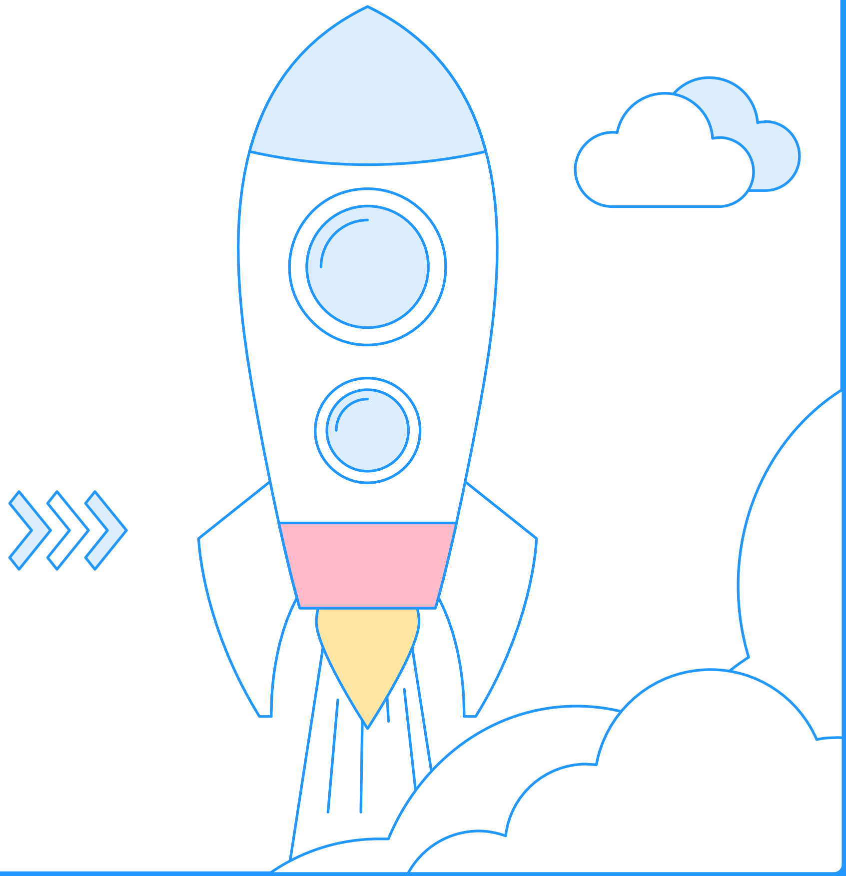
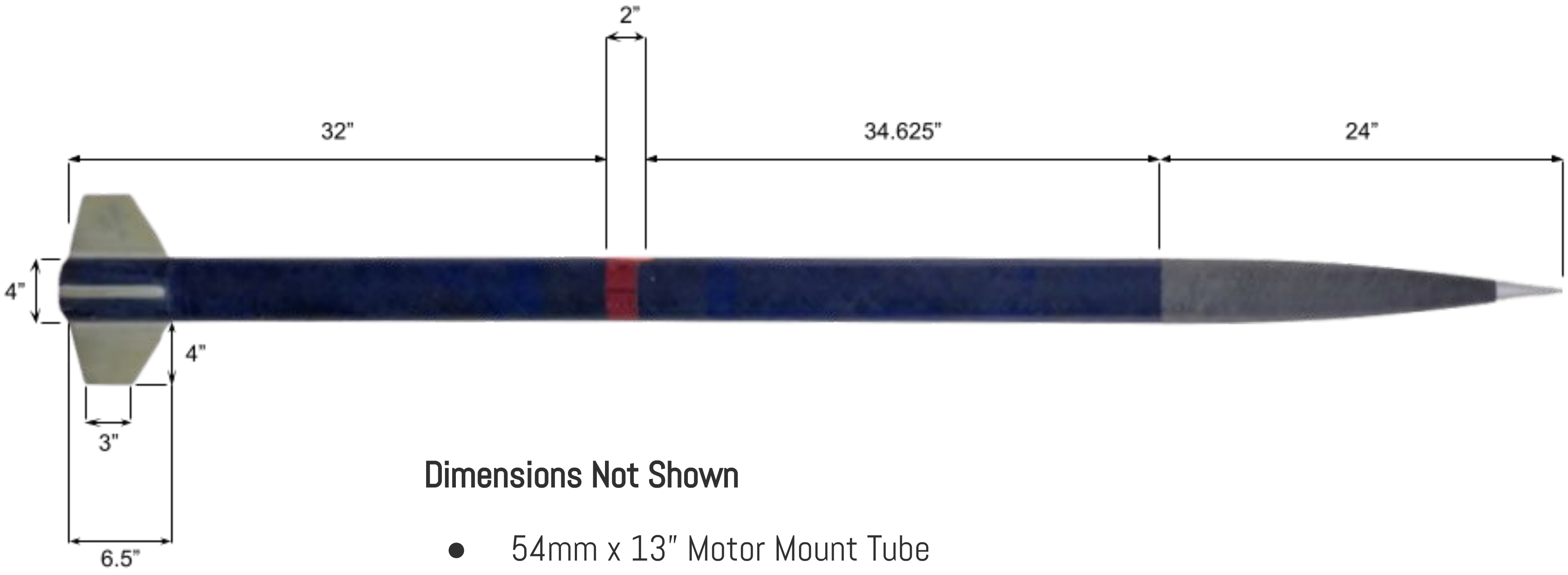
SLOSH

Flight Readiness Review
Madison West Rocket Club

Part I: Vehicle



Launch Vehicle Dimensions



Dimensions Not Shown

- 54mm x 13" Motor Mount Tube
- Total Vehicle Length: 92.625"

Separation Points Visual

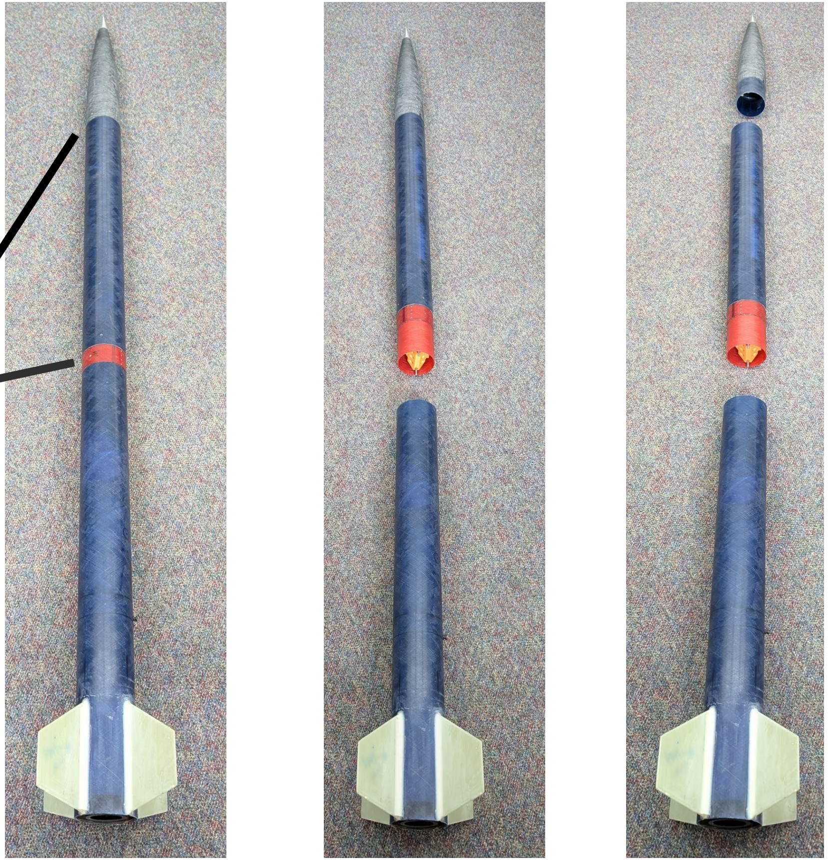
Separation Event 1: Apogee (4900 ft)

- Separation of booster and payload section
- Drogue deployment

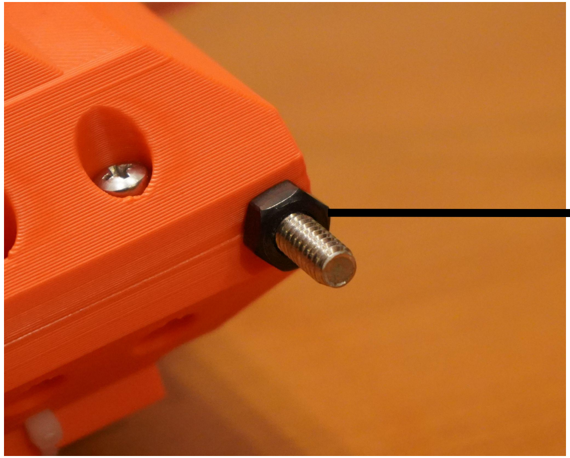
Separation Event 2: 700 feet

- Separation of nose cone and payload section
- Main chute is deployed

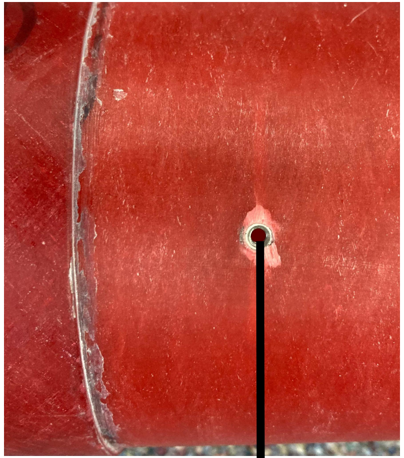
**Tethering shock cords omitted in this diagram*



Key Design Features

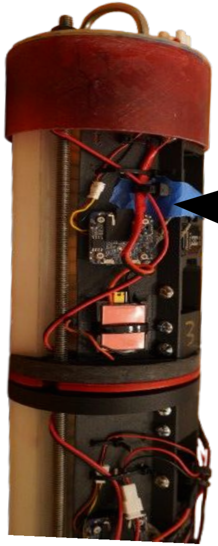


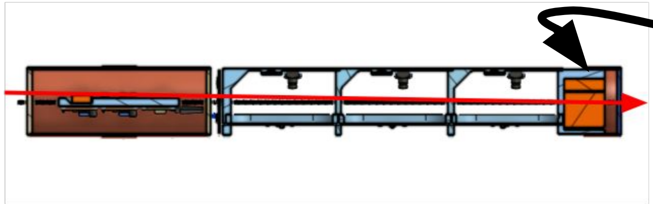
Normal Nuts



PEM nuts that Connect upper tube and e-bay coupler

E-match wires



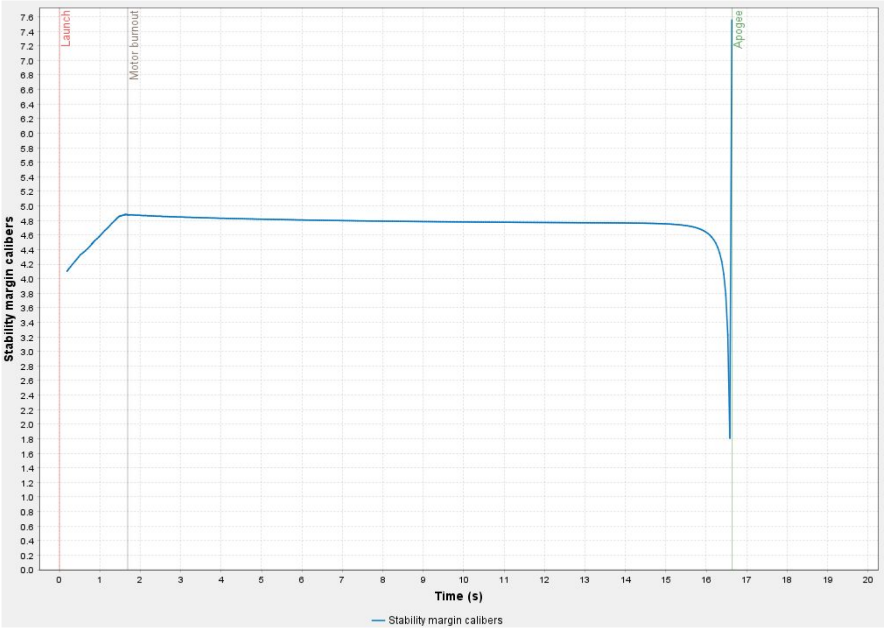


-Run e-match wires through payload
-Bolt Upper Tube to E-bay Coupler through pem nuts.
-Use all normal nuts instead of lock-nuts.

Vehicle Motor and Stability

- AeroTech K-1103X plugged motor
- Thrust : Weight Ratio: 13.1:1 (Req 5:1)
- Rail exit velocity: 90.8 ft/s (Req. 50 ft/s)
- Static Stability Margin: 4.19 Calibers

Aerotech K1103 Motor Casing



Vehicle Mass Values

	Dry mass	Wet mass	Burnout Mass
Booster Section	*4.69 lbs*	*7.91 lbs*	*6.08 lbs*
Upper Section	*8.76 lbs*	*8.76 lbs*	*8.76 lbs*
Nose Cone section	*2.62 lbs*	*2.62 lbs*	*2.62 lbs*
Total Mass	*16.07 lbs*	*19.29 lbs*	*17.46 lbs*

Vehicle Descent Rates

Simulated

Flight Stage	Descent Under Drogue	Descent Under Main
Descent Rate	83 ft/s	19 ft/s

Measured First Flight

Flight Stage	Descent Under Drogue	Descent Under Main
Descent Rate	84.8 ft/s	16.2 ft/s

Measured Second Flight

Flight Stage	Descent Under Drogue	Descent Under Main
Descent Rate	80.6 ft/s	20.4 ft/s

Vehicle Kinetic Energy At Impact

- During both flights, the vehicle hit the ground in 3 separate but tethered parts as expected.
- Maximum kinetic energy = 75 ft-lbf.
- All values comply with this requirement.

Section	Predicted	Actual (Flight one)	Actual (Flight two)
Booster	8 ft-lbf	6 ft-lbf	10 ft-lbf
Upper	49 ft-lbf	36 ft-lbf	57 ft-lbf
Nose Cone	29 ft-lbf	21.5 ft-lbf	34 ft-lbf

Interfaces with ground systems

- Arming holes
- Rail buttons

Apogee and drift vs Wind Speed

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%)

Wind speed	Approximate Drift given nominal descent time (87.8s)	Approximate Drift given descent time of first flight (63.3 s)	Approximate Drift given descent time of second flight (95s)
0mph	0 ft	0 ft	0 ft
5mph	644 ft	464 ft	697 ft
10 mph	1288 ft	928 ft	1393 ft
15mph	1932 ft	1393 ft	2090 ft
20mph	2575 ft	1857 ft	2787 ft

Vehicle Demonstration Flight 1

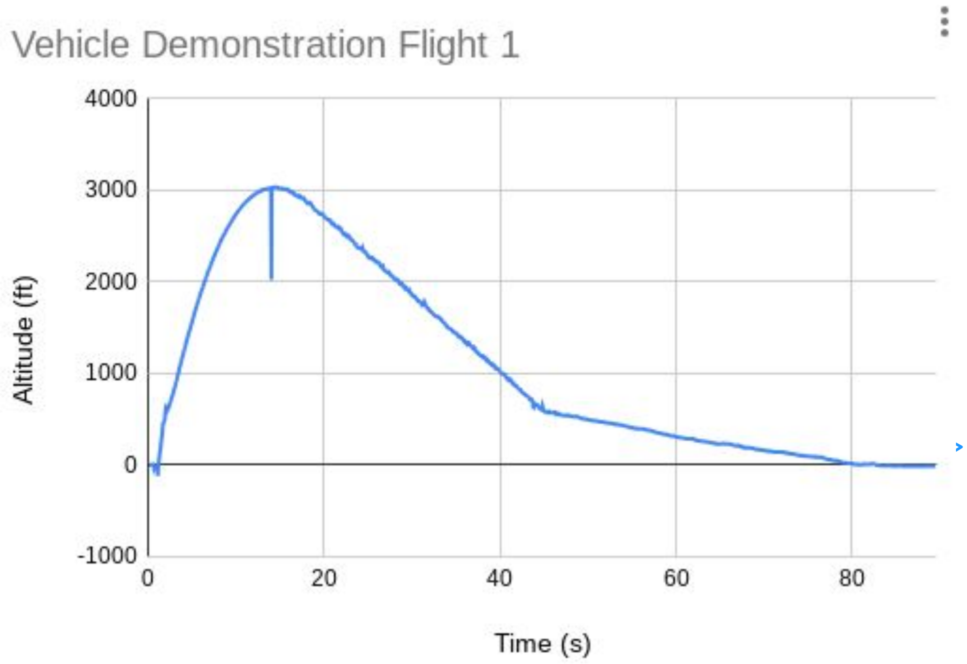
- February 22, 2025
- Motor Failure (Nozzle Structural Failure, no damage to other components)
- Burn calculations made with frame-by-frame analysis of a video of the launch
- Recovery system functioned nominally
- More drift than expected due to high **upper-level** winds at altitude (~40mph at 1000ft), total 2,550 ft (ground level winds were <20mph)
- 906g of ballast was used to compensate for the payload


Rocket Under Boost


Motor Nozzle Post-Launch

Vehicle Demonstration Flight 1 Data

- Apogee at 3034 ft (61.5% of predicted)
- Time to apogee: 14.5 Seconds
- Total descent time: 71.25 Seconds



Landed Configuration Photos - Flight 1

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Landed Configuration Photos - Flight 1

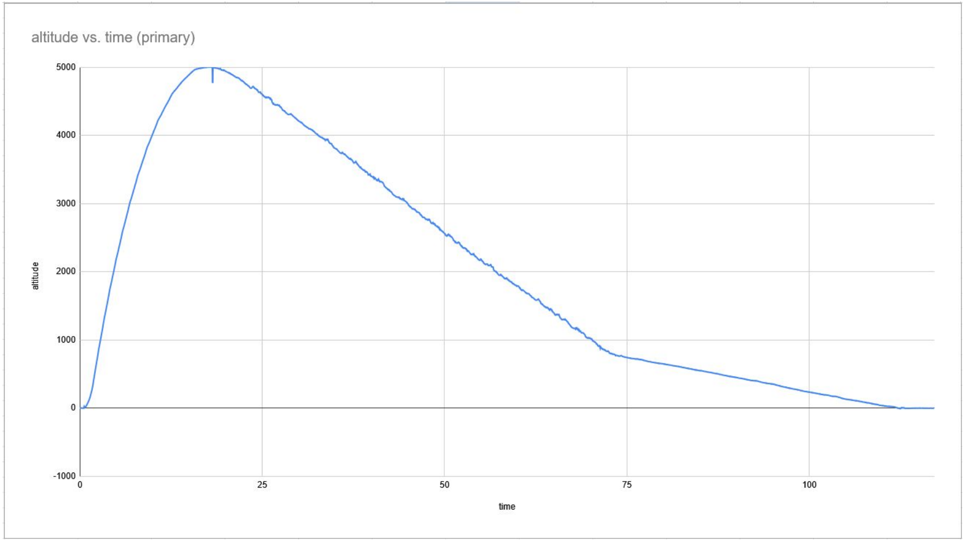
Vehicle Demonstration Flight 2

- Three payload tanks, roughly the same weight as ballasted demo flight 1, attempted Payload Demonstration Flight
- Ascent nominal, no motor failures
- Apogee at 4,999 ft (99 ft higher than predicted apogee, 499 higher than target) and deployed drogue
- Error in programming the flight computers led to a main deployment higher than expected (900 ft rather than 700 ft)
- Total descent time of 95s, which does not meet descent requirements

Vehicle on pad, March 8th

Vehicle Demonstration Flight 2 Data

- Apogee at 4999 ft (102% of predicted)
- Time to apogee: 18 s
- Total descent time: 95 s



Flight 2 Landed Configuration Photos

Flight 2 Landed Configuration Photos

Flight 2 Landed Configuration Photos

Parachute Drag Coefficients

	Parachute Type	Main Parachute	Drogue Parachute
Flight one	***Simulated C_D Value***	1.8, simulated in OpenRocket and RasAero II	1.5, simulated in OpenRocket and RasAero II
	Actual C_D Value	2.3	1.5 (with additional body drag)
Flight two	***Simulated C_D Value***	1.8	1.5
	Actual C_D Value	1.6 (Decrease of 0.7 from Flight 1)	1.5 (with additional body drag)

Testing and Results

- Drogue parachute deployment test
- Main parachute deployment test
- Parachute evaluation tests

Drogue Parachute Deployment Test

- 2.3g Black Powder
- Fired via launch site ignition system
- Successful test
  - Vehicle separated successfully with no damage

Post-pop test results

Main Parachute Deployment Test

- 2.0g Black Powder
- Fired via launch site ignition system
- Successful test
  - Vehicle separated successfully with no damage

Post-pop test results

Parachute Evaluation Setup

- Performed due to inconsistencies in main parachute C_D values between flights 1 and 2 (2.3 to 1.6)
- Several ground tests were conducted to evaluate the C_D of the main parachute
- These tests were mostly inconclusive

A tension scale was used to measure the force being applied to the parachute at a constant speed

Riding in pickup truck beds is legal in WI as long as you are at or over 16 years old and under 25 mph. All people in the truck bed were at least 16 and we were traveling at ~15 mph.

Parachute Evaluation Results

Attempt 1

- Car speedometer used
- Speed used for testing: 22 ft/s
- Results inconclusive due to the effects of wind not being accounted for in the speedometer readings

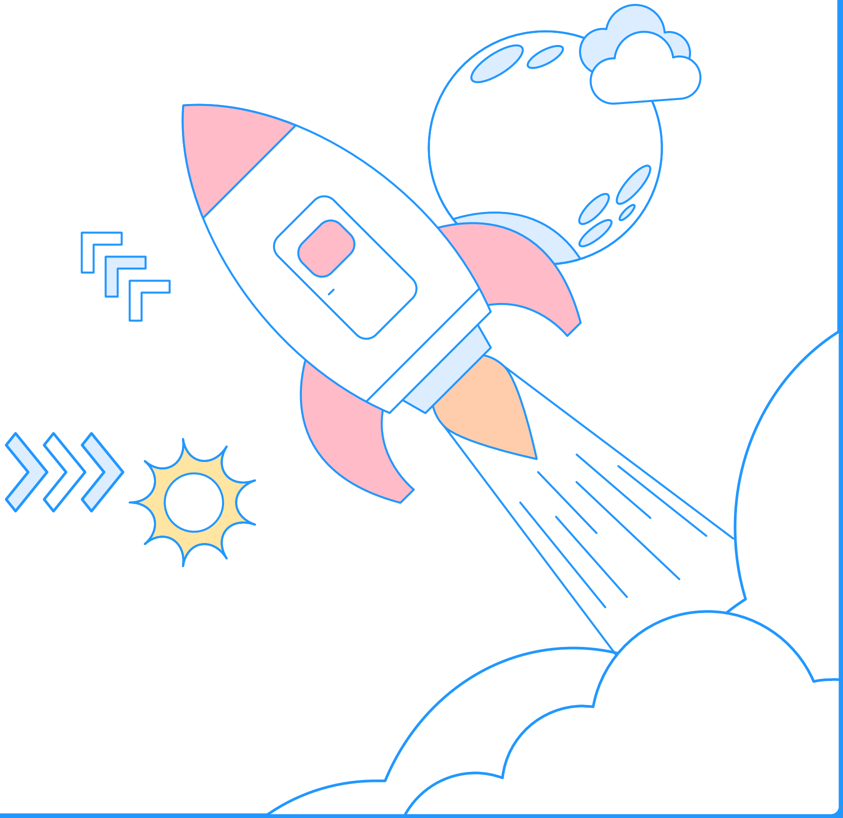
Attempt 2

- Anemometer used
- Average speed used for testing: 22 ft/s
- Results untrustworthy due to vehicle wake turbulence (Results varied from 2.0 to 8.0)
- Future testing planned post-FRR submission

Vehicle Requirements Verification

Requirement	Predicted	Flight one	Flight two	Met
Vehicle Requirements	Handbook: 2.1-2.17 and 2.20-2.23			Yes
Recovery Requirements	Kinetic Energy, Arming Switches, Altimeter Data, Independent Circuitry, Tracking Device, Hardware Specification			Yes
Descent time	87.8 sec	67.1	95 sec	No
Drift Distance	2,575 ft (20 mph wind)	2550 ft(40 mph wind)	2,800 feet (<10mph winds)	No

Part II: Recovery



Recovery System

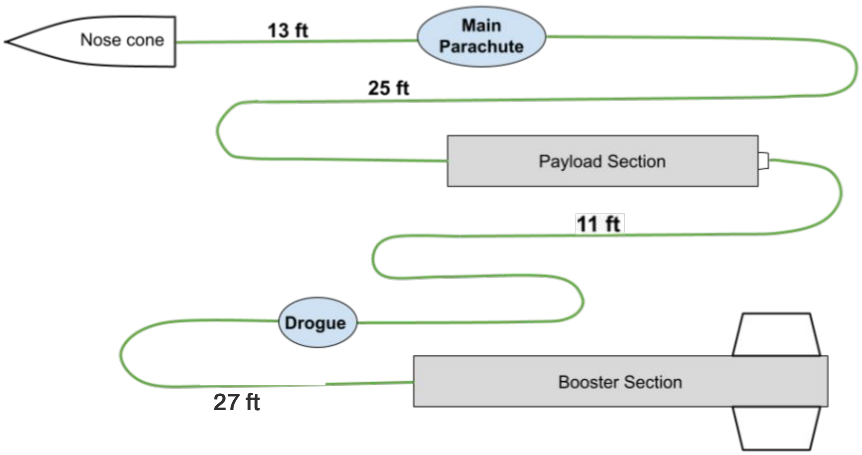
Changes Since CDR

- Predicted Apogee increased to 4,900 ft due to changes in mass.
- Threaded motor forward closure + forged eyebolt (second flight only)
- Used NASA suggested technique to attach main parachute and nomex

Unchanged Components

- Main parachute manufactured to 66"
- Recon Recovery 12" Drogue Parachute
- 3/8" Kevlar Shock Cord
- 1/4" Attachment Hardware
- Forged eye bolt in the Nose Cone Section
- Dual-redundant StratoLogger CF Flight Computers

Recovery Component Locations



-38′ of shock cord connecting the nose cone to the payload section

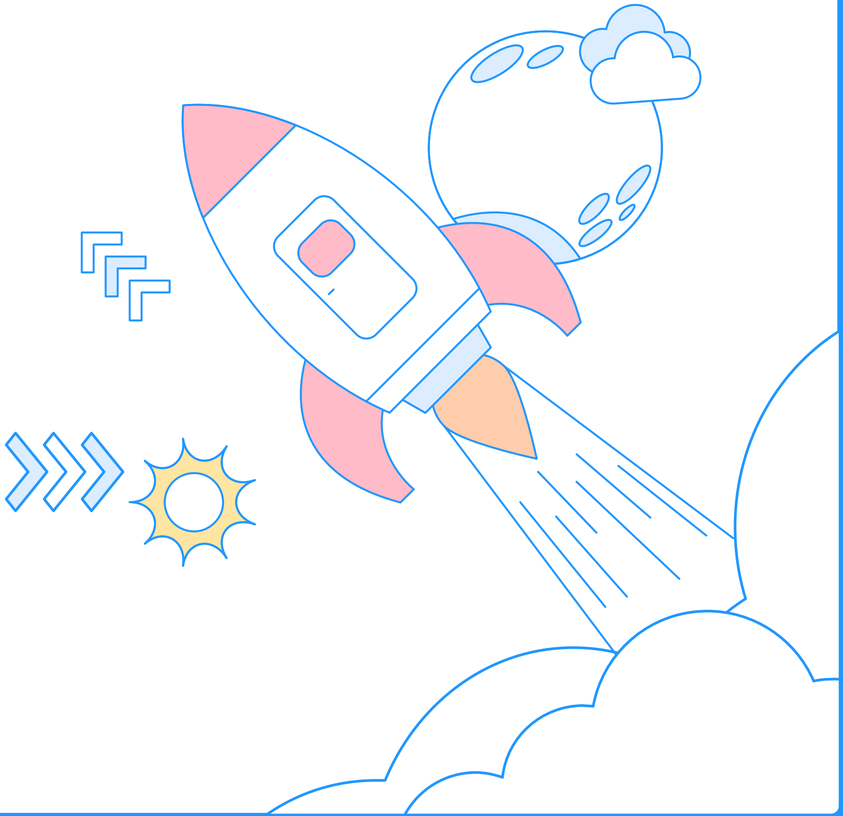
-38′ of shock cord connecting the payload section to the booster section

-The **main parachute** is integrated with the 38′ shock cord, in the nose cone

-The **drogue parachute** is integrated with the 38′ shock cord, in the booster section

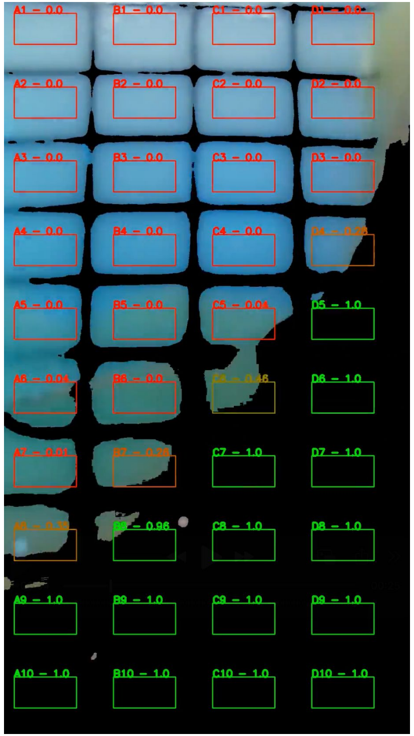
-Both ejection charges are floating charges, located near the tip of the nose cone and the end of the motor as labeled

Part III: Payload



Payload Objective

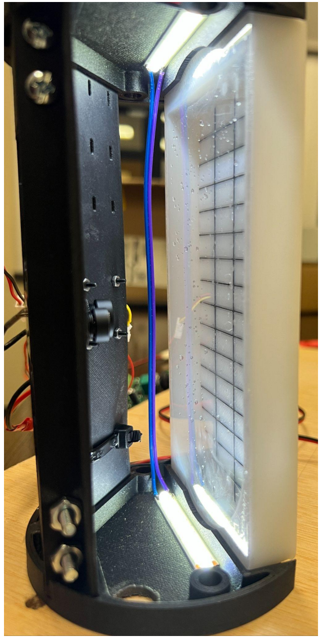
- Slosh = “as any motion of the free liquid surface inside its container caused by disturbance to partially filled liquid containers,” Ibrahim (2005)
- Baffles are often used to mitigate the sloshing effect, prevent slamming
- We are comparing 2 baffle designs to determine which is the most effective.
- We are measuring slosh in an SL rocket to determine which baffles dampen the slosh the greatest, and by how much during the flight.

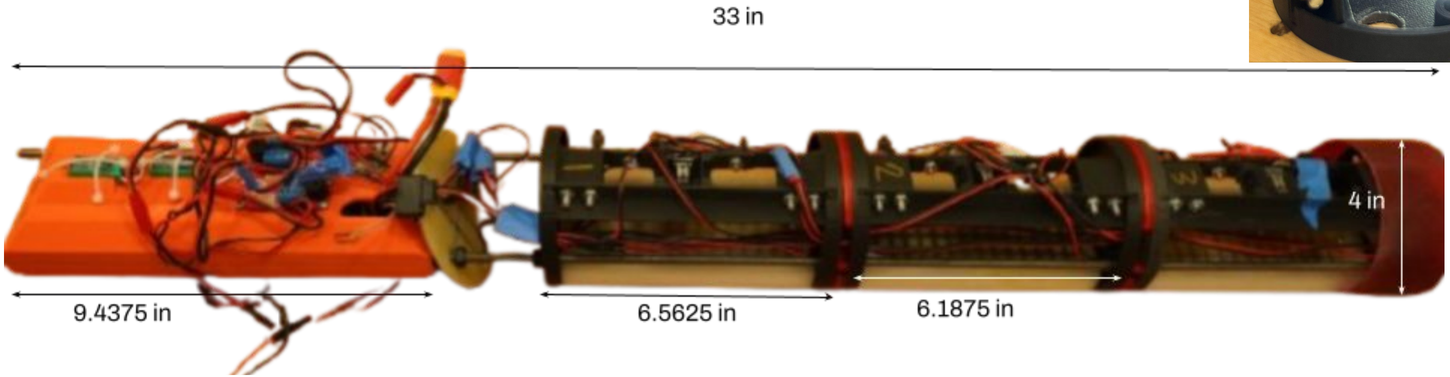


Frame of video taken from our video analysis program

Payload Design and Dimensions

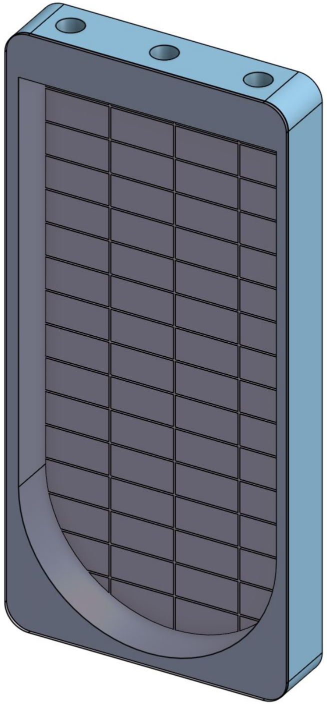
- 3D printed polystyrene tanks are inserted into mounts
- Each mount holds the camera system and LED lights to illuminate the tank
- Two baffle designs + control tank

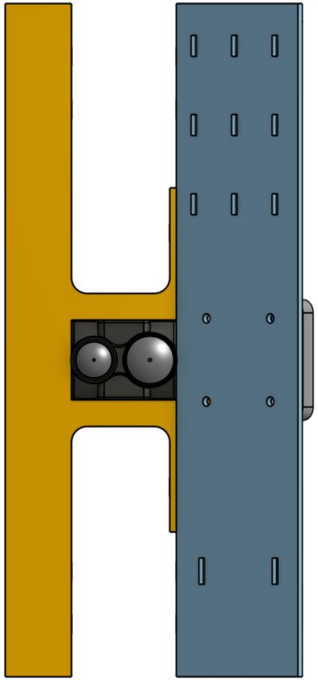




Payload Design Features Overview

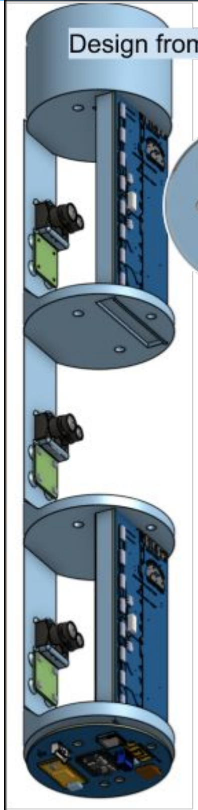
- Tanks
  - Baffles
  - Camera System
  - Lights
- Electronics Bay





Changes from CDR

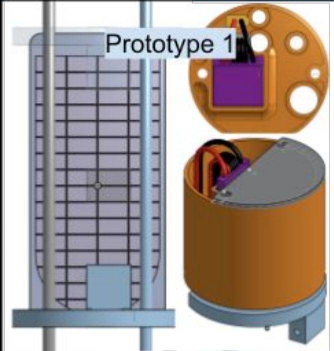
Design from CDR

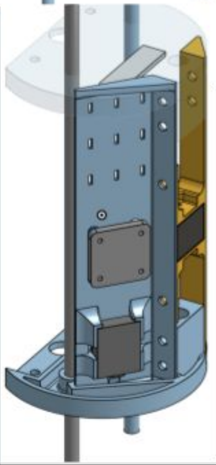


Changes:
-Moved tank further away from camera
-Changed battery mount to include wire box and different sized battery
-Added LED light strips
-Better mount: stronger with screws for tank

Problems:
-Not structurally sound
-Tank not fully in FOV of camera
-Batteries cannot sustain
-LEDs not bright enough

Prototype 1

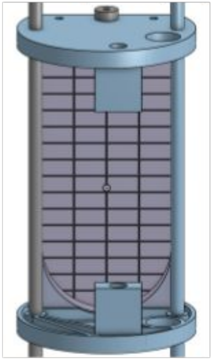




Changes:
-Widened tie rods
-Changed tank design to HIPS and acetone with TPU seal
-Removed PWM converter
-Bigger battery and moved into ebay

Problems:
-Tie Rods block tank
-Not enough room for 3 tanks
-Tank leaked

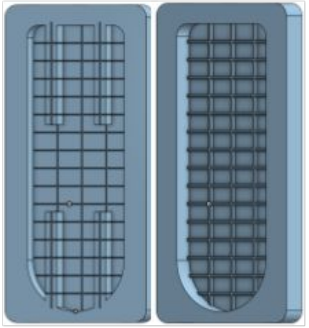
Prototype 2



Changes:
-Widened tank margins
-Added sun shades
-Added spacers between units
Added baffle designs
-Changed fill hole to back of tank

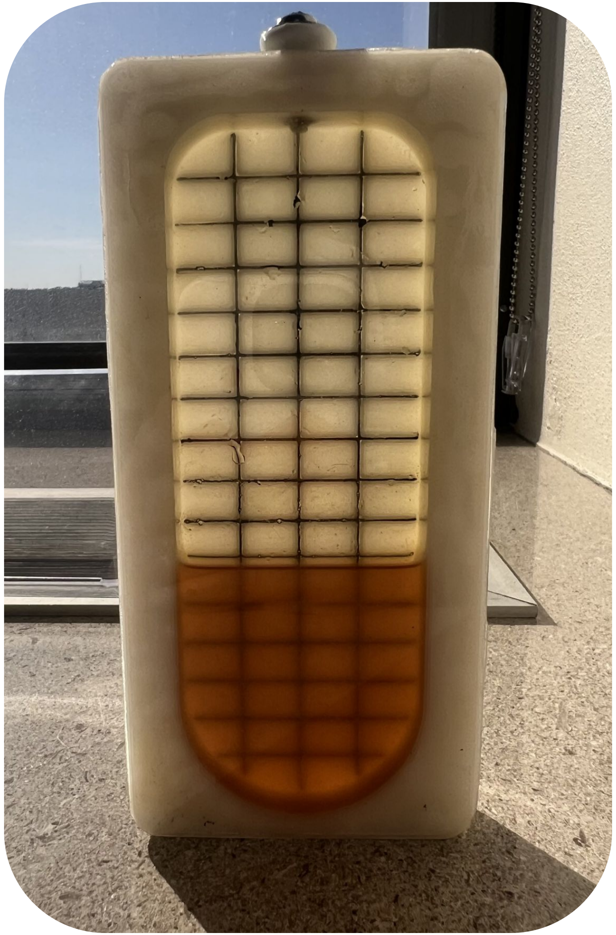
Problems:
-Entire tank not visible
-External light changes mess with camera

Final



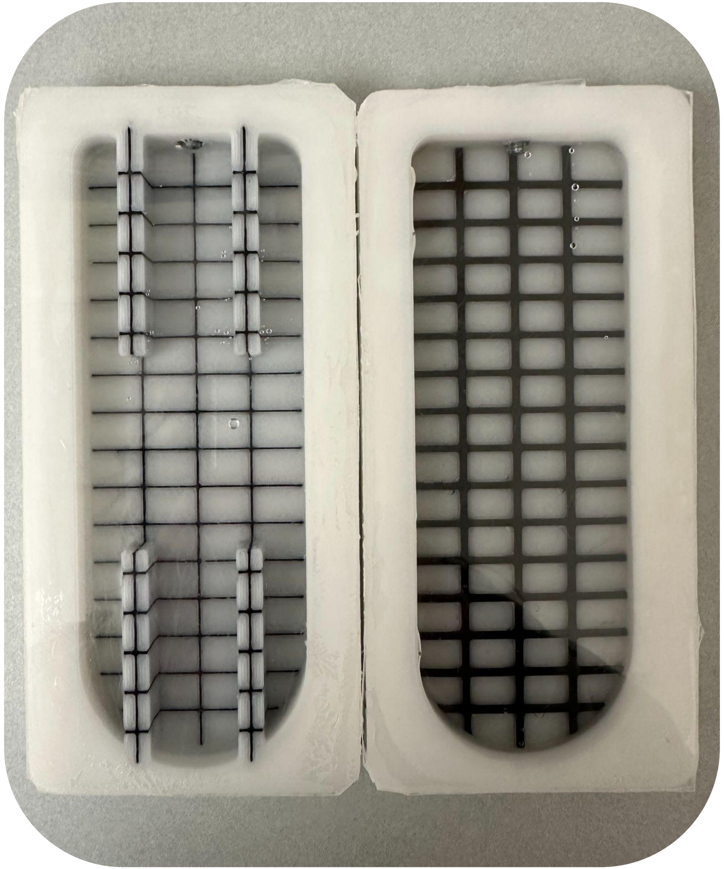
Tank System

- 3 tanks stacked
- Round on bottom, rectangular on top
- 3D printed high impact polystyrene covered with clear plastic
  - Solvent welded using acetone
- 4 threaded inserts to hold in place
- Sealed with screw and squishy TPU 3D printed stopper
- Filled with brightly colored water
  - Anti-foaming agent added



Baffles

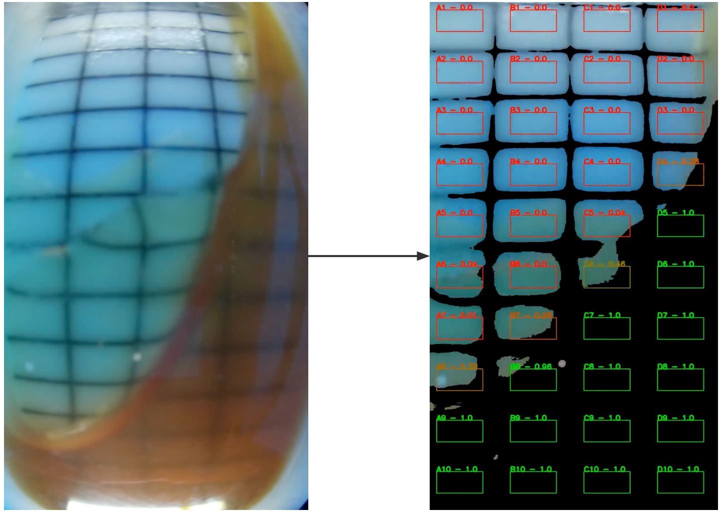
- Based on 3D baffle designs
- Vertical and raised grid baffles
  - Chosen based on test footage and research



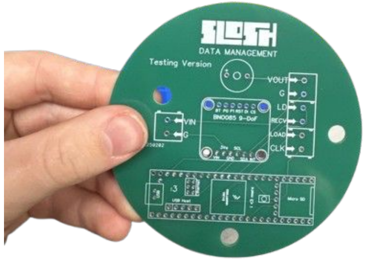
Baffle Designs

Data Collection System

- Runcam Hybrid 2 cameras
  - 1 per tank
  - Video data stored in real-time to SD
- Changes since CDR
  - Electronic Sensor System and Data Management System
  - Inertial Logger
- Data Processing Procedure



Results of our video data processing



PCB for the Inertial Logger. We will be reusing our test Data Management boards to reduce cost and overcome problems with shipment time and design iteration.

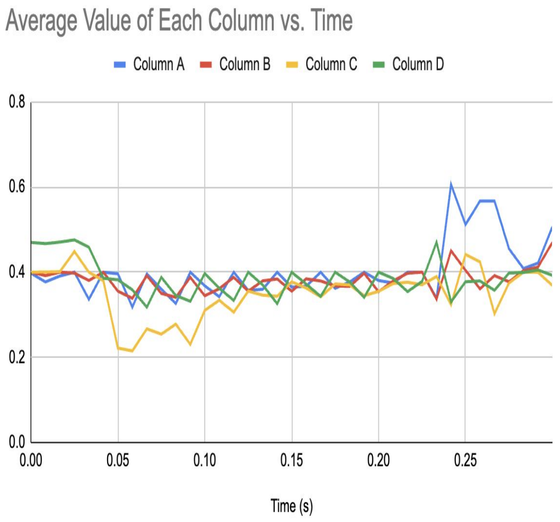
Data Analysis Procedure

Variable data: The variable data is defined as what percentage of each grid is covered by water. Each grid will be assigned a value from 0 to 1 based on the percentage of the grid that is covered by water.

- **Average values** : We will calculate and compare the average values of each column over the same time interval.

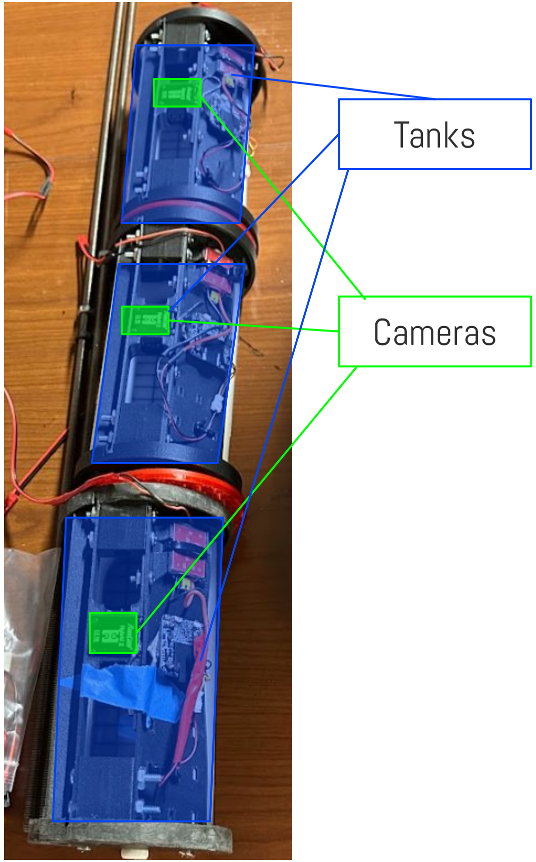
- **Rate of change** of the averaged values: We will calculate the rate of change of the averaged values of each column. In this way, we are able to calculate the rate at which water is moving.

- **Standard deviation** : The standard deviation of the averaged values of each row and column will be calculated to determine the amount of turbulence introduced to the system.



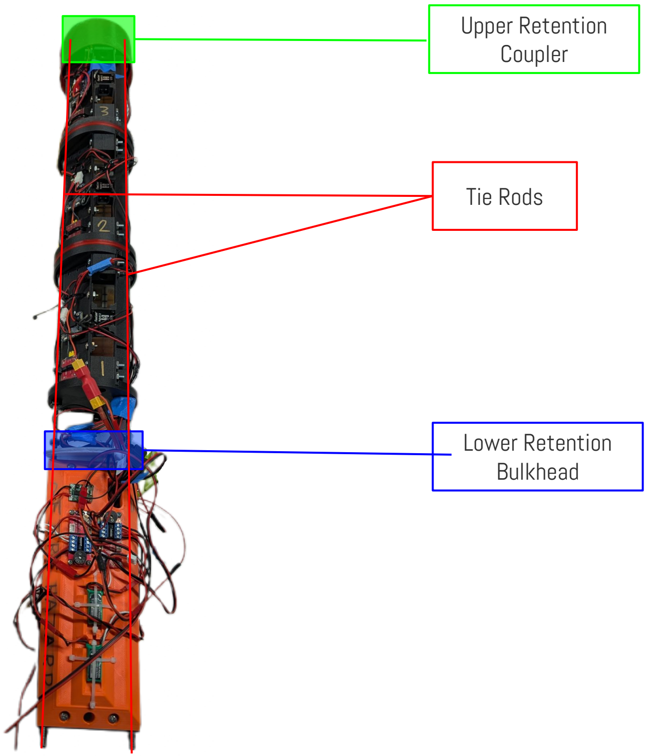
Payload Integration

- Integration process
  - Each tank inserted
  - Wires connected to power source from each module
  - Camera power checked
  - Wires tied down with zip ties to prevent pinching with the upper tube



Payload Retention

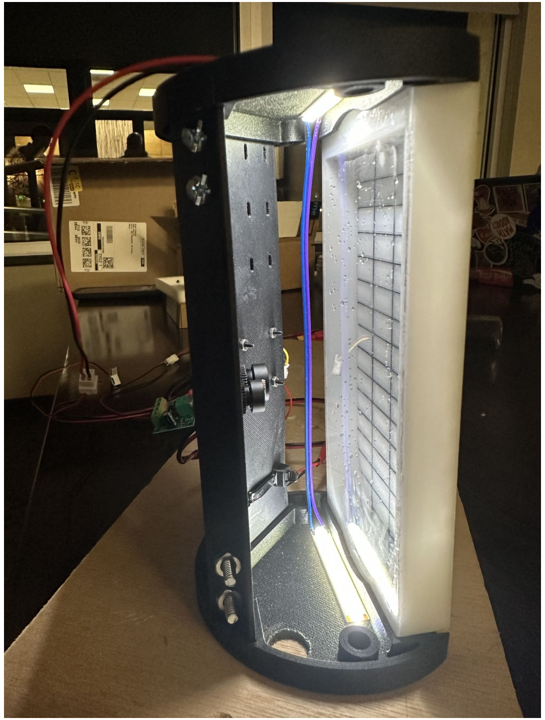
- ¼" steel threaded tie rods
    - 3" spacing
- Upper Retention Coupler
- Lower Retention Bulkhead



Fully integrated payload and electronics bay showcasing the full retention system

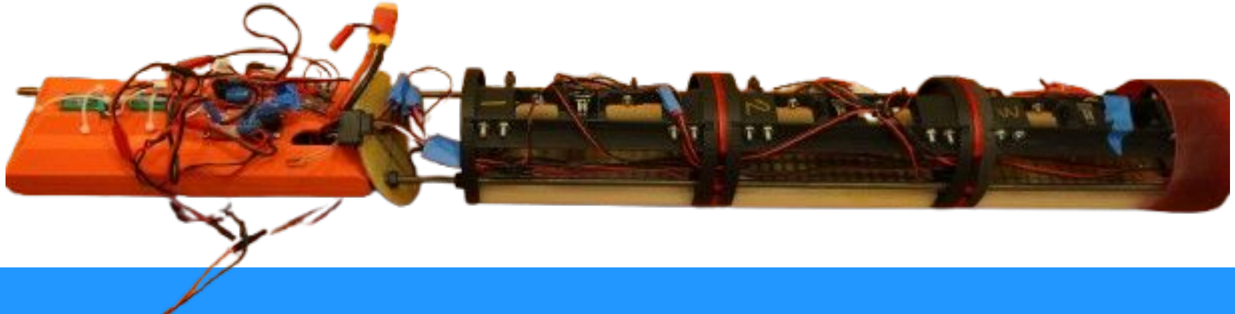
VDF Flight Attempt 1 - Payload Results

- Payload consisted of one tank, one camera, and an LED strip on the top and bottom
- Results
  - Need anti-foaming agent (simethicone)
  - Foaming interfered with the data extraction code
  - Slosh patterns were more irregular
    - Affected by a motor issue
  - Second flight similar, but these was no motor issues to contribute to the direction of slosh
  - Necessity to have darker color water (dark orange)



Payload Demonstration Flight Attempt (VDF 2)

- Payload consisted of 3 tanks, 3 contiguous cameras, and LED system for each tank
- Results
  - Mostly successful, re-attempt needed
  - No foaming
  - Glare from translucent body tube that disrupted data
  - Inconsistent lighting between different baffle systems
- PDF attempt 2 will have a light blocking system



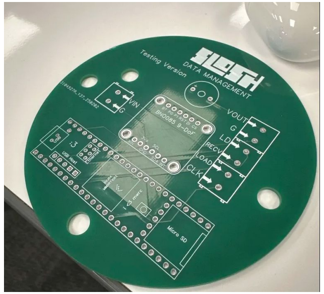
Payload Demonstration Flight Plans

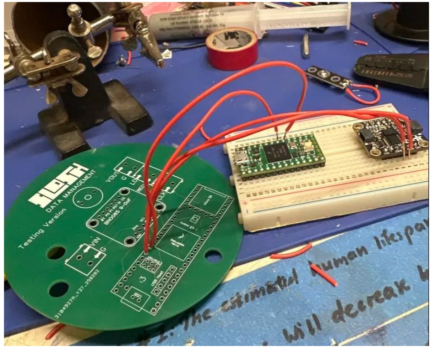
Payload Changes

- Concept - Light blockers
- Baffle designs will be recolored to help with image processing
- Inertial Logger will be added to log accelerometer data

Vehicle Changes

- Avionics sled updated with light shields for the flight computers
- New ballast arrangements to better match the simulations to the test flights





Payload Requirements Verification

	Expected	Flight one	Flight two	Met
Handbook Payload Requirements	4.1, 4.4: Our payload is designed and manufactured by our payload team and does not contain any energetics or a UAS			Yes
Team-Derived Slosh Requirements	Horizontal sloshing	Water movement was irregular	Water movement was mitigated by baffles	Yes
Team-Derived Data System Requirements	Recorded all information without disruption	Foaming of water	Light partial-disruption of data collection	No

Team-Derived Requirements Verification

Currently, our rocket does not abide to the below team requirements, particularly the events timing for recovery, some disruption in data collection, and drift and descent times for our vehicle. We are testing and changing our designs to abide to these requirements, as presented here.

Vehicle	Recovery	Payload
Stability	Events timing	Data collection
Drift	Deployment	Water retention
Descent		Decrease in slosh