Project Hermes

2023 NASA Student Launch Initiative
Critical Design Review (CDR)

ResistoJets Rocketry 4-H Club of Morris County

[redacted]

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Glossary

4-H - Youth Organization (Our team's host administration)

FCC - Federal Communications Commission (Government Agency)
FAA - Federal Aviation Administration (Government Agency)
NASA - National Aeronautics and Space Administration (Government Agency)
SLS - The Space Launch System rocket (NASA's current rocket)

STEM - Science, Technology, Engineering, and Math

MSDS - Material Safety Data Sheet
PPE - Personal Protective Equipment

FPS - Feet per Second
TWR - Average Thrust to Weight Ratio of the Vehicle during Ascent

SLI - Student Launch Initiative
USLI - University Student Launch Initiative

NAR - National Association Of Rocketry (Rocketry Governing Body)
TRA - Tripoli (Rocketry Governing Body)
HPR - High Power Rocketry
K Motor - Using the level 2 K class of high power rocket motors
L1, L2, and M1 - Classifications of rocketry certifications created by NAR and TRA

SDR - Software Defined Radio
USB - Universal Serial Bus
APRS - Automated Packet Reporting system
LIPO - Lithium-Ion Polymer Battery

PDR - Preliminary Design Review
CDR - Critical Design Review
FRR - Flight Readiness Review
LRR - Launch Readiness Review
PLAR - Post-Launch Assessment Review

1. Summary of CDR Report

1.1 Team Summary

Name of team and mailing address:
ResistoJets Rocketry 4-H
[redacted]

Mentor: Luke McConoughey
[redacted]

<u>Our team plans to launch at the final competition launch in Huntsville on April 15th.</u>
Our team has spent 180 hours working on the CDR milestone.

1.2 Launch Vehicle Summary

Target altitude: 3,800 feet
Final Motor Selection: K1100T
Dry mass of vehicle without ballast: 10.98 lb
Dry mass of vehicle with ballast: 12.18 lb
Wet mass of vehicle: 15.1 lb
Burnout mass of launch vehicle: 13.42
Landing mass of launch vehicle: 13.42
Rail Size: 1010 T Slot

Recovery system:
Our recovery set-up uses a fully redundant dual deploy system, with a 48" Fruity Chutes Main parachute and a 15" Spherachutes Drogue Parachute. We will be using two Stratologger CF flight computers in our dual deploy system with independent battery, switch, and charges.

The drogue parachute is connected to the airframe with an U-bolt on the avionics bay and solid eye bolt on the motor centering ring. The drogue harness is 3/8" tubular kevlar 25 feet long with two loops that are connected via quick links. The drogue parachute is tied to the harness approximately five feet aft of the avionics bay.

The main parachute is attached to the airframe with an U-bolt on the avionics bay and an U-bolt on the nose cone bulkhead. The drogue harness is 3/8" tubular kevlar 30 feet long with three loops that are connected via quick links. The main parachute is connected to the third loop on the harness estimated to be 10 feet behind the nose cone.

1.3 Payload summary:

Payload title: 2022-2023 NASA USLI Payload Challenge:
Our payload consists of a robotic arm mechanism that upon landing will rotate itself about the Z axis of the rocket until it faces an upward position (if the rocket lands on its side), after which it will extend out an arm with a small motorized camera that will complete radio transmitted instructions to take pictures of its surroundings. It then saves the pictures to internal storage in the rocket, after it is finished it shuts itself off and is later recovered.

2. Changes Made Since PDR

2.1 Changes made to vehicle criteria

- Avionics bay and payload moved closer to aft of vehicle
  - To place the protuberances further behind the center of gravity
- Upper airframe extended
  - To raise the center of gravity
- Nose cone lengthened
  - Raises center of gravity
- Fin height increased
  - Higher static stability at rail exit
- GPS Tracker added, at base of nose cone
  - Previously missing from PDR
- Ballast weight has been changed to sand
  - Previously planned to use metal BBs, which is disallowed
- Removed carbon fiber tip to tip lay-up
  - Deemed unnecessary from subscale flights
- Added Runcam 2 4k camera to vehicle
  - Opposite to payload protuberance during launch to balance out drag
- Changed rail buttons to raised rail buttons
  - Necessary for the launch rail to be clear of the payload protrusion

2.2 Changes made to payload criteria

- Top of payload shroud tapered
  - Reduces drag, helping us reach our altitude target
- Camera arm changed to 3-D printed plastic
  - Previously carbon fiber changed for ease of manufacturing.

2.3 Changes made to project plan

- Full testing plan added
- STEM Engagement program updated
- Social media presence increased

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement

Our goal is to create a safe, simple, and reliable launch vehicle that will satisfy all SLI requirements and complete many SLI challenges.

Our mission success criteria includes:

- A stable, vertical ascent, a safe and successful launch with recovery of the vehicle in reflyable condition
- Altitude accuracy - the rocket shall reach an apogee within 15% error of the target.
- Successful payload launch and landing.
- Successful implementation of these innovative technologies:
    - Reloadable rocket motors
    - Composite structures
    - 3D printing
- Physically robust and visually appealing structure.

We also want the vehicle to serve as a medium of sharing our incredible story in STEM engagements and future team outreach activities beyond SLI.

3.1.2 Final design choices

3.1.2.1 Aerostructure System

For the Aerostructure system, here are our final design choices:

- 4” diameter G10 filament-wound fiberglass airframe tube from Wildman Rocketry
    - The airframe is split into a booster section, a payload/avionics bay, and upper airframe. There will be separation points in between each section for recovery.
    - Inner diameter is 3.9”
    - Outer diameter is 4.02”
    - Booster airframe tube is 37.4” long
    - Payload airframe tube is 26.375” long
- Four ⅛” G10 Fiberglass fins with fin tabs for through-the-wall fin mounting. The leading edges and trailing edges will be beveled. The dimensions of the fins are listed below.
    - Root chord: 11.9”

- Tip chord: 2.3”
- Height (semi-span): 4.724”
- Sweep length: 9.2”
- Sweep angle: 62.8 Degrees.
- Tab length: 6.6”
- Tab height: 0.875”
- Tab position: 0.15” from fin bottom
- Fin position: 0.5” from airframe bottom

- 12” long motor mount tube for 54mm motors - G12 filament-wound fiberglass from Wildman Rocketry
    - Attached to airframe tube via three centering rings (0.125” thick G10 fiberglass)
    - Has 0.75” exposed for Aeropack motor retainer mounting
- 12” long G12 filament-wound fiberglass coupler for the avionics bay
    - Has 2 ¼” thick G10 fiberglass bulkheads on each end
    - A fiberglass vent band is included for switch access on the pad
    - The payload is also attached to the avionics bay via a rotating ring below the vent band.
- 4” diameter Wildman Rocketry nose cone - 6:1 Von Karman shape
    - This includes an 8” length coupler
    - 1.2lb of sand ballast is also added into the tip of the nose cone.

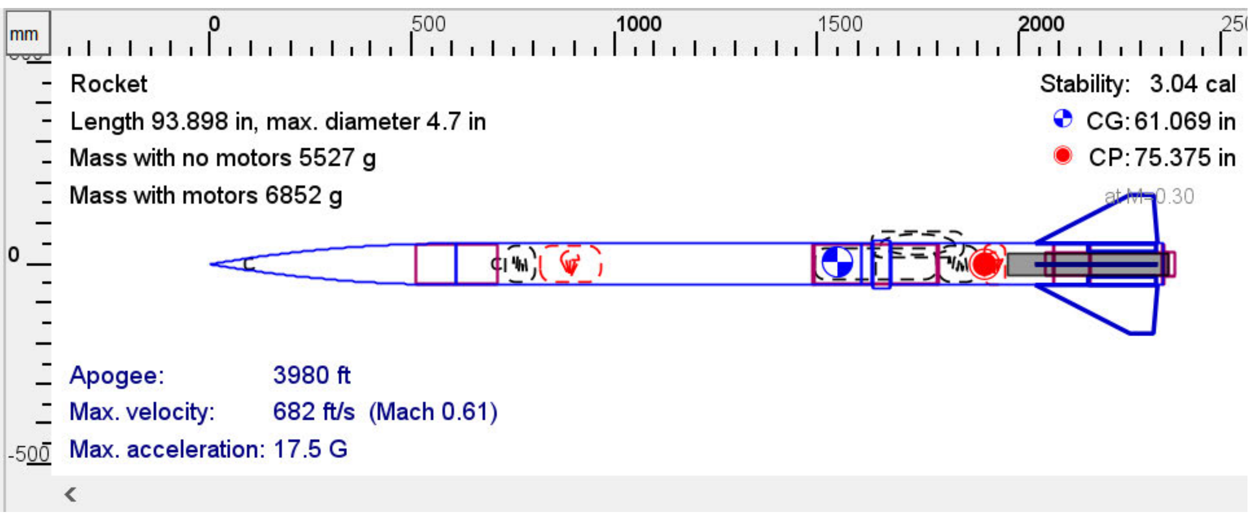

Figure 1. Open Rocket design of the vehicle

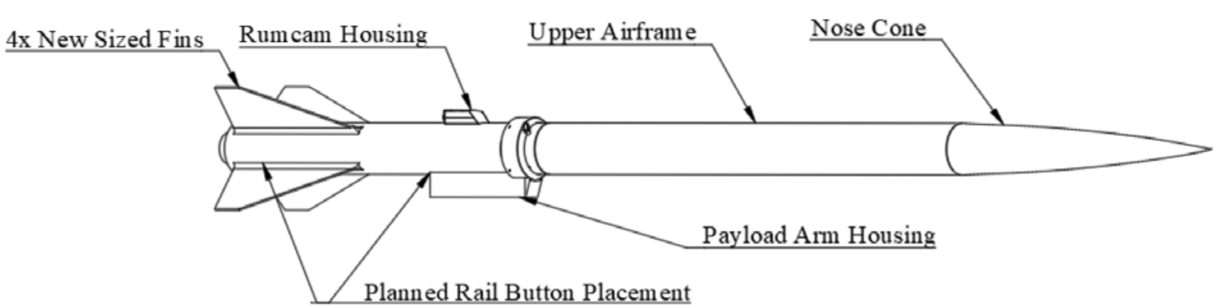

Figure 2. Diagram showing the external components of the launch vehicle

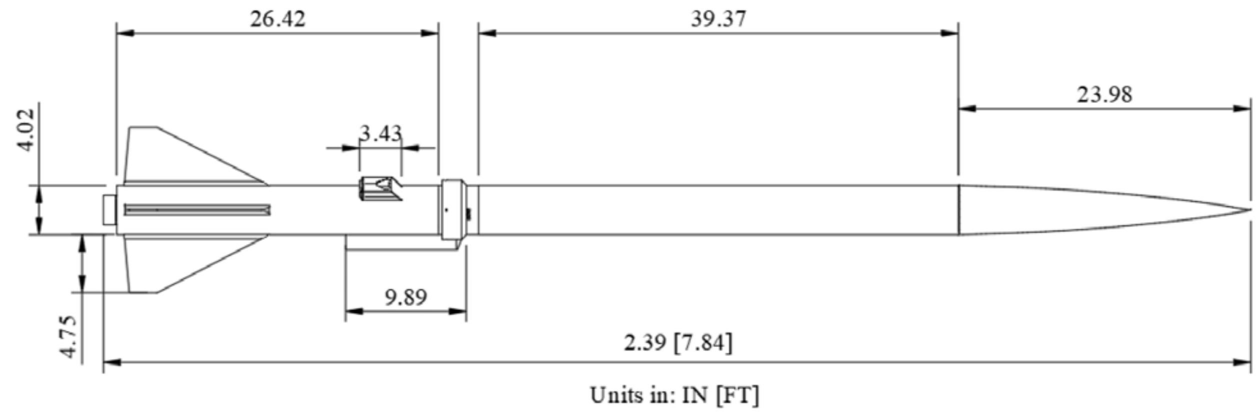

Figure 3. Diagram showing the length of launch vehicle components

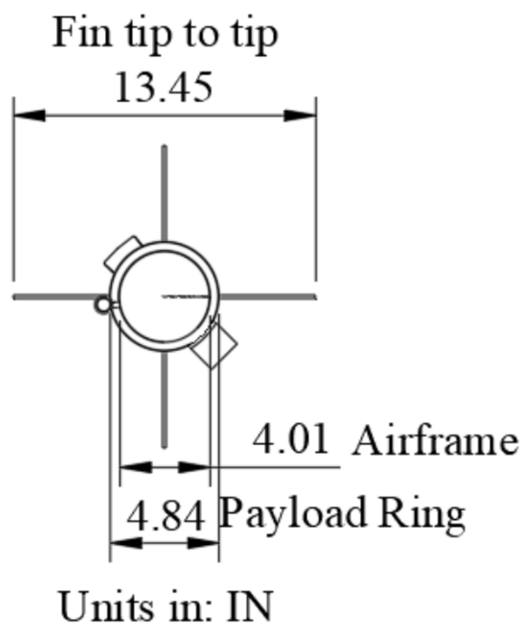

Figure 4. Diagram showing measurements of the launch vehicle from a top down perspective

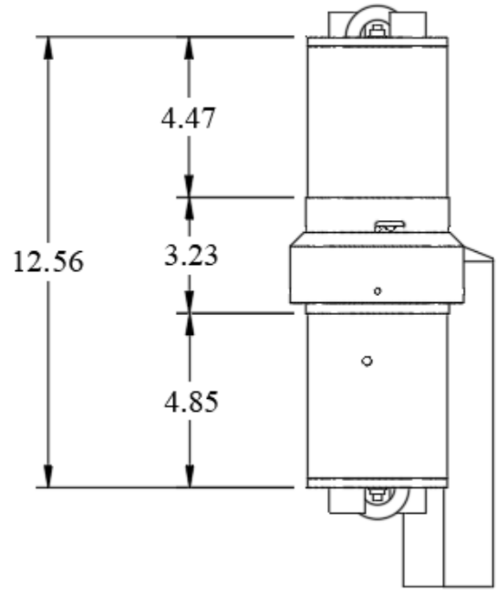

Figure 5. Measurements of avionics bay coupler and shoulders.

Our rocket's structural components are all fiberglass since it's sturdy yet lightweight. Composite materials such as fiberglass are easy to work with, yet they have good material properties such as compressive & impact strength, tensile strength, and stiffness. It's also a very common choice for bigger vehicles in high power rocketry, which adds reliability to the design. Thus, our aerostructure will be robust and reliable, satisfying the goal of our vehicle mission statement.

3.1.2.2 Vehicle Fabrication Plan

For the rocket construction, we will manufacture the rocket in these steps:

For the booster:

1. Cut the stock airframe into the booster and payload sections
2. Cut the fin slots into the sustainer
3. Glue 2 centering rings together to make the thicker, stepped aft centering ring
4. Assemble the motor mount assembly:
    a. Mark the locations of each centering ring
    b. Slide on the forward and middle centering rings
    c. Use CA glue to tack the rings on, then epoxy with fillets.
    d. Use a fin jig to tack all 4 fins on, making sure the forward edges of the fin tabs are in contact with the bottom face of the middle centering ring
    e. Slide the aft centering ring up against the aft edges of the fin tabs
    f. Make internal epoxy fillets along the fin roots and the aft centering ring
5. Use a manual mill to make 4 slots on the booster airframe, making sure that they extend all the way to the bottom of the airframe.

6. Insert the motor mount assembly into the airframe, making sure that the booster harness is positioned properly
7. Make external epoxy fillets along the fin root chords using proper sized shaping tools and tape masks for consistency and integrity.
8. Taper the ends of the fillets and remove the tape masks, revealing a clean joint
9. Finally, epoxy the Aeropack motor retainer onto the aft end of the motor mount tube

For the avionics bay:

1. Mark the position of the vent band on the coupler
2. Using tape masks, carefully glue the vent band to the coupler
3. Mark and drill holes for the avionics bay lids
4. Assemble the rest of the avionics bay, including the sleds, the electronics, the recovery attachments, and the payload attachment.

We will use a combination of CA glue and US635 epoxy system (or Glenmarc G5000 rocketpoxy) to glue components together. CA glue will be used for tacking parts together during construction to make assembly faster, but CA glue will never be used for structural strength. For bonding fiberglass composite parts, we will follow these steps:

1. Sand bonded surfaces with 220 grit sandpaper to remove the oxide layer and roughen up the surface, creating a strong mechanical and chemical bond surface.
2. Use isopropyl alcohol and/or acetone to clean the bonded area of dust or impurities
3. Mask off other surfaces to prevent epoxy from unintentionally bonding any other areas
4. Mix epoxy to the right viscosity and apply to bonding surfaces

3.1.2.3 Propulsion System

Our propulsion system consists of the following components and features:

- Aerotech 54/1706 Case
- K1100T Motor
- Aeropack 54L Motor Retainer

Due to current availability, our vehicle will utilize an Aerotech 54/1706 case for the motor hardware. This size is a perfect size for our application, as K motors around the 1700 N-s impulse range will cause the apogee to fall in the middle of the allowed altitude range. Aerotech products are also very reliable and user-friendly, with a wide user base and community support. We chose the K1100T as our motor because it fits our criteria of impulse range and initial thrust. The impulse range that fits our vehicle the best is from 1400 N-s to 1700 N-s. The K1100T falls into the range at 1472 N-s, which proves its effectiveness for our mission. Its initial thrust also results in a high 15:1 thrust to weight ratio, which is imperative for a safe liftoff and pad exit velocity.

The motor will be retained inside the rocket with a standard Aeropack screw-on motor retainer. This is the most common choice of motor retention in the hobby, therefore it is very straightforward to install during vehicle construction and for use at the field. Its body and cap are both made out of anodized machined aluminum, which is incredibly robust and heat resistant, meaning that it can be used indefinitely. During construction, we will epoxy the body of the retainer to the end of the motor tube, making sure that we leave 0.5” of motor tube exposed to do so. Additionally, the body of the retainer has machined grooves inside the bond surface, allowing for excellent mechanical bond strength, which adds on to the reliability of the system. Finally, the 54L retainer size is designed specifically for Wildman Rocketry fiberglass motor mounts, ensuring a tight tolerance fit for robustness.

3.2 Subscale Flight Results

3.2.1 Subscale Rocket

3.2.1.1 Goal of Subscale Rocket

Prior to subscale testing, our biggest risk and concern was the flight dynamics effect of our payload protuberance. Because of the possible risks of this, we built our subscale to be as small and light as is reasonable in order to reduce the risks of potential anomalies.

Payload Protuberance

Post-PDR, our initial plan was to fly the rocket with just the payload on its own. However, after risk assessments it was decided that the risks of weathercocking from this were too severe. We decided to add a subscale RunCam 2 4K camera housing opposite to where the payload is in its launch configuration. The goal with this was to balance out the asymmetrical drag of the rocket to prevent adverse weathercocking.
This change worked well and we observed a clean and straight ascent on both subscale flights.

In our subscale flights, in addition to verifying that there won’t be dangerous flight effects from our external housings, we wanted to understand how the drag of the protuberances would impact our apogee. We conducted simulations in OpenRocket and RasAeroII and understood that our apogee would be between 750 feet and 1,500 feet.

Additional Design Verifications

Additionally, we wanted to test the only other “unique” parts of our rocket, the fin geometry and dual deploy system. Our subscale fins were cut to be a scaled version of the full-scale fin geometry, and assembled in the airframe the same way as planned for the full scale. For the dual deploy, we had to adjust the avionics bay to work in our subscale design. One of the main changes was reducing from a fully redundant dual deploy system, to a single Stratologger system to fit into the physical confines of the vehicle. This maintained the same Stratologger, battery, pull-pin safety, and ejection charge design as the full scale.

3.2.1.2 Scaling Factors

Physical Dimensions

Our subscale rocket is 57% of the full scale rocket, with an airframe diameter of 2.22 inches. The rocket used a 29mm G80 DMS Rocket motor, which gave similar scaled performance and acceleration to the full scale.

Materials

Going back to our primary goal of this vehicle, we want this subscale to be designed to minimize the impact of potential anomalies. As such we wanted to use light weight materials. We opted to use cardboard and wood instead of fiberglass. The justification for fiberglass on the full scale was to have the vehicle remain in pristine condition after many flights, be operable in adverse weather, and handling high power flight loads. None of these were a concern with the subscale, as we only planned for a maximum of three flights, were able to launch any day we wanted, and would be flying on a mid power rocket motor. We traded off the full scale material verification on this vehicle to maximize safety.

The avionics bay was also made of cardboard, wood, and 3-D printed plastic, for ease of build, and more complicated materials not being necessary in this case.

The payload sim remained as 3-D printed plastic.

Other modifications

Unlike the full scale, on the subscale the nose cone would separate to deploy the main parachute, rather than the upper airframe and nose cone separating from the avionics bay together. This was deemed desirable to allow us to use a simpler avionics bay design.

3.2.1.3 Subscale Specifications

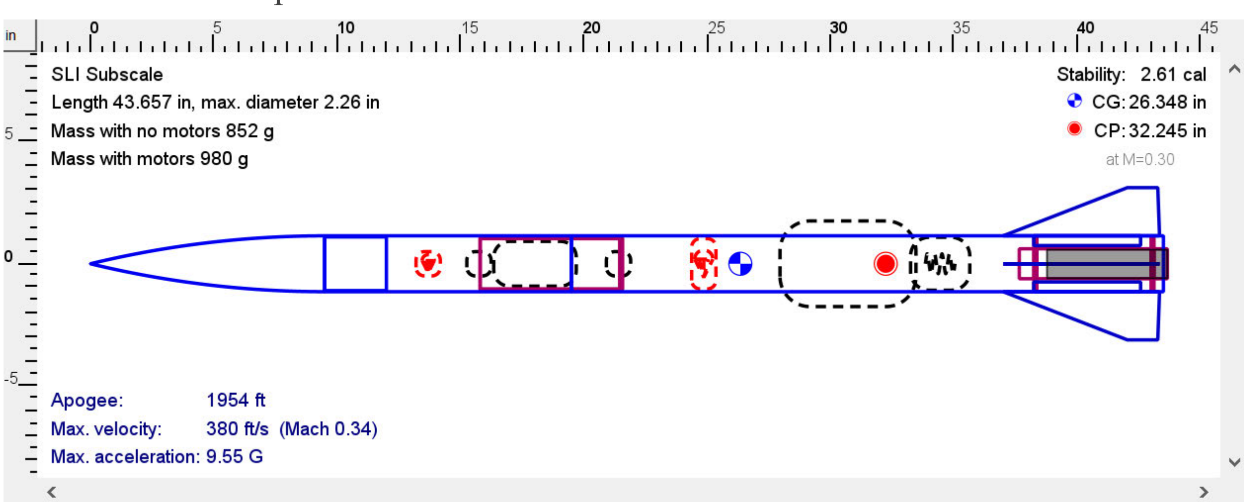

Figure 6. Open Rocket design of our subscale rocket.

Subscale design and simulation specifications:

Length: 43.7 inches
Max velocity: 380 ft/s
Max acceleration: 9.5 Gs
Lift-off weight: 1009g
Stability: 2.6 cal
Flight time: 59 seconds

3.2.2 Subscale Flight Results

We conducted two flights of our subscale vehicle, the first one was deemed a failure because the nose cone broke off of its shock cord resulting in an incomplete landing configuration. We conducted a second, successful flight after this.

3.2.2.1 Flight 1

On 12/18/22, We had our first subscale flight. The injection molded shock cord attachment point on the nose cone broke during the main parachute deployment event. The rest of the flight went well and we collected useful data. Because of this failure we decided to do a re-flight for our official subscale flight. More ejection testing was conducted and the nose cone was repaired before the next flight. We lowered the ejection charge powder to help prevent another flight failure.

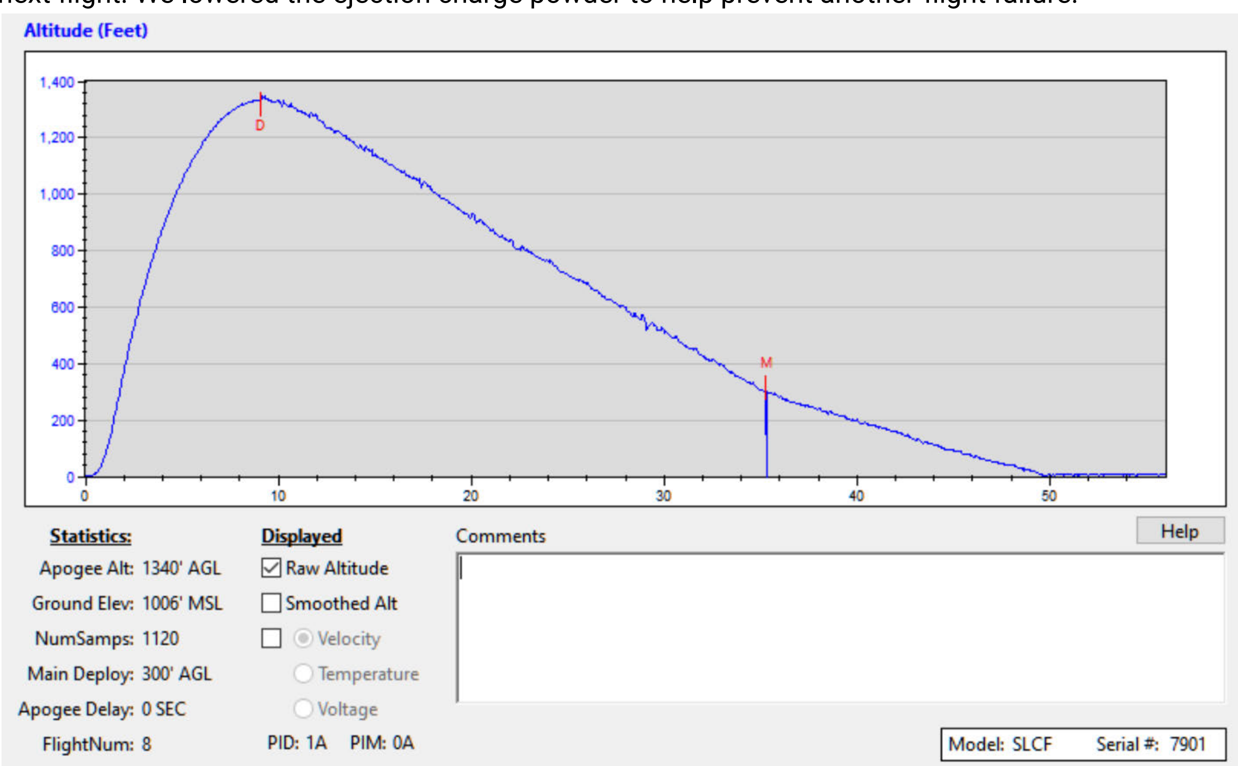

Figure 7. Data from Subscale flight 1 collected from a Perfectflite Stratologger CF

3.2.2.2 Official Subscale Flight (#2)

Our subscale was launched 12/29/2022 at approximately 3PM local time. The winds were on average 5 miles per hour, with gusts up to 15 miles per hour. The air temperature was 45 degrees fahrenheit, with a humidity of 65%. Skies were clear of clouds and it was observed to be “looking great” in regards to launch conditions. The launch condition observations and simulation were conducted in the field prior to final rocket assembly.

We had a straight, clean ascent profile on this flight, as well as good recovery events, thanks to our extra ground testing. The rocket drifted to a neighboring property, where we had to get assistance retrieving our rocket. All systems performed as expected and we have found no issues that need work ahead of our full-scale project.

Differences in simulated and reported apogee are expected as the goal of these flights was to understand the effect of the payload protrusions on the flight characteristics. Continued in 3.2.3.

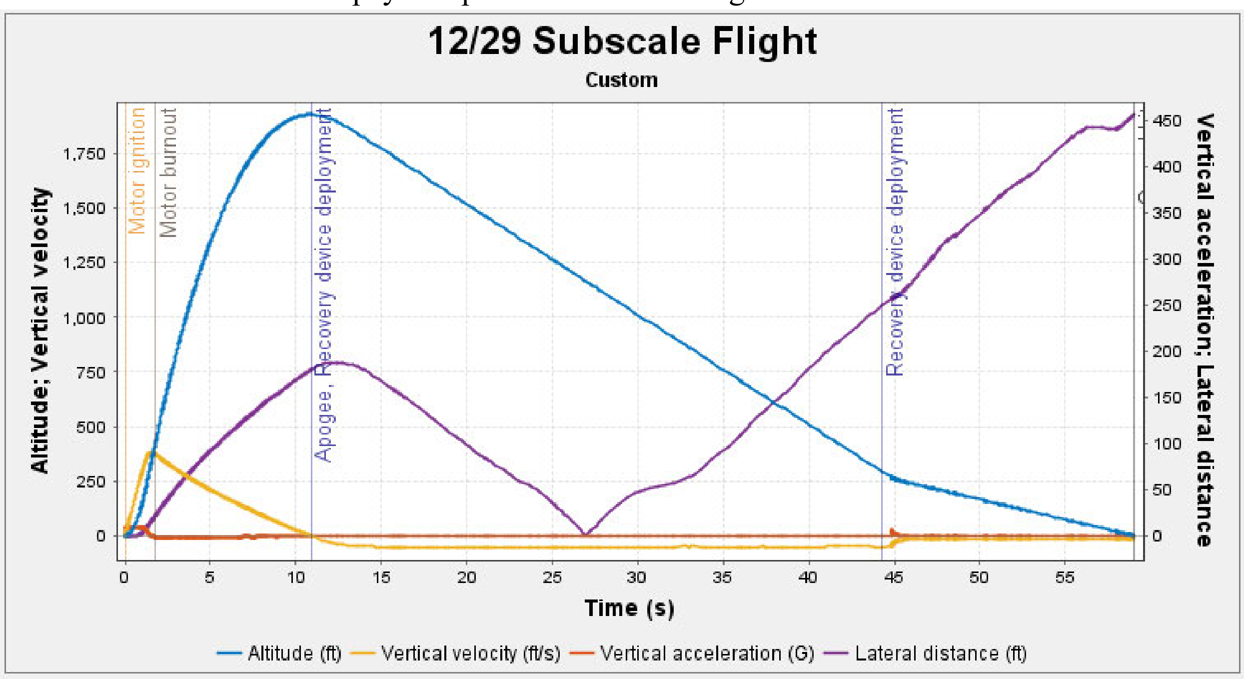

Figure 8. Simulated Subscale Flight Data

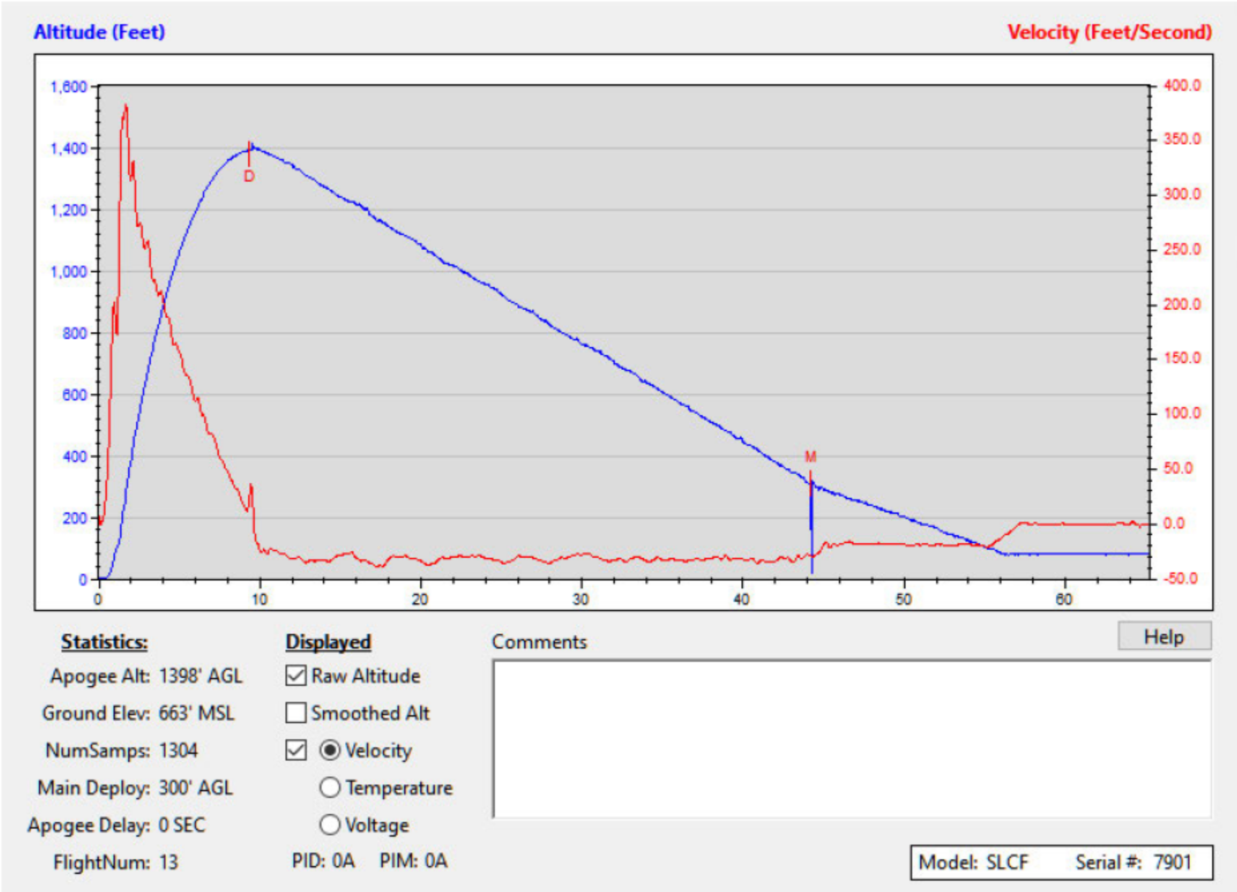

Figure 9. Flight data collected from Perfectflite Stratologger CF


Figure 10. Image of the subscale landing configuration on the official flight

3.2.3 Impact of Subscale Flight

During the building of our subscale rocket, we realized we need raised rail buttons to prevent the launch rail from hitting the payload protrusion. This was implemented on the subscale using a 3d printed spacer with success. However it was observed that the full scale will need a more rigid solution.

Additionally, in designing the subscale we decided to add a subscale Runcam 2 4k housing on the opposite side of the vehicle to where the payload is in its launch position to balance out drag. This change has been copied over to the full scale.

We are now much less concerned about missing our full scale altitude target of 3,800 feet after observing a low impact of the protuberances on the subscale flight. Our estimate is that the protuberances have a roughly -7% impact on the flight apogee. With our current full scale simulations, this gives us an expected apogee of around 3,651ft. Shy of our target of 3,800ft, however we anticipate we will be able to meet this goal.

3.3 Recovery Subsystem

3.3.1 Recovery System Design

The recovery system of our vehicle will employ a standard dual deploy setup. The descent will consist of 2 stages, the first being drogue descent, and the second being main descent. Each stage will be initiated with their own separation event, which are controlled by redundant pyrotechnic charges connected to the avionics system. Our vehicle demands a dual deployment system due to the high apogee altitude, which requires a faster descent speed to shorten the descent time and to avoid prolonged drift in fast upper level winds. Additionally, this configuration is ideal for our application since it entails the most reliability with a high performance.

Our dual separation mechanism is reliable since it isolates each deployment stage from each other, which means that the drogue and main deployments are not systematically related.

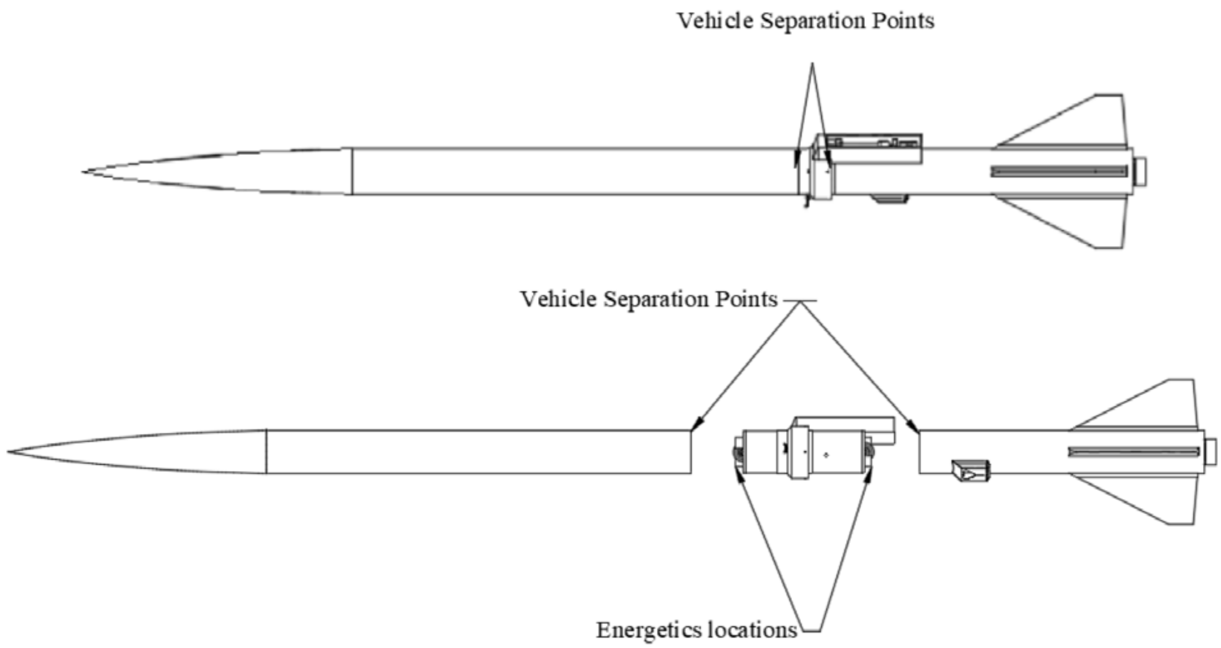

Figure 11. Diagram showing vehicle separation points

3.3.1.1 Drogue Descent Stage

The drogue descent stage consists of the following:

- Spherachute 24" (15.28" Diameter) Hemispherical Parachute
- 25 feet of harness - ⅜” thick tubular kevlar rated up to 3600 lbs of tension force
    - 2 loops on the ends of the harness
- 2 Quicklinks
- 1 U-bolt attached to the avionics bay
- 1 Eye Bolt attached to the forward centering ring
- One large OneBadHawk swivel
- An approximately 13”x13” fireproof nomex blanket

3.3.1.2 Main Descent Stage

The main descent stage consists of the following:

- Fruity Chutes IRIS ULTRA 48" STANDARD Parachute
- 30 feet of harness - ⅜” thick tubular kevlar rated up to 3600 lbs of tension force
    - 3 loops - 2 for the ends and 1 for parachute attachment
- 2 Quicklinks
- 1 U-bolt attached to the avionics bay
- 1 U-bolt attached to the nose cone bulkhead
- One large OneBadHawk swivel
- An approximately 13”x13” fireproof nomex blanket

3.3.2 Avionics

Our dual deployment avionics plan remains the same as it was in the previous milestones. We will be using two fully independent and redundant Strattologger CF flight computers. Each equipped with their own battery, arming switch, and ejection charges.

The main change in regard to avionics is the addition of the GPS tracker, which was missing from the PDR milestone.

Tracker Overview

Our team will be using a Big Red Bee APRS amateur radio GPS tracker. It operates on the 432.100 MHz (70cm) frequency and will be using the team captain's ham radio technician license.

Tracker Location

To comply with competition rules, our tracker will be located in the nose cone of the launch vehicle. This is to physically distance it from the ejection charges and their systems to prevent potential unwanted interference. The tracker will be about 31 inches forward of the ejection charges on the avionics bay,

RF Shielding

There will be copper tape on the nose cone bulkhead and avionics forward bulkhead. Ignitor leads will be cut to minimum length to reduce risks. Additional copper tape may be added in the avionics bay where there is room, especially to protect the flight computers.

Battery Markings

All batteries will be wrapped in a red or orange high-visibility tape with their locations indicated on the outside of the vehicle. Points necessary to access batteries, such as screws that need to be removed, will be highlighted in red.

Indicators that avionics are working

The Stratologgers make a distinct siren that indicates when one, or both are working. We will know if the GPS tracker is working by receiving the GPS location from it starting at its power-up.

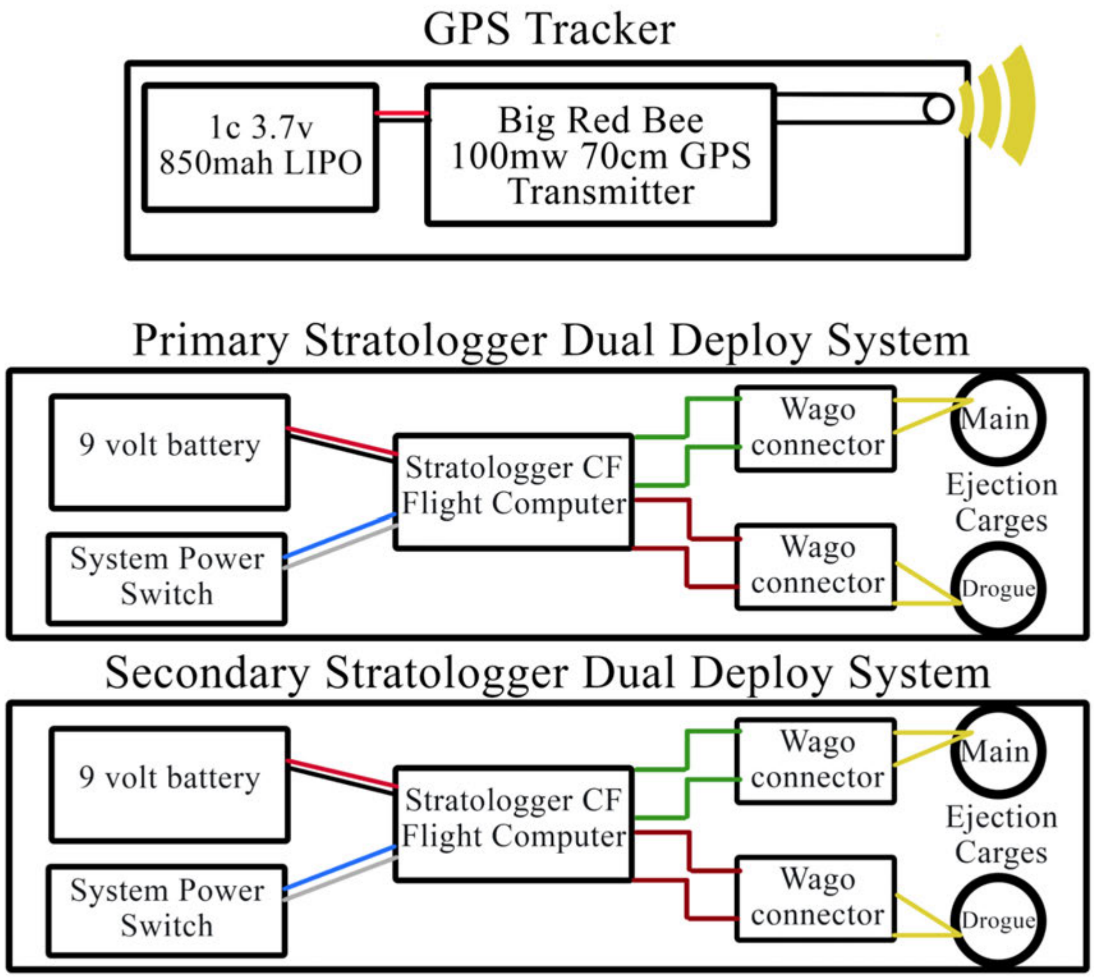

Figure 12. Recovery electronics diagram highlighting complete independent redundancy.

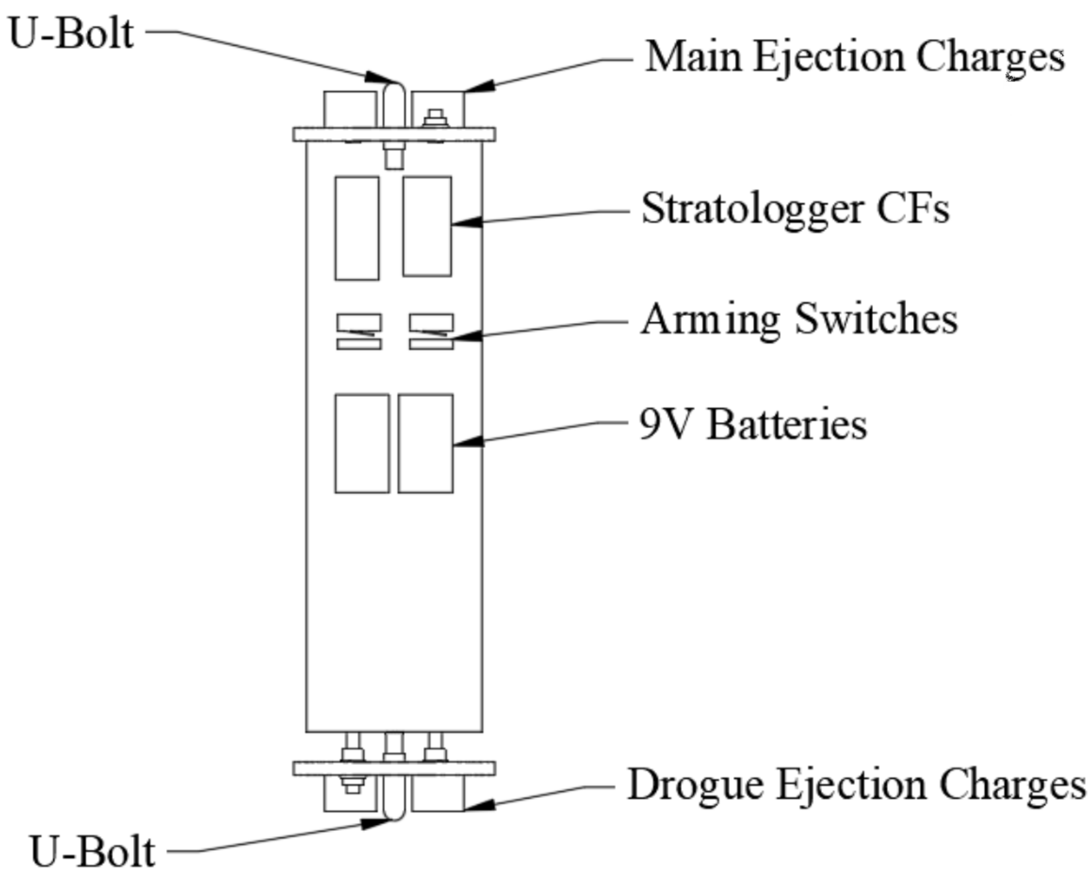

Figure 13, Avionics Bay Sled Layout

3.3.3 Recovery System Concept of Operations (CONOPS)

The recovery system of the vehicle has the primary goal of providing a safe descent for the vehicle. It shall deploy upon apogee and function throughout the entire descent phase of the flight. At apogee, the booster and avionics bay will separate, deploying the drogue parachute, which will make the vehicle descend in 2 connected sections at a fast rate. The drogue descent prevents the rocket from entering a stable nose-down descent, while also preventing a prolonged descent susceptible to significant wind drift. At a predetermined altitude of 600 feet, the avionics bay and payload section will separate, deploying the main parachute. At this point in the mission, the vehicle will descend in 3 connected sections at a slow rate safe enough for ground impact. This rate, approximately 20 feet per second, will reduce the vehicle kinetic energy to an allowed value and prevent the vehicle from being permanently damaged upon landing. Once the rocket is safely resting at ground level, the recovery system is finished with its operations.

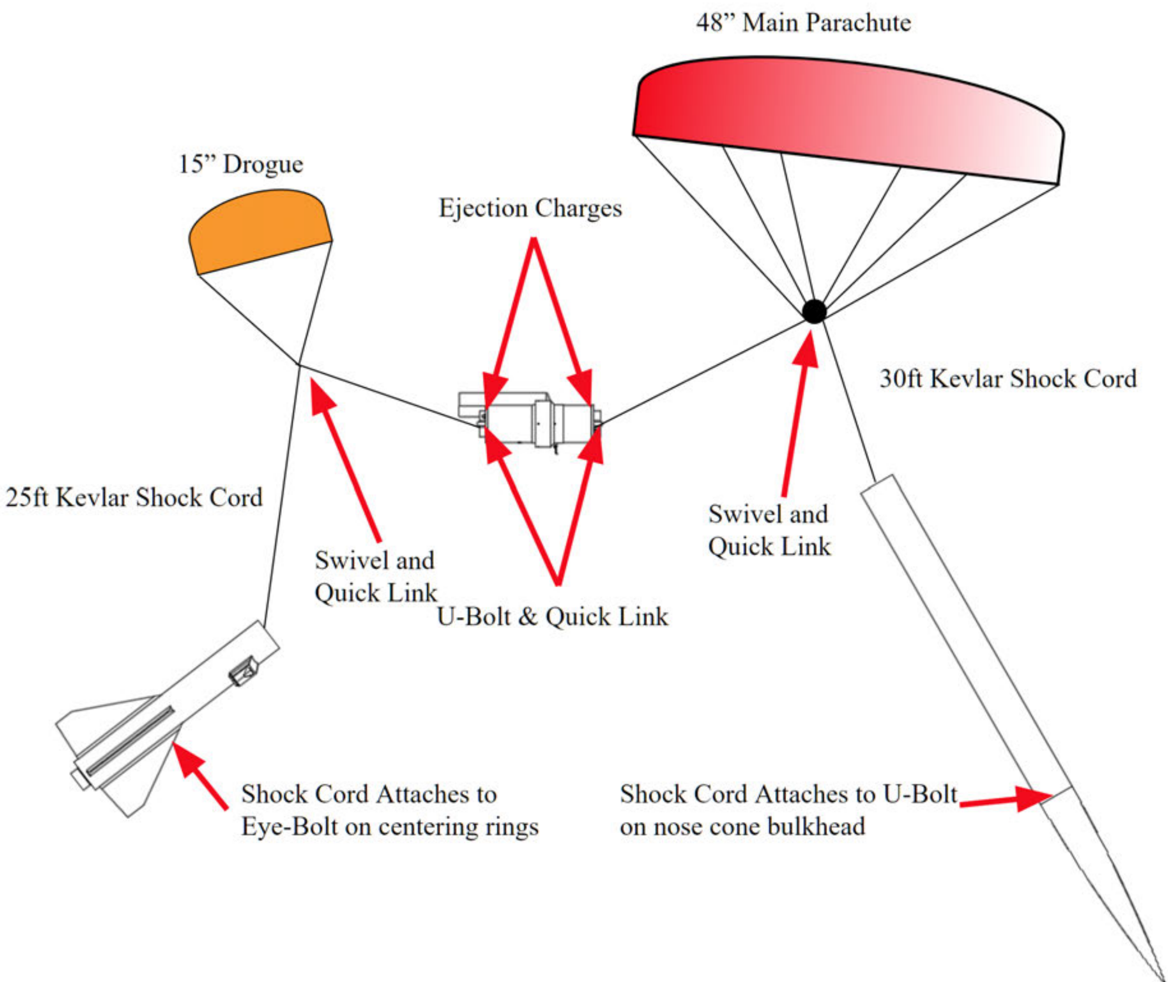

Figure 14. Recovery Drawing

3.4 Mission Performance Predictions

Apogee (ft)	-	3924
Thrust to weight ratio	-	14.30:1
Center of Pressure (in. from nose)	-	61.06
Center of gravity (in. from nose)	-	75.37
Drogue parachute size (in)	-	15.28
Drogue Recovery harness length (ft)	-	25
Main parachute size (in)	-	48 in / 2.2 Cd
Main Recovery harness length (ft)	-	30

Gross lift off weight (lb)	-	15.1
Wet mass (lb)	-	15.1
Dry mass (lb)	-	12.2
Mass Margin (% of mass)	-	14%
Total length (in)	-	94
Diameter (in)	-	4.02 (Max 4.7)
Airframe material(s)	-	Fiberglass
Fin material(s)	-	G10
Fin thickness (in)	-	0.15

3.4.1 Simulations and Stability

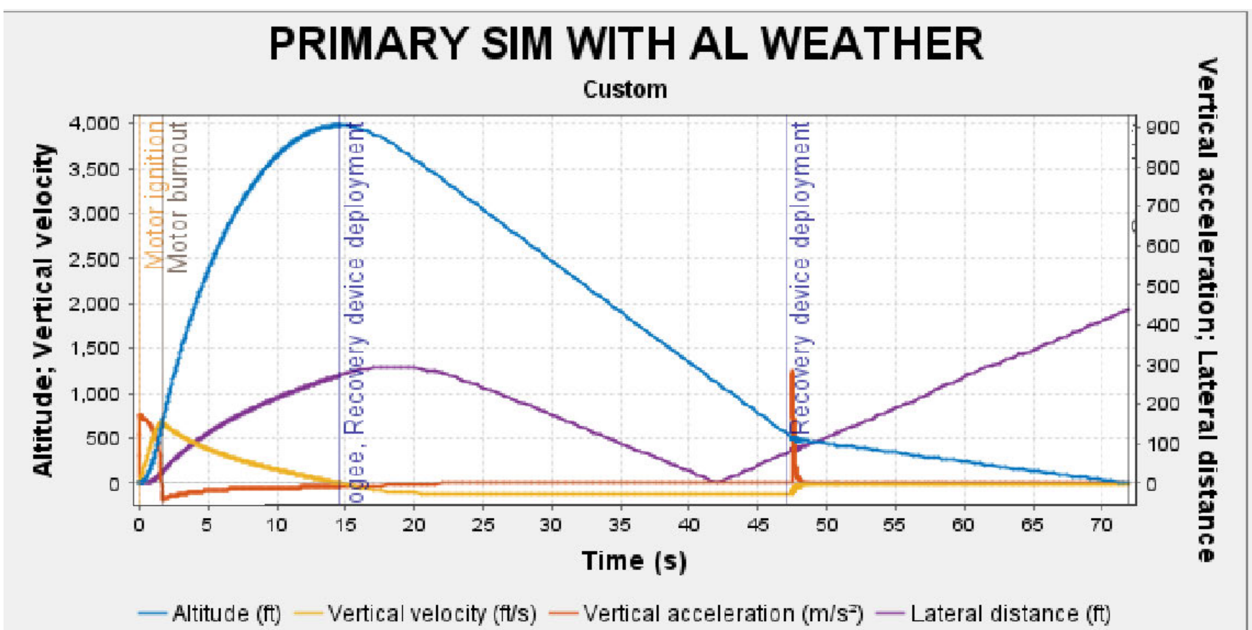

Figure 15. Primary Open Rocket sim with expected Huntsville weather

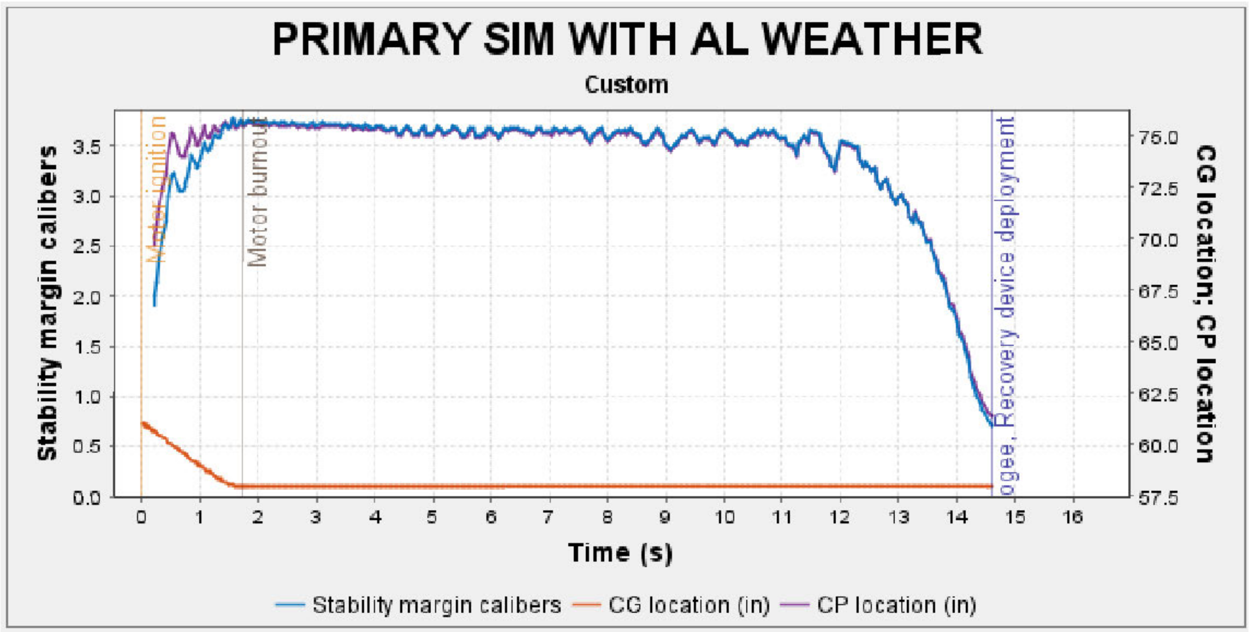

Figure 16. Simulation Showing the Stability details.

3.4.2 Kinetic Energy

The following kinetic calculations were performed using omnicalculator.com and data from our OpenRocket design and simulations,

Kinetic energy under drogue parachute:
Descent rate: 114 ft/s

1. Upper Airframe - 1013.4 ft-lb
2. Avionics Bay + Payload - 786.32 ft-lb
3. Sustainer - 750.699 ft-lb

Kinetic energy under under main parachute:
Descent rate: 20 ft/s

4. Upper Airframe - 31.1911 ft-lb
5. Avionics Bay + Payload - 24.2019 ft-lb
6. Sustainer - 23.1055 ft-lb

Each section complies with the maximum kinetic energy of 75 ft-lbf rule at the time of landing.

3.4.3 Descent Drift Analysis

Our descent time is expected to be 57.4 seconds. This will inform all calculations,

OpenRocket Simulations

These drift simulations are conducted with a launch pad angle of zero degrees as we do not have the information to decide which direction it will be angled relative to the wind.

5 MPH - 214 ft
10 MPH - 416 ft
15 MPH - 707 ft
20 MPH - 953 ft

Hand Calculations

T * V
Where T is descent time and V is velocity from wind.
5 MPH - 420 ft
10 MPH - 841 ft
15 MPH - 1,262
20 MPH - 1,682

We cannot expect basic calculations to be very accurate because it does not account for any of the ways the vehicle is affected by wind, but instead it just gives us a worst case scenario of what we can expect. This is useful to verify that the OpenRocket simulations are reliable as they do not exceed this maximum possible drift.

We can conclude that these drift figures are reasonable as the most extreme estimates comply with the rules, and the expectedly more realistic simulation gives us a very wide safety margin.

4. Payload Criteria

We are continuing our plan to complete the USLI Payload challenge as outlined in the PDR. To summarize our plan for this payload, it is an externally mounted arm attached to the avionics bay that will automatically orient and level itself at landing. We had chosen this plan during the PDR because of fundamental problems found in our originally proposed payload design. No major changes have been made to the payload criteria, including parts used or designs.

The following changes have been made:
Camera arm shaft changed to 3-D printed plastic from carbon fibers to make assembly easier.
The payload shroud has been tapered at the top, reducing the drag of the component.

Additionally, previously placeholder models have been replaced with build ready parts.

4.1 Design of Payload Equipment

4.1.1 Design

Payload general CONOPS

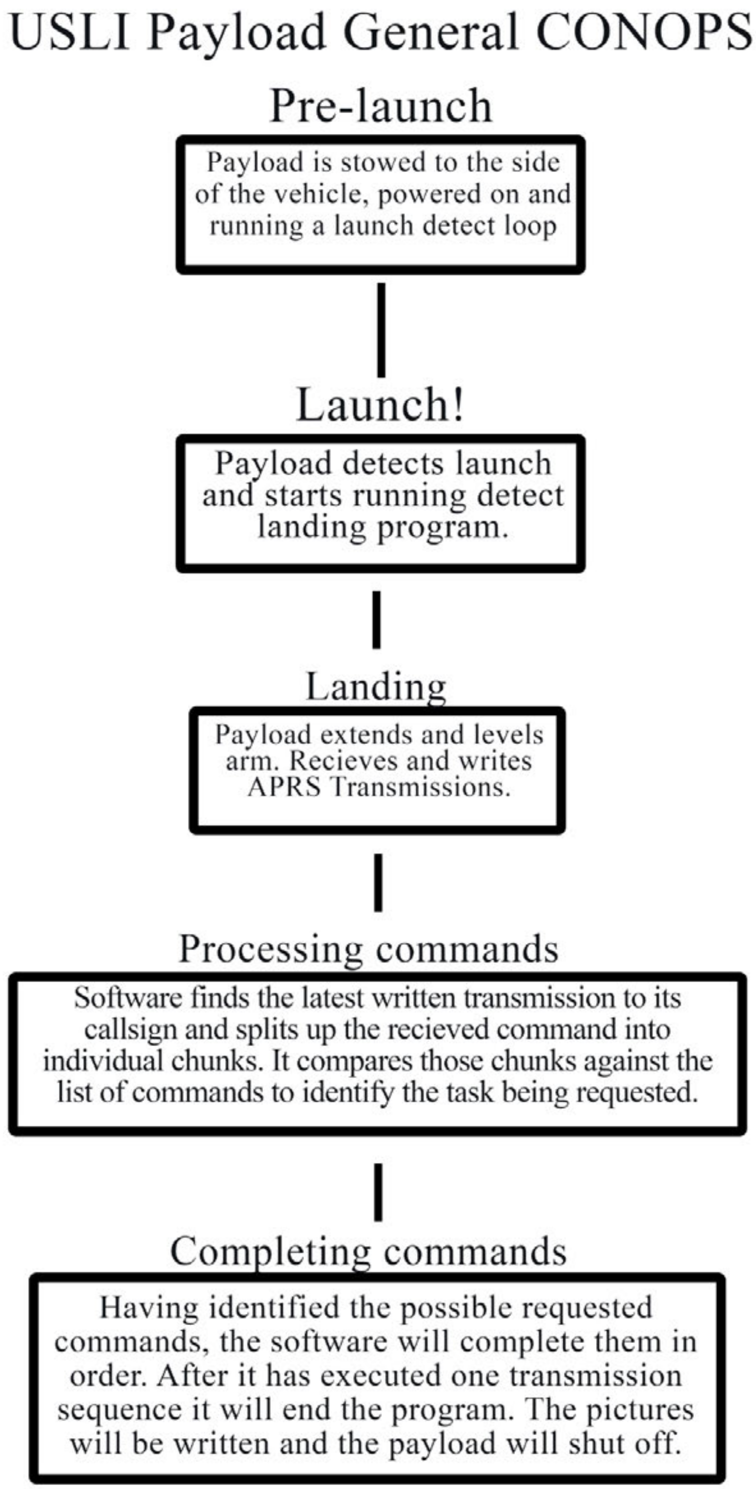

Figure 17. The Payload general CONOPS

4.1.1.2 Payload retention system.

The payload is installed by dropping onto the fixed gear that is epoxied onto the avionics bay, in order to prevent it from sliding off something is needed at the bottom of the fixed gear to keep the payload from moving up.
The payload will bolt into a retainer that will physically inhibit the payload shell from moving upward by being in contact with the fixed gear. However, the retainer will not inhibit any of the functions of the payload, specifically the revolution capability.

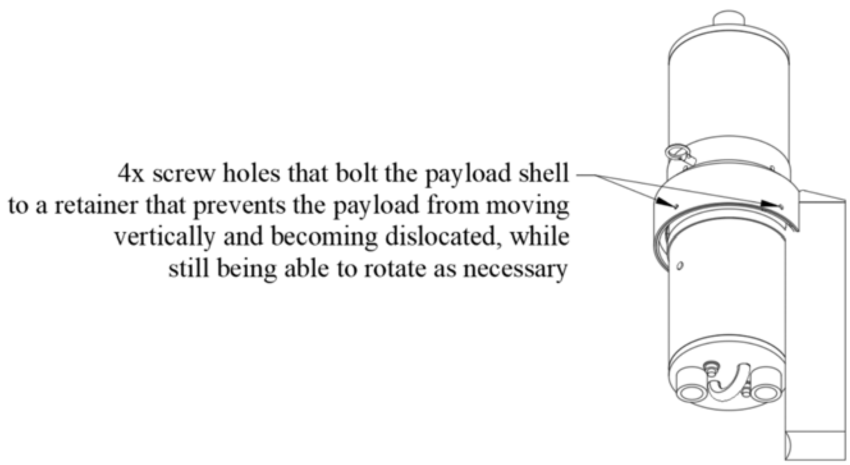

Figure 18. Diagram of payload retention method

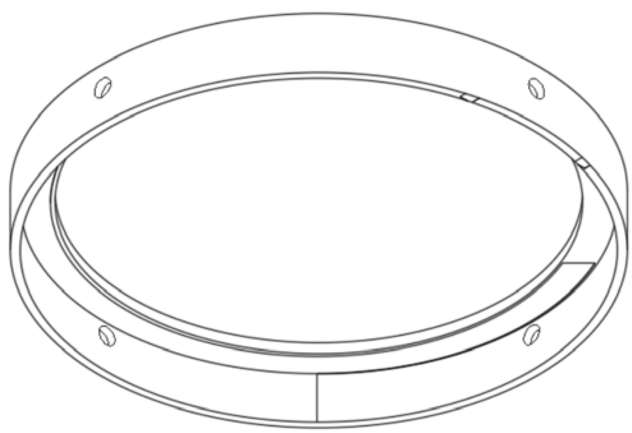

Figure 19. Drawing of payload retainer that restricts the payload from moving past the avionics bay affixed gear.

Payload software CONOPS

The software CONOPS is as follows: The Raspberry Pi receives the APRS signals via a program that runs constantly, writing the APRS commands to a log file. Before commencing any payload work, the Python program will wait to detect that the payload has flown, and landed, with the barometric pressure sensor. After this, the payload arm will extend and level its arm.The Python script will be configured to open the latest log file, and find the latest (last) mention of the payloads callsign, which will proceed the latest commands. The script will have a predefined set of actions to take for every command (i.e. "A1") and then sorts through the received string and completes the task as seen fit.

4.1.3 Demonstrate that the design is complete

In development during the CDR milestone, no changes to the design have needed change other than adjusting 3-D printed parts to be sized correctly and fit with the real world hardware. Additionally, no issues have been encountered in the software development that require changes. We are confident that this design is as complete as it will be ahead of full demonstrations, like being integrated with the launch vehicle.

The following parts have been built or tested:

- Motor revolution system. The motor is able to propel itself around a central gear that would be installed to the avionics bay.
- Camera mounting and servo control with Raspberry Pi.
- Selected camera working with Raspberry Pi.
- Receiving APRS packets
- Processing APRS packets to get a sample string of instructions.
- Processing the string of instructions and demonstrating that the tasks are completed in order.
- Subscale flight test of payload protrusion, showing no additional changes need to be made to the payload exterior shell for a safe and effective flight.

4.1.4 Discuss the payload electronics with special attention given to safety switches and indicators

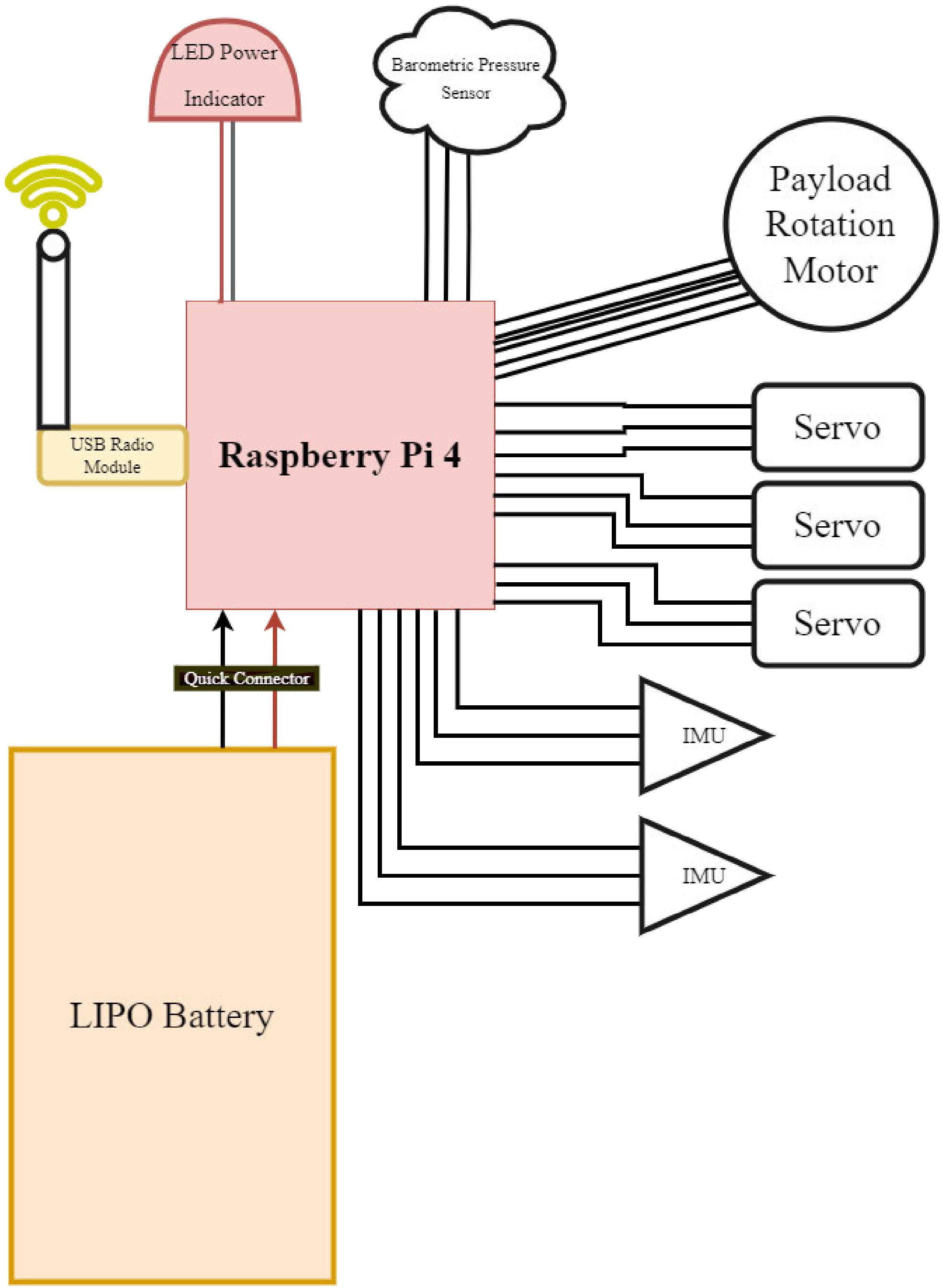

Figure 20. Payload electronics wiring diagram

Our payload is mounted to the avionics bay to resolve an issue with our previous payload design. The payload computer and battery are both very large and therefore difficult to integrate into fully independent [of the launch vehicle] payload. The avionics bay also gives us a nominal landing configuration for the payload: flat to the ground at a minimum angle. If the payload were mounted to the booster section, it would consistently land at a severe angle caused by the fins.

4.1.5 Payload Justiciation

Our payload has the following unique features:

- The exterior housing
- Being integrated into the avionics bay
- Constructed with 3D printed plastic

The justifications are as follows:

Exterior payload housing

The purpose of our payload being on the exterior of the vehicle is to simplify the payload deployment and to not have the payload interfere with the operation of the vehicle in any way. While our approach adds more moving parts to the payload, it gives us full control over the successful deployment of the payload while not introducing hazards to the rest of the mission.

Integration with the avionics bay

In having the payload on the outside of the vehicle, we need a location to put the computer and batteries. The only place we can do this without exposing the batteries or computer to extreme pressures or heat is in the avionics bay or nose cone. There is a NASA Student Launch rule requiring all vehicle protuberances to be below the center of gravity. In order to comply with this rule we cannot put the payload at the nose cone.

Payload made out of 3-D printed parts

Our payload does not need to withstand any severe stresses or heat. Because of this we opted to use the easiest material to design and build our payload out of, 3-D printed plastic. This allows us to create new parts for the payload very quickly and make revisions as needed.

5. Safety

5.1 Workspaces

We have been granted access to the Rutgers Makerspace. Some of their resources include: 3D printers, laser cutter, and woodshop. As for safety they have provided a course that all of our team must complete in order to use the Makerspace.
Alongside that we will still be using our team member's homes as workspaces also.
Mitigations from the Personnel Hazards analysis will be employed during any work where we see fit.

5.2 Materials / Packing list

Below are lists of the items to be brought to launches and build sessions

Most “small” tools will go in ‘Toolbox’ but bigger things like cordless drill won't fit, sandpaper, tape, etc, and bigger/yucky stuff go in ‘Black box’. Cameras and electronics equipment go in ‘Orange Box’

5.2.1 Safety Equipment

The Safety Officer is responsible for ensuring that the following items are on hand for assembly and launch.

√	**Item Name**	**Storage Location**
	Safety glasses	Shop
	Respirator	Shop
	Gloves	Shop
	Ear Protection	Shop
	First-aid kit	Shop
	Fire extinguisher	Shop

Table 1. Safety Equipment packing list

5.2.2 Tools and Parts

The Team leader is responsible for ensuring that the following items are on hand for assembly and launch.

√	**Item Name**	**Storage Location**
	Electric drill and bits	Toolbox
	Sandpaper	Black Box
	Scale	Black Box
	CA glue	Black Box
	Tape measure	Toolbox
	Masking tape	Black Box
	Duct tape	Toolbox
	Pliers	Toolbox
	Zip ties	Toolbox

	Hobby knife	Toolbox
	Screwdrivers/multi-bits	Toolbox
	Batteries	Toolbox
	Multimeter	Toolbox

Table 2. Tools and Parts packing list

5.2.3 Rocket Components

During travel, the vehicle will be assembled in an inert travel configuration. All parts should be put together to avoid misplacement.

√	**Item Name**
	Nose Cone
	Upper Airframe
	Avionics Bay & Payload
	Sustainer
	Main parachute
	Drogue parachute
	Reusable Nomex wadding
	Fireproof insulation
	Rocket motor
	Motor casing
	Motor retainer
	Recovery harness
	Shear pins
	Screws

Table 3. Rocket Components packing list

5.3 Procedures

Pre-launch procedures

1. Motor Preparation (No later than 24 hours before launch)

   PPE required: safety glasses, latex gloves

   a. Prepare motor hardware. Clean with warm soapy water. Dry.
   b. Sand cardboard of the motor reload grains with high grit sandpaper and clean surface.
   c. Follow motor assembly instructions, but glue the grains into the liner with Elmer's All Purpose Glue-All Max. Do not install the ejection charge at this time.

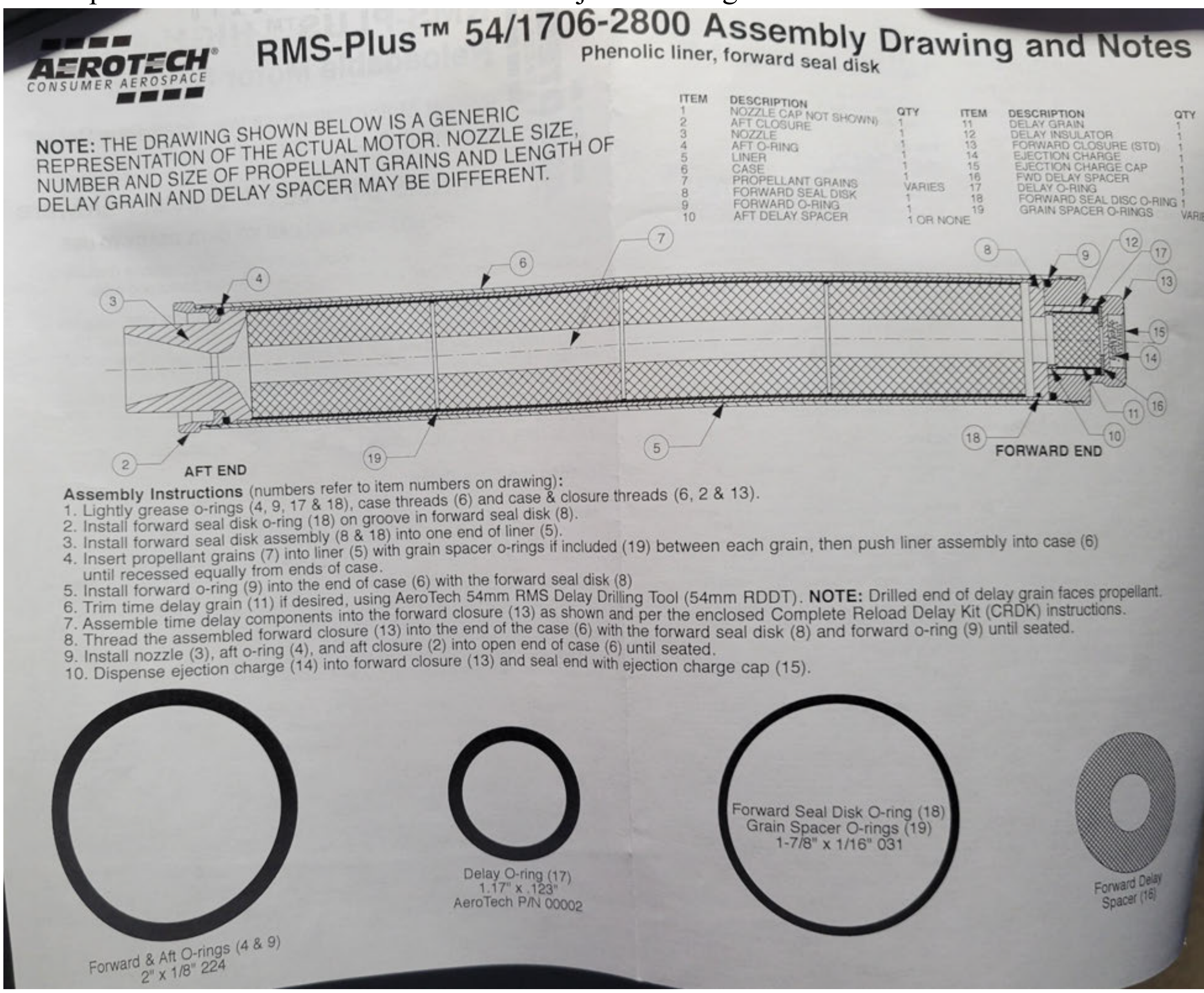

Figure 21. Motor assembly instructions

   d. Store the assembled motor in a sealed metal container until launch day.

2. Pre Launch Day Preparation

   a. Check flight computer software configurations. Ensure the parachute deployment altitudes are as they should be.
   b. Install the flight computers onto their standoffs on the Avionics bay
   c. Install Payload computer
   d. Test the Tracker and Ground station.

e. Install the tracker into the nose cone tracker bay
f. Plug the payload arm cables into the computer
g. Mount the Arm and install the retaining screws.
h. Connect Cables
i. Power on the payload and test all systems.
j. Shut off the payload and prepare the assembly for transport.
k. Charge all batteries
l. Pack for launch day according to the packing list.

3. Avionics Bay Preparation
    a. Ziptie new 9-volt batteries to the avionics sled.
    b. Plug in the 9-volt batteries to the flight computers and install the Remove Before Flight safety rod. This will power the computers off.
    c. Install the Payload battery
    d. Pull the remove before flight pin to test the altimeter start up
4. Recovery System Preparation
    a. Install the battery into the nose cone tracker bay and power on the tracker.
    b. Close the nose cone tracker bay
    c. Install igniter for the ejection charges
    d. Place the igniter in the charge case and insert fireproof cellulose insulation on top.
    e. Have the mentor measure the black powder charges and place them in the charge case.
    f. Securly tape over the charges.
    g. Repeat for all four ejection charges.
    h. Insert reusable Nomex wadding
    i. Add fireproof insulation
    j. Fold and pack the parachute
    k. Assemble the airframe sections
    l. Install the shear pins
5. Assembly Checks
    a. Send the APRS Test command to the payload and observe if the performance is nominal.
    b. Try receiving the GPS tracker signals.
    c. Ensure airframe screws/shear pins are securely fastened.
6. Motor integration
    a. Install the motor closures.
    b. Place the motor into the rocket and screw on the motor retainer. Check good retention.
7. Pre-RSO
    a. Fill out RSO card
    b. Weigh rocket
    c. Place Center of gravity marker and center of pressure markers.
8. Take the rocket to the RSO table.

Launch Procedures

After all steps of pre-launch preparations are complete we are ready to begin launch operations.

1. Assign people to carry all necessary items for launch setup before the next loading cycle (where the pads are opened for rocket setup) starts.
2. Walk out to the pad
3. The person on camera duty will place the cameras now
4. Inspect the pad
    a. Clean the rail if necessary
5. Load the rocket onto the rail
6. Send the payload orientation command. This will position the payload to where it should be for flight and ensure the payload is still operational.
7. Check the GPS tracker downlink.
8. Pull the remove before flight pin to arm the avionics.
    a. Make sure everyone except the person pulling the pin is clear of the pad and rocket for safety.
9. Make the rocket vertical.
10. Install the ignitor.
11. If we want to take a team picture with the rocket, this is the time.
12. Leave the pad.
13. Maintain watch of visual indicators on the rocket until launch. Monitor the GPS tracker downlink until launch. If either of these stop working make sure the RSO does not send it. If permitted, do a run-out check to ensure the Stratologger altimeters are still powered up and on standby right before launch.
14. During launch, maintain visual track as well as possible, try to see where it lands.

Recovery

1. Check where it landed according to the GPS tracker.
2. Assess how many people should be sent to recover it based on the distance and weather.
    a. The team safety officer should implement the recovery safety plan at this time.
    b. This should include an assessment of heat, humidity, distance needed to travel.
    c. Decide if it's safe for all members to go for recovery and if there are any additional precautions, such as bringing water and radios.
    d. The safety officer will deliver this report as a short briefing right after touchdown.
3. Recovery team waits for permission to recover from the range. Additionally waits for the expected payload operations to finish if this is not considered by the range.
4. Recovery team departs.
5. When the recovery team arrives, stop a distance away from the vehicle and observe the payload. If it is still operating, wait for it to finish.
6. Take images of the vehicle as it landed.
7. Begin recovery process
8. Pack the parachutes and shock cords in their respective airframes.
9. Put the airframe components back together as best as can be reasonably done (there may be dirt or other debris preventing this).

10. Carry the vehicle to where instructed. This may be a recovery inspection area. Otherwise, back to our table.
11. Complete any inspections by the range if applicable, then return to our table.
12. Disassemble the vehicle.
    a. Ensure all ejection charges are fired. If they are not, carefully safe them by inserting the remove before flight pin disconnecting the ignitors.
    b. Disconnect the avionics bay from the recovery lines.
    c. Disconnect all batteries

Special Weather Procedures:

- Light Rain
    a. Continue procedures as normal with extra precautions. Have many towels nearby and take care not to get electronics or connectors wet.
    b. Take care to keep the rocket motor and black powder in a dry, sealed container as long as possible. Tape rocket motor nozzle once it's in the rocket to prevent moisture from entering.
    c. Keep the rocket covered when taking the rocket to the pad and cover for as long as possible before launch
- Heavy Rain
    a. Delay launch until rain either stops completely or turns into light rain
- Thunderstorms
    a. Follow safety instructions by launch officials
- Exceedingly High Wind
    a. Follow RSO instructions
    b. Do not launch if we believe there will be too much drift
- Bad Field Conditions
    a. Minimize team personnel walking in the field

5.4 Hazard Analysis

5.4.1 Likelihood Scale

The likelihood of a hazard occurring

Value	Definition
E	Extremely Improbable
D	Extremely Remote
C	Remote
B	Probable
A	Frequent

Table 4. Likelihood Scale

5.4.2 Safety Severity Scale

The severity/damage of a hazard occurring

Value	Name	Definition of severity
5	Minimal	No risk of harm to people and/or permanent damage to equipment. Minor time or procedure setback.
4	Minor	Possible risk to personnel and/or damage to non-critical equipment. Time setback, possible cost to fix.
3	Major	Likely harm to people and/or damage to critical equipment. Time setback, cost to fix, injury.
2	Hazardous	Injury to people and/or critical damage/failures. Major project setbacks, cost impact, and injury. May result in disqualification if there is not enough time to fix critical failures.
1	Catastrophic	Major damage or injury and/or unable to continue competing.

Table 5. Safety Severity Scale

5.4.3 Total Risk Scale

The combination of both the likelihood and severity of a hazard to get an idea of the general risk (FAA Risk Matrix)

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Red]	[Red]	[Red]
Remote C	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Improbable E	[Green]	[Green]	[Green]	[Yellow]	[Red] *

High Risk [Red]
Medium Risk[Yellow]
Low Risk [Green]

* High Risk with Single Cause Failures

Figure 22. FAA 8040.4B Risk Matrix

Image Source: https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8040.4B.pdf

5.4.4 Personnel Hazard Analysis

Hazard	Risk	Cause	Effect	Mitigation	Verification
Inhalation of noxious fumes (glue, paint, epoxy, etc.)	C4 Medium	Improper use or failure to use PPE	Irritation of the nose, throat, and lungs. Repetitive and high amounts of exposure can result in sensitization and asthma	Safety officer and mentor ensure the availability and use of PPE including personal respirators, and make sure the workspace is properly ventilated	Spare PPE will be on hand, everyone will be informed of what PPE is needed for a task, windows will be opened, fans will be on, some work must be done outdoors weather permitting
Glue/epoxy on skin	B5 Low	Failure to use gloves and unclean workspace	Skin tearing and burns	Make sure members wear gloves while handling glue and epoxy and keep the workspace clean	Workspace will be a clean flat surface, paper towels and other cleaning devices will always be on hand, excess gloves will be provided
Dust or debris in eyes	C4 Medium	Failure to wear eye protection during sanding, drilling, etc	Eye irritation	Ensure the availability and use of eye protection	Team members will use eye protection when doing anything where foreign objects have the potential to make contact with their eyes
Injury due to power tool misuse	D1 High	Loose clothing, untrained user, faulty equipment	Minor to severe injury, death	Regular inspection of power tools, train the member using the power tool, and proper attire, and make sure the user of the tool has read and understands the user manual	Have 2 members present while using any large or non hand held power tool, make sure everyone has PPE on, possible safety briefing before the operation
Inhalation of	C3	Failure to wear a	Irritation of the	Safety officer and mentor ensure the	Fiberglass work done outside or in a

fiberglass dust	Medium	respirator/mask while working with fiberglass	airways	use of respirator/mask, and that the space is properly ventilated	space that can be cleaned easily and is well ventilated or can be made semi open air, respirators provided when needed
Accidental ingestion of fiberglass dust	D4 Low	Failure to use gloves and wash hands after working with fiberglass	Throat and stomach irritation	Make sure members wash their hands after working with fiberglass and wear gloves during the work	Clean workspace after heavy fiberglass work, cover as much of your body as you can and wash your hands and arms afterwords
Electrocution	D1 High	Compromised power tools, power cords	Minor to major electric shock, death	Checking all power tools, cords, and outlets before use, make sure all members understand the danger of electricity	Safety officer will inspect any item with potential for serious electrocution injury before use
Collision with launch vehicle	C3 Medium	Failure of parachute or separation, vehicle stability, rail issue	Bruising or concussion	Ensure that the launch vehicle is inspected by the team safety officer, mentor, and RSO before launch, pay attention during launch, make sure heads up is given if the rocket lands near spectators	If any team member thinks the rocket is unfit to fly it will not be flown, if an unexpected mid flight event happens make sure everyone is aware of it
Motor explosion	D2 Medium	Unburned fuel, accidental ignition	Burns, asphyxiation, death	Make sure motor has fully burned out before recovering, keep potential ignition sources away from motor, motor only to be handled by the team mentor	The safety officer will be responsible for keeping the work space around motors safe.
Tripping hazard	C4 Medium	Messy workspace	Bruising, concussion	Always keep workspace tidy and clean up after each use	Safety officer will make sure there are no tripping hazards or make sure they are obvious and easily avoidable
Hypothermia, hyperthermia,	D4 Low	Improper attire, lack of water	Exhaustion, fainting,	Make sure members are properly dressed and have access to water	Safety officer will inform team members what they need to

dehydration					wear/bring to launch the day before based off of weather forecast
Accidental black powder ignition	D2 Medium	Mishandling of black powder by improper personnel	Burns, hearing loss	Ensure black powder is kept away from potential fire/heat sources and all handling of black powder is done by team mentor	Any and all handling of black powder will be done by team mentor with PPE and in a non hazardous environment away from fire sources
Hearing damage	D4 Low	Improper distance from launch pad, failure to use hearing protection while using power equipment	Long or short term hearing loss	Make sure all team members stand the proper distance away from the launch pad during launch, ensure members wear ear protection when necessary	Spectating distance will be strictly enforced by the safety officer, ear protection will be available if needed during use of loud tools/equipment or launch
Fire	D1 High	Easily flammable materials at launch pad, heat sources in close proximity to flammable material	Burns, asphyxiation, death	Clear launch pad of flammable materials, make sure to separate flammable materials and heat sources in the workspace, keep a fire extinguisher nearby	Fire extinguisher will always be available at launch, depending on the launch the fire department will be notified of the launch beforehand, fire/flammable material will be kept out away from the rocket at launch

Table 6. Personnel Hazard Analysis

5.4.5 Environmental Hazards Analysis

Hazards caused by the environment:

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**
Accident caused by wind	D5 Low	Unexpected wind fluctuation	Vehicle trajectory change to potentially cause	Check weather frequently before launch and if proper conditions are not met delay the launch.	The team safety officer will ensure the launch does not proceed if weather is unacceptable by referring

fluctuations			accident		to the weather plan.
Low cloud coverage at launchsite	D5 Low	Unsafe condition for launch due to loss of visibility	Interference or collision with aircraft, birds, humans	Follow RSO's instruction on when it's safe to launch	The launch will be prevented by the safety officer and RSO until it's safe to proceed
Landscape unconducive to safe and successful launch and recovery	C5 Low	Launch vehicle landing in trees, bushes, powerlines, and across fast flowing/deep water	Personal injury, loss of rocket	Call power company if the launch vehicle lands on powerlines, call property owner to ask for help/permission to retrieve launch vehicle safely	We are very familiar with our launch sites and know who to call if we need assistance/permission retrieving a rocket
Rain	D5 Low	Rain affecting motor, trajectory, recovery of launch vehicle	Unsafe/unstable launch	Delay launch in heavy rain if necessary	Refer to the weather plan for procedures in light and heavy rain
Humidity	D5 Low	Parts swelling, parachute failure, adhesive improperly drying	Separation failure, unintended separation, recovery failure	Make sure humidity conditions are taken into account when building and launching launch vehicle	Avoid painting and similar tasks if humidity is too high, adjust part fitment if swelling occurs
Hail	E4 Low	Hail pieces damaging launch vehicle	Airframe damage, trajectory alteration, recovery failure	Postpone launch if hail storm is forecast	Check the weather forecast frequently before and during launch
Temperature	D5 Low	Air density changes with temperature	Launch vehicle trajectory change	Make sure to include the correct temperature in simulations	Input temperature data into flight simulations and act accordingly

Table 7. Environmental Hazards Analysis (Hazards caused by the environment)

Hazards to the environment:

Hazard	Risk	Cause	Effect	Mitigation	Verification
Pollution from motor	E5 Low	Fumes, smoke, and gasses from motor	Damaging local ecosystem at launch area	Choosing a launch site away from vulnerable ecosystem	None of our launches have resulted in ecological damage, we launch on primarily farm land after harvest
Pollution from vehicle parts	C5 Low	Parts unintentionally separating, launch vehicle landing in unrecoverable location	Damaging local ecosystem at launch area, unintentional littering	Make sure launch vehicle is structurally sound and assembled properly before launch, ensure enough space on the launch site for safe recovery	Team captain, team safety officer, and range safety officer will all conduct various checks that the vehicle is safe for flight.
Pollution caused directly by team members	C5 Low	Team members leave trash behind, don't clean up properly	Littering, damaging local ecosystem at launch area	Remind team members to pick up all garbage and other materials before leaving launchsite	All of our team members will pick up after themselves and other members, our goal is to leave no trace wherever we launch
Collision with property/buildi ngs	E4 Low	Launch vehicle landing/crashing into buildings or property	Damage to property or buildings	Make sure there is enough space at the launch area for safe recovery	Conduct drift simulations to ensure the vehicle drift will not exceed the launch site recovery area.
Fire	E2 Medium	Motor not burning all the way before landing, unintended trajectory	Motor burning near flammable materials at launch or landing	Keeping flammable away from launchsite, and have a fire extinguisher ready incase of fire	Fire extinguisher will always be available at launch, depending on the launch the fire department will be notified of the launch beforehand
Wildlife damage	E4 Low	Launch vehicle striking birds during flight, colliding with other animals at	Harm to local wildlife	Delay launch if birds are flying over launchsite, Launchpad placement away from animals/nests or burrows	It is uncommon to have large groups or regular flybys of birds at the launch sites we use, LCOwill delay if there is high risk of a bird strike

		lower altitudes or landing			

Table 8. Environmental Hazards Analysis (Hazards to the environment)

5.4.6 Vehicle Failure Modes and Effects Analysis

5.4.6.1 Vehicle Failure Severity Scale

Separate severity scale for vehicle failure more focused on project setback and monetary setback (the likelihood in this section is the same as the scale used above)

Value	**Name**	**Definition of severity**
5	Minimal	Unlikely to need much work or money to fix. Not likely to impact flight unless other problems occur.
4	Minor	Minor work or money needed to fix. Not likely to impact flight unless other problems occur.
3	Severe	Requires considerable amount of work or money to fix. Potential to negatively impact flight or fly-off.
2	Major	Major risk to program, major probability of failure to achieve mission goals. Very costly and time consuming fixes.
1	Catastrophic	Catastrophic to program or complete failure of fly-off objectives Program recovery extremely difficult or end-goal not met.

Table 9. Vehicle Failure Severity Scale

Hazard	Risk	Cause	Effect	Mitigation	Verification
Excessive landing speed	C4 Medium	Parachute torn, burned, tangled. Improper parachute size	Damage to vehicle and payload	Ensure that parachutes are properly packed, use correct parachute size Conduct extensive simulation of vehicle landing speed	The simulations should indicate a safe landing velocity, defined in the SLI Handbook
Fin damage	D3 Medium	Damage caused during previous flights, poor construction, improper materials used	Altered trajectory, unstable flight, resulting in damage or loss of vehicle	Stress test fins before flight, and ensure use of strong materials	The fins should remain structurally intact with no visible or audible damage
No ejection	C1 High	Flight computer, ejection charge, or wiring malfunction	Loss of vehicle, potential damage to property, injury to humans	Use proper inspection and procedures when working on the dual deployment system	Refer to the pre launch procedures instructions for safe setup of ejection charges, black powder handled by mentor
Early separation	C2 High	Failure of motor, ejection charges, shear pins, or drag separation	Potential for loss of vehicle and damage to property	Conduct ejection tests, ensure ejection charges are properly prepared	Preflight shear pin test, accurate simulations
Failure to separate	C1 High	Failure of shear pins, ejection charges, late ejection charge	Potential loss of vehicle and damage to property, injury to humans	Conduct ejection tests, ensure ejection charges are properly prepared	Ground ejection system testing, and proper ejection charge preparation, Refer to the recovery system preparation procedures section
Shock cord failure	D3 Medium	Shock cord improperly fastened, tangled	Unintended part separation, recovery failure,damage to or loss of vehicle,	Double check that the shock cord can’t get caught on anything, make sure the shock cord is properly secured and stress tested	Ejection ground test, preflight visual inspection and stress test, use shock cord rated for the expected forces

			injury to humans		
Parachute damage	B4 Medium	Improperly folded, insufficient heat protection	Recovery failure, damage to or loss of launch vehicle	Ensure proper folding and correct amount of heat protection	Consistency in the folding technique and folding pattern, measured and consistent amount of cellulose housing insulation “dog barf”, and a Nomex blanket
Parachute deployment failure	C1 High	Improper fastening, tangled strings, ejection/separation failure, obstructions in deployment path	Excessive landing speed, damage to or loss of vehicle, damage to property or buildings, injury to humans	Properly fold and pack parachute, test ejection system, have a clear deployment path for the the parachute	Consistency in the folding technique and folding pattern, no obstructions for parachute by design,
Rail button failure	C4 Low	Loose/tight rail buttons, misalignment, improper placement	Altered trajectory, damage to vehicle	Make sure the rail buttons are in the correct position on the body of the launch vehicle and aligned correctly	Use of alignment tools and measurements during assembly, railbutton stress test
Ignition failure	B5 Low	Malfunctioning motor, cheap igniter, corroded ignition cable/cable leads, no continuity	Unable to launch, late ignition, damage to vehicle	Use high quality igniters, buy motors from reliable sources, Don't use old cables	Ignitors and motors properly stored (and extras), motor purchases through verified and credible online sources (buyrocketmotors.com)
Forgotten or lost components	D2 Low	Not having all the components to successfully and safely launch the vehicle	Delays, unable to launch, unsafe launch, damage to or loss of vehicle	Have a check list of all components needed to launch	Item checklist verified and checked by safety officer and others if necessary
Motor	E2	Weak motor	Damage to or loss	Use high quality motor retainers	Motor retainer stress test, test

expulsion	Medium	retainer, improperly constructed motor mount section	of vehicle, injury to humans	installed correctly, proper design and building of motor mount	launches
Battery fire/hazard	D2 Medium	Catastrophic failure resulting in batteries being punctured	Battery catching on fire, exploding	Integrate batteries in a way that provides protection from potential punctures	Batteries are secure and protected from damage by design
Payload losing power	C4 Medium	Batteries disconnecting in flight, batteries dying before mission completion	Delays in project, mission failure if during launch week	Test battery connectors, battery life before first launch.	Prevent usage of old, damaged, or heavily used batteries, and use undamaged connectors
Camera failing to orient	B4 Medium	Jamming in orientation gears, failure of sensors, servos	Delays in project, mission failure if during launch week	Test all moving parts in a variety of situations before first launch.	Do a full range of motion test before launch, reliable design
Data storage failure	C4 Medium	Data storage device coming loose during launch	Failure for payload to operate, save images	Stress test data storage retention system, use robust retention system	The use of sturdy materials and careful construction in the assembly of the retention system for the data storage

Table 10. Vehicle Failure Modes and Effects Analysis

5.4.7 Project Risk Analysis

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**

Lack of funding	D4 Minor	Not doing enough fundraising	Not having enough money/supplies to complete project and travel to launch	Don't leave fundraising until the last minute, be active throughout the program in finding new ways to fundraise	At the CDR, our project funding goals are met in all areas except travel reimbursements. We may send less people to nationals, or members may have to pay for parts of their own travel.
Part shortage	C3 Medium	Ordering parts too late or parts unavailable	Not having necessary supplies to build and launch the vehicle and payload	Order parts early, find alternative sources or parts	We already have 70% of the parts needed for our full scale launch vehicle
Rushed work	B3 High	Improper planning, poor management, or procrastination	Lower quality of reports, presentations, design, and finished product	Don't leave things until the last minute, follow a well thought out project plan	Distribute work evenly, adapt time management as needed
Launch area issue	C3 Medium	Unable to find a suitable launch area, launch area unavailability	Inability to launch and test vehicle and payload	Start early finding and securing a launch area (have a backup if needed)	We have multiple launch site options that we're able to use
Workspace issue	C3 Medium	Unable to find a suitable workspace or workspace not available	Inability to build launch vehicle and payload	Start early finding and securing a workspace (have a backup if needed)	We have access to a Makerspace, and we plan on having most of our work doable at a home workspace
Transportation	D4 Low	Inability to find transportation for team members, materials, and launch vehicle	Delays, inability to build, test, and launch vehicle	Secure transportation and have backup if needed (or carpool)	Our members have already proved that they are willing and able to assist in transport for others when needed

Delay due to weather	E4 Low	Weather (snow, heavy rain, storm, etc.) causing delays	Not being able to finish project in time because of delays	Leave extra time in the project timeline and schedule for delays, backup dates and locations	Have secondary launch dates or locations in case of cancellations
Members unavailable	B3 High	Poor planning, sickness, schedule conflict, or not enough members	Inability or delays to finish project deliverables	Make sure team members are reliable and have no reasons to be frequently busy when they are needed	Schedule and confirm dates in advance for as many members as possible and have backup dates
Equipment issues	C4 Medium	Non functioning tools or a lack of the needed tools and equipment	Delays, inability to build, test, and launch vehicle	Identify tools that are needed early and make sure to keep them in functioning condition	Regular maintenance and care for equipment
Poor planning	B3 High	Poor time management, forgetting steps or deadlines in project plan	Working close to deadlines, missing deadlines, unable to finish project in time	Make sure project plan is reviewed by multiple members and is changed as needed throughout the project	All members will have an input on the schedule and timeline and changes can be made accordingly

Table 11. Project Risk Analysis

5.5 MSDS

Item Name	**Link to MSDS**
Epoxy	https://www.apogeerockets.com/downloads/MSDS/ROCKETPOXY_MSDS.pdf
Spray Paint	https://www.rustoleum.com/MSDS/ENGLISH/249114.pdf

Rocket Motor	https://www.apogeerockets.com/downloads/MSDS/Aerotech/Motors.pdf
CA Glue	https://www.highlandwoodworking.com/msds/ca-adhesives-msds.pdf
Igniter	https://www.apogeerockets.com/downloads/MSDS/Aerotech/Igniters.pdf
Black powder	https://goexpowder.com/wp-content/uploads/2018/05/sds-sheets-goex-black-powder.pdf

Table 12. MSDS

6. Project Plan

6.1 Testing

Subject	Goal	Test	Safety	Verification	Mitigation
Payload	Ensure payload hardware is sized and fits together properly.	Assemble payload as pieces of hardware are finished	Proper use of assembly tools.	The hardware components should fit together and if applicable move properly.	Modify the design of hardware to fix the issues.
Payload	Ensure components of	Test each component	Take frequent breaks	The software	Check the code

	software are working properly before beginning new parts.	of the software before finishing them to ensure they're finished.	from computers to avoid eye strain.	components should complete their intended task and work with the rest of the program.	thoroughly for issues and work through the problem.
Payload	Finish development by running initial test procedures.	Verify full-up system operation by running a demo.	Ensure the payload is in a location it will not damage anything or be damaged.	The payload should complete the demo instructions and have saved the pictures as intended.	Make sure the payload was assembled correctly and that there are no connection issues. Work through issues.
Payload	Preflight checks to verify all connections are good and nothing was damaged in transit.	Run a demo program of the payload that will demonstrate all systems working properly.	Ensure the payload is in a location it will not be damaged or damage anything and that team members are aware of the test and do not interfere.	The operator should observe a good test of the payload, demonstrating all critical parts.	Ensure payload is assembled correctly and is not damaged.
Vehicle	Test fitting.	Test fitting pieces together as they're ready.	Be cautious of sharp edges and respect tools.	All parts should fit together effortlessly to ensure a smooth build.	Sand parts until they have the desired fit.
Vehicle	Verify ejection charges are properly sized for the airframe and shear pins.	Conduct ejection testing with a vacuum. Adjust charge sizes as appropriate.	Treat the prepared vehicle with care and caution. When conducting the testing, make sure the vehicle has range to separate to the fullest length of shock cords.	The parachutes should be fully ejected and the shear pins should be fully sheared.	Increase/ decrease charge sizes to be appropriate. We should find the minimum sized charge that will work and then multiply it by 3.

Table 13. Project Plan Testing

6.1.1 Payload Testing

During the payloads development, it has been tested constantly as new progress is made to verify that the work being done is completed and satisfactory. However, to ensure mission success there will be additional testing with the finalized payload. Our testing plan consists of two campaigns. The first one to cover the first integration of the payload and work through any issues, and the second to be a repeatable series of tests before launch.

Payload Testing Campaign 1 - First Integration

Campaign goals

Our first campaign will serve to close out payload development by looking for real world issues and fixing them. The focus of these tests will be on:

Software

Ensuring the software works and interacts with the hardware appropriately. This includes control of motors and servos, good reading of IMUs, and good reception of APRS commands.

Hardware Compatibility

How each piece of hardware interacts with each other and checking that everything is as expected. This will test motions of the payload, such as the rotation, arm deployment, and camera gimbal.

Operations

Making sure it's able to carry out its mission. This includes full systems tests, such as long distance tests of its APRS reception capabilities. Testing the power on duration. Practicing receiving the images from the payload.

Payload Testing Campaign 2 - Launch Closeouts

During the integration and preparations before each launch we will watch the payload status closely as to not miss any issues that would require time consuming fixes if found later on. We will also have a test program built into the payloads software to test hardware deployment after integration. This should serve to show that our assembly of the payload was successful and the payload is ready for flight.

Before flying, our team will train on payload integration, deployment, and recovery. The payload is a complicated system and it's important that we are familiar with every aspect so that we can properly use it without making mistakes, and if there are problems we know how to fix them.

6.1.2 Vehicle Testing

Our vehicle testing consists of prelaunch tests and then a flight test.

For ground testing, we're going to test ejection charge deployment until we have a safety factor of 3. To do this, we're going to gradually decrease the charge size until we find where it doesn't deploy and then triple that size to get the flight load. We will conduct final ejection tests with the flight load charge to ensure the recovery system withstands these forces. Similarly to the payload integration training, these many ejection tests will also serve to familiarize us with the vehicle preparation that we would encounter before launch. All of this repeat practice should ensure our launch days go as smoothly as we can make them.

For flight testing, all of our flight tests are intended to be full-up qualified flights of the payload and vehicle. Because of our limited launch opportunities before the FRR, we will be utilizing every opportunity to its fullest for both the payload and vehicle.
After this, we will have one to two full flights with the payload installed and working towards our altitude target.

6.2 Requirements Compliance

6.2.1 Compliance plan

6.2.1.1 Management and Safety requirements

Item	Verification Method	Plan
Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	Demonstration	Our team members will conduct all of the project work excluding hazardous work. Being a new team, we have no old work to reuse besides content created this year. We do not tolerate self plagiarism.
The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Demonstration	Our team will provide our goals and meet the deadlines that are required for the Student Launch program. If we find that we will be unable to achieve our goals we work to adjust our goals/plans as necessary
The team shall identify all team members who plan to attend Launch	Inspection	The travel roster is submitted before January 9th.

Week activities by the Critical Design Review (CDR). Team members will include:		
Students actively engaged in the project throughout the entire year.	Demonstration	Students that are not actively engaged and unwilling to do so are removed from the team.
One mentor/no more than two educators.	Inspection	Our team lists the educators and mentor in our reports.
Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities in order to be eligible for STEM Engagement scoring and awards. These activities can be conducted in person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR due date.	Demonstration	Proof of completion will be submitted with the FRR.
Teams will email all deliverables to the NASA project management team by the deadline specified in the	Demonstration	The team captain will ensure all work is finished ahead of the deadlines and submitted on time.
All deliverables shall be in PDF format.	Demonstration	The team captain will ensure all items are formatted properly before being submitted.
In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Demonstration	We will continue including an accurate table of contents as we have in previous milestone reports.
In every report, the team will include the	Demonstration	We will continue properly

page number at the bottom of the page.		formatting the page layouts of our reports as we have in the previous milestones.
The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Demonstration	Our team will act professional in regards to our presentation. The members giving the presentation will be dictated by their ability to attend practices, attend the final presentation, and exhibit professionalism surrounding the presentation.
Teams will track and report the number of hours spent working on each milestone.	Demonstration	We will continue tracking and reporting the number of man hours spent on each milestone.
Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	Demonstration	The safety officer was responsible for compiling the checklist draft that was provided in the CDR and will finish the checklist for the FRR.
Each team shall identify a student safety officer.	Inspection	The safety officer was identified in the proposal and later.
During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit	Demonstration	It is the responsibility of the team captain to ensure our test launches will be conducted with authorization from the launch sites.

authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		
Teams will abide by all rules set forth by the FAA.	Inspection	The safety officer has outlined an extensive safety plan in each of the milestone reviews that include FAA rule compliance statements.

Table 14. Requirements Compliance Management and Safety requirements

6.2.1.2 Vehicle requirements

Item	Verification Method	Plan
All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	Inspection	The launch vehicle was designed to comply with this rule.
The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,500	Test	Our vehicle is designed to comply with this rule and will be test flown to ensure compliance and make

feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.		adjustments if necessary.
Teams shall declare their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.	Inspection	Our altitude target was declared in the PDR as 3,800 ft.
The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Demonstration	The vehicle is designed to comply with this rule and is demonstrated in the subscale flight to be re-flyable the same day if it was desired.
The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Inspection	It is documented in all milestone documents that our vehicle is designed to have three independent sections. Sustainer, payload/avionics bay, and upper airframe.
Coupler/airframe shoulders which are located at in-flight separation points will be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section).	Inspection	The vehicle is designed to have over 4 inches of coupler at each separation point.
The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	We will work during our full scale demonstration flights to meet this requirement and make adjustments if necessary.
The launch vehicle and payload will be	Inspection /	Altimeter batteries and tracker

capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Demonstration	batteries are known to exceed this requirement. Payload demonstration will be required to verify the chosen batteries comply.
Motor requirements	Inspection	We will be using the Aerotech K1100 rocket motor that we understand to meet all motor, ignitor, and ground support equipment requirements. This motor is discussed in the PDR and CDR.
Pressure vessel requirements	Inspection	Our team does not use any pressure vessels on our vehicle.
The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Analysis	Our simulations provided in the CDR comply with this.
The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.	Analysis	At the CDR milestone, our expected TWR is 14.30:1
Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Inspection	The vehicle was designed to comply with this rule. Simulations provided in the CDR indicate that the center of gravity will be several inches above any protrusions. We will observe that this rule is complied with before flights,

The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Inspection	Our simulations at the CDR indicate a rail exit velocity of 94.8 fps.
All teams will successfully launch and recover a subscale model of their rocket prior to CDR.	Inspection	The subscale flights were conducted prior to the CDR deadline and analysis and proof are provided in the milestone.
The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale rocket will not be used as the subscale model.	Demonstration	The subscale was designed and built to operate and perform as similarly to full-scale as possible with priority given to safety considering our goals of the subscale.
The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Inspection	Data collected from the payload's flight computer is provided in the CDR report.
The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	Inspection	There is evidence of the subscale being built as well as many distinguishing features between our subscale and full scale.
Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the CDR report. This includes but is not limited to nosecone, recovery system, airframe, and booster.	Inspection	These images are provided in the CDR report and presentation.
The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of	Inspection	The subscale rocket design details are provided in the CDR

your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.		and are shown to be 56% of the full scale vehicle.
Vehicle Demonstration Flight—All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.).	Demonstration	Our team will complete a satisfactory full scale launch in the months following the CDR, but prior to the FRR and report on it in the FRR milestone.
If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	Demonstration	We will be launching the full scale vehicle with the payload and external camera active.
Teams shall fly the competition launch motor for the Vehicle Demonstration Flight.	Demonstration	We will be flying the K1100 motors that we will use at launch week.
The vehicle shall be flown in its fully	Demonstration	The full scale vehicle will be

ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.		flown the the planned ballast as it is intended to be permanently affixed to the vehicle.
After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Demonstration	The team captain will be responsible for ensuring there are no changes without proper approval.
Proof of a successful flight shall be supplied in the FRR report.	Demonstration	The team captain will ensure the FRR meets all requirements. Complete flight data will be provided from the redundant flight computer aboard the vehicle.
Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	Demonstration	These pictures will be provided in the FRR milestone similarly to how they were for the Subscale in the CDR.
Vehicle Demonstration flights shall be completed by the FRR submission deadline.	Demonstration	The team captain will schedule flights and ensure the work necessary to conduct them is completed.

All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline.	Demonstration	We intend to complete all full scale flights with the payload installed and enabled. Evidence of this will be provided in the FRR milestone.
Payload Demonstration Flight—All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The 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	The payload demonstration flights will be conducted alongside the vehicle demonstration flights giving us several opportunities to satisfy the requirements for success. Additionally, ground testing of the payload will be conducted to give us the greatest probability of success in each flight.
The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	Demonstration	We will demonstrate the payload is satisfactorily retained during the flights. We will conduct ground ejection tests of the vehicle that will verify deployment events do not damage the payload.
The payload flown shall be the final, active version.	Demonstration	The payload lead will ensure the final version of payload is flown prior to the FRR.

Payload Demonstration Flights shall be completed by the FRR Addendum deadline.	Demonstration	The team captain and payload lead will ensure the payload demonstration flight is conducted.
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.	Demonstration	All vehicle flights will be conducted with this information applied to the vehicle. The team captain will ensure this requirement is met at the final competition launch.
All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Demonstration	The team captain and safety officer will be responsible for ensuring this requirement is satisfied prior to flights.
Vehicle Prohibitions	Inspection	The vehicle is designed to comply with all of these rules. Evidence of compliance can be found in milestone documentation.
Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Inspection	Our vehicle's only transmitter, the GPS tracker, uses 100mW of power.

Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Inspection	Our team's transmitter uses a ham radio frequency to reduce the chances of causing or receiving interference.
Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Inspection	The vehicle is designed to comply with this rule. The main uses of metal are the nose cone tip, motor hardware, and screws.
The full scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude.	Inspection	The vehicle is designed to comply with this rule. It has been successfully demonstrated in the subscale flight, shown in the subscale altimeter graphs in the CDR.
The main parachute shall be deployed no lower than 500 feet.	Demonstration	The main parachute deployments are currently planned to be at an altitude greater than this. It will be the responsibility of the team captain to ensure the flight controllers are properly configured.
The apogee event may contain a delay of no more than 2 seconds.	Demonstration	The primary and secondary charges are planned to be at a zero and one second delay respectively. It will be the responsibility of the team captain to ensure the flight

		controllers are properly configured.
Motor ejection is not a permissible form of primary or secondary deployment.	Demonstration	The motor ejection charge will be inert on all flights.
Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	Demonstration	It will be the responsibility of the team captain to ensure these tests are conducted and are concluded when the result meets all goals.
Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Inspection	The vehicle sections are designed to have a low (<65 ft-lbf) kinetic energy during launch. Each vehicle section will be weighed before launch and then flight data will be used to verify the kinetic energy of each section in the FRR.
The recovery system will contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events.	Inspection	The vehicle is designed to use 2 fully independent Stratologger CF systems, including independent batteries and switches.
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Demonstration	The switches we are using are spring loaded to be in the on position and thus are not expected to power off. Additionally the Stratologger CFs are able to weather a short loss of power and successfully continue the flight, adding

		redundancy to the system.
The recovery system, GPS and altimeters, electrical circuits will be completely independent of any payload electrical circuits.	Inspection	In the milestone reports, each of these systems are demonstrated to be designed with completely independent power supplies.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Demonstration	It is the team captain's responsibility to ensure the proper number of shear pins are used, and that the ejection charges used are powerful enough to result in a clean separation.
The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Inspection	In current simulations provided in the cdr, the worst case launch scenario (the vehicle being launched in 20 mph wind, and launching heavily angled down wind) will not exceed 2,500 feet from the pad.
Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.	Demonstration	At the time of the CDR, all simulations indicate a descent time of less than 80 seconds. However, this will need to be observed in real flights.
An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	Inspection	The receiver is documented to be included in the vehicle design at the time of the CDR.

Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.	Inspection	The vehicle, which does not have any components that separate, will have a GPS tracker installed on it, as documented in the CDR,
The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Inspection	The tracker will be physically distanced from the rest of the electronics and the vehicle includes several layers of shielding.

Table 15. Requirements Compliance Vehicle requirements

6.2.2 Team derived requirements

6.2.2.1 Vehicle Requirements

The requirements we as a team want to achieve are the following: a vehicle we can use to achieve five or more successful flights, it needs to have a center of gravity no more than 65” measured from the top of the vehicle to comply with the rules for external housings.

6.2.2.2 Recovery Requirements

We’re looking for two things from our recovery system: survivability and reliability. We want our recovery system to be able to survive non-catastrophic anomalies, such as slightly early or late parachute deployments.

6.2.2.3 Payload Requirements

Our team is participating in the USLI Payload challenge. In addition to the requirements set in the handbook section for this challenge, we aim to have a payload that accomplishes the requirements in the simplest way, while not impacting our launch vehicle drastically.

6.2.2.4 Team derived requirements compliance

Requirement	Verification Method	Plan

Center of gravity less than 65” from top of vehicle	Demonstration	Our design and simulation show we comply with this rule to a wide safety margin, however we will demonstrate that this is true once our full scale is built.
Vehicle reusable up to at least 5 flights.	Analysis	Our vehicle is built to theoretically handle this task, however we can only prove that it’s successful by flying and analyzing the condition of the launch vehicle after the flights.
Durable recovery system	Analysis	We are using high quality parachutes and great parachute protection methods, however we will need to analyze the state of our recovery hardware after each flight to verify it remains in good condition.
Payload simplicity	Analysis	The success of our payload will have to be analyzed after the end of the mission to decide if we achieved our goal of keeping it as simple as possible.

Table 16. Team derived requirements compliance

6.3 Budgeting and Timeline

6.3.1 Line Item Budget

All critical flight items have been purchased at the time of the CDR. The following is our remaining budget.

Item	Estimated cost	Notes
STEM Engagement	$2000-4000	Rutgers University has sponsored our STEM engagement program.
T-Shirts/other team accessories	$500-1000	Rutgers University has provided us access to their customized swag shop
Back up equipment/parts and club-owned equipment.	$0-5000	Potential use of NJ Space Grant support.

Table 17. Line Item Budget

6.3.2 Funding

Our funding goals per the last milestone have been met in all areas except travel reimbursement.

Source	Value	Purpose
Morris County 4-H Office	$5000	Any
NJ Space Grant Match	$5000	Undefined

Rutgers Directors Fund	$3000	STEM Engagement/Vendor Specific
Rutgers John and Anne Gerwig Director's Fund	$1000	STEM Engagement/Vendor Specific

Table 18. Funding

6.3.3 Timeline

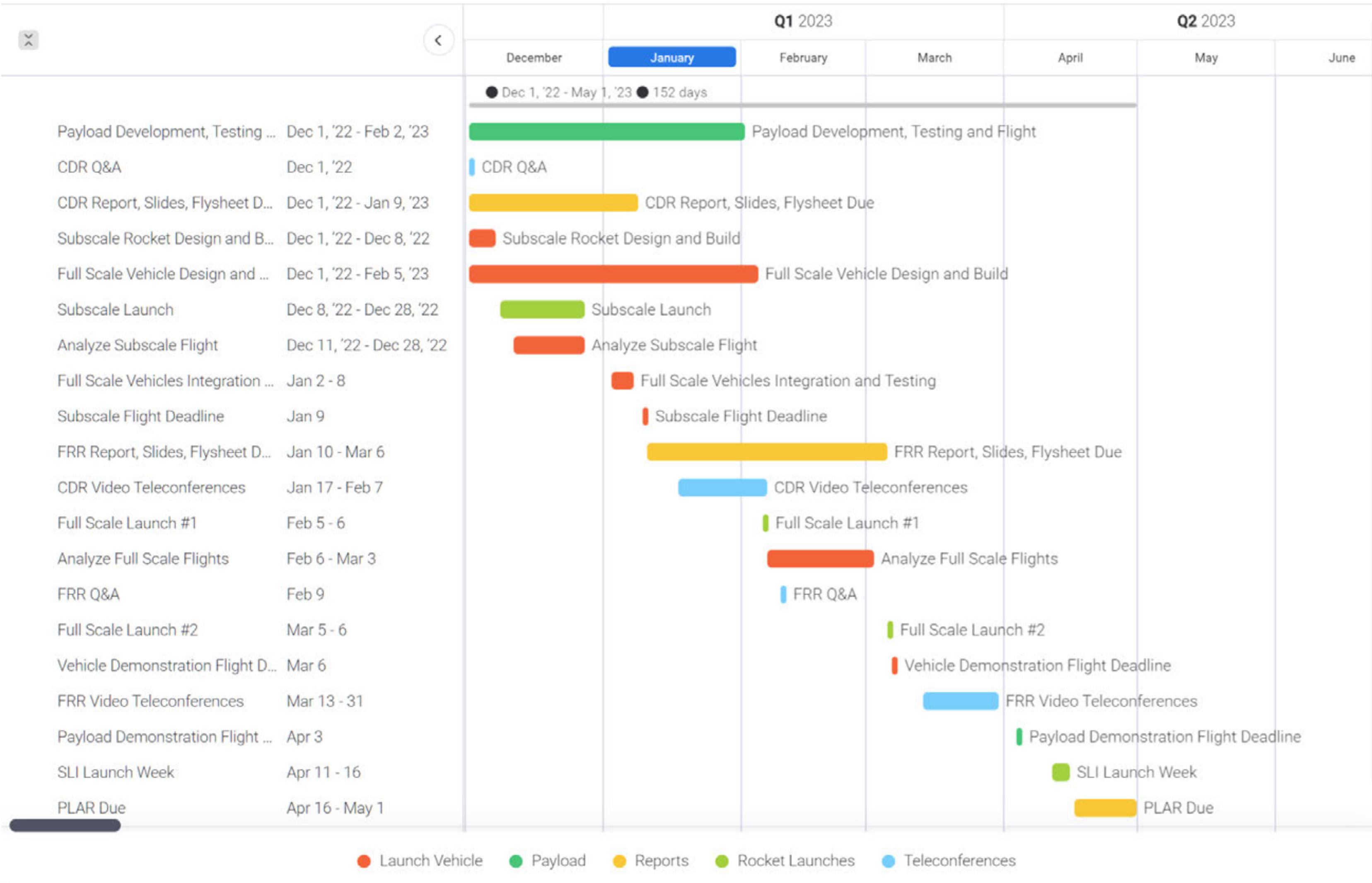

Figure 23. Timeline

6.4 Social Media and STEM Engagement

A very large goal of ours during the SLI program is having a strong social media presence and STEM engagement program. This is important to us as we are a new club working to get established. Our club's current goal with our Student launch, American Rocketry challenge, and club launches is to teach members about rocketry and project management. As our current members slowly age out of the club, we want to hand over projects and goals to new people in future years so they have the opportunity to learn with the same opportunities we had.

Our social media and "marketing" presence works to achieve this, however that has a small reach being limited to just our county. Our goal with our STEM Engagement program is to seed many other clubs across the state to eventually have their own rocketry teams.

6.4.1 Social Media

Since our proposal has been accepted, we have been pouring lots of effort into our social media presence. Our focus has been towards Facebook, as it allows our partners, like official 4-H presences, to share our posts where lots of potential members will see it. We also are spending time on Instagram, as it allows us to get promotion from the American Rocketry challenge. We use Flickr to host our images and video clips in the easiest way, helping us quickly find material that can be used for social media posts or videos.
Our YouTube channel doesn't have any SLI specific videos yet, however we are working on a SLI subscale video that will be finished when we have time after the CDR milestone.

Title	Handle	Purpose	Active for:
YouTube	Morris County 4-H YT	Launch/Build Videos	11 Months
Facebook	ResistoJets Rocketry	Community Engagement/Outreach	3 Months
Instagram	(@resistojetsrocketry4h)	Partner building and reaching younger audiences	1 Month
Flickr	nj4hspace	Image and video hosting	2 Weeks
Website	nj4h.space	Club website	3 Months

Table 19. Social Media Presence

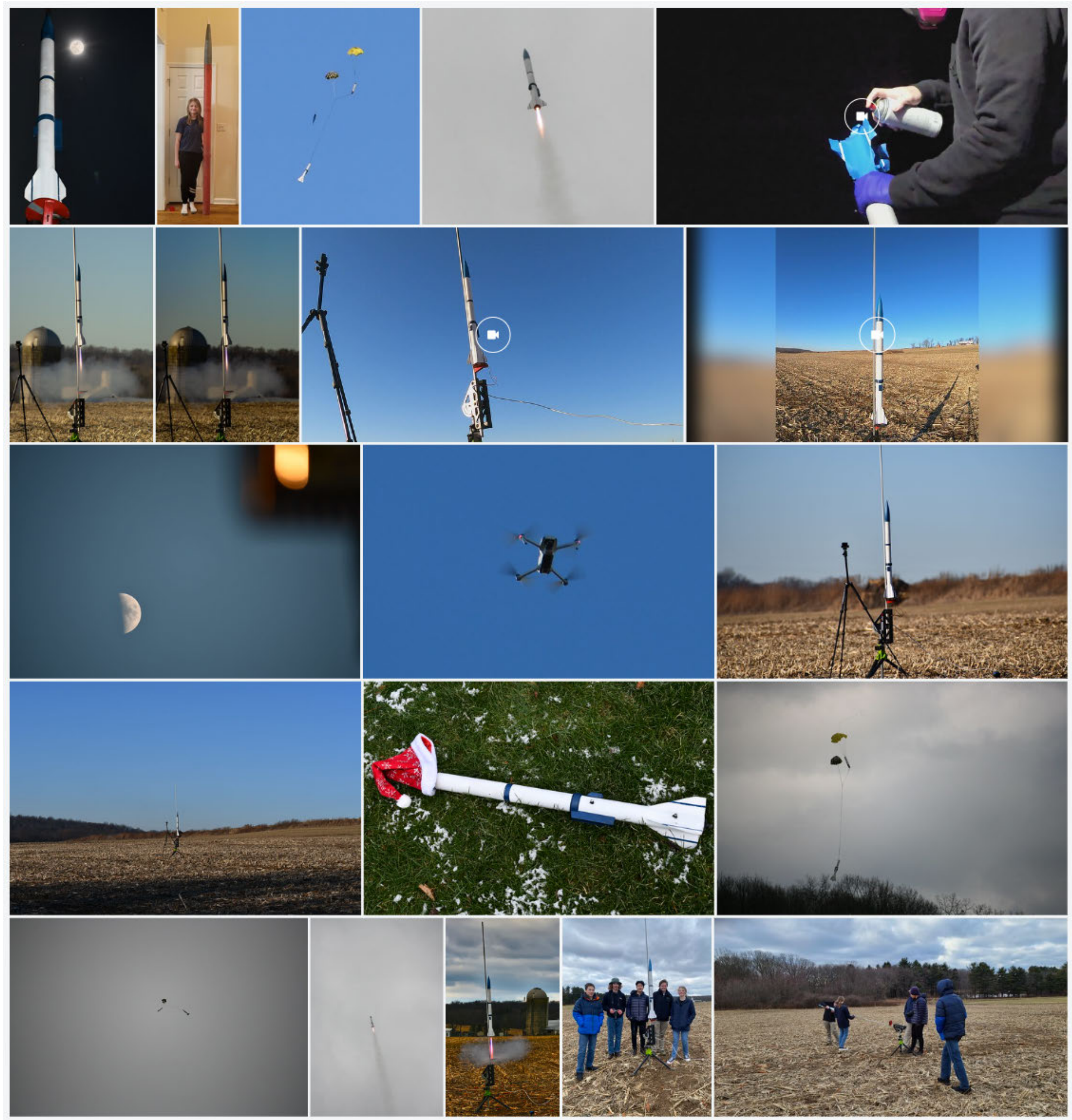

Figure 24. Our Flickr posts since our subscale flights.

6.4.2 STEM Engagement

We've realized we're going to have a hard time achieving the STEM engagement requirements traditionally, such as giving in person classes, with our small team and busy schedules. However, we've also decided that's not the most impactful thing we can do.

Rutgers University, NJ's land grant university, has sponsored our STEM engagement program. Our goal with this is to distribute an education packet, along with 250-300 rocket kits and motors, to 4-H clubs across the state and other youth groups. Rutgers is sponsoring this by fully funding the program and assisting with distribution. Our team is working with distributors to order the kits, and have a plan to ship motors to the recipients. The club adult leaders will utilize our education packet to teach members about rocketry before following our instructions on building the rockets. They will deliver us a report on the number of members they taught, as well as pictures from their events.