Critical Design Review

January 25th, 2024

Presentation Overview

- Launch Vehicle Final Design
- Recovery System Final Design
- Subscale Flight Results
- Payload Final Design
- Requirements Verification Status
- Questions

Our Team

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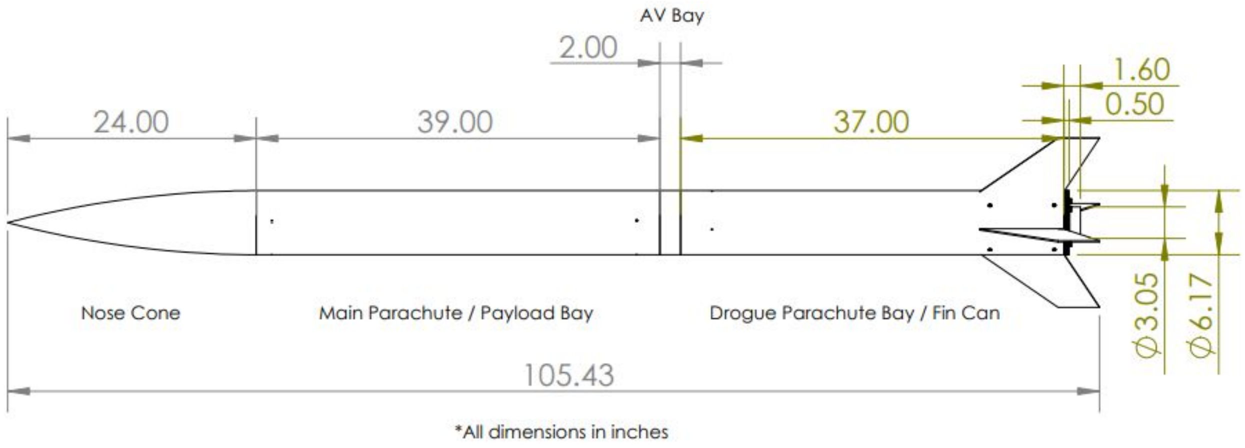
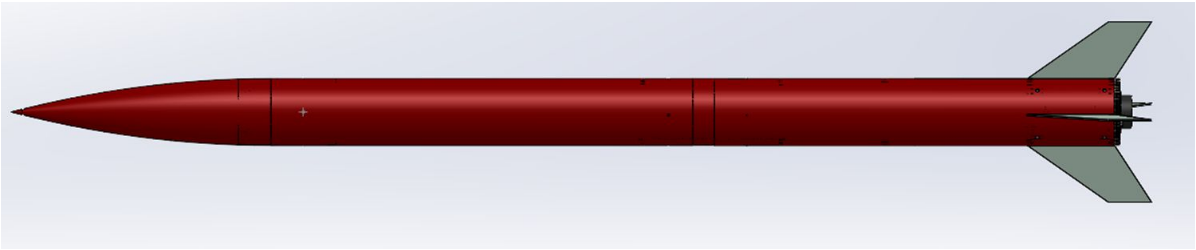
Launch Vehicle Design

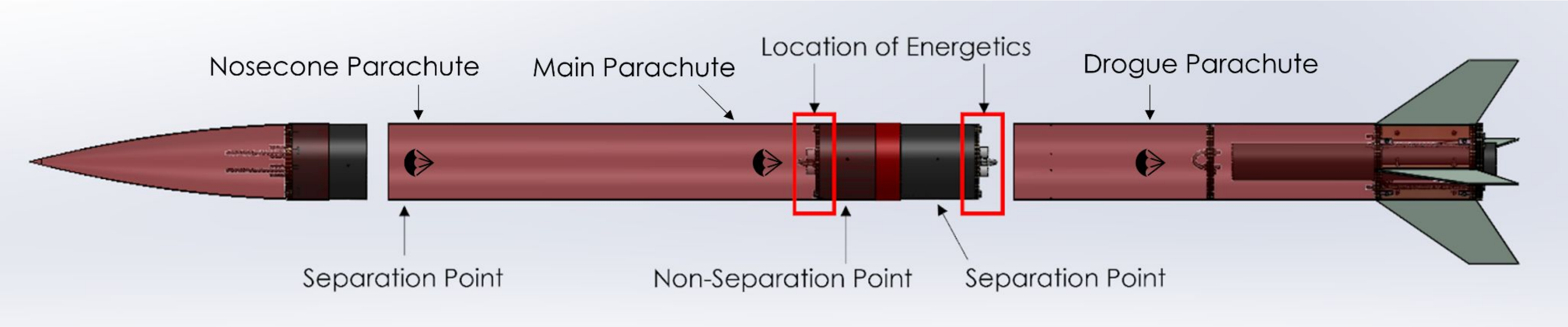
Final Launch Vehicle Dimensions





Points of Separation

- Two separation points
  - Held together with 4/40 Nylon shear pins
- One non-separation point
  - Held together with Nylon push clip rivets

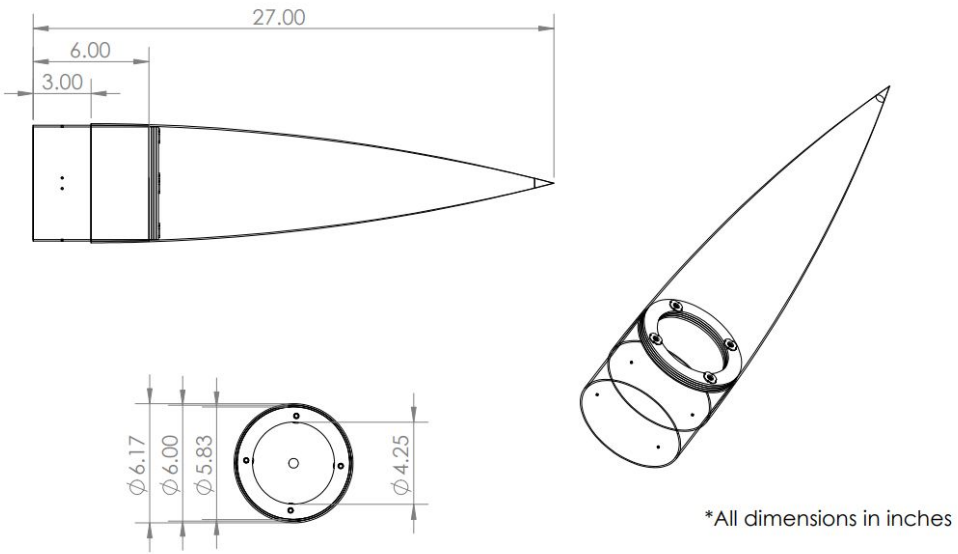


Material Selection

Component	Chosen Material	Notes
Airframe	G12 Fiberglass	- Extremely durable, highly resistant to compressive forces, cracking, abrasion, delamination, shattering, etc. - Water resistant
Bulkheads	Aircraft-Grade Birch Plywood	- Lightweight, yet strong material - All bulkheads will be ½ in. thick - Fabricated from four layers of identical ⅛ in. thick plies epoxied together
Fins	G10 Fiberglass	- Highly resistant to abrasion, cracking, shattering, etc. - Lower risk of fin flutter - Known thickness (⅛ in.), thus a tighter fit into the airframe

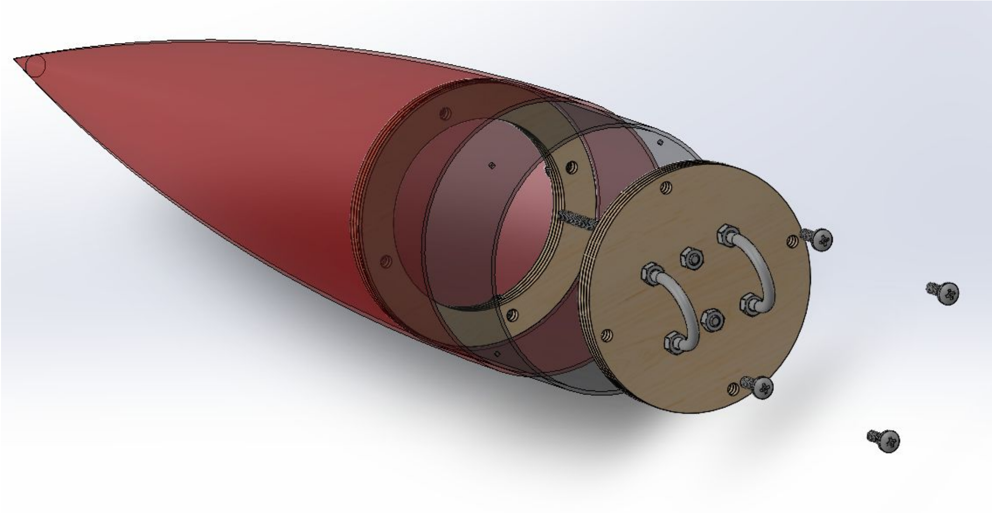
Nose Cone

- 4:1 tangent ogive
  - Provides adequate aerodynamic performance
  - Reduced length and weight over 5:1 tangent ogive
  - 24 in. long with 3 in. shoulder
- Houses permanent centering ring and removable bulkhead



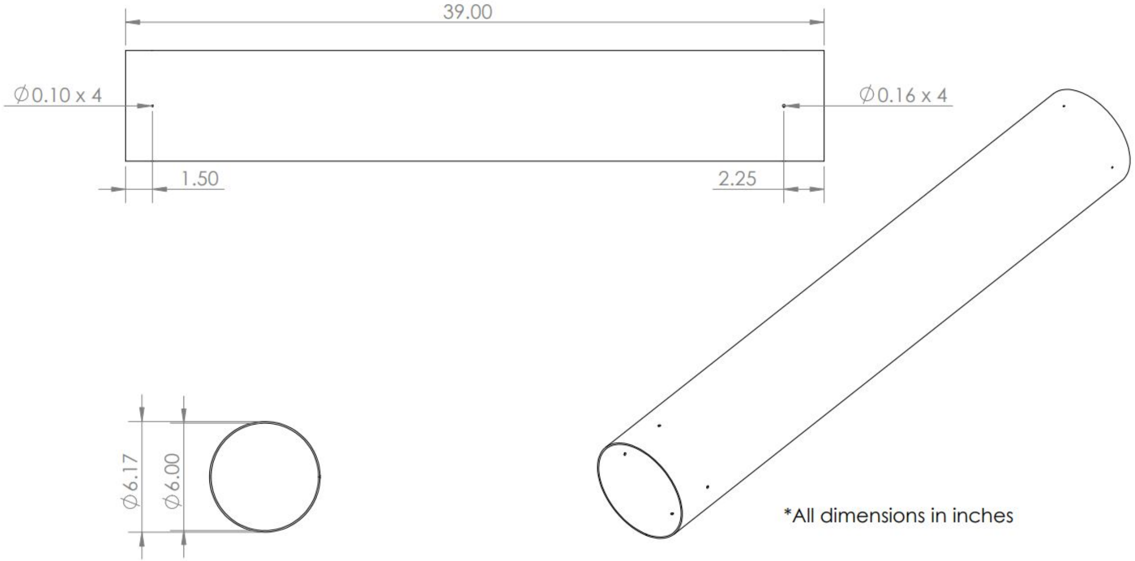
Removable Nose Cone Bulkhead

- Attached to permanent nose cone centering ring with four bolts
  - Centering ring located at forward end of nose cone shoulder
- Contains 2 U-bolts
  - Payload Deployment Bay
  - Parachute
- Has two threaded rods to slide the nose cone electronics sled onto



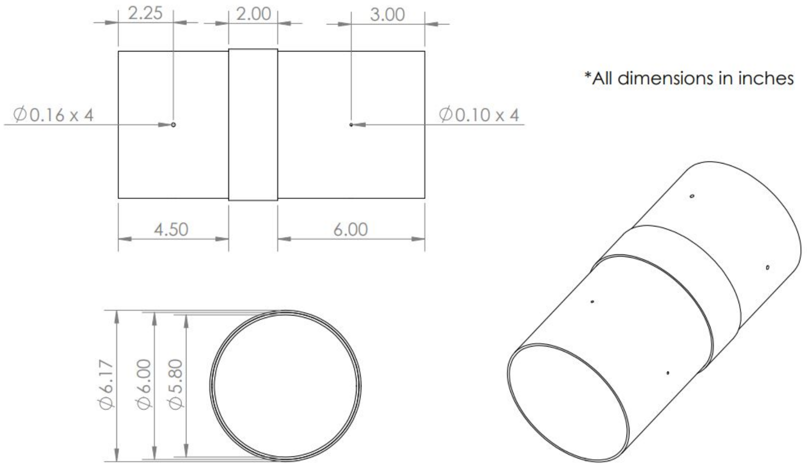
Main Parachute / Payload Bay

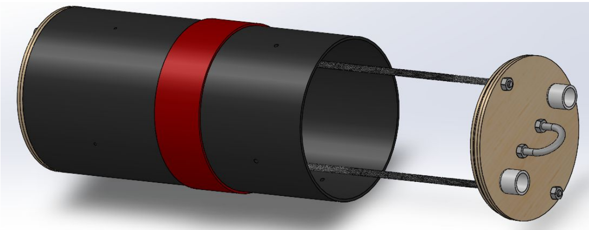
- Houses nose cone parachute, payload deployment bay, main parachute, deployment bag, and shock cord
- Attached to nose cone with 4 shear pins
- Attached to AV bay with 4 rivets



AV Bay

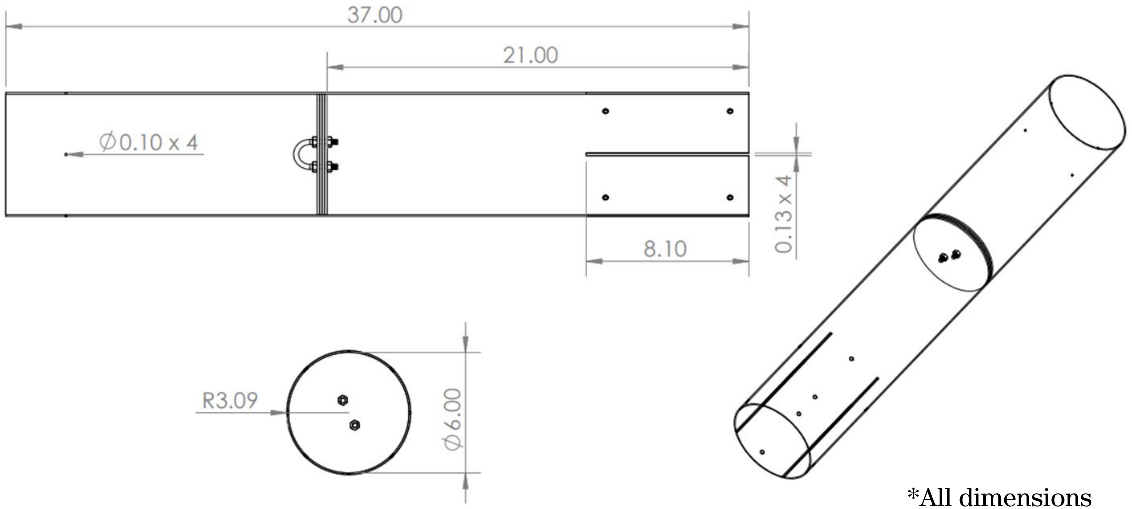
- Houses electronics sled on 2 threaded rods
- Made from a 12.5 in. long coupler section
- 2 in. airframe section permanently epoxied to coupler section to act as a switchband
- Bulkheads on either end contain blast caps and U-bolts for recovery





Drogue Parachute Bay / Fin Can

- Contains drogue parachute, shock cord, permanent fin can bulkhead, and removable fin system
- Connected to the AV bay with 4 shear pins

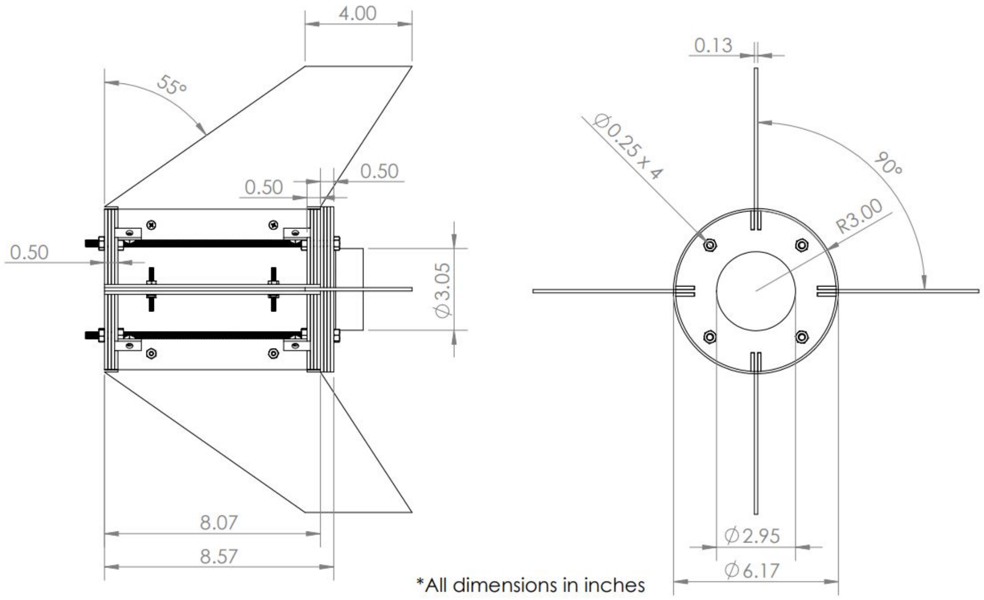


*All dimensions in inches

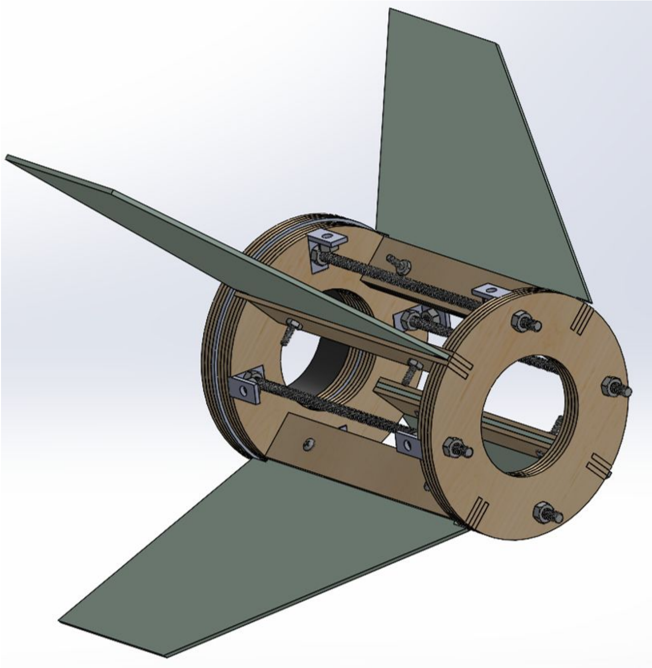
Removable Fin System

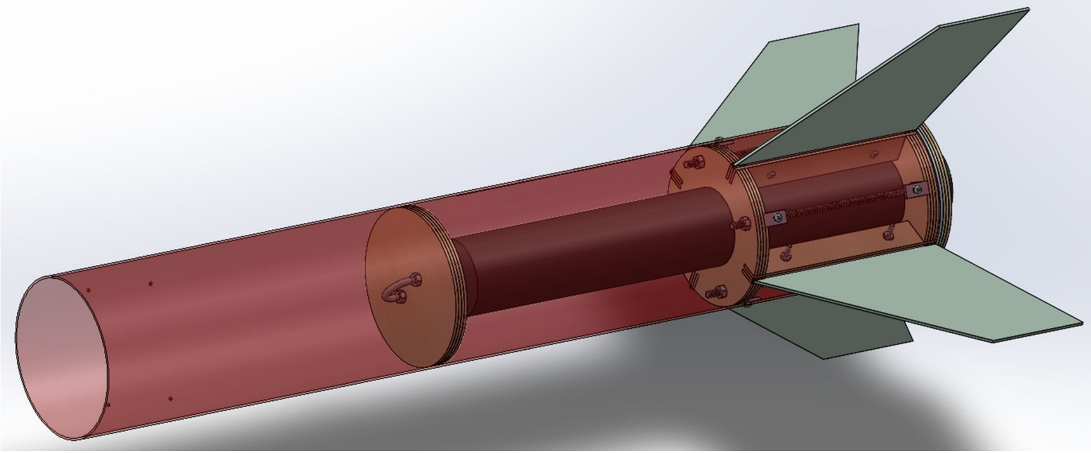
Consists of:

- 2 bulkheads (½ in.)
- 1 thrust bulkhead (½ in.)
    - 1 thrust plate (⅛ in. 6061 Al)
- 8 runners (2 per fin)
- 4 G10 fiberglass fins
- (4) ¼ in. stainless steel threaded rods for structural rigidity and to hold ballasts
- 8 custom L-brackets
- Secured to fin can using (8) #8-32 machine screws



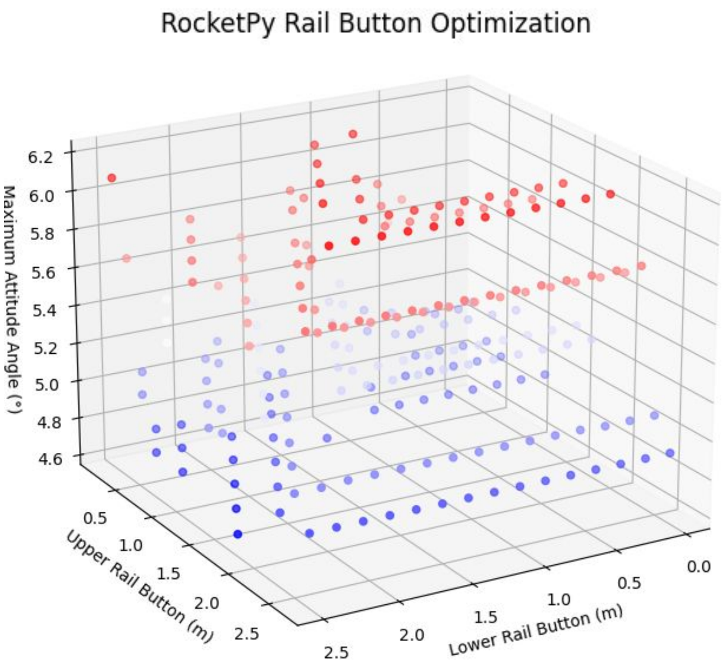
Removable Fin System Continued





Rail Button Placement

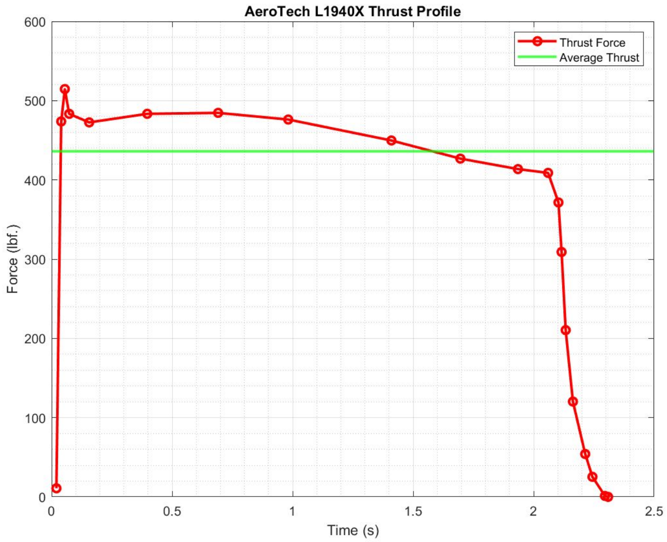
- Rail button placement was optimized using RocketPy
- Minimization of the maximum attitude angle in the pitch or yaw direction resulted in the upper rail button placed at the CG, and the lower rail button placed furthest aft



Final Motor Selection

- With the additional mass of the launch vehicle at the CDR milestone, the team has selected the AeroTech L1940X to propel the launch vehicle.

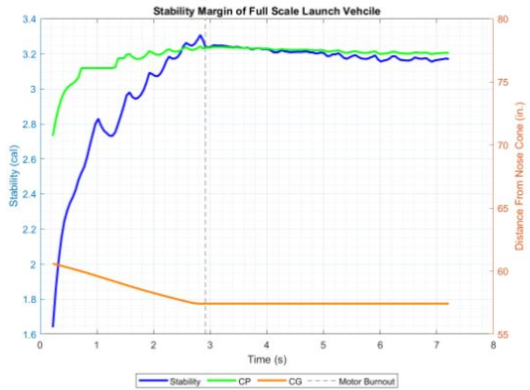
Motor	Propellant Mass (slug)	Total Mass (slug)	Total Impulse (lb•sec)	Average Thrust (lb)	Maximum Thrust (lb)	Burn Time (sec)	Casing	Length (in)
L1940X	0.1250	0.2642	973.24	435.97	521.21	2.2	RMS-75/3840	22.04

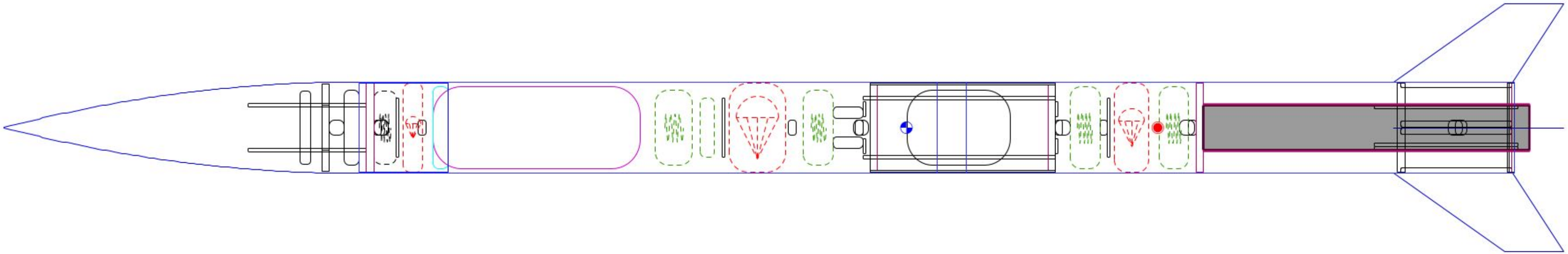


- Avg. Thrust to Weight Ratio: **8.64**
- Maximum Acceleration: **9.29 G's**
- Maximum Velocity: **555.24 ft/s**
- Maximum Mach Number: **0.51**

Launch Vehicle Stability

Software	Stability Margin	Center of Gravity (in.)	Center of Pressure (in.)
OpenRocket	2.70	61.23	77.90
RocketPy	2.66	61.23	77.65
RasAeroII	2.65	61.23	77.59





Launch Vehicle Mass

Nose Cone		Payload Bay	
Component	Weight (lb.)	Component	Weight (lb.)
Nose Cone	3.81	Payload Bay	4.94
Centering Ring	0.14	Shock Cord	0.84
Removable Bulkhead	0.26	Main Parachute	1.01
Nose Cone Sled	0.18	Main Parachute Nomex	0.06
Shock Cord	0.26	Payload Parachute	0.20
T-nuts	0.03	ayload Parachute Nome	0.06
Bolts	0.09	Deployment Bag	0.26
Threaded Rods	0.18	SAIL	7.88
U-Bolts	0.44	Quick Links	0.82
		Deployment Mech.	2.82
Total	5.39	Total	18.89

AV Bay		Motor	
Component	Weight (lb.)	Component	Weight (lb.)
Blast Caps	0.16	Forward Seal Disk	0.47
AV Bay Sled	0.95	Motor Retainer	0.29
AV Bay Bulkheads	0.62	Motor Casing	2.51
AV Bay Coupler	1.23	Motor Structure	1.21
AV Bay Switchband	0.25	Propellant Mass	4.02
AV Bay Threaded Rods	0.27		
AV Bay U-Bolts	0.44		
Total	3.91	Total	8.50

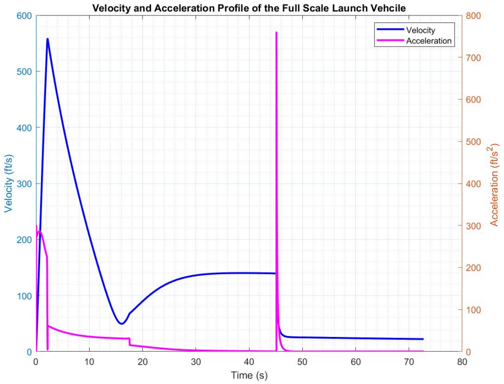
Fin Can	
Component	Weight (lb.)
Fin Can	4.68
Drogue Parachute	0.13
Drogue Nomex	0.04
Fin Can Shock Chord	0.58
Quick Links	0.49
Fin Can U-Bolt	0.21
Fin Can Bulkhead	0.32
RFS Bulkheads	0.46
Runners	0.21
Thrust Plate	0.27
Thrust Bulkhead	0.20
RFS Threaded Rods	0.38
Fins	1.47
Fin Hardware	0.07
Welded L Brackets	0.16
RFS Hardware	0.03
RFS Ballast	3.20
Total	12.89

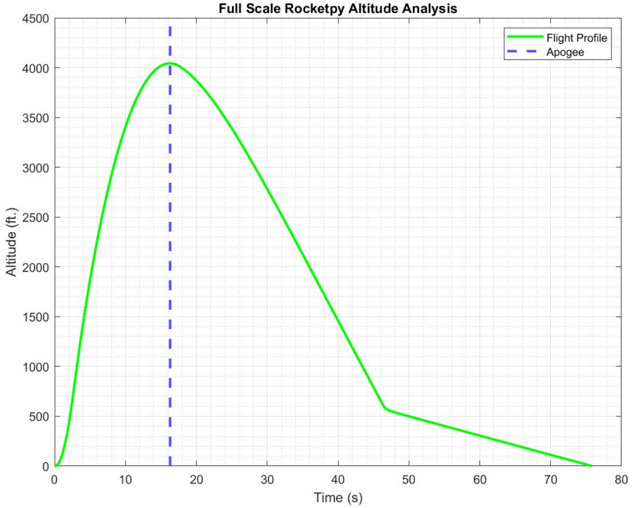
Total Vehcile (lb.)	49.59

Predicted Full Scale Launch Results

<u>Flight Simulation Results:</u>

- Apogee: **4048.67 ft.**
- Apogee Time : **16.26 s.**
- Maximum Velocity: **544.24 ft/s**
- Maximum Acceleration: **9.29G's**
- Ballast Required: **3.2 lb.***



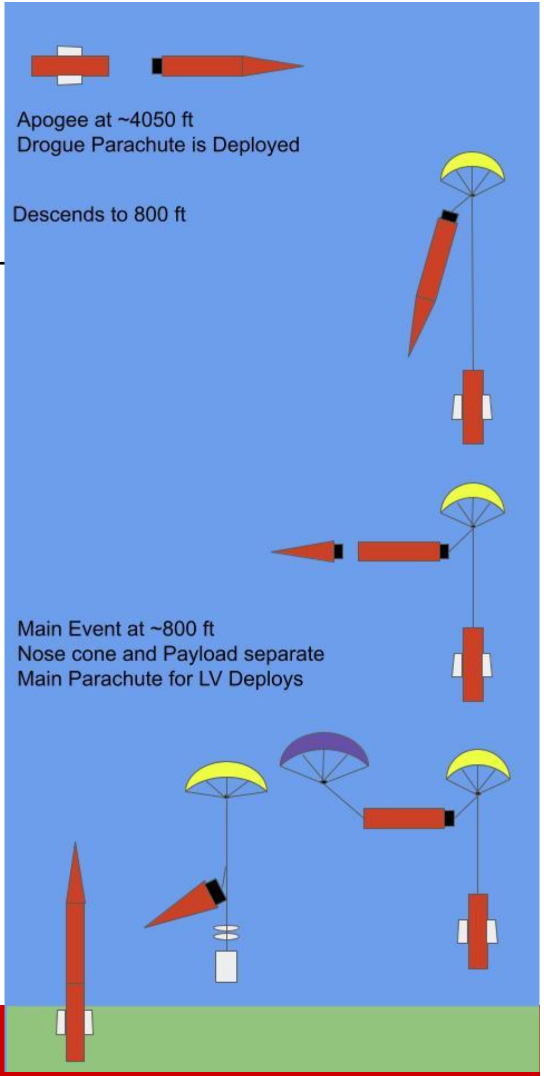


*Ballast dependent on launch day wind speed

Recovery System Design

Recovery Overview

- The drogue parachute deploys at apogee
  - Secondary charge is set to a one second delay after apogee
- Main parachute deploys at 800 ft
  - Secondary charge set at 750 ft
- The nose cone parachute deploys after nose cone separation at 800 ft
- Payload is separated from the nose cone ~450 ft

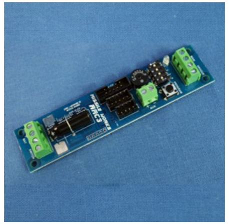


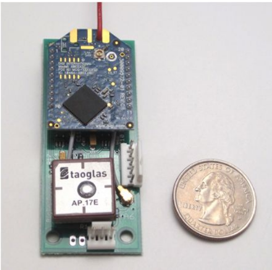
Recovery Components

- Avionics:
  - 1 RRC3 “Sport” Primary Altimeter
  - 1 Eggtimer Quasar Secondary Altimeter and Launch Vehicle Tracker (420.25 MHz)
  - 1 Big Red Bee 900 Nose Cone Tracker (900 MHz)
- Parachutes
  - Drogue Parachute: Fruity Chutes 15” Classic Elliptical
    - Protected from ejection charges via Nomex cloth
  - Main Parachute: Fruity Chutes 96” Iris Ultra Compact
    - Protected from ejection charges via a deployment bag that is attached to the removable nose cone
  - Nose Cone Parachute: Fruity Chutes 48” Classic Elliptical
    - Protected from ejection charges via Nomex cloth
  - ⅝” Kevlar Shock Cord Harness
- Separation
  - 4 Ejection Charges of FFF Black Powder

Avionics

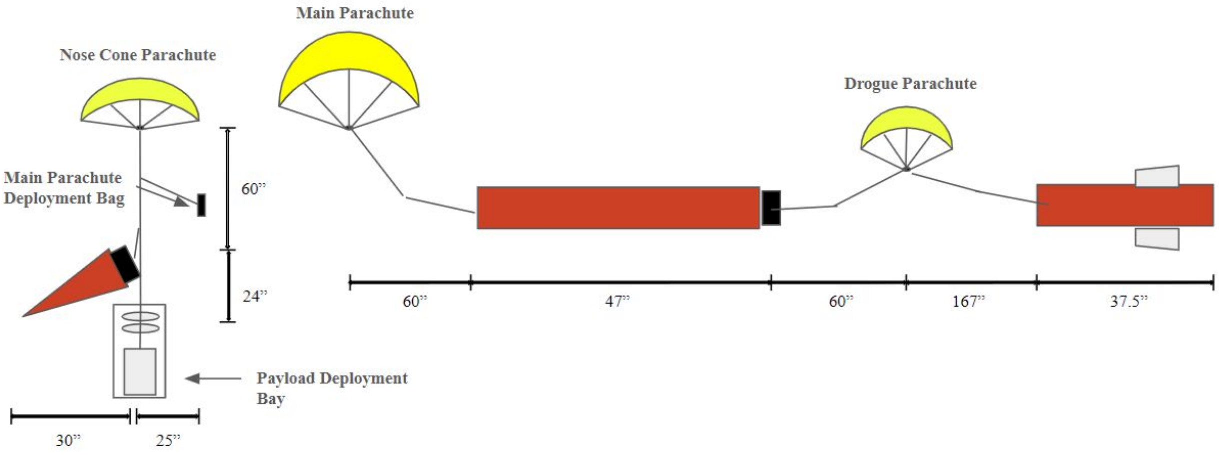
- Primary Altimeter: MissleWorks RRC3 “Sport” Altimeter
  - Drogue charge at apogee
  - Main charge at 800 ft AGL
- Secondary Altimeter: Eggtimer Quasar
  - Drogue charge 1 second after apogee
  - Main charge at 700 ft AGL(100 ft increments)
- Launch Vehicle Tracker: Eggtimer Quasar
  - Functions at the secondary altimeter as well
  - Operates on 70 cm bandwidth, transmitter frequency of 420.25 MHz
  - Paired with Eggfinder LCD receiver
- Nose Cone Tracker: Big Red Bee 900
  - Transmitter Frequency of 900 MHz
  - Paired with Big Red Bee receiver



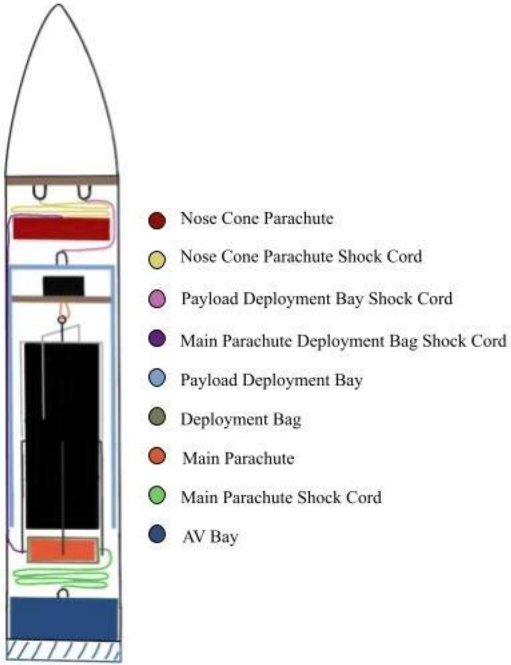


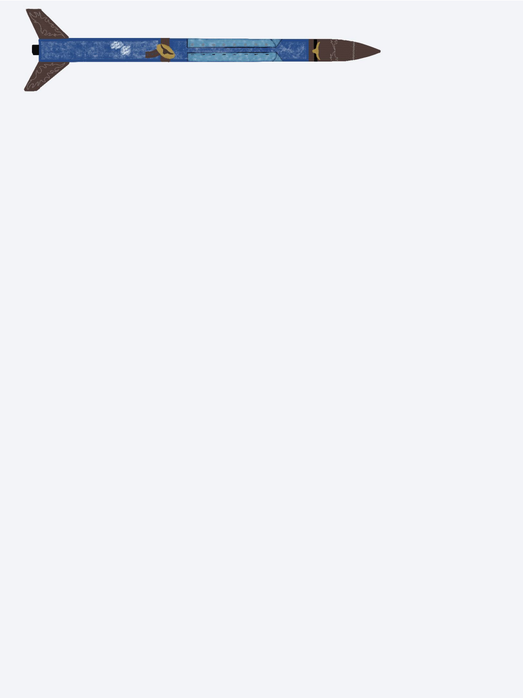
Recovery Harness

- ⅝ in. Kevlar webbed shock cords shall be used to keep separating sections of the launch vehicle together, and to hold the parachutes through the use of loops in the shock cord with quick links.
- The shock cord will be attached to the U-bolts located on the bulkheads of the launch vehicle.



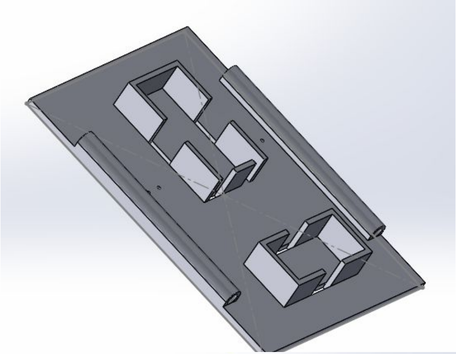
Packing Diagram and Animation

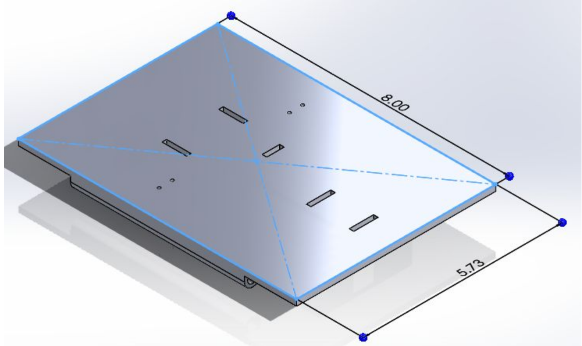




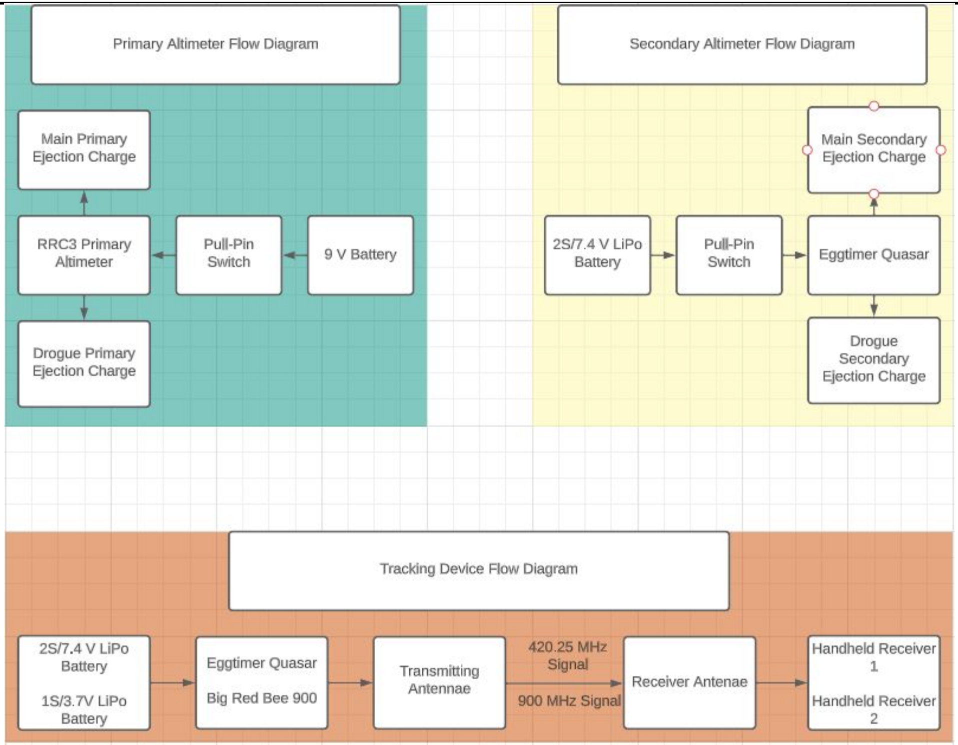
Avionics Sled Design

- Modeled in SolidWorks
- Fabricated via 3D Printer with PETG filament
- Smaller slot for 9V battery used to power the RRC3 primary altimeter
- Larger slot for 2S 7.4V LiPo battery used to power the Quasar secondary altimeter and tracker
- The top surface features mounting space for altimeters, tracker, and pull-pin switch arming devices via threaded heat inserts and standoffs.





Electrical Schematic for Avionics



Kinetic Energy at Landing

Descent Velocity Requirements for Points

Section	Section of Mass	Descent Velocity Necessary to be Awarded Points	Descent Velocity Necessary to be Awarded Bonus Points
Nose Cone	.167 slugs	29.97 ft/s	27.90 ft/s
Main Parachute/ Payload Bay and Avionics Bay	.376 slugs	19.97 ft/s	18.59 ft/s
Drogue Bay/ Fin Can	.540 slugs	16.67 ft/s	15.52 ft/s

Kinetic Energy at Landing

Section	Section of Mass	Velocity Under Main Parachute	Impact Energy
Nose Cone	.167 slugs	15.83 ft/s	20.97 ft-lb
Main Parachute/ Payload Bay and Avionics Bay	.376 slugs	15.38 ft/s	44.47 ft-lb
Drogue Bay/ Fin Can	.540 slugs	15.38 ft/s	63.89 ft-lb

Descent Time and Wind Drift

Assuming there is constant wind down range:

Maximum Wind Drift:

- Launch Vehicle: 2391.81 ft
- Nose Cone: 2077.72 ft

Descent Time

- Launch Vehicle: 81.54 seconds
- Nose Cone: 70.83 seconds

Wind Velocity	Launch Vehicle Drift Distance	Nose Cone Drift Distance
0 mph	0 ft	0 ft
5 mph	597.95 ft	519.42 ft
10 mph	1195.90 ft	1038.86 ft
15 mph	1793.85 ft	1558.30 ft
20 mph	2391.81 ft	2077.72 ft

$$t = \frac{h_a - h_m}{v_d} + \frac{h_m}{v_m}$$

$$t_n = t_d + \frac{h_m - h_p}{v_p} + \frac{h_p}{v_n}$$

Maximum Opening Shock Force

Upon parachute deployment, the launch vehicle will experience a shock force

- Maximum shock force experienced by the launch vehicle from main deployment: 298.70 lbf
- The Kevlar Webbed shock cord is rated for a maximum shock force of 6600 lbf.
- Shock Cord Factor of Safety: 22

Equation:

$$F = \frac{m\Delta v}{t}$$

Subscale Flight Results

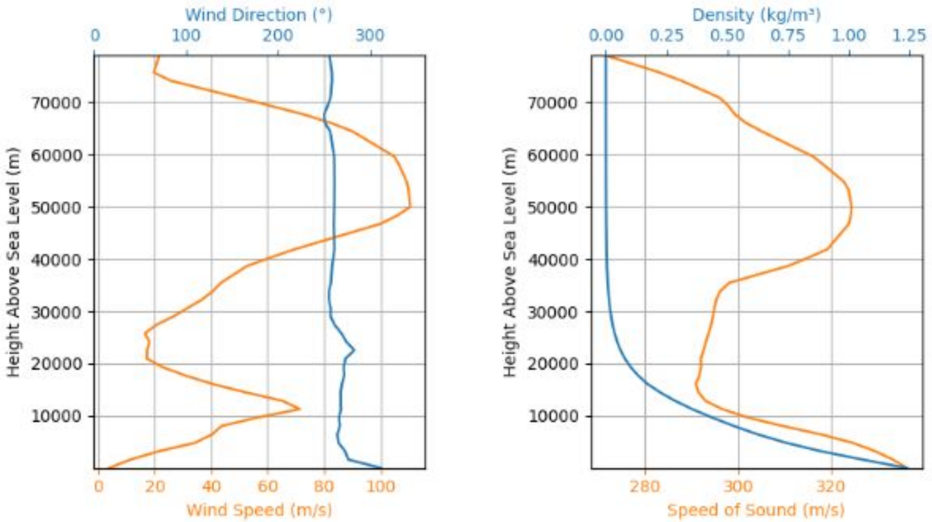
Flight Conditions

Time of Flight: **11/18/2023 2:00 PM**

Temperature: **73° F**

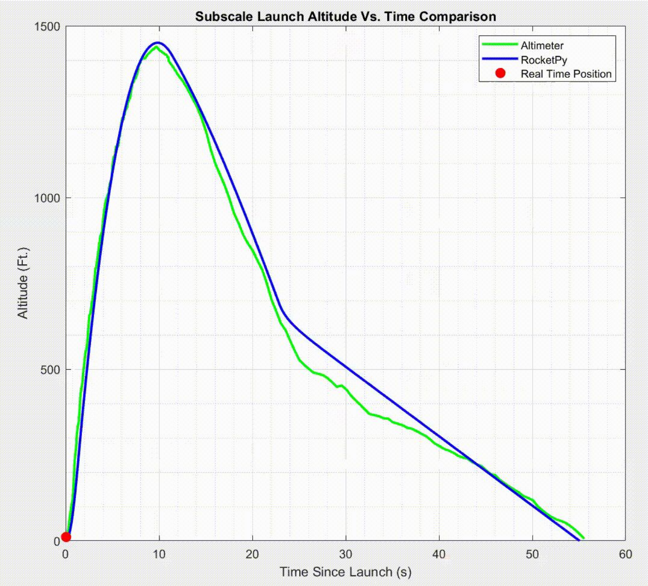
Wind Speed: **12 MPH**

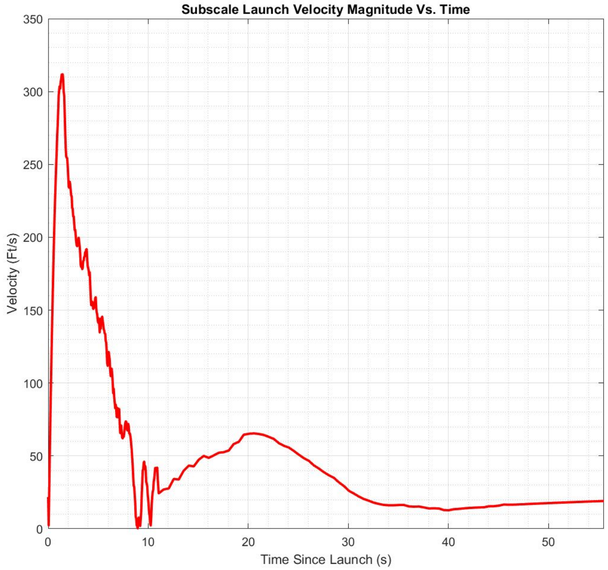
	Weight	CG	CP	Stability
OpenRocket	15.1	41.98	51.26	2.31
Weight (lb.)	14.9	42	51.26	2.31



Flight Data

RocketPy Predicted	Altimiter Measure	Difference (ft.)	Difference (%)
1444 ft.	1439 ft.	5	0.346





QUASAR_A0271D 1.02a

Flight Summary

Flight No.: 31
Flight Status: Landed

Apogee:.........1439
Time to Apogee.....10.05

Max Velocity.....528 (Est.)
Time to MaxVeloc.....0.95

Recovery Landing Configuration

* **NOTE**: This is a <u>recreation</u> of the nose cone landing configuration (photo was not taken on launch day)

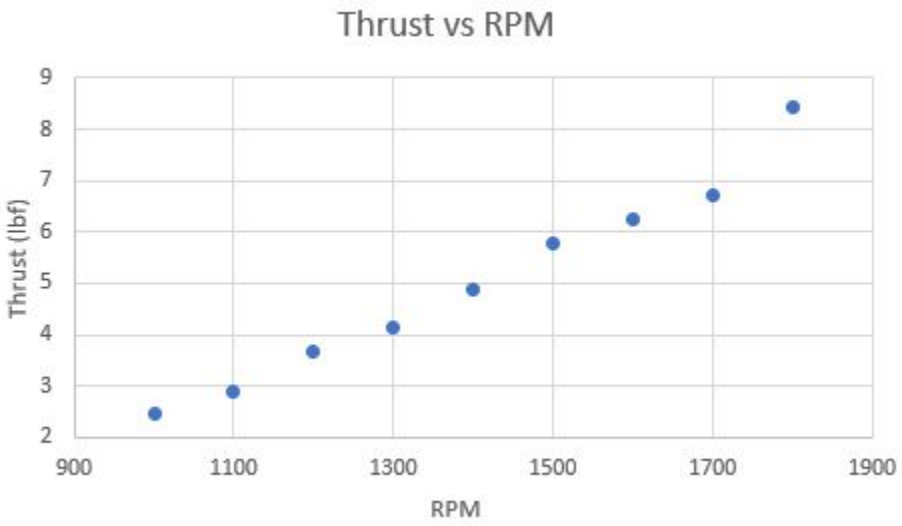
Payload Design

Final Payload Dimensions

- 24.25” tall
- Weighs 7.65 lbs
- Autonomously controls descent velocity

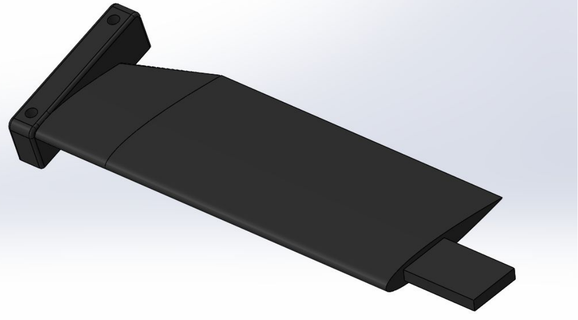
Rotor Blades

- CFD Simulation
- 2 blades per hub
- 15” blade
- 2” chord



Rotor Blade Fabrication

- 3D printed using CF-PC
- 3 piece assembly
- Joined using PET-Gloop
- Carbon fiber layup to increase strength



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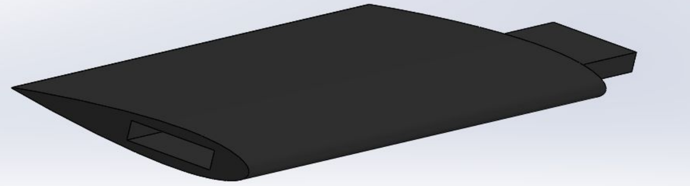

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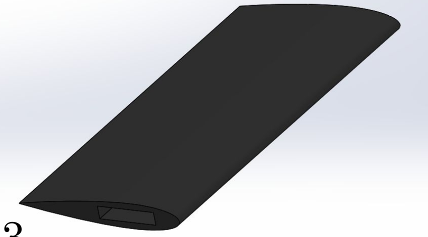

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Powerplant

- 330 kV brushless motor designed for 700 class R/C helicopters
- 150A ESC

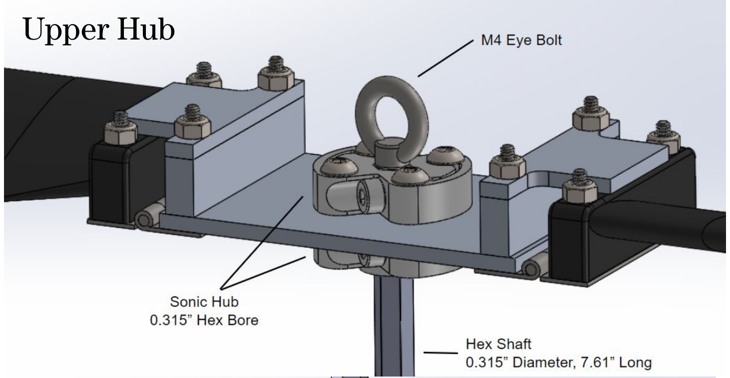
Hub Assembly

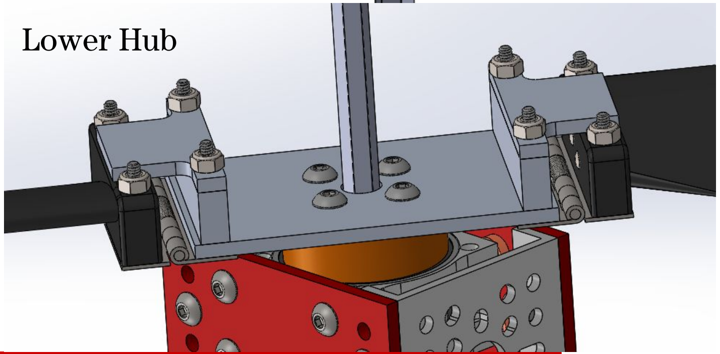
Upper Hub

- ⅛” aluminum plate
- Eye bolt screwed into hex shaft for release mechanism
- Sonic set screw hubs bolted through hub

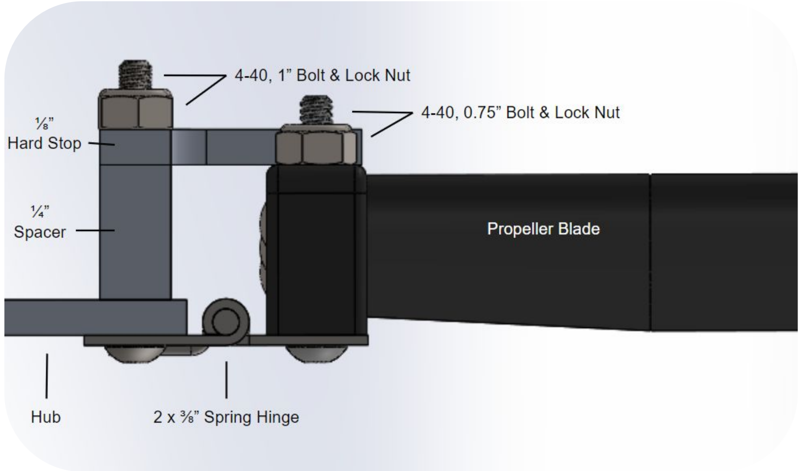
Lower Hub

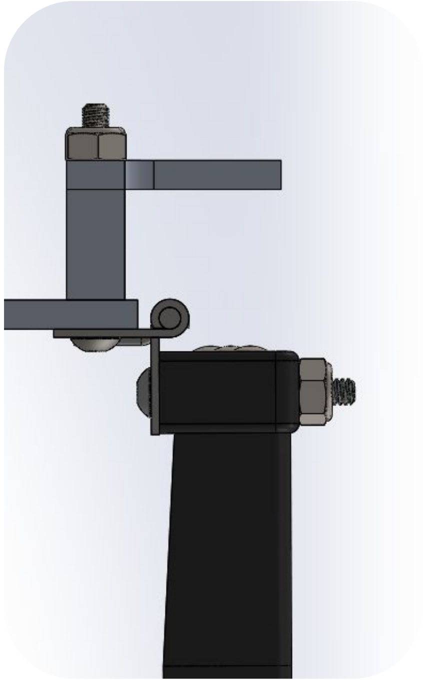
- Similar to upper hub
    - Bolted directly to the GoTube





Hub-to-Propeller Assembly



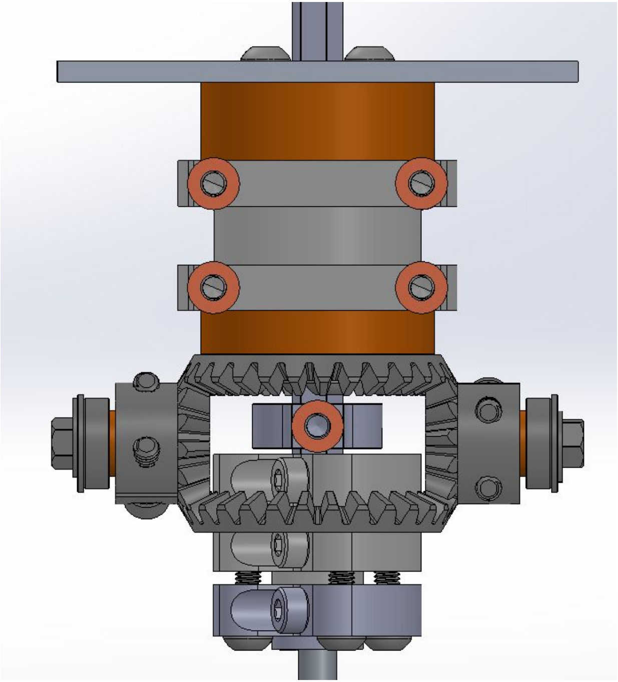


- Spring-loaded hinge
- Hub bolted to hardstop
  - Prevents propellers from moving beyond the horizontal position

Gear Box

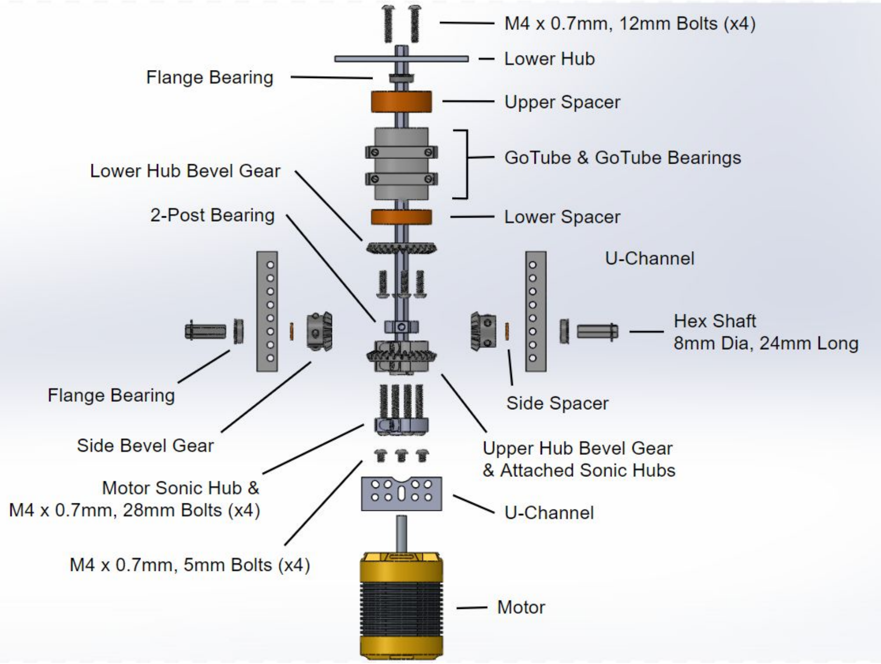
- 2 Concentric Axles
  - Bottom bevel gear - hex shaft - upper hub
  - Upper bevel gear - GoTube - lower hub
- 6 Bearings
  - 2 GoTube bearings
  - 4 hex shaft bearings
    - 1 between bevel gears
    - 1 between GoTube and hex shaft
    - 2 for vertical bevel gears

→ Coaxial Rotation



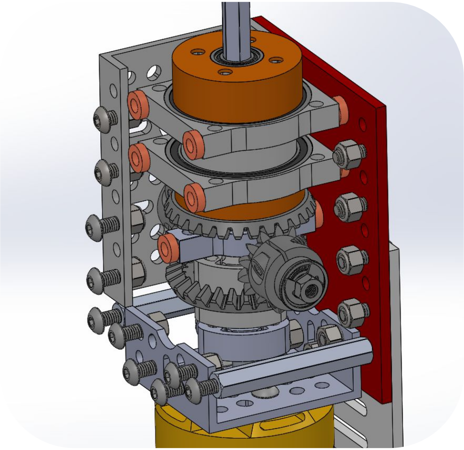
Gear Box

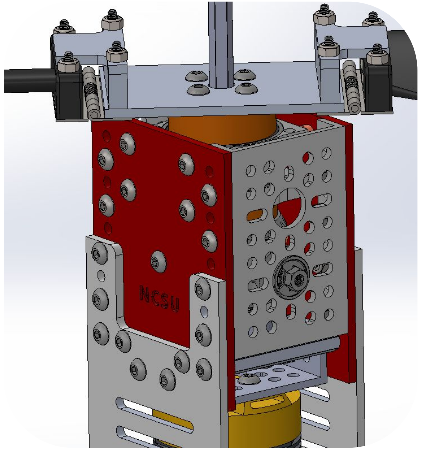
- Spacers
  - Upper and lower spacer
    - Prevents lower hub - upper bevel gear assembly from moving
  - Side Spacer (2x)
    - Prevents vertical bevel gear shaft from sliding
- Motor Assembly
  - Round sonic hub secured to motor shaft
    - Bolted to lower bevel gear
  - Motor assembled to U-channel

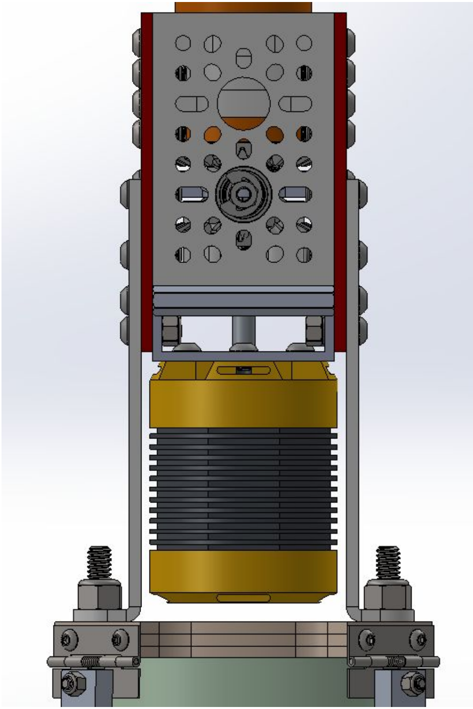


Gear Box

- Outer Structure
    - U-Channels and red plates bolted together
    - Plates bolted to bearings
    - L-bracket connects the gearbox to the SAIL body

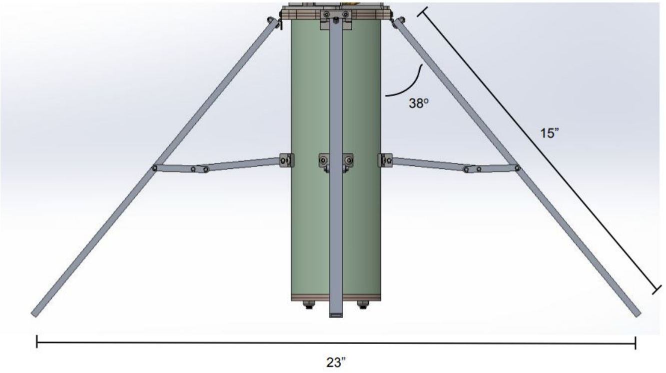


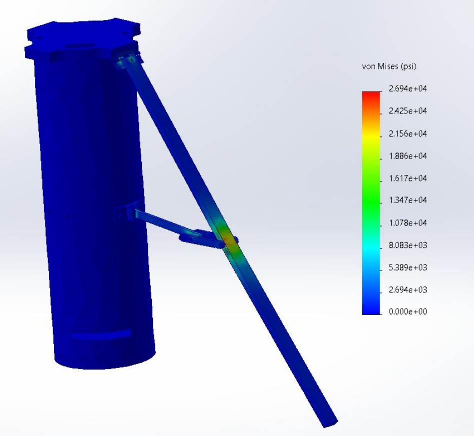


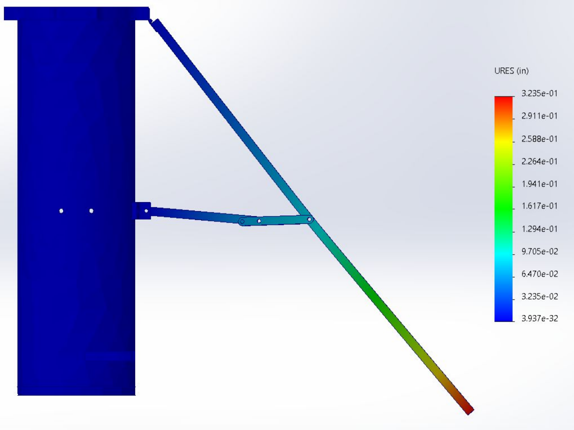


Landing Leg Assembly

- 15” Legs
  - ½” x ¼” aluminum tube
- 23” Diameter



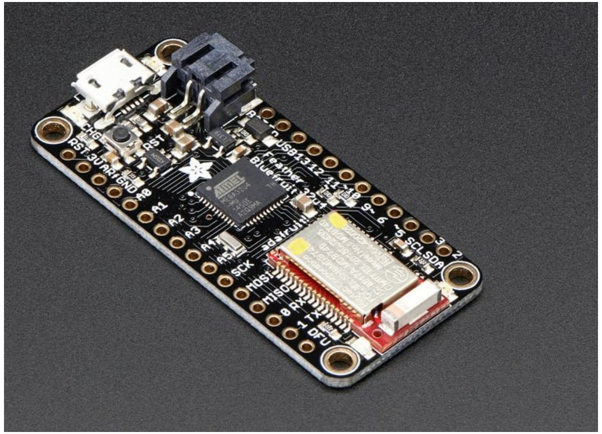




- Withstands up to 34.9 lbf
  - 0.32” Deformation
  - Lower stress than material yield strength

SAIL On Board Electronics

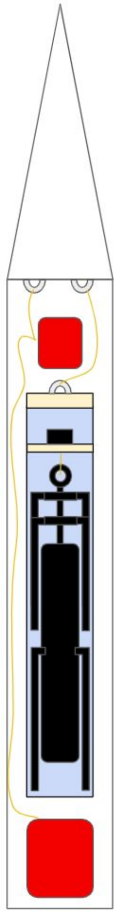
- Two purposes:
  - Motor control (power on/off)
  - Data collection for STEMnaut survivability
- Adafruit feather → Motor control and logging data
- Data collection
  - MPL3115A2 Altimeter (velocity, pressure)
  - Mini Spy Camera (sound level, STEMnaut visual inspection)
  - Adafruit 9-DOF Absolute Orientation IMU (sustained G's)



Adafruit Feather

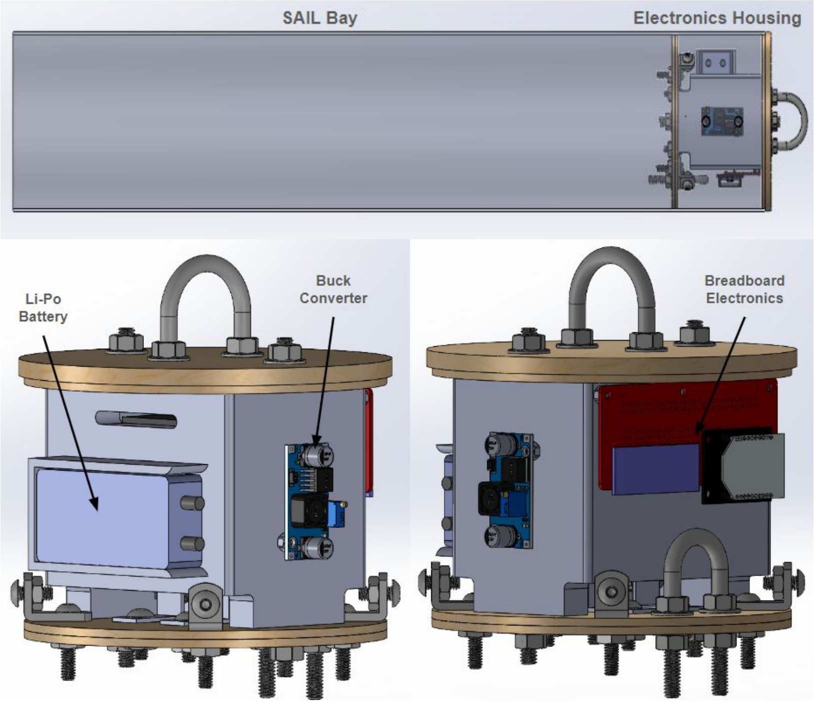
Payload Integration

- SAIL will be stowed in Deployment Bay
- Deployment Bay will slide into main/payload section of launch vehicle
- U bolt on top of deployment bay will be connected to a shock cord, with the other end attached to the nose cone bulkhead.



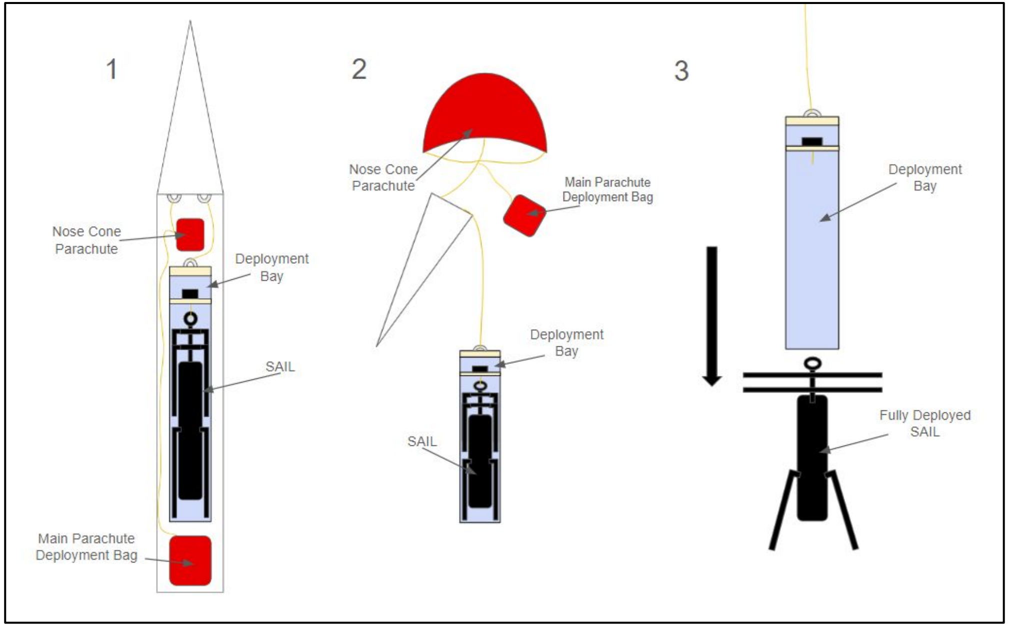
SAIL Deployment Bay

- Deployment bay will retain SAIL within launch vehicle
  - Acts as protection against shock cord entanglement during separation and descent
- Release electronics and latch secured between two bulkheads
- Entire payload system (lander + release system) contained within deployment bay

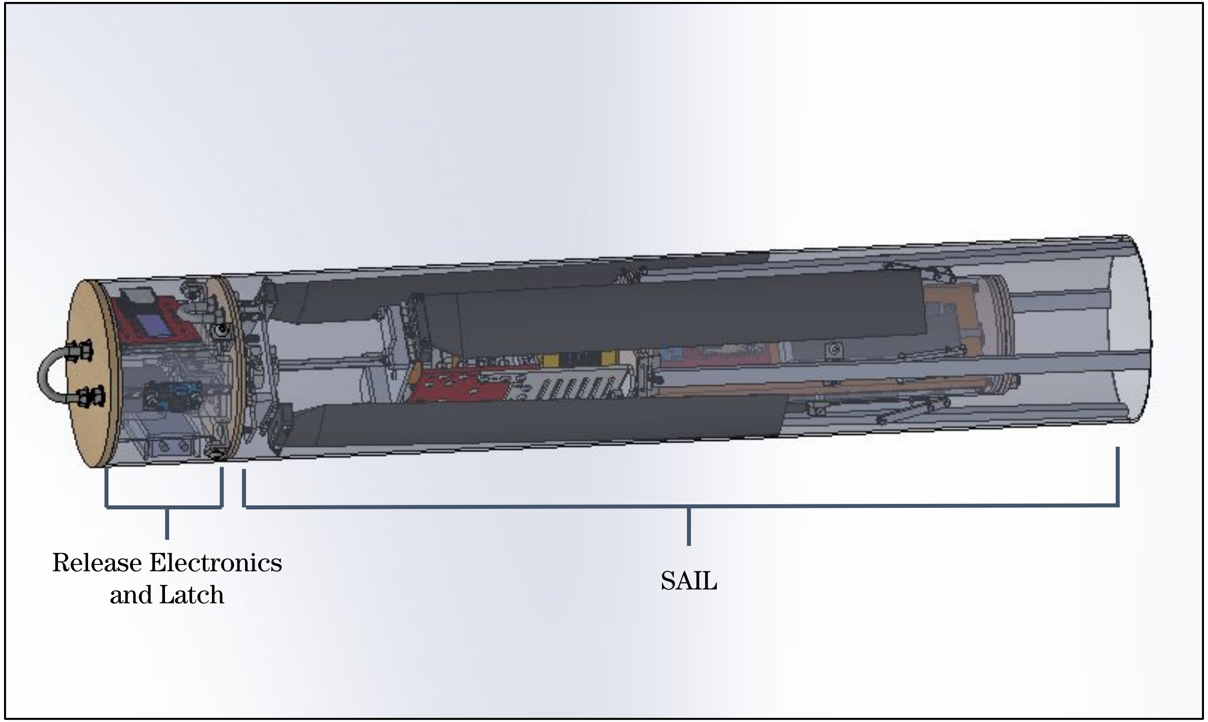


Payload Retention and Deployment Event

- Deployment bay houses SAIL for launch until release
  - Top of SAIL connected to RF controlled latch
- Enclosement will keep rotor blades and legs folded
- SAIL will fall out of bay when released, unfolding the rotors and legs



The Integrated Payload



Payload Interfaces

- Entire payload system (SAIL + Release) housed within Deployment Bay
- Ground station will serve two purposes:
    - Releasing SAIL into free fall once RSO permission is given
    - Ceasing motor operation in case of emergency
- Interfacing done by RF command using XBee transceivers

STEMnauts

- Several metrics recorded for STEMnaut safety:
    - Sustained G forces (IMU)
    - Rotational G forces (IMU)
    - Landing Velocity (Altimeter)
    - Pressure Levels (Altimeter)
- Acceptable levels based on human survivability metrics
- In addition, visual inspection post launch to verify STEMnaut retention

Requirements Verification Status

Requirement Updates

Test Plans

Requirement Verification Updates

- Requirements pertaining to subscale fabrication and flight as well as full scale design have been verified. An example is provided below.
- Plans for verifications requiring the full scale or payload to have been built are discussed in CDR.
- See section 6 of CDR to view testing plans for requirement verification.

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by Vehicle Demonstration Flight data, stays under 65 ft-lbf will be awarded bonus points.	The Recovery Team designs a recovery system such that the maximum kinetic energy experienced by the heaviest section of the launch vehicle does not exceed 65 ft-lbf.	Analysis	Recovery	Verified	See Section 3.4.1 for kinetic energy calculations.

Testing Plans

- Testing is in place to ensure components are up to standard
- Section 6.3 in the CDR document highlights the success criteria for each test plan.

Launch Vehicle Tests

- Tests viewed in sections 6.1.1 - 6.1.10.
- Requirements for Test Plans
  - NASA Requirements: 2.3, 2.18, 2.18.2, 2.19.1, 2.19.1.1, 2.19.1.9, 2.23.9, 3.1.1, 3.1.2, 3.2, 3.4, 3.6, 3.8, 3.9, 3.13, 3.13.2
  - Team Derived: LVF 3 - LVF 5, LVD 3, RF 3 - RF 5
- Dates of Completion: 1/8/2024 - 2/23/2024

Payload Tests

- Tests viewed in sections 6.2.1 - 6.2.7.
- Requirements for Test Plans
  - NASA Requirements: 4.1, 4.2.3, 4.2.4, 4.3.2, 4.3.3
  - Team Derived: PF 3 - PF 6
- Dates of Completion: 1/8/2024 - 3/29/2024

Questions?