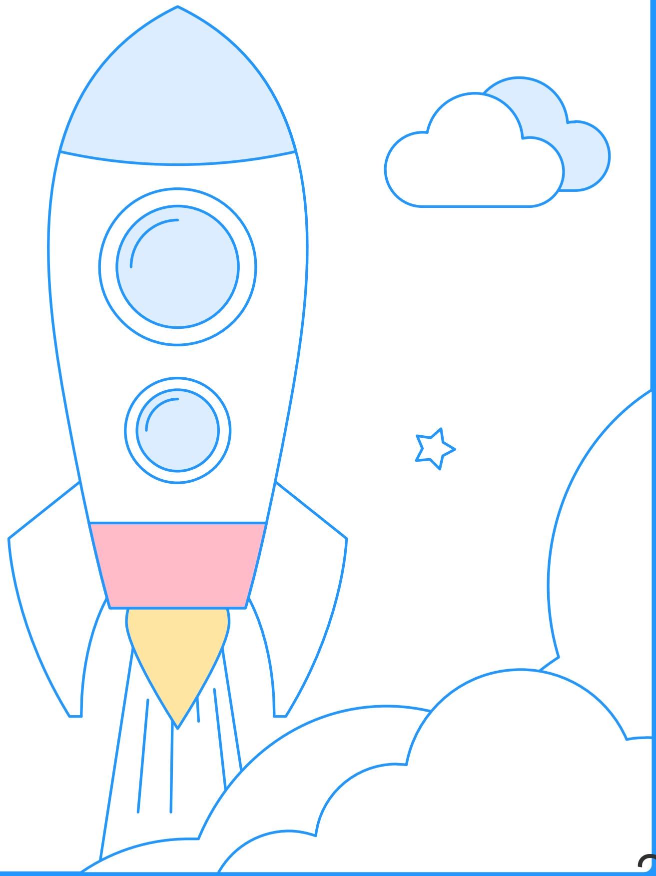
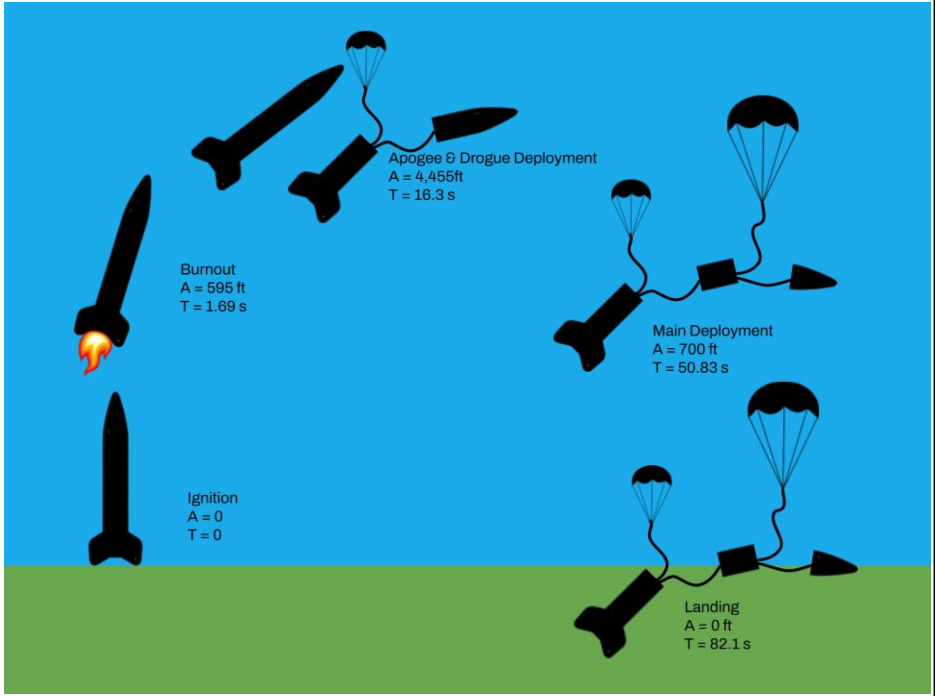
SLOSH

Madison West Rocket Club - CDR

Part I: Vehicle

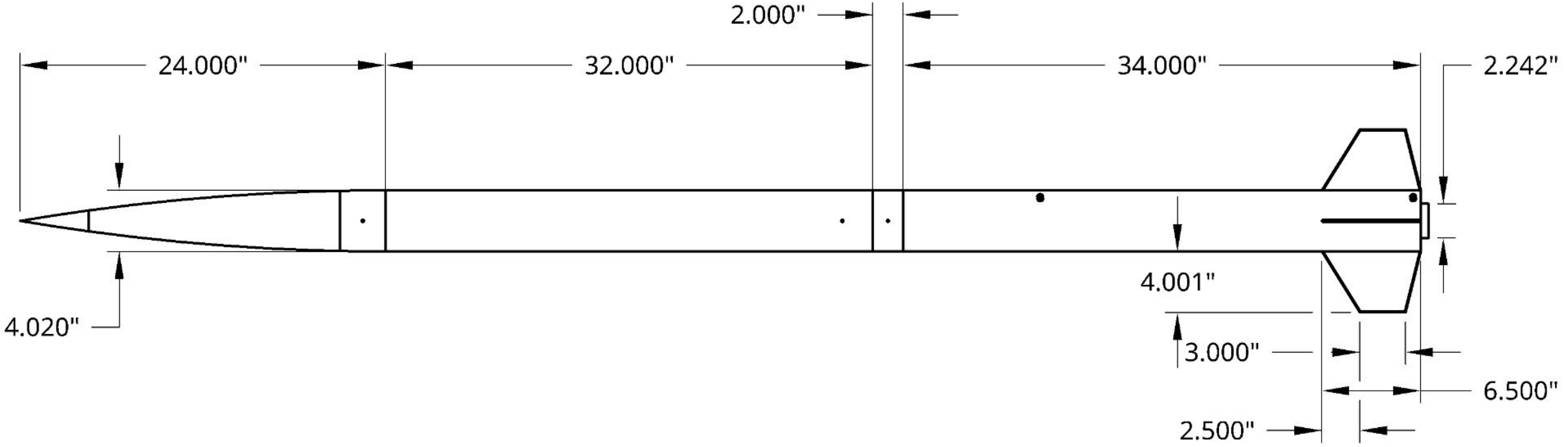


Mission Profile



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

Vehicle Dimensions



Vehicle Materials + Justification

System	Component	Material(s)
Recovery	Parachute (Drogue and Main chutes)	Ripstop Nylon
Recovery	Shroud Lines	Kevlar Twine
Recovery	Shock Cord	⅜" Kevlar Cord
Misc. Hardware	Tie Rods, U Bolts, etc…	Steel
Vehicle	Body Tubes, Fins, Nosecone, Centering Rings, Couplers, Motor Mount, Bulkheads, Switchband	Fiberglass

Recovery System

-Drogue Parachute

-Deploys at apogee (4455ft)

-Manufactured by the team

-12" ripstop nylon parachute, elastic shroud lines (50.8cm, 2mm round)

-Packed in booster section below the coupler and above the motor assembly

-Slows rocket to a decent rate of 114.2 ft/s

-Main Parachute

-Deploys at 700 feet

-Manufactured by the team

-66" toroidal parachute, elastic shroud lines (114cm, 2mm round)

-Packed in nose cone

-Recovery harness type, size, length

-Slows rocket to a decent rate of 18.95 ft/s

Team-Manufactured Scale Main Parachute

Recovery System, Continued

⅜" Tubular Kevlar

-Shock Cord

-3,600 lb breaking strength, 900°F temperature tolerance

-Nose cone-to-payload section shock cord's optimal length is 38′, calculated for reliability and general strength

-38′ of ⅜" tubular kevlar shock cord (nose cone to payload)

-38′ of ⅜" tubular kevlar shock cord (payload to booster)

¼" U-bolt

¼" Forged eye bolt

-Mounting Hardware

-¼" U-bolts, wherever possible, 1,300 lbs working load capacity

-¼" forged eye bolt inside of the nose cone, 1,500 lbs working load capacity

-¼" U-bolt passes through forward fiberglass bulkhead

-Deployment Altimeters

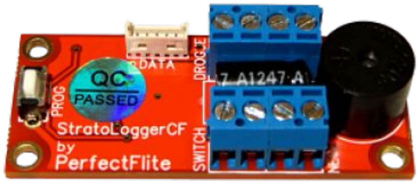
-Two PerfectFlite StratoLoggers

-Barometric dual-deployment altimeter, two for redundancy

-Resistant to false trigger wind gusts

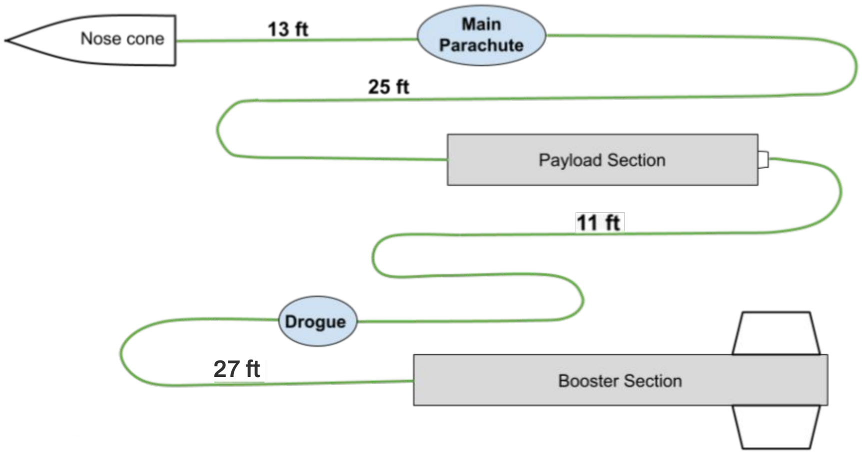
-7.4V 2S 100mAh LiPo batteries

-Low weight, only 10.8 grams



PerfectFlite Stratologger

Recovery Component Locations



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

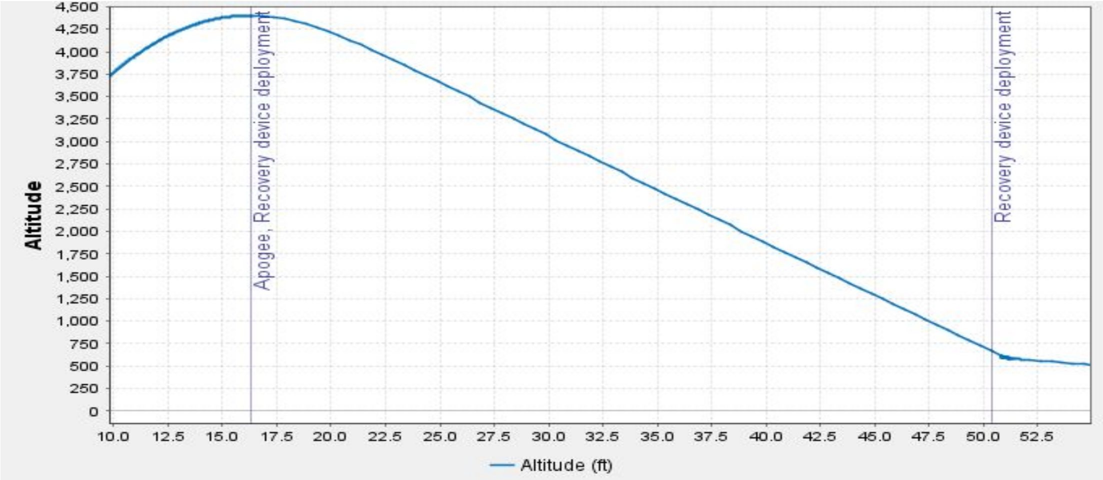
-**32′** of shock cord connecting the payload section to the booster section

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

-The **drogue parachute** is integrated with the 32′ shock cord, in the booster section

Recovery System Concept of Operations (CONOPS)

1. Apogee: The main flight computer will deploy the primary drogue ejection charge.
2. Apogee +1 second: The secondary flight computer will deploy the backup drogue ejection charge.
3. 700 ft: The main flight computer will deploy the primary main chute ejection charge.
4. 600 ft: The secondary flight computer will deploy the backup main chute ejection charge.



Separation Points Visual

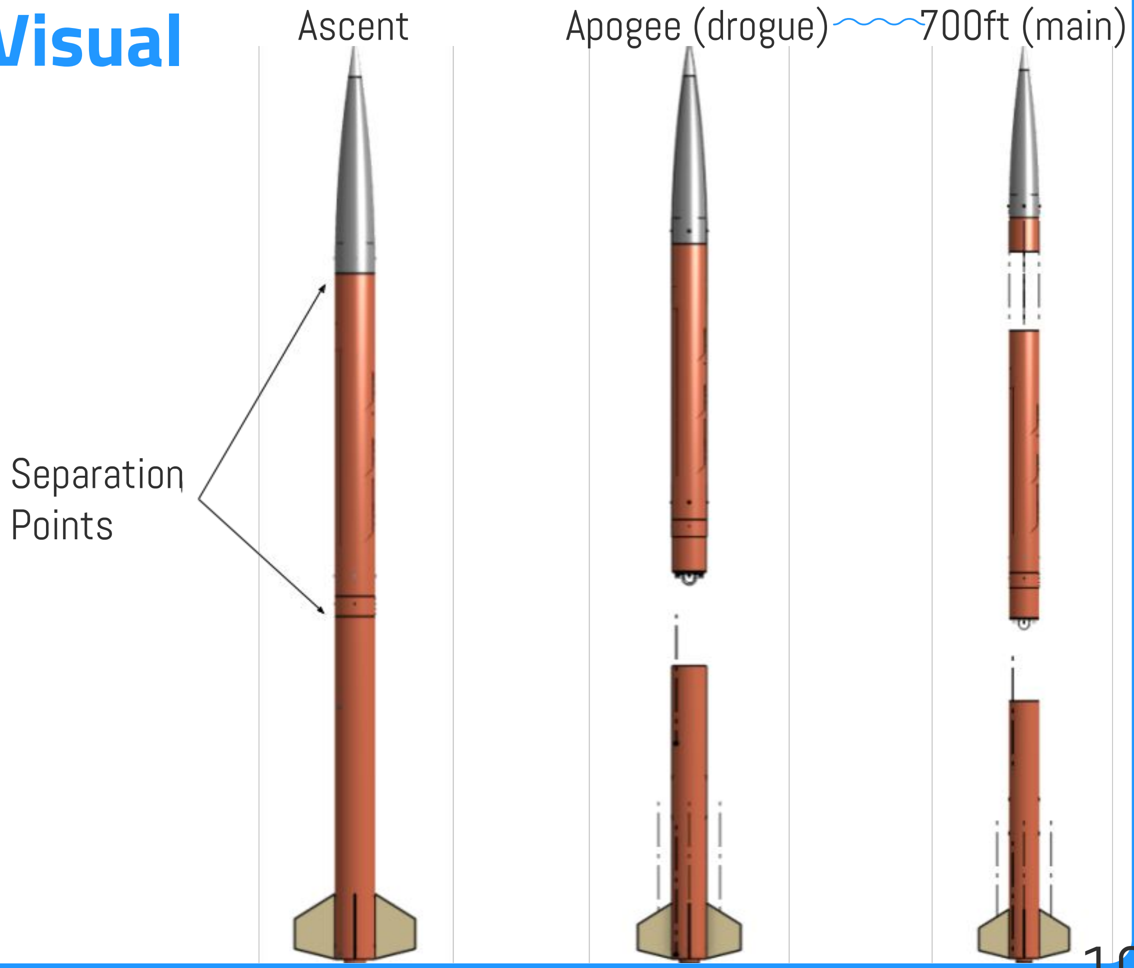
Separation Event 1: Apogee

- Separation of booster and payload section
- Drogue deployment

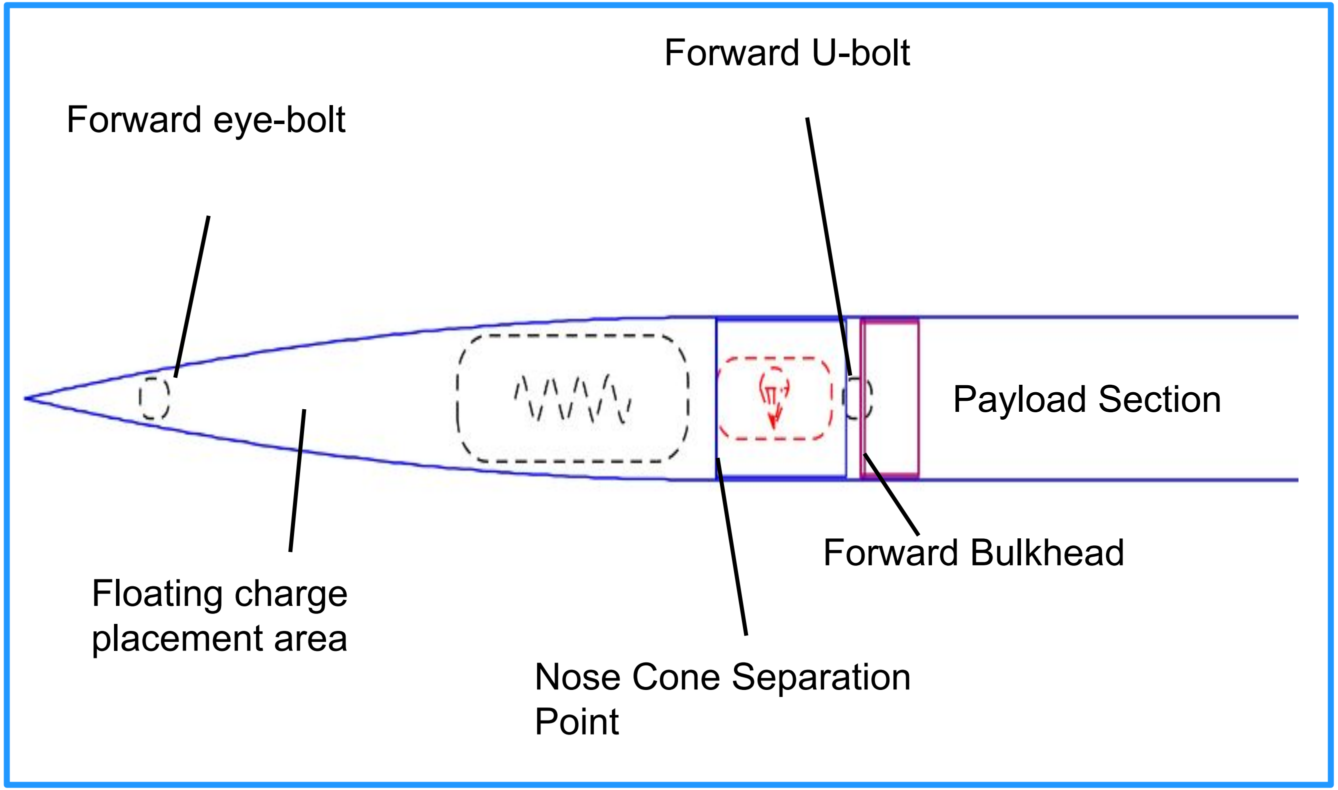
Separation Event 2: 700 feet

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

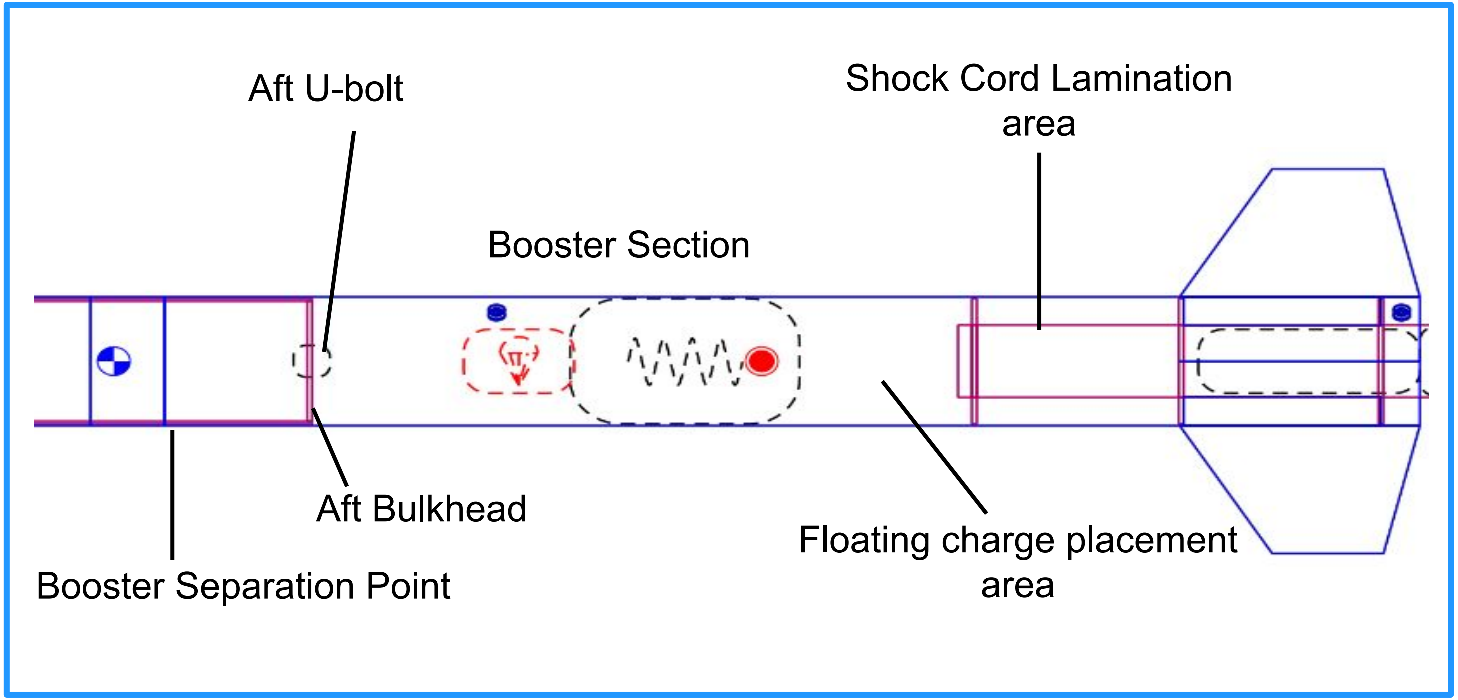
*Tethering shock cords omitted in this diagram



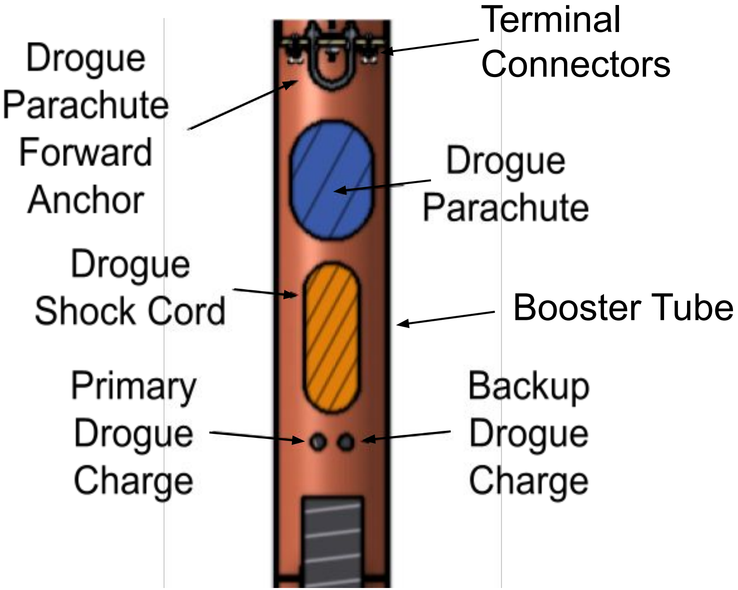
Separation Point Close-up: Nose Cone

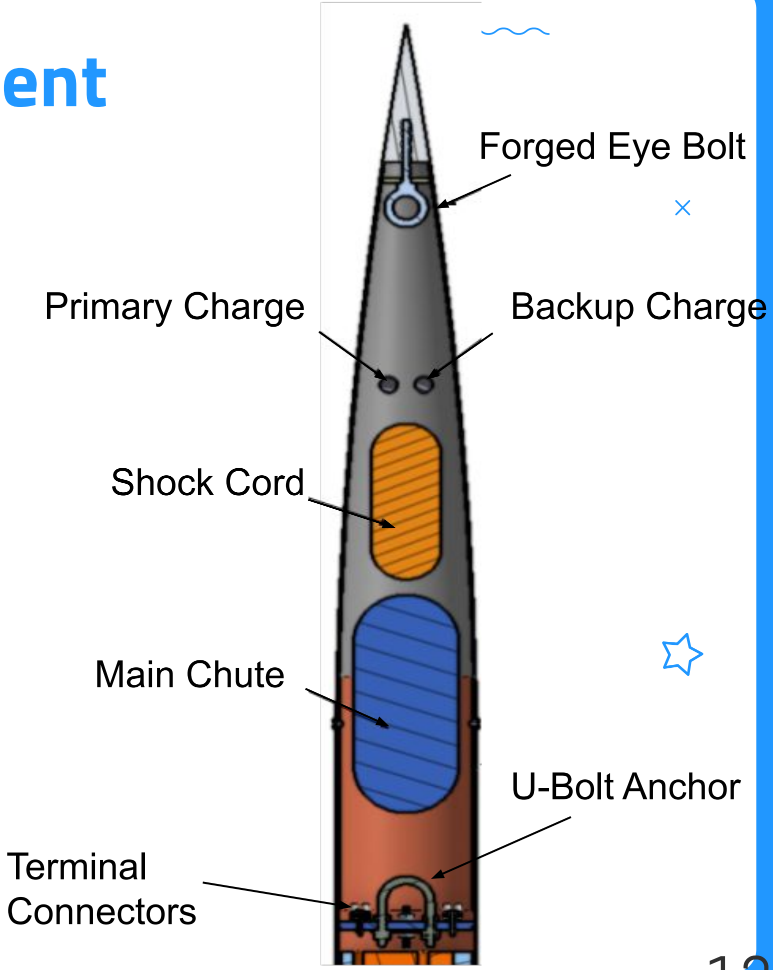


Separation Point Close-up: Booster

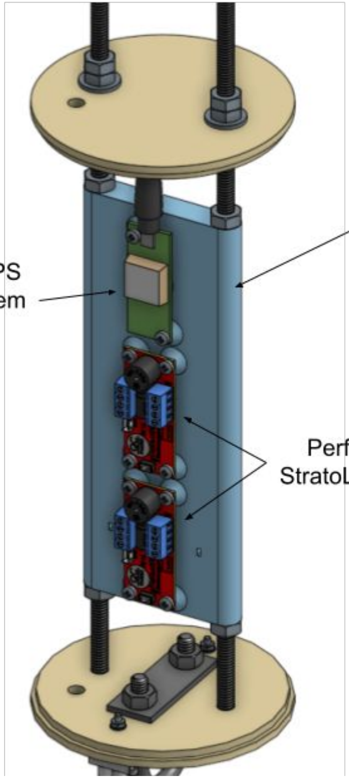


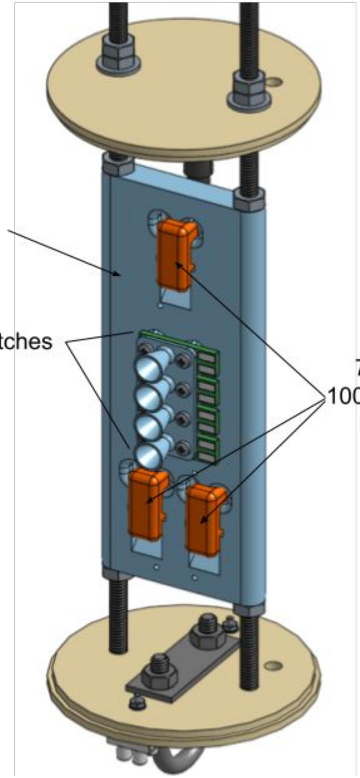
Recovery Subsystem Component Diagrams

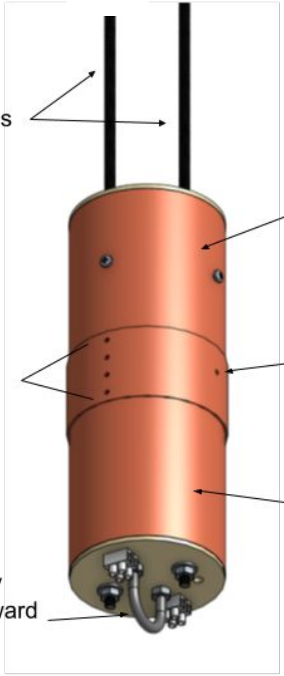




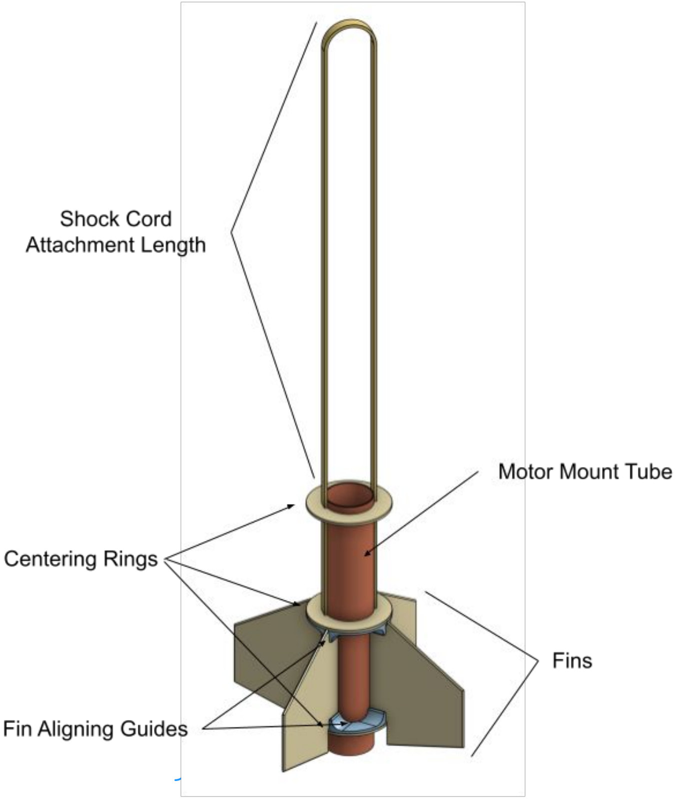
Electronics Bay Component Diagram

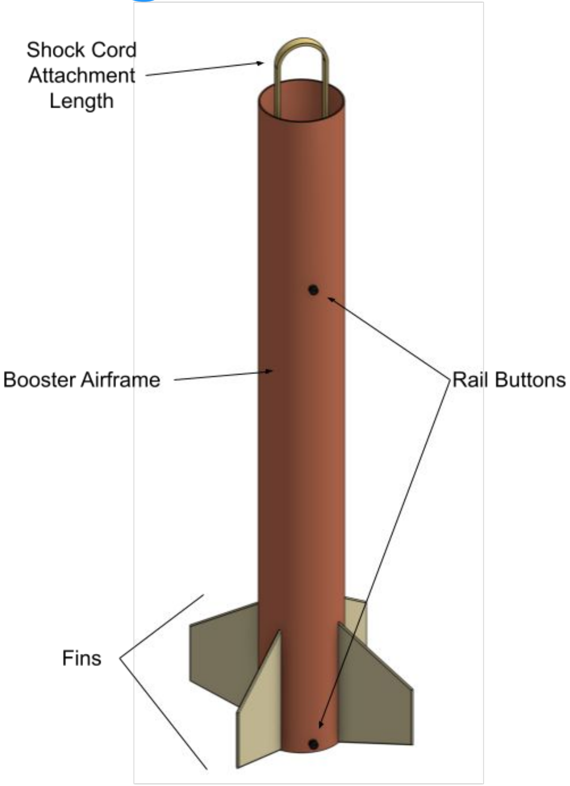




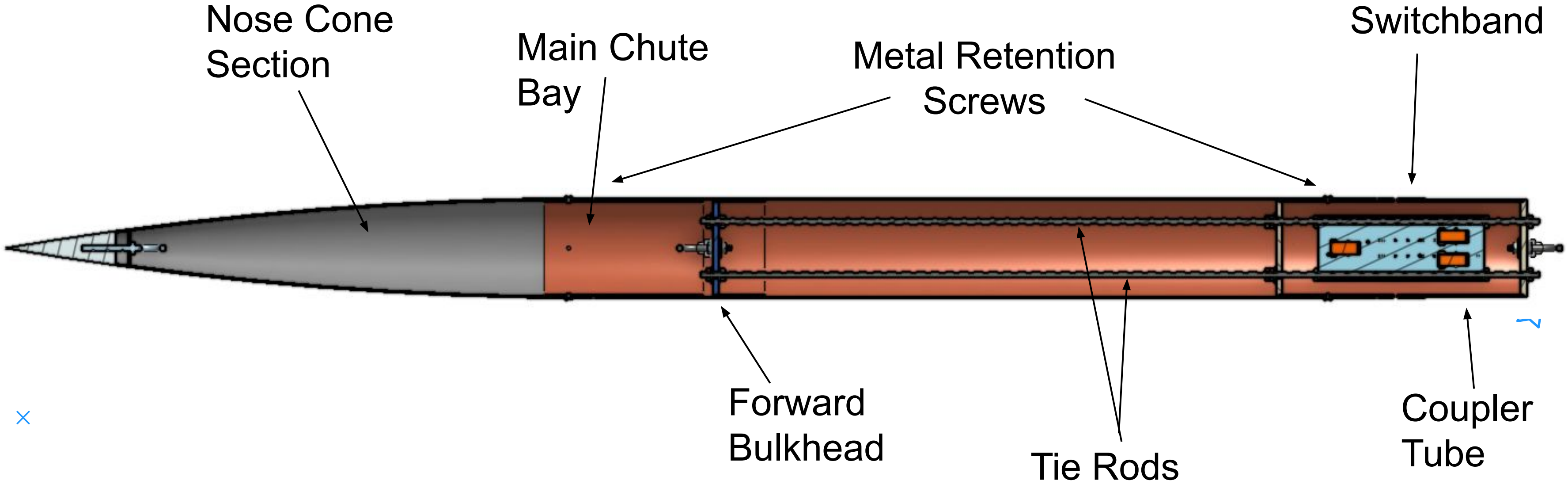


Booster Section Component Diagram

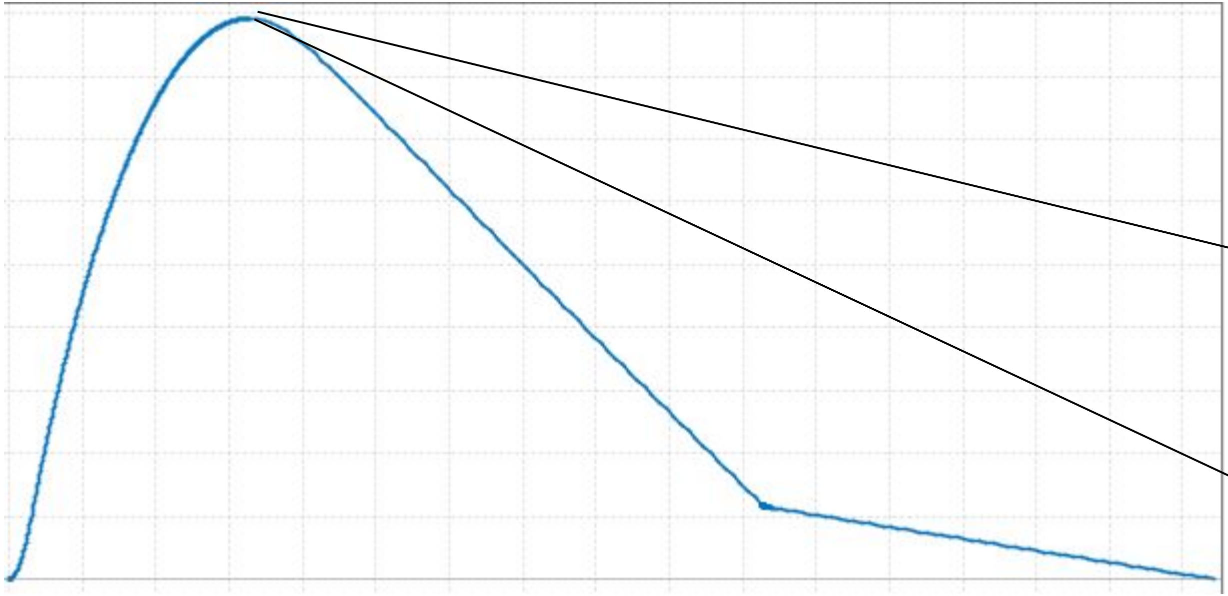




Upper Section Component Diagram



Final Altitude Declaration and Justification



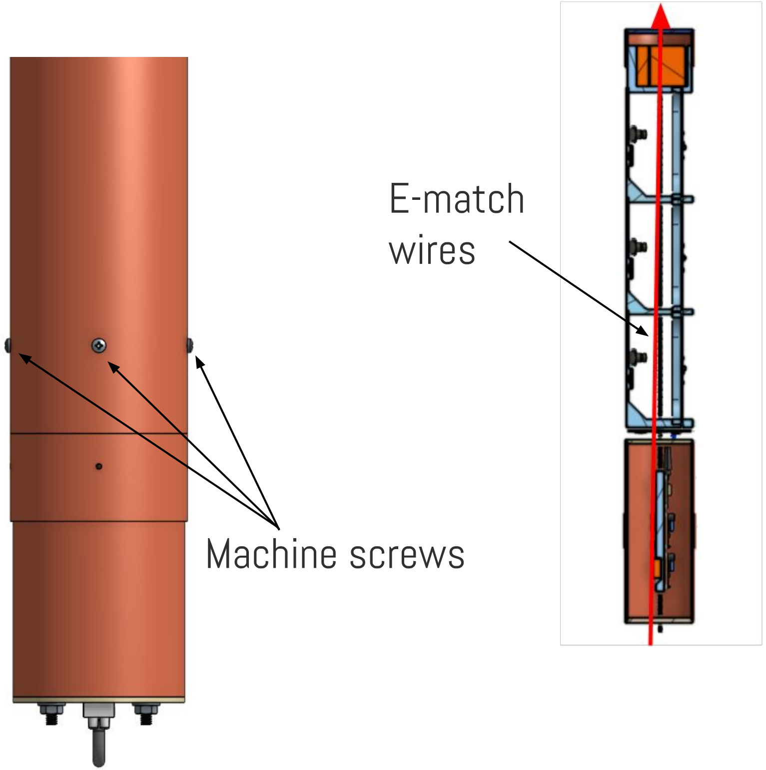
Our target altitude is 4,500 feet

The Vehicle's simulated apogee is 4,455 feet, approximately 16.3 seconds after launch

Key Design Features

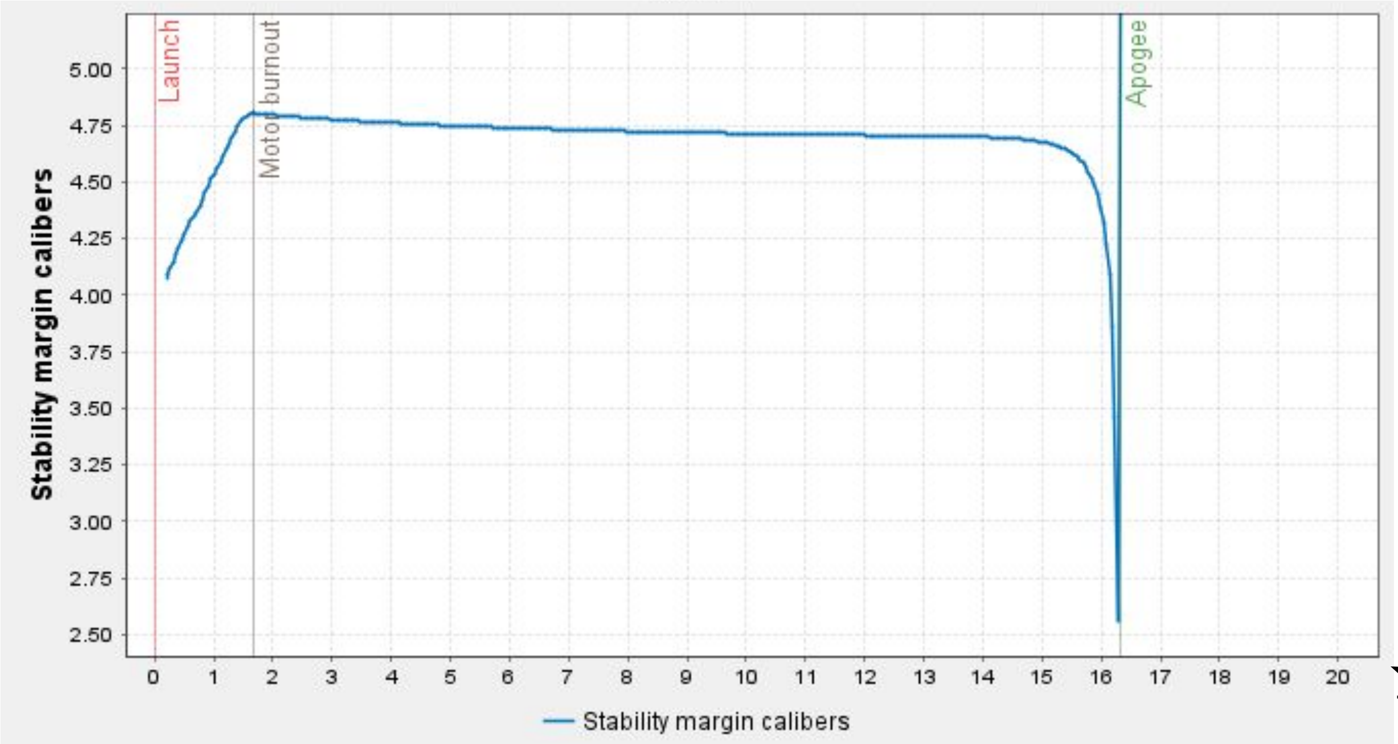
- Electronics bay bolted into upper section

- E-match wires run from electronics bay to forward bulkhead along tie rods.



Stability Visualization

Rocket Flight Stability



Time in Seconds

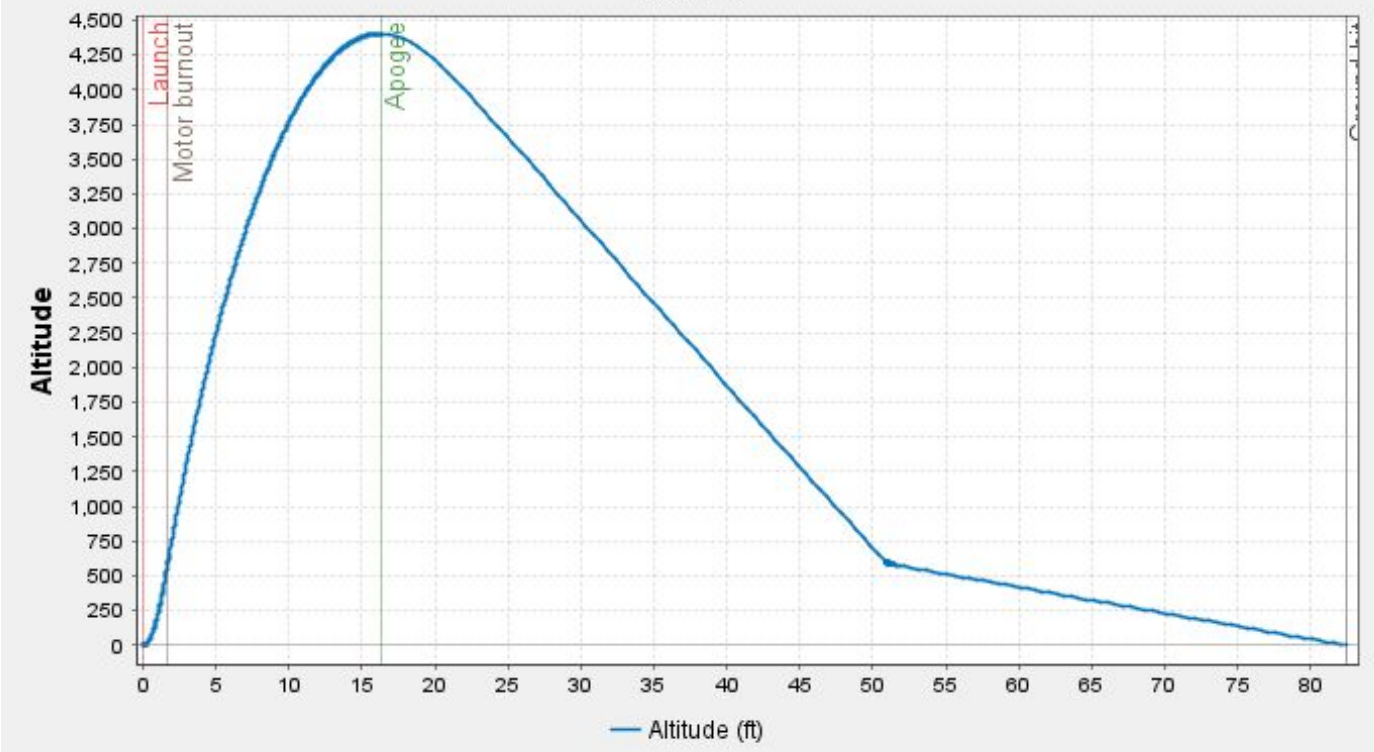
Final Motor Choice

Full Scale Model:
AeroTech K-1103-P
Plugged

Half Scale Model:
AeroTech HP-G138-P
Plugged

K-1103 Motor Casing

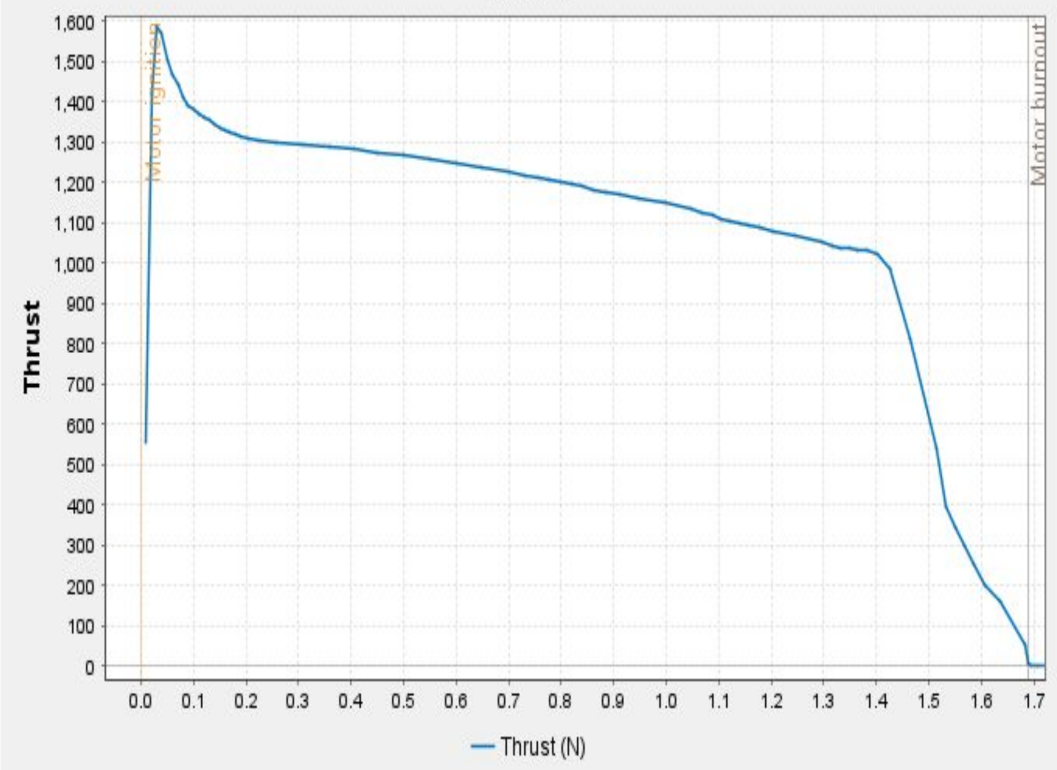
Altitude Profile



Wind speed vs Apogee

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

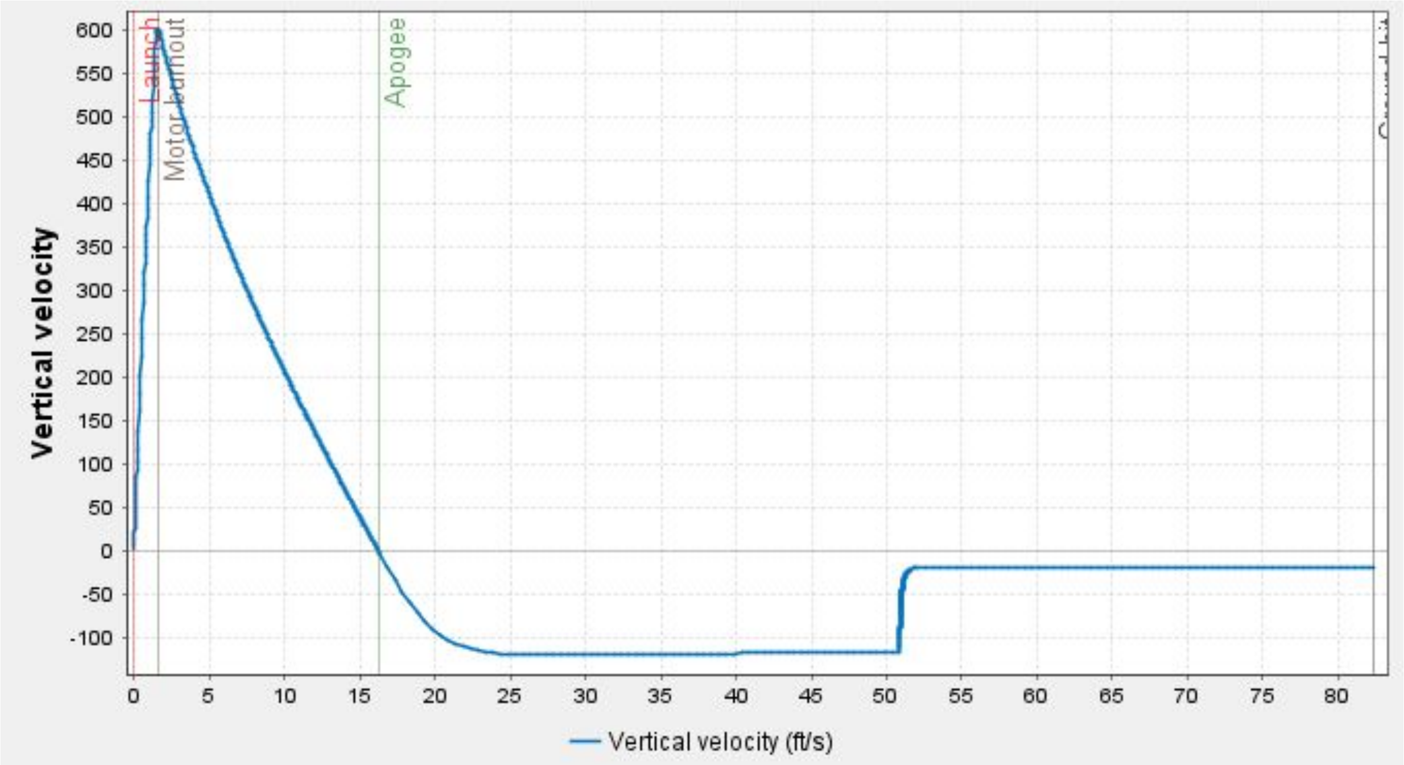
Thrust Profile



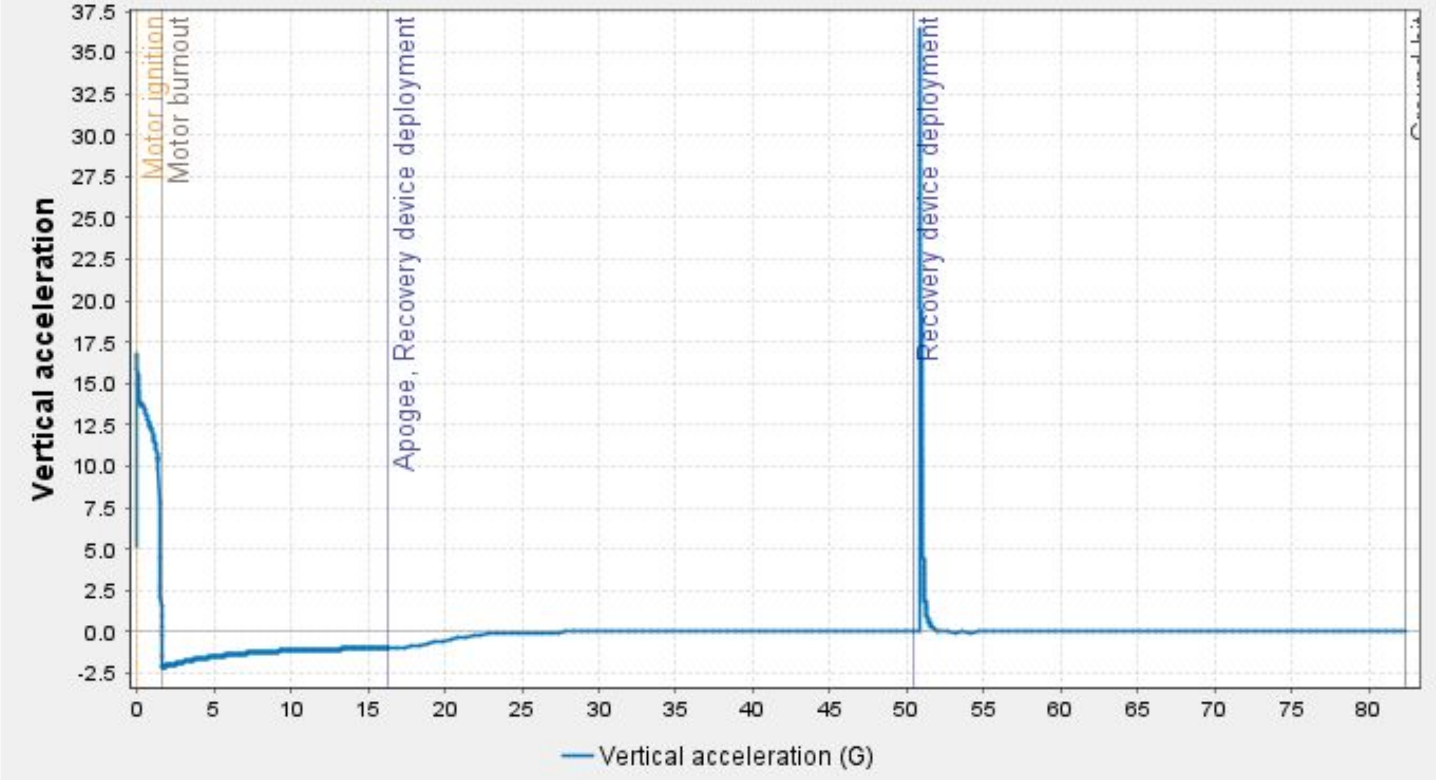
Average thrust to weight ratio ≈ 12.3 : 1

Rail exit velocity ≈ 85 ft/sec.

Velocity Profile



Acceleration Profile



Kinetic Energy

At Impact

Nose cone	7.92 ft-lbf
Upper Section	40.99ft- lbf
Booster Section	34.69 ft-lbf

At main parachute release (under drogue parachute, before separation)

Nose cone + Upper Section	1776.07 ft-lbf
Booster Section	1259.42 ft-lbf

Predicted Drift

Wind speed(mph)	Drift
5 mph (7.33 ft/s)	488.4ft
10 mph (14.67 ft/s)	976.8ft
15 mph (22 ft/s)	1465.2ft
20 mph (29.33 ft/s)	1953.6ft

Mass of Each Section

Section	**Mass** (rounded to 2 significant figures)
Entire Vehicle - Dry Mass	16.89 lbs
Entire Vehicle - Wet Mass	20.10 lbs
Entire Vehicle - Burnout and Landing Mass	18.28 lbs
Nose Cone	1.35 lbs
Upper Section (including payload and electronics bay)	9.00 lbs
Payload and Electronics Bay	4.50 lbs
Booster Section	6.47 lbs
Recovery Components (Parachutes and Shock Cords)	3.30 lbs

Mass Margin

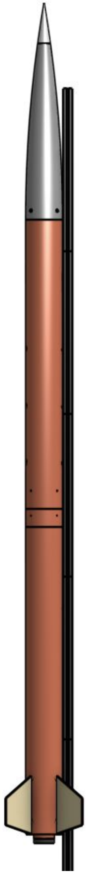
- Increase in mass (+10% / +912g)
  - Apogee decreases by ~500 ft
  - Estimated flight time decreases by ~10 sec
  - Results still within NASA requirements

- Decrease in mass (-10% / -912g)
  - Apogee increases by ~500 ft
  - Estimated flight time increases by ~10 seconds
  - Results not within NASA requirements

Interfaces (External)

External (Vehicle to Launch Components)

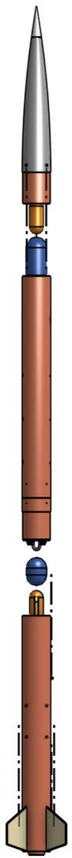
- Rail buttons to launch rail
    - ½ inch from vehicle's base
    - 25 inches from base
- Base of motor retainer to launch pad surface



Interfaces (Internal)

Within Launch Vehicle

- Nose cone to upper section tube
    - Separation point, secured in-flight with shear pins
    - 4 inch shoulder
- Upper section to tube coupler
    - Bolted together
    - 4 inch shoulder
- Tube coupler to switch band
    - Secured with epoxy
- Tube Coupler to Booster Section
    - Separation point, secured in-flight with shear pins
    - 4 inch shoulder
- Booster Tube to Motor Retention System
    - Components secured with epoxy
- Shock Cord to Motor Tube
    - Secured on either side of tube with epoxy



(image does not show all interfaces)

Subscale Test Flights

We conducted 2 flights of our subscale model.

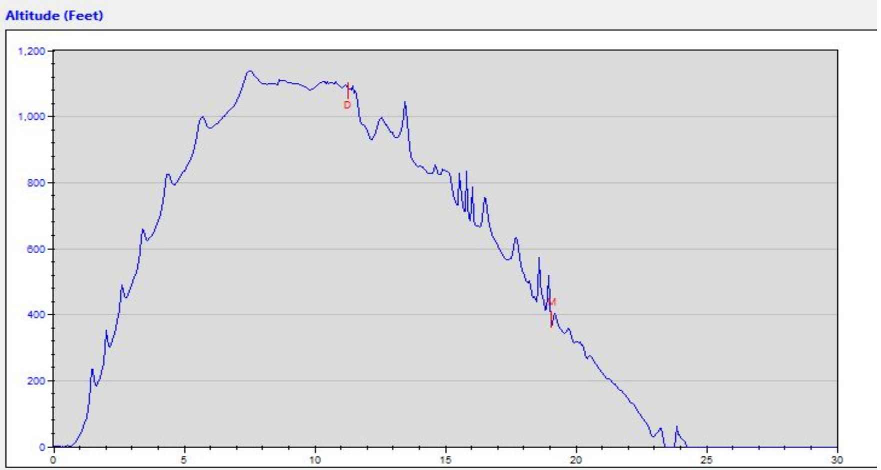
- On the first flight, the main parachute remained encased in its Nomex protector.
- The vehicle landed at a higher speed than expected.
- Damage to the vehicle was minimal and we conducted a second flight.
- On flight 2, all parts of the flight went nominally.

Scale Model Info

- ½ scale of full scale vehicle.
- Launched on an AeroTech G-138 motor.

Scale Model Flight Data & Analysis (Flight 1)

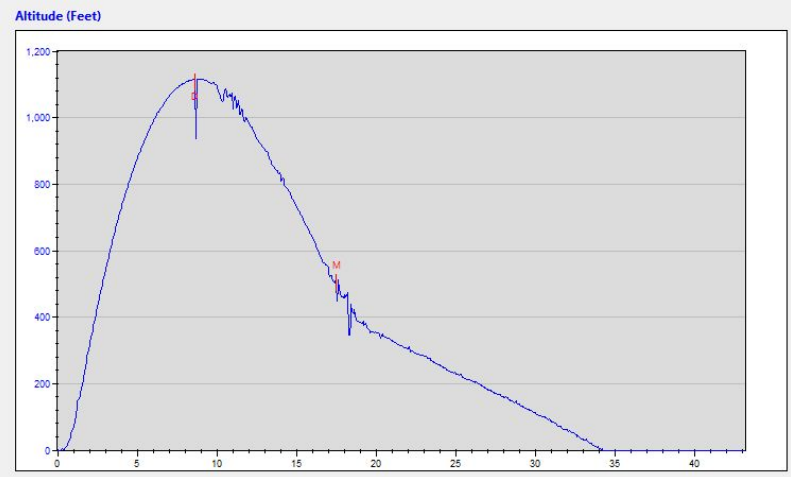
Main Computer



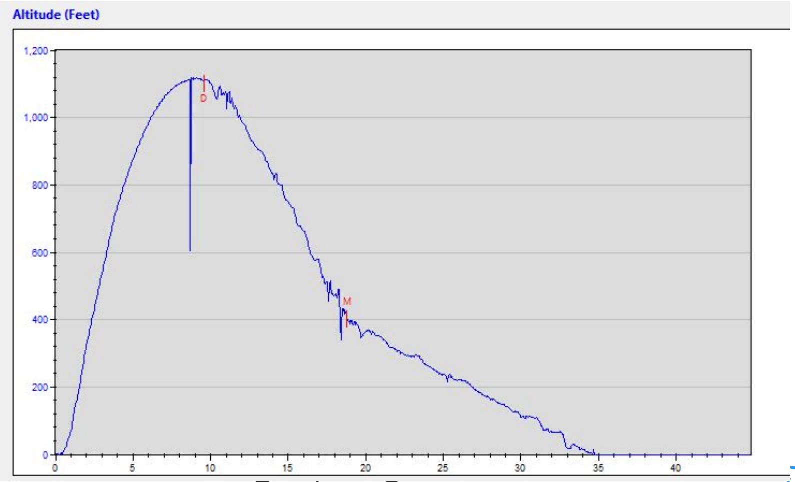
Backup Computer

- Apogee of 1126 ft
- 8 seconds to apogee
- Total flight time ≈ 23 seconds

Scale Model Flight Data & Analysis (Flight 2)



Main Computer



Backup Computer

- Apogee of 1118.5 ft
- 8.75 seconds to apogee
- Total flight time ≈ 34 seconds.

Tests of the Staged Recovery System

We tested our subscale staged recovery system twice, once on the first launch of the scale vehicle and once on the second launch.

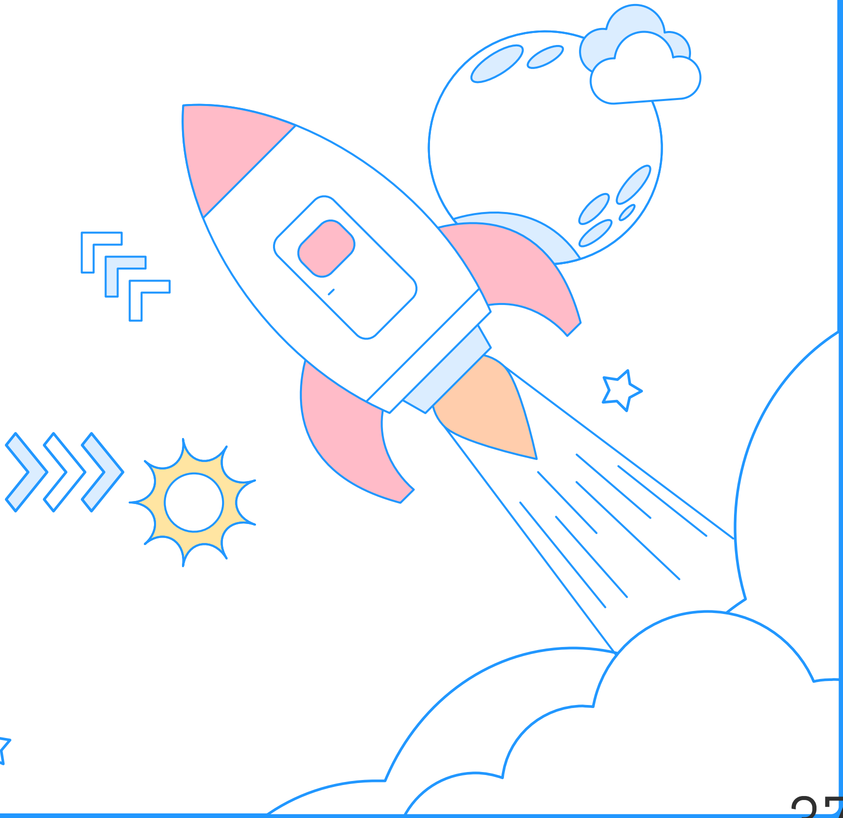
- On the first launch, all components of the recovery system ejected as planned
- The main parachute did not inflate

- On the second test, the entire recovery system functioned as planned

We plan to conduct tests of our recovery system prior to our full-scale launch.

Flight 1 main parachute configuration

Part II: Payload



CONOPS

Purpose

Reducing the amount of slosh—defined as uncontrolled movement of water in a container in a tank—can prevent the vehicle from going off course by maintaining stability as well as slamming on the tank walls.

Solutions

We are testing different baffle designs in our rocket. We expect to be able to measure slosh with our camera and sensor system and also to detect a dampening in slosh with our baffles

Scope

-3 flat watertight tanks, half filled with water. Side facing camera is clear and other side is sensors

-One control tank with no baffles, 2 with different baffle designs.

-The data is collected through electronic sensor system—a set of 64 exposed contacts—and camera system—1 per tank

-Data from sensors is collected and stored on an SD card.

Impacts

-Easy Integration

-Safe design

-Easy to analyze data

-Easy to capture data

CONOPS cont.

Concept—Alternatives chosen from PDR

PDR: 3 round tanks
Chosen: Flat, rectangular tanks with one side clear and the other sensors.
Reasoning: takes up less space and provides easier analysis

PDR: Ring or Panel Baffle Designs
Chosen: Vertical Baffles
Reasoning: We condensed to flat tanks. We also learned from previous research papers that vertical baffles would work the best at reducing side to side slosh, which we expect to see in the rocket.

PDR: Two-end mounted cameras
Chosen: 1 camera per tank
Reasoning: That was the amount needed for the flat tanks. It also reduces the cost and points of failure.

PDR: Distortion grid
Chosen: Silkscreened grid on back of tank
Reasoning: This helps the camera counteract fish eyeing and is also built into the PCB sensor board

PDR: Capacitive Water Level Sensors
Chosen: grid of 64 exposed contacts in a 4x16 grid in each tank.
Reasoning: Integrates directly into tank design. Can be custom made and is cheaper than the off the shelf sensors

PDR: Collect the data from the sensor system and store it on an SD card on a control board.
Chosen: Same
Reasoning: This was a simple and effective design that integrated well with our payload

CONOPS cont.

Stakeholders

People involved with the creation of the payload and experiment include 8 students, 2 mentors, and 1 consultant.

References

We referenced several research papers in our CDR, mainly Ibrahim, R.A., 2005. Liquid Sloshing Dynamics: Theory and Applications. Cambridge University Press, ISBN 978-0521838856, 927 pp.

Operational Environment

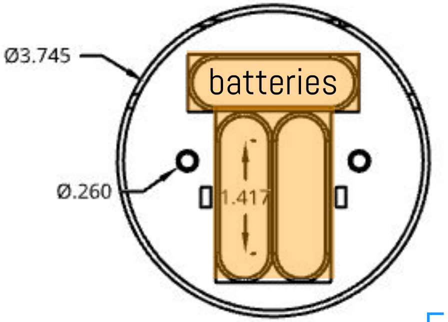
Our workshop has four rooms: one for machinery/construction, one for electronics assembly, one for computers and meetings, and one for storage.

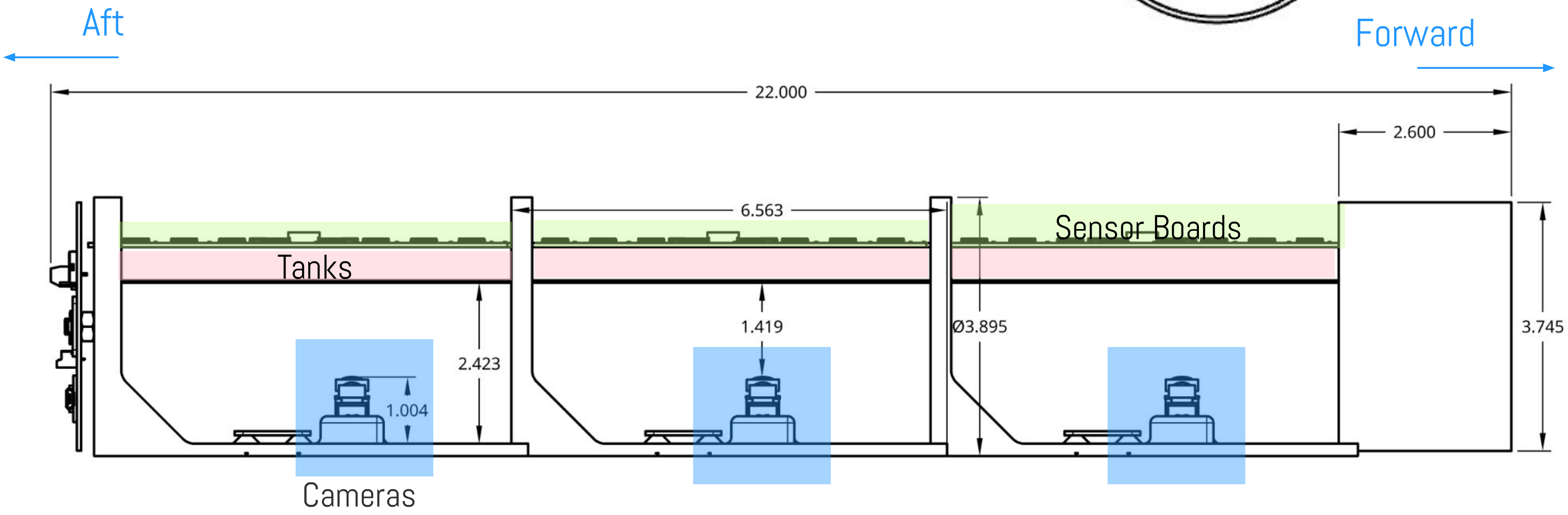
The payload will be placed in the rocket which will experience motor thrust, gravity, corrective forces, and aerodynamic forces.

Scenarios—Payload Procedure

1. Payload is inserted into the rocket and secured with the payload retention system
2. During the flight, the water inside will slosh around, and the data will be recorded with the camera and sensor system
3. After the launch, the payload is removed the data from launch to apogee is analyzed.

Final payload dimensions

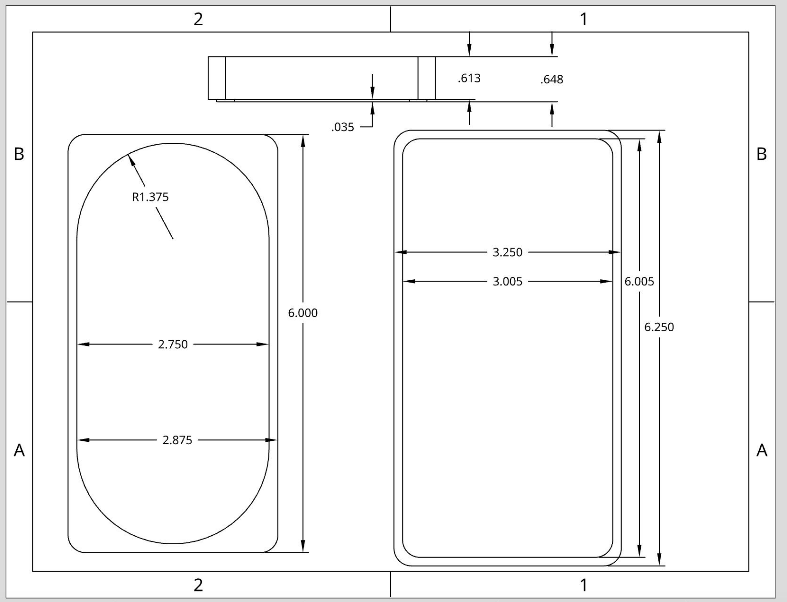


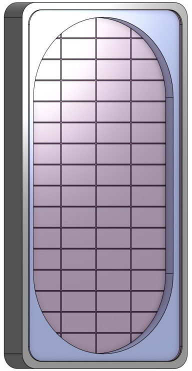


Test plans and procedures

Tests Performed	Tests Planned
- Tank Thickness Test - Frequency Study - Tank Shape Test	- Deployment Test - Camera Heating Test

Final Tank Design





A flat tank design

- Easier to manufacture
- Space efficient
- Accurate and useful data
- Simpler data collection

One clear wall

One wall with printed distortion grid and sensors

Tank Thickness Test

- Tested 3 widths to ensure no issues caused by "no slip condition"
- Tested several times to account for human error
- ½ " chosen as final

Tank Shape Test

- Tested and analyzed a "pill" shape and rectangular tank
- Tanks had printed grids for analysis
- Data points plotted

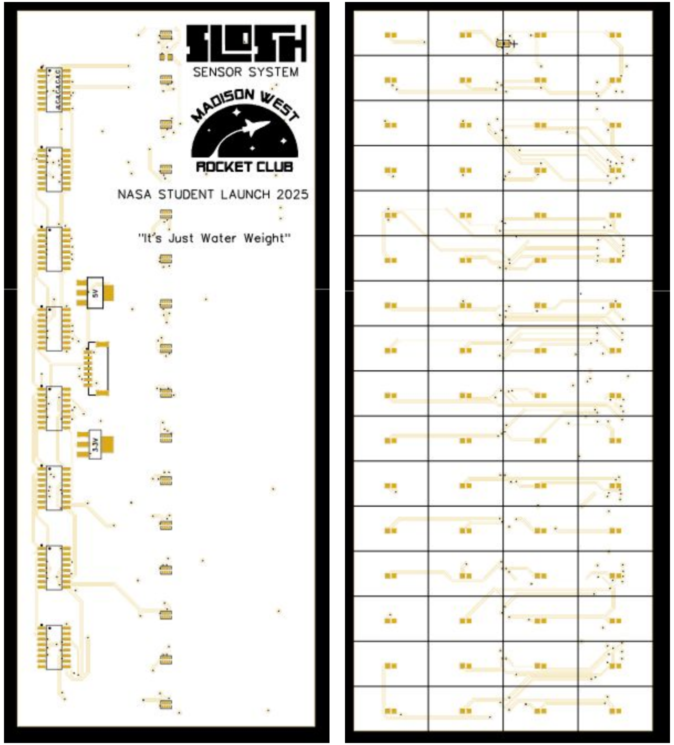
Final Sensor and Camera Design

Camera

- Runcam Hybrid 2.
- Small, large FOV
- LED Lighting Bar
- 11.1V 2600mAh battery

Sensor

- Printed circuit board (PCB) as back wall of each tank
- Exposed copper pads to sense the water level
- 74HC165 shift register
- Array of pulldown resistors



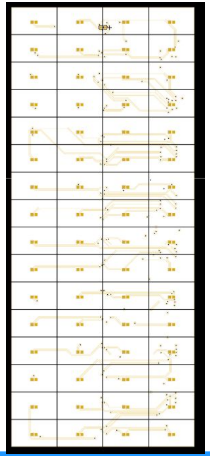
Final Data Analysis Procedure - Data Collection

Introduction: We will be collecting two types of data: variable data and discrete data. The variable data will be collected by the camera system and is defined as what percent of each grid is covered by water. The discrete data will be collected by the sensor system. Both data types will undergo the same data analysis process.

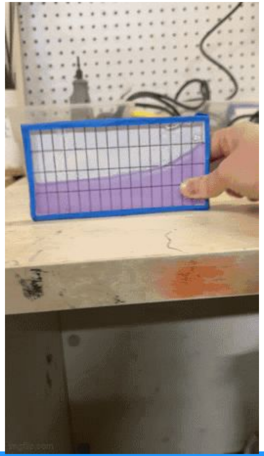
Discrete Data:
- Collected by the sensor system
- Defined as whether or not the sensor sends a "0" (Dry) or "1" (Wet)

Variable Data :
- Collected by the camera system
- Defined as what percentage of each grid is covered by water

Sensor Data Collection



Variable Data Collection Test:



Final Data Analysis Procedure - Data Analysis

Data Analysis : The data will be analyzed separately by each flight stage. We will calculate the average of each column and row of different tanks over the same time interval. To study the amount of turbulence introduced to the system, the standard deviation of the average values will be calculated. By comparing the data among different tanks over the same time interval, we are able to study the effect of baffles on reducing the amount of slosh.

Average:

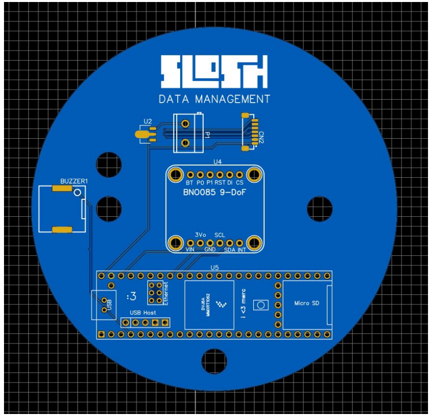
The average of the data of each column and row of each tank will be calculated and compared to study the amount of slosh reduced by the baffles.

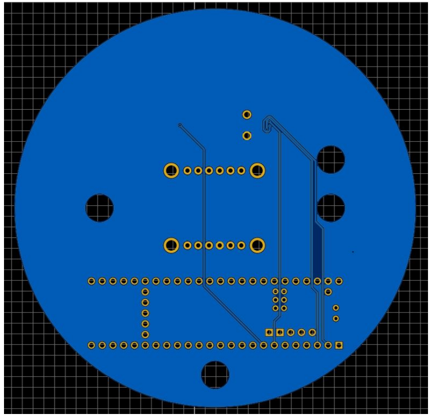
Standard Deviation :

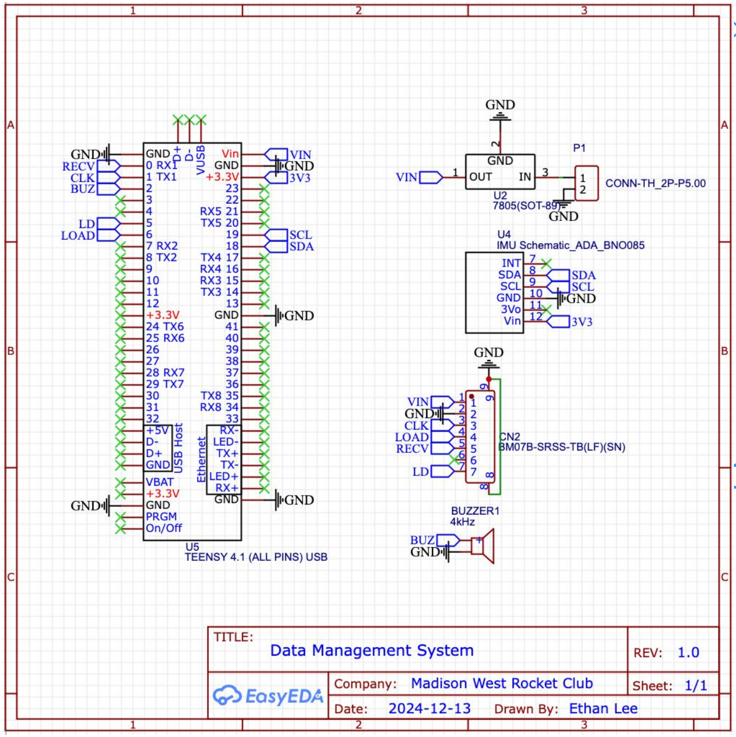
- The standard deviation of averaged values will be calculated, they will be plotted on a deviation vs. frame number graph.
- We chose a standard deviation approach because the larger the standard deviation of the values, the higher contrast between each column. Indicating higher heights.

Final Data Management Design

- What does it do?
- Major Components
  - Teensy 4.1 microcontroller
    - Non-volatile PSRAM module
  - BNO085 breakout IMU

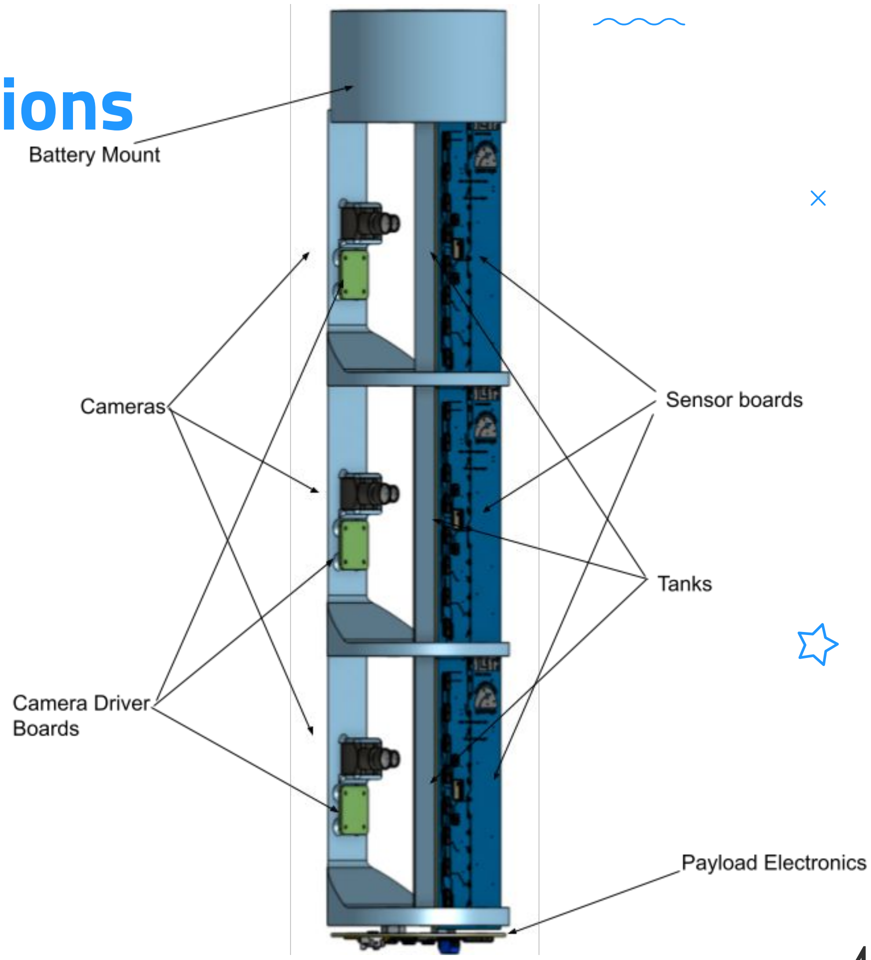




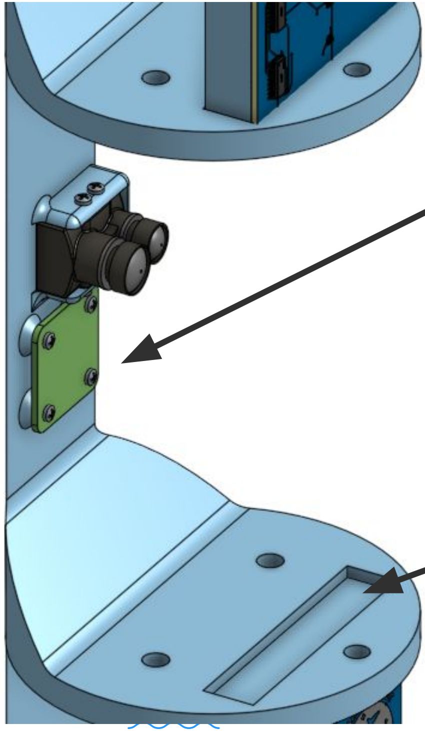


Payload component locations

- Tanks and sensor boards stacked
- Cameras mounted horizontally, level with center of tanks
- Batteries at the top of the payload
- Data Management Control Board at the bottom of the payload

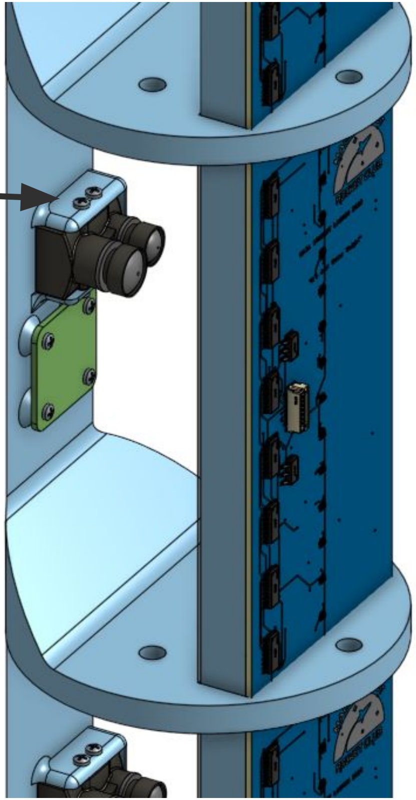


Payload integration plans

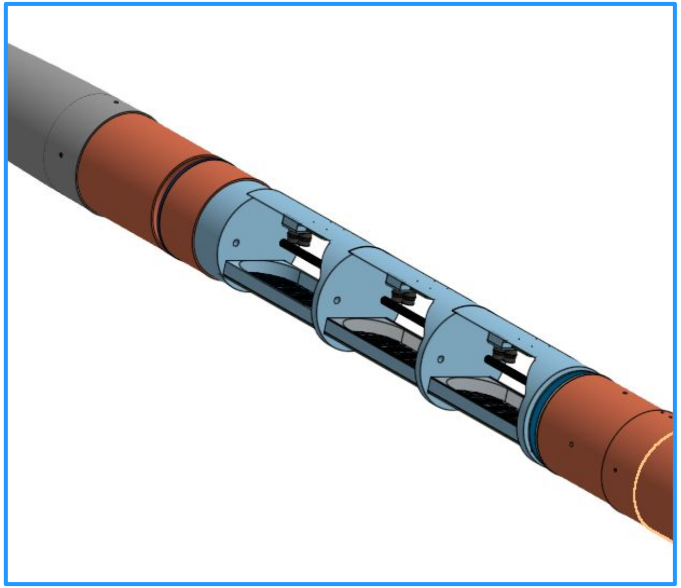


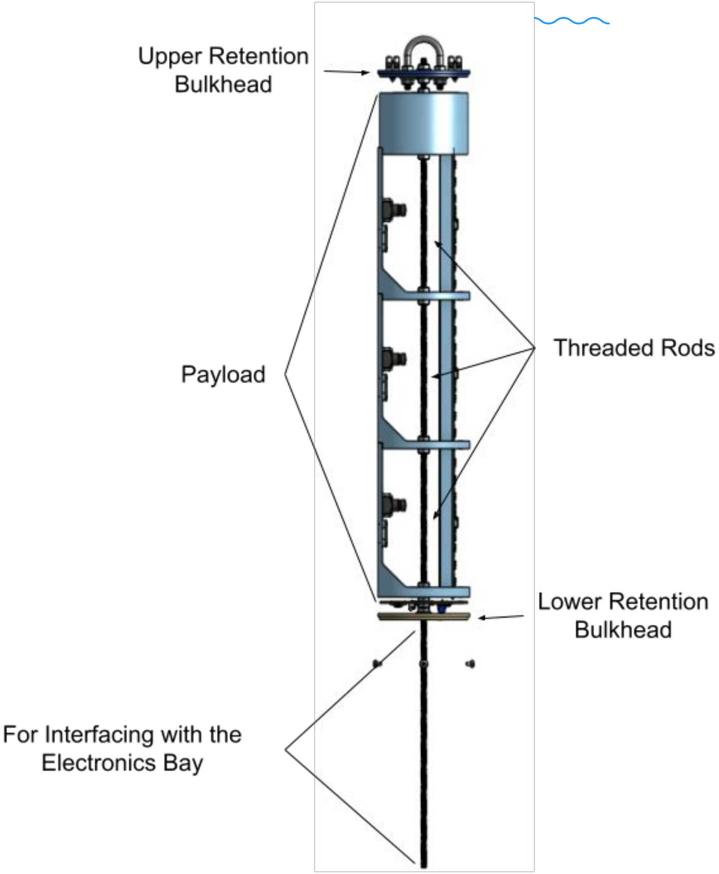
Screws hold the camera system in place

Indents to hold the tank in place

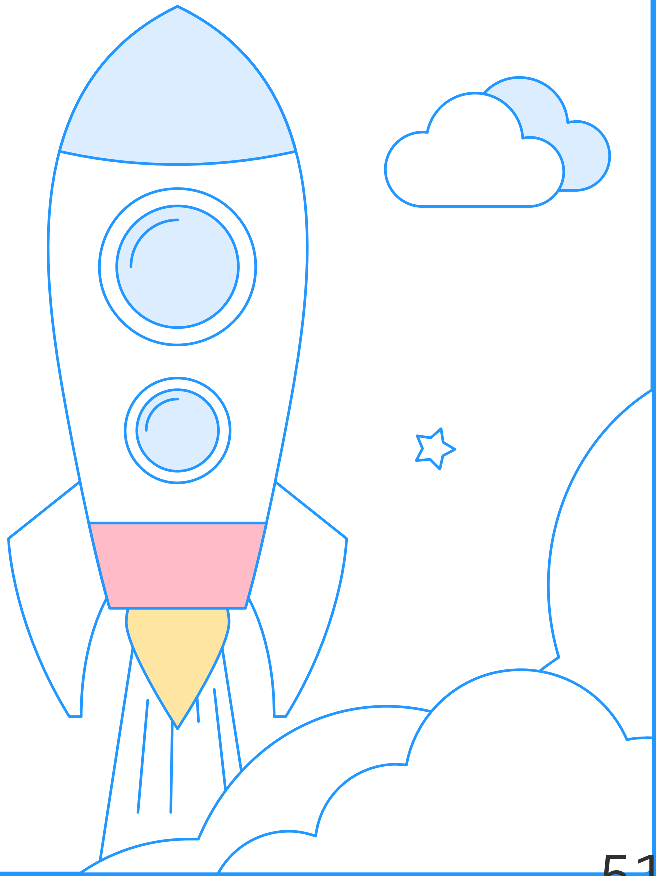


Payload retention system



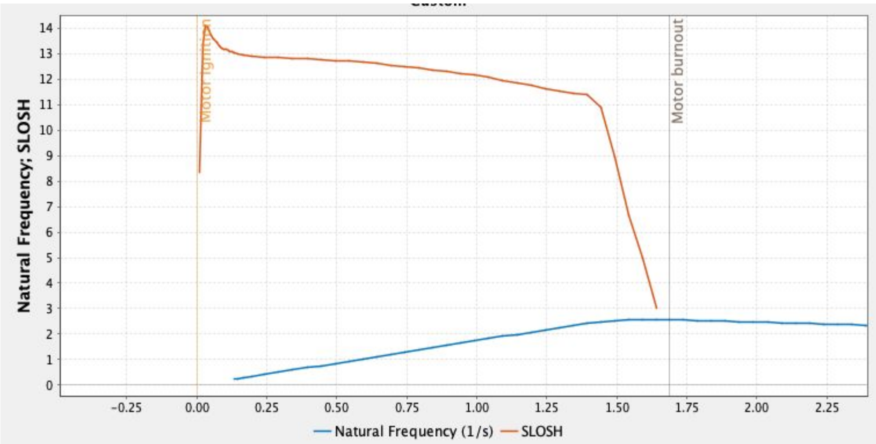


Part III: Safety and Requirements



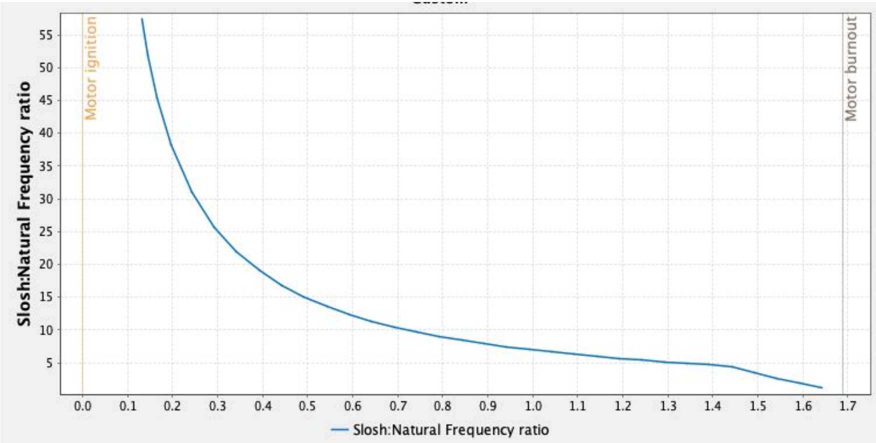
Frequency Study

SLOSH: Frequencies of sloshing in tanks.
Natural Frequency: Frequency of Natural Oscillations of the vehicle during flight



The ratio of the resonant frequencies of the two will not approach 1 during the relevant portion of the flight.

SLOSH : Natural Frequency Ratio: The ratio between resonant frequencies of sloshing in tanks and vehicle oscillations.



Team-Derived Requirements Verification

Rocket design abides to these requirements and will be reviewed at each milestone using simulations and excessive testing. If requirements are not met, changes to the design will be made so that the design meets requirements.

Vehicle

- Stability
- Successful flight

Recovery

- Events timing
- Successful Deployment

Payload

- Decrease in slosh
- Water retention
- Successful data collection