Critical Design Review Report

Student-Led Observations of Sinusoidal Hydrodynamics

(SLOSH)

NASA Student Launch 2025 for Middle and High School

Madison West High School

30 Ash Street, Madison, WI 53726

January 8, 2025

Table of Contents

Table of Figures

List of Tables

Summary of CDR Report

Team Information

Madison West Rocket Club
Madison West High School
30 Ash Street, Madison, WI 53726

HPR Mentor

Brent Lillesand, NAR#79225, Certification Level 3, blillesand@charter.net, (608)-358-1635

Attendance

We plan to attend the launch in Huntsville, Alabama, during launch week.

Hours

In total, we spent 158 hours working on the CDR milestone.

Social Media Presence

Instagram: @westrocketry
Facebook: @madison.west.rocketry
YouTube: @madisonwestrocketry3308
Website: https://madison-west-rocketry.github.io/SL/

Launch Vehicle

Competition Launch Motor: Aerotech K-1103 (Total Impulse: 1,810 Ns)
Secondary Motor Choice: AeroTech K-805 (Total Impulse: 1,762 Ns)
Target Altitude: 4,500 feet
Recovery: Dual-deployment with two parachutes
Rail Size: 8’ 1010
Rail Exit Velocity: 87.1 ft/s

Individual Sections Size and Mass

Vehicle Dry Mass: 16.89 lbs
Vehicle Wet Mass: 20.10 lbs
Vehicle Burnout and Landing Mass: 18.28 lbs
Nose Cone: 1.35 lbs
Upper Section (incl. Payload & Electronics Bay): 9.00 lbs
Payload & E-Bay: 4.5 lbs
Booster Section: 6.47 lbs
Recovery Components (Parachutes and Shock Cords): 3.30 lbs

Payload: Slosh Baffles

Our payload is designed to test the effectiveness of different baffle designs in reducing the amount of slosh in a liquid tank during rocket acceleration. We will record fluid displacement using cameras and sensor systems.

Changes Made Since PDR

Changes to Vehicle Criteria

Ensure Requirements

We implemented minor changes to our vehicle design to ensure it meets NASA requirements. We validated that all couplers had at least 4” (1 body diameter) of engagement and all shoulders had at least 3” (0.75 body diameters) of engagement. We decreased our drogue parachute size to 20” from 12” to reduce our descent time from ~90 s to ~66 s and ensure that our flight time fits within NASA requirements.

Ensure Accuracy

We amended our vehicle design to account for all components, including eye and U bolts, and we made slight adjustments to the locations of parachutes and shock cords. We fixed minor inaccuracies, increasing the thickness of centering rings and bulkheads to reflect the correct products, and we reorganized mass components in our payload bay to reflect the actual payload model.

Other Changes

Additional design changes include moving the upper bulkhead forward in the airframe, to add space for our payload, and validating measurements of the payload bay and ebay. We added a short section of tube coupler, to enhance the stability of the upper bulkhead, and reduced motor tube length, to allow the use of a fiberglass tube that the club already has, instead of paying and waiting for fabrication of a new tube. We slightly shortened the vehicle’s coupler tube, to add space in the payload bay and stay compliant with NASA requirements. Additionally, we added a new bulkhead to separate the payload from the electronics bay to facilitate integration.

Changes to Payload Criteria

Tank System

We condensed our cylindrical tank design to a 2D design, allowing more payload space and simpler analysis. The 2D tank creates waves in two dimensions, rather than three, and new, more efficient sensor grids will also help streamline data collection and analysis, leading to fewer points of failure. This design will make it easier to study surface waves and slosh in the tanks.

Camera System

Our initial payload contained 2 cameras per tank, which cost more and allowed more points of failure. We changed the design of the tank from 3D to 2D, so only one camera is necessary, cutting costs and decreasing the chances of overheating. We will use the distortion grid on the PCB board to counteract any fish eyeing from the camera.

Electronic Sensor System

We updated our sensor system, which initially combined capacitive sensors and exposed contacts inside the tank, to one that uses only exposed contacts, which are smaller and provide higher data resolution.

Changes to Project Plan

Testing

We have made minor changes to our testing plan since the PDR: We will run new tests for our updated payload design, including the new data collection system. We will prioritize the issues found in our scale model test flight, such as parachute deployment and arming hole placement, in our vehicle test process.

Timeline & Budget

We plan to hold true to our timeline reported in the PDR, and we will work to begin writing, construction, and planning earlier. Our budget has been updated to reflect the new payload and vehicle design, including the new camera and sensor systems.

Vehicle Criteria

Design and Verification of Launch Vehicle

Mission Statement

Our mission is to successfully send the vehicle to the projected apogee, deploy the parachutes at the correct altitudes during launch, and safely land the vehicle, while ensuring that the payload is able to collect significant data.

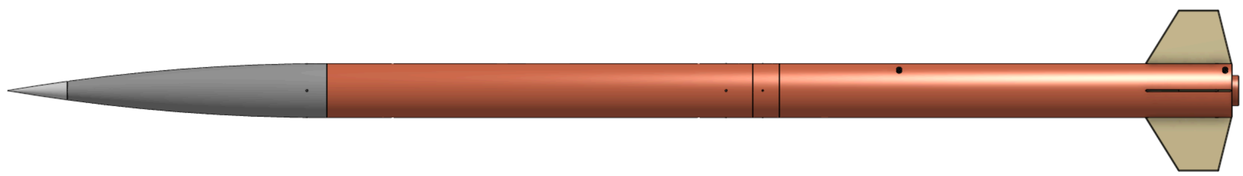


Figure 1: CAD Model of Full Vehicle

Final Design Choices

Nose Cone

We chose a 24”-long ogive fiberglass nose cone with a diameter of 4”, manufactured by Wildman Rocketry. We chose this design over the alternatives because of its length, which allows for a better aerodynamic profile and a higher center of gravity, giving us a more optimal static stability margin.

Upper Section

The chosen design for the upper section of the rocket is a 32” tube that contains the payload section, main chute, shock cord, and mounting hardware, as well as the forward end of the ebay. The payload consists of the 32” section of 4” body tube, terminated on one end with 10” of coupler tubing, with a 4” interface in the upper tube, 2” covered by a switch band, and another 4” exposed and interfacing with the booster section for a separation point. There is a removable bulkhead to seal the end of the coupler tubing. The other end of the payload section ends with an upper bulkhead. We chose this design because it allows for easy access to the payload section, incorporates the ebay, and is easier to manufacture and design.

Electronics Bay

The design chosen for the electronics bay is integrated into the payload section. It consists of a 3D-printed mount inside the payload section, retained by the same tie rods that retain the payload. The ebay is located against the removable bulkhead of the payload section, allowing for wiring to be routed through the bulkhead to deployment charges. We chose this design because it is practical and functional.

Booster Section

The chosen design for the booster section is a 34” tube containing the motor, motor retention system, centering rings, and the drogue parachute and its shock cord. The fins are mounted via through-the-wall fin tabs that are almost 1” in width. The fins themselves are canted away from the ground to avoid breakage when landing. The motor tube is 13” and will overhang from the base of the rocket by 0.5”. This section also contains two rail buttons, one 25” from the base of the rocket, and one 0.5” from the base. This ensures that the rocket will have a rail button on the rail for as long as possible during liftoff. The buttons are spaced far enough apart that it will be easy for the vehicle to be guided in a straight line off the launch rail.

Individual System Design

Nose Cone Section

We opted for a fiberglass 5:1 ogive nose cone manufactured by Wildman Rocketry. Fiberglass is strong enough to withstand aerodynamic forces. Its aluminum tip is threaded, allowing us to install a ¼” forged eye bolt as the forward attachment point of our main shock cord. This nose cone is a common product in high-power rocketry and has been flown by other members of the rocketry community, as well as our mentors, in the past, without issue.

As seen below, a 6.5” section of Wildman Rocketry coupler tubing is inserted into the nose cone and bolted in radially, leaving 4.5” exposed to interface with the upper tube. The nose cone also contains a straightened section to interface with the coupler, not modeled in our CAD design below. This coupler section also contains two holes for shear pins to ensure our vehicle does not separate prematurely.

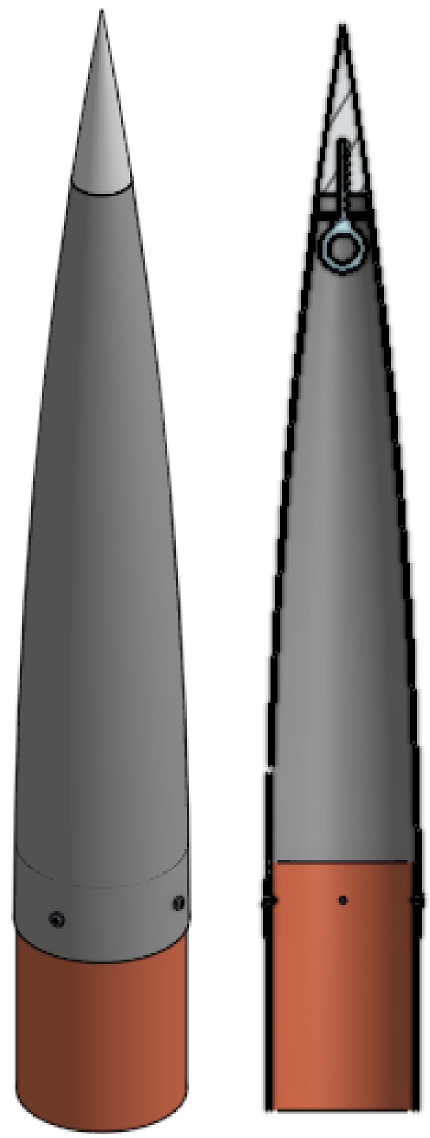


Figure 2: CAD Model of Nose Cone

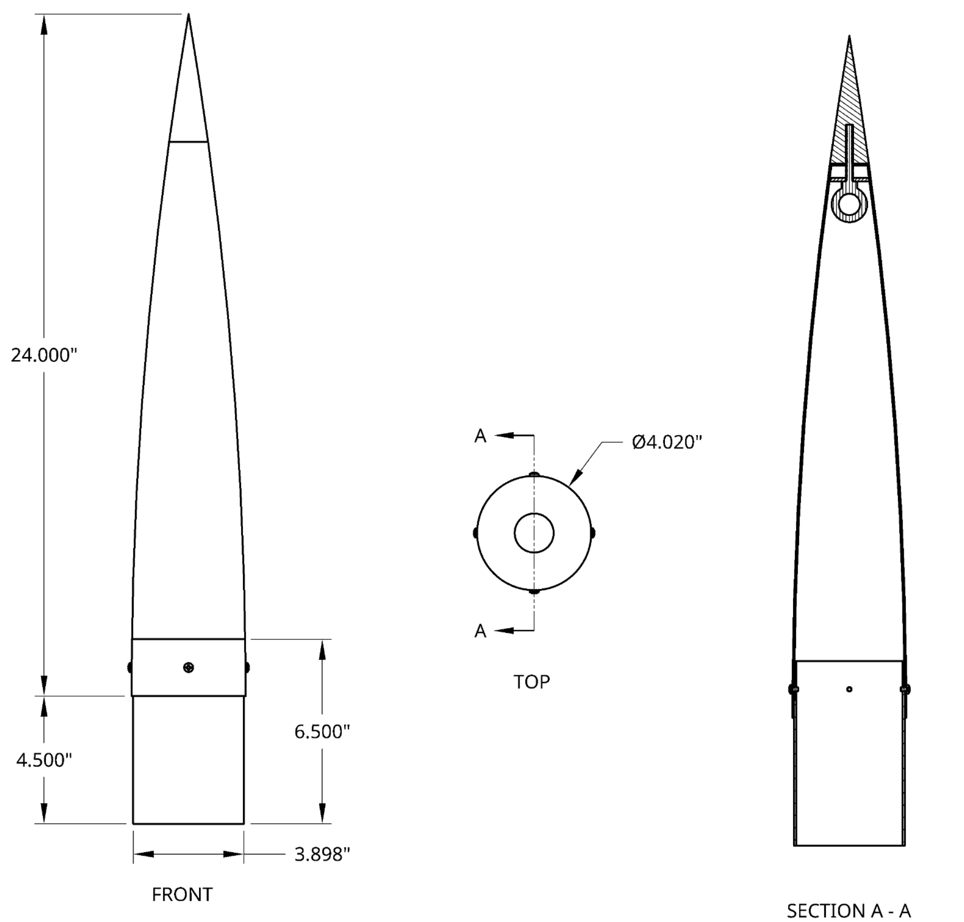


Figure 3: Nose Cone Section Dimensioned CAD Drawing

Upper Section

The upper section of the rocket contains our payload and interfaces with the electronics bay as well as the nose cone section. This selection also contains the payload retention system. The airframe of the upper section is a 32”-long, 4”-diameter fiberglass tube, manufactured by Wildman Rocketry. This airframe is more than strong enough to withstand the forces of flight during our launch, and this material has been tested on many previous flights by our mentors and the rocketry community.

The upper section interfaces with the nose cone section via the 4.5” coupler section of the nose cone. The electronics bay is bolted into the upper section with four radial bolts, and the material overlap between the upper section and electronics bay is 4”.

The forward end of the upper section contains a bulkhead to which the main recovery system is anchored via a ¼" U-bolt. This bulkhead also contains screw terminals for connecting the main event deployment charges.

The upper section and payload retention system is held together by two ¼" stainless steel threaded rods, terminated on one end by the upper section's upper bulkhead and on the other end by the electronic bay's aft bulkhead. The forward end of the upper section contains two holes for shear pins that align with the holes in the nose cone section. This ensures that the vehicle will not separate prematurely.

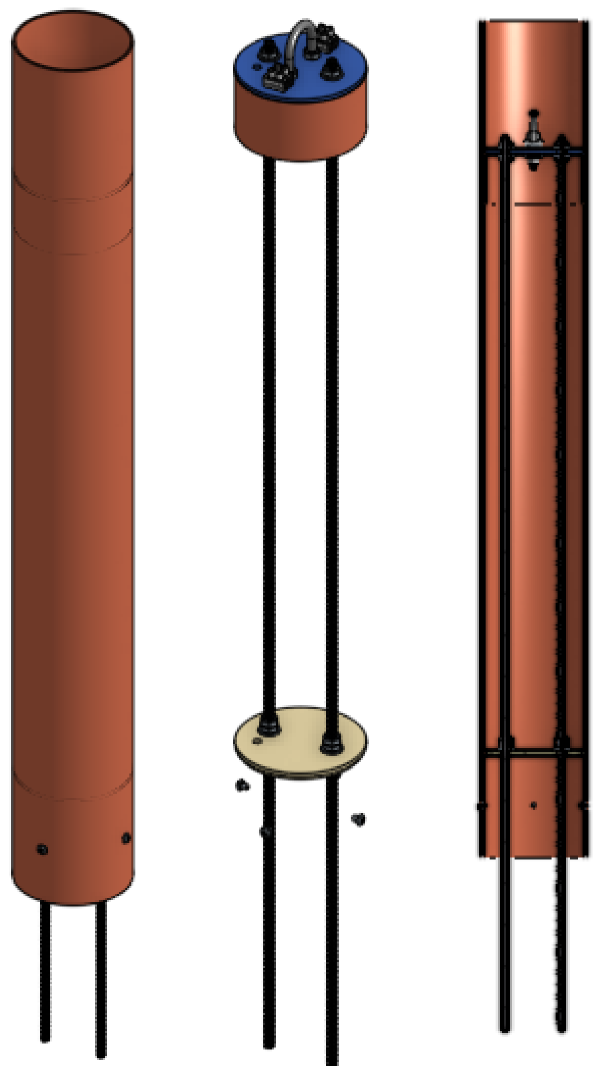


Figure 4: Upper Section External and Internal CAD Model

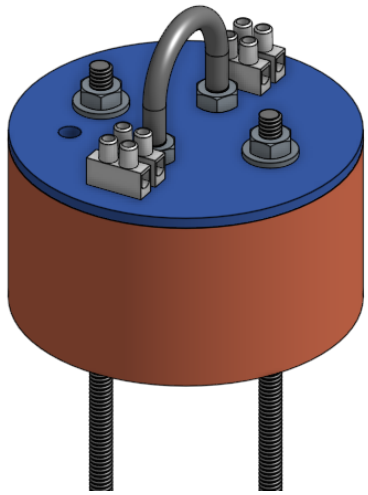


Figure 5: Upper Section Forward Payload Retention and Main Attachment Point

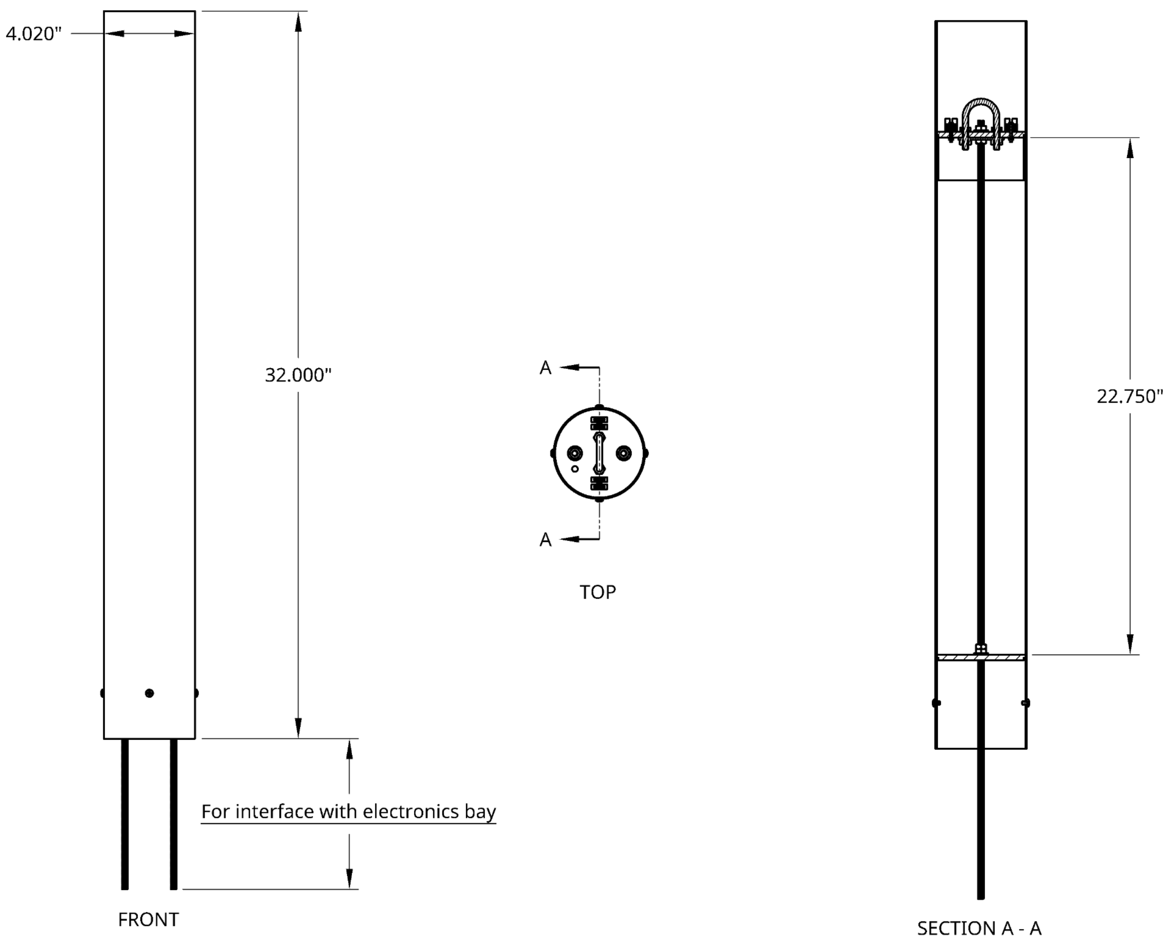


Figure 6: Upper Section Dimensioned CAD Drawing

Payload Retention

Our payload is retained by two ¼" stainless steel threaded rods and bulkheads on either end. Each module of the payload is attached to these rods, thereby reducing vibrations and ensuring that every module is secure and will not come free during flight. The bulkheads on either end are also secured to these threaded rods, and they will ensure that the payload remains inside the vehicle during any high-g portions of the flight.

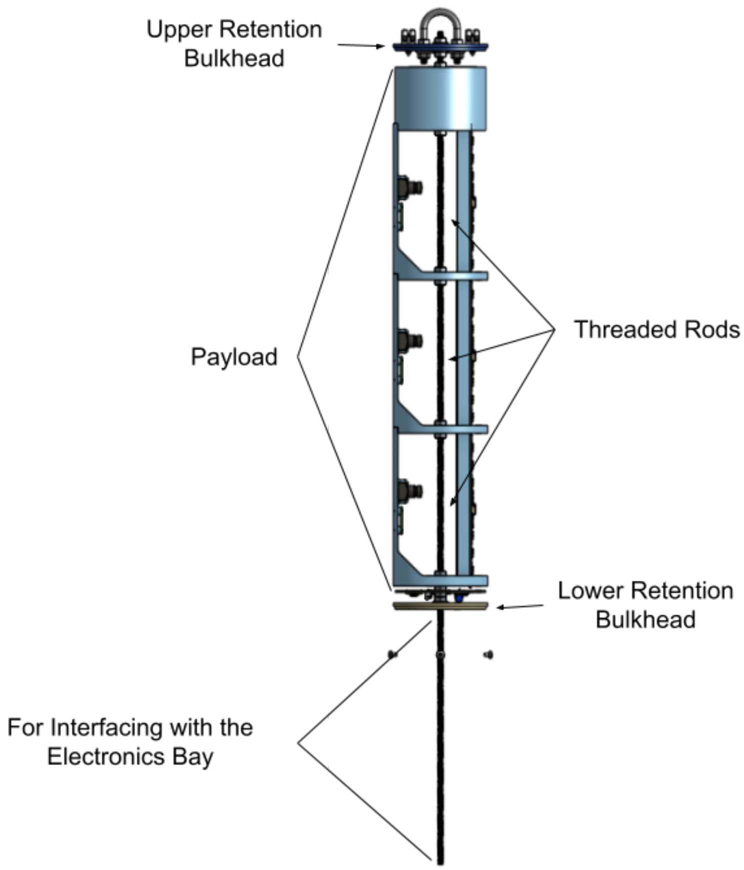


Figure 7: Payload Retention Diagram

Electronics Bay

The electronics bay of our vehicle consists of a 10” section of fiberglass 4” diameter coupler tubing, manufactured by Wildman Rocketry, as well as a 2” section of airframe to serve as a switch band. The electronics bay is capped on both ends with ¼”-thick G10 fiberglass bulkheads and stepped to ensure they fit inside the electronics bay. The electronics bay is held together with the same threaded rods as used in the upper section and payload retention system. These rods and the nuts placed on them will compress the electronics bay and ensure it does not come open during flight. Finally, four holes are drilled in one side of the switch band to arm the two flight computers, GPS tracker, and payload, and three vent holes are drilled around the other three sides of the switch band, to ensure the flight computers can get accurate readings.

Additionally, the aft bulkhead of the electronics bay contains a ¼" stainless steel U-bolt as the forward anchor point of the drogue recovery system. This bulkhead also contains screw terminals for connecting the drogue event charges. The electronics bay interfaces with the upper section via a 4" section of coupler tubing and is bolted in using four radial bolts. The electronics bay also interfaces with the booster section via a 4" section of coupler tubing; this interface is a separation point at apogee. The electronics bay also contains two holes in the aft coupler section for shear pins to ensure the vehicle does not separate prematurely.

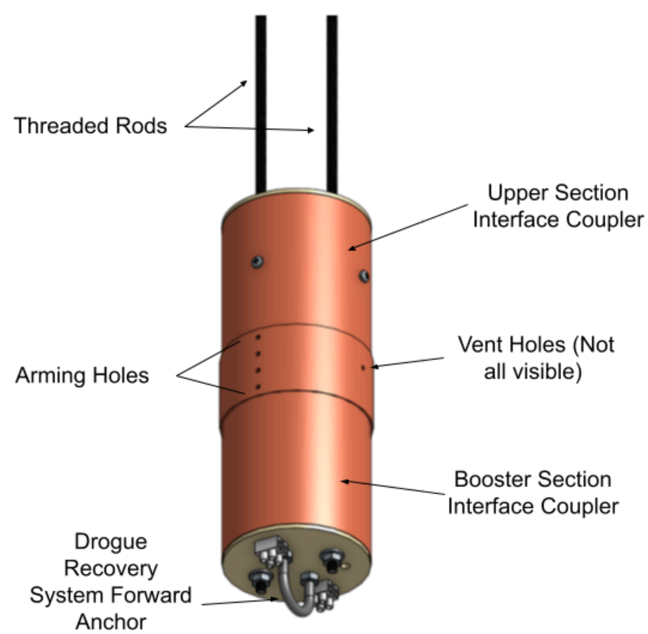


Figure 8: Electronics Bay Aft Bulkhead CAD Model

The inside of the electronics bay contains our two Perfectflite StratoLogger CF flight computers, as well as our GPS tracker, three 7.4 V 2S 100 mAh LiPo batteries for the flight computers and GPS tracker, and four screw switches to arm the flight computers, GPS tracker, and data management system individually. We decided to place the data management arming switch in the electronics bay for ease of access when setting up the vehicle on the launch pad.

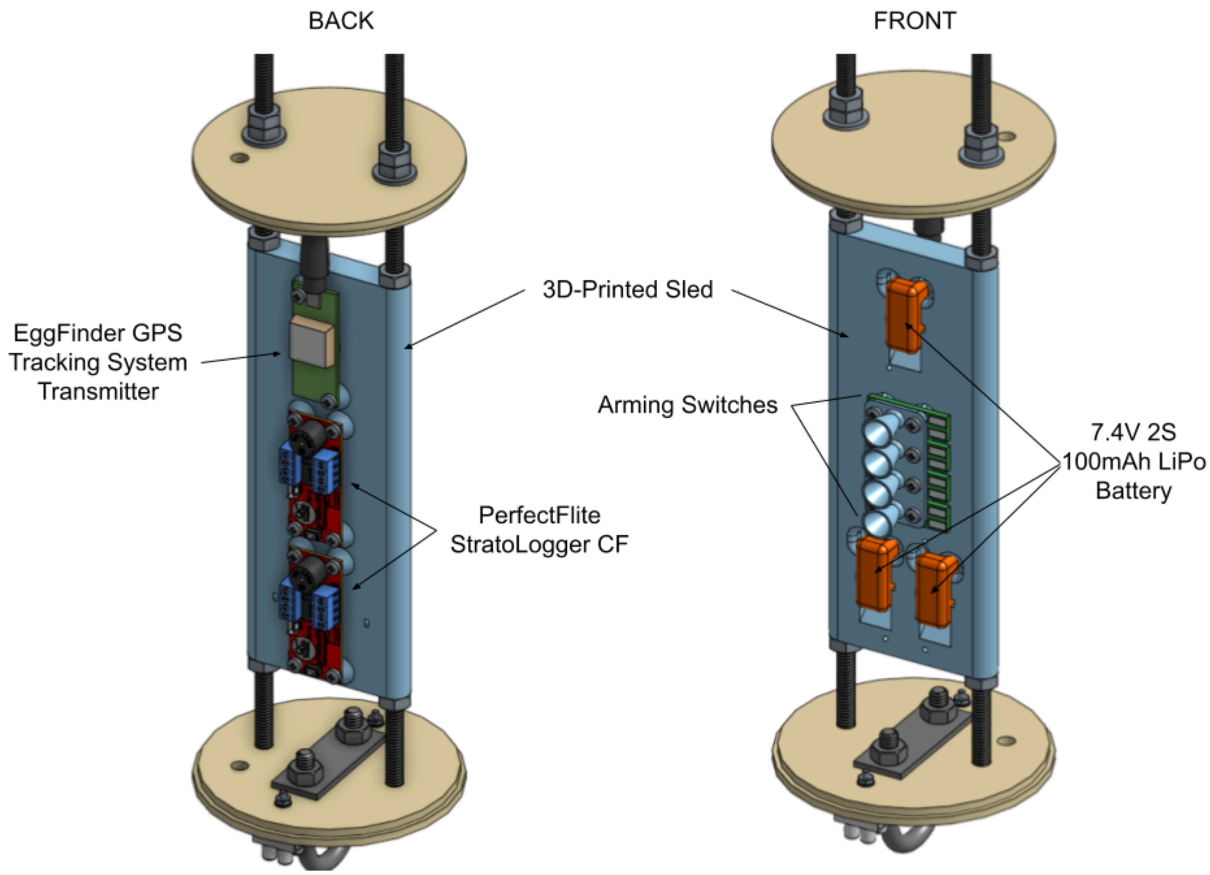


Figure 9: Electronics Bay Internals Diagram

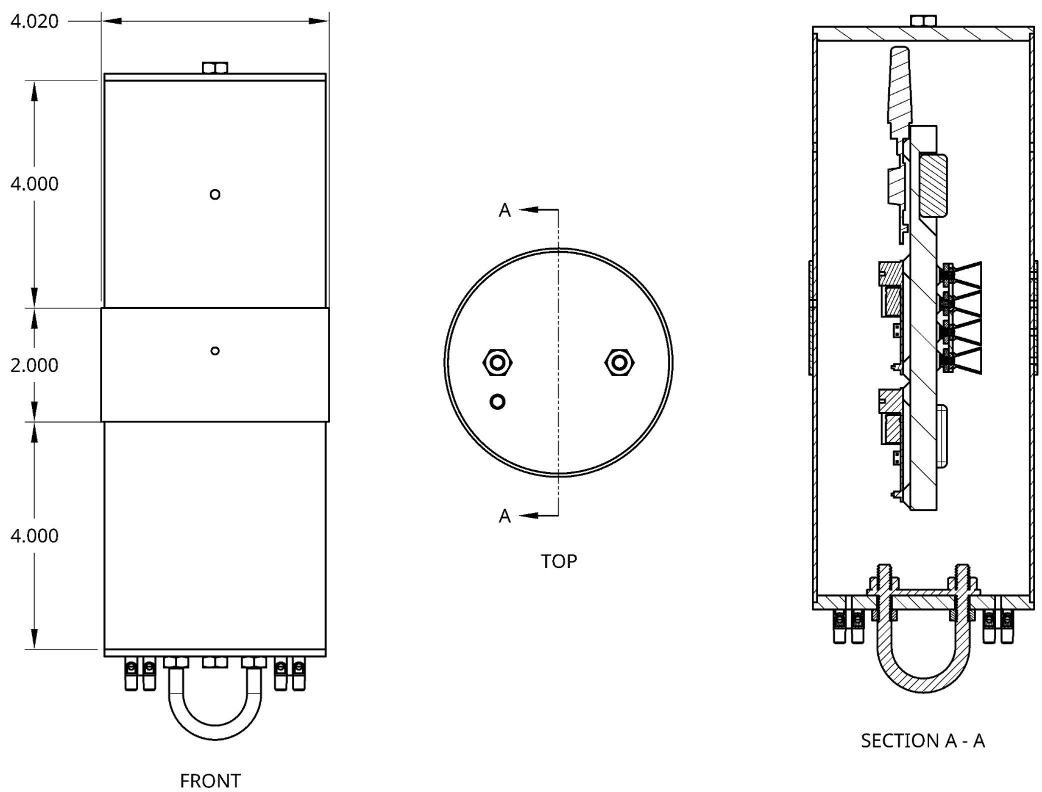


Figure 10: Electronics Bay Dimensioned CAD Drawing
Note: Threaded rods and some hardware are omitted in this drawing

Booster Section

The booster section of our vehicle consists of a 34" long 4" diameter fiberglass tube manufactured by Wildman Rocketry. This tube is strong and has been proved as an airframe on several high power flights by our mentors and the rocketry community. This tube contains two holes for shear pins that align with the holes in the electronics bay. These shear pins ensure the vehicle will not separate prematurely. The aft end of this tube contains the vehicle's fin can, including the motor mount tube, centering rings, and fins, as well as the motor retainer and shock cord attachment length. The shock cord is attached to the motor mount tube by adhering a length on either side of the tube with epoxy, connecting in a loop above the motor mount tube. This length is sized to reduce shear loads on the Kevlar material. This attachment length is then tied to the drogue shock cord.

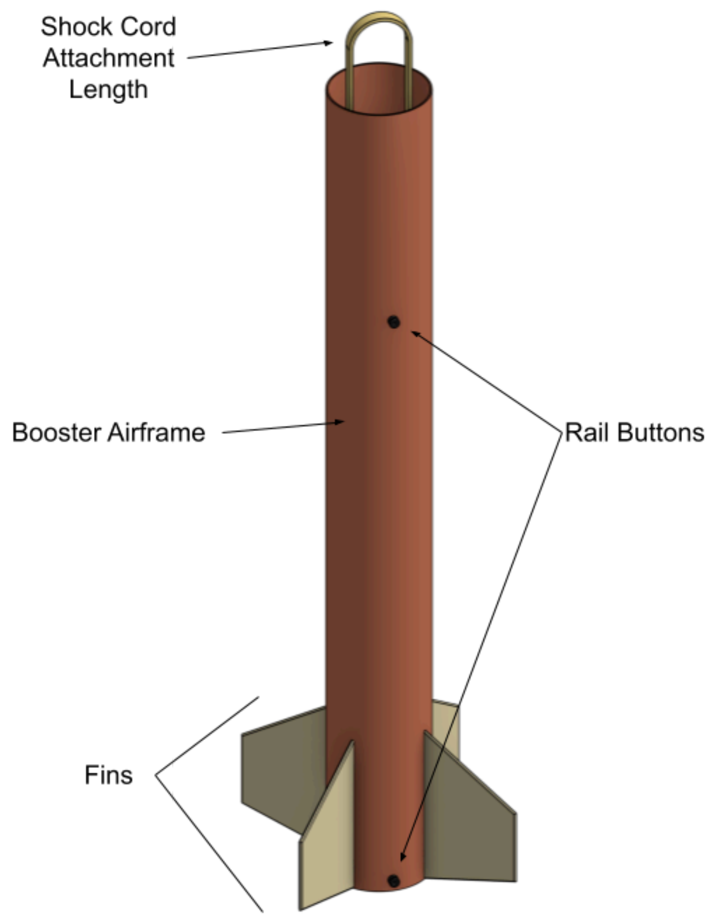


Figure 11: Booster Section CAD Model Diagram

To ensure the fins are mounted straight in the fin can, two 3D-printed guides are attached to the inner faces of the two aftmost centering rings, which will hold the fins in the proper position until they are epoxied into place. The fin can will be assembled outside of the booster section airframe and then inserted into the airframe via the fin slots cut into the airframe. Two 1010 rail buttons are also placed on the booster section airframe, spaced to ensure the vehicle remains guided by the rail until a sufficient rail exit velocity is achieved.

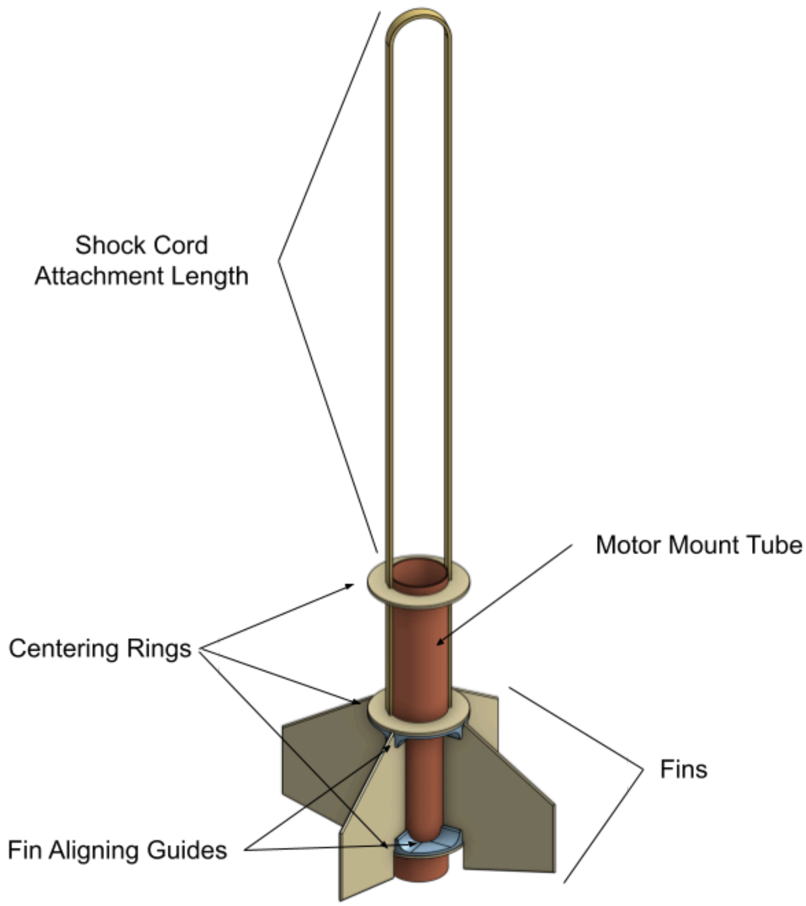


Figure 12: Booster Section Fin Can CAD Model Diagram

The drogue shock cord is attached to the booster section via the shock cord attachment length, a short length of Kevlar that is adhered, using epoxy on both ends, to the motor mount tube, passing through the centering rings and fin guides. This attachment method has been proved on several high power flights in the past by students and mentors. The shock cord attachment length is then tied to the full length of the drogue shock cord to ensure it remains attached during flight.

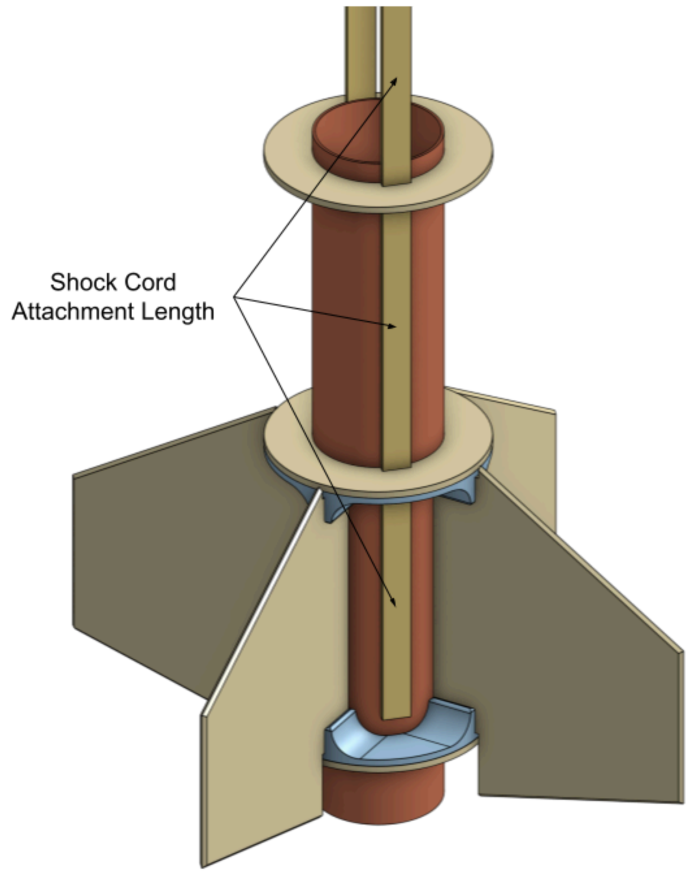


Figure 13: Booster Section Aft Shock Cord Attachment Solution CAD Model Diagram

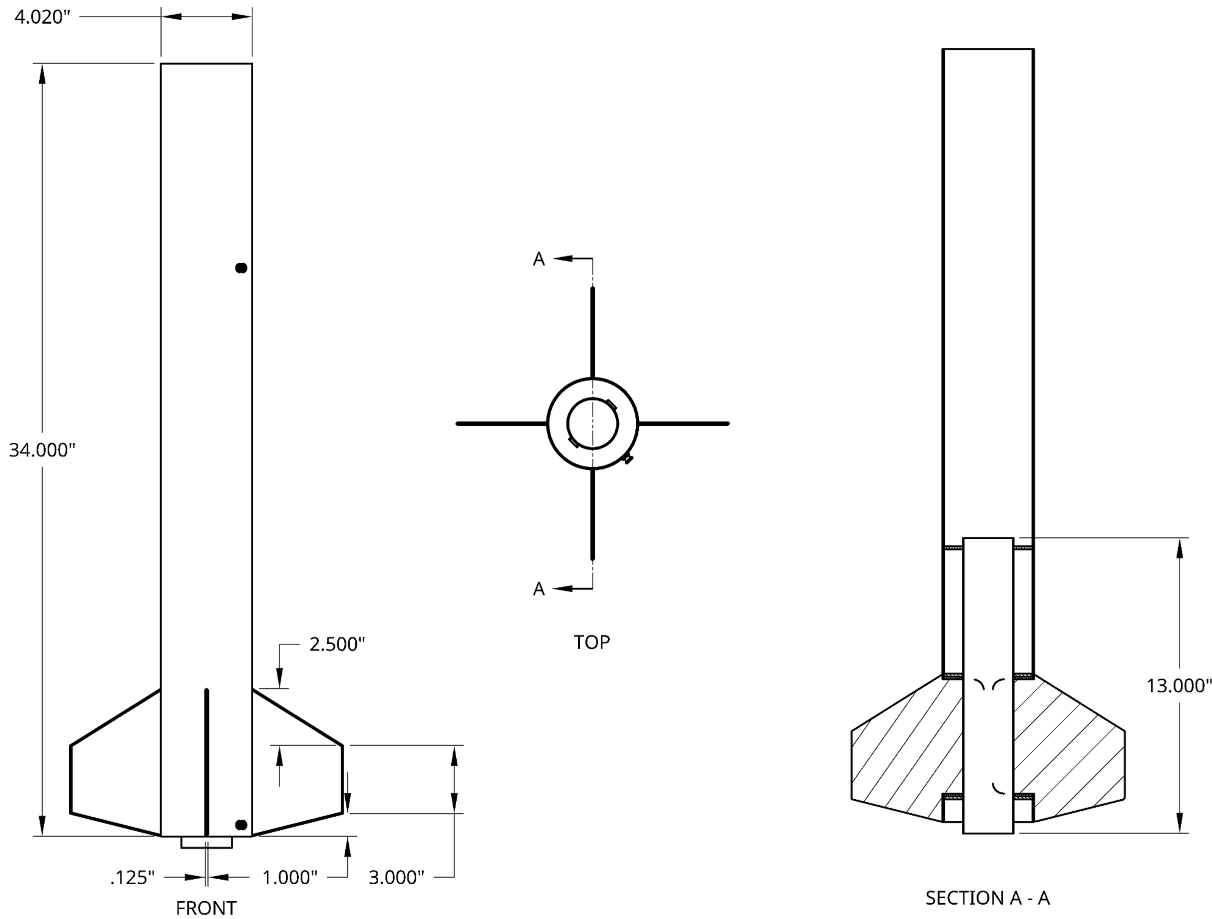


Figure 14: Booster Section Dimensioned CAD Drawing

Separation Points and Energetic Charge Locations

At apogee, a deployment charge placed inside the booster tube will separate the booster section from the upper section, which is tethered with a shock cord. During descent, at 700 feet, a deployment charge placed inside the nose cone section will separate the nose cone section from the upper section. Backup charges will be placed adjacent to the primary charges.

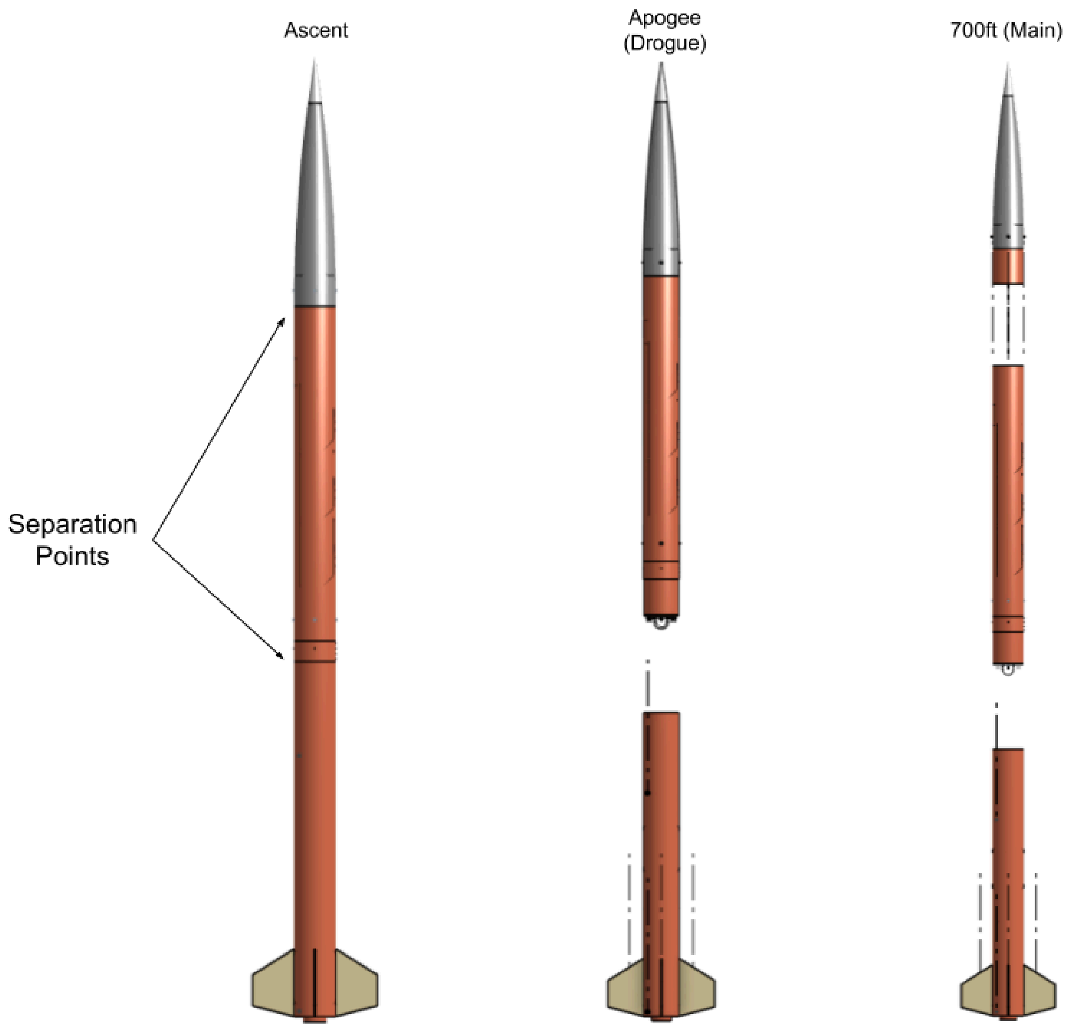


Figure 15: Vehicle Separation Points Diagram
Note: Tethering shock cords are omitted in this diagram

The deployment charges in our vehicle will be floating-style charges, connected to the electronics bay via individual screw terminals. A primary and backup for both our drogue and main deployment events results in four total charges.

The primary and backup drogue event charges will be placed just above the motor, below our drogue chute and protector. This ensures that our parachute remains protected from the deployment of the charge and that the entire drogue recovery system is able to exit the booster section successfully. The close-up of the booster section below shows the drogue event charge locations (Fig. 16).

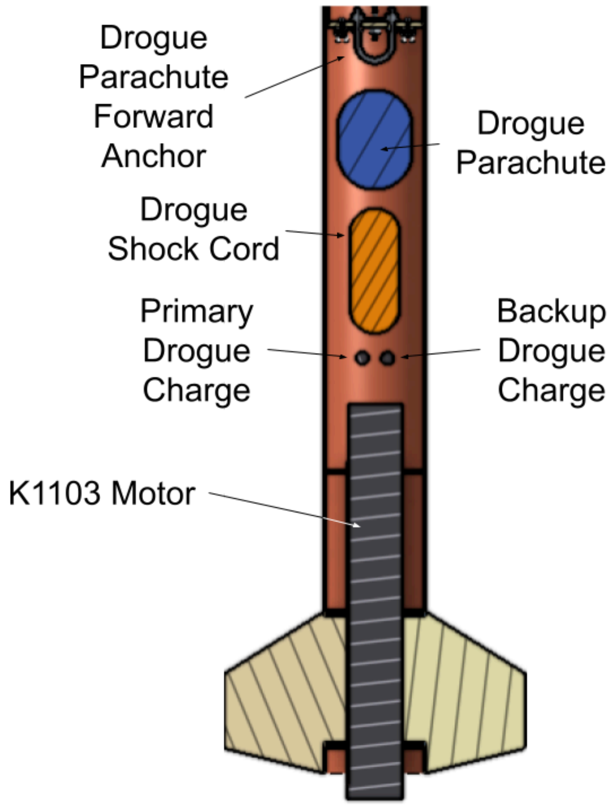


Figure 16: Drogue Event Deployment Charge Locations

The primary and backup main event charges will be placed above the main shock cord, forward of the rest of the main recovery system, in the tip of the nose cone section. This ensures that our parachute remains protected from the deployment of the charge and that the entire main recovery system is able to exit the booster section successfully. The close-up cross-section of the nose cone section below shows the main event charge locations (Fig. 17).

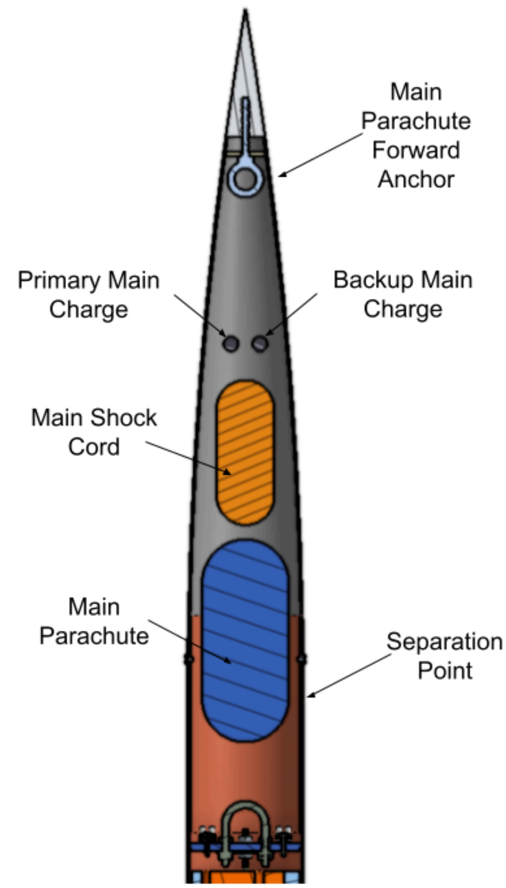


Figure 17: Main Event Deployment Charge Locations

Subscale Flight Results

Materials and Scaling Overview

Our scale model was designed to be a ½ scale model of the full-scale vehicle in all dimensions, with a few key exceptions. The airframe diameters and lengths, as well as the motor mount tube and length, were all scaled by a factor of ½. We chose a 54mm-diameter fiberglass airframe manufactured by Wildman Rocketry and a 29mm-diameter fiberglass motor mount tube, also manufactured by Wildman Rocketry. These tube diameters were deemed to be a sufficient size for the scale model, and we selected them because they are standard sized. All of the coupler tubing used in our scale model was 54 mm coupler tubing, manufactured by Wildman Rocketry. The lengths were scaled by a factor of ½. The centering rings and bulkheads were manufactured with ½ the thickness of the full-scale design and matched to the scale model design to ensure ease of assembly.

The drogue and main parachutes of our scale model recovery system were sized to create the same descent speed as the full-scale model. This allowed us to have our scale model kinetic energy upon impact to be ½ that of our full scale. Since K_E=0.5mv^2, reducing our mass by ½ reduced our kinetic energy by ½, as well. The shock cord lengths on our scale model were sized to be ½ that of the full scale vehicle.

The nose cone of our scale model was custom-manufactured by students to be a 12”-long, 54 mm-diameter fiberglass nose cone. The nose cone was created using fiberglass sleeves, and the tip was custom-formed, using steel-infused epoxy in a 3D-printed mold. This method allowed us to make our nose cone quickly and accurately instead of having to order a commercially manufactured nose cone.

Flights Overview

We performed two subscale flights at a launch site in Verona, Wisconsin, both on an Aerotech HP-G138 motor. During the first flight, both of our onboard PerfectFlite StratoLogger flight computers deployed both the drogue deployment charges at the peak of flight, with one set to fire with a 1-second delay, and the main deployment charges, one at 500’ and one at 400’. During this first flight, the main parachute failed to inflate after deploying, remaining encased in its Nomex protector. This resulted in the scale vehicle impacting the ground at a higher-than-expected velocity, resulting in minor damage to the upper section of the scale vehicle. We deemed this damage sufficiently small to warrant a second flight, and we re-integrated the scale vehicle, swapping the main parachute’s Nomex protector for a smaller one.

During the second flight of our scale vehicle, flown with the same deployment parameters as the first flight, both the drogue and main parachutes inflated, and the scale vehicle recovered with no further damage.This successful flight supported our analysis of the Nomex protector being too large in the first flight. On this second flight, one of our main parachute shroud lines became disconnected upon inflation. This prompted us to review our manufacturing techniques and ensure we have plans to make robust parachutes for the full-scale vehicle.

Flight 1 Data and Analysis

Averaging the results of our two flight computers, our first scale model flight flew to an apogee of 1126 ft in approximately 8 s. The total flight time was approximately 23 s.

Below are flight profile graphs from both of our two PerfectFlite StratoLogger flight computers.

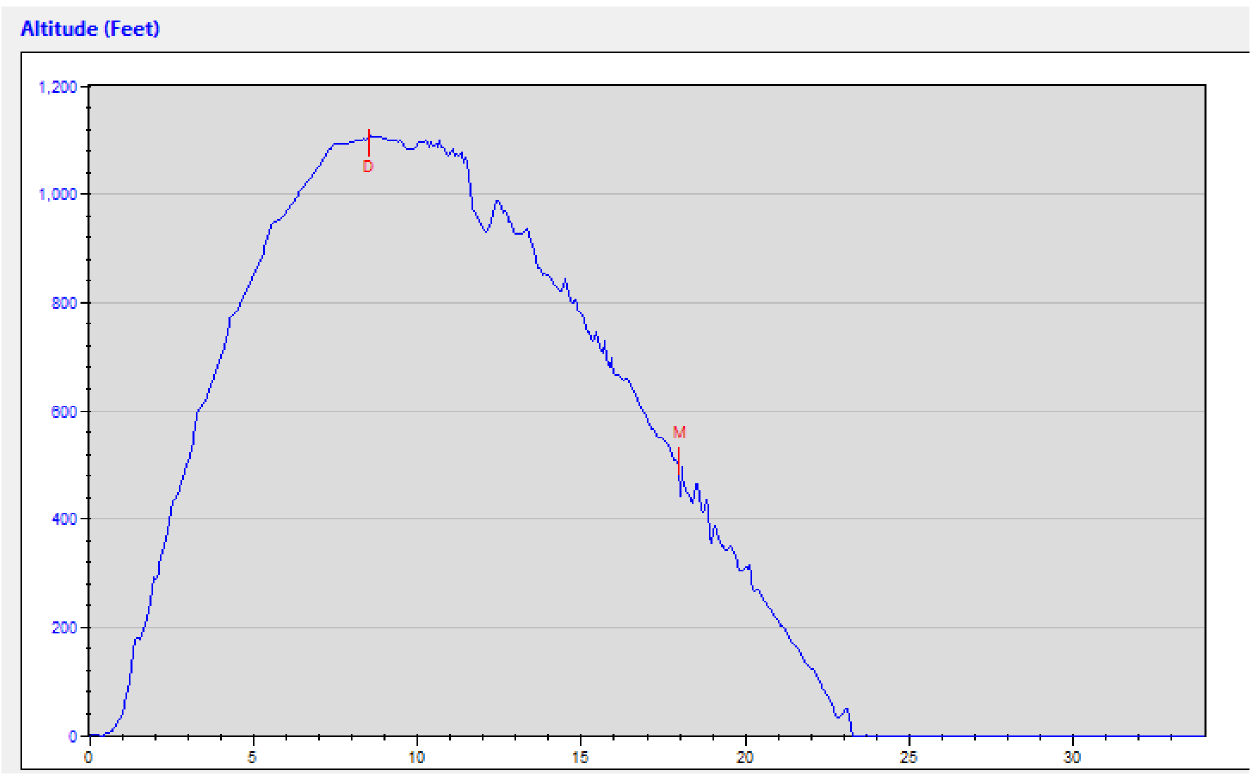


Figure 18: Scale Model Primary Flight Computer Flight 1 Profile

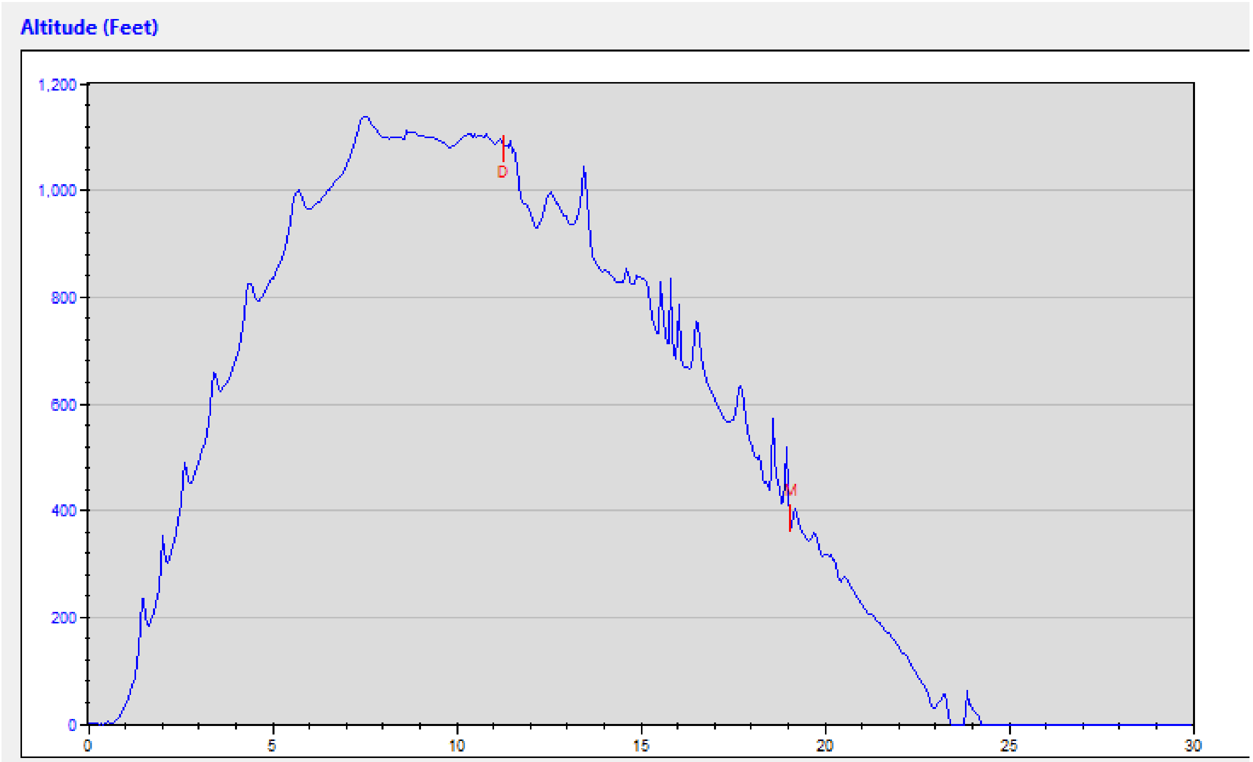


Figure 19: Scale Model Backup Flight Computer Flight 1 Profile

As seen in Figure 19, the data are “choppy” and inconsistent. This is likely due to the vehicle spinning as it ascended, with varying light levels hitting the barometer chips on the flight computers. The barometer that is used by the PerfectFlite StratoLogger CF is sensitive to light, and the switch band of the electronics bay was unpainted and translucent. This resulted in varying light entering the electronics bay, making the data inconsistent. This phenomenon is not seen in the second flight, as the weather was cloudy during the second flight, resulting in less light present to enter the electronics bay.

Additionally, due to the main parachute failing to deploy upon the firing of the deployment charges, the descent rate of the scale model did not change after the charges were deployed. This caused the vehicle to impact the ground within a shorter time than we expected. This failure prompted us to take extra care when packing the main parachute of the scale model and adding the proper chute packing and sizing of the Nomex blanket to our Failure Modes and Effects Analysis.

Flight 2 Data and Analysis

Averaging the results of our two flight computers, our second scale model flight flew to an apogee of 1118.5 ft in approximately 8.75 s. The total flight time was approximately 34 s.

Below are flight profile graphs from both of our two PerfectFlite StratoLogger flight computers.

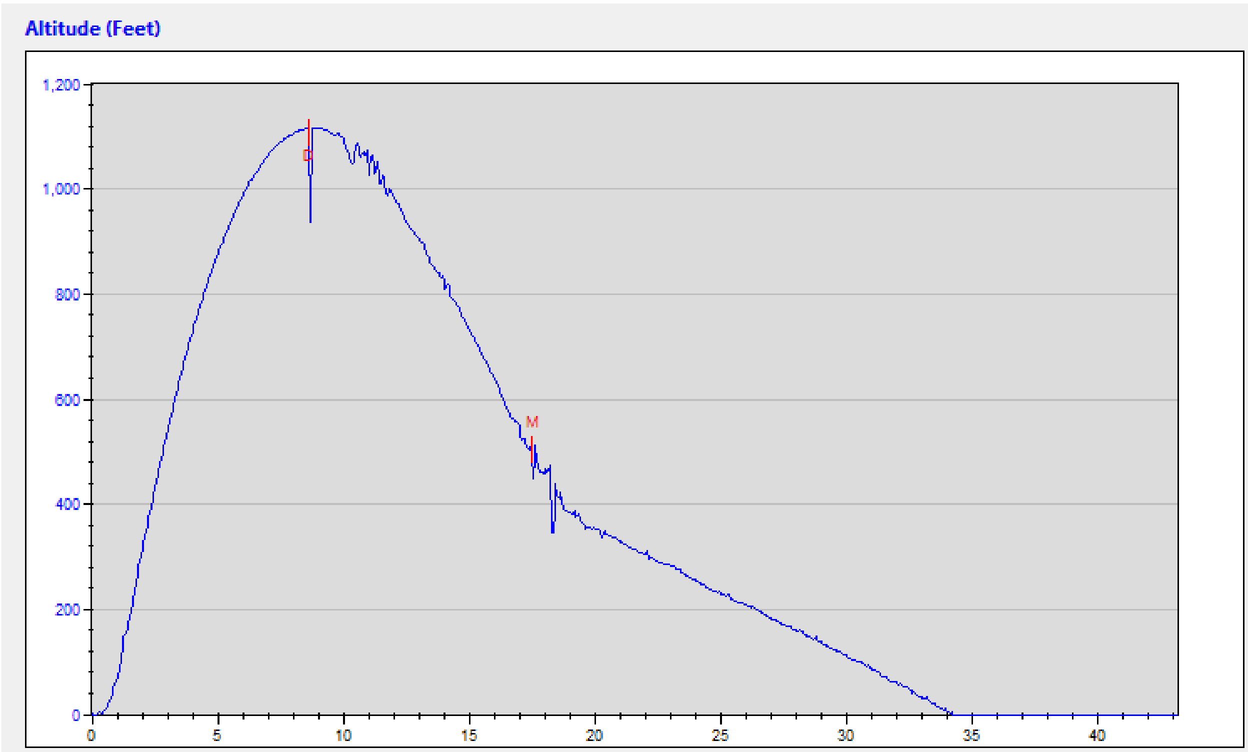


Figure 20: Scale Model Primary Flight Computer Flight 2 Profile

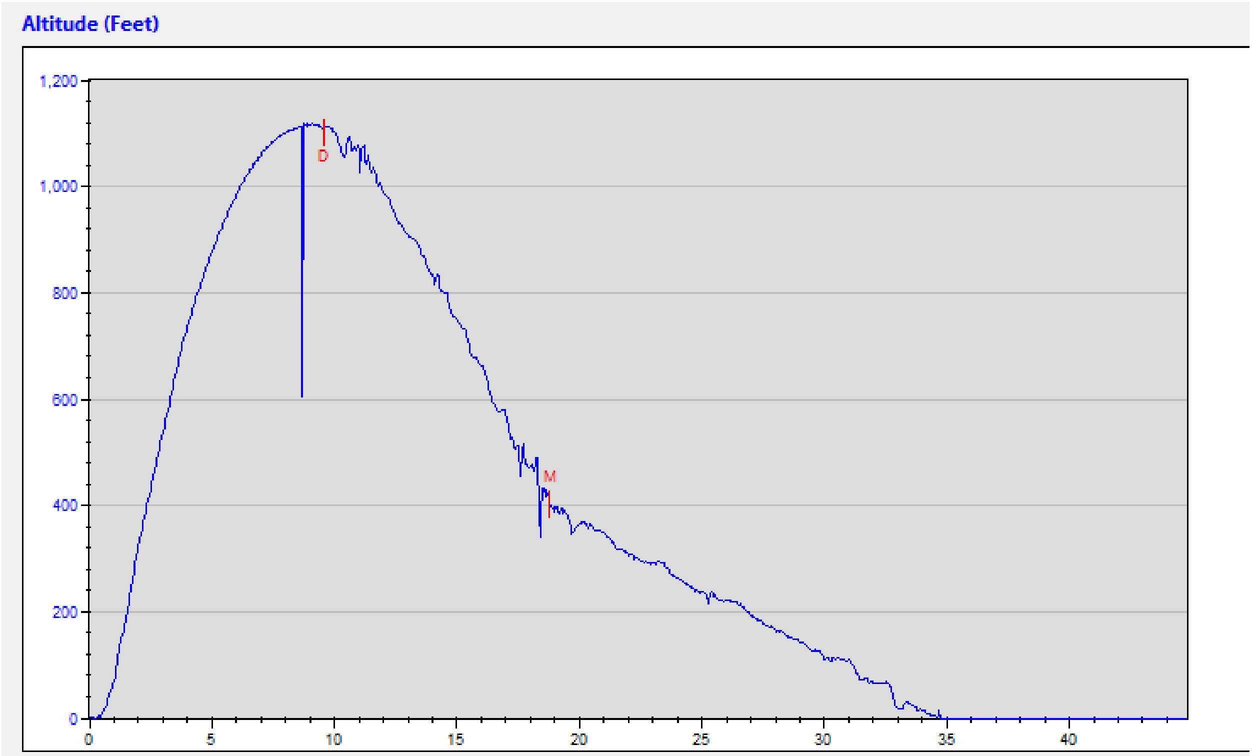


Figure 21: Scale Model Primary Backup Computer Flight 2 Profile

On this second flight, the data the flight computers gathered were much cleaner, with fewer inconsistencies. Additionally, on this second flight, the vehicle oscillated less than the first flight, likely contributing to the cleaner data.

The primary flight computer deployed our main parachute at 500 ft, and it inflated at approximately 400 ft. The vehicle impacted the ground later than in our first flight due to the successful inflation of the main chute.

Simulation Comparison

Our scale model was simulated to an apogee of 1248 ft, with a time to apogee of 9.1 s and a total flight time of 46.4 s. Comparing this to our measured scale model flight results, our flight was mostly accurate to our simulations, however it undershot our target altitude by approximately 130 ft and undershot our simulated descent time by approximately 12.4 s. This is likely due to our scale model being overweight, resulting in a lower apogee altitude and a faster descent rate.

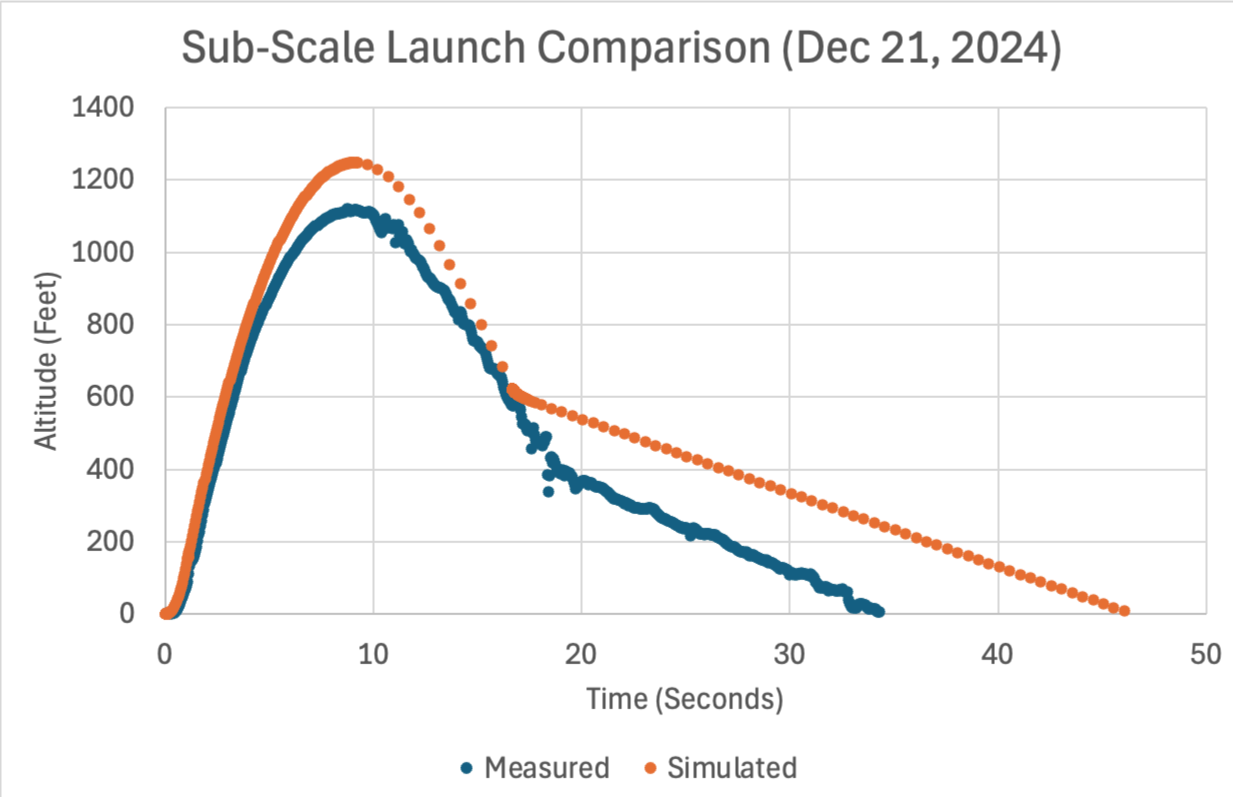


Figure 22: Scale Model Flight vs Simulation

Scale Model Landed Configuration

The following images represent the configuration in which our scale model vehicle landed.

Flight 1

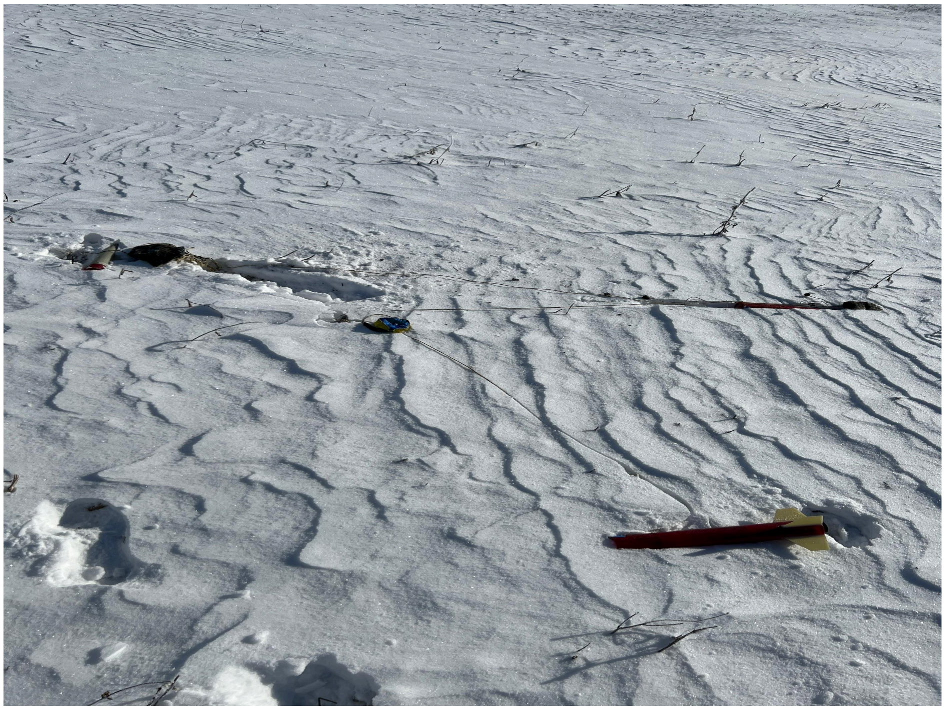
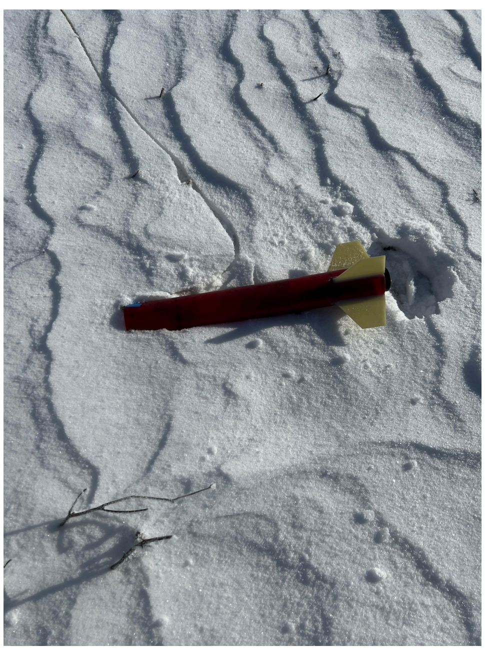


Figure 23: Full Landing Configuration (Flight 1)



Figures 24, 25, & 26 (left to right): Booster Section (Flight 1); Upper Section (Flight 1); Nose Cone Section (Flight 1)

Flight 2

Figure 27: Full Landing Configuration (Flight 2)



Figures 28, 29, & 30 (left to right): Booster Section (Flight 2); Upper Section (Flight 2); Nose Cone Section (Flight 2)

Recovery Subsystem

Concept of Operations

Our recovery system will be powered by two PerfectFlite Stratologger dual deployment altimeters, which will be powered on at the launchpad via two separate screw switches. After launch is detected, the main computer will fire a black powder charge when the vehicle reaches apogee, and one second later the backup will also fire a change. This charge will separate the booster section from the payload section, forcing the drogue chute out of the drogue bay.

This 12” drogue parachute will slow the vehicle to a speed of 114.2 ft/s. Then, at an altitude of 700 ft, the main computer will activate a second black powder charge, separating the nose cone from the payload section and deploying the 66” toroidal main parachute. This event will then be followed by the backup computer deploying the backup charge at 600 ft. The main parachute will slow the vehicle to a relatively low rate of 18.95 ft/s due to the high drag coefficient of the toroidal chute. The vehicle will impact the ground with this speed, which should not damage any part of the payload or vehicle.

Main Parachute

Our vehicle’s main parachute, with a 66” diameter, will be manufactured by the students. This parachute will be attached to the airframe by a 38’-long, ⅜” tubular Kevlar shock cord. Mentors and students will ensure our parachute meets comparable standards. Kevlar is very burn-resistant, with a continuous temperature tolerance of 900 ^{o}F, and will easily withstand the brief temperature spike of the ejection charge. A 3,600 lbs breaking strength makes the material even more reliable.

Our calculations have brought us to the conclusion that the optimal length for the nose cone-to-payload section shock cord is 38’ (456”), and the optimal length for the payload-to-booster system cord is also 38’ (456”). The shock cord itself will be connected to the nose cone with a ¼" stainless steel forged eye bolt, rated for 1,500lbs of working capacity, and to the payload section with a ¼” stainless U-bolt, rated for 1,300lbs of working capacity. This U-bolt will pass through the forward fiberglass bulkhead, which will be secured to the vehicle by two tie rods that run through most of the payload section. The main parachute will be deployed at 700 ft by the flight computer, with a black powder charge separating the nose cone from the payload section.

All of the ¼" U-bolts and the singular eye bolt within the rocket are rated for much higher loads than the anticipated strain experienced by the rocket components during flight. The Kevlar cord epoxy attachment on the booster has also been successfully tested with higher loads than those expected in our rocket.

During our first subscale flight, the main parachute failed to open. This was due to the use of an oversized Nomex protective blanket in combination with overly tight packing. On the next flight, we adjusted the Nomex size and packing to ensure successful deployment. For the full-scale flight, we will ensure the parachute is packed properly and not wedged or stuck in the parachute bay, and we will choose an appropriately sized Nomex blanket once we have manufactured our parachute.

On our second subscale flight, one of the shroud lines on the main parachute came untied. This had a small effect on descent time and speed; however, for our full-scale flight, we will double check the knots on the shroud lines and dot them in a very thin layer of epoxy to ensure they do not come undone. The descent rate after main parachute deployment was calculated as 18.95 ft/s.

Drogue Parachute

Our drogue parachute is a custom, student-manufactured 12” diameter ripstop nylon parachute, which will provide sufficient drag to slow the vehicle for the majority of its descent. The drogue can also handle the mass and possible variations in the deployment speed of the vehicle and has been tested on vehicles of similar size with positive results. It is attached to the booster section via a 1/4" stainless steel U-bolt that has a working load capacity rating of 1,300 lbs. The parachute will be packed in the booster section directly below the coupler and above the motor assembly. Deployment will be triggered by a black powder charge that separates the booster section from the payload section. The descent rate under the drogue parachute has been calculated to be 114.2 ft/s.

Parachute Placement

A total of 13' of shock cord will connect the nose cone to the main parachute, and 25' of shock cord will connect the main parachute to the forward bulkhead U-bolt. Similarly, there will be 21' of shock cord connecting the drogue parachute to the aft bulkhead U-bolt, and 11' of shock cord connecting the drogue parachute to the laminated kevlar cord attached to the motor mount in the booster section. Below is a figure showing the location and placement of each shock cord section and both parachutes.

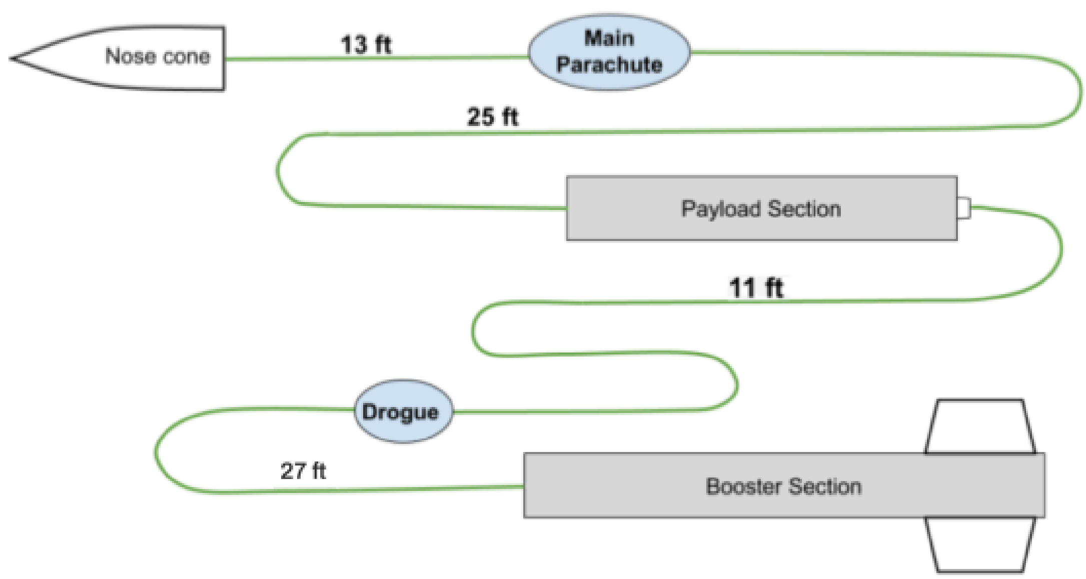


Figure 31: Parachute Placement on Shock Cords

Separation Points

Below are figures showing the vehicle's separation points during flight. Figure 32 shows the separation point of the booster and payload section, which will separate at apogee, deploying the drogue chute. Figure 31 shows the separation point of the nose cone and payload section, which will separate at an altitude of 700 feet, deploying the main chute.

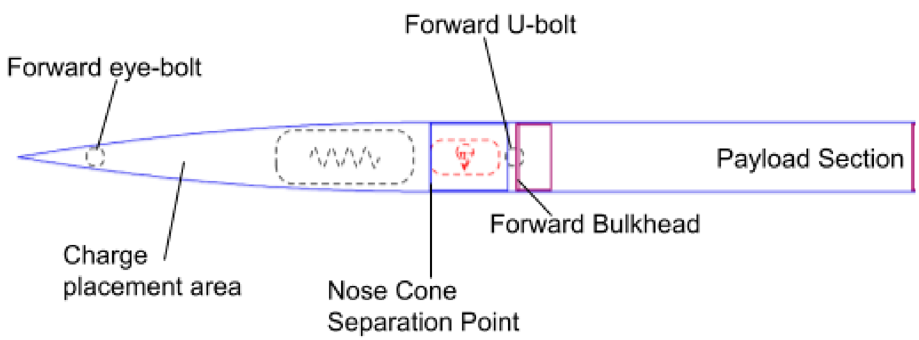


Figure 32: Forward Separation Point

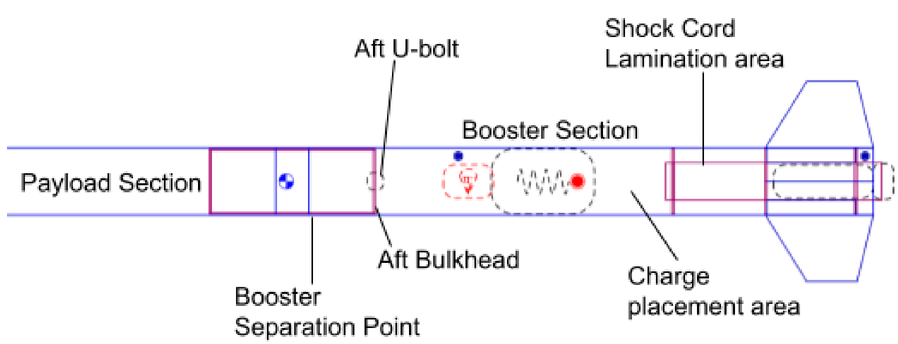


Figure 33: Aft Separation Point

Deployment Computers

The figure below illustrates our deployment computer and backup wiring configuration. Our mentors and the amateur rocketry community have used this wiring configuration on several high-power flights, and our setup has been proven reliable via these flights. Additionally, this configuration successfully activated the black powder charges on both of our scale flights. This configuration is redundant because each computer is wired to separate batteries, switches, and charges.

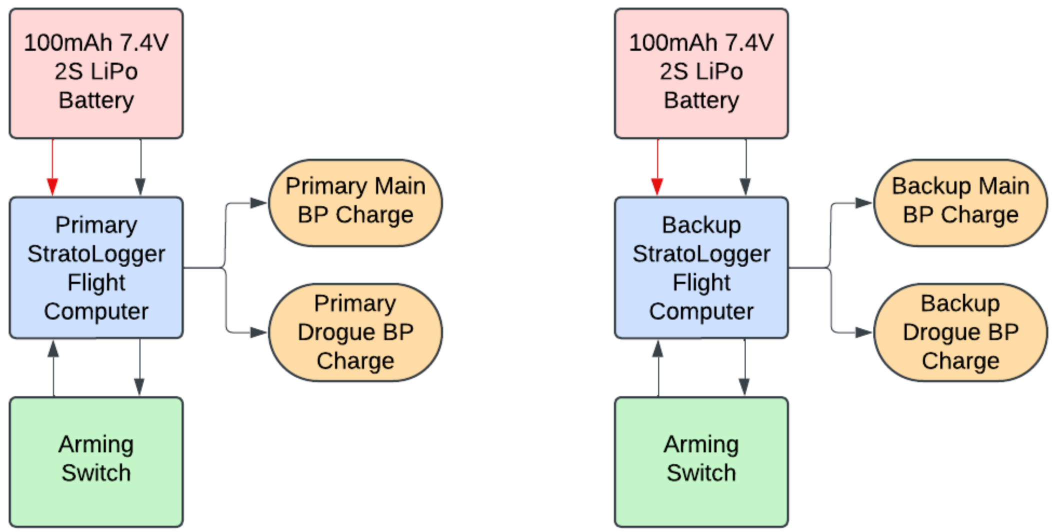


Figure 34: Flight Computer Wiring Overview

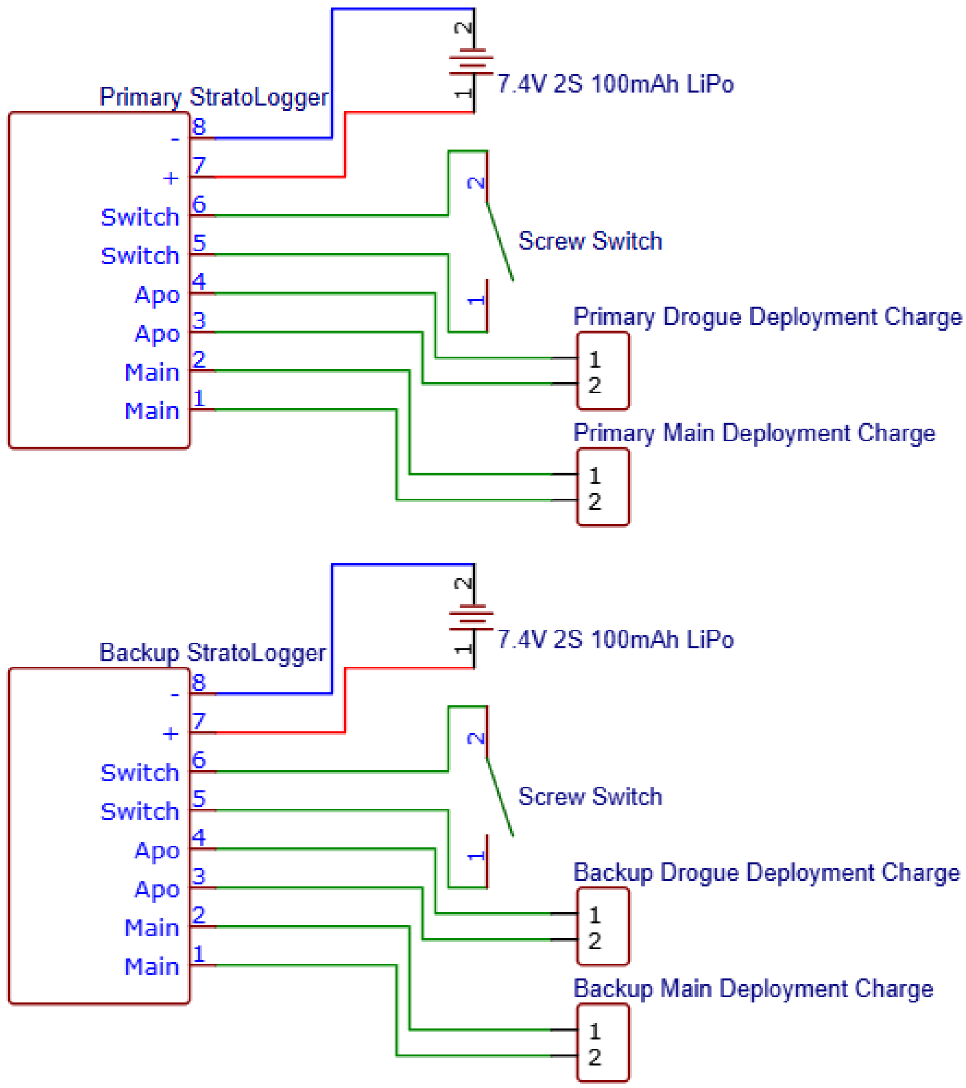


Figure 35: Flight Computer Wiring Diagram

This wiring configuration was tested on our scale model launch and performed as expected.

For our final design, we chose to use PerfectFlite StratoLoggers as both our main and backup deployment computers. We chose this configuration over our alternative–using a StratoLogger as the primary flight computer with the MissileWorks RRC3 as a backup–due to the proven reliability of the StratoLogger and the fact that many members of the team, and our mentors, are very familiar with this computer. Although our alternative design would have provided dissimilar redundancy, using two StratoLoggers greatly reduces the chance of user error in any step of the process, and the StratoLogger is considered a more reliable altimeter option. Similar redundancy is our approach to limit the chances of user error becoming prominent.

The deployment computers, along with the batteries and arming switches, will be housed in a 3D-printed sled in the electronics bay, located in the coupler section of the vehicle. On either side of the e-bay and coupler section, there will be a fiberglass bulkhead, and the aftmost will have screw terminal strips mounted to the bulkhead as a way of easily connecting black powder charges. The forwardmost bulkhead (located forward of the payload) will have an identical setup. Both bulkheads will be held in place by the tie rods that run the majority of the length of the payload section of the vehicle. Two wires from each deployment altimeter will run alongside the tie rods to the forward bulkhead to activate the main and backup parachute deployment charges.

Additionally, both altimeters will be activated by separate screw switches mounted to the electronics sled. These switches also require two additional holes to be drilled in the switch band on the coupler section.

We have selected the Palm Beach Bots 2S 100mAh LiPo battery to power both our flight computers and GPS tracker. This battery has a nominal voltage of 7.4V, which is more than sufficient to power these systems. Additionally, due to the low current draw of our tracker and flight computers, the 100 mAh capacity will be sufficient to keep the system powered both on the pad and during flight. These batteries also have more than sufficient current to activate the charge igniters. Each flight computer, as well as the GPS tracker, has its own battery.

Tracking Equipment

Overview

Our vehicle will use two radio tracking systems, an EggFinder commercial GPS Tracking System and an RDF beacon, to locate the vehicle in the air and after touchdown. These two systems operate on different frequencies and can be tuned to avoid interference with other tracking systems and communications equipment.

EggFinder GPS Tracking System

The EggFinder GPS Tracking System is a GPS tracking system sold by EggTimer Rocketry. It consists of a transmitter, placed inside the vehicle, and a handheld receiver, communicating in the license-free 33 cm band (902-928 MHz). This tracking system will provide us with GPS coordinates of our vehicle and will direct us towards the landed vehicle during recovery. The transmitter will be placed inside the electronics bay to ensure it remains protected from any impacts or deployment charges. The exact frequency of the transmitter and receiver can be tuned to prevent interference with other teams using the same tracking system. We plan on tuning the transmitter to 911.25 MHz unless otherwise required to avoid interference.

RDF Beacon Tracking System

Our vehicle will also contain a Radio Direction Finding (RDF) tracking system to ensure that we can reliably locate the vehicle in the event that the EggFinder GPS Tracking System fails. The transmitter is an open-source design and can be built and tuned to frequencies inside the 1.25 m band (220 - 225 MHz). The transmitter emits radio signals that can be received using a directional antenna. This directional antenna can then be used to point the user towards the transmitter's location and triangulate the position of the transmitter. Our transmitter will be placed inside the booster tube during flight, encased in a Nomex bag to protect it from the deployment charges, and attached to the attachment point on the aft end of the electronics bay. The transmitter will be tuned to prevent interference if needed. Several of our high-power rocketry mentors have obtained an Amateur (Ham) Radio License, allowing us to legally use these transmitters in the 1.25 m band. We plan on tuning the transmitter to 222.67 MHz unless otherwise required to avoid interference.

Vehicle Integrity

We have conducted all necessary tests to ensure vehicle integrity. Starting with the fins, we have decided upon a trapezoidal shape because that design led to the best stability in our simulations.

The trailing edge of the rocket is tapered away from the ground to limit structural damage from collisions with the ground (during landing). Additionally, we will ensure that the motor will not move during flight. The motor retention system consists of a standard 54 mm motor retainer that holds the motor in place for the duration of the flight via a lid near the top of the retainer. For all connections (such as fins and bulkheads) that require fillets, we will use ¼” fillets, which are thick enough to withstand the forces placed on each one while not being overly large. This thickness has been proven to work from other vehicles with similar sizes and masses. Additionally, we have determined each individual part in the vehicle to be able to withstand the forces of the vehicle’s flight.

Individual Section Masses

Section	**Mass** (rounded to 2 significant figures)
Entire Vehicle - Dry Mass	16.89 lbs
Entire Vehicle - Wet Mass	20.10 lbs
Entire Vehicle - Burnout and Landing Mass	18.28 lbs
Nose Cone	1.35 lbs
Upper Section (including payload and electronics bay)	9.00 lbs
Payload and Electronics Bay	4.50 lbs

Booster Section	6.47 lbs
Recovery Components (Parachutes and Shock Cords)	3.30 lbs

Table 1: Section Mass

Vehicle Redundancy

To ensure that the OpenRocket simulation we have been using is redundant, we cross-checked our design with the simulation software RasAeroII and have obtained similar results. The predicted apogee obtained in our OpenRocket simulation is 4455 ft, whereas the apogee predicted by RasAeroII is 4458 ft. Predicted flight times and drift distances were also extremely similar. Based on these comparisons, we are confident that the OpenRocket simulations that we are using as our main source of data are reliable.

Vehicle Materials and Justifications

The following table shows the materials selected for the vehicle and the justifications for each material choice.

System	Component	Material(s)	Justification
Recovery	Parachute (Drogue and Main chutes)	Ripstop Nylon	Ripstop Nylon is lightweight, easy to manufacture, and the industry standard.
Recovery	Shroud Lines	Kevlar Twine	Kevlar is extremely tough and lightweight.
Recovery	Shock Cord	⅜” Kevlar Cord	Kevlar is extremely tough and lightweight.
Recovery	Anchor Point Hardware	Stainless Steel	Steel is strong, inexpensive, and

			can be obtained in the size we need.
Vehicle	Threaded Rods	Stainless Steel	Steel is strong, inexpensive, and can be obtained in the size we need.
Vehicle	Airframe, Fins, Nose cone, Centering Rings, Couplers, Motor Mount, Bulkheads, Switch band	Fiberglass	Fiberglass is lightweight, strong, and easy to manufacture. It is also durable and temperature resistant.

Table 2: Vehicle Materials

Vehicle Dimensions

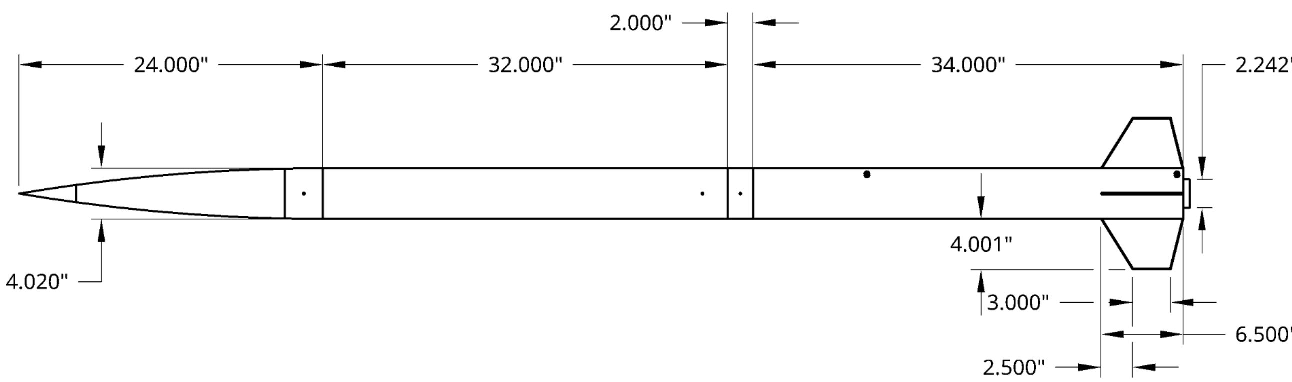


Figure 36: Vehicle Outer Dimensions

Vehicle Item	Dimension
Total length	92.5”
Nose Cone	
Length	24”

Shoulder	4.5”
Base Diameter	4”
Shoulder Diameter	3.843”
Electronics bay	
Length	10”
Diameter	4”
Switch Band Length	2”
Upper Section	
Upper Tube Length	32”
Upper Tube Diameter	4”
Booster Section	
Body Tube Length	34”
Body Tube Diameter	4”
Motor Tube Length	13”
Motor Tube Inner Diameter	2.12” (Standard 54mm Tube)
Motor Tube Outer Diameter	2.242” (Standard 54mm Tube)
Fin Count	4
Fin Cant	0°
Fin Root Chord	6.5”

Fin Tip Chord	3”
Fin Height	4”
Fin Sweep Length	2.5”
Fin Sweep Angle	32°
Fin Thickness	0.125”

Table 3: Vehicle Dimensions

Mission Performance Predictions

Flight Profile Simulations

Below are simulations of our vehicle’s profiles of different variables during the flight. We have run tests on similar vehicles and will ensure that our launch vehicle will be sufficiently robust to withstand all expected loads of the flight. Our current vehicle design experiences no loads harsh enough to cause damage to the craft in our planned construction.

Altitude Profile

We have simulated a model of our vehicle’s design using the software OpenRocket. Below is the graph of our vehicle’s predicted altitude profile, including the flight sequence versus the altitude. The vehicle will launch under the power of an AeroTech K-1103 plugged motor. Following ignition, the vehicle will accelerate until motor burnout, 1.6 s after launch. After burnout, the rocket will continue to ascend until it reaches an apogee of 4455 ft, approximately 16.3 s after launch. At apogee, the vehicle’s flight computer will deploy the drogue parachute. The vehicle will then descend at a rate of ~114 ft/s until the main parachute deploys at an altitude of 700 ft, approximately 51 s after launch. Finally, after descending at a rate of 18.95 ft/s, the vehicle will touch down 82.1 s after liftoff. The simulation used a coefficient of drag (C_d) of 1.5 for the drogue chute and 1.8 for the main chute. These values were based on parachute profiles and prior flight experience. The C_d of 1.8 for the main chute is lower than the C_d that the vehicle will likely experience, although use of this value allows for simulation under worst-case conditions. The total flight duration is expected to be 82.1 s with an approximately 1,465 ft drift under 15 mph winds.

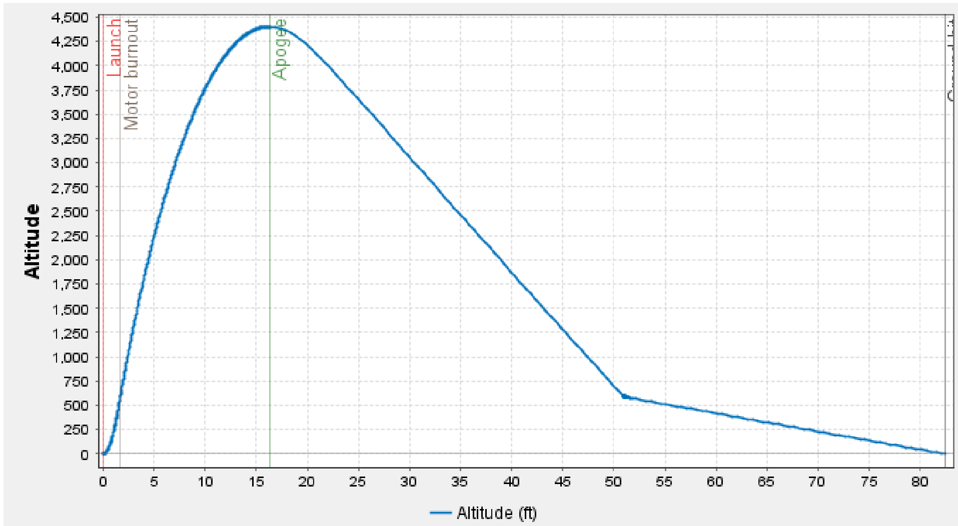


Figure 37: Altitude Profile of the Entire Flight

Our simulation under no wind reported an undershoot of our targeted altitude of 4,500 ft by 1%. This is likely due to margin of error in the simulation. This small variation in predicted apogee compared to our target is sufficiently small that we can ignore this minor undershoot in the development of our vehicle. If this undershoot becomes an issue, we can remove some of the planned additional weight in our vehicle's payload section. This weight is not a ballast, but is instead so we can simulate the payload with a higher than expected weight, allowing for the payload to be heavier than expected.

Wind Speed vs Altitude

The National Association of Rocketry's (NAR) maximum allowed wind speed for a launch is 20 mph. Our vehicle was simulated under varying wind conditions: 0 mph, 5 mph, 10 mph, 15 mph, and 20 mph. A 20 mph wind at the time of launch would result in an 89 ft (2%) reduction in the vehicle's expected maximum altitude.

Wind Speed	Apogee (ft)	∆ Apogee (ft)
0 mph	4455	0 ft (0% difference)
5 mph	4449	-6 ft (-0.1346% difference)
10 mph	4431	-24 ft (-0.54% difference)
15 mph	4403	-52 ft (-1.67% difference)
20 mph	4366	-89 ft (-2% difference)

Table 4: Wind Speed vs. Altitude

Thrust Profile

The AeroTech K-1103 motor, our primary motor selection, has a projected thrust profile shown below. The motor will reach its maximum thrust of 1,587.82 N after 0.03 s. The thrust will then decrease quickly, followed by a slower, steady decrease, until it drops rapidly just before motor burnout. The average thrust-weight ratio of our vehicle is 12.3 : 1.

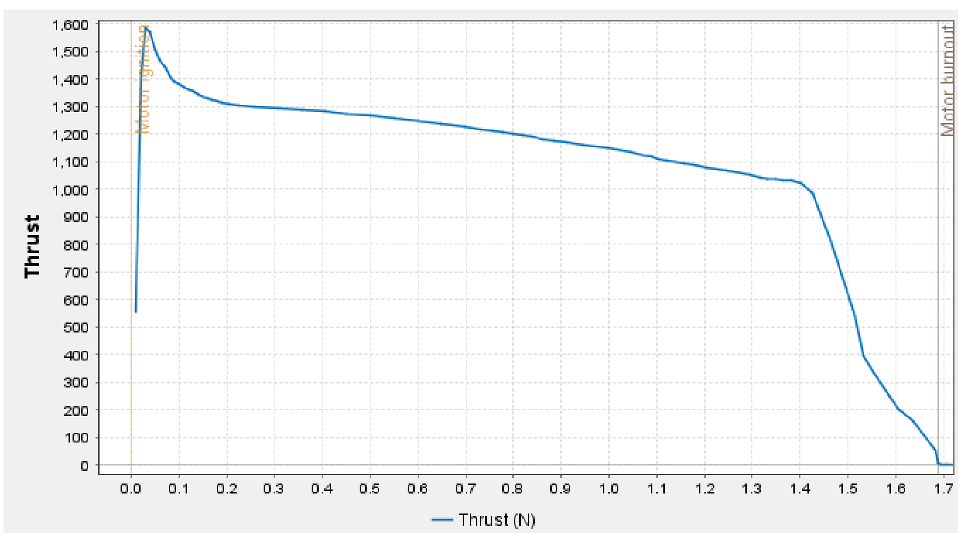


Figure 38: Thrust Profile

Velocity Profile

The graph below shows the rocket's velocity profile. The vehicle will reach its maximum velocity of 605 ft/s (412 mph) 16.3 s after launch. The vehicle will remain subsonic for the entirety of its flight, with a maximum mach value of 0.543.

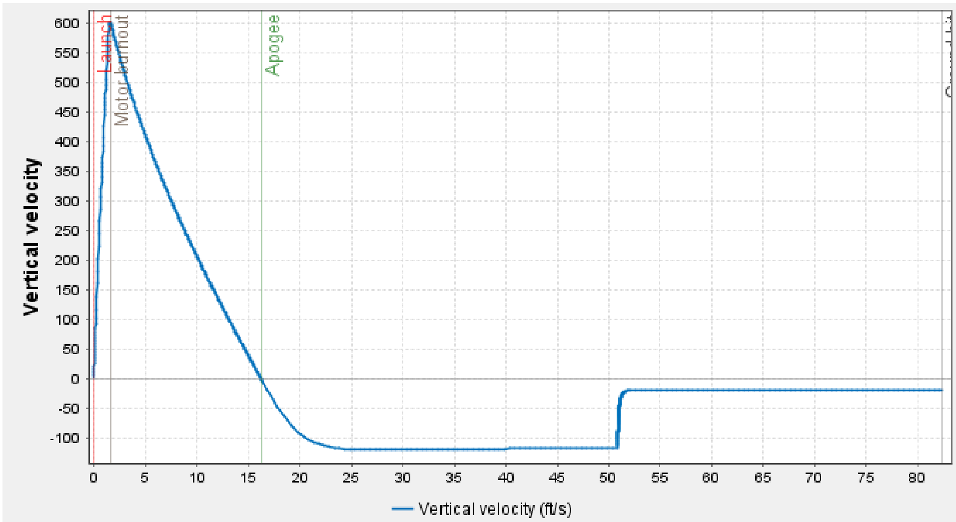


Figure 39: Velocity Profile

Acceleration Profile

The below graph (Fig. 40) shows our vehicle's acceleration during the burn period. Inaccuracies in OpenRocket's deployment force calculations resulted in an extreme overestimate of the deployment force at 36.5 g. To obtain a more accurate estimate and cross-check these values, we used two online calculators at max-q-rockets.github.io, which utilizes calculation method one from "Parachute Recovery Systems Manual" (Theo W. Knacke, 1991). This method returned a more reasonable estimate of approximately 4.8 g at main parachute opening. Once we have an accurate estimate of the acceleration force on the main parachute, the highest force the vehicle will experience is predicted to be 16.8 g (540.5 ft/s^2) during the burn phase of the flight.

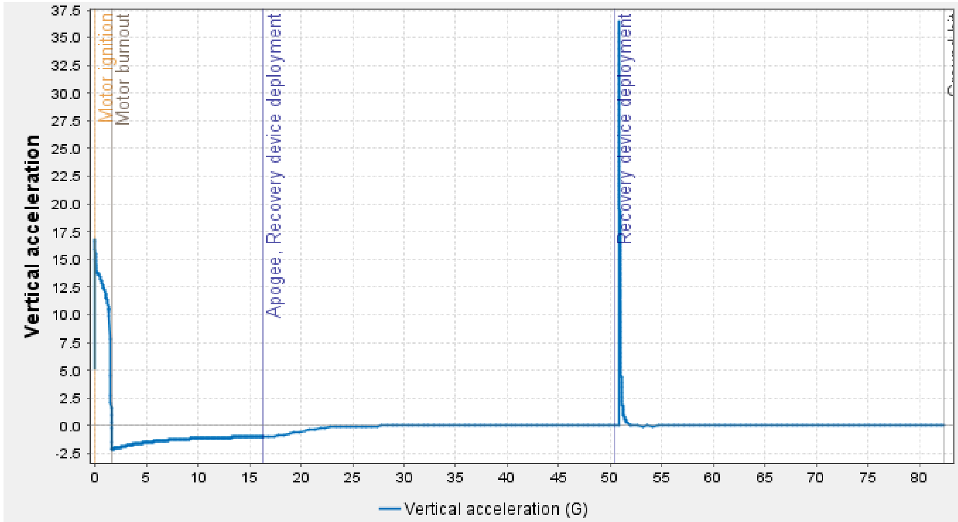


Figure 40: Vertical Acceleration During the Entire Flight

Vehicle Flight Sequence

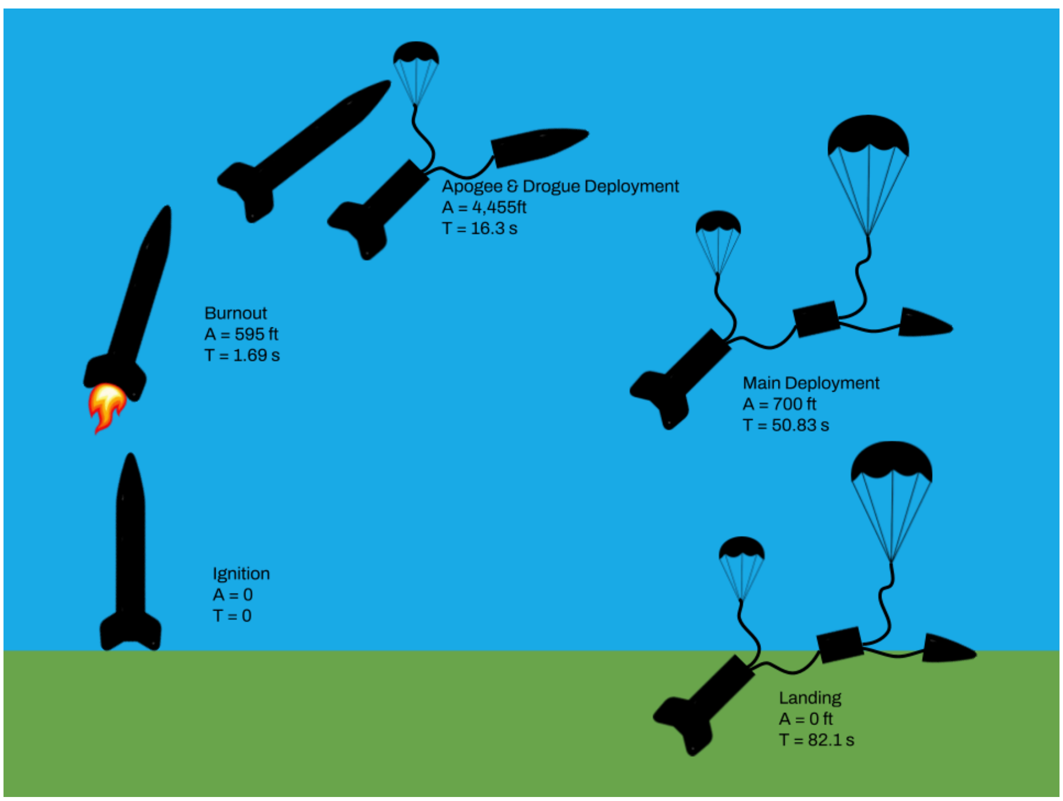


Figure 41: Chart of Vehicle Flight Sequence

The chart above shows our vehicle's flight sequence. Our vehicle will be a standard dual-deployment craft, with a primary flight computer used to deploy drogue and main parachutes. We will also have a backup computer onboard in case of failure of the main computer. The drogue parachute will be deployed at the rocket's apogee, and the main chute will be deployed at an altitude of 700 ft. At no point during the flight will the payload separate from the rocket. The vehicle will be recovered in three tethered sections.

#	Event	Time (s)	Altitude (ft)	Trigger
1	Ignition	0	0	Launch Controller
2	Burnout	1.69	595	--
3	Apogee	16.3	4,455	--
4	Drogue Deployment	16.3	4,455	Flight Computer
5	Main Deployment	50.83	700	Flight Computer
6	Landing	82.1	0	--

Table 5: Flight Sequence of Events

Simulation Redundancy

To ensure our simulations were consistent, we also simulated our vehicle using the software RasAeroII. These simulations yielded nearly identical results when we checked them side by side. All results were well within our margin of error, and we confirmed that our rocket will fly well within NASA regulations.

Stability

Figure 42: Vehicle Stability

The vehicle's center of gravity (CG) is located at 57.831 " from the top of the vehicle, and the vehicle's center of pressure (CP) is located at 74.175 " from the top of the vehicle. The static stability margin is 4.07 calibers or 17.8% of the vehicle's length, which we have deemed acceptable based on previous flights and the advice of our mentors.

Descent Time Calculation

- Descent time was obtained from our simulations in OpenRocket, where we ran the majority of our simulations. From those simulations, we determined descent time to be approximately 66.6s
- Drift was roughly calculated by multiplying the descent time by the wind speed in mph.

Wind Speed vs Drift

Assuming the drogue and main parachutes are released when expected, and that apogee is reached directly above of the launch pad, we expect the descent time to be between 65 and 67 s, leading to drift of the vehicle as follows:

Wind speed (mph)	Approximate Drift (ft)
0 mph (0 ft/s)	0ft
5 mph (7.33 ft/s)	488ft

10 mph (14.67 ft/s)	976ft
15 mph (22 ft/s)	1465ft
20 mph (29.33 ft/s)	1953ft

Table 6: Wind Speed vs Drift

Kinetic Energy at Impact

We calculated kinetic energy for each individual section of the vehicle at impact using the formula KE = 1/2mv^2. The velocity was determined to be the terminal velocity of the entire vehicle at impact, which we had calculated as 18.95 ft/s using the formula $V_t = \sqrt{(2mg/\rho A C_d)}$, where m is the mass of the vehicle, g is the acceleration due to gravity (32.1 ft/s^2), ρ is the air density (assumed to be 0.002377 slugs/ft^3), A is the area, (estimated as the area of the main parachute, or 1089 in^2), and C_d is drag coefficient (estimated as 1.8). To ensure accurate results, in addition to our hand calculations, we also determined the vehicle's terminal velocity using an online calculator. According to this calculator, the terminal velocity of the vehicle is 18.96 ft/s. The discrepancy between results is within our margin of error and is likely due to the software's use of slightly different assumptions for air density compared to our hand calculations.

Using all of these values, the values of the kinetic energy of each tethered section at impact are as follows.

Part	**Kinetic energy under main at impact (ft-lbf)** Using hand calculated descent velocity (18.95 ft/s)
Nose Cone	7.9 ft-lbf
Upper Section	41 ft-lbf
Booster Section	34.7 ft-lbf

Table 7: Kinetic Energy at Impact

Additionally, we performed kinetic energy calculations using an online calculator to verify the accuracy of our results. The values given by the online calculator were within our margin of error (0.1 ft-lbf).

In the unlikely case that the main parachute does not deploy, the nose cone section and upper section will not be separated and will hit the ground together. Similar to the expected scenario, we hand-calculated results and then compared these results to the results given by an online calculator. According to our hand calculations, the descent velocity of the vehicle under the drogue parachute is 114.21 ft/s. According to the online calculator, the descent velocity of the vehicle under the drogue parachute is also 114.27 ft/s. The discrepancy is also within our margin of error. In this scenario, the kinetic energy for each section would be given as follows:

Section	**Kinetic energy under drogue at impact (ft-lbf)** Using hand calculated descent velocity (114 ft/s)
Upper section + nose cone section	1780 ft-lbf
Booster section	1260 ft-lbf

Table 8: Kinetic Energy at Impact if Main Chute Does Not Deploy

We also calculated each kinetic energy using an online calculator and obtained results within our margin of error.

Payload Criteria

Payload Concept of Operations

Purpose	Slosh is defined “as any motion of the free liquid surface inside its container caused by disturbance to partially filled liquid containers,” according to Ibrahim (2005) in the book “Liquid Sloshing Dynamics: Theory and Applications”. Slosh is common in any liquid holding containers, such as tanker trucks or rocket fuel tanks. This can be an issue, as the movement of water can cause unevenness and change the center of gravity in trucks or rockets, causing them to veer off course. Slamming is also an issue, as water can forcefully hit the tank walls and cause damage to parts (N. Pujara, personal communication).Research indicates that baffles reduce the amount of slosh and thus minimize these issues. There are many different baffle designs for different purposes. However, there is still some uncertainty about an ideal baffle design and the slosh that will occur in real-life scenarios, especially under acceleration (Housner, 1963; Jaisawal et al., 2008).
Solutions	We propose measuring slosh in an SL rocket to determine which baffles dampen the slosh the greatest, and by how much, from launch to apogee. We are answering two questions: Can we measure slosh using a camera and/or a sensor grid system and can we rely on prior research of cylindrical container theory of slosh reduction by baffles to reduce slosh frequency in a cross sectional situation?
Scope	We will stack three tanks half-full of water vertically in the payload section of the rocket. One tank will be the control, with no baffles. The other two tanks have different baffle designs that we will compare to

	each other and the control. Each tank includes 64 water level sensors to determine the height of the water and a camera to image the movement of the water inside the tank. The data will then be analyzed to determine the reliability of our camera or grid system in detecting slosh and whether the presence of baffles leads to a reduction or damping of the motion/slosh of water inside the tank.
Stakeholders	The following students are involved in the production and operation of the payload system: Sarita Desai: Payload Design Lead Everett Gihring: Integration Lead Cameron Luedtke: Imaging Specialist Ethan Lee: Software Engineer Jeane Pan: Data Specialist Mei Dryer: Payload Technician Zijun He: Data Specialist Lead/ Hardware Engineer Ayelet Blum: Safety The following mentors assisted with payload concept and ideation: Professor Ankur Desai, Dept of Atmospheric and Oceanic Sciences, UW-Madison Madison West Rocket Club Mentor and Retired Engineer Brent Lillesand We also consulted with the following: Professor Nimish Pujara, Dept of Civil and Environmental Engineering, UW-Madison
References	Evans, D.V., and McIver, P., 1987. Resonant frequencies in a container with a vertical baffle. *J. Fluid Mechanics*, 175, 295-307, https://doi.org/10.1017/S0022112087000399

	Housner, G.W., 1963. Dynamic Analysis of Fluids in Containers Subjected to Acceleration (Appendix F), in *Nuclear Reactors and Earthquakes, TID-7024*. Washington, DC: U.S. Atomic Energy Commission. Ibrahim, R.A., 2005. *Liquid Sloshing Dynamics: Theory and Applications*. Cambridge University Press, ISBN 978-0521838856, 927 pp. Jaiswal, O.R., Kulkarni, S., and Pathak, P., 2008. A Study of Sloshing Frequencies of Fluid-Tank System. *The 14th World Conference on Earthquake Engineering (WCEE)*, Oct 12-17, 2008, Beijing, China.
Concept	In our PDR, we described 3 round tubular tanks stacked vertically: a control, a ring baffle design, and a panel baffle design. We decided that due to space and analysis concerns, a flat, rectangular tank was the best design for our payload. One side of the tank is clear, to allow the camera to see inside. We also learned from previous research papers that vertical baffles would work the best at reducing side to side slosh, so we opted to use vertical baffles in our payload, rather than horizontal. Additionally, we reduced our cameras per tank from two to one. Due to the 2D tank shape, only one camera is necessary per tank, greatly reducing the cost and points of failure. We also integrated our alternative design of using a distortion grid by projecting a grid onto the tank to counteract lens fisheye from the camera. We also selected a grid of 64 exposed contacts in a 4x16 grid in each tank for our electronic sensor system. We selected our preliminary design from the PDR for the data management system. We collect the data from the sensor system and store it on an SD card on a control board.

Operational Environment	Our workshop has four rooms: one for machinery/construction, one for electronics assembly, one for computers and meetings, and one for storage. The payload will be placed in the rocket, which will experience motor thrust, gravity, corrective forces, and aerodynamic forces.
Scenarios	The payload within the rocket is secured using the payload retention system. During the flight, the water inside of the payload will slosh around, and the slosh will be recorded using our camera and sensor system. To study the effects of baffles on the amount of slosh of water, we will collect two types of data: variable data and discrete data. The cameras will collect variable data, defined by what percent of each grid is covered by water. The sensors will collect discrete data. Depending on whether the sensor senses water or not, the result will be either wet or dry. The sensor will be in the center of each grid. In this context, the result will be wet if the sensor is covered by water. After the launch, we will remove the payload and upload the data from launch to apogee to analyze it. This entire payload procedure is detailed further in the launch procedure section.
Impacts	This design is beneficial to the payload design team because the design ensures all other teams can continue their operations and easily integrate multiple system designs into the payload itself. In addition, the payload design allows for efficient reproduction and easy modification to the overall design. This design is safe based on our analysis of the risks and concerns regarding the payload and in light of our designated mitigation plans. Potential damage to the payload systems, such as the camera system overheating, will be prevented by thoughtful and thorough investigation and prevention of risks within the payload systems.

	This design is beneficial to the data analysis team because the discrete data from the sensors and variable data from the cameras both offer opportunities to confirm our results and ensure our preliminary findings are not errors derived from the systems themselves. In addition, the simplified two-dimensional tank shape ensures a consistent definition of the “Left” and “Right” side of the tank and prevents overcomplicated calculations that would occur in a three-dimensional tank system. This design is beneficial to the imaging team because the shift from a three-dimensional tank to a two-dimensional tank adds additional space that the camera can occupy. In addition, the increased separation between the camera and the tanks gives the camera a larger field of view, allowing it to view a larger section of the tank and, by extension, the experiment.

Table 9: Payload CONOPS

Tank System Design

The tank system was designed to replicate a cross section of an oval shaped tank, as it is the most space efficient and is stacked vertically. There is not ample open area inside the payload section, so we decided that a flatter tank would more accurately represent slosh while still fitting inside the rocket body tube. The flat tank also simplifies our data analysis. The 2D tank allows us to analyze slosh in two dimensions to easily identify the wave pattern. A 3D tank may have been too complicated to fit to a curve and would require much more advanced data collection and analysis systems. The data collection system also benefits from the flatter tank. A 2D sensor grid is much easier to assemble and use. Additionally, we do not require the camera to see multiple sides of the tank. The tank is watertight to ensure correct data and to protect the other electronic components from receiving damage. One side of the tank will be transparent, to allow the camera system to view the motion inside, while the other side will be the electronic sensor system, to capture data from the water. The three tanks are stacked on top of each other and held in place with the payload retention system.

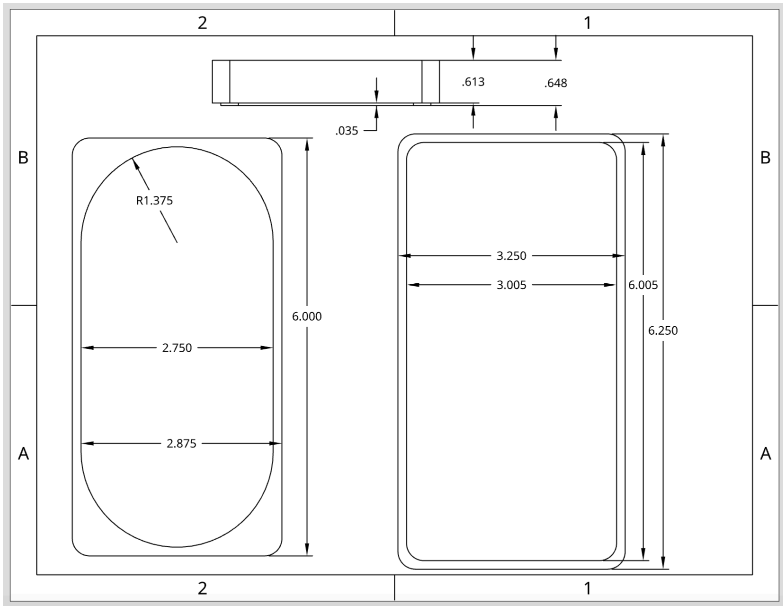


Figure 43: Dimensioned Drawing of the Tank

Tank Thickness Test

While designing the tanks, the concern arose that a tank that is too thin could affect the motion of the water due to friction from the walls, described in fluid mechanics as the “no slip condition.” To determine whether this was a significant issue, we devised a test. This test consisted of pouring water through multiple prototype tanks with different thicknesses—¼, ½, and ¾ "—and timing how fast the same amount of water flowed through the tank. We started timing at the beginning of the pour and stopped when no more water remained in the tank. We repeated this process several times for redundancy and to account for human error.

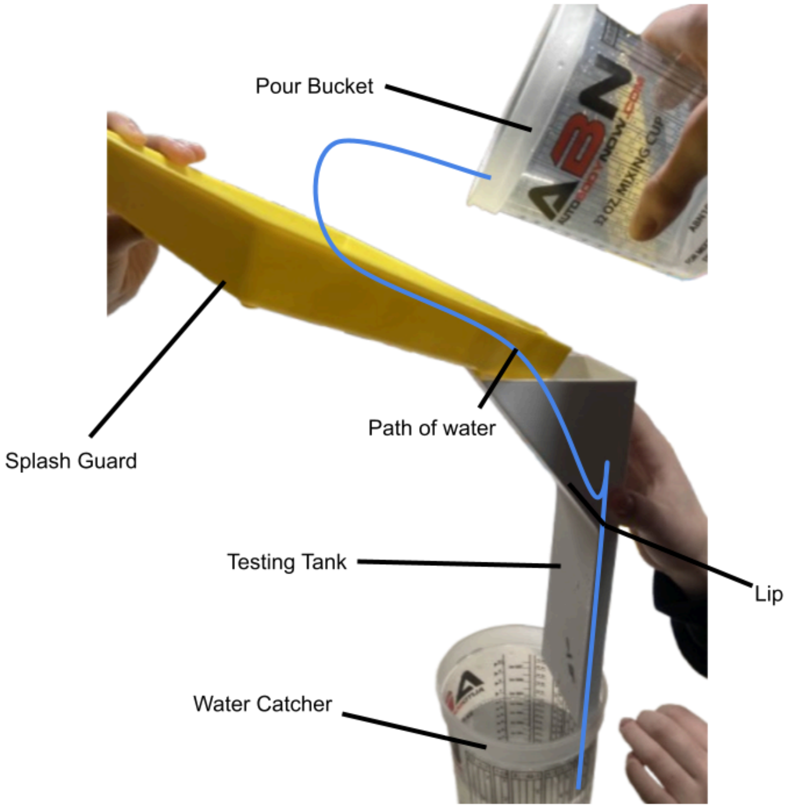
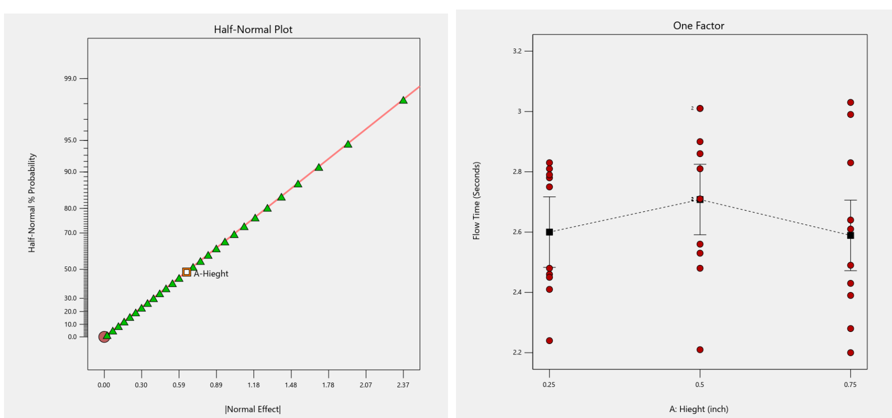


Figure 44: Tank Thickness Test Setup



Figures 45 & 46 (left to right): Tank Thickness Test Results

These plots indicate that tank thickness had no significant effect on water flow. However, although water flow through the tank was the same, due to the no slip effect, the water was still affected by a thin ¼ " tank in a sloshing test, as it dampened much faster compared to a thicker ¾ " tank. This led us to choose a ½ " thick tank for our final design because it allows room for the sensors and camera in the rocket while also not changing the behavior of the water.

Tank Shape Test

We also tested multiple tank shapes to determine the most accurate cross section of a 3D tank. Our preliminary tank design was a 3D pill shaped design, and we deliberated whether having right angle rectangular corners over rounded corners would affect the water's movement such that the rocket's movement was not the sole factor in the slosh of the water. To assess these potential effects, we 3D printed two tank prototypes, pictured below, and filled each half full with water. The tanks had a 4x16 black grid printed onto them for video analysis. We then recorded videos using an iPhone camera, at a frame rate of 60 FPS, of each tank lying horizontally, then being turned upright to simulate a side to side sloshing motion.

Figure 47: Different Tank Shape Designs

Analysis of this test provided us with very informative results. To analyze the data, frames from each video were plotted with time in seconds on the x-axis and the amplitude of each column on the y-axis. The y-axis is average water height in the column with grid lines as units. A damped sine curve was fitted to all four columns individually.

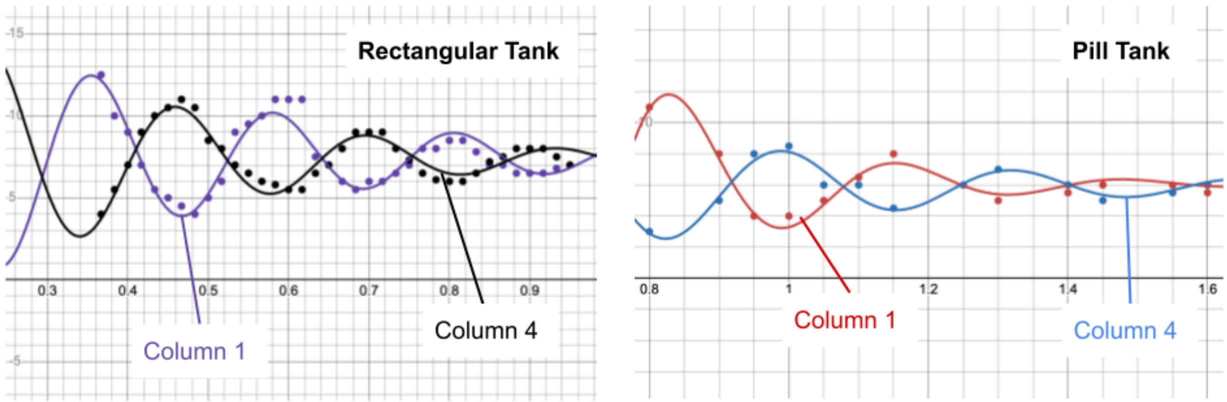


Figure 48: Tank Shape Test Results Graphs

The frequency of these graphs matches the expected frequency, using the equation in the frequency test section at approximately 20 Hz. As seen in the graphs, the tanks damped at around the same speed, demonstrating that tank shape does not significantly affect the slosh inside. However, due to the fact that much of our referenced research is based on pill shaped tanks, we selected a round-cornered tank for our final design to be the most accurate cross section.

We also noticed that a wave in the second and third column was present but undetectable with the resolution of the sensor grid and was very small.

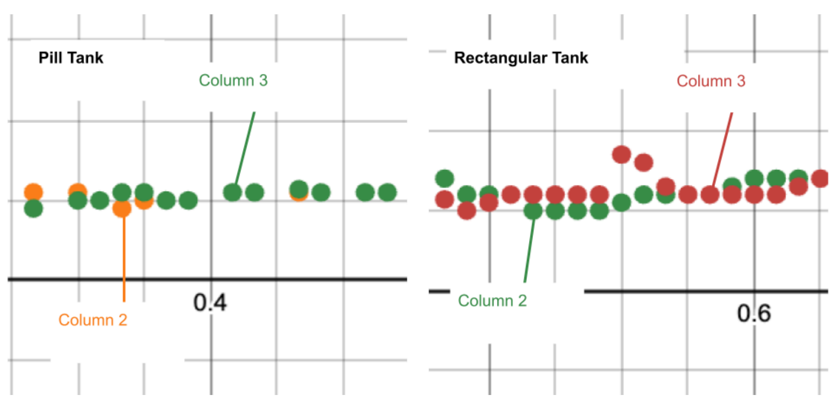


Figure 49: Inner Column Motion

The large waves on the ends were results of these inner waves being amplified and limited on the tank walls. This gives us valuable insight on our potential results in the rocket, as well as baffle placement and design.

Baffle System Design

With respect to the baffle system decision, we learned from Ibrahim (2005) that "the baffles should be placed in regions that exhibit high velocities. For example [...] the highest horizontal velocities occur at the center of the tank. Baffles should be most effective in these locations." We used this to determine where to place the baffles. However, we do not have enough information yet to determine where the highest velocity is located in our tank. According to Ibrahim(2005), "the effect of different types of baffles is usually determined experimentally, except for a very few special cases where semi-empirical formulas have been obtained." This supports the idea that we cannot create an ideal baffle design before testing. However, in order to mitigate horizontal slosh, vertical baffles are most successful, according to this source. We chose two vertical baffle designs that can change width, amount, distance apart, and length, based on the additional data we obtain. To determine length, "It is found that a surface-piercing barrier can change the resonant frequencies significantly while the effect of a bottom-mounted barrier is usually negligible." (Evans and McIver, 1987). We therefore have baffles only in the top section of the tank and will adjust the length based on the height of the water.

The Evans and McIver book lists six parameters that influence baffle design:

(1) The vehicle's mission profile and trajectory.

(2) The damping requirements for a given container, or liquid-slosh-motion amplitudes at various liquid levels.

(3) The physical characteristics of the tank, such as its geometry, elastic deformation, and insulation.

(4) The liquid filling and draining requirements.

(5) The physical properties of the liquid.

(6) The handling, slosh, and impact loads that must be sustained by the devices.

Once we identify more of these parameters in our ongoing bench tests, we will be able to create a more successful baffle design.

The overall payload design, integration, retention, and data analysis are insensitive to the choice of baffle design, as these merely incorporate 3D-printed barriers within the tank system. Thus, we have chosen to defer this design component until we have completed the payload bench test. Using additional literature review, we will determine two optimal vertical baffle configurations (length, width, spacing) and test those in the workshop with a simulated impulse. An example design of the unimodal baffle configuration is shown below:

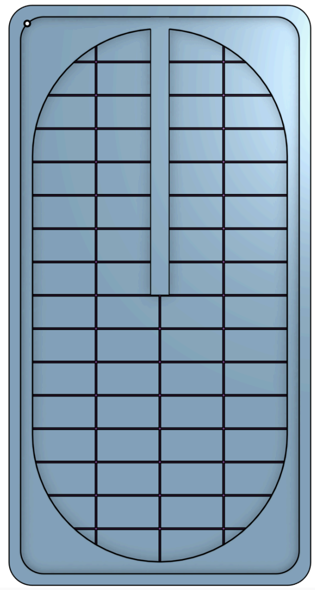


Figure 50: Example Baffle Design

Camera System Design

Our camera system contains a set of RunCam Hybrid 2 split-style cameras aimed at the tank system. Each tank in the tank system has a dedicated camera and lighting bar to provide illumination inside the vehicle during flight. Each camera records at 1080p 120 fps and saves footage to a dedicated SD card built into the camera's driver board.

Due to the split style of the cameras, they are separated into a driver board and the camera module. The camera module is carefully aligned to be aimed at the center of the tank, while the driver board is mounted below the tank.

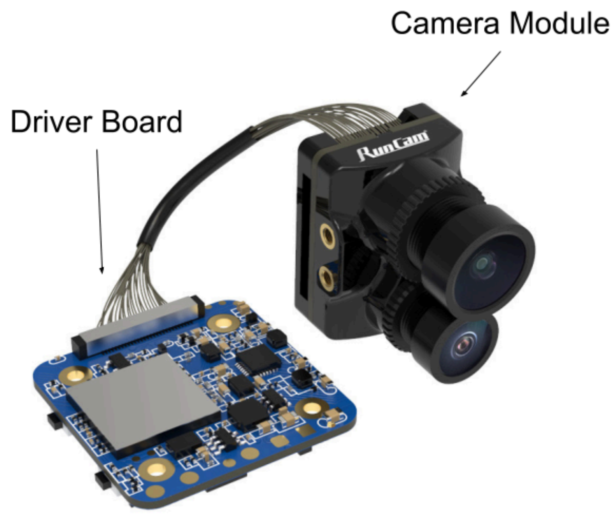


Figure 51: RunCam Hybrid 2 Diagram

This split style allows the camera to fit into the tight dimensions of the payload. The driver board is connected to the camera module via a ribbon cable. The driver board contains an SD card slot, indicator LEDs, terminals for power, and 2 buttons for controlling the camera.

The cameras will all be powered by one 11.1 V 3S 2000 mAh 18650 battery. The cameras accept 5-20 V as an input, and the battery has been sized to fit our necessary runtime needs. This battery is not switched with the rest of the payload, and the cameras will instead be powered on during assembly of the payload. The lighting bars are also powered via this battery.

Figure 52: Lighting Bar

Each camera is contained with a 3D-printed mount and is bolted in using 4 M2 screws. This configuration helps reduce vibration and ensures neither camera will separate from the mount during flight. Each camera's driver board is mounted below the camera module using 4 M2 screws and built-in standoffs. The driver board is mounted such that the buttons and SD card slot are accessible to allow for easy arming of the camera system and easy retrieval of data after flight.

As shown below, each camera is mounted perpendicular to the vehicle's long axis, with the high definition lens aligned with the center of its respective tank. This horizontal mounting allows us to use more of each camera's field of view to record the tanks, as the cameras record in landscape mode.

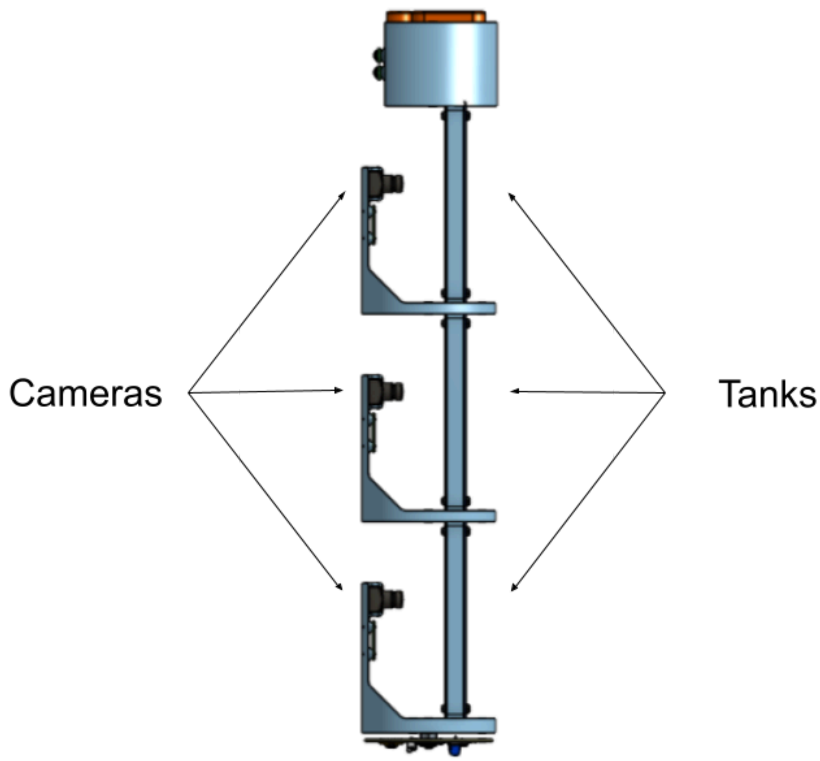


Figure 53: Camera System Mounting Side View

The camera system to monitor the movement of fluid in the payload has been developed in order to give us the best data possible while still being easy to manufacture, install, and maintain. Through demonstration and analysis of the design we created, we determined that this is the best design to use for the camera system.

Electronic Sensor System Design

In order to obtain alternative data from our tanks, as well as a backup, in case our cameras fail, we have implemented an electronic sensor system into our payload design. This system integrates directly with the tanks system, with a printed circuit board (PCB) as the back wall of each tank. This PCB contains several chips and sensors to record the water movement inside the tank during flight. One side of each PCB will face the inside of its respective tank and will have exposed copper pads to act as water detection sensors. Each sensor is connected to a 74HC165 shift register, and once a sensor is bridged, it will send a signal to its respective shift register. The sensors serialize the parallel data from the sensors and condense the data into a single stream. Serializing the data allows the three sensor boards to daisy-chain into each other with only 7 wires needed between each board: VIN, GND, CLK, LOAD, DIN, DOUT, LD. The VIN and GND pins are used to power each board; the CLK and LOAD pins are used to control the shift register; the DIN and DOUT pins are used to stream data from one board to the next; and the LD pin is used to allow the control board (which has an IMU) to illuminate an LED inside the tank to alert the camera system to launch. Finally, each sensor board contains an array of pulldown resistors to ensure noise is not detected by the shift registers. The PCB sensor boards are colored white to ensure the water can be differentiated from the board.

Below is a schematic of the sensor boards and the PCB layout.

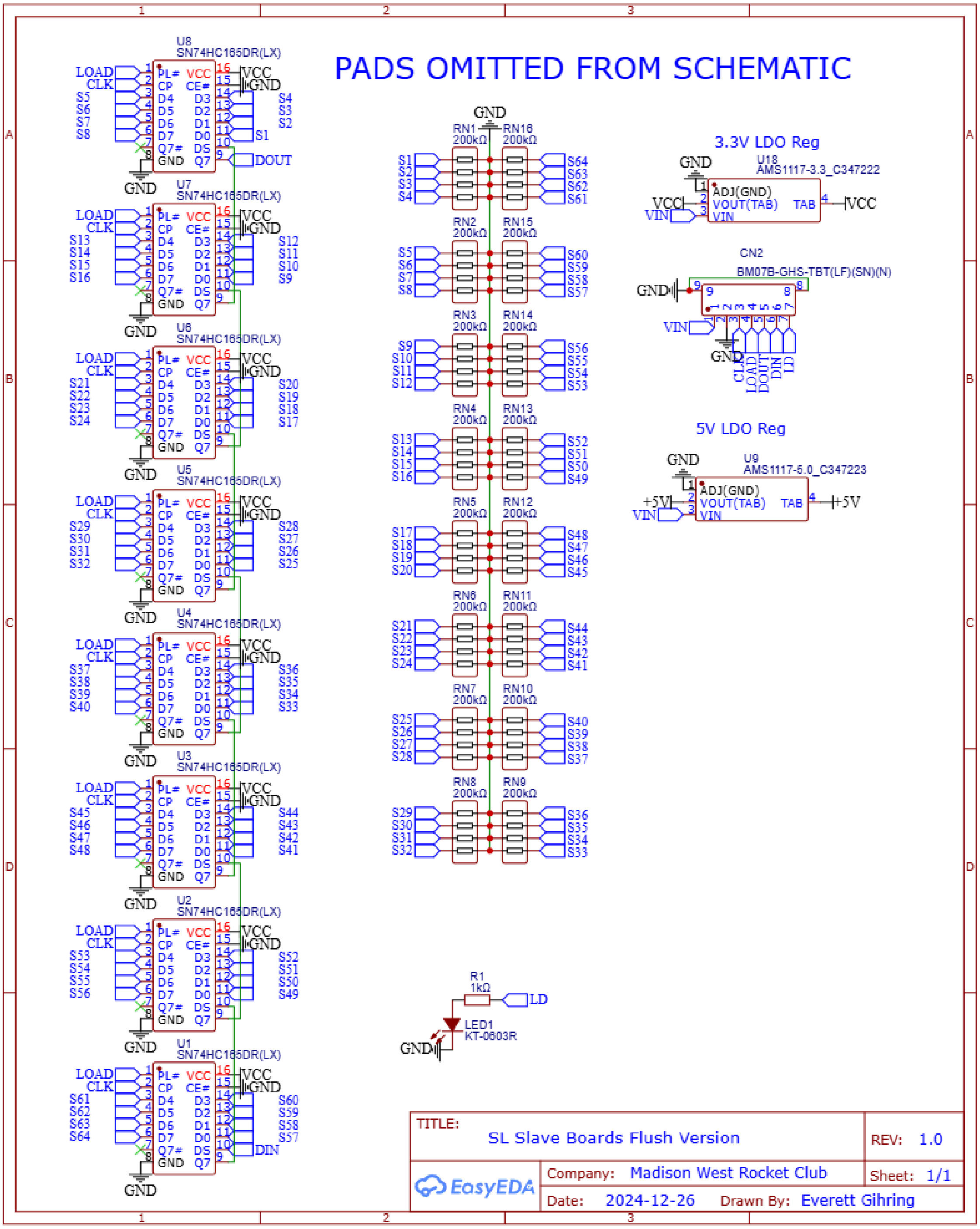


Figure 54: Electronic Sensor System PCB Schematic

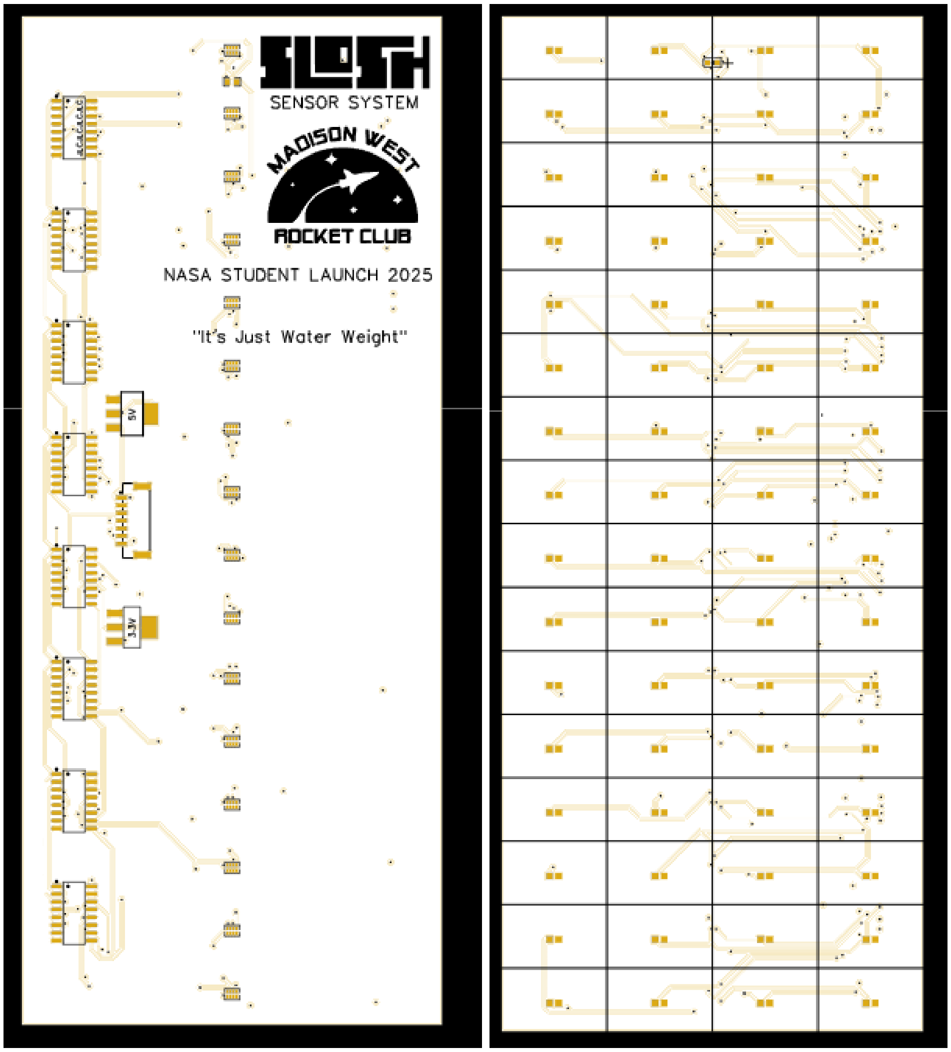


Figure 55: Electronic Sensor System PCB Layout

Data Management System Design

To collect and package the data outputted by the electronic sensor system, we must implement a control system. Our data management system is integrated with our electronic sensor system and acts as an end point of the daisy chain, down to which our data flows. The main components of the data management system are the Teensy 4.1 microcontroller with the PSRAM addon, the Adafruit BNO085 IMU breakout, along with a 1x7 JST connector to interact with the sensor boards. Additionally, a buzzer module is included in the system that will beep three times on a successful system initialization, which can be ensured at the pad.

To store data, we use two redundant methods to ensure the safety of our payload data. First is the Teeensy 4.1's onboard MicroSD card slot, which will be fitted with a card large enough to store multiple magnitudes more than the projected flight information's size. However, forces within the rocket may cause the MicroSD card to become ejected or unwritable. This cannot be mitigated by intermittently writing to the MicroSD card during flight, as latency may be too high to process at 120 Hz or above.

By using a secondary non-volatile data logging system, we can circumvent the risk of a loose or non-writable MicroSD card. We will be using a non-volatile PSRAM module supported by the Teensy 4.1 platform to save data secondarily to the MicroSD. This module is soldered onto the microcontroller, and cannot come loose during flight.

Both redundant storage systems will have more than enough capacity to store payload data. Using an overestimate of ((8*3)+(4*4))*120*20, We can calculate that approximately 96,000 bytes are needed to store data. This is because each update of the sensor system will have 3 64-bit blocks for each sensor grid, and 4 floating point (32 bit precision) numbers. This will be recorded at 120 Hz (our camera's frame rate) and for 20s, an overestimate of our time to apogee of 16.3s. This totals to an estimated 96 KB for 20s of flight data. Our PSRAM module has 8 MB of storage, while our SD card will have upwards of 64 MB, both of which are more than sufficient.

The data management system will be mounted at the end of the payload system, opposite the batteries. Tie rods will go through the board to integrate it with the larger payload system. Holes for wiring are provided within the payload design as well.

Below is a schematic of the data management system, and a PCB layout with holes for wiring and integration.

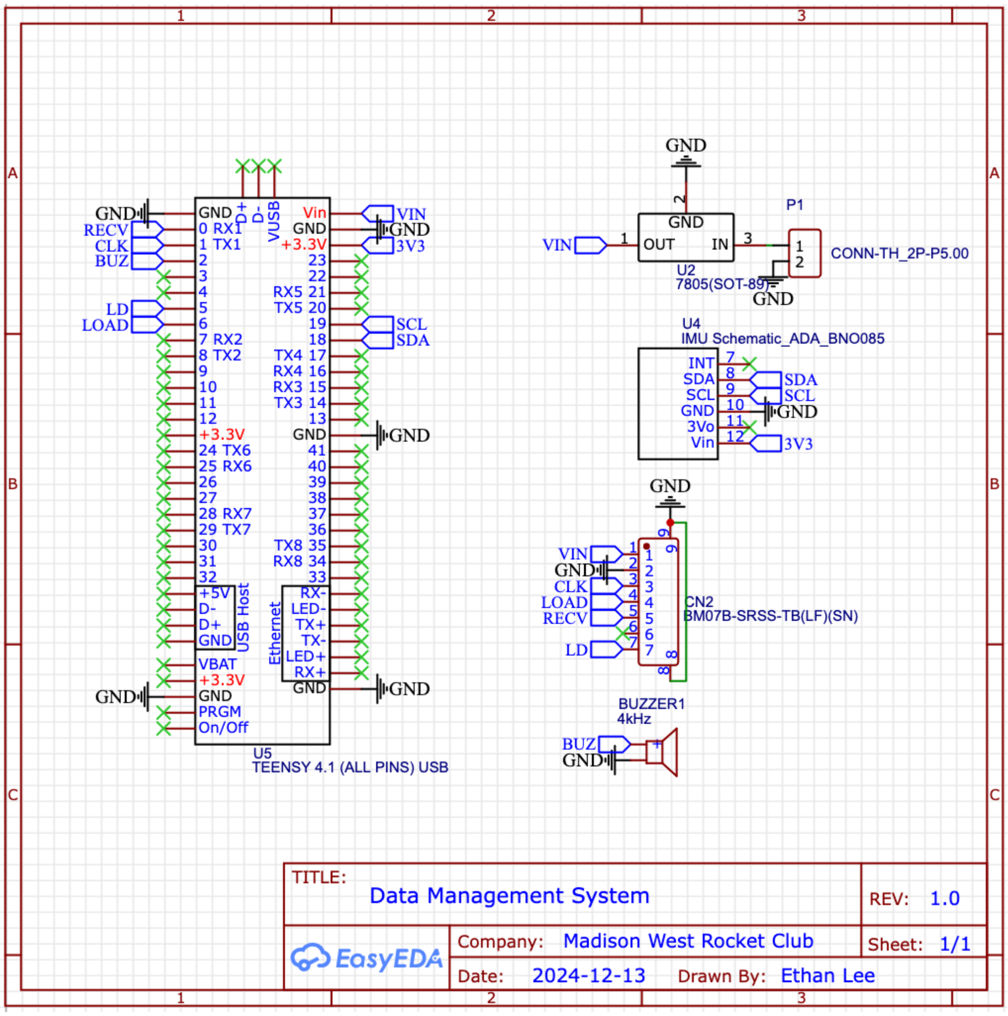
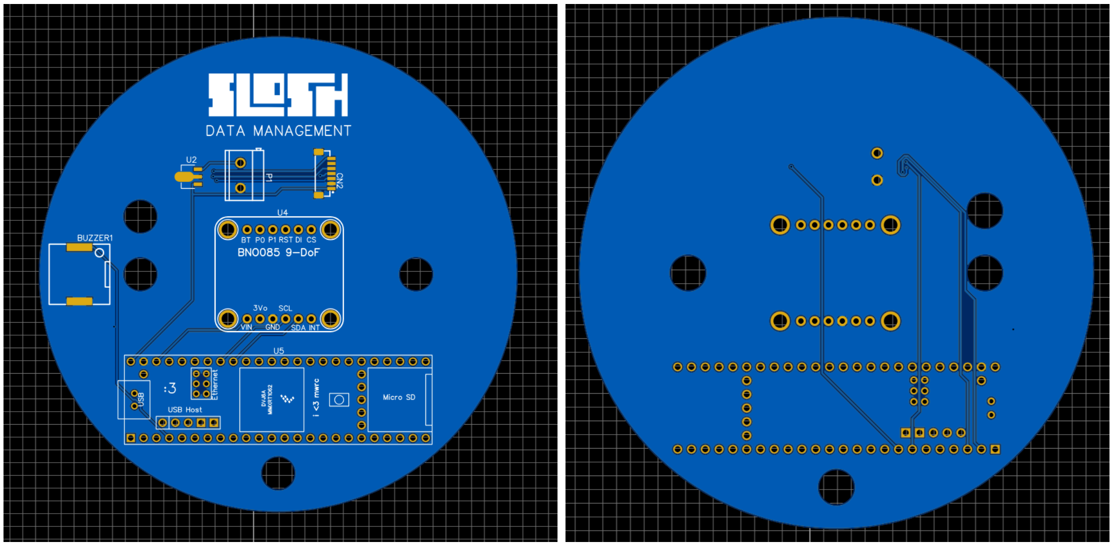


Figure 56: Data Management System PCB Schematic



Figures 57 & 58: Data Management System PCB Layout

Data Analysis Procedure

To study the effects of baffles on reducing the slosh, we will be collecting two types of data: variable data and discrete data. The variable data will be collected by the camera system and is defined as what percent of each grid is covered by water. The discrete data will be collected by the sensor system. Both data types will undergo the same data analysis process. However, the two different types of data will undergo individualized data cleaning, due to the differing data types.

Data Collection Procedure for Discrete data:

Depending on whether each individual sensor in the system senses water or not, the result will be either wet or dry and will return a “1” and a “0” respectively. Therefore, the data extracted will be a two-dimensional array of “0”s and “1”s. After the data are collected, we will calculate the average of each column and row in order to diminish the degree of possible error due to a sensor malfunction. Currently, we will be analyzing the column data. However, in the event we would like to obtain additional information about the horizontal movement, we can also perform a data analysis using row data at a later date.

Data Collection Procedure for Variable Data:

The data from the Variable Data have a higher data resolution than the discrete data. However, the collection of the Variable Data (Camera System) is more difficult due to the variation that occurs within each grid square. In addition, the camera we are using, the Runcam Hybrid 2, uses a fisheye lens, which will lead to a phenomenon fittingly called "fish eyeing." To correct for this distortion, we have two approaches, one primary and one secondary method. For the primary method, we will employ a transform function to correct for the fisheye effect. In the event this method is ineffective, we will use an online fisheye correction website to correct for the effect. Then, for each grid, we will check the illumination values to determine if the grid is wet or dry. Then, we will assign a value of "0" and "1" respectively. Creating a grid similar to the one derived from the discrete data.

Data Analysis Procedure for Both Data Types

To study the wave height, we will calculate the average values of each row and column of each tank over the same time interval. To study the degree of turbulence introduced to the system, we will calculate the standard deviation of the averaged values. We decided upon this metric because if the average value of each column is similar or the exact same, the standard deviation is near-zero, the height of water is most likely the same, and there is most likely no slosh. Conversely, if the standard deviation is non-zero, this most likely indicates slosh. We will also use our grid system to measure wave height using the camera. By comparing the data among different tanks over the same time interval, we are able to study the effect of baffles on reducing the amount of slosh. Finally, we will plot the standard deviation at each point in time for each baffle on a graph and perform an analysis of the results. Slosh data will be observed overall and in each specific stage of the vehicle's ascent: pre-launch, boost, and coast.

Data Analysis Criteria:

Through the data collection and analysis, we derive a Standard Deviation versus Time graph. In order to properly analyze the data and ensure both have a fair evaluation, they will be assessed using the same two parameters: The maximum height of the graph (to determine the maximum height of the sloshing fluid) and the decay of the graph (to determine the damping coefficient). Therefore, the lower the standard deviation, the more effective the baffle is at mitigating large fluid movement, and the quicker the graph equilibrates, the faster it is at stabilizing the fluid.

Data Agreement and Selection:

Due to the two different types of data obtained from the data collection, there are two scenarios that can occur. The first scenario is that the graphs of Standard Deviation versus Time for both data types are in clear agreement. In this case, there is nothing we need to do and the data analysis and collection went smoothly. However, in the event the two data types offer conflicting results, there is a need to determine which one is giving more accurate results. First, we will inspect the entire analysis process to ensure no mistakes were made. After passing this inspection, we will first determine if any of the sensors obtaining discrete data were faulty. Next, we will check if the camera system obtained reasonable data and had a clear threshold to determine the difference between wet and dry conditions within the payload. In the event the sensors with discrete data were broken, we will primarily use the variable data. If the opposite is true, we will then mainly use the discrete data. On the other hand, if both are found to be faulty, this experiment is determined to be a failure and additional analysis will have to be conducted to analyze if any clear results can be obtained. Conversely, if both are found to be in proper working order, we will mainly use the variable data, as it has a higher data resolution and can give us a clear picture of what exactly is occurring within the payload at all stages of the rocket launch.

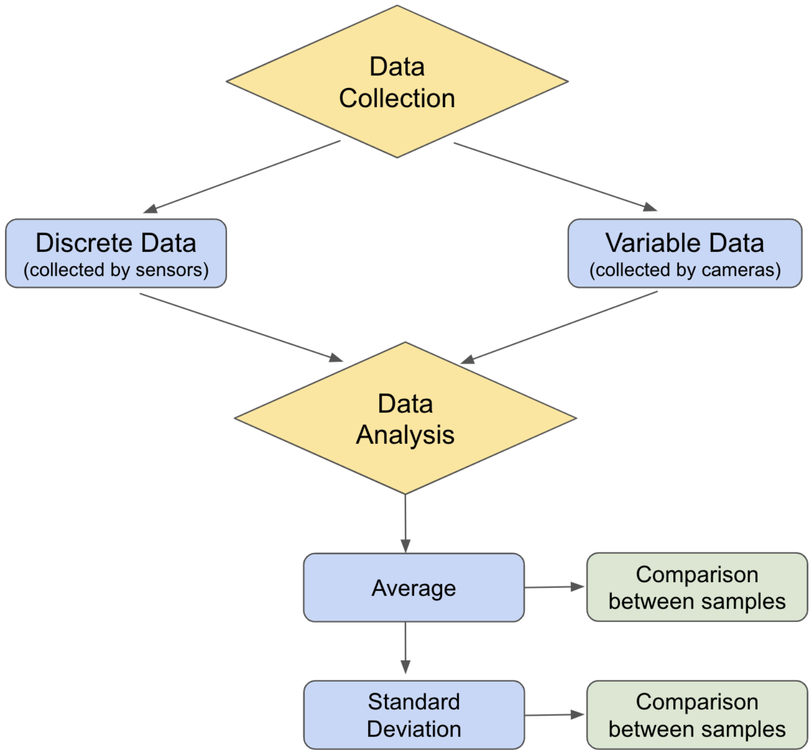


Figure 59: Data Analysis Procedure

Payload Materials

The following table shows the materials used in our payload, as well as justifications for our material choices.

System	Component	Material(s)	Justification
Tank System	Baffles	3D-Printed PLA plastic	PLA allows us to create the intricate and highly customized shapes and designs required by the baffle component of the tank system.
Tank System	Tank cover	Clear Plastic	Clear plastic allows us to more

			easily capture images that are clear
Tank System	Tank cover mounting adhesive	Epoxy	Epoxy is strong and will seal the tanks well.
Tank System	Internal fluid	Water	Water is easily available and easy to work with, allowing us to replace the fluid easily, if necessary.
Camera System	RunCam Hybrid 2 Cameras	Various materials, including fiberglass circuit boards, a plastic camera cover, and glass lenses	These materials are the default materials that are provided with the camera, and they will not interfere with any other component of our payload.
Camera System	Lighting bars	Various materials, including LEDs, a plastic diffusing layer, metal contacts, and external ceramic resistors.	These materials are the default materials that are provided with the lighting bar, and they will not interfere with any other component of our payload.
Camera System	Battery	11.1V 2600mAh LiPo Battery	This battery meets our capacity requirements, and the 11.1V voltage allows us to run the cameras at a lower power consumption, as opposed to a 7.4V battery.

Camera System	Power delivery wires	22 AWG solid-core insulated wire	This wire is easily available to us, being present in our workshop, and it is rated to withstand a current load greater than the Camera System's current draw by an acceptable safety factor.
Electronic Sensor System	Sensor Boards	Custom fiberglass circuit board, including copper trace lines, integrated circuits, and plastic screw terminals	This circuit board and added components allows us to compactly record data and daisy-chain the collected data via screw terminals.
Electronic Sensor System	Connecting wire	22 awg solid-core insulated wire	This wire is easily available to us, being present in our workshop, and it is rated to withstand a current load greater than the Electronic Sensor System's current draw by an acceptable safety factor.
Data Management System	Control Board	Custom fiberglass circuit board, including copper trace lines, integrated circuits, header pins, and plastic	This circuit board allows us to integrate all of the circuits and chips required by the Data Management System, and the plastic screw terminals allow the board to deliver power to the Electronic Sensor System and

		screw terminals	receive signals from the Electronic Sensor System.
Data Management System	Connecting Wire	22 awg solid-core insulated wire	This wire is easily available to us, being present in our workshop, and it is rated to withstand a current load greater than the Data Management System's current draw by an acceptable safety factor.
Data Management System	Battery	11.V 2600mAh 18650 battery	The Data Management System, using a Teensy 4.1, uses a nominal voltage of 3.3V. An 11.1V battery will provide enough voltage to power both the Data Management System and the Electronic Sensor System. This battery also has enough capacity to support both of these systems by an acceptable safety factor.
Integrating Components	Main Payload Mount	3D-Printed PLA plastic	PLA plastic allows us to create large, complex mounts on which to mount all the payload systems.
Integrating Components	Bottom Payload Mount	3D-Printed PLA plastic	PLA plastic allows us to create large, complex mounts on which to mount all the payload systems.
Integrating Components	Top Payload Mount	3D-Printed PLA plastic	PLA plastic allows us to create large, complex mounts on which to

			mount all the payload systems.
Integrating Components	Battery Mount	3D-Printed PLA plastic	PLA plastic allows us to create large, complex mounts on which to mount all the payload systems.

Table 10: Payload Materials

Payload Integration Design

Each part of the payload will be held in place with a 3D-printed mount. The mount is designed to contain each part of the payload, including the sensor system, camera system, and tank system. To load the mount, each tank will be carefully slid into place, and will be held in place. The camera system is held in place with a combination of parts of the mount, and screws.

Payload Retention Design

Our payload is retained by 2 ¼” steel threaded rods and bulkheads on either end. Each module of the payload is attached to these rods, reducing vibrations and ensuring that every module is secure and will not come free during flight. The bulkheads on either end are also secured to these threaded rods, and they will ensure that the payload remains inside the vehicle during any high-g portions of the flight.

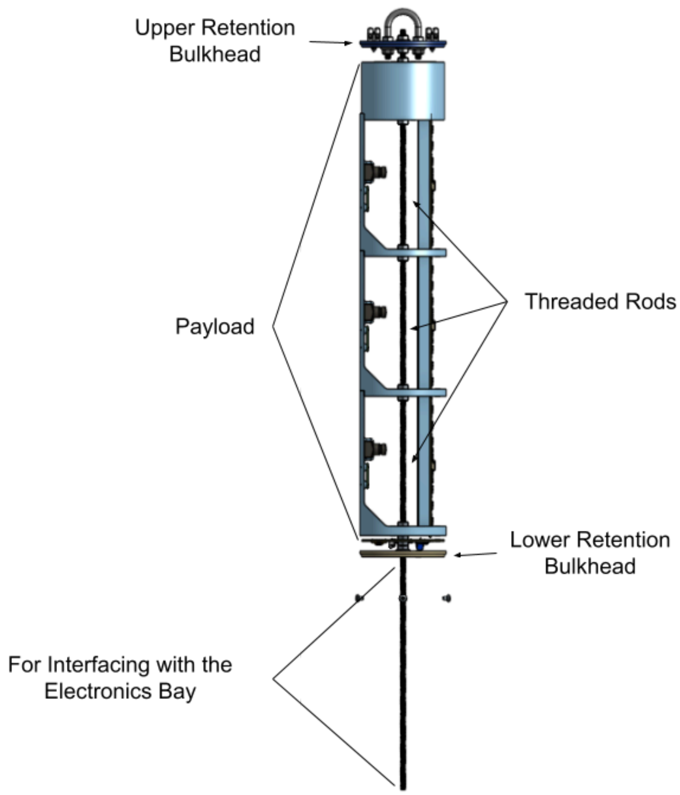


Figure 60: Payload Retention Diagram

Safety

Launch Concerns

The following figures address launch concerns regarding the experiment:

Frequency Study

While designing our vehicle and payload, the concern arose that the frequencies of the vehicle during launch could match resonant frequencies of sloshing in our payload tanks. If the natural frequency of the vehicle matched the frequency of one of our tanks, it could cause the vehicle to become unstable due to this coupling. We conducted a study to determine whether or not this would be an issue.

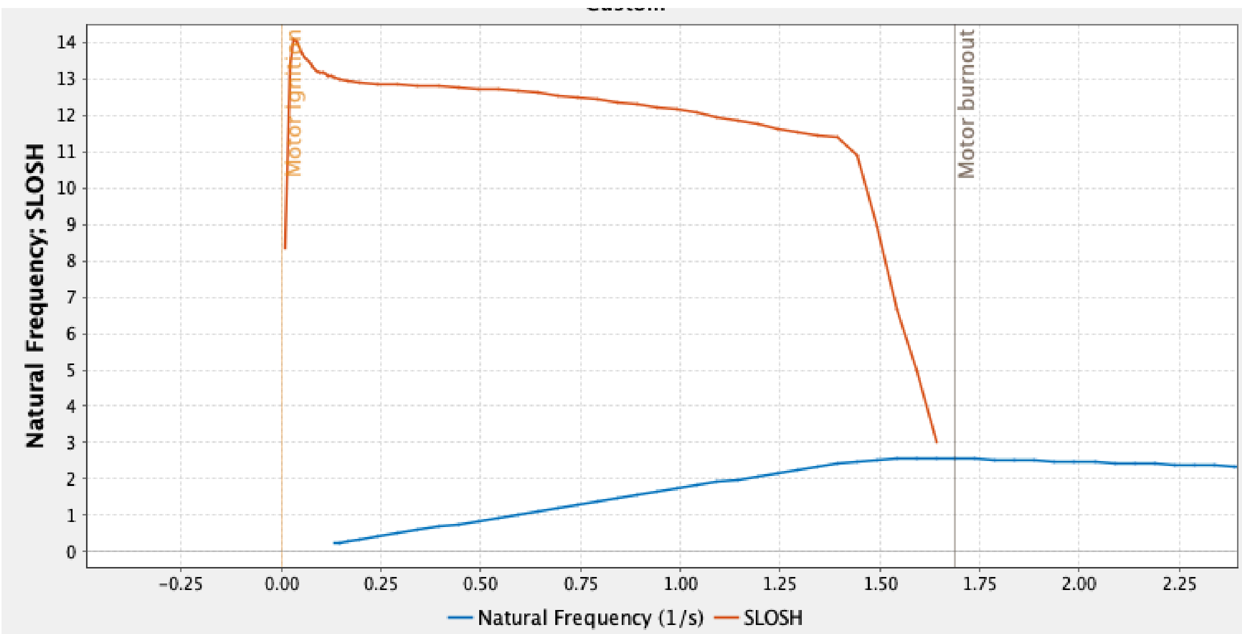


Figure 61: Frequency of Vehicle vs Slosh in Tanks

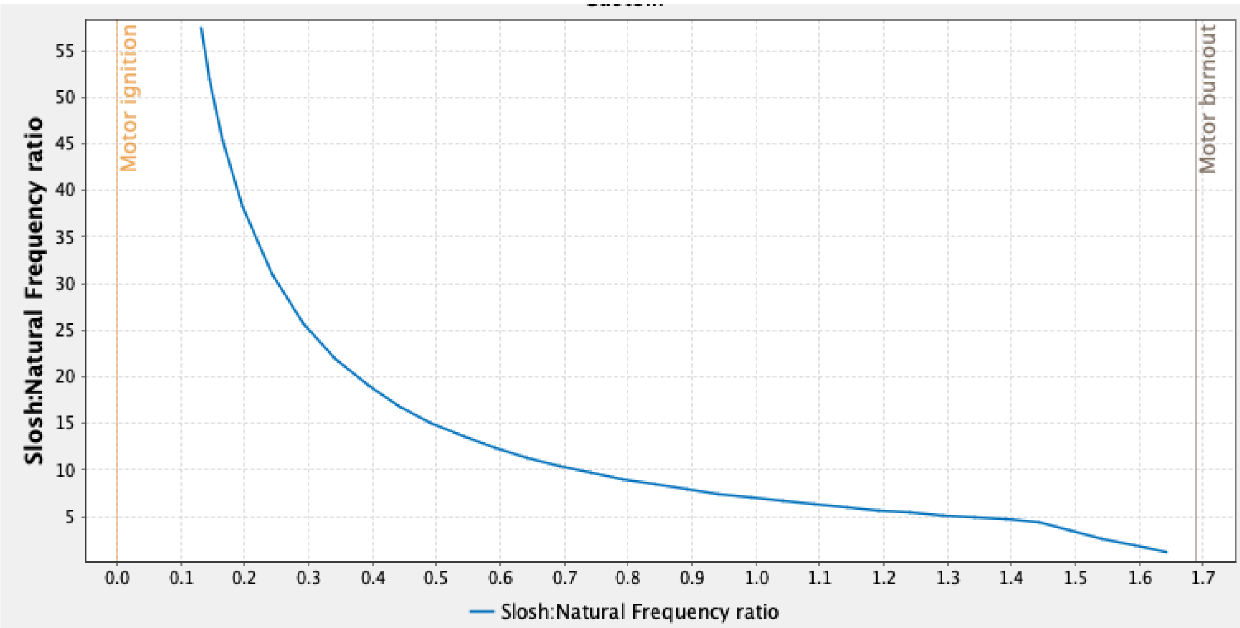


Figure 62: Ratio of Slosh/Natural Frequency

The charts above shows the frequency of slosh within the payload versus the natural frequency of the vehicle during ascent, and the ratio between the two frequencies. We calculated these frequencies using the methods shown below.

Vehicle

To calculate the natural frequency of our launch vehicle, we began with the equation for air density. Using this number, we calculated the dynamic pressure on the vehicle. Using that, we calculated the dM/dα (derivative of the longitudinal corrective moment with respect to angle of attack). We used this to compute the natural frequency of the rocket throughout the burn phase of its flight using the formula *sqrt*(*dM*/*dα*)/2π.

Slosh

To calculate the frequency of sloshing in our payload's tanks, we used the formula found in A Study of Sloshing Frequencies of Fluid-Tank System by Jaiswal, O.R., Kulkarni, S., and Pathak, P. (Jaiswal, O.R., Kulkarni, S., and Pathak, P., A Study of Sloshing Frequencies of Fluid-Tank System. The 14th World Conference on Earthquake

Engineering (WCEE), Oct 12-17, 2008, Beijing, China based on Housner, G.W., 1963. Dynamic Analysis of Fluids in Containers Subjected to Acceleration (Appendix F), in Nuclear Reactors and Earthquakes. Washington, DC: U.S. Atomic Energy Commission. TID-7024:).

$$f_c = \frac{1}{2\pi}\sqrt{\frac{3.16\, g \tanh\left(3.16\,\frac{h}{L}\right)}{L}}$$

Figure 63: Formula for Sloshing in Rectangular Tanks
(eq 5.2 in Jaiswal et al., 2008; based on Housner, 1963)

In this equation, f_c is the frequency of slosh (Hz), g is the gravitational force on the tank ((vehicle thrust-drag)/mass) (m/s^2), h is the height of water in the tank (m), and L is the length of the rectangular tank along direction of excitation (m). We simplified this equation using the constants of our tank measurements to $f_c=\sqrt{(45.1*g)}$.

Conclusion

To ensure that the frequencies of these two measurements will not coincide, we decided that the resonant frequencies of these two systems must not fall within a multiple of 3 from each other, to ensure there is no coupling between the vehicle and the tanks. We found that while the vehicle was under power, the ratio of the resonant frequencies will not approach 1 during the relevant portion of the flight.

Additional less likely concerns are listed with mitigations below:

- ***Camera system failure*:** Camera systems could malfunction or shut down during launch. To prevent this, ground testing and prior use will be conducted to ensure functionality.

  - ***Sensor systems inoperable*****:** Slosh comparison between tanks requires sensor systems to be functioning. To prevent issues, we will carefully review our designs before fabricating them.
  - ***Tanks break/leak*****:** Fluid holding tanks may leak during flight. Tank materials have been tested for leakage and are water tight.
  - ***Electronics tangled/damaged*****:** Wires and electronic parts are contained within the payload section and ebays and come into vicinity with fluid-filled tanks. If wires are damaged or tangled, they may not function which could lead to flight failure. Test flights and organized separation of electronics are done prior to launch to mitigate this risk.
- **Vehicle:**
  - ***Structural failure*****:** Launch may cause vehicle parts to break. Materials were strategically selected for durability and tested.

Operations Procedure

The following lists the operations procedure prior to launch, as written by NAR and NASA requirements:

1. Confirm the flyer is certified to fly the presented rocket/motor combination.
2. Ensure the motor is properly mounted, fins are secure, and launch lugs or rail buttons are correctly attached.
3. Weigh the rocket and confirm the motor is appropriate for its weight using motor charts.
4. Verify the motor is approved, provides a thrust-to-weight ratio (TWR) >4, and has a delay or electronics ensuring safe recovery.
5. Check rocket stability; at least 2 calibers of static stability or proven design. If marginal, request proof of stability or prior flight success on the same motor.
6. Verify that the rocket will not exceed the site altitude waiver.
7. Verify that the igniter is not in the motor (for mid-power and HPR) and that electronics remain unarmed until on the pad.

8. Verify the recovery system, including proper delay settings, fresh batteries, ejection charges, and secure connections.
9. Ensure that the flight data card is completely filled out, noting any special requirements or certification flight details.
10. Sign the flight card to certify the rocket has been inspected.

Launch Procedure and Checklists

The following lists the procedures relating to the launch of the rocket. (**Bolded information** must be completed by the listed personnel or with the listed PPE):

Chronological Launch Checklist:

1. Bring rocket and tools to the table
2. Install batteries to receiver and ensure signal is received
3. Install RDF Beacon, ensure good transmissions
4. Install EggFinder, ensure good radio and GPS connection
5. Perform payload, electronics, and rocket procedures
6. Integrate rocket with shear pins
7. Insert motor
8. Lower rail
9. Place the rocket on the rail, prop it up with a clamp if needed
    a. One person should observe that no damage occurs
10. Raise rail
11. Power on forward Stratologger, verify 3 quick beeps
12. Power on aft Stratologger, verify 3 quick beeps
13. Power on the payload using it screw switch, verify beep codes
14. **Certified adult** insert igniter
15. All personnel away from the pad, behind the launch controller
16. Verify RDF Beacon is nominal
17. Verify EggFinder is nominal

Recovery Prep Procedure:

1. Check shock cords are securely attached to recovery attachment point
2. Main chute per Fruity Chutes folding procedure (refer to this PDF)
    a. Pack chute with Nomex
3. Drogue parachute per Fruity Chutes folding procedure (refer to this PDF)
    a. Pack chute with Nomex
4. Check that the shock cord is securely connected to the stainless steel eye bolt within the nose cone and to the U-bolt in the payload section inside the rocket
5. Fold the main parachute, a procedure initiated by the club
6. Fold the drogue parachute, a procedure initiated by the club
7. Wrap Nomex blanket around both the drogue and main parachutes to protect them from the heat of the ejection charges
8. Pack shock cord into the rocket, coiling the shock cord in order to avoid tangling during parachute deployment
9. Prepare and load ejection charges, measuring and filling the ejection wells with the adequate amount of black powder and insert igniters
10. Connect altimeter wires to ejection charges
11. Arm the altimeters and confirm they are operational
12. Insert the drogue parachute into the rocket
13. Proceed with preparing the payload
14. Insert the payload into the payload section of the rocket
15. Insert the main chute into the payload section of the rocket

Payload Procedure:

1. Insert SD cards into cameras
2. Turn on cameras
3. Start recording
4. Ensure tanks are filled and sealed
5. Insert tanks
6. Turn on LED lights

7. Turn on the electronics
8. Slide payload on threaded rods
9. Slide top bulkhead on top
10. Secure bulkhead in vehicle

Electronics Procedure:

On the ground:

1. Secure batteries to sled
2. Plug in batteries
3. Pull test all the wires, make sure connections are firm
4. Tighten nuts on the avionics bay

On the rail:

1. Turn on deployment altimeter 1
2. Listen for correct 3 beep code
3. Turn on deployment altimeter 2
4. Listen for correct 3 beep code

Rocket Transportation Procedure:

1. Vehicle wrapped in a secure manner to prevent breakage during transportation
2. All potentially breakable systems and components will be removed and wrapped carefully and independently
3. All electronics will be unplugged from a power source.
4. Batteries will be removed
5. Everything will be transported to Huntsville by mentor’s vehicle

Rocket Launch Procedure:

1. Put packed drogue in booster section
2. Put coupler tube into booster section
3. Load electronics into coupler section

4. Close off the coupler section with bulkhead
5. Load in payload
6. Close of payload section with bulkhead
7. Put upper section on to coupler section
8. Put the main chute in the upper section
9. Put nose cone on upper section

Motor Procedure:

1. **Certified adult** put motor into the rocket
2. Put the retainer on

Igniter Procedure:

1. Put rocket on rail
2. **Certified adult** handles ignitor insertion

Troubleshooting:

ON GROUND

1. Identify the source of the issue
2. Evaluate the severity of the issue
3. Ensure the issue is safely fixable
4. Review relevant procedure and rework from where the issue occurred
    a. If issue resolved, continue with the launch procedure
    b. If issue not resolved -> 5
5. Identify specific issue and consult specialized team member and mentors
    a. If fixable, fix and continue with launch procedure
    b. If not fixable, deintegrate and resort to backups

ON RAIL

1. Ensure rocket can be safely accessed
2. **Certified adult** disarm rocket
3. Remove rocket from rail

4. Follow on ground troubleshooting procedure

POST-LAUNCH

1. Identify any issues that occurred during launch
    a. Evaluate effect and develop mitigation to prevent repeat
2. Identify post-launch issue
    a. If payload related -> 3
    b. If vehicle related -> 4
3. Consult with **payload team**
    a. If data related, consult **data team** and recover any usable data from flight
4. Consult with **vehicle team**
    a. Review post-launch procedure

Recovery procedure:

1. Record the flight of the rocket until touchdown
2. Note the touchdown direction from the launch site
3. Disarm flight controller
4. Track rocket via the following conditions:
    a. If a good GPS fix is acquired
        i. (Optional) Enter GPS coordinates into a cell phone to aid in location
        ii. Begin walking towards the rocket, and use the EggFinder LCD module to aid direct searching
        iii. Listen for StratoLogger beeps
    b. If no GPS fix is acquired but RDF Beacon has a connection
        i. Walk in the direction of the rocket touchdown
        ii. Once close, use RDF Beacon to direct search
        iii. Listen for StratoLogger beeps
    c. If neither tracking system has a connection
        i. Begin walking in the direction of the touchdown
        ii. Listen for StratoLogger beeps

iii. Attempt to regain connection with RDF Beacon and EggFinder

5. Upon location of the rocket, do not touch it
6. Visually verify each section has separated and there are no live charges

Post-flight procedure:

1. Take 3 pictures of the full landed configuration, every component in sight
    a. Repeat from various angles
2. Take 3 pictures of the nose cone section
    a. Repeat from various angles
3. Take 3 photos of the ebay/payload section
    a. Repeat from various angles
4. Take 3 photos of the booster section
    a. Repeat from various angles
5. Re-check charge status
    a. Drogue Primary
        i. Deployed? Y N
    b. Drogue Backup
        i. Deployed? Y N
    c. Main Primary
        i. Deployed? Y N
    d. Main Backup
        i. Deployed? Y N
6. Check StratoLogger status
    a. High Pitch (Primary)
       Powered On? Y N
    b. Low Pitch (Backup)
       Powered On? Y N
7. If there are any live charges, **certified adult** cuts the leads with wire cutters
8. Verify all live charges are cut and removed
9. Picture with the landed rocket

10. Turn off RDF Beacon
11. Turn off EggFinder if accessible
12. Pack chutes loosely into the rocket, fit sections together
13. Carry the rocket back to the launch site
14. Clean up

Safety and Environment

Personnel Hazard Analysis

The following risks could endanger the successful completion of our project (listed with mitigations). Each hazard has two separate rankings of likelihood and severity on a scale of 1-10, 10 being the most likely or severe.

- **Facility Risks**
    - ***Workshop inaccessible:***
        - Effects: Project progress will be slowed and momentarily halted without workshop space.
        - Mitigation: If this occurs, the design and manufacturing process can temporarily be relocated to Mr. Lillesand's house. Likelihood: 8, Severity: 4
    - ***Classrooms unavailable:***
        - Effects: Meetings may become more difficult, due to the inconvenience of communicating and switching locations.
        - Mitigation: Should the primary room become inaccessible, we can also utilize other options, such as reserving a meeting room in a local library, temporarily meeting in a club member's house, or meeting online. Likelihood: 3, Severity: 2
    - ***Launch site unavailable:***
        - Effects: We cannot launch the rocket and therefore cannot gather data.

        - Mitigation: We routinely schedule redundant launch windows to ensure that we will have enough opportunities to carry out all necessary flights. We are currently working with three rocketry organizations (NAR section WOOSH, QCRC, Tripoli WI) to maximize our launch opportunities. Likelihood: 3, Severity: 5

- **Personnel Risks**
    - ***Physical injury:***
        - Effects: Physical injury due to any rocket manufacturing will lead to an immediate meeting addressing safety procedures required in the workshop.
        - Mitigation: Personal Protective Equipment is mandated during all construction tasks and preparation of the rocket for flight or static test. All preparation/handling of energetics will be done by mentors. Adult supervision is provided at all times. Using headphones and personal electronics during rocketry activities and workshop hours is strictly prohibited. Likelihood: 3, Severity: 4
    - ***Toxicity***:
        - Effects: Improper use of workshop space and excessive exposure to toxic chemicals may lead to slight injury. Any member affected by chemicals used in the workshop may suffer from injury.
        - Mitigation: SDS documentation is available for all chemicals used in the project, and dangerous chemicals are avoided as much as possible. Adult supervision is provided at all times, and PPE use is mandated. Likelihood: 2, Severity: 6
- **Budget Risks**
    - ***Budget overrun:***
        - Effects: Without sufficient funds, project delays may affect production schedules.
        - Mitigation: Should our raking fundraiser not gather enough money to fund our project, we plan to create a winter fundraiser to supplement

our funds. If this isn't sufficient, we will reach out to former club members and other club-associated people to ask if they would be willing to donate. We anticipate this would be able to cover any budget deficit. Likelihood: 5, Severity: 4

- **Project Risks**
  - ***Project behind schedule:***
    - Effects: If project progress falls behind schedule, we will struggle to meet milestones on time.
    - Mitigation: Project progress is constantly compared against a list of required milestones, and working hours are extended as necessary to meet all milestones. All deadlines are considered hard. Likelihood: 7, Severity: 4
  - ***Key team member unavailable:***
    - Effects: Progress will be affected by the absence of the team member.
    - Mitigation: No task is assigned to a single team member. All tasks are carried out by a pair or a small group of equally knowledgeable students. Students are not allowed to limit their participation in the project to a single area of expertise. Likelihood: 3, Severity: 3
  - ***Technical roadblock:***
    - Effects: Progress will be delayed if a technical issue arises, and additional work will need to be completed.
    - Mitigation: A thorough feasibility review is conducted before the Preliminary Design Review Report is submitted. Alternative solutions and advice from experienced mentors will be sought. Likelihood: 4, Severity: 7
  - ***Personal disagreements:***
    - Effects: Team morale may be hindered by personal disagreements within the group.

        - Mitigation: Should an intra-team conflict occur, adults will protect the progress of the project and mediate the resolution. All students were informed of this rule before their admission to the program. Likelihood: 1, Severity: 1
    - ***Part unavailability:***
        - Effects: Unavailability of parts will result in project deployment and possible reworking.
        - Mitigation: Multiple vendors have been identified for key components to maintain part availability redundancy. All purchasing happens at first availability. Likelihood: 6, Severity: 3
- **Vehicle Risks**
    - ***Repeated test flight failure:***
        - Effects: Repeated test flight failure will cause progress to decrease.
        - Mitigation: The rocket design has been supervised by multiple high-power certified mentors, and a thorough examination will be performed before each flight. Consideration will be given to weather conditions, to maximize the probability of safe flight and successful recovery. All flight data will be analyzed, to identify problems before the next flight. Likelihood: 3, Severity: 5
    - ***Vehicle lost/irreparably damaged during test flight:***
        - Effects: Vehicle damage during test flight will result in extra manufacturing to fix lost or damaged parts.
        - Mitigation: A sufficient time reserve will be built into the project schedule, to allow for vehicle replacement, if necessary. The airborne vehicle will be tracked using 2 different redundant methods. Likelihood: 3, Severity: 5
    - ***Propellant unavailability:***
        - Effects: Propellant unavailability will lead to project progress slowing.

    - Mitigation: All purchasing is conducted as soon as practically possible. Motor alternatives are thoroughly investigated during the vehicle. Likelihood: 3, Severity: 4
  - ***Final vehicle overweight:***
    - Effects: The final vehicle overweight will affect the rocket's ability to reach the target altitude.
    - Mitigation: 30% of total vehicle weight is added to the initial estimate of vehicle weight, and all simulations are done with a C_d set to 0.7. This ensures the vehicle will still be able to reach the target altitude with an unexpected increase in mass. Likelihood: 2, Severity: 5
- **Payload Risks**
  - ***Construction falls behind schedule:***
    - Effects: Delay of construction will add an additional challenge to our project and may lead to slowing of progress.
    - Mitigation: Construction of the payload, which is mostly 3D printed, will begin as soon as designs are finalized. Several of our team members and mentors own 3D printers, ensuring we remain on schedule for construction. Likelihood: 7, Severity: 4
  - ***Unexpected integration failure:***
    - Effects: Integration failure will lead to progress delay.
    - Mitigation: The design of the payload is overseen by multiple engineers, as well as the HPR Mentors, and the integration of the payload is reviewed at each design milestone. Likelihood: 4, Severity: 7
- **Environmental Concerns**
  - ***Wind:***
    - Effects: In the event of windy conditions on the day of launch, the rocket's trajectory may be slightly altered.

- Mitigation: The vehicle has been designed to have a stability margin above the specified minimum in the handbook, to greatly decrease the chances of change in trajectory from external factors.
- ***Unable to recover:***
  - Effects: In the event we are unable to recover the rocket, the materials used may cause unintentional pollution.
  - Mitigation: Multiple tracking systems will be used, to ensure that we know the location of the rocket at all times.

Failure Modes and Effects Analysis

The following table shows specific risk for each subsystem of the rocket and mitigations to prevent them. Risks were mitigated according to priority numbers, the higher number indicating that the risks are more concerning.

Subsystem	Risk Details	Potential Causes	Potential Impact	Mitigation	Likelihood of occurrence after mitigation	Severity	Ease of detection	Risk Priority Number
Structure	Airframe fails to separate	Ejection charges too small Deployment of avionics fail to set off charges	Rocket descends too quickly Potential for loss of rocket Damage to rocket due to high kinetic energy at impact	Extensive ejection testing	2	8	2	32
Recovery	Parachutes fail to deploy	Parachute gets stuck in airframe Parachute gets tangled	Rocket descends too quickly Potential for loss of rocket Damage to rocket due to high kinetic energy at impact	Design with generous room for parachutes Use easy-to-pack material Test folding procedure to prevent tangling	2	6	5	60

Avionics	Tracking failure	Loss of telemetry from flight computer and commercial trackers	Loss of precise GPS tracking for recovery	Multiple tracking methods	2	6-could make recovery impossibl e	3-check connection strength	54
Structure	Rail guides detach during rail mounting	Structure failure during mounting	Inability to load rocket on launch rail	Rail guides will be surface-mounted with epoxy Caution will be used when loading the rocket onto the launch rail	2	3- could delay launch	1	6
Avionics	Electronics fail to turn on	Broken electrical connections Poor soldering Forces of flight	Unable to deploy parachutes and record data	Testing of electrical connections Preparation of spare electronics	3	4-could delay launch	2-all electronics either give audible signals or transmit to the ground station while powered on	24
Avionics	Overheating of batteries	Extreme temps and long waiting period on pad	Electronics unable to function properly	Keep parts of rocket as cool as possible, prior to loading onto pad Paint rocket a thermally reflective color	5	5-could delay flight or result in avionics not functioni ng properly	4	100
Avionics/ Recovery	Ejection charges ignite prematurely	Shorted connections Altimeter malfunction	Structural damage Personal injury	Use of PPE around ejection charges Multiple people checking electronic connections and charges	2	8-potenti al injury or failure to launch	1	16
Propulsion	Ignitor failure	Motor fails to light	Rocket does not launch	Test ignitors Bring multiple ignitors	2	1	1	2
Propulsion	Motor failure	Imperfection in grains Mechanical failure of casing	Potential for catastrophic failure (CATO) Leakage of	Check density of motor grains Operate motor at a conservative chamber	2	10-potent ial for CATO	8	160

		Failure of liner	motor gasses	pressure Test ignition system Use lithium grease and O-rings properly				
Structure	Mechanical failure of airframe fins	High angles of attack lead to substantial aerodynamic forces Fins oscillate	Rocket becomes unstable	Surface mounted fins with tip-to-tip epoxy fillets	2	9	6	108
Structure	Mechanical failure of body tubes	High angles of attack lead to substantial aerodynamic forces Bending at couplers leads to high loads	Total loss of rocket	Reasonable margin of stability to limit both angle of attack and wind cocking Thick and strong body tubes	3	10	8	240
Vehicle	Missing vehicle parts	A part breaks during transport A part is left behind or forgotten	Potential cause for inability to launch	Procedures and checklists developed to ensure care of all rocket parts Multiples of parts are brought to launch	1	4	1	4
Avionics	Ejection charges become disconnected	Installation done incorrectly Become disconnected during transport or handeling	May make launch impossible	Charge leads are folded over to create more material	4	5-could delay flight or result in avionics not functioning properly	4	80
Avionics	Arming holes become blocked	Rail buttons make it so that rail blockers arming holes	May make arming the rocket difficult	Put arming holes away from rail buttons	1	1	2	2
Recovery	Parachute does not unfold	Parachute packed too tight	Damage to rocket Risk for personal injury	Mentors teach and double check rocket folding Recovery Prep Procedure	2	4	7	52

			Potential loss of rocket					
Recovery	Shroud line disconnects	Shroud line snaps Shroud line comes untied	Potential damage to rocket Risk for personal injury	Mentors teach and double check rocket folding Recovery Prep Procedure is followed	2	6	5	60
Structure	Payload screws stripped	Improper tool was used when turning on the payload	May cause turning on the payload impossible	Proper designated tools will be used at all times	1	3	5	15
Payload	Tank breaks/leaks	Tank sealed incorrectly Tank breaks during handling, transport, or flight	Potential loss of data and rocket damage	Tank printed onto acrylic to seal, filled prior to transport, and double checked before installation	3	5-depends on amount leaking	1	15
Avionics	Switches damaged	Use of improper tool	Potential inability to launch	Use of proper tool Following of procedures	2	6-could prevent launch	4	48

Table 11: FMEA

Project Plan

Testing

Vehicle

Frequency Study

Description

The frequencies of the vehicle during launch could match resonant frequencies of sloshing in our payload tanks and could cause the vehicle to become unstable, due to this coupling. We conducted a study to determine whether or not this would be an issue. The math and graphs of this study can be found under the Launch Concerns section.

Success Criteria

The ratio of oscillation between the vehicle and slosh inside the payload does not approach one, which would result in coupling.

Results

Success, see Launch Concerns section for test details.

Deployment Test

Description

The vehicle will be fully integrated with parachutes, protectors, shear pins, and the primary drogue event deployment charge, then placed horizontally on a soft surface. The drogue event deployment charges will be wired to a remote firing system via the forward bulkhead, and the primary drogue charge will be fired. Team members will observe the vehicle to see if the aft separation point separates. This test will then be re-run for the main event deployment charges.

This test aims to ensure the vehicle will successfully deploy the parachutes at the intended points of flight.

Success Criteria

If the drogue and main charges successfully separate the rocket at the intended points, the test is a success. If the vehicle suffers damage, separates at an unintended point, or does not separate when intended, the test is a failure. Depending on the failure mode, the deployment charge sizing may be increased.

Results

N/A, this test has not yet been performed, and is scheduled to be performed once the vehicle is fully assembled.

Payload

Tank Thickness Test

Description

This tests whether a tank that was too thin would interfere with the flow of the water inside.

Success Criteria

If the selected tank thickness can successfully allow water flow, the test is a success. If the selected tank thickness restricts water flow, the test is a failure.

Results

Success, this test proved that tank thickness was not a significant factor in water flow. However, we could still observe some differences between a ¼ " and ½ " tank, leading us to choose a thicker tank. See Tank System section for more details and testing setup.

Tank Shape Test

Description

This test recorded and plotted 2 different tank shapes—1 with rounded corners and 1 rectangular—to determine if the tank shape had any significant effect on the wave motion. We turned each tank rapidly and compared the results.

Success Criteria

If a tank shape can be selected, the test is a success. If neither tank shape fits the required wave motion, the test is a failure.

Results

Success, this test showed that both tank shapes were extremely similar and thus we could choose either for our experiment. The test is described in more detail under the Tank System section as well.

Camera Heating Test

Description

This test intends to verify that the cameras can withstand the heat inside the vehicle on the pad. The cameras will be placed inside a box along with a meat thermometer, which has the display sticking out the side so it can be observed. The box will be heated with a distant heat lamp, and the cameras will start recording before we put them in the box. We will monitor the temperature inside the box using the meat thermometer.

Success Criteria

If the temperature inside the box approaches 110℉, the test is a failure. This temperature has been determined as the failure point of the cameras via analysis of the components. The test will be terminated before this point. If the temperature inside the box stabilizes below 110℉ or the temperature remains below 110℉ for 3 hours, the test is a success.

Results

N/A, this test has not yet been performed, and is scheduled to be performed once the team acquires excess cameras.

General Requirements Compliance:

1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Student team members shall only be a part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit penalties. **- The mentor assists students by helping with skills, and not with construction, design, or any other project related activities. Each member is only part of one team. Very little, if any, work is taken from previous projects.**

1.2. The team will provide and maintain a project plan that included but is not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations. **- We have developed a project plan to handle all of these items.**

1.3. Team members who will travel to the Huntsville Launch shall have fully completed registration in the NASA Gateway system before the roster deadline. Team members shall include:

1.3.1. Students actively engaged in the project throughout the entire year. - **Every member of the team actively contributes to the project and is on the team from start to finish.**

1.3.2. One mentor (see requirement 1.13). - **We have one mentor.**

1.3.3. No more than two adult educators. - **We have two adult educators.**

1.4. Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR addendum due date. - **We engage in frequent outreaches that engage well over 250 participants in Educational Direct Engagement STEM activities.**

1.5. The team shall establish and maintain a social media presence to inform the public about team activities.
Social Media presence is as follows.

- **Instagram: @westrocketry**
- **Facebook: @madison.west.rocketry**
- **YouTube: @madisonwestrocketry3308**
- **Website: https://madison-west-rocketry.github.io/SL/**

1.6. Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No PDR, CDR, or FRR milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit the PDR, CDR, or FRR milestone documents will be eliminated from the project. - **We will submit the CDR and FRR within the submission deadline.**

1.7. Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) shall be provided action items needed to be completed following their review and shall be required to address action items in a delta review session. After the delta session, the NASA management panel shall meet to determine the teams' status in the program and the team shall be notified shortly thereafter. - **We will address action items in this scenario, if necessary.**

1.8. All deliverables shall be in PDF format. - **Submissions are all in PDF format.**

1.9. In every report, teams shall provide a table of contents including major sections and their respective subsections. - **We have and will have a table of contents for each report.**

1.10. In every report, the team shall include the page number at the bottom of the page.
- **We have and will have a page number at the bottom of each page in each report.**

1.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to: a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort. **- We have the computer equipment necessary for each teleconference.**

1.12. All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads shall be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 – 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions. **- We will use the pads and rails provided to us.**

1.13. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The team mentor shall not be a student team member The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of two flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April. **- The team mentor fits all of these criteria and is planning on attending Launch Week.**

1.14. Teams will track and report the number of hours spent working on each milestone **- We track and will report the number of hours spent working on each milestone.**

Vehicle Requirements Compliance:

2.1. The vehicle shall deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on their competition launch will not be eligible for the Altitude Award. **- The apogee is predicted to be approximately 4,455 feet.**

2.2. Teams shall declare their target altitude goal at the CDR milestone. The declared target altitude shall be used to determine the team's altitude score. **- The declared target altitude is 4,500 feet.**

2.3. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications. **- Our design has been constructed in such a way to meet this requirement. More details can be found in the *Final Design Choices* and *Individual Section Design* sections of the document.**

2.4. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. **- The vehicle will have three independent sections. A Nose Cone Section, an Upper Section, and a Booster Section. The Nose Cone and Booster sections will be tethered to the Upper section.**

2.4.1. Coupler/airframe shoulders which are located at in-flight separation points shall be at least two airframe diameters in length. (One body diameter of surface contact with each airframe section.) **- We have made sure that all airframe and coupler shoulders at in-flight separation points are at least two airframe diameters in length.**

2.4.2. Coupler/airframe shoulders which are located at non-in-flight separation points shall be at least 1.5 airframe diameters in length. (0.75 body diameter of surface contact with each airframe section.) **- We have made sure that all airframe and coupler shoulders at non-in-flight separation points are at least 1.5 airframe diameters in length.**

2.4.3. Nosecone shoulders which are located at in-flight separation points shall be at least ½ body diameter in length. **- The nosecone shoulder has a length of 4.5", which is more than one body diameter (4.02").**

2.5. The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens. **- The design of the vehicle and payload employment was consciously designed to be easy to implement, and we will conduct a practice-pack to ensure we are able to prep the rocket within the specified time frame.**

2.6. The launch vehicle and payload shall be capable of remaining in launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged. **- The rocket is designed to be in a ready-to-fly state for more than 3 hours, and the battery life of all electronics is over 8 hours. In theory, none of our electronics will overheat during a time frame of about 8 hours, and we will conduct a test once we have the final design to ensure that is the case.**

2.7. The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider. **- Our motor uses the included AeroTech igniters, which are compatible with a standard 12-volt direct current firing system.**

2.8. The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider). **- The design of the rocket was constructed with the above requirement in mind and does not require any external circuitry or special ground support.**

2.9. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association

(TRA), and/or the Canadian Association of Rocketry (CAR). **- Our current motor choice is an AeroTech K1103 motor that fits within the above requirements.**

2.9.1. Final motor choice shall be declared by the Preliminary Design Review (PDR) milestone. **- Our choice of the AeroTech K1103 was declared at the PDR milestone.**

2.9.2. Any motor change after PDR shall be approved by the NASA management team or NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment shall not be approved. The only exception is teams switching to their secondary motor choice, provided the primary motor choice is unavailable due to a motor shortage. **- We will be sure to follow the outlined plan, should we need to switch to our backup motor choice. We will not need to switch for any other reason besides inability to acquire the AeroTech K1103 motor.**

2.10. The launch vehicle shall be limited to a single motor propulsion system. **- The design uses a single motor propulsion system.**

2.11. The total impulse provided by a High School or Middle School launch vehicle shall not exceed 2,560 Newton-seconds (K-class). **- Our motor choice is a K-class motor with a total impulse of 1789 Newton-seconds.**

2.12. Pressure vessels... **- Our vehicle does not use pressure vessels.**

2.13. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail. **- Our vehicle has a static stability margin of 4.08 at the point of rail exit.**

2.14. The launch vehicle shall have a minimum thrust to weight ratio of 5.0 : 1.0. **- Our vehicle has a thrust to weight ratio of 12.3 : 1.0.**

2.15. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability. **- We will have no structural protuberances.**

2.16. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit. **- Our rail exit velocity is approximately 87 ft/sec.**

2.17. All teams shall successfully launch and recover a subscale model of their rocket. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data shall be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor). **- Our current scale model uses a G-138 Motor, and we understand that success of the subscale is at the sole discretion of the NASA review panel.**

2.17.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale model will not be used as the subscale model. **- We have made a separate rocket that functions as our scale vehicle at a ½ scale of the original.**

2.17.2. The subscale model shall carry an altimeter capable of recording the model's apogee altitude. **- The subscale model has two PerfectFlite StratoLogger flight computers onboard.**

2.17.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project. **- We created an entirely new vehicle, built specifically as a scale model of our full scale vehicle. All parts were constructed specifically for the scale model and are not reused from any other design.**

2.17.4. Proof of a successful flight shall be supplied in the CDR report. **- We have submitted a successful flight.**

2.17.4.1. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) will not be accepted. **- Complete altimeter flight profile graphs are in the CDR report. Videos will be submitted with the CDR presentation.**

2.17.4.2. 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. **- Quality pictures of the landed configuration are in the CDR report.**

2.17.5. The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4” diameter 100” length rocket, your subscale shall not exceed 3” diameter and 75” in length. **- The subscale rocket has 50% of the dimensions for length and diameter of the full scale rocket.**

2.18. **- N/A for CDR**
2.19. **- N/A for CDR**

2.20. 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. **-**

When we are at the point of painting the outside of the vehicle, we will ensure the above requirement is taken into account.

2.21. All Lithium Polymer batteries shall be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware. **- Our design contains LIthium Polymer batteries, shielded and secured inside the electronics bay.**

2.22. Vehicle Prohibitions

2.22.4. The launch vehicle shall not utilize forward firing motors. **- Our vehicle does not use forward firing motors.**

2.22.2. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.). **- Our design does not use a motor that expels titanium sponges of any kind.**

2.22.3. The launch vehicle shall not utilize hybrid motors. **- The design does not use a hybrid motor.**

2.22.4. The launch vehicle shall not utilize a cluster of motors. **- Our vehicle does not use a cluster of motors.**

2.22.5. The launch vehicle shall not utilize friction fitting for motors. **- Our design does not employ the use of friction fitting in our motor under any circumstances.**

2.22.6. The launch vehicle shall not exceed Mach 1 at any point during flight.**- Our vehicle will not exceed Mach 1 at any point during flight.**

2.22.7. Vehicle ballast shall not exceed 10% of the total unballasted weight of the rocket, as it would sit on the pad (i.e., a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast). **- Our vehicle ballast does not exceed 10% of the total unballasted weight.**

2.22.8. Transmissions from on-board transmitters, which are active at any point prior to landing, shall not exceed 250 mW of power (per transmitter.) **- Our on board transmitters do not exceed a power of 250 mW per transmitter.**

2.22.9. Transmitters shall not create excessive interference. Teams shall utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams. **Our transmitters do not create any kind of excessive interference, and we will utilize methods to mitigate interference.**

2.23.10. Excessive and/or dense metal shall not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses. **- Our vehicle does not use any kind of excessive or dense metal.**

Recovery Requirements Compliance:

3.1. The full-scale launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO. **- Our rocket design uses a drogue parachute deployed at apogee and a larger main chute deployed at a lower altitude.**

3.1.1. The main parachute shall be deployed no lower than 500 feet. **- Our main**

parachute will be deployed at 700 ft, and the backup deployment set at 600 ft.

3.1.2. The apogee event shall contain a delay of no more than 2 seconds. **- Our apogee event will have no delay, and the backup event will have a delay of one second.**

3.1.3. Motor ejection is not a permissible form of primary or secondary Deployment. **- Our vehicle does not use motor ejection as a form of primary or secondary deployment.**

3.2. Each team shall perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles. **- We performed a successful ground ejection test for all electronically initiated recovery events prior to the launch of the scale model, and we will do the same for our full-scale vehicle.**

3.3. Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing. **- Kinetic energy for each tethered section of the vehicle is lower than the required 75 ft-lbf and recommended 65 ft-lbf.**

3.4. The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers. **- Our recovery system uses StratoLogger CFs, which are commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events.**

3.5. Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries. **- Each of our altimiters has its own**

dedicated power supply, and all recovery electronics will be powered by commercially available batteries.

3.6. Each altimeter shall be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad. **- Our design contains dedicated mechanical arming switches, which are accessible from the exterior of the rocket airframe.**

3.7. Each arming switch shall be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces). **- Our arming switches are capable of being locked in the "ON" position.**

3.8. The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits. **- Our recovery system, GPS and altimeters, and electrical circuits are completely independent of any payload electrical circuits.**

3.9. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment. **- Our design will incorporate removable shear pins that will be used for both chute compartments.**

3.10. Bent eyebolts shall not be permitted in the recovery subsystem. **- Our design does not use bent eyebolts.**

3.11. The recovery area shall be limited to a 2,500 ft. radius from the launch pads. **- In all of our simulations, which include 20 mph winds (the maximum allowed by the NAR), the rocket does not drift close to 2,500 ft from the launch pads.**

3.12. Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down). **- The descent time of our launch vehicle is projected to be 65.8 seconds.**

3.13. An electronic tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver. **- Our design uses a GPS tracking system, which transmits the vehicle's position to a ground receiver.**

3.13.1. Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic tracking device. **- All of the individual sections will be tethered together.**

3.13.2. The electronic tracking device(s) shall be fully functional during the official competition launch. **- We will use checklists to ensure that our electronic tracking device(s) shall be fully functional during the official competition launch.**

3.14. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing). **- We have designed our recovery electronics so that they are not affected by any other on-board electronic devices.**

3.14.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device. **- Our design complies with the above requirement.**

3.14.2. The recovery system electronics shall be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics. **- The recovery system electronics will be shielded from all other on-board transmitting devices.**

3.14.3. The recovery system electronics shall be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system. **- Each element of our recovery system will be shielded from all magnetic waves.**

3.14.4. The recovery system electronics shall be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics. **- The recovery system electronics shall be shielded from any other on-board devices that might adversely affect the orientation of the recovery system electronics.**

Payload Requirements Compliance:

4.1. Teams may design their own science or engineering experiment. Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method. **- Our team designed an experiment to test the effects of baffles on the amount of slosh of water during the flight.**

4.4.1. Black powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations. **- We are only using black powder for the recovery system and not any surface operations.**

4.4.2. Teams shall abide by all FAA and NAR rules and regulations. **- The payload meets all the FAA and NAR requirements.**

4.4.3. Any payload experiment element that is jettisoned during the recovery phase shall receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA. **- There will be no experiment element jettisoned during the recovery phase.**

4.4.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS. **- We are not utilizing a UAS payload.**

4.4.5. Teams flying UASs shall abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft. **- The payload meets all applicable FAA regulations.**

4.4.6. Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle. **- We are not utilizing a UAS payload.**

Budgeting

Line Item Budget

Expense Area	Item	Quantity / Size	Vendor	Unit Price	Total Cost	Shipping Fees + Taxes	Notes
Full Vehicle	Fiberglass 4" Body Tubes	66"	Wildman Rocketry	$141.27	$141.27	$90.42	Shipping fees are included in the first occurrence of each company
	Fiberglass 4" Coupler Tube	9"	Madcow Rocketry	$33.00	$33.00	$26.87	
	FIberglass G10 Fin Stock	2x 1 sq ft	McMaster-Carr	$29.38	$58.76	$10.00	
	Fiberglass Motor Tube 54 mm	20"	Mach 1 Rocketry	$30.00	$30.00	$41.00	
	Centering Rings G10 Stock	1 sq ft	McMaster-Carr	$29.38	$29.38	$10.00	
	Drogue Chute 12" Recon	12"	Wildman Rocketry	$31.95	$31.95	$1.60	
	Fiberglass Bulkhead Stock G10, 1/4"	1 sq ft	McMaster-Carr	$29.38	$29.38	$2.94	
	Fiberglass 4" Body Tubing for ebay Spacer	2"	Wildman Rocketry	$141.27	$141.27	$7.06	
	Main Chute 66" Toroidal	66"	Manufactured by club	-	-	-	Material acquired and available from past donation
	Fiberglass Nose Cone	4" dia, 24" len	Madcow Rocketry	$97.00	$97.00	$4.85	3D Print Possible
	Eggfinder complete package(transmitter+receiver)	1	Eggfinder	$155.00	$155.00	$12.00	
	Tubular Kevlar Shock Cord	2x of 38' of ⅜"	Giant Leap Rocketry	$107.66	$107.66	$5.99	
Total	-	-	-	$1,168.22	$1,197.60	$233.43	-
Scale Vehicle	Fiberglass 2" (54mm) Body Tubes	33"	Wildman Rocketry	$52.27	$52.27	$89.21	
	Fiberglass 2" (54mm) Coupler Tube	4.5"	Madcow Rocketry	$17.00	$17.00	$36.26	

	FIberglass G10 Fin Stock	1 sq ft	McMaster-Carr	$29.38	$58.76	$10.00	
	Fiberglass Motor Tube 29 mm	10"	Mach 1 Rocketry	$7.50	$7.50	$4.31	
	Centering Rings G10 Stock	1 sq ft	McMaster-Carr	$29.38	$58.76	$10.00	
	Drogue Chute 5"	5"	Manufactured by club	-	-	-	Material acquired and available from past donation
	Fiberglass Bulkhead Stock G10, 1/8"	1 sq ft	McMaster-Carr	$29.38	$58.76	$10.00	
	Fiberglass 2" Body Tubing for ebay Spacer	1"	Wildman Rocketry	$52.27	$52.27	$2.61	
	Main Chute 27" Toroidal	27"	Manufactured by club	-	-	-	Material acquired and available from past donation
	Fiberglass Nose Cone	2" dia 12" len	Madcow Rocketry	$40.00	$40.00	$2.00	3D Print Possible
	Tubular Kevlar Shock Cord	2x 19' of ⅜”	Giant Leap Rocketry	$26.92	$26.92	$5.99	
Total	-	-	-	$455.59	$543.73	$189.63	-
Payload	3D-Printed Parts	N/A	Self_Made	$100.00	$100.00	$3.77	
	RunCam Hybrid 2	3 cameras	Amazon	$99.99	$299.97	-	There might be a cheaper vendor available
	Led lighting bar	3 bars	Adafruit	$2	$5.85		There might be a cheaper vendor available
	Adafruit BNO085 9-DOF IMU	3 IMUs	Adafruit	$24.95	$74.85	$16.34	There might be a cheaper vendor available
	Data Gathering Custom PCB	5 PCBs	JLCPCB	$12	$60.00	$10.45	
	Data Management Custom PCB	5 PCBs	JLCPCB	$12	$60.00	$3.00	
	3s 18650 battery	2 batteries	Amazon	$19.99	$39.98	-	
Total	-	-	-	$945.09	$640.65	$33.56	-
Launches	Scale Model Motor (Aerotech G138)	2 scale motors	Aerotech	$31.99	$63.98	$78.10	
	Full-Scale Motor (Aerotech K1103X)	5 motors	Aerotech	$167.99	$839.95	$42.00	
	Test Launch Site Fees	5 launches	Tripoli Wisconsin / NAR	$15.00	$75.00	-	
Total	-		-	$214.98	$978.93	$120.10	-
Travel/Transport	Flights	19 People	Southwest	$309.00	$5,871.00	-	Subject to change with ticket prices
	Lodging	5 rooms for 5 nights	Embassy Suites	$127.00/room	$3,175.00	-	
	Rental SUV to haul vehicle	6 days	TBD	$150.00	$900.00	-	
	Rental minivans for transport in AL	2 minivans for 6 days	TBD	$200.00	$1,200.00	-	
Total	-	-	-	$786.00	$11,146.00	-	-
Total	-	-	-	$3,569.88	$14,506.91	$576.72	

Total Cost	$15,083.63						

Table 12: Budgeting

Funding plan

Funding Sources and Allocation of Funds

Madison West Rocket Club has multiple methods to earn enough funding to sustain a significant effort within the NASA Student Launch. We have raked many yards during the fall season and raised funds to continue the Rocket Design and development process without any interruptions. As of Sunday January 5, 2025, we have earned approximately $9,000 from 2 months of fundraising(October and November). We not only met our goal of $7,000, but we exceeded it by quite a large margin. While we have met all current funding goals, in the event that more funds are needed, we have 3 alternatives to obtain additional funding: Calling for donations from the community, developing a snow shoveling program to earn money in the winter, and finding sponsors for the club.

Material Acquisition Plan

Thanks to our club's long history, we have accumulated a large amount of extra materials in our workshop. We have fiberglass tubing, casings, shock cord, ripstop nylon parachute materials, and a nose cone for our rocket. In the event the vendors either do not have the product we need, or they are unable to provide it to us in a reasonable time, we will use the previous ones we have acquired from our workshop. We will need to purchase materials that we are unable to 3D print for our payload, as well as motors.

Development Timeline

Timeline Key

(yellow)	Workshop
(blue)	Organizational meeting

	SLI writing sessions
	NASA SL Events dates and due dates
	School
	Fundraising and Outreach

January 2025	
Wednesday 8	Subscale Flight Deadline
Wednesday 8	CDR due
Monday 13	Organizational meeting
Friday 17	Workshop
Saturday 18	SLI writing session
Monday 20	Organizational meeting
Friday 24	Workshop
Saturday 25	SLI writing session
Monday 27	Organizational meeting
Friday 31	Workshop
February 2025	

Saturday 1	SLI writing session
Monday 3	Organizational meeting
Wednesday 5	CDR Teleconference
Friday 7	Workshop
Saturday 8	SLI writing session
Monday 10	Team photos due
Tuesday 11	FRR Q&A
Tuesday 2/11- Monday 3/17	Work on FRR
Friday 14	Workshop
Saturday 15	SLI writing session
Monday 17	Organizational meeting
Friday 21	Workshop
Saturday 22	SLI writing session
Monday 24	Organizational meeting
Friday 28	Workshop
March 2025	
Saturday 1	SLI writing session
Monday 3	Organizational meeting
Friday 7	Wingra Science Night

Saturday 8	SLI writing session
Monday 10	Organizational meeting
Friday 14	Workshop
Saturday 15	SLI writing session
Monday 17	FRR due
Wednesday 19	Outreach
Thursday 20	Outreach
Friday 21	Workshop
Saturday 22	SLI writing session
Monday 24	FRR teleconferences
Friday 28	Workshop
Saturday 29	SLI writing session
Monday 31	Organizational meeting
April 2025	
Monday 7	Organizational meeting
Friday 11	Workshop
Monday 14	Payload Demonstration Flight
Thursday 17	Launch week Q&A
Friday 18	Workshop

Wednesday 30	Team arrives in Huntsville, AL
May 2025	
Thursday 1- Friday 2 Saturday 3 Sunday 4 Monday 19	All-day Launch Week Events Launch day Backup Launch Day. PLAR submitted

Table 13: Timeline