Flight Readiness 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

March 16, 2025

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Summary of FRR 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 219 hours working on the FRR 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: 90.8 ft/s

Individual Sections Size and Mass

Vehicle Dry Mass: 16.07 lbs
Vehicle Wet Mass: 19.29 lbs
Vehicle Burnout and Landing Mass: 17.46 lbs
Nose Cone section: 2.62lbs
Upper Section (incl. Payload & Electronics Bay): 8.76 lbs
Payload & E-Bay: 5.94 lbs
Booster Section (dry): 4.69 lbs
Recovery Components (Parachutes and Shock Cords): 1.93 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.

Changes Made Since CDR

Changes Made to Vehicle Criteria

We altered the spacing of the retention tie rods, which retain major parts of the upper section. We increased the spacing from 2.15 to 3 in. This change was made to leave greater space for the payload and to avoid blocking the camera's view of the tank. During the flight, we used a lighter rocket by 0.8 lbs. We made this decision to limit kinetic energy at impact. This led to an altitude change, as detailed in the mission performance predictions. During the actual first flight, we used a smaller payload (as detailed in the flight one section). To reach our new lighter mass, we calculated a ballast of 2.11lbs, which we attached to the tie rods and placed in the upper section. Originally, we planned to attach the electronics bay coupler to the upper tube and the nose cone to the nose cone shoulder just using bolts. However, to ensure that these bolts stay in place throughout flight, we decided to attach these bolts to PEM nuts, which were placed so they were flush with the side of the electronics bay coupler and nose cone shoulder. We counter sunk into the outside of each attachment point, so the bolts would be flush with the outer diameter of the vehicle. While we originally planned to use lock nuts, we determined that the lock nuts were not necessary to keep each part in place, and they would simply be an impedance to assembly. While attaching the main parachute and its Nomex, we employed a technique suggested to us by the panel of CDR teleconference reviewers.

Changes Made to Payload Criteria

Tank System

We changed the 2D tanks' pill shape water container to an asymmetrical style. Previously, both the top and bottom inner corners were rounded, but this caused issues with our slosh. The rounded top corners caused the water to fall back down, interrupting the flow of slosh. We changed the design to feature square top inner corners, to prevent the disruption and get better data from the slosh. We also adjusted the left and right margins to allow a better camera view. The previous design in the CDR was not completely visible in the camera shot, preventing access to valuable data. We also adjusted the grid, so that the proportions would match the new margins.

Electronic Sensor System

After CDR, we decided to remove the electronic sensor system, due to manufacturing concerns and development time constraints. We also experienced an unforeseen equipment failure with our hot air soldering station, resulting in our reduced capability to assemble the Electronic Sensor System.

Baffle Design

At CDR, we had preliminary designs, based on water dynamics literature, that showed that baffles worked best at the peaks of the wave and that an increased contact between the baffle and the water better decreased the slosh. Due to this, we created two baffle designs, a vertical baffle and a raised grid baffle. After both on-ground testing and testing within the rocket during our vehicle test flights, we observed that both baffle designs decreased slosh.

Changes Made to Project Plan

Since CDR, we have performed and planned new tests to evaluate the performance of our vehicle. We performed a set of tests on the parachutes to evaluate the coefficients of drag. Additionally, we updated our funding plan and budget, to match the team's current expenses.

Vehicle Criteria

Design and Construction of Vehicle

Booster Section

We started by assembling the fin can. The fins and centering rings were manufactured on a CNC mill out of 1/8" diameter G10 fiberglass purchased from McMaster-Carr. We epoxied the first centering ring 1 inch from the base of the vehicle, and the second one 6.4 in from the base of the vehicle.

Two 3D-printed fin aligning rings were exposed to the aftmost centering rings, to keep the fins aligned straight.The final centering ring was epoxied one inch from the top of the motor mount, in order to provide structural integrity and to keep the shock cord from peeling off from the motor mount tube.

The top two centering rings had holes cut into either side that were 0.125” x 0.5”, the exact size of the shock cord. During the glue-up, we pulled the shock cord down through those grooves and laminated it to the sides of the motor tube (also shown below).

Figure 1: Fin Can Assembly

We cut notches in the booster tube for the fins and slid it on over the assembled fin can. We attached the tube at all interfaces (centering rings and fins) with epoxy fillets.

Figure 2: Fin Can Insertion

The external fin fillets were formed with West Systems epoxy, then filled and sanded smooth. The fillets were filled with epoxy combined with a thickening agent and then sanded down with progressively higher grit sandpaper, to ensure an aerodynamic surface. Finally, we rounded over the exposed edges of the fin, to increase performance.

Figure 3: Assembled Booster Section

Upper Section

The upper section was created in 3 major parts: the payload, which lies inside of the upper tube, and the vehicle. The payload construction is outlined in the payload design section. The vehicle-based parts of the upper section include the upper tube itself; a ballast during the first two vehicle flights, to compensate for the slightly lighter payload; 3 bulkheads; and a section of coupler tubing, to protect the payload from ejection gases. We bought the upper tube from Wildman Rocketry and cut it to the length of 32 in. According to our design, we drilled holes in the upper tube and through the coupler, using a hand drill and a 3D-printed aligner. We then attached PEM nuts to the set of holes in the electronics bay coupler, such that the PEM nuts would be flush with the coupler. These PEM nuts hold the bolts that connect the upper tube and the electronics bay coupler. We then used a countersink drill bit to slightly drill into the upper tube, so the bolts would be flush with the upper when driven in. During the first flight, we created a ballast of 960g, so the mass of the ballast along with the mass of the smaller payload would equal our predicted mass for the final payload. We achieved this weight using lead beads within a plastic casing and copper beads within a plastic bag inside a 3D-printed enclosure attached to the retention tie rods (mentioned within the payload retention section) with nuts. We attached 2 screw terminals and a U-bolt to the top and bottom bulkheads, and drilled holes in each for wires and tie rods to pass through. We epoxied a coupler to the top bulkhead to keep out ejection gases.

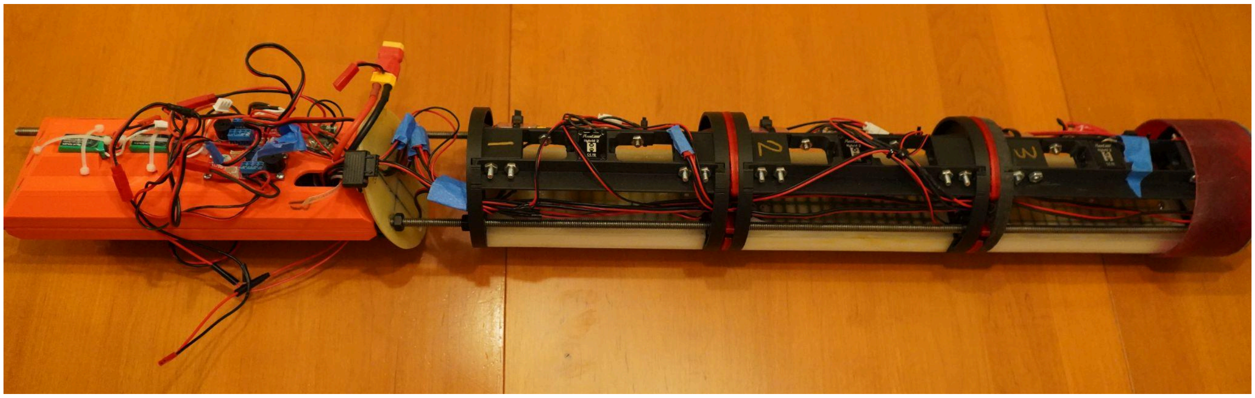

Figure 4: Full Payload and E-Bay assembly

Nose Cone

We bought our nose cone and nose cone shoulder common off the shelf (COTS) from Wildman Rocketry. We attached the nose cone to the shoulder with the same method as our attachment of the electronics bay coupler to the upper tube, explained above.

Payload Retention

We purchased 2 stainless steel tie rods COTS and cut them to length (34 in). We attached the electronics bay, payload, ballast, and 3 bulkheads to the tie rods with standard nuts.

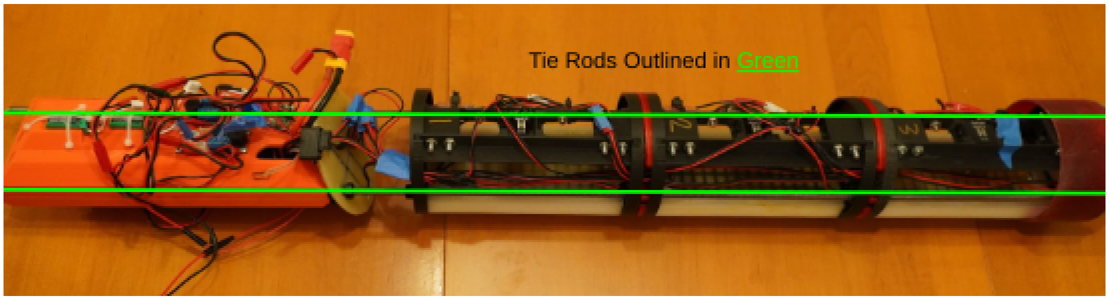

Figure 5: Full Payload and Electronics Bay Held Together by Tie Rods

At the top of the payload section and bottom of the e-bay coupler, there is a floating bulkhead that has a U-bolt and screw switches (top shown below) for recovery attachment.

Figure 6: Upper Bulkhead

There is also a bulkhead at the top of the e-bay coupler. The bulkheads at each end of the coupler help to retain the electronics bay, and the bulkhead at the top of the payload helps to protect and retain the payload, shown below.

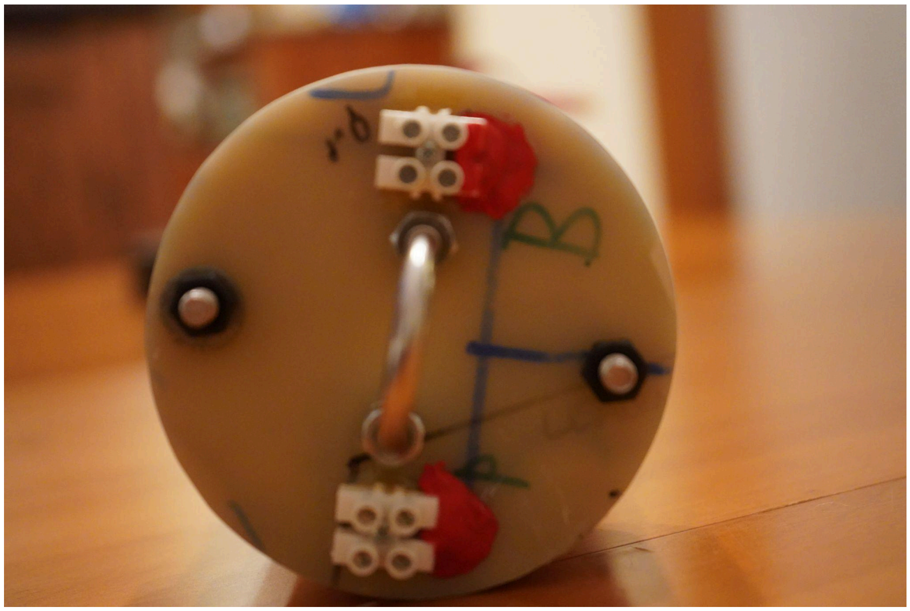

Figure 7: Payload Retention Bulkhead

Electronics Bay

Our electronics bay adheres to our CAD models, except for certain components which do not affect its functionality. The electronics bay consists of a 10” section of 4” diameter fiberglass coupler tubing, purchased COTS from Wildman Rocketry. We epoxied a 2” length of 4” diameter fiberglass airframe to the center of the coupler tube, to act as a switch band.

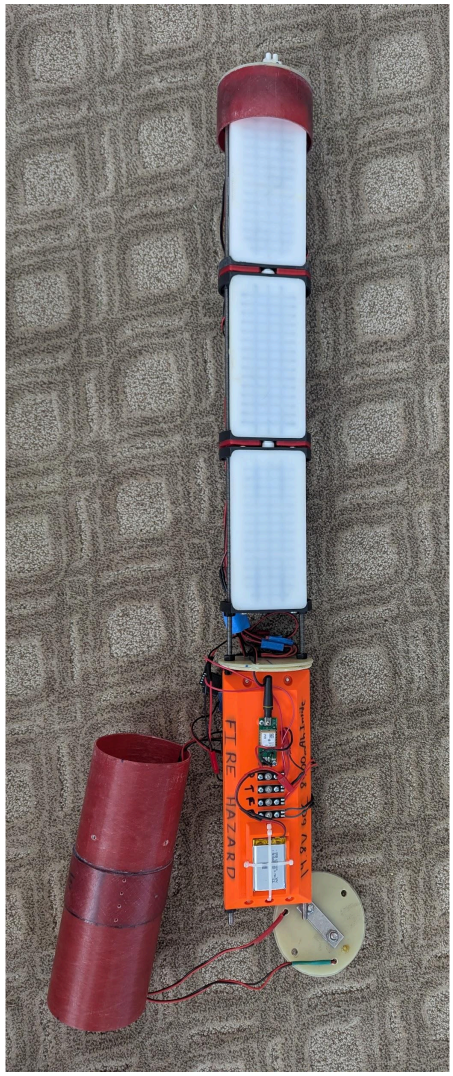

Figure 8: Avionics Mounting Sled and Payload Assembly

We used our CAD model to make 2 3D-printed jigs, to aid in drilling the arming and vent holes in the correct locations. The holes were drilled to match the CAD model. Additionally, we used a 3D-printed jig to drill holes to mount the upper section to the electronics bay. We installed Penn Engineering & Manufacturing (PEM) nuts to the inside face of the electronics bay, to act as a backing for the bolts that hold the electronics bay to the upper section.

Figure 9: PEM Nut Location

The bulkheads were machined on a CNC mill out of 1/8" G10 fiberglass sheets, purchased from McMaster-Carr. Each section of the stepped bulkheads were machined separately and then were bonded together, using the threaded rod holes as a guide. The threaded rod spacing was changed from CDR to 3”, to allow more lateral space for the payload.

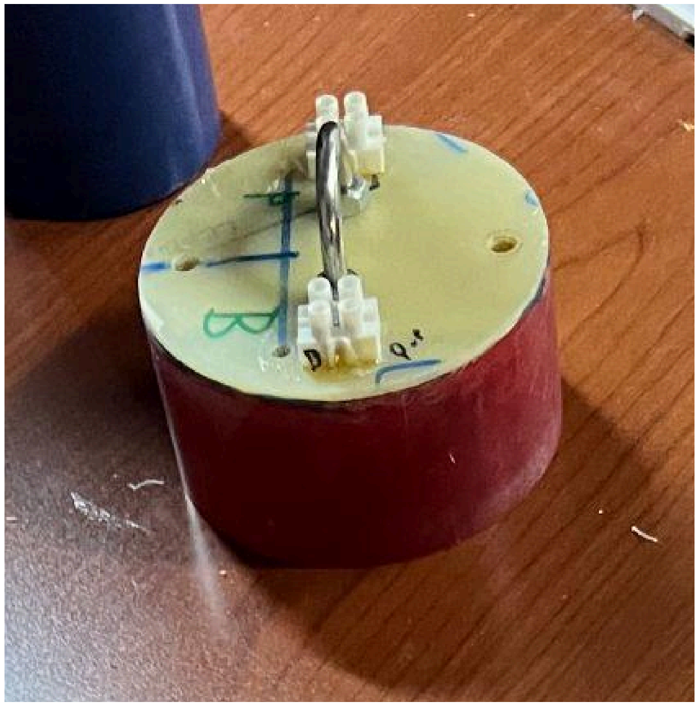

Figure 10: Upper Retention Bulkhead Assembly

The 3D-printed avionics mounting sled was redesigned to accommodate the payload battery. The components remained the same: 2 StratoLogger CF flight computers, an EggFiner GPS Tracking Transmitter, 3 LiPo Batteries to power the flight computers and tracker, and 4 screw switches to arm the flight computers, tracker, and payload. The sled was printed from high-visibility orange material and was marked as a fire hazard.

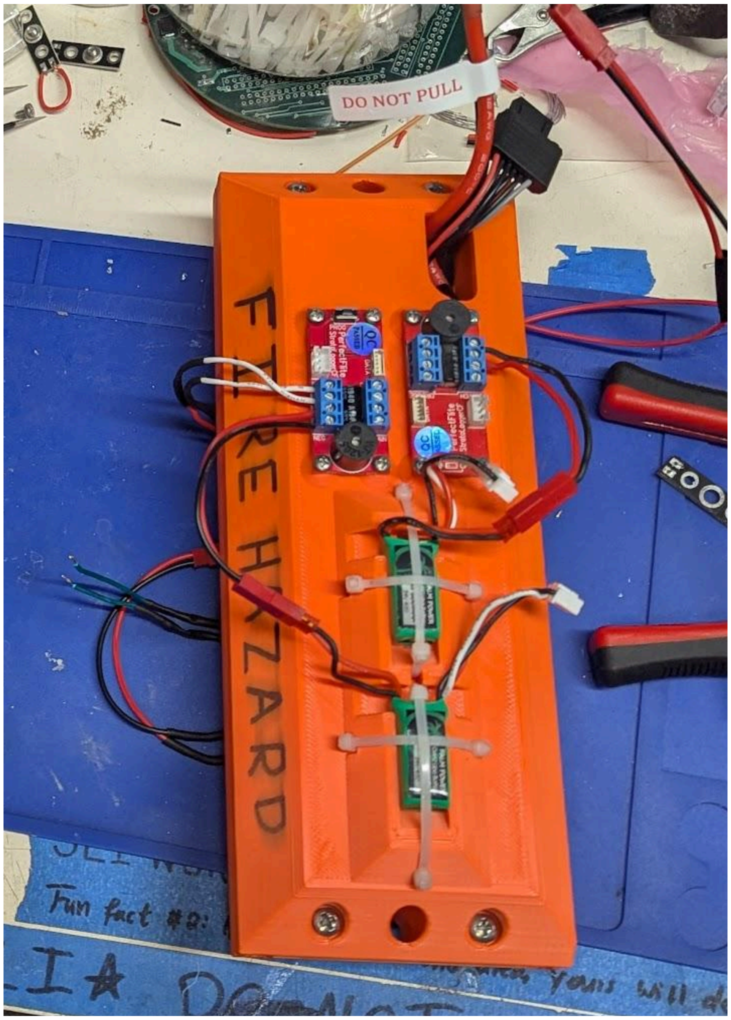

Figure 11: Electronics Bay Avionics Mounting Sled Assembly

Recovery Subsystem

Drogue Parachute

Our drogue parachute was the same as outlined in our CDR report: a 12” ripstop nylon skirted parachute purchased COTS from Recon Recovery. The parachute is contained in a nomex protector during ascent and is deployed at apogee. Due to the amount of drag generated by the body of our vehicle during descent under drogue, our calculations of the drogue coefficient of drag are somewhat inaccurate.

We used data provided by “Shape Effects on Drag” from the NASA Glenn Research Center to estimate the drag coefficient of the rocket body to be 0.25. After evaluating the data taken from both of our test flights, we collected an accurate drag coefficient variable, which allowed us to very roughly estimatethe drogue parachute coefficient of drag as 1.5, which coincides with the published value.

Main Parachute

In our simulations so far, the main parachute has been simulated at 66”. We attempted to match this size during manufacturing; however, the exact diameter of our manufactured parachute ended up at 65.6”. The parachute itself is made from 20 gores of alternating blue and yellow ripstop nylon, to match our school’s colors. Each gore is 10.3” long, and the diameter of the iris of the parachute is 10.5“.

Figure 12: The Main Parachute Folded In Half

Figure 13: The Main Parachute Inflated In Wind During Recovery

In our simulations, a drag coefficient of 1.8 was used for the main parachute. This value was acquired from previous parachutes of similar sizing. After analyzing the descent data from the test flight, we calculated the parchute's drag coefficient to be 2.3. The flight computers are set to deploy the main parachute at an altitude of 700 ft, consistent with our CDR report. During both of our test flights, the primary flight computer successfully deployed the main parachute with the primary deployment charge.

Flight 2 data analyzation

During our second test flight, the flight computer deployed the main parachute at an altitude of 900 ft, 200 ft higher than the target deployment altitude of 700 ft. The total descent time of the second flight was 95 seconds, which violates NASA's flight requirement of a maximum 90-second flight. Our flight requirements violation was likely a direct outcome of our flight computer failure deploying the main parachute too high. Throughout the flight, the rocket drifted ~2,800 feet from the launch pad.

Energetics

Our vehicle contained 4 separation charges, including 2 primary and 2 backup charges, one of each for each parachute. Both main parachute charges were located in the top of the nose cone, above the main parachute, and were connected to the screw terminals in the forward bulkhead. Both drogue parachute charges were located just below the drogue parachute in the booster tube and connected to the screw terminals in the aft bulkhead. A mentor attached all charges before launch, acting with caution in case of the highly unlikely event of accidental firing. A mentor prepared all charges before launch.

Charge purpose	Amount of black powder
Primary for main parachute	2.0g
Backup for main parachute	3.0g
Primary for drogue parachute	2.3g
Backup for drogue parachute	3.5g

Table 1: Deployment Charge Sizing Chart

Separation Points

As discussed in the CDR, our vehicle has two separation points; one for drogue deployment and the other for main parachute deployment. The first separation point is located between the booster section and payload section of the rocket, where the electronics bay coupler interfaces with the booster tube. The second is located near the top of the vehicle, where the nose cone shoulder interfaces with the upper part of the payload tube. The image(s) below depict the separation points as they are in our finished constructed vehicle.

Figures 14, 15, & 16: Full Vehicle, Lower Separation Point, Upper Separation Point

Deployment Computers

Consistent with our CDR, our electronics bay contained two Perfectflight Stratologger flight computers, one as our primary and the other as our backup, to provide redundancy. To ensure complete system redundancy, our vehicle was constructed providing each Stratologger its own 7.4V Lipo battery and screw switch for arming. The primary computer is programmed to ignite the drogue deployment charge at apogee, and the main parachute charge at 700 feet, and has functioned correctly on all of our scale flights. The backup computer is set to ignite the drogue charge one second after apogee, and the main parachute charge at 600 feet.

Telemetry

Our vehicle contains two methods of tracking: an EggFinder GPS Tracking System and an RDF Radio Tracking System.

The EggFinder GPS Tracking System uses a Global Positioning System (GPS) module and a UHF radio transmitter to gather GPS data and relay it to a ground receiver. The EggFinder transmitter is placed inside the electronics bay section of the vehicle and is mounted to the avionics mounting sled. The transmitter is powered by a 1,800mAh 3.7V LiPo Battery mounted to the sled, to ensure a long runtime, in case pad idle times or recovery times are longer than expected.

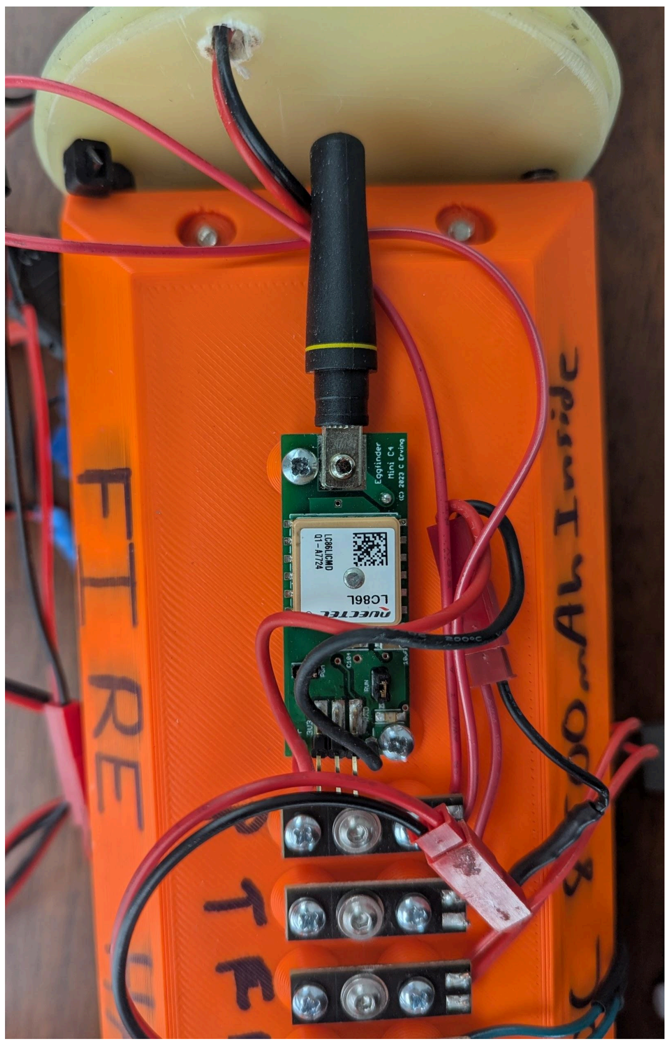

Figure 17: EggFinder GPS Tracking System Transmitter as Mounted

The RDF Radio Tracking System consists of a transmitting beacon emitting a signal over 222.67MHz and a directional receiver that can be used to triangulate the vehicle's position after landing. The transmitter is placed inside the drogue recovery bay of the vehicle and is connected to the aft end of the electronics bay via a quicklink. The transmitter is powered by an internal battery and can remain powered on for several days, more than long enough for us to locate the vehicle, in case pad idle times or recovery times are longer than expected.

The EggFinder GPS Tracking System is tuned to 915.0MHz during flight and the RDF Radio Tracking System is tuned to 222.67MHz during flight.

Mission Performance Predictions

Flight Profile Simulations

The following sections display mission performance predictions for our launch vehicle during flight, as well as a comparison to altitude data gathered during our vehicle and payload demonstration flights. All simulations were performed using the OpenRocket software with a model that was constantly updated as we built our rocket to reduce any discrepancies. For some values, various online calculations or hand calculations were used. Additionally, we conducted a redundant simulation in RasAeroII to ensure accuracy.

Simulated Altitude Profile

The graph below shows a simulation of our vehicle's projected altitude under no wind. Our vehicle launches with an AeroTech K-1103X plugged motor, which, after ignition, will power the vehicle until motor burnout, 1.6 s after launch. Following burnout, the vehicle will coast to a simulated apogee of 4929 ft, approximately 17.2 s after launch. At apogee, our drogue parachute will deploy, and the vehicle will descend at a rate of ~83 ft/s. Once the vehicle reaches an altitude of 700 ft, the main parachute will deploy, slowing the vehicle to a descent rate of ~19 ft/s. Finally, the vehicle will touch down, at approximately 105s after launch. We simulated our descent with a coefficient of drag (C_d) of 1.5 for our drogue parachute and 1.8 for our main parachute, based on parachute profiles and prior flight testing. Additionally, we calculated the approximate drag area of our vehicle using OpenRocket and added a massless parachute to our simulation to account for body drag, resulting in a drogue descent rate that was very close to the measured descent rate. The total flight time is expected to be approximately 105s, and the descent time approximately 87.8 s with a drift of approximately 1932 ft under 15 mph of wind.

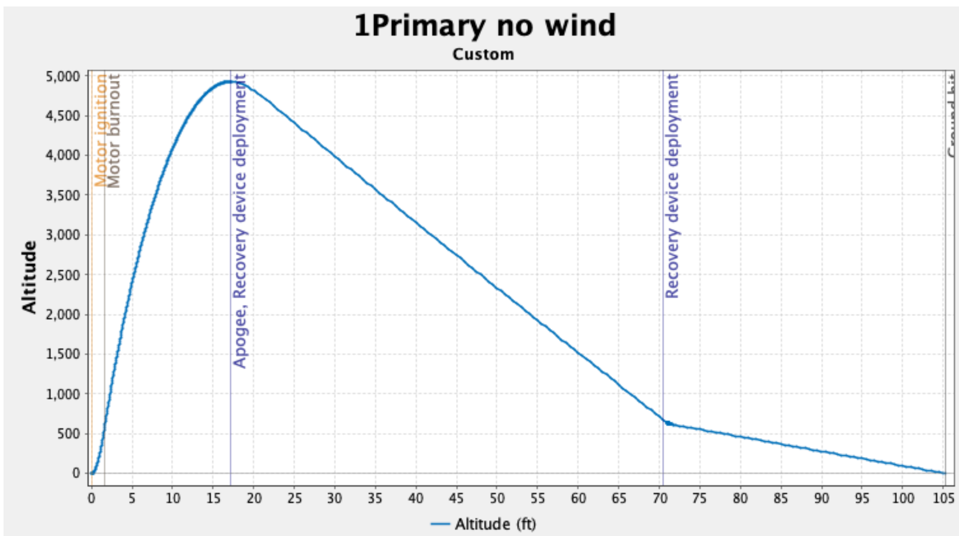

Figure 18: Simulated Altitude Profile of the Entire Flight

Our simulation under no wind reported an overshoot of our targeted altitude of 4,500 ft by 9%, and we overshot our predicted altitude by 0.5%. Because of an unforeseen weight reduction, our predicted altitude increased by ~400 ft. This weight decrease still falls within NASA requirements and was deemed acceptable.

Actual Altitude Profile

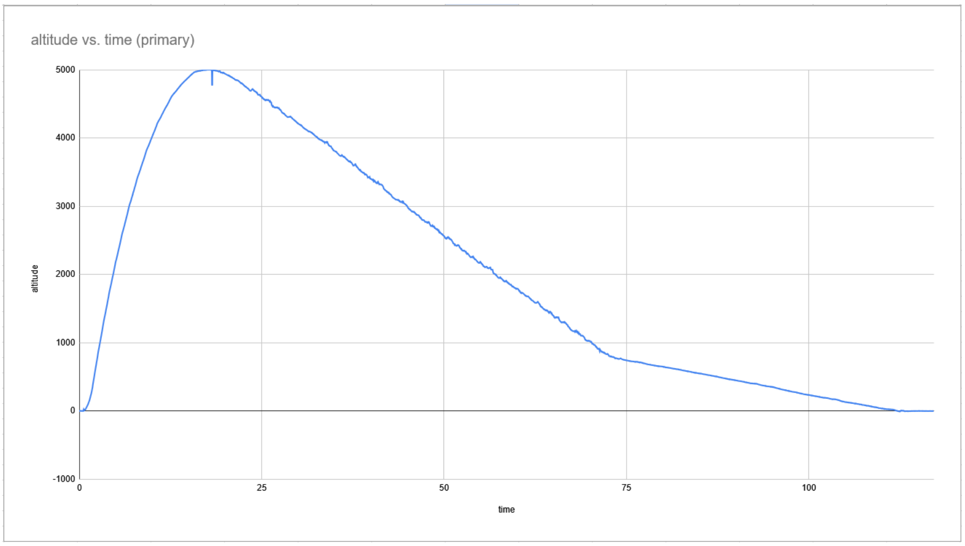

Figure 19: Actual Altitude Profile of the Vehicle Demonstration Flight

During our vehicle demonstration flight, our vehicle reached an apogee of ~5,000 ft. This is approximately 100 ft above our predicted altitude, likely due to the difficulty of accurately calculating the surface finish of the vehicle. Due to errors in flight controller programming, described further in the vehicle demonstration flight section, the main parachute deployed at 900 ft, instead of 700 ft.

Wind Speed vs. Altitude

Our vehicle was simulated under varying wind conditions: 0 mph, 5 mph, 10 mph, 15 mph, and 20 mph. Under a 20 mph wind at the time of launch, the maximum allowed by the NAR, the vehicle would experience a 98 ft reduction in altitude at apogee.

Wind Speed	Apogee (ft)	∆ Apogee (ft)
0 mph	4929	0 ft (0%)
5 mph	4922	-7 ft (-0.1%)
10 mph	4903	-26 ft (-0.5%)

15 mph	4873	-56 ft (-1.1%)
20 mph	4831	-98 ft (-2%)

Table 2: 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 thrust-weight ratio of our vehicle is 13.1 : 1.

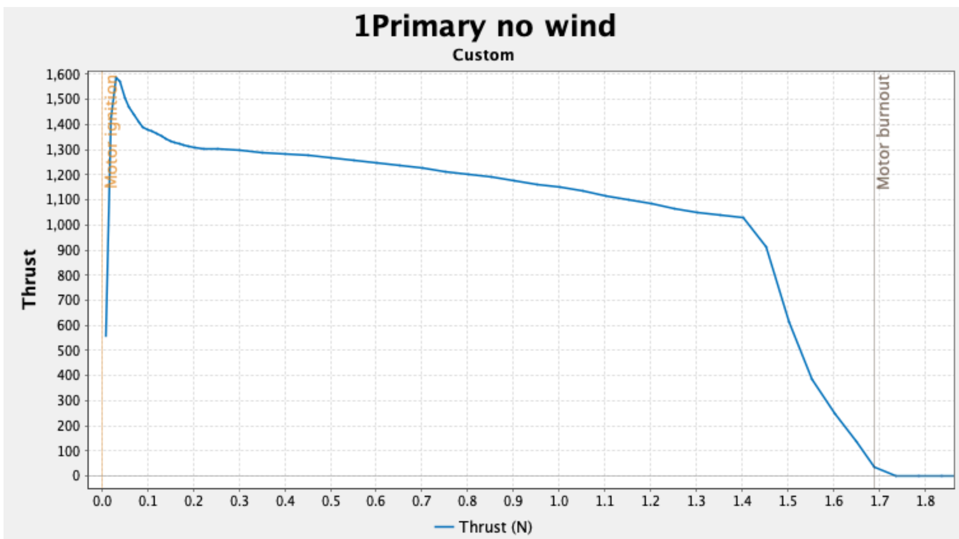

Figure 20: Thrust Profile

Velocity Profile

The graph below shows the rocket's simulated velocity profile. The vehicle will reach its maximum velocity of 636 ft/s (433 mph) 1.6 s after launch. The vehicle will remain subsonic for the entirety of its flight, with a maximum mach value of 0.57. The vehicle will exit the launch rail at a velocity of 90.8 ft/s.

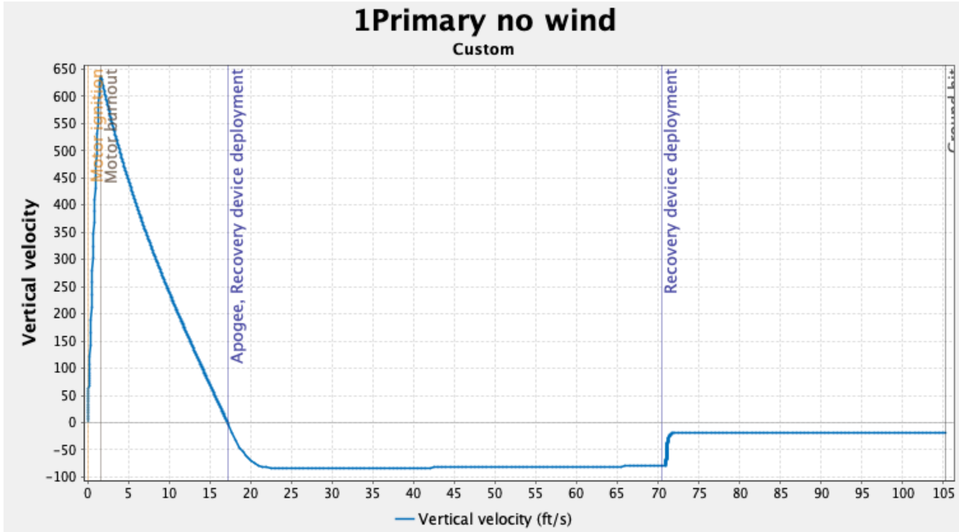

Figure 21: Velocity Profile

Acceleration Profile

The following chart shows our vehicle's simulated acceleration during its flight. OpenRocket's simulations for parachute deployment force are inaccurate and give a value of 17.7 G. To obtain a more accurate estimate, we used 2 calculators. One was an online calculator that utilizes calculation method one from "Parachute Recovery Systems Manual" (Theo W. Knacke, 1991). This returned a deployment force of ~2.4 G at deployment. We also used a calculator called OS Calc, developed by Gary Peek and Jean Potvin of the Parks College Parachute Research Group, which utilizes its own calculation method for deployment force but needs parachute opening time to function. This returned an even lower estimate of 1.5 G at deployment. With this accounted for, the highest acceleration our vehicle will experience is 17.5 G (565 ft/s^2), shortly after ignition. With our tests and vehicle demonstration flight attempts, we verified that it was constructed to meet expected loads.

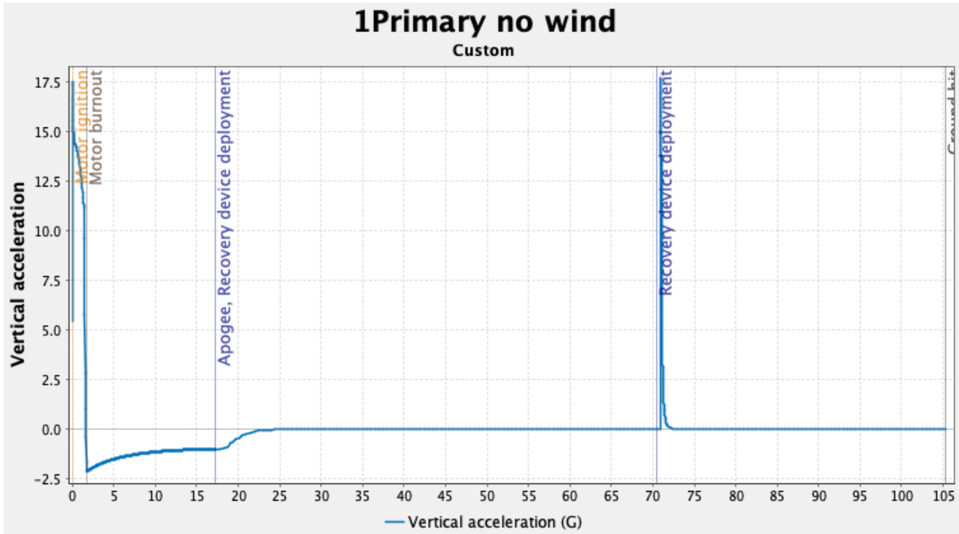

Figure 22: Vertical Acceleration During the Entire Flight

Vehicle Flight Sequence

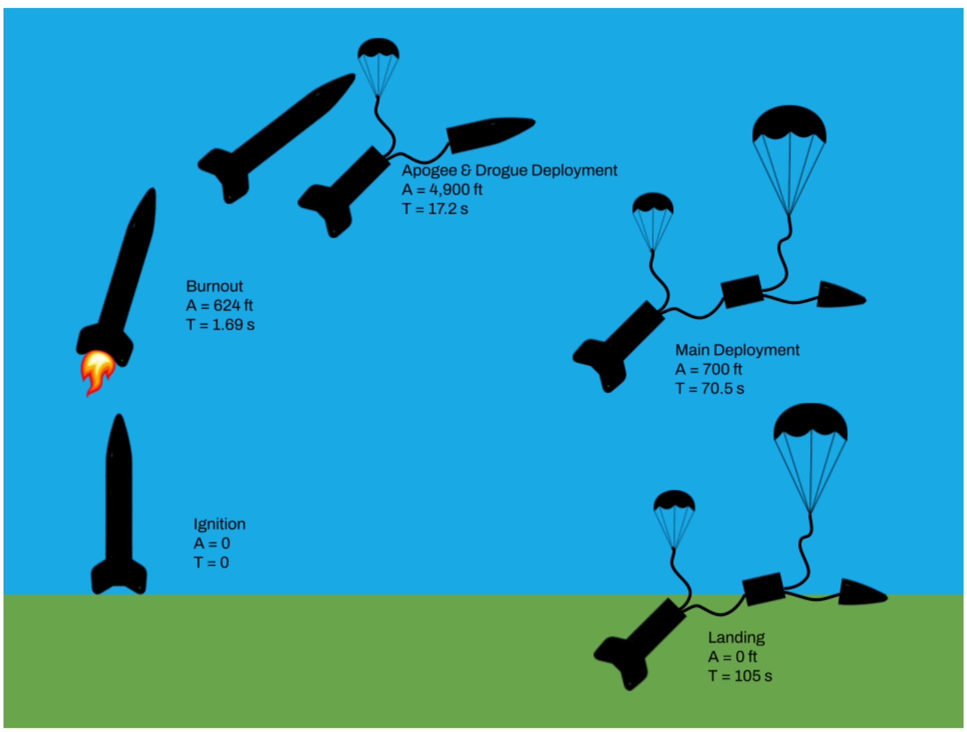

Figure 23: Chart of Vehicle Flight Sequence

The chart above shows our vehicle's predicted flight sequence. We have constructed a standard dual-deployment craft, with a primary flight computer used to deploy drogue and main parachutes, and a backup flight computer for redundancy. At apogee, the drogue parachute will deploy, with the backup charge set to deploy one second after apogee. The main parachute will be deployed at an altitude of 700 ft, and the backup charge will fire at 600 feet. At no point during the flight will the payload separate from the rocket, and the vehicle will be recovered in three tethered sections: nosecone, upper section, and booster section.

#	Event	Time (s)	Altitude (ft)	Trigger
1	Ignition	0	0	Launch Controller
2	Burnout	1.69	624	--
3	Apogee	17.2	4,900	--
4	Drogue Deployment	17.2	4,900	Flight Computer
5	Main Deployment	70.5	700	Flight Computer
6	Landing	0	105	--

Table 3: Flight Sequence of Events

Actual Sequence of Events

The following table shows actual times and altitudes for events from our second VDF attempt. We were unable to get a value for motor burnout, as it is difficult to detect using barometer data. These times and altitudes were similar to our expected values.

#	Event	Time (s)	Altitude (ft)	Trigger
1	Ignition	0	0	Launch Controller

2	Burnout	unknown	unknown	--
3	Apogee	~18	4,999	--
4	Drogue Deployment	~18	4,999	Flight Computer
5	Main Deployment	71	900	Flight Computer
6	Landing	~113	0	--

Table 4: Actual Sequence of Events

Simulation Redundancy

We simulated our vehicle primarily using OpenRocket, but we also used RasAeroII for redundancy. When simulating our design with RasAero, we got an estimated apogee of 4,921 ft. We also got a time to apogee of 17.2 seconds, which is what we got from OpenRocket as well (under no wind). While RasAero is incapable of holding the data for our precise payload component locations and some of the recovery hardware, we added mass components, so that the mass of the rocket in both simulations is exactly the same. RasAero gave a CP location of 74.1 inches from the nose, while OpenRocket gave us a CP location of approximately 74.2 inches from the nose. Other predicted values differed similarly between simulations, and these differences were well within our margin of error. The descent speed and descent time were more difficult to calculate in RasAero but we got a time that matches similarly to OpenRocket simulations and is also slightly below the NASA requirement of 90 seconds.

Stability

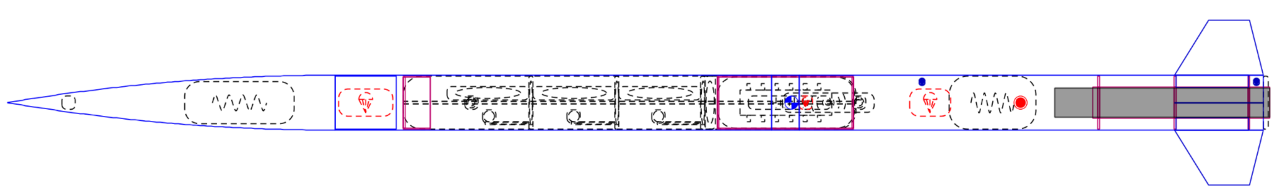

Figure 24: Vehicle Stability

A depiction of our vehicle's design is shown above. The blue circle (located inside the coupler) depicts the center of gravity (CG), and the red circle (near the shock cord) depicts the center of pressure (CP). The CG was measured to be ~52 in from the vehicle's nose with no motors, and with a motor, it is ~57.4 in from the nose. The center of pressure is ~74.2 in from the nose. The vehicle's static stability margin is 4.19 calibers (18.2 %), and the static stability margin is 4.20 calibers at rail exit.

Descent Time Calculation

We obtained the predicted descent time of the vehicle through OpenRocket, in which we ran most of our simulations. From this, we determined that the vehicle will have a descent time of 87.8 seconds. We obtained the descent time of the 2 flights by viewing the altimeter data from the flights and subtracting the time of apogee (when the vehicle reached its peak height) from the time of landing (when the altimeter data stopped showing decreases in height). From this, we determined the first flight had a decent time of 71.25 seconds, and the second flight had a descent time of 95 seconds.

Wind Speed vs. Drift

These values were approximated by multiplying the descent time of the vehicle with the wind speed.

Wind speed	**Approximate Drift given nominal descent time(87.8s)**	**Approximate Drift given descent time of first flight (71.25s)**	**Approximate Drift given descent time of second flight (95s)**
0mph	0 ft	0 ft	0 ft
5mph	644 ft	522 ft	697 ft
10 mph	1,288 ft	1,045 ft	1,393 ft

15mph	1,932 ft	1,567 ft	2,090 ft
20mph	2,575 ft	2,090 ft	2,787 ft

Table 5: Wind Speed vs. Drift

The flight time during the second flight was greater than expected, due to the release of the main parachute at 900 ft, instead of the planned 700 ft. This also led to greater drift than expected. We recognize that given the radius of the launch site in Huntsville (2,500 ft), in the case of 20mph wind during launch, given our nominal descent time, our rocket has the potential to drift outside of this radius. However, because our descent time is close to the maximum flight time requirement of 90 seconds, we plan to make changes to decrease our descent time. In particular, we plan to reef the shroud lines of the parachute by tying them closer to the parachute and thereby decreasing the surface area of the parachute during descent. This will decrease our descent time by an amount determined by how much we reef the shroud lines. Consequently, the maximum drift under 20mph winds will be less than 2,500 ft.

Kinetic Energy at Impact

All kinetic energy was calculated using the formula KE=1/2mv^2. We individually weighed each section of the rocket, as well as individual parts of the sections, multiple times to verify accuracy. We obtained the predicted hand-calculated velocity by comparing an online calculator's results with the results of our OpenRocket simulations. We obtained the descent velocity of the 2 flights by taking the average velocity of the altimeter data under the main parachute.

Part	**Kinetic energy under main at impact** Using hand-calculated descent velocity (19 ft/s)	**Kinetic energy under main at impact** Using measured descent velocity of first flight (16.2 ft/s)	**Kinetic energy under main at impact** Using measured descent velocity of second flight (20.4 ft/s)
Nose Cone	8 ft-lbf	6 ft-lbf	10 ft-lbf
Upper Section	49 ft-lbf	36 ft-lbf	57 ft-lbf
Booster Section	29 ft-lbf	21.5 ft-lbf	34 ft-lbf

Table 6: Kinetic Energy at Impact

Section	**Kinetic energy under drogue at impact (ft-lbf)** Using hand-calculated descent velocity (83 ft/s)
Upper section + nose cone section	1,219 ft-lbf
Booster section	564 ft-lbf

Table 7: Kinetic Energy at Impact if Main Parachute Does Not Deploy

Payload Criteria

Payload Objective

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”. Baffles are often used to mitigate the sloshing effect, which can cause risk, due to slamming on the tank walls. We are comparing 2 baffle designs to determine which is the most effective. We are measuring slosh in an SL rocket to determine which baffles dampen the slosh the greatest, and by how much during the flight.

Changes Made Since CDR

Component System	**Change Made**	**Justification**
Tank	We increased the right and left margins of the tank. In the CDR, they were 0.125 in each, but we increased the width to 0.469 in.	We increased the margins, so that all parts of the grid would be visible in the view of the camera. If grid sections were out of view, it would obstruct proper data collection, which was why we made the change.
Tank	We designed vertical baffles and gridded baffles. Previously, we had a vertical baffle concept with a single baffle.	We chose these designs after researching past papers and observing slosh from our test flight.
Tank	We changed from a completely round tank to a half-round, half rectangular tank (see figure XX).	The round tank on top altered the slosh too much and made the data collection difficult, as it blocked the sensors. However, we still wanted a round tank, due to it matching our research, so we kept it on the bottom.

Tank	In the CDR, we planned to use 3D-printed PLA and epoxy to seal the clear plastic to the tank. We changed our printing material and clear plastic to high impact polystyrene and used acetone to make a watertight seal.	Polystyrene dissolves in acetone, which we used to securely attach the tank cover, to create a more watertight seal.
Tank	We added a simethicone anti-foaming agent to the water in the tanks.	The simethicone anti-foaming agent was added to the water to improve data integrity. During the test flight, we discovered that the accuracy of our camera data was lower, due to excessive bubbles and foaming caused by forces in flight. We added an anti-foaming agent in the second flight to prevent this.
Tank	We dyed the water a bright orange color.	This maximized the contrast between the water in the tank and the glare from our transparent blue tank. This optimized our footage for the data extraction code, which uses color to calculate the amount and placement of water in each frame of footage.
Electronic Sensor System	We removed our electronic sensor system outlined in the CDR.	We could not get the PCB boards functioning in time for the flight or FRR. Also, we found the cameras more reliable than expected, removing the need for additional data.
LEDs	In the CDR, we were planning to use Adafruit LED lighting bars. We have changed our design to use LED strip lights with adhesive backings	The lighting bars contained only one LED each, with a diffuser attached. These were not bright enough to illuminate the tank

	instead.	and also took up too much space. The light strips are smaller and brighter. The adhesive allows us to secure the lights to the mounts.
LEDs	We moved the location of the LED lights from one side of the tank to the top and bottom.	Provides brighter and more even light for the camera to view the tank, without blocking the view or causing glare.
Wiring	Changed 11.1V 2,600mAh LiPo Battery to 14.8V 8,000mAh LiPo Battery	We calculated the capacity needed for the NASA required minimum of 3 hours of payload runtime and launch, without going below 20% of battery capacity to avoid damaging the LiPo.
Wiring	Added buck converters to the wiring system.	The converters ensure correct and consistent voltage for the LED strips and cameras.
Wiring	Moved our battery mount from above the payload into the e-bay.	Our battery was too large to fit into the payload section with 3 tanks.
Retention System	Changed the tie rod spacing from 2.5 to 3 in apart.	The narrow tie rods blocked the camera's view of the tank, so we made them wider, to avoid blocking the tank.
Retention System	Redesigned the camera and tank mount to have stronger design elements, such as rails from top to bottom of the tank, to hold the camera (see figure XX).	Our original design was not structurally sound and broke easily.
Retention System	Changed printing material for mount from PLA to Carbon filled PA6 (Nylon).	We realized that the PLA would not be strong enough to support our design, so we switched the material to nylon carbon fiber, which is more durable.

Table 6: Payload Changes Since CDR

Payload Design

Design Overview

Our payload consists of 3 tanks, stacked vertically and filled with dyed water, each with a camera facing them, to record the slosh during flight. We have one control tank with no baffles, one with vertical baffles, and one with grid baffles. We will collect the data with the cameras and analyze it by comparing the 3 videos, to determine the effectiveness of the different baffle types in the rocket. The tanks are held in place with screws and are on a mount holding the cameras, as well as LED lights, to illuminate the tanks during flight. The payload is then placed on threaded rods passing through the electronics bay and beyond the payload and held on with nuts.

Tank System

Our payload has 3 tanks. The tanks of our payload consist of two components: a 3D-printed body and a clear sheet. The tank is modeled off of a cross-section of a tubular tank, as it would give us the best data and would be most space efficient. The 2D tank allows us to analyze slosh in two dimensions. A 3D tank may have been too complicated and would require much more advanced data collection and analysis systems. With this configuration, only one camera is required per tank. The body is made of high impact polystyrene (HIPS), which is cost-effective and long lasting. We also chose HIPS, as we could use acetone to glue the body to the cover, also made of polystyrene, as the dissolved material would create a watertight seal and prevent leaks. As seen in the image below, there are 4 indents for threaded inserts used to screw the tank in place, and one hole to insert and remove water for testing.

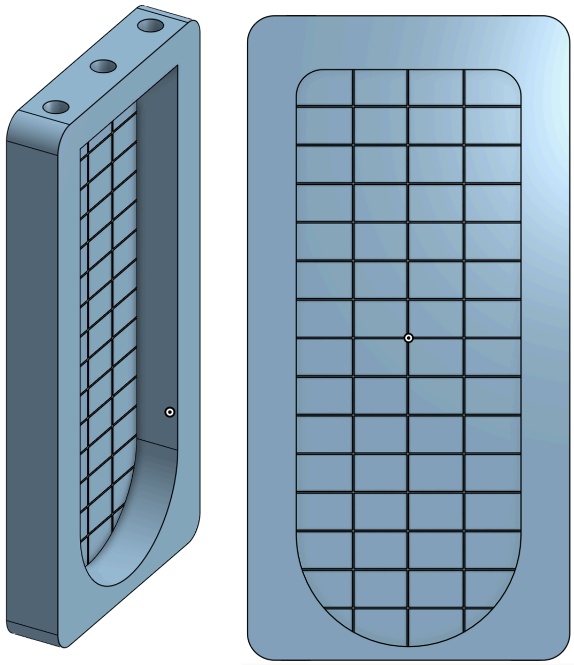

Figure 25: CAD Model of Tank

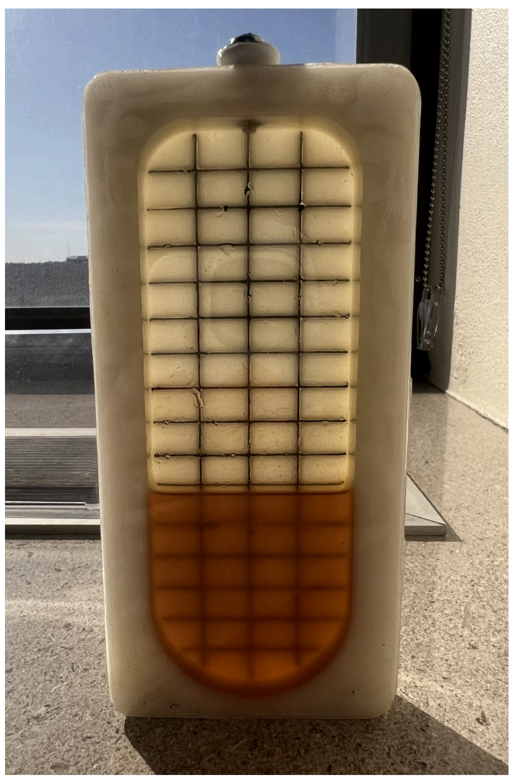

Figure 26: Constructed Tank

The tank is sealed with a 3D-printed cushion made of TPU, sandwiched between the tank and washer, held in place with a screw. This design prevents any leakage, and also makes the tank contents easy to exchange, which protects the electronic components. The clear polystyrene sheet allows the cameras to view the tank's interior. The tank has a grid printed on the back for the camera collection code to calibrate to.

Camera System

Our payload has 3 cameras; one for each tank. These cameras view the interior of the tank to collect data on the slosh. The cameras we are using are RunCam Hybrid 2 split-style cameras. The cameras are powered by the batteries through a buck converter 5V at a working current of 480mAh. To program the cameras to the most optimized settings for our experiment, we use an app that generates a QR code, which is scannable by the cameras. The data is gathered from the camera system via removable micro-SD cards, which are read by a computer after the payload flight. The cameras are powered on shortly before placing the rocket on the launch pad via a button on the camera controller and continuously record video of the tanks until after landing when the cameras are shut off.

Baffle System

Our payload includes 3 tanks, each with a distinct baffle system. One has no baffles to act as the control. We will use the data from the control to compare with the two other baffle styles to better understand which design has a more beneficial impact. During the Vehicle Demonstration Flight, we tested two different baffle types. One was a vertical baffle design, pictured below.

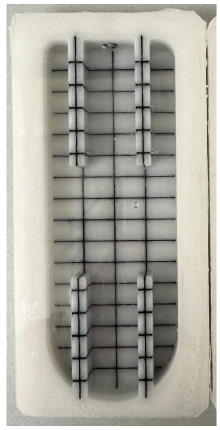

Figure 27: Vertical Baffle

The other was a raised grid that lay against the tank wall furthest from the cameras. This design worked well, but we experienced some issues with our data collection, due to the lighting. The lighting strips we used created shadows and affected the view of the cameras. Our body tube also isn't fully opaque, leading to some more variables in our lighting. We will be testing first vinyl, then sun shade, to block the natural light. We will also be adjusting our lighting system to avoid any future issues with data collection.

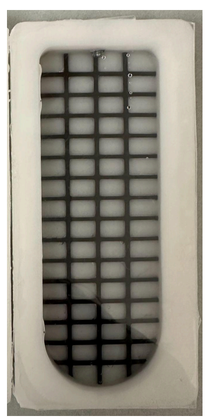

Figure 28: Grid Baffle

Power

Due to a lack of space inside the payload section of the vehicle, the payload's battery is placed inside the electronics bay during flight. The battery is contained in a custom, 3D-printed enclosure, which also serves as the mounting point for our avionics (detailed more in the Electronics Bay Section). The payload battery is a 4S 60C 8,500mAh LiPo battery. We chose this because it can sustain each part of our payload for more than a 3-hour duration.

We performed calculations to determine the mAh needed to sustain the payload. We ran a model payload with one LED lighting bar (top and bottom) and one camera for one hour. We then calculated the voltage we drew from the battery. For one hour, the camera and battery drew 266 mAh. For 3 hours, we would need 997.5 mAh. We estimated the data management system to pull 250 mAh, or 937.5 for 3 hours. We used this information to determine that our battery needed a capacity of at least 7680 mAh. This discrepancy is because the battery power should not fall below 20% and risk damage. Also, we made this calculation, it was planned to incorporate the sensor boards, which we estimated to pull 1,000 mAh. We decided to use an 8,500mAh battery, just in case. Even though we do not need this much capacity anymore, we already purchased and integrated the battery, after making the decision to remove the PCB boards.

Figure 29: Payload Battery

The enclosure is colored a bright orange for high visibility and is marked as a fire hazard on several sides. The power leads from the battery are split into two lines via a set of connectors, and one is regulated via a buck converter mounted to the outside of the enclosure via double-sided tape. Both lines are routed through the upper bulkhead of the electronics bay and into the payload section, where they are split further to power each camera and the payload lights. The battery is disconnected from the payload, removed from its enclosure, and placed in a fireproof, protective bag before charging.

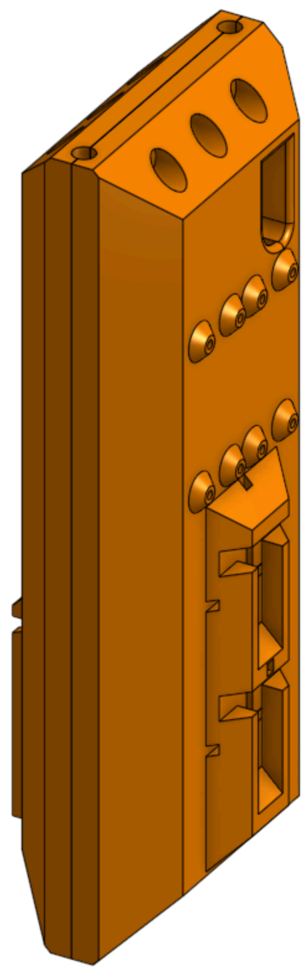

Figure 30: Battery Enclosure and E-Bay Sled CAD Model

Wiring

The payload is wired using 22 AWG stranded wire, with JST-RCY connectors between the battery and payload modules. The payload lights are daisy-chained together using 2 pin JST-CH connectors, while the cameras are powered individually via a split power source fitted with JST-RCY connectors.

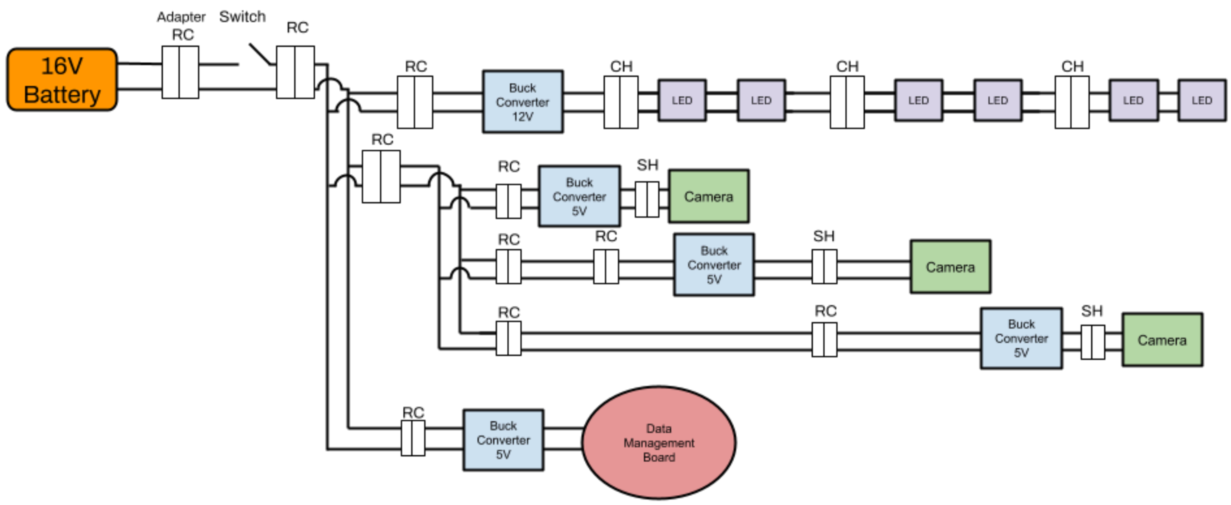

Figure 31: Payload Wiring Diagram

3D-printed spacers are placed in between each payload module, to relieve stress on the wire connections. Tape is placed over any camera module connections at risk of pinching or catching on the upper tube during integration. Additionally, any fragile or weak connection points are reinforced with hot glue, to ensure they do not physically break, but can still be disconnected if necessary.

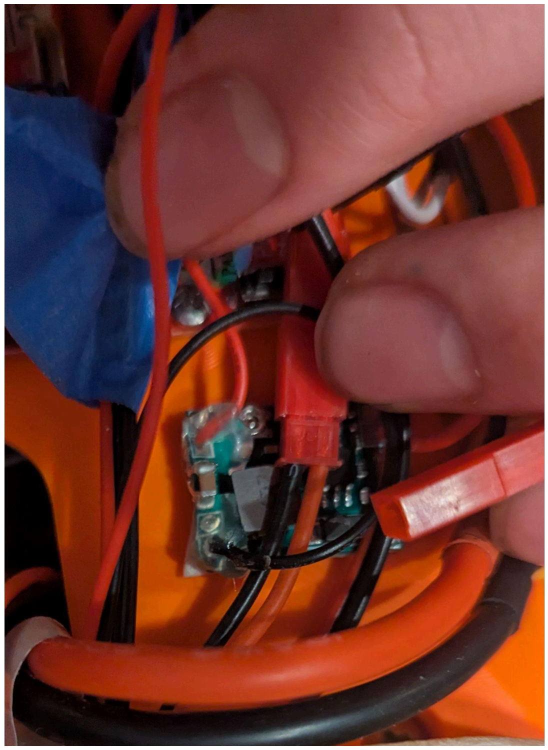

Figure 32: Payload Wire Reinforcement

Data Analysis Procedure

Data Collection Process

We are using the Runcam Hybrid 2 cameras to monitor the movements of water and collect variable data. The camera has a high field of view, leading to a non-linear perspective of the tanks that is harder to accurately analyze. To correct for this distortion, we used an inverse barrel distortion transformation to correct for lens effects. We analyze individual values in the red and green channels of the video to determine if a pixel is “wet” or “dry.” We then assign a value from 0 to 1 to each grid space based on the percentage of the pixels within that rectangle that are wet. Due to issues with the camera distortion correction, we are currently working with 10 out of 16 rows of data. These rows are in the middle of the tank, where the majority of the slosh takes place, so most effects are still observed. We are actively working to fix this problem with our distortion correction.

Data Analysis Process

To determine how water is moving between different columns, we will calculate the average values of each column of each tank over the same time interval. To study the amount of turbulence introduced to the system, we will calculate the standard deviation of the averaged values. To find the difference in water speed, we will calculate the rate of change of the averaged values for each column.

- Average values
  Calculations: We will calculate the average values of the illumination values of each column to determine the amount of water that is moving between different columns in each time frame.
- Standard Deviation
  Calculations: The standard deviation of the averaged values of each column will be calculated to determine the amount of turbulence introduced to the system.
- Rate of change of the averaged values
  Calculations: We will calculate the rate of change of the averaged values by dividing the difference between the two values of two time frames by the time difference. In this way, we are able to calculate the rate at which water is moving between columns and understand how effective our baffles are at mitigating water slosh.

We analyzed the camera data of the first 0.3 seconds of the boost section of the first test flight which carried only one tank in the payload. Due to current technical limitations, we were only able to obtain data for ten rows per column. We calculated the average values of each column with the data we have. Based on the results, we are able to claim that our data analysis system is functioning successfully.

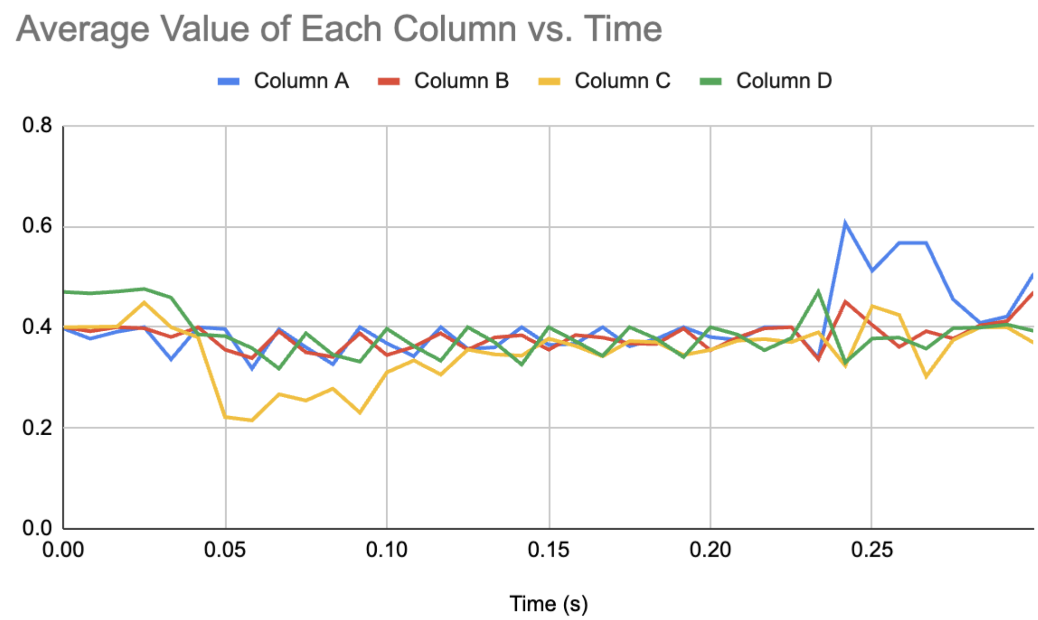

Figure 33: Data Analysis Result of Flight 1 Boost Section

Payload Retention System

Our payload is retained by two ¼-20 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.

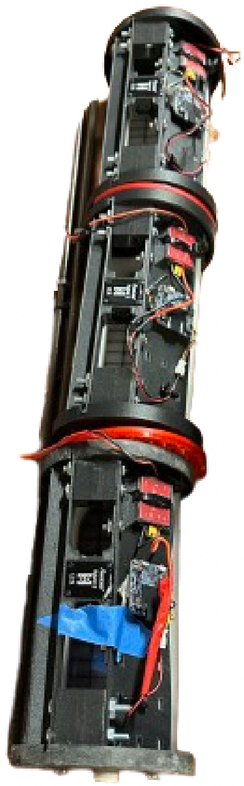

Figure 34: Fully Constructed Payload

Camera and Tank Mount

Each tank within our payload is screwed into a 3D-printed enclosure. This enclosure also contains mounting points for the RunCam Hybrid 2 Cameras, as well as their driver boards, buck converters for regulating power to the cameras, and pass-throughs for wires and zip ties.

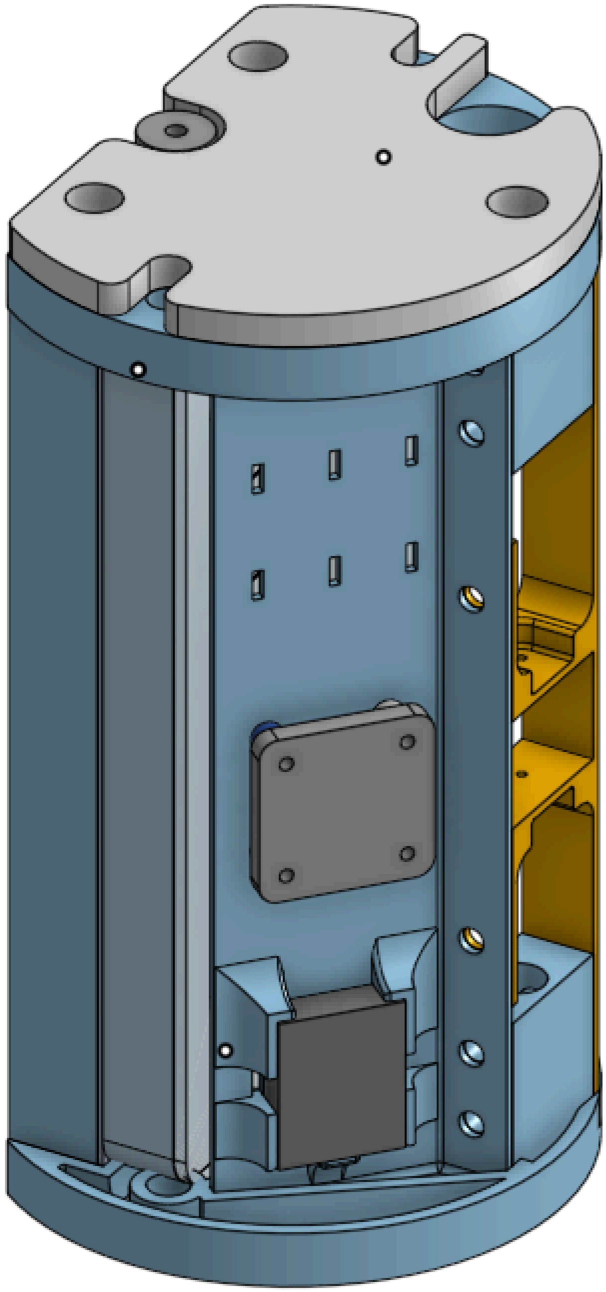

Figure 35: Payload Enclosure CAD Model

The enclosures are each slid onto the two ¼-20 threaded rods and secured in place with nuts. In between each enclosure is a 3D-printed spacer to prevent stress on the wires running between each enclosure.

Figure 36: Payload Tank Enclosure

This method of payload retention has proved effective during both of our test flights. During inspection of the payload components post-flight, no damage was found-proving the integrity of our payload retention system, even under inadvertent flight conditions such as the motor failure of our first test flight.

Flight Reliability

In order to verify the integrity and reliability of our payload during flight, we employed several protection and inspection procedures, to ensure the payload remains undamaged before and during flight, as well as after landing. We reinforced any fragile wire connections with hot glue and wire reliefs. The payload wires were retained with zip ties, to avoid pinching them with the upper tube during integration.

Payload Construction Process

The payload's 3 tanks were 3D-printed to contain 5 indents for threaded inserts, which were inserted using a heat inserter into the indents. Acetone was then used to glue the tank body to the polystyrene cover, to create a watertight seal.

Mounts for each tank were individually 3D printed. The cameras were then screwed in sideways on one side of the mount. Then we soldered the wires to the correct length, shrink-wrapped them to prevent damage, connected them, and threaded them through the mounts. We stuck in the LEDs, using double sided adhesive, and plugged the wires into the batteries. We tested the LEDs and cameras to see if they were on. We then taped and zip-tied down loose wires. We then put the battery into the electronics bay and slid the payload onto the threaded rods. Finally, we screwed nuts on the rods, to secure the payload.

Figures 37 & 38: Flight 1 Payload Construction

Schematics

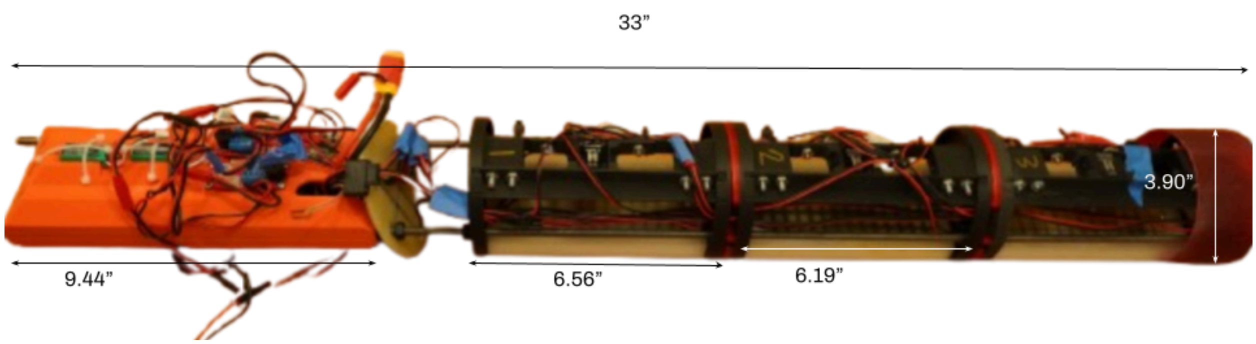

Figure 39: Payload Dimensions

Component	Predicted Measurement	Actual Measurement

Tank Mount Length	6.50”	6.56”
Payload Retention Coupler	3.90”	3.90”
Avionics Sled	9.00”	9.44”
Tank Length	6.00”	6.19”
Total Payload Length	33.00”	33.0”

Table 9: Actual vs. Predicted Measurements

Materials

System	Component	Material(s)	Justification
Tank System	Baffles	3D-Printed High Impact Polystyrene (HIPS)	The baffles are printed with the tanks, which are made of HIPS, as it is durable, temperature-resistant, and easy to print. Additionally, it is compatible with the gluing of the tank cover, as it dissolves in acetone, allowing for a watertight seal.
Tank System	Tank cover	Clear polystyrene	Clear polystyrene allows for a very thin clear cover for the camera system and is compatible with the glue.
Tank System	Tank cover mounting adhesive	Acetone glue	Acetone glue dissolves polystyrene and allows for a watertight seal between the tank cover and the tank body.
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	Commercially available LED strip cut into 50 mm segments, acrylic adhesive on the back, flexible PCB substrate, diffuser material on top.	These materials allow the LED strips to cut to specific sizes for our tanks, are waterproof, flexible, and easily accessible.
Camera System	Battery	4S 60C 16.8V 8500mAh LiPo Battery	This battery meets our capacity requirements, and the 8500mAh allows us to run the cameras for the 3 hours required.
Camera System	Buck Converter	UBEC Step Down power converter	Specifically designed for cameras, provides a clean reliable source of power for the cameras, and allows the camera to be electrically isolated.

Camera System	Power delivery wires	22 AWG stranded wire	This wire is easily available to us; it is rated at 5A, and the camera consistently draws 480mA.
Data Management System	Control Board	Custom fiberglass circuit board, including copper trace lines, integrated circuits, header pins, and plastic screw terminals	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 receive signals from the Electronic Sensor System.
Data Management System	Connecting Wire	22 AWG insulated wire	This wire is easily available to us in our workshop. It is rated to 5A, and the data management system draws around 250mA.
Data Management System	Battery	4S 60C 16.8V 8,500mAh LiPo Battery	The Data Management System, using a Teensy 4.1, uses a nominal voltage of 3.3V. This 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	Payload	3D-Printed	Carbon fiber nylon allows us to

Components	Mount	carbon fiber nylon	create large, strong, complex mounts foreach tank. It is high temperature resistant, and highly dimensionally stable.
Integrating Components	Battery Mount	3D-Printed ASA plastic	ASA has a higher-than-average heat resistance, can be printed in bright colors, and has good impact resistance.

Table 10: Payload Materials

Differences from earlier models

As we constructed our payload, we created multiple different versions and made edits to create a more successful payload that meets our team derived requirements.

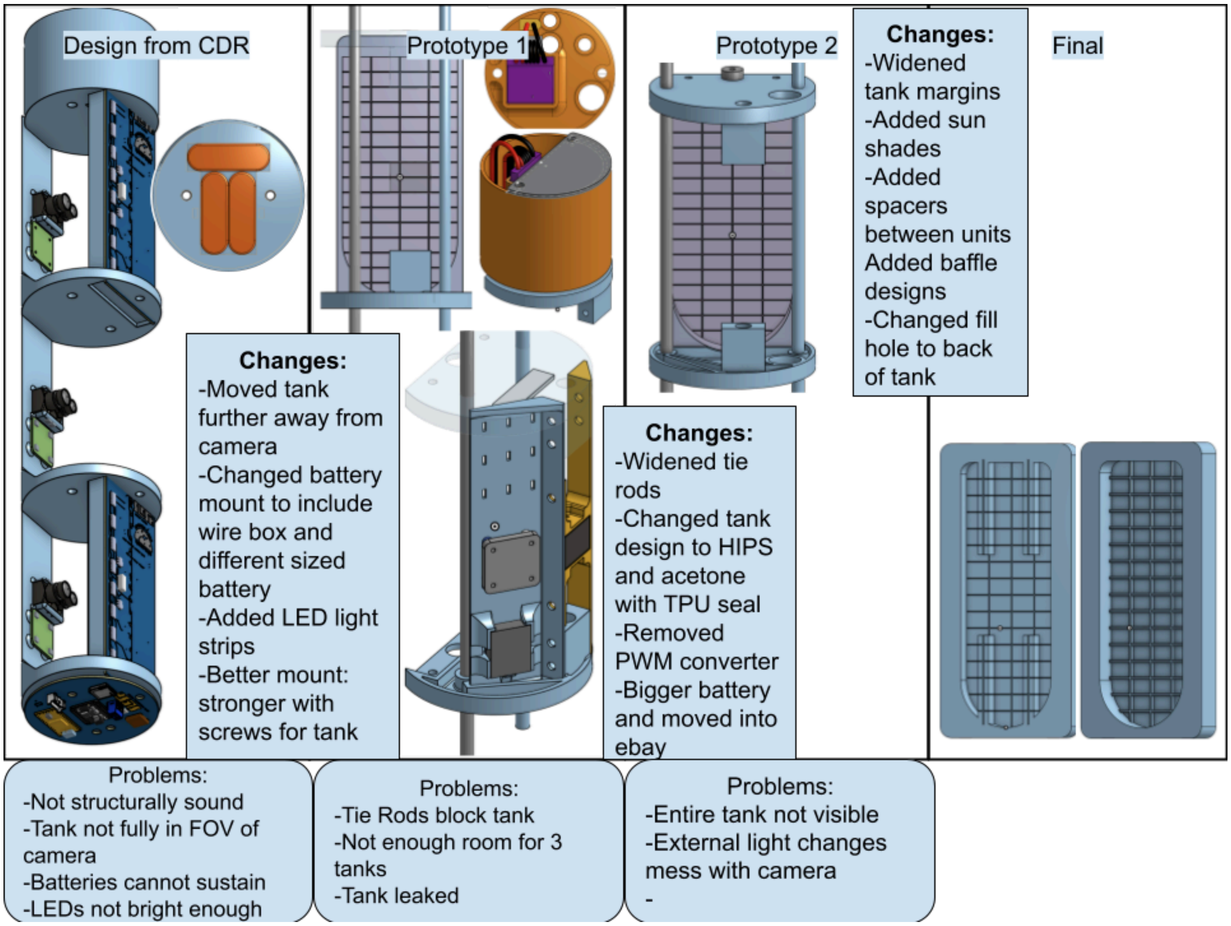

Figure 40: Changes Between Versions

Version 1: CDR

Our first camera and tank mount design from CDR broke easily when 3D-printed in PLA and did not have a space for the LED lighting bar or a secure tank retention system. The LED bar we planned to use was also larger and less bright than we expected. The mount also did not include space for various wiring elements, such as the buck converters. We also needed a new battery mount, as we decided to use one battery, rather than 3, for simplicity.

Version 2: Wide Tie Rods

While creating the CAD of a more structural version, we noticed that the tie rods were spaced too close together and blocked the camera's view of the tank. We communicated with the vehicle team to change the spacing between tie rods from 2.5 to 3 in. We ordered new bulkheads and cut new holes to accommodate this design change. Additionally, we created a battery mount for our larger battery with a junction box to hold the wires. We also moved the tank farther away from the camera, in order to maximize the amount that the camera can view. The new structural design included holes for zip ties and spaces for buck converters. We also added LED light strips above and below the tank. We controlled the brightness of these using a PWM convertor.

Version 3: Better Tanks

Our first attempt at constructing the tanks was unsuccessful, as there were many leaks. We solved this problem by using acetone to dissolve HIPS and create a watertight seal between the 3D-printed tank and cover. We sealed the tank with a squishy 3D-printed TPU component and a screw. When we tested this tank with the camera, it was not fully visible, as some grid squares were cut off. We widened the tank margins to mitigate this issue and make data analysis successful. We also deemed the PWM converters unnecessary and removed them, as the brightest LED setting was the most ideal.

Version 4: Full Payload

The medium battery could not sustain our payload for the NASA required 3 hours, so we chose a larger battery. However, with 3 tanks, we did not have room for a battery mount for the larger battery. We moved the battery into the e-bay to solve this issue. When we stacked the individual tank units, we added spacers between them, to distribute the load across the payload, as there were nuts protruding that created pressure points. We also came up with 2 baffle designs.

Version 5: Final

After flying our second flight, we realized that glare from the sun caused data collection issues. To mitigate this, we implemented sun shades. We also decided that because we were not going to incorporate electronic sensor boards into our design, we could move the water fill hole to the back of the tank. We also changed the baffle color to blue, to improve data analysis for high contrast with the water.

Payload Flights

Payload Test Flight 1

Date of Flight

02/22/2025

Purpose of flight

We wanted to observe slosh in a test control tank to make a more informed decision for our placement and shape of baffles. We also wanted to collect data for our data analysis team to use to test their procedure.

Flight Configuration

The test flight payload consisted of one tank, one camera, and an LED strip on the top and bottom. We chose this for simplicity and also to be able to manufacture and acquire materials in the short time frame we had. The flight got delayed multiple weeks due to weather, giving us more time than expected. However, creating a working payload with all three tanks would still have not been feasible in our time frame. The test flight payload is pictured below:

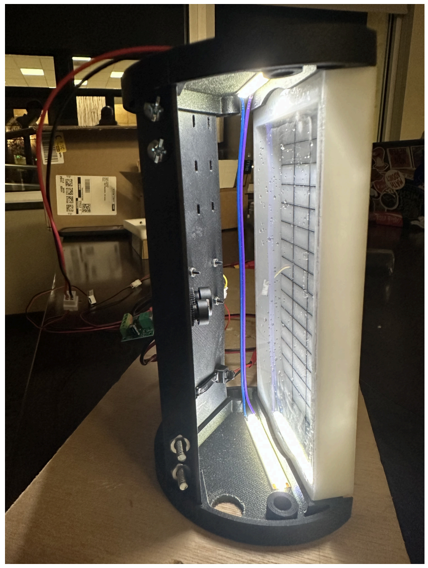

Figure 41: Test Flight Payload

The payload was flown on the first vehicle demonstration attempt, with a plan to refly a full payload as a separate payload demonstration flight. This test flight used a smaller battery than the final design.

Launch Preparation and Integration

Prior to our launch, we integrated the payload using the following steps:

1. Remove upper tube
2. Plug in payload battery
3. Verify LED lights are on
4. Verify blue light on camera driver board is flashing
    a. If not flashing, press the camera shutter button once and wait until blue light is flashing
5. Tuck all wires into the battery mount
6. Tighten all nuts, shake payload section with tube off to ensure everything is secure
7. Verify tank is not leaking after the shake test

Results

From this flight, the payload team was able to learn many things. The first of these things is that an anti-foaming agent is necessary in future flights to prevent excessive bubbles and foaming caused by forces in flight, which we observed in this flight. This foaming interfered with the data extraction code, which relies on color.

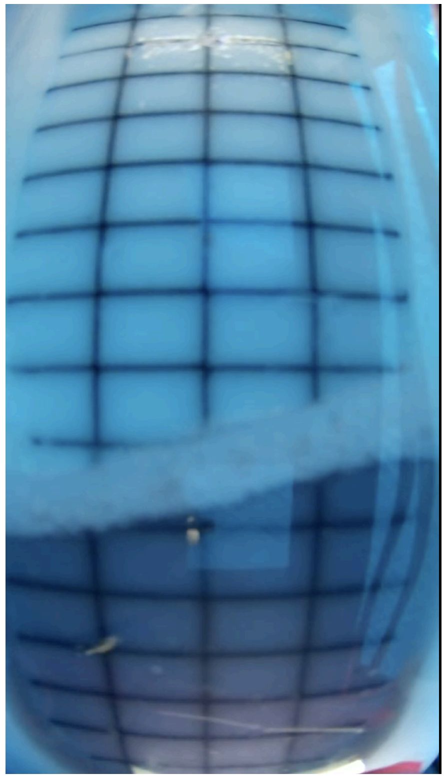

Figure 42: Foaming in Tank

We also observed interesting slosh patterns that were different than expected. The slosh patterns were more irregular than expected, and the tanks remained upside down for a significant portion of the coast and drogue phases. We predicted horizontal side-to-side slosh, while we observed more circular, random slosh. While these results may have been partially a result of the motor failure, they helped improve our baffle design.

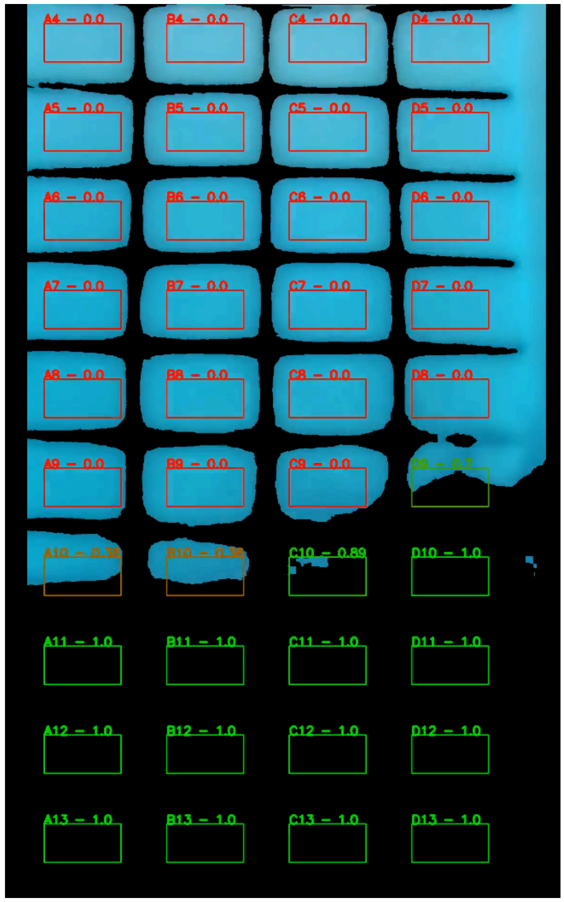

Figure 43: Data Analysis Program Applied to Flight 1 Data

Finally, due to the translucent blue color of our body tube, we found it difficult to isolate the correct color channels in some lighting conditions. In future flights, we have decided to change our water dye to a dark orange color, to more easily isolate the differing colors in the payload, as well as implementing light blockers to prevent any glare or colored light entering the payload.

Payload Test Flight 2

Date of Flight

03/08/2025

Success Criteria

We determined whether or not the test flight was successful based on the data we received from the cameras. If the video footage from the 3 cameras was fully contiguous, well lit by the LED system, and did not have excess surface foaming, we would deem it a successful flight.. The payload would need to be usable for next launch as well, so that if any part sustained irreparable damage, the flight would not be considered successful.

Flight Configuration

We conducted this flight with a full payload, expecting it to be our payload demonstration flight. We had 3 tanks and cameras, as well as the baffle designs. We had enough time to build and wire a full payload, so we chose to do so for this flight. Inserted below is an image of the payload we launched.

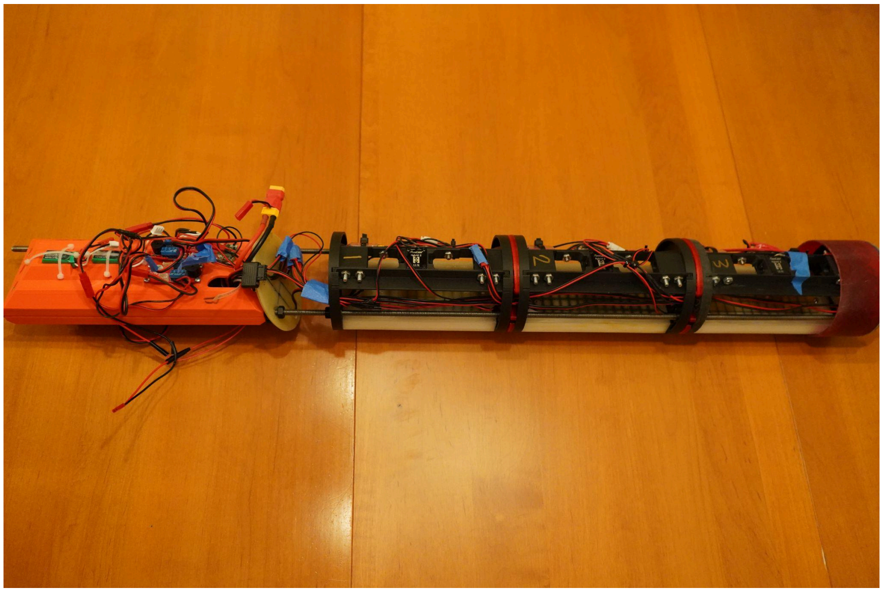

Figure 44: Second Flight Payload

Results

Our second test flight was mostly successful. Our video footage was fully captured, the tanks were well lit by the LED system, and surface foaming was successfully prevented by the simethicone anti-foaming agent. However, due to unexpected glare on the transparent tank face plates, our data was rendered inaccurate. This glare was caused by our translucent blue body tube and open tank enclosure design that allowed for light to leak through. For our payload demonstration flight, we will have a light blocking system implemented to combat camera glare, due to light leakage through the translucent tube.

Additionally, we again observed irregular patterns in the slosh. Since there were no motor issues during the second launch, we cannot attribute irregular slosh to the motor failure. Rather than just horizontal, it seems to have a vertical component as well, indicating a need to review and reevaluate the data collection and fitting analysis models.

Analysis of Payload Retention System

The payload retention system was successful on this flight. The payload remained secure and correctly attached throughout all stages of flight.

Demonstration Flights

Vehicle Demonstration Flight

Flight 1: Partial Success

The first launch of our full-scale vehicle suffered a motor failure that caused a number of performance deviations. However, the vehicle itself did not suffer any failures. Below is a breakdown of our launch steps and flight results.

Deployment Tests

Before we launched the vehicle, we performed two ground recovery deployment tests, to ensure the vehicle would deploy the parachutes at the intended times. To prepare for this test, we opened our electronics bay section, disconnected one drogue lead and one main lead from the flight computers, and routed them through two of the vent holes in our switch band, securing them with zip ties. This allowed us to access the leads, when it was time to perform the deployment test. Our mentor installed the motor casing to plug the motor mount tube during the deployment test to prevent ejection gases from escaping.

We closed up the electronics bay section, and our certified mentor connected a charge (sized according to the amount specified in the CDR)"to the drogue screw terminal. The drogue parachute was packed in its nomex sheet and inserted into the booster section, along with the charge, which was handled by our mentor. We installed two shear pins to secure the booster section to the upper section and carried the vehicle to the RSO inspection area to perform the test.

We propped up the vehicle against a toolbox, aiming the upper section away from the spectator area. We connected the routed charge leads to the launch site's ignition system and performed a continuity test. Before deployment, we covered the fins and aft end of the vehicle with a towel, for protection during the test.. All personnel were cleared to the spectator area, and the RSO fired the deployment charge via the site's launching system.

The vehicle separated at the correct separation point, and the parachutes were pulled out of the booster section correctly. After the RSO declared the range as open, we approached the separated vehicle and inspected it, finding no damage to the airframe, bulkheads, motor mount tube, upper centering ring, or motor casing. The shock cord, drogue parachute, and attachment hardware were all in good condition.

Figure 45: Drogue Deployment Test Results

We reassembled the vehicle and performed the same steps for the main deployment test, packing and installing the main parachute, with our mentor connecting and installing the main deployment charge. We secured the nose cone section to the upper section and brought the vehicle to the deployment test area. Then, we tested the main parachute deployment via the same procedures as the drogue deployment test.

During the main deployment test, the vehicle separated at the intended point, and the main parachute successfully deployed from the nose cone section. After receiving clearance from the RSO, we approached the deployed vehicle and inspected it for damage. All components were undamaged, and we deemed both deployment tests successful.

Figure 46: Main Deployment Test Results

Launch Preparation and Integration

Our vehicle was weighed before and after launch, and our simulations were updated accordingly. During integration, we discovered that our vehicle was approximately 760g underweight. We deemed this safe to fly, and we adjusted our predicted altitude to be 4800 ft. The vehicle weight before launch was 18.6 lbs, and the vehicle weight after launch was 16.9 lbs.

After deployment tests, we reconnected the charge leads to the flight computers, turned on our EggFinder tracker, and put together our electronics bay. We powered on the payload and ensured it was recording. Our mentor connected our main event primary and backup charges to their respective screw terminals, and we assembled the upper section, bolting it into the electronics bay.

We packed the main parachute, wrapped it in a Nomex protector, and inserted it into the nose cone section, along with the shock cord and deployment charges, handled by our mentor. We secured the nose cone section to the upper section via two shear pins and gave it a small shake to ensure it was secure.

We then repeated this process to integrate the upper section into the booster section: packing the drogue parachute, having a mentor connect the primary and backup charges to their respective screw terminals, inserting all components into the booster section, and securing the boost section to the upper section with 2 shear pins. Importantly, this section contained our RDF tracking transmitter, which was connected to the aft end of the electronics bay via a quicklink.

We ensured both tracking devices were transmitting properly and that the GPS tracking system had acquired a satellite fix. We then filled out a flight card and brought the vehicle to the RSO station to be inspected, before being instructed to put the vehicle on the pad. Once the vehicle was on the pad, we encountered a problem arming the StratoLogger flight computers. The arming holes had become misaligned, resulting in one of them becoming inaccessible from the outside.

We removed the vehicle from the launch pad, brought it back to our working table, opened the electronics bay, and realigned the sled to match the arming holes. Once we repeated the process of getting the vehicle on the pad, we were able to successfully arm both the flight computers, and both computers reported continuity on both channels.

All students were cleared to the spectators area, and our mentor installed the motor’s igniter and plug. After verifying that both of our tracking devices were transmitting, we gave the OK to the RSO, and they launched the rocket.

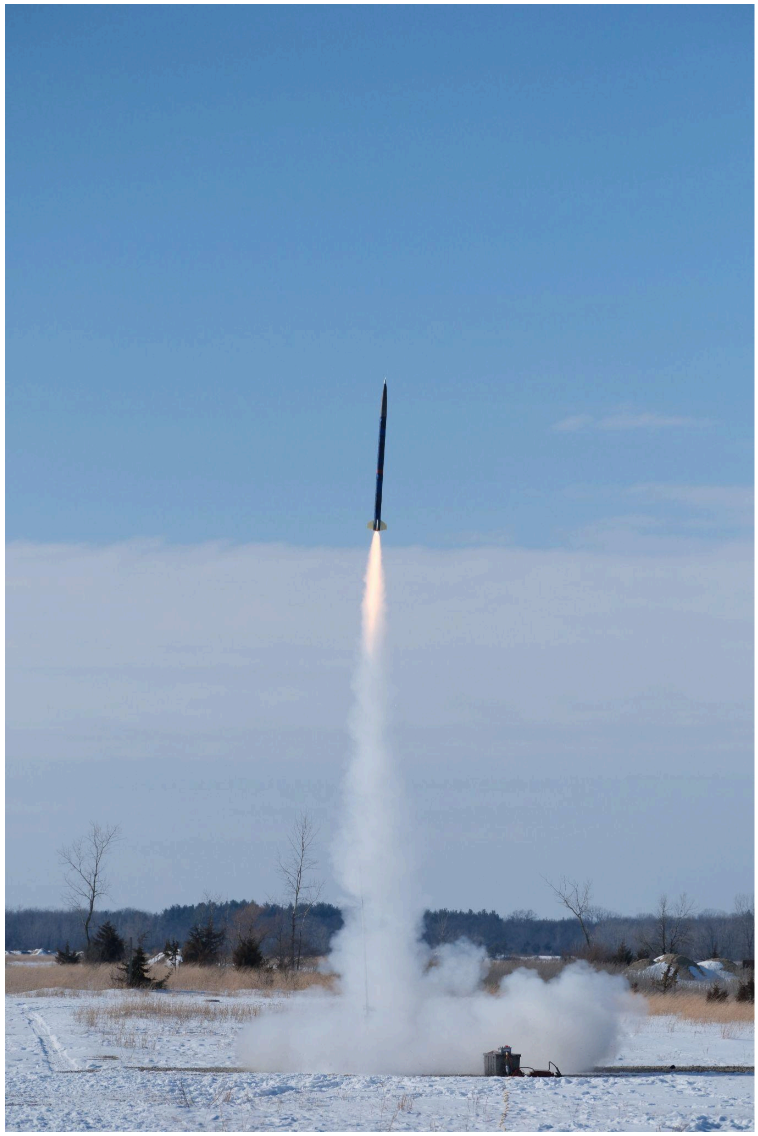

Figure 47: Test Flight 1

Vehicle Ascent and Motor Failure

Approximately 0.5 seconds into the burn, our Aerotech K1103 motor experienced a failure. A portion of the motor nozzle broke off from the aft section of the motor and was ejected from the vehicle. The vehicle pitched over hard, reaching a right-pitching angle of approximately 20°. 0.8 seconds later, the motor snuffed out and produced no thrust. The vehicle underwent several oscillations during this time of about 5 to 10°, before continuing to ascend in a stable position for 0.25 seconds. At this time, the motor relit and burned for another 0.5 seconds, before beginning to chuff aggressively. This continued for another 0.6 seconds. Below is the data we collected from a frame-by-frame 30 FPS video shot of the launch.

Degrees are from a ground perspective, not the actual tilt:

- F67: Ignition.
- F81: A beginning of a black puff is seen. This point is likely when the nozzle failed.
- F82: Puff disappears; rocket stabilizes a bit.
- F83: Rocket pitches over about 5 degrees left.
- F84: Rocket continues oscillating.
- F85: Rocket yaws further left, about 5 more degrees.
- F87: Rocket continues to yaw 5-10 more degrees.
- F88: Rocket continues yawing left.
- F89: Rocket stops gaining left-oriented yaw and instead pitches to the right about 5 degrees.
- F90: Rocket pitches to the right to the point that it is visibly only about 5 degrees to the left.
- F91: Rocket yaws back right, to the point where it's facing basically straight up.
- F92: Partially out of frame, but the bottom of the rocket shows the vehicle pitches heavily to the right, around 20 degrees.
- F93-104: Out of frame.
- F105: The contrail shows that the rocket pitched to the right throughout several frames–we estimate between F93-F98–to the maximum extent of 25 degrees, then corrected itself and began pitching left (probably between frames F98-F105).
- F105: Also shows the rocket beginning to sharply yaw to the right again, about 10 degrees.
- F106: Rocket continues to yaw right.
- F107 The motor snuffs and stops burning, and the rocket visibly tilts right 10 more degrees.
- F108-F110: Rocket continues, without a burn, to yaw right.
- F111-F112: Rocket stabilizes to an upright position, as visible from the ground.
- F113: Rocket begins visibly pitching towards the left again, about 5 degrees.
- F114: Rocket continues pitching left.
- F115: Rocket visibly stabilizes again.
- F116-F120: Rocket continues at a visibly stable upwards angle.
- F121: Motor visibly appears to reignite.

- F122: Motor may have reignited.
- F123: It is highly probable that the motor has visibly reignited.
- F124: Confirms motor is relit.
- F125-127: Motor continues, lit.
- F128: First visual of a lit chunk of grain about 100-150 feet below the rocket's position. It probably fell out of the hole in the nozzle around frame 110-112 (time at 100-150 height lower).
- F129-F139
- F140: Rocket begins to pitch left 5 degrees again.
- F141-F144: Rocket continues its bearing; **chuffing begins**.
- F145: Motor** cuts out** again.
- F146: Rocket continues its bearing, without its motor burning.
- F147: Motor **relights.**
- F148: Motor stays lit.
- F149: Motor **cuts out.**
- F150: Motor begins relighting.
- F151: Motor **relights.**
- F152: Motor has **cut out** again.
- F153: Motor **relights.**
- F154-F155: Motor stays lit.
- F156: Motor **cuts out.**
- F157: Motor **relights.**
- F158: Motor ** cuts out.**
- F159: Motor **relights.**
- F160: Motor stays lit.
- F161: Motor **cuts out.**
- F162: Motor **relights.**
- F163: Motor **cuts out.**
- F164: Motor relights.
- F165-F168: Continues burning on its bearing.
- F169: Motor cuts out.
- F170: Motor relights.
- F171-F182: Motor stays fairly stabilized, at least from a ground perspective.
- F183: Rocket begins pitching left.
- F184: Rocket yaws left to a 5-10 degree extent from a ground perspective.
- F185-F188: Continues this course.
- F189: Stabilizes, at least visually.

- F190-F198: Rocket begins a pitch to the right (visually a maximum of 15 degrees), then stabilizes itself around F197.
- F199: Rocket stabilizes, for the most part.
- F200-F215: Stays on its course.
- F216: Contrail stops being produced; motor finishes burnout.
- F217-F230: Lost visual.
- F231: Visual regained.
- F232: Rocket stable.
- F233: Rocket stays stable.
- F234: Lost visual.
- F235-F246: Rocket not visible.
- F247: Visual regained.
- F248-F255: Rocket stays stable (per ground visual) on course.
- F256-F265: Visual lost.
- F266: Visual regained.
- F267-F292: Rocket stays stable on course.
- F293: Visual apogee and event drogue parachute.
- F294-F336: rocket begins stably descending.
- F337-end of video: Out of frame.

The overall outcome of the frame-by-frame analysis provided a gateway to understanding the partial CATO and its impact on flight stability and burn time. The Aerotech K1103 motor initially burned for approximately 0.5 seconds, before experiencing a nozzle failure at F81, causing an immediate shift in the vehicle's trajectory. From the ground, we observed–between F83 and F92–the loss of controlled thrust, with the motor fully snuffing out at F107.

However, a reignition sequence followed, followed by chuffing and multiple relights between F121 and F170. This erratic behavior suggests that a significant portion of the propellant was still burning in an uncontrolled manner, due to compromised internal pressure. The presence of a burning grain chunk falling from the rocket (F128) further supports this conclusion, indicating that the structural integrity of the motor was compromised. By F216, the contrail ceased, marking the final burnout. Despite these irregularities, the rocket managed to stabilize at multiple points before reaching apogee at F293. The data collected from this analysis provides crucial insights into motor reliability under flight conditions, emphasizing the need for reinforced nozzle integrity and potential modifications to prevent such failures in future launches.

Flight Breakdown

Our hypothesis for the failure is that one of the chunks of propellant broke off to the extent that it essentially carved out a bigger throat in the nozzle, causing it to fail. This is seen in frame 81 of the video, where a “black puff” is seen, and probably displays the point where the propellant broke free. In frame 128, a chunk of propellant is seen flying off the rocket, likely due to the fact that the nozzle’s throat hole had been expanded and allowed for a burning grain to eject itself from the rocket.

The flight was flown on February 22nd, 2025, at Richard Bong State Recreation Area, located south of Milwaukee, as seen on this map. The temperature was an average 24℉, with a constant wind speed of ~15 mph and gusts of 30-40 mph, especially around an altitude of 2,000 ft, which we believe explains our large drift distance of 2,300 ft. The motor flown was an AeroTech K1103 plugged motor. We flew with one payload tank for control data and a ballast mass of 960g, to account for the missing two tanks. The target altitude was 4,500 ft, and the estimated altitude was approx. 4,900 ft in our simulations. Our altimeters measured a peak altitude of 3,034 ft.

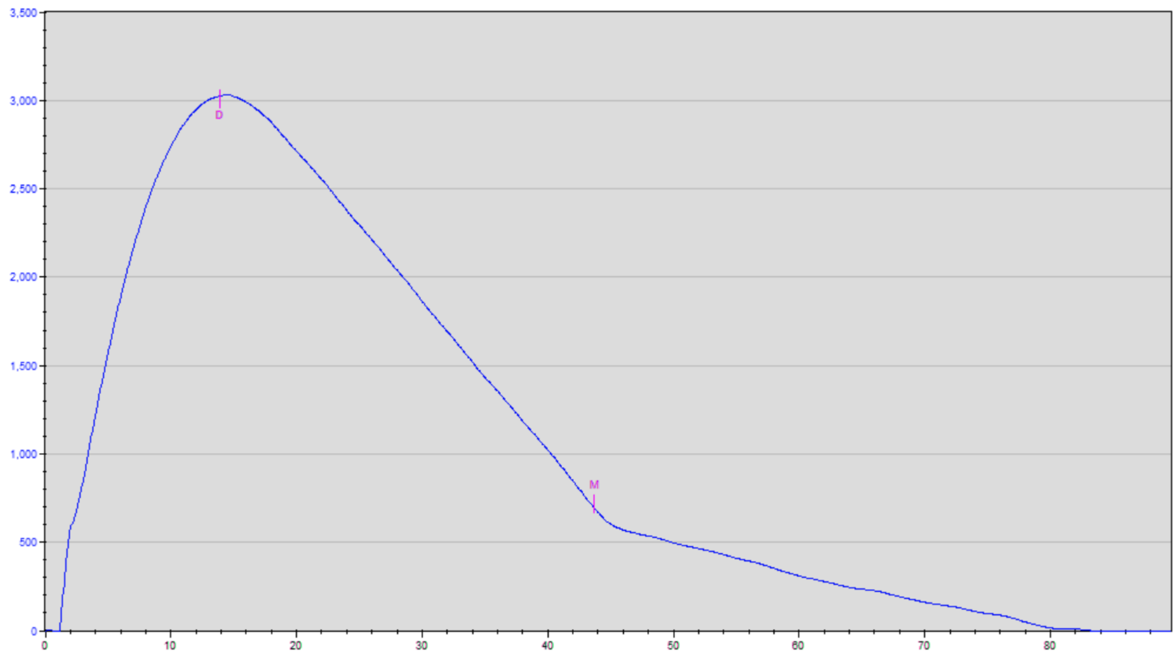

Figure 48: Flight 1 Measured Flight Profile

Pictures of the landed configuration of all sections of the launch vehicle are shown below.

Figure 49: Flight 1 Landed Configuration of Booster Tube

The vehicle hit a tree on the way down, and the branch it took down with it is on top of the shock cord. The tree the vehicle hit on the way down is shown below.

Figure 50: Flight 1 Tree Missing Branch

The vehicle landing configuration is very spread out, so the following image is the shock cord that connects the booster to the upper section.

Figure 51: Flight 1 Landed Configuration of Booster Tube to Drogue Shock Cord

Figure 52: Flight 1 Landed Configuration of Drogue Parachute

The below figure is the landed configuration of the upper section. This is connected to the drogue parachute via the shock cord that runs off the picture's right side. The left side shock cord connects to the main parachute's Nomex protector, and you can see the main parachute itself in the background, caught in a gust of wind.

Figure 53: Flight 1 Landed Configuration of the Upper Tube

Figure 54: Flight 1 Landed Configuration of Main Parachute (caught in gust of wind)

The above figure shows the landed configuration of the main parachute. The shock cord going off to the right connects to the upper section, and the shock cord coming down from the main parachute connects to the nose cone.

Figure 55: Flight 1 Landed Configuration of Main Parachute and Nose Cone

The figure below shows a more close up-of the nose cone section, though in both the above and below figures, it is difficult to identify the shock cord between the main parachute and nose cone.

Figure 56: Flight 1 Landed Configuration of Nose Cone

At apogee, which was reached 14.5 seconds after ignition and was approximately 3,034 ft, the drogue parachute was ejected by the primary ejection charge. The rocket drifted down at approximately 84.8 feet per second for 29.2 seconds, before the main parachute was deployed by the main ejection charge at 700 ft (about 43.7 seconds into the flight). The parachute took approx. 1 second to inflate and slowed the rocket to 16.2 ft/sec. The rocket descended under main for 42 seconds until touchdown. The total flight time was 85.75 seconds.

Flight 2: Partial Success

The second demonstration flight of our vehicle was a complete success. All components of the vehicle performed as expected. Below is an analysis of our preparation steps and the vehicle's performance.

Launch Preparation and Integration

Arriving at the launch site, we removed the upper section of the vehicle and armed the payload. After determining the payload was functional, our mentor connected our primary and backup main deployment charges, and we integrated the upper section with the electronics bay via the installed PEM nuts and 4 screws.

Our mentor installed our drogue primary and backup deployment charges. We packed our drogue parachute in its nomex protector, before installing the upper section and electronics bay into the booster section with 2 shear pins.

Additionally, on this second flight, we used a new motor casing that featured a threaded forward closure. Before integrating the booster section, we connected a forged eye bolt to this new closure and connected our drogue shock cord to it once the motor was inserted by our mentor.

Figure 57: Forged Eye-Bolt located in Nose Cone

Flight Results and Analysis

This flight used an Aerotech K1103X motor. We chose to fly no ballast on this flight, due to our flown payload being within an acceptable mass margin of error. Below is a graph of our vehicle's altitude versus time and velocity versus time during the second flight. The vehicle ascended to an altitude of 4,999 ft in 18.2 seconds. This is 499 ft above our target altitude of 4,500 ft and 70 ft above our predicted altitude of 4,900 ft. This flight used a more sophisticated payload than our first flight, detailed in the Payload Demonstration Flight section.

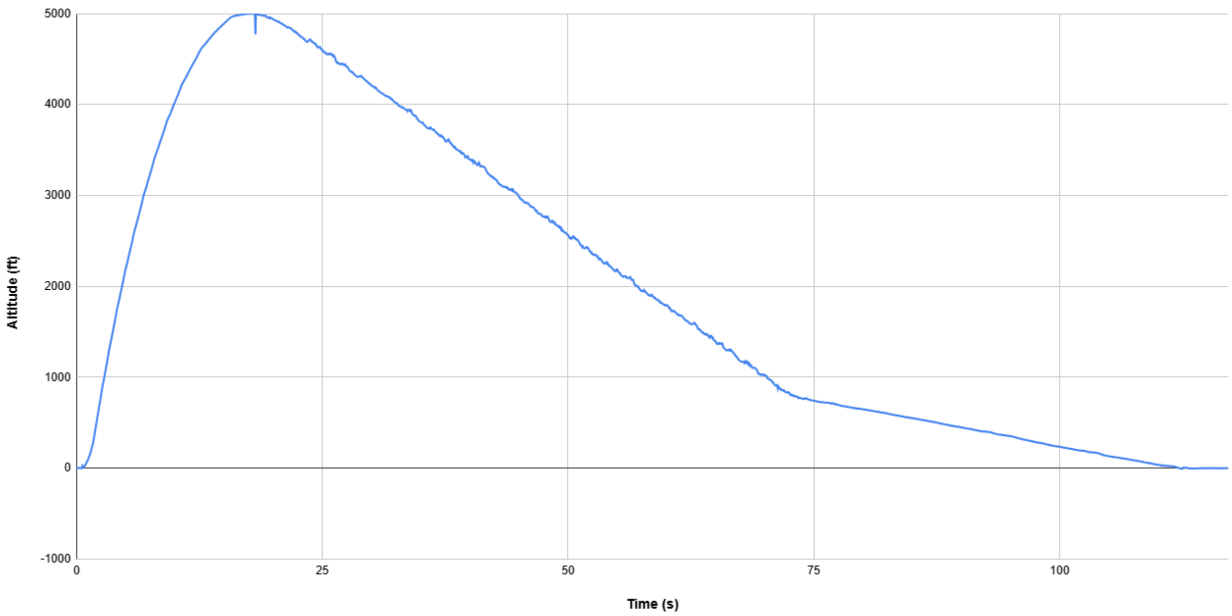

Figure 58: Flight 2 Altitude Profile

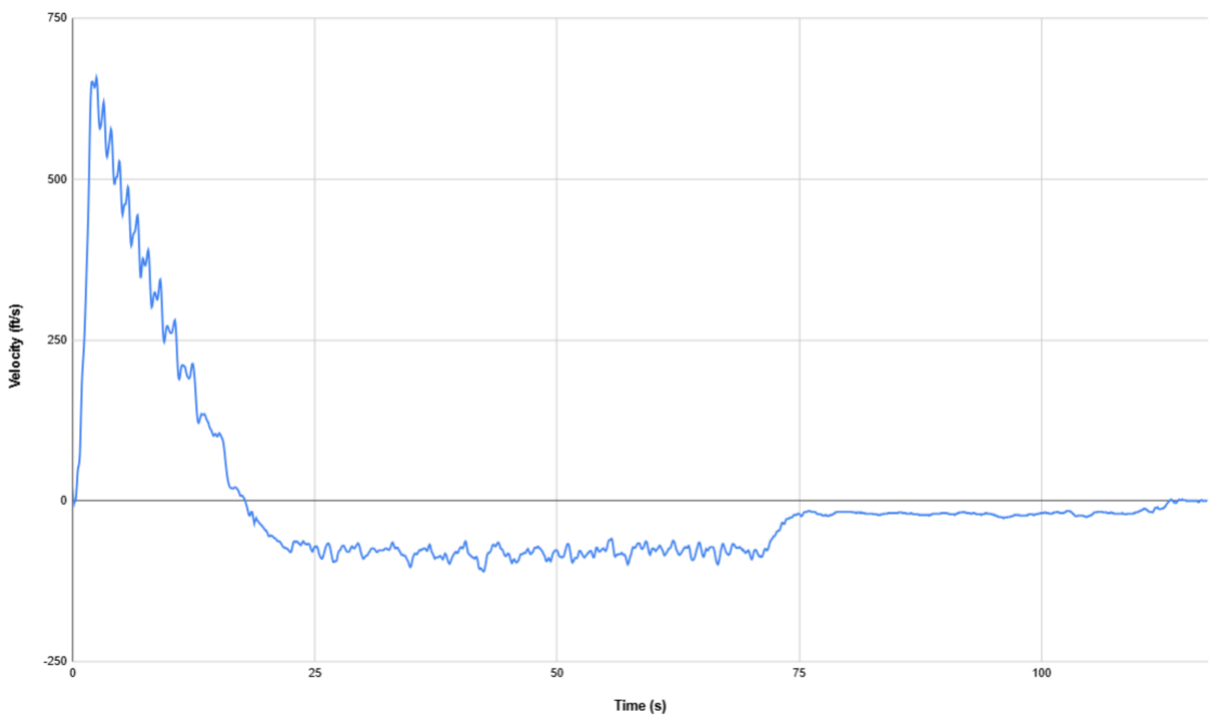

Figure 59: Flight 2 Velocity Profile

This second flight was performed on March 8th, 2025 at the Richard Bong State Recreation Area in Wisconsin. The winds were relatively low; under 10 mph for the duration of the launch.

The vehicle ascended straight up, with the motor performing a full burn of 1.6s. The primary flight computer deployed the drogue parachute at apogee, with the backup charge firing a second later. The vehicle descended under drogue at a rate of approximately 80 ft/s. This was less than our original predicted descent rate of 114 ft/s, likely due to the drag of the rocket body during descent, which was not factored into the descent rate found by our simulation software and hand calculations. Since this flight, we added an additional, massless parachute to our simulations, with an effective drag area the same as the approximate drag area of our vehicle body tubes (as mentioned in the mission performance predictions section). This resulted in a descent rate of ~83 ft/s, which is very close to our observed descent speed.

Figure 60: Flight 2 Vehicle Ascent

Due to an error in programming the flight computers, the primary flight computer deployed the main parachute at an altitude of 900 ft, 200 ft higher than our planned 700 ft. The vehicle slowed to a descent rate of 20.0 ft/s, which is 1.0 ft/s faster than our targeted descent rate under the main parachute of 19.0 ft/s. The vehicle's kinetic energy fell within the NASA requirements, and no components of the vehicle or payload were damaged. The increased main deployment altitude caused a longer descent of 95 seconds, violating the descent time requirement of 90 seconds. To ensure this doesn't happen in the future, we will confirm that the flight computers are programmed properly before the launch, add a cover for the programming button, so it cannot be pressed by wires during the flight, and listen to the full beep sequence on bootup of the flight computers, comparing it to the expected beep sequence. We also plan to slightly choke our main parachute to ensure we do not violate descent time requirements, but we will also confirm that this does not violate kinetic energy guidelines.

Below are images of the vehicle as it landed after the second flight.

Figure 61: Upper Section as Landed After Flight 2

Figure 62: Drogue Parachute as Landed After Flight 2

Figure 63: Main Parachute as Landed After Flight 2

Figure 64: Nose Cone Section as Landed After Flight 2

Flight Breakdown:

At apogee, which was reached 18 seconds after ignition and was approximately 5,000 ft, the drogue parachute was ejected by the primary ejection charge. The rocket drifted down at approximately 80 feet per second for 53.1 seconds, before the main parachute was deployed by the main ejection charge at ~900 ft (about 71.3 seconds into the flight). The parachute took approx. 2 seconds to inflate and slowed the rocket to 20.4 ft/sec. The rocket descended under main for 41.9 seconds until touchdown. The total flight time was 113 seconds.

Lessons Learned

From this flight, we learned to inspect the flight computers prior to launch. The StratoLogger CF flight computers emit a series of beeps containing information about the configuration, including the main event deployment altitude setting. With this feature, we can listen to the flight computers as they power up and ensure the settings are accurate. Additionally, we added the inspection of the flight computers to our checklists for further flights.

Safety and Procedures

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, ten being the most likely or severe.

- **Facility Risks**
    - ***Workshop inaccessible:***
        - Effects: Project progress will be slowed and temporarily 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, and adult supervision will always be present. 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. Members exposed to workshop chemicals may suffer injuries.
        - 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: If our raking fundraiser doesn’t raise 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 just one 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 purchases are made as soon as components become available. 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. Weather conditions will be considered, in order to maximize the chances of a 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 evaluated during vehicle development. 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 impossible	3-check connection strength	54
Structure	Rail guides detach	Structure failure	Inability to	Rail guides will be	2	3- could	1	6

	during rail mounting	during mounting	load rocket on launch rail	surface-mounted with epoxy Caution will be used when loading the rocket onto the launch rail		delay launch		
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 Failure of liner	Potential for catastrophic failure (CATO) Leakage of motor gasses	Check density of motor grains Operate motor at a conservative chamber pressure Test ignition system Use lithium	2	10-potent ial for CATO	8	160

				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 Potential loss of rocket	Mentors teach and double check rocket folding Recovery Prep Procedure	2	4	7	52

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 before transport, and double-checked before installation	3	5-depends on the amount of 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
Payload	Particulate past bulkhead into the payload	Ejection charges create high-pressure	Potential camera damage	Put duck seal around the payload bulkhead Tighten the nuts all the way	2	6	6	72
Recovery	Flight computer deployment altitude setting error	Gas escapes into the e-bay causing pressure sensors to fail	Parachute eject at a higher or lower altitude than expected violated descent time requirements Potential rocket damage	Mentors double check flight computer programming	2	7	2	28

Table 11: FMEA

Launch Operations Procedures

Deployment Tests

- Set up folding table
- Place disassembled vehicle on folding table
- Remove upper tube if not already removed
- Verify payload integrity (nothing broken, nuts tight)
- Open electronics bay
- Disconnect drogue charge leads from StratoLogger (do not move sled positioning)
- Route drogue charge leads through vent hole
- Twist drogue charge leads together
- Tape drogue charge lead to switch band
- Disconnect main charge leads from StratoLogger (do not move sled positioning)
- Route main charge leads through vent hole
- Twist main charge leads together
- Tape main charge lead to switch band
- Reassemble avionics bay
- Plug motor mount tube with motor **(Mentor)** or wadding
- Connect drogue deployment test charge to drogue screw terminals
- Pack drogue parachute
- Insert drogue deployment test charge
- Insert drogue shock cord and parachute
- Insert upper section into booster section
- Secure upper section into booster section with shear pins
- Perform drogue deployment test using WOOSH pad leads
- Return vehicle to folding table
- Disconnect spent charge
- Remove motor or MMT plug

- Note amount of BP used
- Remove upper tube
- Verify payload integrity (nothing broken, nuts tight)
- Connect internal main charge leads to main charge screw terminals if not already connected
- Connect main deployment test charge **(Mentor)**
- Plug retention coupler bulkhead passthrough holes
- Integrate upper tube and secure with bolts
- Pack main parachute
- Insert main deployment test charge into nose cone **(Mentor)**
- Insert main parachute and main shock cord into nose cone
- Insert nose cone into upper section
- Secure nose cone with shear pins
- Insert upper section into booster section, secure with blue tape
- Perform drogue deployment test using WOOSH pad leads
- Return vehicle to folding table
- Disconnect main shock cord from retention coupler
- Remove upper tube
- Disconnect spent charge
- Note amount of BP used
- Tuck charge lead wires back into avionics bay
- Open avionics bay (do not move sled positioning)
- Connect charge lead wires to StratoLoggers
- Reassemble avionics bay

Payload Integration

- Remove upper tube if not already removed
- Plug in payload battery
- Verify LED lights are on

- Verify blue light on camera driver board is flashing
  - If not flashing, press the camera shutter button once and wait until blue light is flashing
- Tuck all wires into the battery mount
- Tighten all nuts, shake payload section with tube off to ensure everything is secure
- Verify tank is not leaking after the shake test

Recovery and Tracking Integration

- Remove upper tube if not already removed
- Connect primary main charge to primary main screw terminal **(Mentor)**
- Connect backup drogue charge to backup main screw terminal **(Mentor)**
- Reintegrate upper tube
- Pack main parachute
- Insert main charges into nose cone **(Mentor)**
- Connect main shock cord to upper section forward U-bolt with a quicklink
- Insert main parachute and shock cord into booster section
- Insert nose cone into upper section
- Secure nose cone with shear pins
- Prep RDF Beacon (power on and put it in a Nomex bag)
- Verify RDF Beacon is transmitting and can be received
- Connect RDF Beacon to upper section aft U-Bolt with a quicklink
- Pack drogue parachute
- Connect primary drogue charge to primary drogue screw terminal **(Mentor)**
- Connect backup drogue charge to backup drogue screw terminal **(Mentor)**
- Insert drogue charges into booster section **(Mentor)**
- Connect drogue shock cord to upper section aft U-bolt with a quicklink
- Insert drogue parachute and shock cord into booster section
- Insert upper section into booster section, align via markings
- Secure upper section into booster section with shear pins

- Power on EggFinder via arming hole
- Turn on EggFinder receiver
- Verify packets are being received
- Wait for EggFinder GPS fix (Procedures may continue during this waiting time, but the vehicle should not be handed to the RSO before a secure GPS fix is acquired)

RSO Tent and Pad Procedures

- Retrieve a flight card from the RSO tent
- Fill out flight card
- Ensure a team member or mentor has the igniter in a safe location
- Remove motor retainer
- Insert motor **(Mentor)**
- Install motor retainer
- Bring vehicle to RSO tent
- Bring vehicle to assigned pad
- Lower launch rail
- Load vehicle on launch rail
- Raise launch rail
- Arm first StratoLogger, wait for full bootup beep pattern to finish
- Disarm first StratoLogger
- Arm second StratoLogger; wait for full bootup beep pattern to finish
    - Ensure correct deployment altitude setting is reported
- Re-arm first StratoLogger; wait for full bootup beep pattern to finish
    - Ensure correct deployment altitude setting is reported
- Ensure all screw switches are tight
- Ensure EggFinder GPS Receiver is receiving and has a fix
- Ensure RDF Beacon is receiving
- Insert igniter **(Mentor)**
- Connect ignition leads

- Test continuity with pad box
- Assign video recorders; ensure all recording procedures are clear with all recorders
    - Record the vehicle during the entire flight
    - Only stop recording after the vehicle has touched down
    - Be aware of surroundings while recording

During-Flight Procedure

- Record the vehicle during all stages of flight
- Do not exit the spectator designation area until the range is declared open
- Track the vehicle with the RDF Beacon and EggFinder beacon
- Make note of GPS coordinates if received, enter into Google Maps

Recovery Procedure

- Travel in a group to touchdown site; use RDF Beacon as necessary
- Ensure all charges are fired
- Take pictures of each section of the vehicle as landed
    - Nose Cone
    - Main Parachute
    - Upper Section
    - Drogue Parachute
    - Booster Section
- Return vehicle to folding table
- Remove upper tube
- Disconnect spent charges
- Turn off payload
- Remove and secure SD card OR leave SD card in the payload
- Pack up

Launch Troubleshooting Procedures

Ground Deployment Test

Failure Mode: Vehicle damaged

- Ensure deployment charge is fired
- Disconnect ignition lead
- Return vehicle to folding table
- Inspect damage
- If repairable at the launch site
    - Repair vehicle
    - Evaluate cause of damage
    - Implement mitigation: padding; different test location
- If not repairable at the launch site
    - Pack vehicle into cars
    - Make a plan for repairing the vehicle at the workshop

Failure Mode: Vehicle fails to separate

- Use continuity tester to ensure charge is fired
- Approach vehicle
- Bring vehicle back to folding table
- Remove shear pins
- Separate vehicle
- Inspect recovery components for damage
- Re-integrate vehicle for a deployment test with larger charges
- Re-perform deployment test

Payload Integration

Failure Mode: Payload damaged

- Power off the payload
- Inspect damaged part
- If repairable at the launch site
    - Repair damaged part; power on payload to ensure functionality
    - Re-integrate payload
- If not repairable at the launch site
    - Pack the payload safely into a car
    - Return the payload to the workshop
    - Make plans for repairing the payload at the workshop

Failure Mode: Payload fails to begin recording

After each step, check to see if the payload began recording.

- Inspect camera power, make any necessary repairs
- Ensure SD card is inserted fully into the camera
- Remove SD card from camera; format and wipe with a computer
- Re-insert SD card into camera
- Check battery voltage
    - If low, charge battery
- Use a multimeter to ensure power delivery is sufficient
    - If not, check battery and regulator connections and make any necessary repairs
- If all other steps failed
    - Pack the payload safely into a car
    - Return the payload to the workshop
    - Make plans for repairing the payload at the workshop

Pad Operations

Failure Mode: Flight computers fail to arm

- Look into arming holes to ensure holes are lined up
    - If not lined up
        - Remove vehicle from pad
        - Disarm any armed flight computers
        - Open electronics bay
        - Align arming switches with arming holes
        - Reassemble electronics bay
        - Return vehicle to pad
- Open electronics bay
- Disconnect charge leads **(Mentor)**
- Test-arm each flight computer
- If one or more computers do not arm, for each:
    - Test battery levels
        - If low, charge or replace battery
    - Inspect wire connections
        - If broken, make necessary repairs
    - Swap out a new flight computer
- Re-integrate electronics bay
- Return vehicle to pad
- Arm flight computers

Failure Mode: Rail buttons disconnect

- Disarm any armed flight computers
- Remove vehicle from pad
- Bring vehicle back to folding table
- Disconnect charges **(Mentor)**

- Inspect rail button attachment locations
- If repairable
  - Repair rail buttons with epoxy
- If not repairable
  - Drill new holes at an offset of 90° from initial rail button holes
  - Install rail buttons in the new holes
- Return vehicle to pad

Failure Mode: Motor fails to ignite

- After RSO clearance and required waiting time, approach vehicle
- Disconnect ignition leads **(Mentor)**
- Remove igniter **(Mentor)**
- Inspect igniter for any damage or burn marks
- If no marks are found:
  - Reconnect ignition leads **(Mentor)**
  - Test continuity with continuity tester
  - If no continuity is indicated:
    - Insert new igniter into motor **(Mentor)**
    - Reconnect ignition leads **(Mentor)**
  - If continuity is indicated:
    - Re-insert igniter into motor **(Mentor)**
    - Reconnect ignition leads **(Mentor)**
- If marks or damage is found:
  - Insert new igniter into motor **(Mentor)**
  - Reconnect ignition leads **(Mentor)**
- Test for continuity
- Give the OK to the RSO to launch

Project Plan

Testing

In order to evaluate our vehicle, several test wer performed. The parachute deployment tests are outlined in the *Flight 1: Partial Success* section of the document, and the parachute evaluation tests are outlined below.

Parachute Evaluation Tests

Disclaimer

In the state of Wisconsin, people over the age of 16 can ride in the back of a pickup truck if they are seated in the box of the truck bed, and the vehicle is traveling below 25 mph. The vehicle was traveling at 15 mph, multiple people were in the bed to ensure safety, and all people in the truck bed were at least 16 years old at the time of testing.

Overview

Due to the difference between the main parachute coefficient of drag (C_D) value between our first and second full-scale test flights, we performed a set of tests to evaluate the C_D of the parachutes. The test used an open-backed pickup truck and a load cell to measure the force of drag of the payload at the nominal descent speed during flight.

Attempt 1: Speedometer

For our first attempt, we used the speedometer on the truck to measure the speed being tested. We drove at a constant speed of 15 mph (22 ft/s), which is near the nominal descent speed of the vehicle under our main parachute.

Figure 65: Parachute Testing Attempt 1 (15 mph)

We were unable to obtain reliable data with this method, as it was difficult to ensure the truck remained at a constant speed. We decided to redo the test with an anemometer to correlate the force data we received with wind speeds to get a more accurate value.

Attempt 2: Anemometer

After being unable to get accurate wind speeds using the speedometer of the truck, we decided to use an anemometer (wind speed measurement device) to correlate the force readings with accurate wind speed data. We had one student measuring the wind speed and another student measuring force data from the parachute.

Figure 66: Parachute Evaluation Attempt 2 (15 mph)

To evaluate the C_D of our drogue parachute, we used a Recon Recovery 60" diameter parachute with the same setup as our main parachute tests. This chute is the same design as our drogue parachute and will have the same C_D as our main parachute.

Figure 67: Scaled-Up Drogue Parachute Test (15 mph)

Results

Due to wake turbulence from the truck used for testing, the results from the test were inconclusive. The values we acquired from the ground tests varied by several orders of magnitude, more than the variance between our two test flights. Due to this and a lack of time before the FRR submission date, we declared the test as inconclusive . We plan to re-test the parachutes at a later date, with an updated testing system, to get conclusive results.

Requirements Compliance

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 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 4,900 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 and was declared at the CDR milestone.**

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 built to meet this requirement. More details can be found in the *Vehicle Criteria* and *Payload Retention* 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 vehicle and payload were consciously designed to be easy to integrate, 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. We have performed heating tests to ensure the flight computers and payload do not overheat during pad time.**

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 K-1103 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 K-1103 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 K-1103 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 contain 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 4.20 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 13.1 : 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 90.8 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. **-** All teams shall complete demonstration flights as outlined below.

2.18.1. Vehicle Demonstration Flight—All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle’s stability, structural integrity, recovery systems, and the team’s ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.) The following criteria shall be met during the full-scale demonstration flight:

2.18.1.1 The vehicle and recovery system shall have functioned as designed. **- The vehicle system functioned as designed. The recovery system had an error in timing main parachute deployment and we are working to fix the issue.**

2.18.1.2 The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year’s project. **- The full scale rocket is a newly constructed rocket built specifically for this year’s project.**

2.18.1.3 The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:

2.18.1.3.1 If the payload is not flown, mass simulators shall be used to simulate the payload mass. **- On our first VDF attempt, we flew a mass simulation in place of a complete payload. On our second VDF attempt, we flew a complete payload, but since then changes were required. The mass will remain the same, but the payload is not finished.**

2.18.1.3.2 The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass. **- Mass simulators were located in the same approximate location as the missing payload mass.**

2.18.1.4 If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight. **- Our payload does not change external surfaces of the rocket nor does it manage the total energy of the vehicle.**

2.18.1.5 Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances. **- We have flown our competition launch motor on both VDF attempts.**

2.18.1.6. The vehicle will be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast shall not be added without a re-flight of the full-scale launch vehicle. **- The vehicle was flown in its fully ballasted configuration on both VDF attempts.**

2.18.1.7 After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA management team or Range Safety Officer (RSO). **- We have not made any changes to the launch vehicle or its components.**

2.18.1.8 Proof of a successful flight shall be supplied in the FRR report.

2.18.1.8.1 Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) shall not be accepted. **- We have complete altitude and velocity versus time plots and proof of partially successful flights in the FRR report.**

2.18.1.8.2 Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes, but is not limited to: nosecone, recovery system, airframe, and booster. **- Quality pictures of the as landed configuration of all sections of the launch vehicle are included in the FRR report.**

2.18.1.8.3 Raw altimeter data in .csv or .xlsx format. **- Raw altimeter data will be submitted with the FRR report in .csv or .xlsx format.**

2.18.1.9 Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum Deadline. **- Two vehicle demonstration flights were completed by the FRR submission deadline. An additional flight is planned for March 22. This flight will serve as the Payload Demonstration flight and, if both required and successful, the Vehicle Demonstration Re-Flight. We will submit an FRR Addendum by the deadline.**

2.18.2 Payload Demonstration Flight—All teams shall successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:

2.18.2.1 The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair. **- The payload will be fully retained during the flight, and we will ensure all retention mechanisms functioned as designed and did not**

sustain any damage. If any of these failures happen, we will attempt another flight.

2.18.2.2 The payload flown shall be the final, active version. **- The payload will be flown on the PDF as the final, active version.**

2.18.2.3 If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required. **- The above criteria have not yet been met.**

2.18.2.4 Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED. **- The Payload Demonstration flight will be completed by the FRR Addendum deadline**

2.19 An FRR Addendum shall be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report. **- We will submit an FRR Addendum for our Payload Demonstration flight and a potential Vehicle Demonstration Re-flight.**

2.19.1 Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline shall not be permitted to fly a final competition launch. **- If we are required to complete a Vehicle Demonstration Re-Flight, we will submit the FRR Addendum by the deadline.**

2.19.2 Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload during launch week. Permission shall not be granted if the RSO or the Review Panel have any safety concerns. **- If our Payload Demonstration Flight is not fully**

successful, we will petition the NASA RSO for permission to fly the payload during launch week, and we will respect the decisions of the RSO and Review Panel.

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 parachute 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 parachute 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. **-We are working to ensure this requirement is not violated, although currently our simulations do show that under 20 mph wind, we may exceed this radius.**

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.**

4.2 USLI Payload Mission Objective: College/University Division **N/A**

4.3 STEMCRaFT Mission Requirements **N/A**

4.4. General Payload Requirements

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.**

Safety Requirements:

5.1 Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations. **Checklists are included in the safety section.**

5.2 Each team shall identify a student safety officer who will be responsible for all items in Section 5.3**. A safety officer is assigned (Ayelet Blum).**

5.3 The role and responsibilities of the safety officer shall include, but are not limited to

5.3.1 Monitor team activities with an emphasis on safety during: 5.3.1.1 Design of vehicle and payload, 5.3.1.2 Construction of vehicle and payload components, 5.3.1.3 Assembly of vehicle and payload, 5.3.1.4 Ground testing of vehicle and payload, 5.3.1.5 Subscale launch test(s), 5.3.1.6 Full-scale launch test(s), 5.3.1.7 Competition Launch, 5.3.1.8 Recovery activities, 5.3.1.9 STEM Engagement Activities. **All safety officer responsibilities were reviewed and confirmed.**

5.3.2 Implement procedures developed by the team for construction, assembly, launch, and recovery activities. **These have been implemented and noted in the safety section.**

5.3.3 Manage and maintain current revisions of the team's hazard analyses, failure modes analyses,procedures, and SDS/chemical inventory data. **These have been maintained and reviewed in the safety section.**

5.3.4 Assist in the writing and development of the team's hazard analyses, failure modes analysis, and procedures. **Safety officer led the writing of the hazard analysis.**

5.4 During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA

Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams shall communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch. **All rules have been reviewed and followed.**

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 Parachute 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 e-bay Spacer	2"	Wildman Rocketry	$141.27	$141.27	$7.06	
	Main Parachute 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 Parachute 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 e-bay Spacer	1"	Wildman Rocketry	$52.27	$52.27	$2.61	
	Main Parachute 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 Summary

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 raked many yards during the fall season and raised funds to continue the Rocket Design and development process without any interruptions. We also successfully organized and ran a bake sale in our school to bring in extra funding for travel. As of Friday February 28th, 2025, we have earned approximately $9,563 from 3 months of fundraising (October and November 2024 and February 2025). 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 for both construction and travel and in the unlikely event that more funds are needed, we have 3 alternatives to obtain additional funding: Calling for donations from the community, developing a car-washing program, 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 have already purchased all required materials that we didn’t already have, including our motors.