:		
Does the motor packaging show any signs of damage or holes, has the propellant been exposed to water?		
Does reload come with all materials: Closures, O-rings, Liner?		
Are the O-rings in good health, are they dry / cracked?		
Has the ejection charge been removed, and the hole to the delay grain been filled?		
Are all closure rings secured and tight?		
Has the Motor Retaining ring been attached, is it hand-tight?		
Safety Officer Sign-Off		
Team Mentor Sign-Off		

Vehicle Final Integration

Is the Upper Section Integrated and signed-off?		
is the Lower Section integrated and signed-off?		
Are the Payload Systems Integrated and Inspected?		
Has the main parachute been packed and secured to the vehicle?		
Has the drogue parachute been packed and secured to the vehicle?		
Are the Launch lungs secured to the vehicle, are they loose?		
Are all shear pins installed?		
Has Speed Tape been applied to shear pins and non in-flight separation points?		
Safety Officer Sign-Off		
Team Lead Sign-Off		
Team Mentor Sign-Off		

5.7.3 Vehicle Launch and Recovery Inspection Sheet

Vehicle Final Inspection

Has the section on PEP assembly been signed off?		
Has the section on PERR-C assembly been signed off?		
Has the section on ACS assembly been signed off?		
Has the section inspecting all sections of the payload systems been signed off?		
Has the section on booster assembly been signed off?		
Has the section on ARCS integration and integration been signed off?		
Has the section on motor assembly and integration been signed off?		
Has the section on vehicle final integration been signed off?		
Safety officer Sign-Off		
Team Lead Sign-Off		

Final Go / No-Go poll

EXO		
PAO		
CAPCOM		
RECO		
T2		
T-DRO		
BOOSTER		
OPS		
VSO		
FLIGHT		

Vehicle Arming Steps

Has the range been cleared by the RSO for the Red team to enter		
Have all protective coverings been removed from the vehicle?		
Are both computers on and reporting healthy?		
When removing the arming pin, do both computers report good continuity on all 4 ejection charges?		
Has the ignitor been inserted, secured to the launch pad, and connected to the controller		
Final Check for remove before flight (RED) tags on the vehicle		
Team Lead Sign-Off		
Safety Officer Sign-Off		
Team Mentor Sign-Off		

Post Flight Inspection

Did the vehicle fly on a straight path with no major pitch events?		
Did telemetry connection to the vehicle continue throughout the flight with little to no interruption?		
Have Photos been taken of the vehicles landed configuration?		
Did the recovery system operate as intended?		
Has the vehicle been safed after the flight before continuing inspection?		
Are all sections of the vehicle still connected?		
Is there any damage to the parachute bays (zippering) as a result of a high deployment velocity?		
Is there any damage to the section from impact with the ground due to high descent velocity (chipped edge of fiberglass tube, cracked fin, cracked motor retention ring, etc.)?		
Safety Officer Sign-Off		
Team Lead Sign-Off		

5.8 Hazard Analysis Methods

Hazard analysis is based on two factors: Likelihood and severity. Likelihood is the rarity of which events occur and severity is what impact(s) an event will cause.

5.8.1 Failure Occurrence Likelihood

Level	Category	Definition
0	Rare	Failure mode is Extremely Unlikely to happen
1	Unlikely	Failure mode is unlikely to occur
2	Plausible	Failure mode has average odds to occur
3	Likely	Failure mode is likely to occur
4	Common	Failure Mode has happened before and/or is very likely to happen

Table 5.7.1: Risk Likelihood Table

5.8.2 Failure Effect Severity

Level	Category	Health and Safety	Equipment	Environment	Project
A	Negligible	No First aid required	Cosmetic Damage	No risk or damage to environment	No impact to Project timeline or goals
B	Minor	First aid was provided. Less than 1 day recovery time.	Damage is noted but can continue to operate with little to no detriment to the machine.	Slight damage to the environment, no clean up or action needed	Less than 1 day delay, no long-term impact
C	Moderate	First Aid Provided. Gause or other large bandage, Recovery time over 1 day	Reversible machine failure, requiring near-immediate repairs.	Damage to the environment that requires team intervention, but no long-term effects or reporting needed.	Delay of up to 1 week, may impact testing / flight schedule, no effect of deadlines
D	Major	Serious Injury requiring hospitalization, no long-term effects.	Total machine failure requiring repairs before continuing usage	Severe damage to the environment, immediate team intervention required, reporting to relevant agency	Delay of over 1 week, testing/ test flights will slip. Risk of missing deadline
F	Catastrophic	Life Threatening injury or serious injury that results in long-term injury/disability	Total irreversible failure of equipment requiring replacement	Extreme damage to the environment requiring immediate government intervention	Delay of over 1-month, high risk of missing deadline, retirement from competition.

Table 5.7.2: Failure Effect Table

5.8.3 Risk Analysis

The table below uses the likelihood analysis and Severity analysis to create a Risk Hazard Matrix. The Matrix is then color-coded into the following Categories.

- White: No-Risk
- Green: Marginal
- Yellow: Slight
- Orange: Enhanced
- Red: Moderate
- Magenta: High

		Severity				
		A - Negligible	B - Minor	C – Moderate	D – Major	F - Catastrophic
Likelihood	1 – Rare	1A	1B	1C	1D	1F
	2 – Unlikely	2A	2B	2C	2D	2F
	3 – Possible	3A	3B	3C	3D	3F
	4 – Likely	4A	4B	4C	4D	4F
	5 – Very Likely	5A	5B	5C	5D	5F

Table 5.7.3: Risk Analysis Matrix

5.8.4 Personnel Hazards Analysis

Hazard	Likelihood	Severity	Risk	Mitigation	Verification	Post Mitigation Risk
Entanglement with large machinery	3 (Working with manual machines)	F (Loss of body part, severe injury, required hospitalization	3F - Moderate	Members only allowed to use machinery are trained properly, and use of buddy system in labs. Removal of all jewelry, loose clothing, and tying hair back to prevent entanglement. Recommendations for team members to request parts to be manufactured on CNC machines to eliminate risk	Before operating machine, members will inspect each other to verify that all hazards have been eliminated prior to energizing machine. Work with machines will be supervised by university staff with experience until members are deemed skilled enough.	1F - Enhanced
Contact with falling equipment	3 (Dropped items or falling items)	C (Injuries including bruising, cuts, hospitalization in worst case scenario)	3C - Enhanced	Secure items that are heavy to worktables, use carts to transport heavy/bulky items. Any item over 40 lbs is a team lift so that no member is straining themselves.	Call out before use to make sure team members are informed about hazards. Oversight by team officers	1C - Slight
Fire	2 (damaged electrical components, improper disposal of rags soaked in solvent, working with hot materials around dust)	F (Loss of workspace, severe burns to personal)	2F - Moderate	Know where fire prevention equipment is stored, store hazardous material in proper containers	Make sure all members are informed on fire safety protocol	1F - Enhanced

Contact with chemical vapors	3 (Use of solvents to clean parts during manufacturing, clean up spilled epoxy or adhesives)	B (Irritation to eyes, lungs)	3B - Slight	Wear proper PPE. Including; gloves, eye protection, lab coat, rinse with water if come into contact	Safety team subsystem leads, will enforce PPE usage, safety procedures	1B - Marginal
Contact with hazardous chemicals (excl. epoxy and adhesives)	3 (Chemical spills, improper chemical usage)	C (Chemical Burns, toxic exposure)	3C - Enhanced	Wearing appropriate PPE; Gloves, lab coat, and eyewear. Wash with water. Dispose in proper container	Call out before use to make sure team members are informed about hazards. Oversight by team officers	1C - Slight
Dust exposure	3 (Particle debris, Smoke,)	D (Short-term respiratory damage, respiratory distress, eye irritation, short-term eye damage)	3D - Moderate	Wearing appropriate PPE; N95, eyewear, lab coat (optional). Working in well-ventilated area. Wash with water	Call out before use to make sure team members are informed about hazards. Oversight by team officers	1C - Slight
Electrocution	3 (Work with custom PCBs, LiPo batteries)	C (Short-term nerve damage, electrical burns)	3C - Enhanced	Ensure team is working with proper PPE, treating all electronic circuitry as if it is live	Oversight by team officers	2C - Slight

Epoxy Contact	3 (Assembling components on vehicle, small repairs, fabricating test samples)	B (Skin Irritation)	3B - Slight	Wear appropriate PPE; gloves, N95, glasses optional	Call out before use to make sure team members are informed about hazards	1B - Marginal
Eye Irriration	3 (Airborne debris, smoke)	B (Temporary eye irritation)	3B - Slight	Wear proper PPE. This includes protective eyewear and wash eyes if contact made	Call out before use to make sure team members are informed about hazards	1C - Slight
Contact with heat sources	3 (Working with epoxy or sharp tools)	B (2nd Degree or blistering burn, First degree or superficial Burn, Skin Irritation)	3B - Slight	Ensure that members are wearing the proper PPE, letting items cool after working them	Call out before use to make sure team members are informed about hazards	1B - Marginal

improper use of power tools	3 (Cuts from drill bits, rotary tools, exact-o blades/box cutters	D (Lacerations, avulsions, hospitalization, plausible)	3D - Moderate	Secure hair, clothing, jewelry, wear proper shoes. Appropriate PPE	Call out before use to make sure team members are informed about hazards	1D - Enhanced
Tripping Hazards	3 (Equipment not put away, wires on ground)	C (Upper body injuries, bruising from walking into objects)	3C - Enhanced	Brief team on picking up equipment in hazardous way	Enforce cleaning procedure	1C - Slight
Dehydration/Heat exhaustion	4 (Hot sunny days, working in hot labs)	B (Fatigue or passing out risk)	4B - Enhanced	Reminding members to drink water and wear breathable clothes, if signs of dehydration or heat exhaustion are present, members must be forced to take break and drink water	Oversight by officers	3B - Slight
Hearing Damage	4 (Proximity of loud or high-pitched noise)	D (Long term hearing damage)	4D - Moderate	Ensure team is wearing hearing protection if around loud/high-pitched for longer than 10 minutes	Call out before use to make sure team members are informed about hazards	1D - Enhanced

5.8.5 Failure Mode and Effect Analysis

HAZARD	Likelihood	Severity	Risk	Mitigation	Verification	Post Mitigation Risk
Onboard Vehicle Fire	1 (Electric fire/fire spread due to motor failure)	F (Falling debris, unaccounted for vehicle separation, ground/brush fire)	1F - Enhanced	To reduce or prevent fire spread, install “fire compartments," separating critical hardware from each other.	Cover exposed wires with insulators and install heat insulators if needed.	1F - Enhanced
Fastener Failure	2 (Excessive force)	F (Irreversible damage to vehicle, falling debris, dangerous flight path to people and surroundings)	2F - Moderate	Increase number of simulations and increase safety factor of flight critical components to 2+	Physical testing to confirm manufacturer specifications	1F - Enhanced
Thrust Structure Failure	2 (Poor construction, motor overperformance causing excessive force)	F (Irreversible damage to vehicle, falling debris)	2F - Moderate	Increase number of simulations and increase safety factor of flight critical components to 2+	Physical testing of motor mount assembly to 200% the expected force of boost	1F - Enhanced

Recovery System Failure: Drogue Stage	2 (Bad product control on ejections charge ignitors, airframe shoulders having high friction, drogue parachute failure)	F (failure to prevent ballistic trajectory, high energy non-ballistic descent)	2F - Moderate	Implement checks for ignitors to ensure continuity, size primary and backup ejection charges to be at least 130% the required force to deploy the system, ensure both parachute and protector are intact before use	Ground testing and maintenance of the airframe to prevent binding	1D - Enhanced
Structural Failure of Bulkheads	2 (Poor construction, faulty modeling/simulation)	F (Falling debris)	2F - Moderate	Design components to a safety factor of 2	Testing of bulkheads to validate computer modeling	1F - Enhanced
Damaged NoseCone, Payload Compartment	2 (Poor,Construction, Flight/transportation damage)	D (instability, Damage to payload, Dangerous flight path to personal and surroundings)	2D - Enhanced	Ensure that the descent rate of section is below damaging levels, provide protective packing when transporting	Inspect material between launches	1C - Slight
Component Misalignment: Motor mount tube/assembly	2 (Poor construction, bad manufacturing plan, bad product control of construction components	D (Launch vehicle does not follow flight path, severe instability)	2D - Enhanced	Use tools from CNC lab to measure all components to verify eccentricity and location	Have multiple engineers verify measurements	1D - Enhanced

Commercial Rocket Motor Failure	2 (Faulty motor preparation, defect from manufacturer)	F (Destruction of vehicle section, Falling debris)	2F - Moderate	Purchase propellant from reliable sources, only team mentor is allowed to handle and assemble the motor	Safety officer will observe preparation and integration	1F - Enhanced
Recovery System Failure: Tether, Riser, or Shock Cord Failure	3 (Excessive force, Burn through from the ejection charge deployment)	F (Falling debris, high-energy non ballistic landing)	3F - Moderate	Use higher quality materials, fire resistant materials/coverings, use tethers that are 200% the strength of the expected loading	Ground testing and inspections between flights and testing. During assembly, multiple engineers verify that connections are torqued to spec	1F - Enhanced
Recovery and Tracking Avionics Power Failure	3 (Faulty wiring, design not resistant to flight forces)	F (Recovery device may not deploy, Ballistic landing)	3F - Moderate	Testing avionics bay assembly to investigate reaction to flight forces, observe set up before and after test flights to validate data	Continuity and "pull tests" will be performed during avionics bay integration to test wire connectivity and attachment	1F - Enhanced
Recovery System Failure: Main Stage	4 (Bad product control on ejection charge ignitors, airframe shoulders having high friction, Main parachute failure, failure to fully deploy from parachute bay	D (High energy non-ballistic landing)	4D - Moderate	Implement checks for ignitors to ensure continuity, size primary and backup ejection charges to be at least 130% the required force to deploy the system, ensure both parachute and protector are intact before use	Ground testing and maintenance of the airframe prevent binding	1D - Enhanced

Altitude Control System Mechanical Failure	3 (material failure of the ball screw, linkages, or aerobraking surfaces)	F (leaving vehicle in unknown aerodynamic state, Dynamic Instability, unsymmetrical deployment leading to high AOA at high velocity)	3F - Moderate	Ensuring all mechanical parts of a safety factor of 3+.	Extensive ground testing: wind tunnel testing, simulated load testing. Asymmetric deployment studies.	2F - Moderate
Altitude Control System Electrical Failure	3 (custom PCB being manufactured wrong causing electrical fault)	D (fire, fatal damage to component leading to ACS staying in the same deployment state)	3D - Moderate	Increased electrical design studies are needed to ensure the PCB design is sound.	Ground testing including testing a sacrificial board to failure to find true limits of system	1C - Slight
Structures: Damage to Thrust Structure	2 (Hard landing due to recovery failure; Landing on Rock, Paved Road, or Compacted Dirt Road)	D (irrepriable damage to Motor Retention System, motor mount assembly damage)	2D - Enhanced	Designing structure to withstand loads twice as high as expected from motor thrust and landing	The structure will be tested by applying a load of at least 180 lbs	1C - Slight

Structures: Thrust structure failure	1 (Motor Peak thrust breaking thrust struture, landing force causing structure failure)	D (irrepriable damage to Motor Retention System, motor mount assembly damage)	1D - Enhanced	Designing structure to withstand loads twice as high as expected from motor thrust and landing	The structure will be tested by applying a load of at least 180 lbs	1C - Slight
Structures: Damaged Body tube	3 (landing on hard or sharp object, hard landing)	C (Section of vehicle needing repair or replacement)	3C - Enhanced	Following standard practice of recovery system recovery to ensure that the vehicle	Ground testing to ensure that parachute ejection charges work and performing parachute drop tests to ensure the vehicle will be recovered safely	2C - Slight
Moduluar Fin Mount: Damage to Fins	4 (landing on hard or sharp object, hard landing)	B (Broken 3D Pritned Fin)	4B - Enhanced	Fin material choice and design is made to impact landing force and will bend but wont break	Fins will be tested on ground in a 3-point bend test and will be tested with the parachute drop test and vehicle demonstration flight	2B - Marginal
Moduluar Fin Mount: Damage to Fin mounting Structure	2 (landing on hard or sharp object, hard landing)	B (Broken 3D Pritned Fin)	2B - Marginal	Fin mount material choice and design is made to impact landing force and will bend but wont break	System will be tested with the parachute drop test and Vehicle Demonstration Flight	1B - Marginal

5.8.6 Environmental Concerns

HAZARD	Likelihood	Severity	Risk	Mitigation	Verification	Post Mitigation Risk
Collisions with Structures	3 (Structures are near minimum clearance for High-Power at Amesbury (1500ft))	D (Damaging Roof, landing on hard surface damaging vehicle)	3D - Moderate	Aiming rocket away from structures. Weather forecasting winds at the surface and at altitudes to visualize wind shear to aid in determining launch direction	Doing simulations with different wind scenarios to find the furthest distance a rocket will drift down/cross range	2D - Enhanced
Contact with Wildlife	1 (Wildlife interacting with vehicle after landing)	C (Animal interacting with residue from flight or damaging vehicle)	1C - Slight	Install deterrents on the vehicle to scare off wildlife. This includes buzzers.	Safety briefing talking about what hazards may be present, educating members on how to interact with wildlife	1B - Marginal
High Temperature	2 (Hot weather in Huntsville, abnormal heat in winter)	C (On-board batteries and support overheating causing damage, heat exhaustion stroke)	2C - Slight	Observing weather forecast and temperatures above 80F classified as hot weather. 90F and above is classified as extreme heat. Bringing pop-up tents, providing shade for the team and equipment, as well as bringing water for the team.	Ensure team members are properly prepped for extreme heat. Possibly running a car with AC to provide a cooler environment for equipment and team	2B - Marginal

Battery Leakage	2 (Battery damage from flight)	D (Fire or chemical residue from combustion of hazardous material)	2D - Enhanced	Protect battery from flight forces and landing forces.	Safety briefing about what hazards may arise or be present, inspect battery between flights for damage	1C - Slight
Fire	2 (Motor failure near ground, on-board fire continuing to landing)	F (Fire on ground, pollution from)	2F - Moderate	Using ground protector next to the launch pad, bringing fire suppression equipment.	Safety briefing about hazards that may be present, walking through emergency proceudre's during drtess rehersals	1F - Enhanced
Unstable Ground	2 (Loose rocks/dirt, mud)	B (Personal or equipment falls)	2B - Marginal	Inspect area of launch pad and prep-area for ground hazards	Safety briefing about hazards that may be present	1A - None
Landscape	3 (Trees, streams, rocks)	D (Unable to recover rocket, water damage to components or electronics, physical damage)	3D - Moderate	Scout out launch-field for hazards and aim away, use forecast to determine wind to help aid aim	Inspect launch site pre-launch to verify mitigation	3B - Slight

Visibility	3 (Exceeding operating limitations of 14 CFR 101.25)	D (Scrubbing launch, delay of 1 day to 1 week)	3D - Moderate	Weather forecasting and scheduling back up at launch windows to allow for weather related delays	Check weather forecasts and creating a launch weather criteria list to allow a safe launch at range	2D - Enhanced
Pollution from vehicle Debris	3 (Debris from vehicle from an in-air failure or damage during landing)	C (Small pieces of debris left from vehicle that pose minimal effect of the environment)	3C - Enhanced	If a failure is noticed, the team forms a "Police Line" and searches the field for debris. Landing site is investigated for debris	Initial inspection of vehicle at landing zone and preparation area to determine if any items have been dislodged or removed	2A - None
Pollution from Team	3 (Wrapper from motor reload, trash from vehicle integration, snack-wrappers)	C (Small debris from team)	3C - Enhanced	f a failure is noticed, the team forms a "Police Line" and searches the field for debris. Ground will be searched for any trash	Installing Pack-in/Pack-out mentality in team. "Leaving field better than when arrived"	2A - None
Humidity	4 (Humid climate)	C (Condensation creating electrical shorts, humidity affecting adhesive or materials)	4C - Moderate	Construction and storage of construction materials and motors in climate-controlled rooms, electronic boards given conformal coating to give them resistance to short across traces	Check forecast	3B - Slight

Winds	4 (High winds preventing launch, winds blowing in unsafe direction)	D (Scrubbing launch, rocket landing outside launch site)	4D - Moderate	Forecast and back-up launch days	Checking forecast and creating a launch weather criteria list to ensure safe launch	3B - Slight
Rain/Weather	4 (Cannot launch in rain or cloud cover)	D (Scrubbing delay launch, delaying of 1 day to 1 week)	4D - Moderate	Weather forecasting and schedule back up windows in case of weather delays	Checking forecast and creating a launch weather criteria list to ensure safe launch	3B - Slight
Low Temperature	4 (Cold plunge in New England Region with temperatures below 40F)	D (Damage to propellant reload, hypothermia and frostbite, reduced performance of battery)	4D - Moderate	Bring heaters, handwarmers, and insulating equipment under 40F. Activities limited/suspended below 10F	Check forecast. If necessary, suspension of outside activities may be called at any point, provide running car with heat	4B - Enhanced
Pollution from Motor Exhaust	5 (Combustion by products from firing commercial rocket motor)	A (Small quantities of greenhouse gases, hydrochloric acid, NOx/SOx compounds)	5A - Enhanced	Use NAR/TRA approved rocket motors	Motors used to launch test vehicles and competition flight will be inspected by safety officer to ensure compliance	5A - Enhanced

5.8.7 Project Risk Analysis

HAZARD	Likelihood	Severity	Risk	Mitigation	Verification	Post Mitigation Risk
Lack of Funding	4 (First Year Attempting NASA USLI, No Current Corporate Sponsorships)	D (Unable to afford Equipment, Unable to Attend Launch in Huntsville)	4F - High	Aggressive Fundraising Campaigns (Crowdsource Campaign and looking for sponsors)	The Business Team Lead will work with the Student Launch Team lead to ensure the club is raising enough money for the competition	4C - Moderate
Failure to Receive parts	2 (ordering from unreliable sellers)	C (Multiple day delays from shipping, ordering new parts)	2C - Slight	Order parts from verified sellers and legitimate websites	Verifying links and auditing purchase orders	1B - Marginal
Damage or Loss of Parts/gear	3 (improper part care during construction, testing, or launch)	C (cannot construct vehicle or continue testing)	3C - Enhanced	Creation of multiple replacement parts when applicable, owning spare sets of equipment	Extra parts ordered for all needed systems	3B - Slight

Rushed/bad workmanship	3 (Approaching deadlines, unreasonable schedule expectations)	D (Testing failures & launch failures due to low-quality construction)	3D - Moderate	Built-in schedule buffers so deadlines aren't stressing	Pre-flight inspection and following tolerances	2C - Slight
Unavailable Launch Area for Test Flights	3 (Unhappy neighbors, fields not in condition to fly, no-waiver to fly)	F (delay of multiple weeks to get to flight, disqualification from the project due to no subscale & vehicle demonstration flight data)	3F - Moderate	Being in contact with multiple NAR sections near us, like St. Albans, VT CRMRC. Attempting launches early in the period to allow for scheduling issues	The Safety officer will work with team mentor to secure fields for testing at least 45 days in advance.	1B - Marginal
Testing failure	3 (bad design, unforeseen mechanisms leading to failure, commercial component failure)	D (Damage to vehicle, failure of subscale or vehicle demonstration flight)	3D - Moderate	Following standard practice as set by team's mentor, designing critical systems to be redundant. Making contingencies and being prepared to retest quickly after a potential failure	Safety officer will ensure that all sub-systems are being designed with a proper safety factor and considerations	3B - Slight

Loss of work area	2 (Fire, loss of lab privileges, Closures during school breaks)	F (Inability to construct vehicle)	2F - Moderate	Follow regulations and rules set by team and workspace occupied	Team Officers will ensure that the team will be utilizing each space we occupy correctly and follow the rules set in place by the safety agreement	1F - Enhanced
Failure in construction equipment	2(Improper maintenance, improper use)	D (Long-term delay in project for replacement)	2D - Enhanced	Ensure members using tools and equipment are trained properly, owning back-up equipment that can be used in the event of a failure	Each member will be responsible for maintaining equipment following the team safety agreement	1B - Marginal
Insufficient Transportation	4 (lack of funding or space to bring available members to off-campus testing, launches, or workplaces)	C (Loss of sufficient labor, loss of transfer of knowledge to new members, loss of work efficiency)	3C - Enhanced	Organize and budget for transportation early and plan expenses in advance	Project management and team leads will be responsible for communicating when activities are being held and plan transportation to the events	2B - Marginal
Lack of members available to work	4 (shared class deadlines or mid-term exams takes out sections of team)	C (Some classes may require multiple days of studying before an exam)	4C - Moderate	Work with team members to “forecast” when class work will be high to help schedule time to work on project with the rest of the team	Team leads meetings to verify that members are not being overloaded with school and project work	2B - Marginal

Lack of Knowledge	5(members new to the club / hobby not understanding what each component does)	B (needing to take a section of the meeting to educate groups of members on standard rocketry practices)	5B - Moderate	Create a resource of online tutorials for members to look at, and create our own PowerPoint slide decks with similar information	Have set meetings throughout the semester where a team lead will discuss their section of the rocket and what every part does	3B - Slight
Bad Timeline Communication	5 (Members not knowing what to work on, sub-teams skipping critical tasks)	C (creates confusion in the team and can potentially derail the project or cause a backlog of work during the milestone reports)	5C - Moderate	Make Sub-team meetings more efficient, creating task checklists, opening new operations positions to aide in project management	Oversight by operations team.	4B - Enhanced

6 Project Plan

6.1 Mission Requirements and Verification

Requirement ID	Summary	Verification Type	Verification Plan	Status
1.1	Teams must be made of 100% students. Excluding Team mentor and Advisors. Students must design and build vehicle. Students are not allowed to handle motors or black powder.	Not Applicable		Compliant
1.2	Teams will provide and maintain a project plan for: milestones, budget, community support, checklists, personnel assignments, STEM engagement and Risk mitigation	Not Applicable		In-Progress
1.3	Team members will register on NASA Gateway if travelling to Huntsville	Not Applicable		Completed
1.4	Teams will engage a minimum of 250 participants in educational Direct engagement STEM activities.	Not Applicable		Not Started
1.5	Teams will establish and maintain a social media presence	Not Applicable		Completed
1.6	Teams will deliver all projects deliverables on time to NASA	Not Applicable		Compliant

1.8-10	All deliverables will be in PDF format, contain page numbers, and Table of Contents	Not Applicable		Compliant
1.11	Teams will be capable of performing video teleconferneces.	Not Applicable		Compliant
1.12	Teams attending launch week will use the provided launch pads	Not Applicable		Not Started
1.13	Each Team will identify a “mentor”	Not Applicable		Compliant
1.14	Teams will report the number of hours worked on each milestone	Not Applicable		Compliant
2.1	Vehicle will deliver the payload to an altitude of 5000ft.	Analysis		Not Started
2.2	Teams shall declare their target altitude at the CDR Milestone	Not Applicable		Completed
2.3	The Launch vehicle will be recoverable and reusable, able to launch on the same day without repairs.	Demonstration	Inspect each component for damage after first launch. Verify functionality and prep for second launch. Confirm ready for relaunch.	Not Started

2.4	Vehicle Section Shoulders, shall be of sufficient length to prevent bending or unNot Started separation	Inspection	Design verified by Safety officer and Team Mentor	Not Started
2.5	Launch vehicle shall be capable of being prepared for flight within 2 hours of the FAA COA activation	Demonstration	Conduct timed demonstration where vehicle is fully prepped 2 hours before activation. Time this by recording full configuration and activation process, while ensuring compliance with safety and operation requirements. Confirm flight readiness in specific time frame.	Not Started

2.6	The vehicle shall be able to be ready on the pad without losing critical functionality for at minimum 3 hours.	Test	Performing a power on test and timing the computer, measuring the battery voltage as the test goes on to project the maximum time the vehicle can be powered on	Not Started
2.7	The vehicle shall be able to be launch by standard 12-volt launch controllers	Inspection	Design verified by Safety officer and Team Mentor	Compliant
2.8	The vehicle shall require no external circuitry to launch	Inspection	Design verified by Safety officer and Team Mentor	Compliant
2.9	Teams will use commercially available e-matches or igniters	Not Applicable		Not Started
2.10	The launch vehice will use a commercially available solid rocket motor that is approved by TRA, NAR, or CAR	Analysis		Compliant
2.11	The Launch Vehicle shall be limited to a single motor propulsion system.	Inspection	Design verified by Safety officer and Team Mentor	Compliant
2.12	The total impulse provided by a College or University launch vehicle shall not exceed 5,120 Newton-seconds (L-class).	Analysis		Compliant

2.13	Pressure vessels on the vehicle must be approved by the RSO	Not Applicable		Not Applicable
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.	Analysis		Compliant
2.15	The launch vehicle shall have a minimum thrust to weight ratio of 5.0:1.0.	Analysis		Compliant
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.	Analysis		Compliant
2.17	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.	Analysis		Compliant

2.18	All teams shall successfully launch and recover a subscale model of their rocket. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between the proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	Demonstration	Demonstration of a 75% scale vehicle, with similar aerodynamic and stability factors to prove the vehicle is stable.	Completed

2.19.1	Vehicle Demonstration Flight — All teams shall sucessfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.).	Demonstration	Vehicle demonstration flight of the full scale vehicle in competition configuration demonstrating recovery systems and active energy control systems (ACS)	In-Progress

2.19.2	Payload Demonstration Flight — All teams shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed	Demonstration	Vehicle demonstration flight of the full scale vehicle in competition configuration demonstrating recovery systems, active energy control systems (ACS), and Payload Systems	Not Started

2.21	The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
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.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
3.1	The full-scale launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	Test and Demonstration	Demonstrated on VDF	Compliant
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Analysis	Analyzed from Demonstration flight Data	Not Started

3.1.2	The apogee event shall contain a delay of no more than 2 seconds.	Analysis	Analyzed from Demonstration flight Data	Not Started
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	Inspection	Design verified by Safety officer and Team Mentor	Compliant
3.2	Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	Test	Assemble recovery mechanisms similar to in flight to ensure all safety and measuring equipment is in place. Activate system to configure with no malfunctions with recording of results. Any failures must be addressed and retest until reliable performance.	Not Started
3.3	Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by vehicle demonstration flight data, stays under 65 ft-lbf will be awarded bonus points.	Analysis		Not Started

3.4	The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	Inspection	Design verified by Safety officer and Team Mentor	Compliant
3.5	Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.	Inspection	Design verified by Safety officer and Team Mentor	Compliant
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	Design verified by Safety officer and Team Mentor	Compliant
3.7	Each arming switch shall be capable of being locked in the **ON** position for launch (i.e., cannot be disarmed due to flight forces).	Inspection	Design verified by Safety officer and Team Mentor	Compliant
3.8	The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.	Inspection	Design verified by Safety officer and Team Mentor	Compliant

3.9	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
3.10	Bent eyebolts shall not be permitted in the recovery subsystem.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
3.11	The recovery area shall be limited to a 2,500 ft. radius from the launch pads.	Analysis		Not Started
3.12	Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.	Demonstration	Demonstrated on VDF	Not Started
3.13	An electronic GPS tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Inspection	Design verified by Safety officer and Team Mentor	In-Progress
3.13.1	Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic GPS tracking device.	Not Applicable		Not Applicable

3.13.2	The electronic GPS tracking device(s) shall be fully functional during the official competition launch.	Demonstration	Monitor performance from GPS calculating its accuracy of tracking and transmitting the correct vehicle position throughout flight.	Not Started
3.14	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Test and Demonstration		Not Started
3.14.1	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Inspection	Design verified by Safety officer and Team Mentor	Compliant
3.14.2	The recovery system electronics shall be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
3.14.3	The recovery system electronics shall be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Inspection	Design verified by Safety officer and Team Mentor	Not Started

3.14.4	The recovery system electronics shall be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	Inspection	Design verified by Safety officer and Team Mentor	Not Started
4.1	USLI Payload Mission objective: College/University Division — Teams are tasked with designing, building, and flying a STEMnaut flight capsule capable of safely retaining four STEMnauts and transmitting, via radio frequency, relevant rocket and STEMnaut landing site data to a NASA-owned receiver located at the launch site. STEMnauts are physical representations of the crew on-board the rocket. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to a proposed payload.	Test and Demonstration		In-Progress

4.2.1	Teams shall choose a minimum of 3 pieces from the below list to a maximum of 8 to transmit to the NASA receiver.	Demonstration	Confirm the success of transmission to receiver and reception of data under simulated launch conditions.	Not Started
4.2.2	The payload shall not have any protrusions from the vehicle prior to apogee that extend beyond a quarter inch exterior to the airframe.	Inspection	Design verified by Safety officer and Team Mentor	In-Progress
4.2.3	Payload shall transmit on the 2-M band. A specific frequency shall be given to the teams later. NASA shall use the FTM-300DR transceiver.	Demonstration	Test transmission functionability under controlled conditions. Ensure system operates as intended. Record results and verify their compliance.	In-Progress
4.2.4	All transmissions shall start and stop with team member call sign.	Demonstration	Monitor and collect information confirming proper identification at start and stop of each communication. Verify complaince	Not Started

4.2.5	Teams shall submit a list of what data they will attempt to transmit by NASA receiver by March 17.	Inspection		Compliant
4.2.6	Teams shall transmit with a maximum of 5W and transmissions shall not occur prior to landing.	Demonstration	Simulate fligtht conditions. Monitor transmission power and timing. Verify and ensure complaince with stated requirements.	Not Started
4.2.6.1	Teams shall not transmit on the specified NASA frequency on launch day prior to landing.	Demonstration	Monitor pre-launch and flight phase frequency. Verify all transmissions comply with requirements.	Not Started
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Not Applicable		Not Applicable
4.3.2	Teams shall abide by all FAA and NAR rules and regulations.	Inspection		Compliant

4.3.3	Any payload experiment element that is jettisoned during the recovery phase shall receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	Not Applicable		Not Applicable
4.3.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	Not Applicable		Not Applicable
4.3.5	Teams flying UASs shall abide by all applicalbe FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	Not Applicable		Not Applicable
4.3.6	Any UAS weighint more than .55lbs. shall be registered with the FAA and the registration number marked on the vehicle.	Not Applicable		Not Applicable
5.1	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Not Applicable		Not Started

5.2	Each team shall identify a student safety officer who will be responsible for all items in Section 5.3.	Not Applicable		Completed
5.3.1	Monitor team activities with an emphasis on safety during:	Inspection		In-Progress
5.3.1.1	Design of vehicle and payload	Not Applicable		In-Progress
5.3.1.2	Construction of vehicle and payload components	Not Applicable		In-Progress
5.3.1.3	Assembly of vehicle and payload	Not Applicable		In-Progress
5.3.1.4	Ground testing of vehicle and payload	Not Applicable		In-Progress
5.3.1.5	Subscale launch test(s)	Not Applicable		Completed
5.3.1.6	Full-scale launch test(s)	Not Applicable		Not Started
5.3.1.7	Competition Launch	Not Applicable		Not Started
5.3.1.8	Recovery activities	Not Applicable		Not Started
5.3.1.9	STEM Engagement Activities	Not Applicable		Not Started
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Not Applicable		In-Progress
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and SDS/chemical inventory data.	Inspection		In-Progress
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Inspection		In-Progress

5.4	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams shall communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Not Applicable		Not Started
5.5	Teams shall abide by all rules set forth by the FAA.	Inspection		Compliant

6.2 Budget

6.2.1 Vehicle Bill of Materials

Part	P/N	Q of Parts	Material	Source	Q of Materials	Base Cost	Tax	Total Cost
Nosecone Bottom		1	PLA	Makerspace	N/A	$-	$-	$-
Nosecone top		1	PETG	Makerspace		$-	$-	$-
I-Nut	3274T71	1	Steel	Mcmastercarr			$-	$-
1/4 20 steel threaded rod		1	Steel	Mcmastercarr			$-	$-
5ft body tube	GT12 3.9	4	Fiberglass:GT12 3.9	Wildman			$-	$-
Coupler tube 1in	GT12 3.9	60	Fiberglass:GT12 3.9	Wildman		$2.33	$0.15	148.5375
Fins		4	Polycabonate	Makerspace			$-	$-
2 Meter Radios		1		Amazon		$49.99	$3.12	$53.11
Flight Batteries		1		Amazon		$21.99	$1.37	$23.36
BNO055	4646	1		Adafruit		$29.95	$1.87	$31.82
3S Li-Po’s		1		Amazon		$34.99	$2.19	$37.18
PWM tester		1		Amazon		$8.99	$0.56	$9.55
ACS motor driver	2448	1	18-8 Stainless Steel	Adafruit		$6.95	$0.43	$7.38
McMaster Threaded Stud	97042A176	2	18-8 Stainless Steel	McMastercarr		$8.92	$0.56	$18.96
Heat Shrink Tubing		1		Amazon		$11.99	$0.75	$12.74
Multi-Wire Stripper Tool		1		Amazon		$19.99	$1.25	$21.24
4-40 Square Nuts	94855A281	1	Zinc plated steel	Mcmastercarr		$3.37	$0.21	$3.58
XT30 Connectors		1		Amazon		$11.99	$0.75	$12.74
4-40 Heat Set Inserts		1		Amazon		$10.99	$0.69	$11.68
ESP32-S3 feather	5477	1	Electronics	Adafruit		$17.50	$1.09	$18.59
BMP388	3966	1	Electronics	Adafruit		$9.95	$0.62	$10.57

ADXL375	5374	1	Electronics	Adafruit		$24.95	$1.56	$26.51
ICM-20948 9-DOF Gyroscope	4554	1	Electronics	Adafruit		$14.95	$0.93	$15.88
RFM69HCW Transceiver Radio	3070	1	Electronics	Adafruit		$9.95	$0.62	$10.57
Raspberry Pi Pico 2 - RP2350	6006	1	Electronics	Adafruit		$5.00	$0.31	$5.31
Breadboard	443	2	Electronics	Adafruit		$19.95	$1.25	$42.39
MPL3115A2	1893	1	Electronics	Adafruit		$9.95	$0.62	$10.57
Flash Memory	6038	1	Electronics	Adafruit		$10.95	$0.68	$11.63
GPS Chip	4415	1	Electronics	Adafruit		$29.95	$1.87	$31.82
Jumper Wires		1	Electronics	Amazon		$7.99	$0.50	$8.49
Remove Before Flight Tags x10		1	Cloth	Amazon	N/A	$17.99	$1.12	$19.11
PolyLite™ ASA (1kg)	PF01011	1	PLA	Polymaker	1kg	$31.99	$2.00	$33.99
PolyLite™ PETG (1kg)	PB01015	1	PETG	Polymaker	1kg	$22.99	$1.44	$24.43
PolyLite™ PETG (1kg)	PB01024	1	PETG	Polymaker	1kg	$22.99	$1.44	$24.43
PolyMax™ PC (750g)	PC02004	1	PC	Polymaker	750g	$38.99	$2.44	$41.43
							$-	$-
Total						$518.48	$32.41	$727.62

Table 6.2.1: Vehicle Bill of Materials

6.2.2 Total Planned Expenses

Group	Cost	% total
Vehicle BOM	727.62	6.61
vehicle buffer (+10%)	72.762	0.66
Plane tickets	3100	28.17
rental cars / gas	1400	12.72
Hotels	2500	22.72
engagement	250	2.27
Rocket Motors and Shipping	1520	13.81
Pre Total	9570.382	
Project Buffer (+15%)	1435.557	13.04
Total	11005.94	100.00

Table 6.2.2: Overall Project Projected Expenses

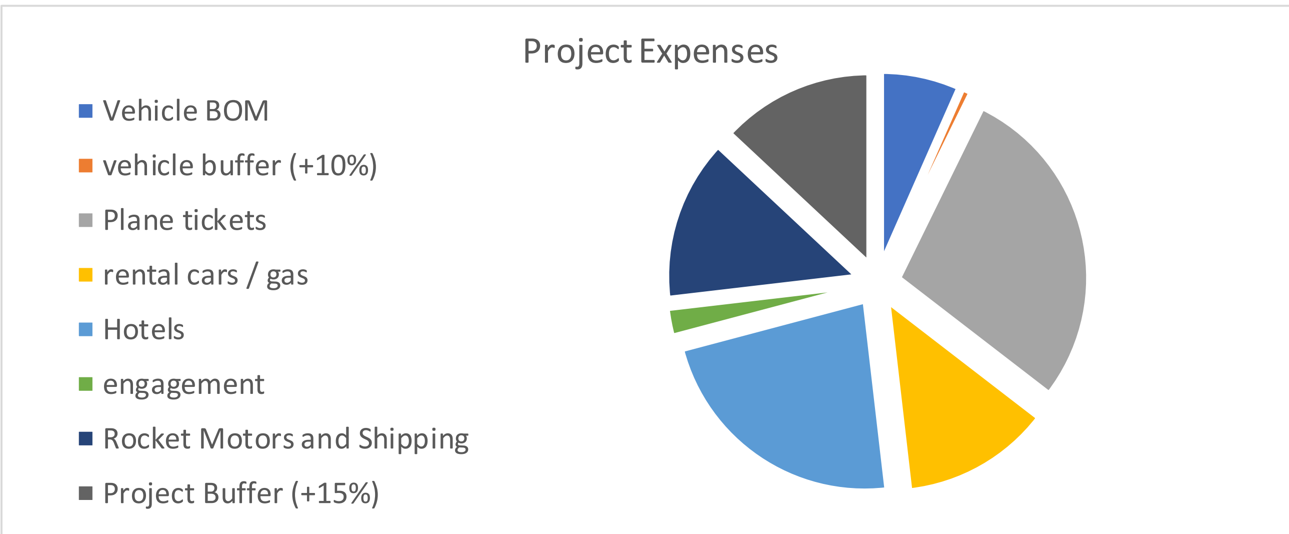


Figure 6.2.1: Pie-Chart of Expected USLI Expenses

Travel Expenses (plane tickets, hotels) are based on the cost of 10 members traveling to Huntsville, AL. for 6 days and 5 nights. Rental car/gas cost is based on getting 3 cars in Hurstville and paying for gas for members driving to test launches during the full-scale vehicle test period.

6.2.3 Current Overall Club and Team Expenses

Currently, the club has spent a total of $2743, this includes buying motors for certification flights, buying recovery equipment for the club like Joly Logic Chute Releases. $1239 has been spent on equipment solely for the USLI team. These expenses have been in the form of buying material for full vehicle construction as the Subscale was able to be constructed with material that we had in stock.

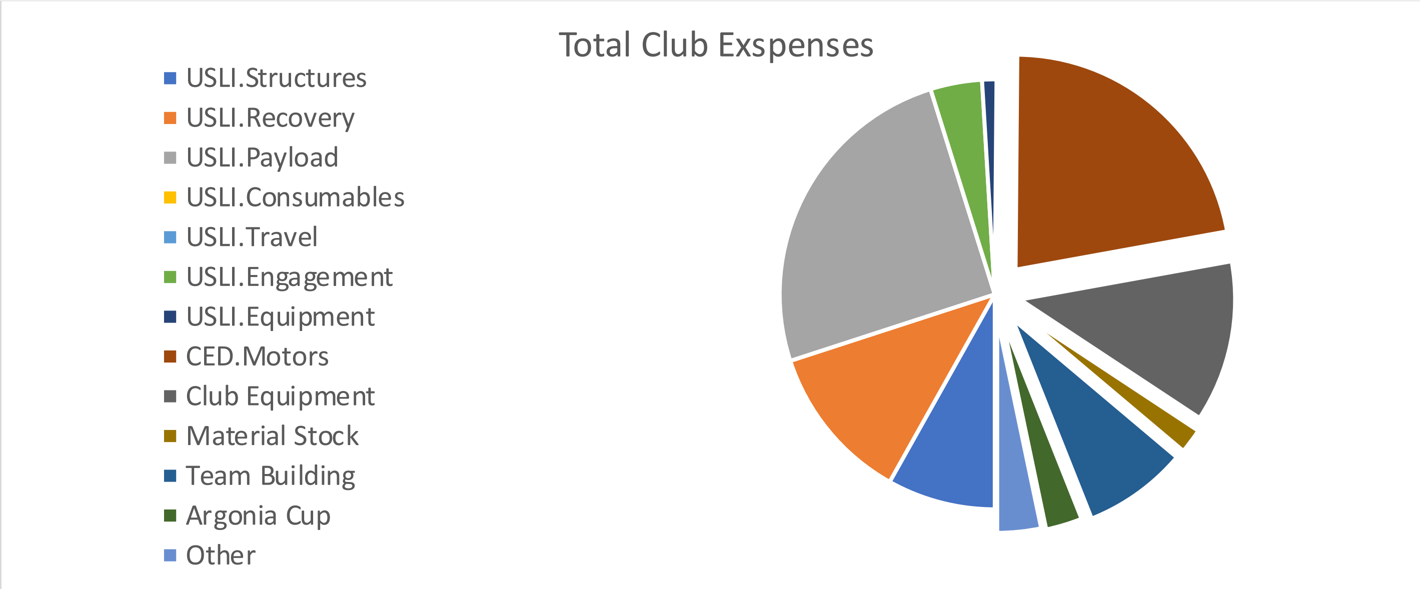


Figure 6.2.2: Pie Chart of Current club expenses

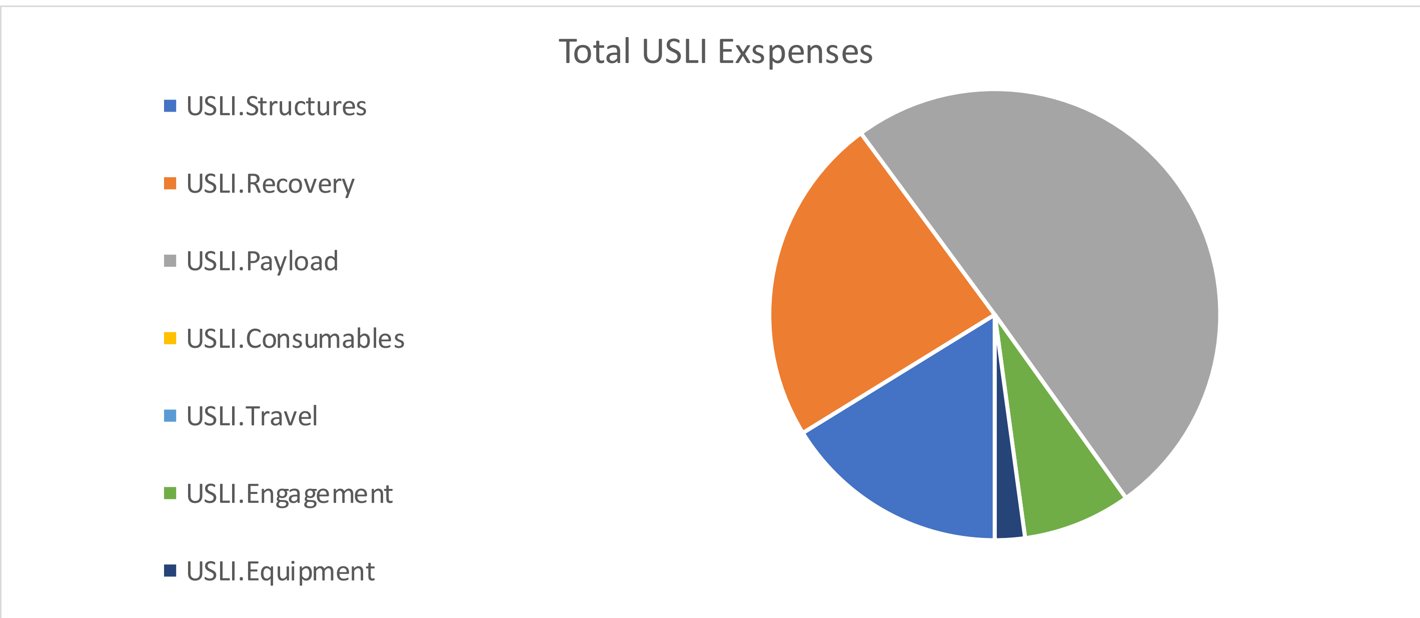


Figure 6.2.3: Pie chart of current USLI team expenses

Planned upcoming expenses are buying new test motors for the VDF and PDF, purchasing the PCB's for the payload, and buying the 3D printer filament for the fins and fin mounting bracket.

The team currently has $2069 in the account and is still waiting for the donation from the FCOE ($2500). The relationship between the club

6.2.4 Funding Plan

The Funding plan remains largely unchanged since the proposal, with 5 main sources of funding coming into our club: Student Government Association, The College of Engineering Deans Office, The Department of Mechanical and Industrial Engineering, GiveCampus crowdsourcing campaign, and corporate sponsorships.

6.2.4.1 Student Government Association

The team received $1324 from the Student Government Association for the annual budget and an additional $1251 after we applied for the grant

6.2.4.2 Francis College of Engineering Deans Office

We received the full amount of $2500 from the FCOE Deans Office, largely in part to our continued assistance with club fairs, open houses, and other events around campus.

6.2.4.3 Department of Mechanical and Industrial Engineering (MIE)

The business team will arrange a meeting with the Chair of the MIE department before the end of the Januray to request additional funding from the department.

6.2.4.4 GiveCampus Crowdsource Fundraising

The business team is currently editing a promotional video for a GiveCapmus page, a GoFundMe style website for college groups to raise money. The goal is to get the campaign started before the holiday season so members can share the link amongst their families.

6.2.4.5 Corporate Sponsorships

Lastly the business team has reached out to Kerry Pucillo, who manages corporate relations at UML. The team will soon start reaching out to local businesses and engineering firms to see if they are interested in sponsoring the team. The team has reached out to a few corporations so far with no luck.

6.3 Project Timeline – Gantt Chart

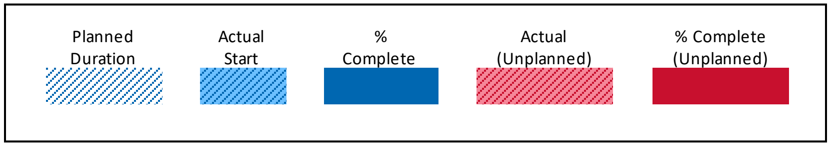
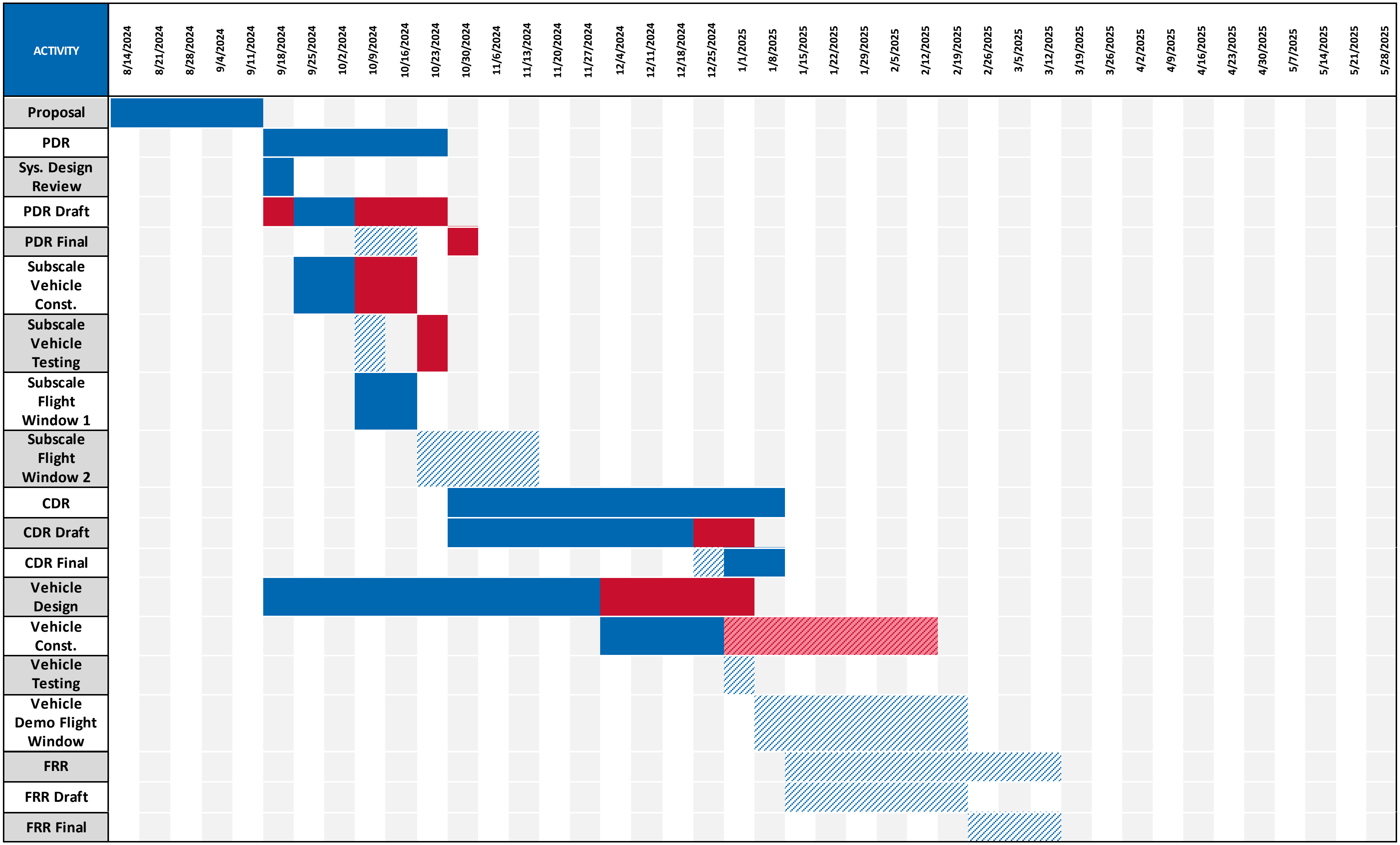


Figure 6.3.1: Project Timeline Legend



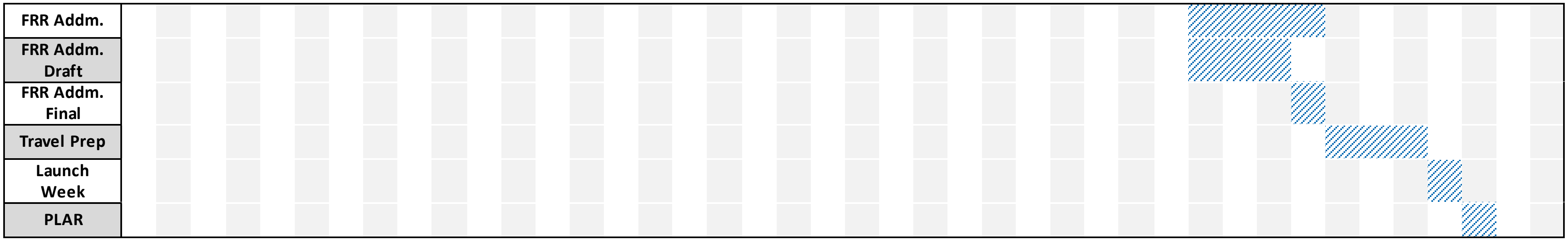


Figure 6.3.2: Project Timeline

6.4 Testing

6.4.1 Radio Transceiver Range Test

The Radio Transceiver test aims to confirm that the information output at the ground station matches the information sent via the serial output of the payload and/or recovery computer. The data must be effectively transmitted at long ranges greater than 4000 ft.

The test will be carried out with one person on each end of the link. The end simulating the transmitter will utilize a laptop connected to the serial output on the computer to read the information from the source. The stations will then be separated incrementally by 10m until either an error is recorded, or the payload/recovery computer fails to transmit. At each point recorded, the antenna will be rotated in a circular manner at a point to account for any transmission range or data loss. The test will continue until the data link is no longer readable and will be repeated for every directional antenna used on the vehicle. Various locations may be used to account for local RF interference.

This Test is necessary to verify the maximum operating distance and to identify any orientation in which the vehicle may lose communication downlink. Any vehicle-related interference must be accounted for to ensure that loss of downlink can be identified. Vehicle flights are possible without a live communication downlink. However, live monitoring of vehicle telemetry will be beneficial to understanding the dynamics during any flight.

6.4.2 Payload DAC-Radio connection integrity test

This test aims to verify that the data output via TTS retains audio quality when connecting the radio transmitter to the payload computer DAC.

The Analog Devices ADK2 development kit will be wired to the DAC output of the payload computer, which will output a frequency response measurement while white noise is played. Following the verification of this frequency headphones will be connected to the DAC output and sample TTS data will be played. The audio will then be evaluated to discern if the intended meaning is conveyed by having various test subjects writing what they hear on a piece of paper. This will be repeated with the Baofeng radio will be connected to the DAC output and the audio will be tested via a separate receiver. The test will verify that the TTS data transmitted will be properly conveyed on launch day. Data from this test will be used to adjust audio output levels such as gain or audio sample rate.

6.4.3 ACS Motor Actuation Test

The ACS motor actuation test is meant to ensure that the CS remains in the proper positioning in both no load and in-flight load. This is to confirm that the ACS is working properly.

Doing this test also allows for any code to be fixed in the airbrake system if it is not working as intended, which lowers the overall risk of the system. This test can also be ran day of launch to confirm the ACS is still working properly.

Due to the nature of the test, changes are almost expected as it is of high importance that this system works as it was designed

6.4.4 ACS Wind Tunnel Test

The ACS wind tunnel test's objective is to obtain a real world drag coefficient for more accurate simulation data. To do this, an anemometer as well as a pitot-static tube will be used to gather velocity and air density. The coefficient of drag equation can then be used to obtain the coefficient drag required.

After conducting this test, no changes are anticipated as this is purely to obtain a coefficient of drag, and not necessarily a certain value for our coefficient.

Appendix A: UML Flight Card for Subscale Demonstration

UML Flight Log Card

Flight: Peregrine explorer flight 1 Subscale

Motor(s):

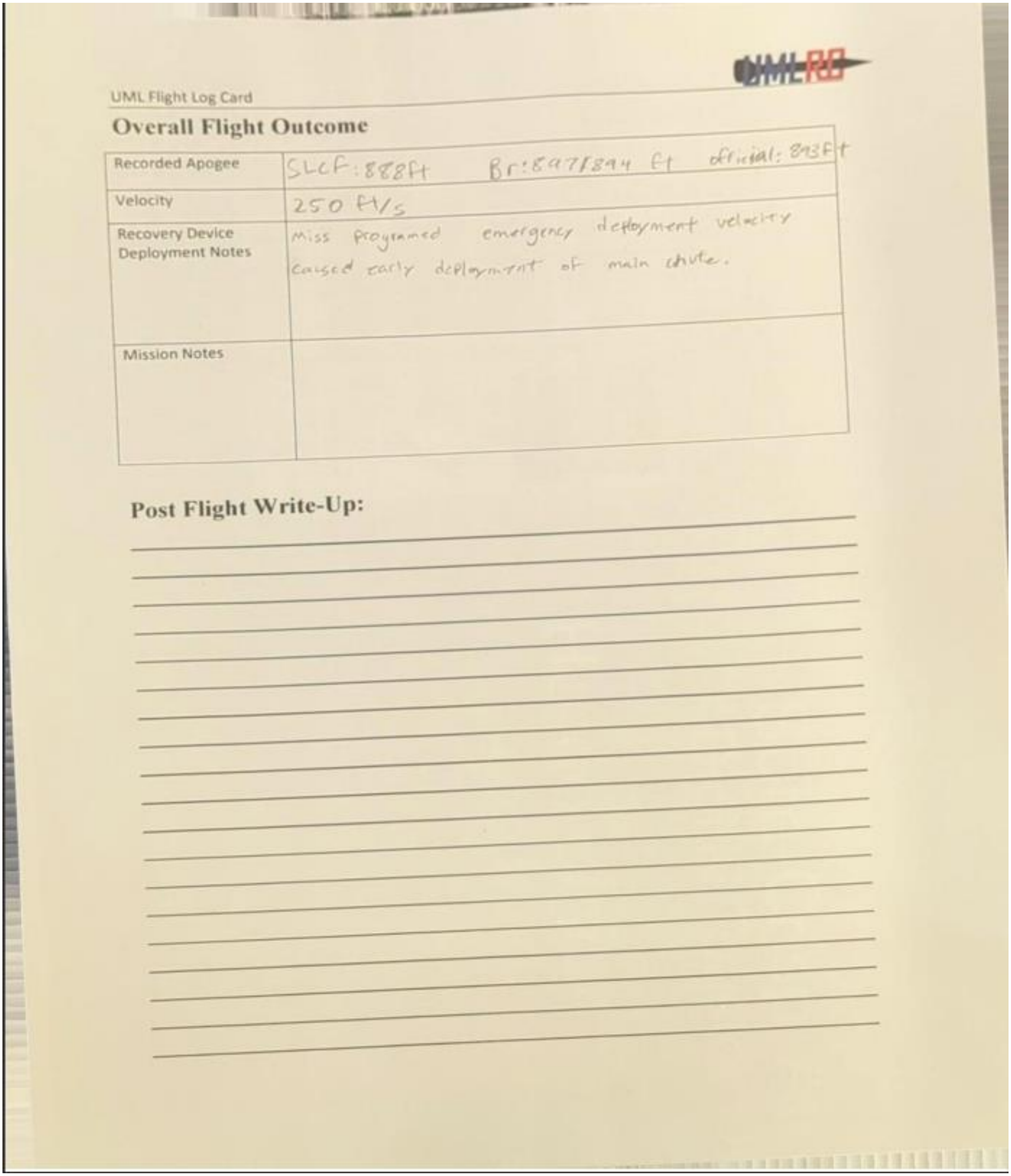
AT H219T-P New blue thunder dc: 012424

Ejection Charges

Charge Line	Blue Raven	Stratologger	Blue Raven	Stratologger		
Size	0.36 g	0.41 g	0.36 g	0.45 g		
Timing	APO	APO	500 ft	450 ft		

Simulated Flight Characteristics

Expected Apogee	1335
Expected V_{Max}	315
Expected A_{Max}	12.5
Wet Stability Margin	10.4 %
Simulated Dry Mass	4.5
Notes:	Subscale
Primary Flight Goals	✓ Safe Flight ✓ Stable Ascent ✓ Recovery Device Deployment ✓ Good Recovery ✓ No Damage / in flyable state
Secondary / Tertiary Flight Goals	• computers • prove NUSLi is stable ✓ cameras



UML Flight Log Card

Overall Flight Outcome

Recorded Apogee	SLCF: 888ft Br: 897/894 ft official: 893Ft
Velocity	250 Ft/s
Recovery Device Deployment Notes	Miss programed emergency deployment velocity caused early deployment of main chute.
Mission Notes	

Post Flight Write-Up: