Flight Readiness Review

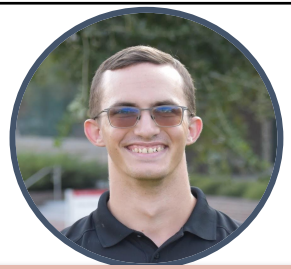
March 29th, 2024

Presentation Overview

- Launch Vehicle Overview
  - Launch Vehicle Verification Testing
- Recovery System Overview
  - Recovery Verification Testing
- Mission Performance Predictions
- Payload Overview
  - Payload Verification Testing
- VDF Results
- Requirements Verification Status

Our Team

Hanna McDaniel
Team Lead



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Structures

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Aerodynamics

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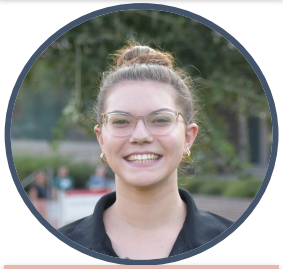
Recovery

Megan Rink
Safety Officer

Frank Rice
Payload Electronics

Joseph Alonso
Payload Structures

Michael Wax
Payload Systems

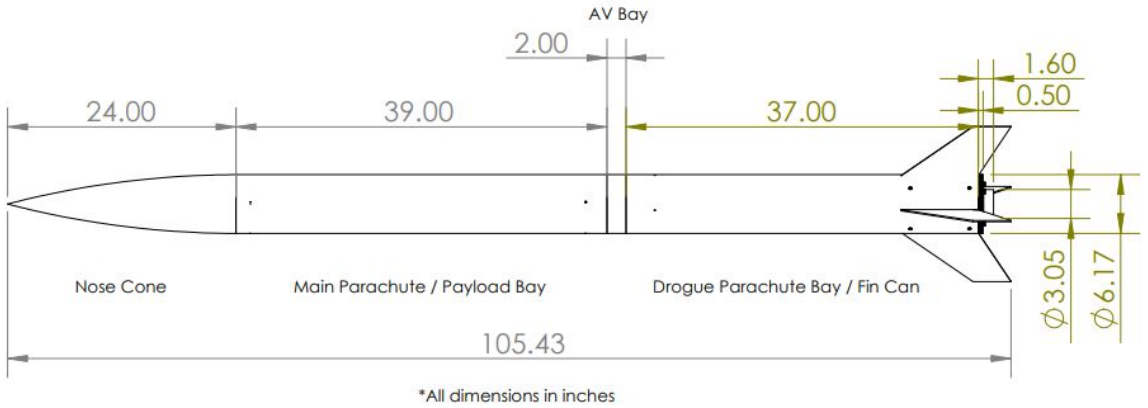


Shyanne Large
Integration

Launch Vehicle Overview

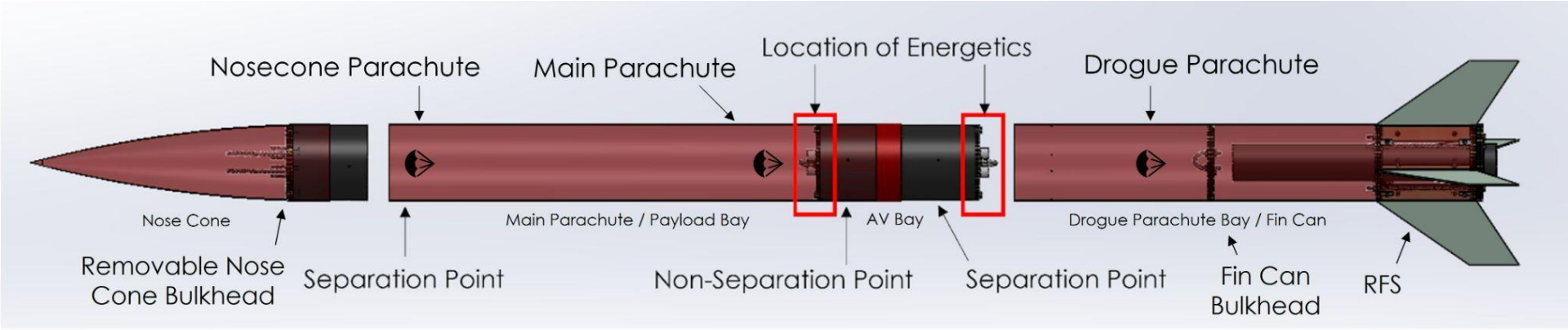
Launch Vehicle Dimensions

- As-built length: 107.43 in.
- Maximum diameter: 6.17 in.
- Launch weight: 51.6 lb
- Airframe components fabricated to ± 1/16 in. of design lengths



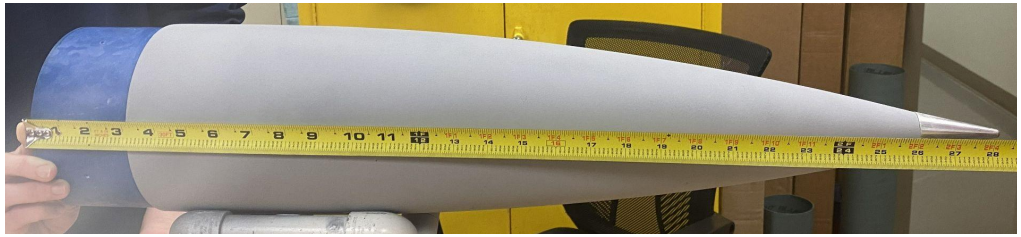
Separation Points

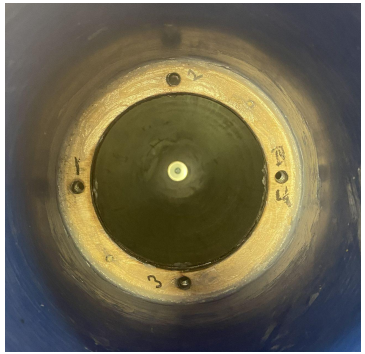
- One non-separation point
  - Held together with four Nylon push-clip rivets
- Two separation points
  - Each held together with two 4-40 Nylon shear pins

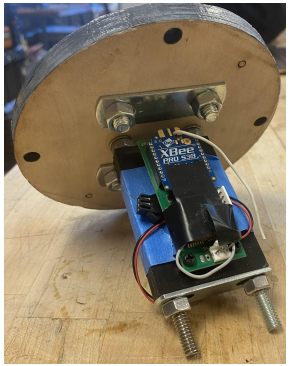


Nose Cone

- Nose cone shoulder 3.0625 in. long
  - Coupler cut 0.0625 in. longer than design length
- Nose cone assembly approximately 29 in. long
  - Nose cone 2 in. longer than predicted due to anodized aluminum tip
- Removable bulkhead and permanent centering ring installed

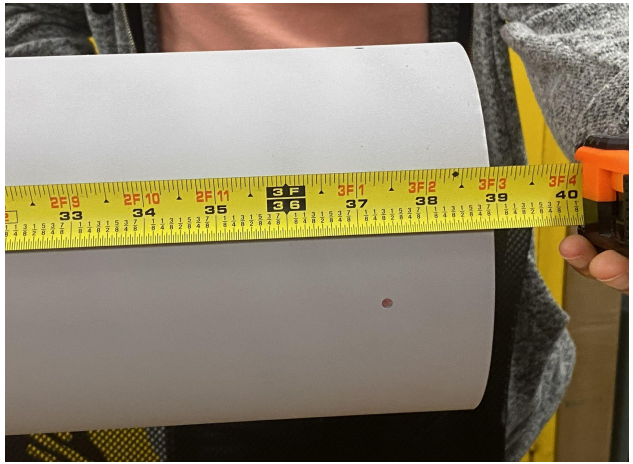


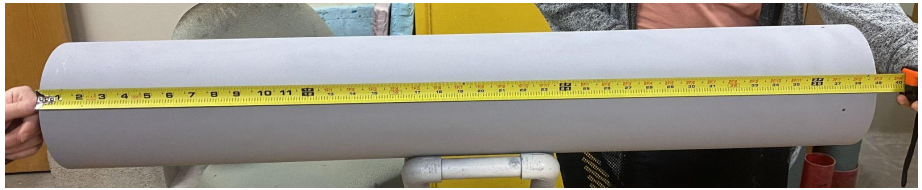




Main / Payload Bay

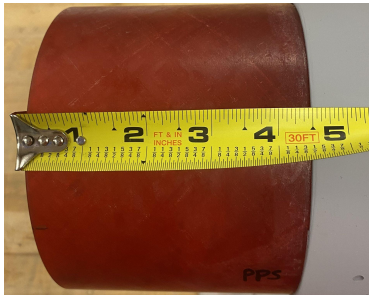
- Design length was 39 in.
  - As-built length is 38.938 in.
- Holes have been drilled for Nylon push-clip rivets and Nylon shear pins

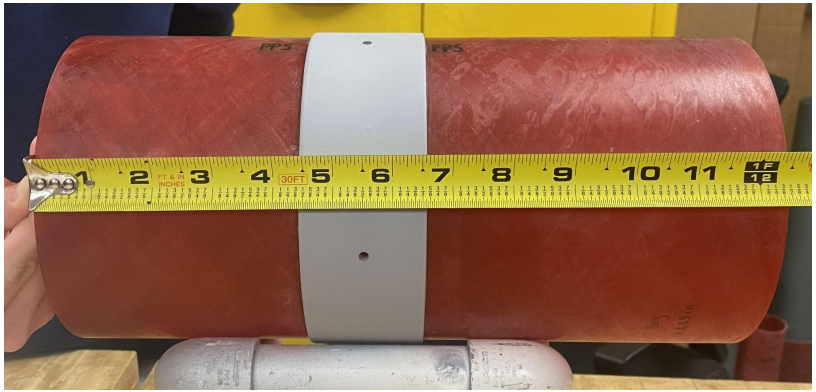




Avionics Bay

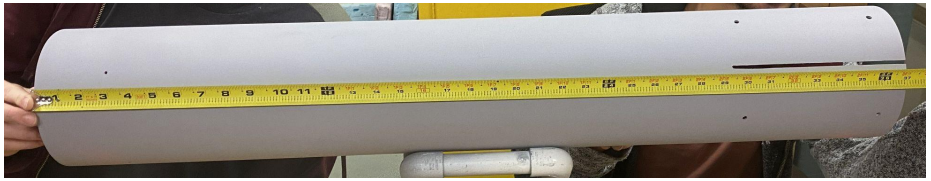
- Design length of AV bay assembly was 12.5 in.
  - As-built length is 12.5 in.
- Design coupler lengths were 4.5 in. (non-separating section) and 6 in. (separating section)
  - As-built coupler lengths match design lengths
- Design switch band length was 2 in.
  - As-built switchband length matches design length





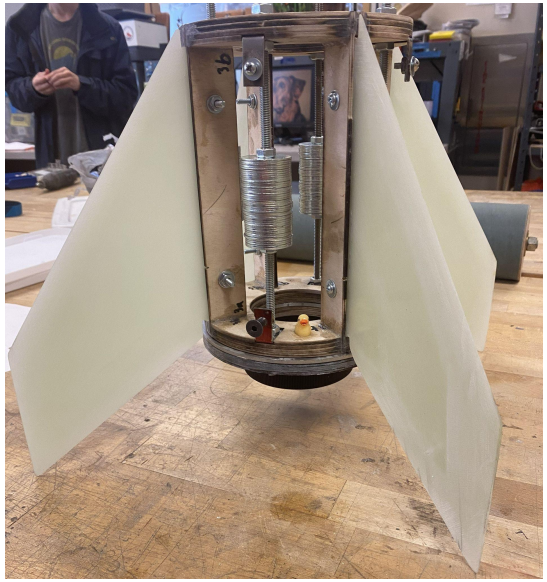
Drogue Bay/Fin Can

- Design length was 37 in.
  - As-built length matches design length
- Fin can bulkhead installed
  - Bottom face of fin can bulkhead is 21 in. from the aft end of the section per design
- Fin slots cut out for the RFS



Removable Fin System

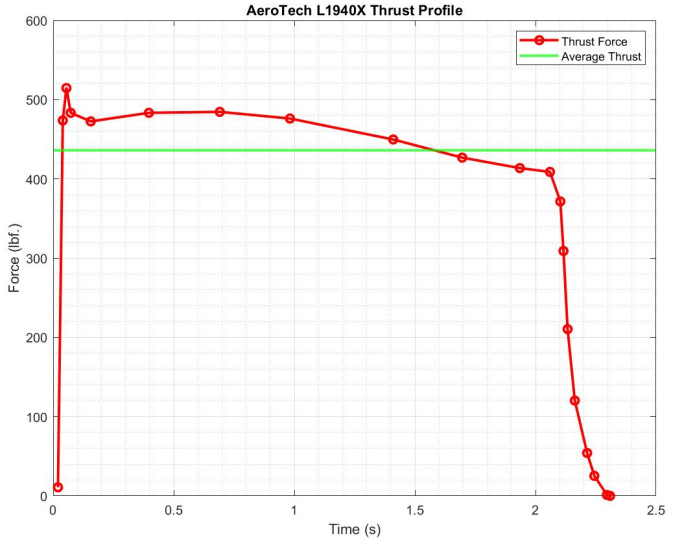
- Design length of runners (distance from outer faces of each RFS bulkhead) 8 in.
  - As-built length matches design length
- Spacing between runner pairs designed to match fin thickness (⅛ in.)
  - As-built spacing matches design spacing



Motor Description

- With successful verification during VDF, the AeroTech L1940X has been proven to propel the launch vehicle to the desired apogee.

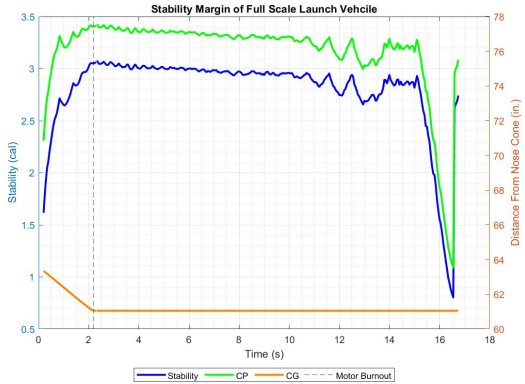
Motor	Propellant Mass (slug)	Total Mass (slug)	Total Impulse (lb•sec)	Average Thrust (lb)	Maximum Thrust (lb)	Burn Time (sec)	Casing	Length (in)
L1940X	0.1250	0.2642	973.24	435.97	521.21	2.2	RMS-75/3840	22.04

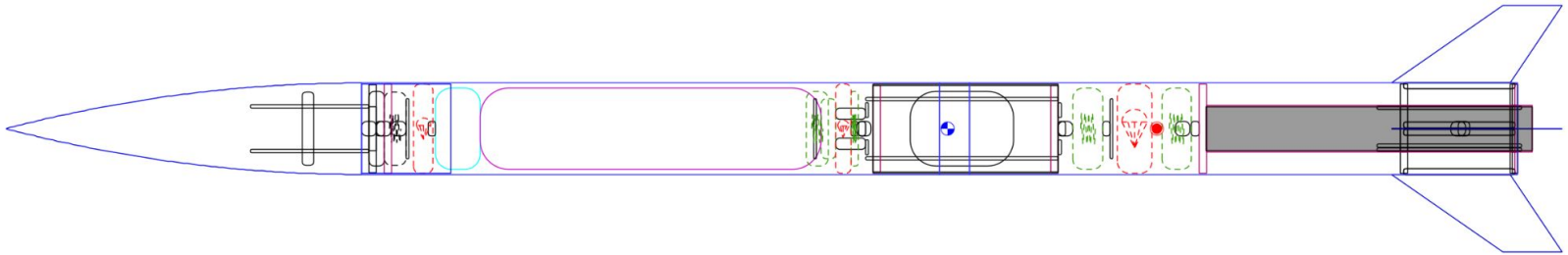


- Avg. Thrust to Weight Ratio: **8.53**
- Maximum Acceleration: **9.16 G's**
- Maximum Velocity: **558.84 ft/s**
- Maximum Mach Number: **0.49**

Stability Margin

With the introduction of a higher accuracy mass distribution payload from CDR, the updated static stability margin is **2.29**.





Vehicle Mass Breakdown

Section	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Nose Cone	5.65	6.67	15.32
Main Parachute/Payload Bay	18.57	18.70	0.73
AV Bay	4.57	5.59	18.36
Drogue Parachute Bay/Fin Can	19.59	20.64	5.08
Total	48.38	51.61	6.27

Nose Cone			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	3.976	5	20.46
Sled and Electronics	0.178	0.156	13.96
Removable Bulkhead	0.972	0.906	7.25
Recovery Components	0.523	0.609	14.15
Total	5.65	6.67	15.32
Main Parachute/Payload Bay			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	4.94	4.70	5.02
Payload Mass Simulator	7.88	8	1.5
Deployment Bay	2.82	3.44	17.06
Main Recovery Components	2.11	1.40	50.71
Nose Cone Parachute Quick Links	0.328	0.344	4.56
Main Parachute Quick Links	0.492	0.516	4.56
Deployment Bay Quicklinks	0	0.344	100
Total	18.57	18.70	0.733
AV Bay			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	1.48	1.8	17.94
Sled and Electronics	0.945	0.734	28.69
Ballast	0.66	0.66	0
Bulkheads and Hardware	1.49	2.4	38.2
Total	4.57	5.59	18.36
Drogue Parachute Bay / Fin Can			
Component Name	Predicted Weight (lb)	As-Built Weight (lb)	Percent Error
Airframe Assembly	4.68	4.90	4.43
Removable Fin System	5.47	5.60	2.31
Drogue Parachute Recovery Components	0.751	0.80	6.16
Drogue Parachute Quick Links	0.492	0.563	12.52
Loaded Motor	8.20	8.78	6.64
Total	19.59	20.64	5.08

Launch Vehicle Verification Testing

G10 FIberglass Fin Durability Test

- Fin should have minimal to no damage upon hitting the ground at greater than or equal to the predicted impact kinetic energy of the launch vehicle's fin can (63.89 ft-lb)
- Achieved a maximum kinetic energy of 67.88 ft-lb
- No visible damage to the fin after 5 consecutive drop tests

Trial #	Recording Time (s)	Gravity (ft/s^2)	Mass (slugs)	Distance (ft)	Velocity (ft/s)	Target KE (lbf-ft)	KE Achieved (lbf-ft)	KE Ratio
1	0.83	32.2	0.181219	10.95833	26.726	63.89	64.72046994	1.012998434
2	0.85	32.2	0.181219	10.95833	27.37	63.89	67.87710775	1.062405819
3	0.82	32.2	0.181219	10.95833	26.404	63.89	63.1703353	0.9887358788
4	0.8	32.2	0.181219	10.95833	25.76	63.89	60.12643455	0.9410930435
5	0.83	32.2	0.181219	10.95833	26.726	63.89	64.72046994	1.012998434

Fastener Shear Loading Test

- Fasteners were tested using procedures outlined in CDR
- Instron Tension & Compression Testing Machine
  - NCSU's Structural Mechanics Lab
- 3 shear pins tested to failure
  - 39.4 lb. average ultimate load per pin (SF = 3.5)
  - Success Criteria: fail under 35-40 lb. load
  - Satisfies LVF 6
- 3 rivets tested to failure
  - 224.4 lb. average ultimate load per rivet (SF=29.9)
  - Success Criteria: SF ≥ 2
  - Satisfies LVF 5

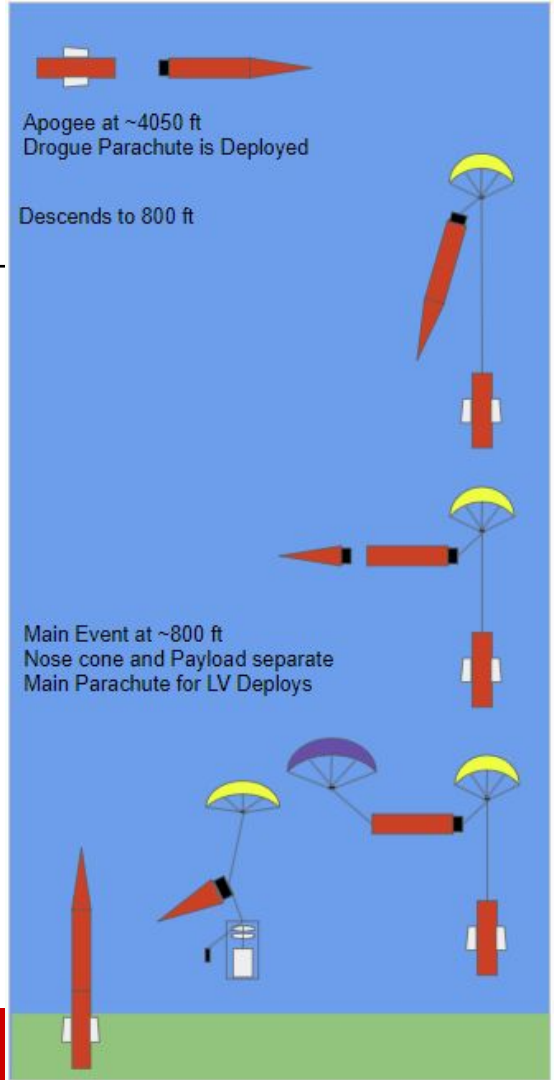
Bulkhead Tensile Test

- Bulkheads were tested using procedures outlined in CDR
- Instron Tension & Compression Testing Machine
  - NCSU's Structural Mechanics Lab
- NC bulkhead yield load - 1248 lb. (SF = 7.6)
- AV bulkhead yield load - 950 lb. (SF = 4.3)
- **Success criteria**: Bulkheads should withstand maximum shock force
- LVD 3 verified

Recovery System Overview

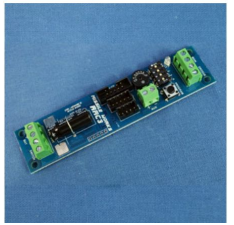
Recovery Events Overview

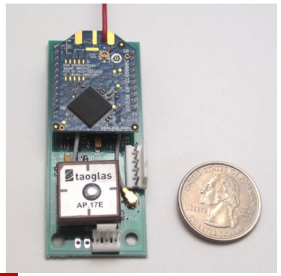
- The drogue parachute deploys at apogee
  - Secondary charge is set to a one second delay after apogee
- Main parachute deploys at 800 ft
  - Secondary charge set at 700 ft
- The nose cone parachute deploys after nose cone separation at 800 ft
- Payload is separated from the nose cone ~450 ft



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

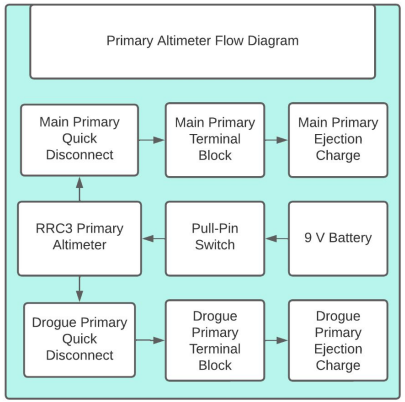


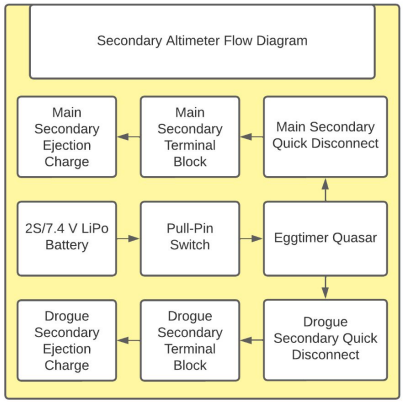


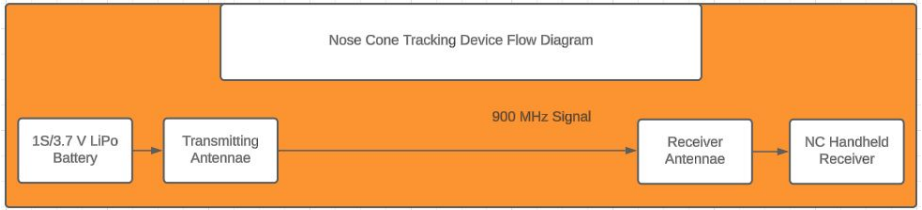
Parachutes

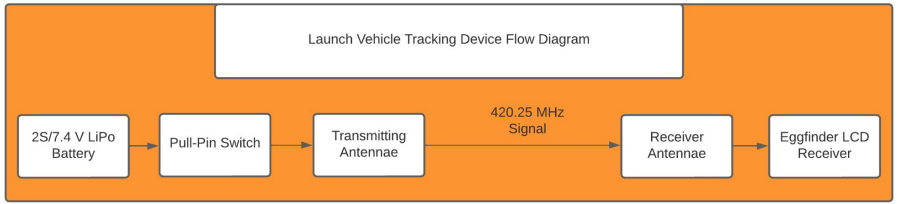
- Drogue Parachute: Fruity Chutes 15” Classic Elliptical
  - Protected from ejection charges via Nomex cloth
  - Descent rate: 112.82 ft/s
- Main Parachute: Fruity Chutes 96” Iris Ultra Compact
  - Protected from ejection charges via a deployment bag that is attached to the removable nose cone
  - Descent rate: 15.38 ft/s
- Nose Cone Parachute: Fruity Chutes 48” Classic Elliptical
  - Protected from ejection charges via Nomex cloth
  - Descent rate before SAIL deployment: 28.99 ft/s
  - Descent rate after SAIL deployment: 21.64 ft/s

Recovery-Avionics Block Diagram



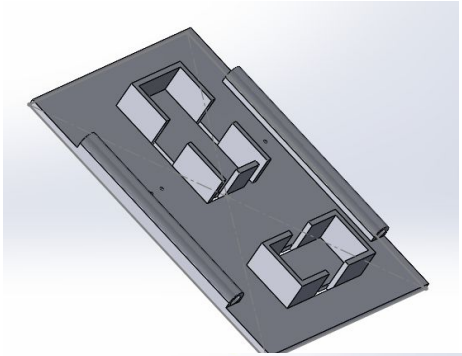


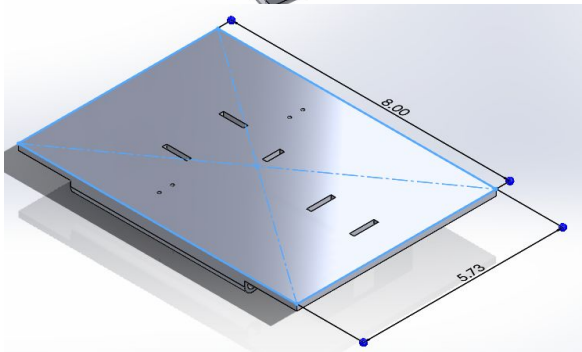




Avionics Sled Design

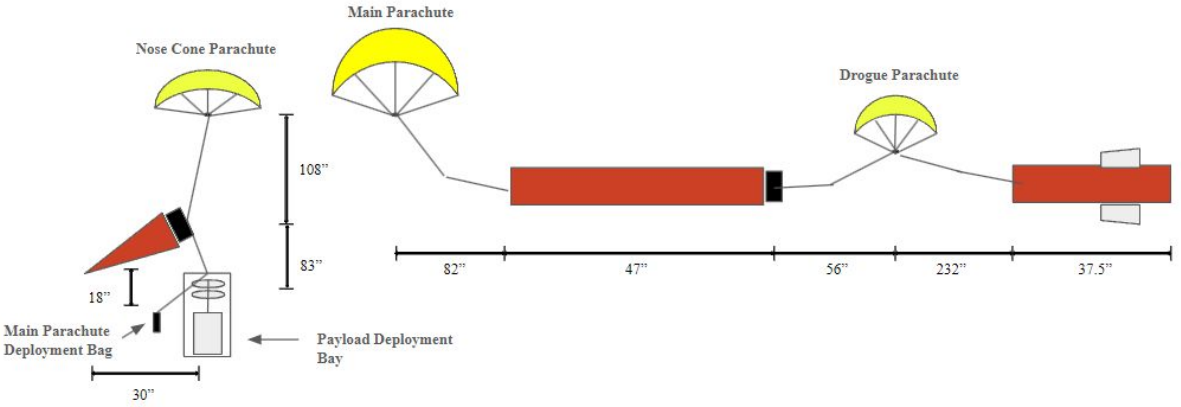
- Modeled in SolidWorks
- Fabricated via 3D Printer with PETG filament
- Smaller slot for 9V battery used to power the RRC3 primary altimeter
- Larger slot for 2S 7.4V LiPo battery used to power the Quasar secondary altimeter and tracker
- Zip ties and electrical tape will be used to secure the batteries in their compartments
- The top surface features mounting space for altimeters, tracker, and pull-pin switch arming devices via threaded heat inserts and M3 standoffs.



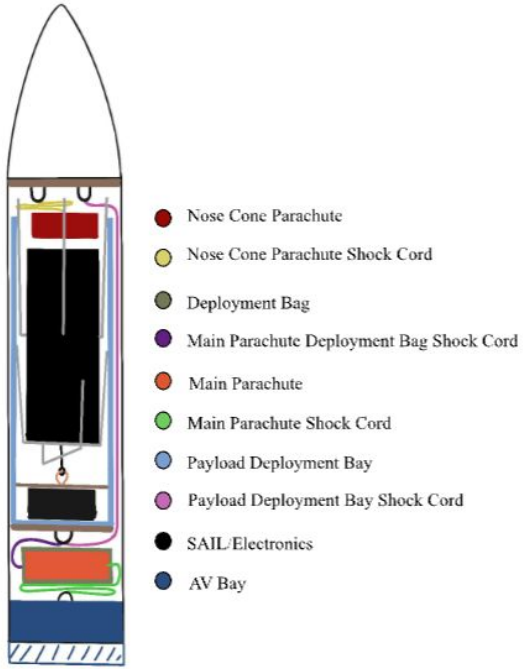


Harnesses and Hardware

- 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 bowline loops in the shock cord with 5/16” steel quick links.
- ¼ in. Kevlar webbed shock cords shall tether the nose cone to the nose cone parachute, and the SAIL deployment bay. All connections are made with 5/16” steel quick links in bowline knots.
- The shock cord will be attached to the U-bolts located on the bulkheads of the launch vehicle.



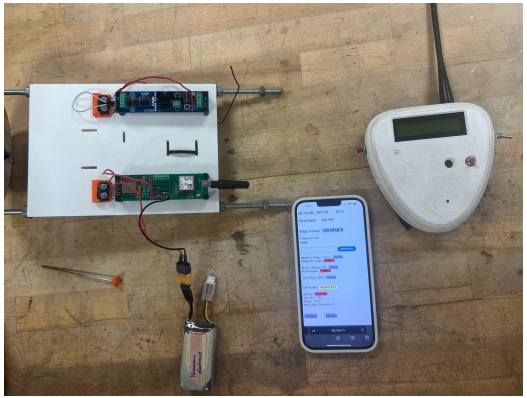
Packing Diagram and Animation



Recovery Verification Testing

GPS Operational Test

- 2 sets of coordinates are compared to determine the accuracy of the GPS.
- GPS detects location within 100 ft.
- Results:



Location	Transmitted	Range
35.77128, 78.67399	35.77116, -78.67375	79.728 ft.
35.77236, 78.67759	35.77240, -78.67755	19.008 ft.
35.77343, 78.67368	35.77346, 78.67370	12.672 ft.

Altimeter Test

- Tests altimeter functionality
- Red LED light in drogue pins, Yellow LED in main pins
- Appropriate LED lights up at corresponding pressure
- Drogue and main deployment altitudes can be checked on computer for confirmation of correct deployment

Full-Scale Ejection Test

- Primary drogue charge: 2.0 grams of FFF black powder
- Primary main charge: 5.0 grams of FFF black powder
- Complete drogue and main separation, no damage to any recovery components

Mission Performance Predictions

Descent Time and Wind Drift

Assuming there is constant wind down range:

Wind Velocity	Launch Vehicle Drift Distance	Nose Cone Drift Distance
0 mph	0 ft	0 ft
5 mph	592.62 ft	452.27 ft
10 mph	1,185.25 ft	904.56 ft
15 mph	1,777.87 ft	1,356.84 ft
20 mph	2,370.5 ft	1809.12 ft

Maximum Wind Drift:

- Launch Vehicle: 2370.5 ft
- Nose Cone: 1809.12 ft

Descent Time

- Launch Vehicle: 80.81 seconds
- Nose Cone: 61.67 seconds

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

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

Kinetic Energy at Landing

- Maximum kinetic energy experienced is 61.11 ft-lb on the fin-can

Section	Section of Mass	Descent Velocity Necessary to be Awarded Points	Descent Velocity Necessary to be Awarded Bonus Points
Nose Cone	.207 slugs	26.919 ft/s	25.063 ft/s
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	19.36 ft/s	18.03 ft/s
Drogue Bay/ Fin Can	.516 slugs	17.05 ft/s	15.87 ft/s

Section	Section of Mass	Velocity Under Main Parachute	Impact Energy
Nose Cone	.207 slugs	21.64 ft/s	48.77 ft-lb
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	15.38 ft/s	47.31 ft-lb
Drogue Bay/ Fin Can	.516 slugs	15.38 ft/s	61.11 ft-lb

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: 314.62 lbf
- Shock force experienced by nose cone: 385.64 lbf
- The Kevlar Webbed shock cord is rated for a maximum shock force of 6600 lbf.
- LV Shock Cord Factor of Safety: 20

Equation:

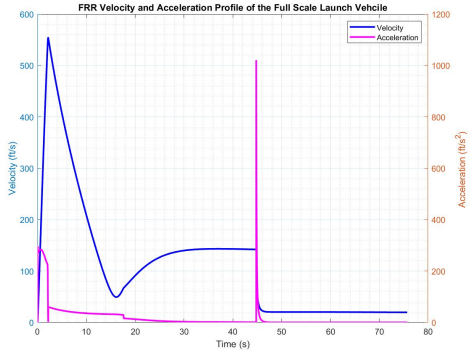
$$F = \frac{m\Delta v}{t}$$

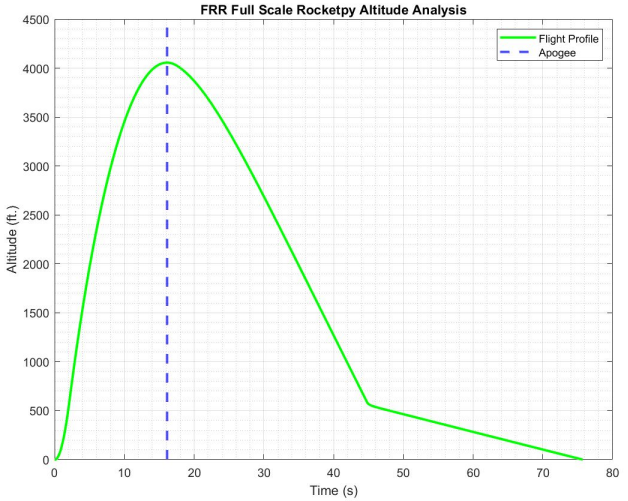
Section	Mass of Section	Parachute Opening Time	Parachute Opening Shock
Nose Cone with Payload	.562 slugs	.142 s	385.64 lbf
Main Parachute/ Payload Bay and Avionics Bay	.400 slugs	.284 s	137.24 lbf
Drogue Bay/ Fin Can	.516 slugs	.284 s	177.04 lbf
Separated Launch Vehicle	.917 slugs	.284 s	314.62 lbf

Predicted Altitude

Flight Simulation Results:

- Apogee: **4056.32 ft.**
- Apogee Time : **16.11 s.**
- Maximum Velocity: **558.24 ft/s**
- Maximum Acceleration: **9.16G's**
- Ballast Required: **2.6 lb.***





* Ballast distributed with 1.84 lb. located on the RFS, and 0.66 lb. located on the forward bulkhead.

Payload Design Overview

SAIL Changes

- Loft added to rotor blade mounting section

  → Improves adhesion of the carbon fiber plies to the 3D-print
- All blade sections now have voids; rectangular pieces used to epoxy them together

  → Improves section alignment and fabrication ease
- Clamping collar to replace snap ring on side bevel gear shafts
  - Snap rings slipped off under high RPM

SAIL Changes

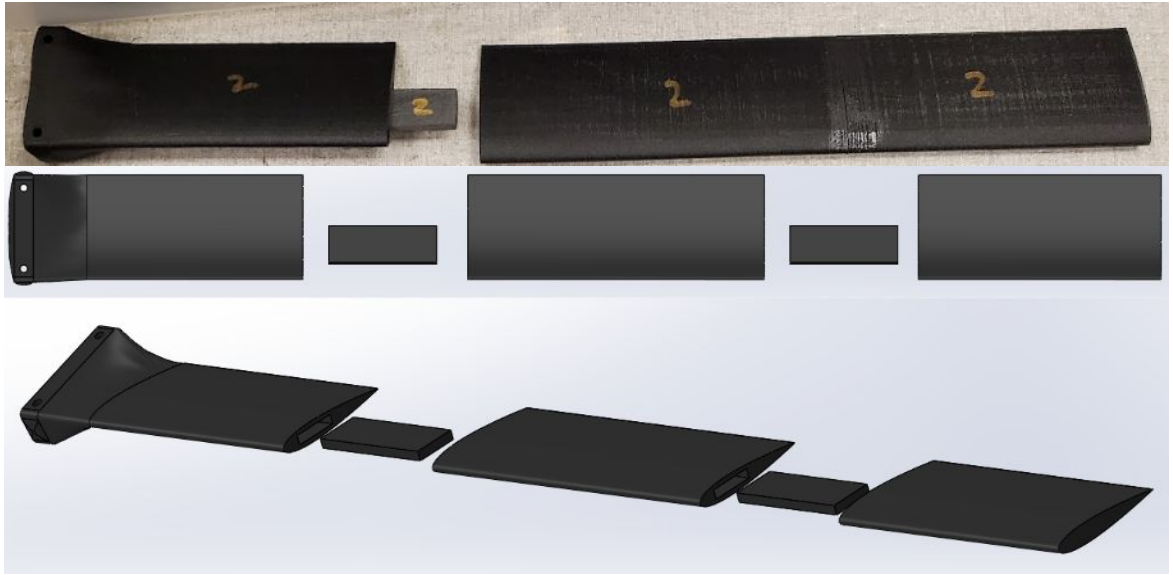
- Legs shortened
  → Deployment bay shortened
    → Opens up more space for recovery components
- Leg mechanism
  - Pins and retaining rings replaced with bolts and nuts
    - Stainless steel pins were difficult to lathe with in-house tools

SAIL Dimensions

- Height
  - Folded: 25”
  - Extended: 23.8”
- Rotor Blade Span Diameter
  - 34.3”
- Leg Span Diameter
  - 15.05”

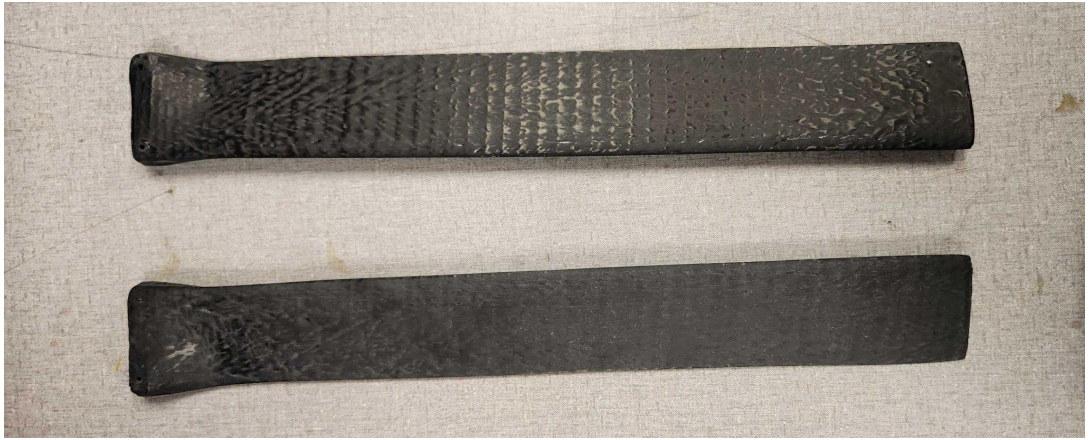
Rotor Blade Fabrication

- 3 sections epoxied together
- Vacuum-assisted resin transfer molding



Rotor Blade Fabrication

- Trimmed and sanded down
- Will brush epoxy on and wet sand
  - Smoothes out the surface



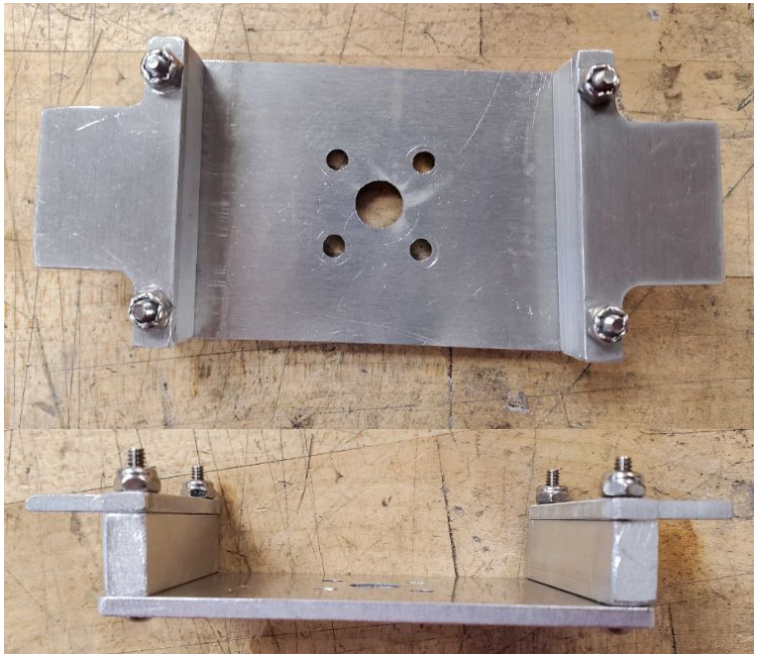
Water Jet Parts

6061 aluminum sheet metal

- ⅛” thick
  - Hubs, Gearbox sides, L-brackets, Linkages
- ¼” thick
  - Hardstop spacers

Hub Assembly

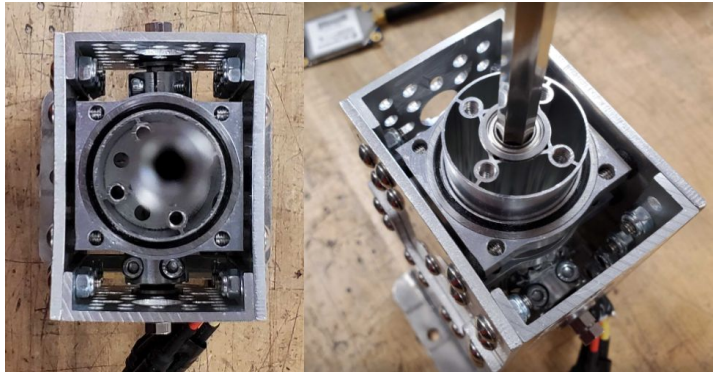
- Rotor blade hubs assembled
- Will have spring hinges bolted on the bottom
  - Secures to the rotor blade mounting holes

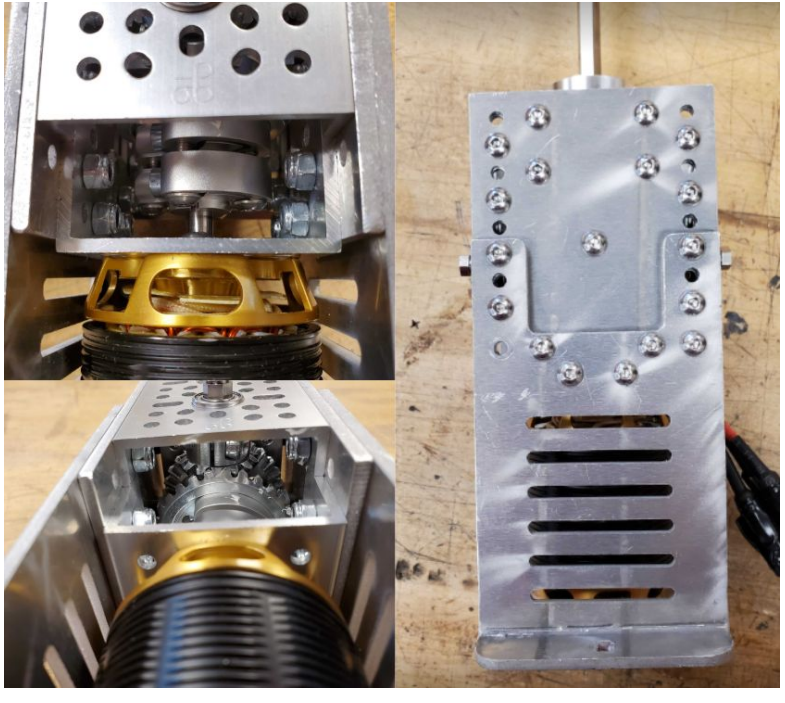


Gearbox Fabrication

Most pieces have been assembled

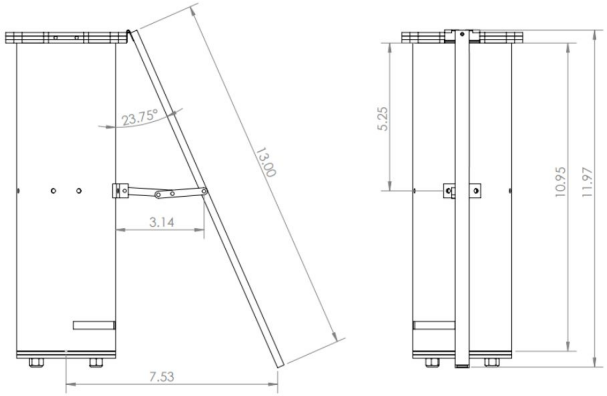
- Motor secured to hex shaft
- Outer structures secured
- Bevel gears oriented
  - Bearings and spacers bolted in place

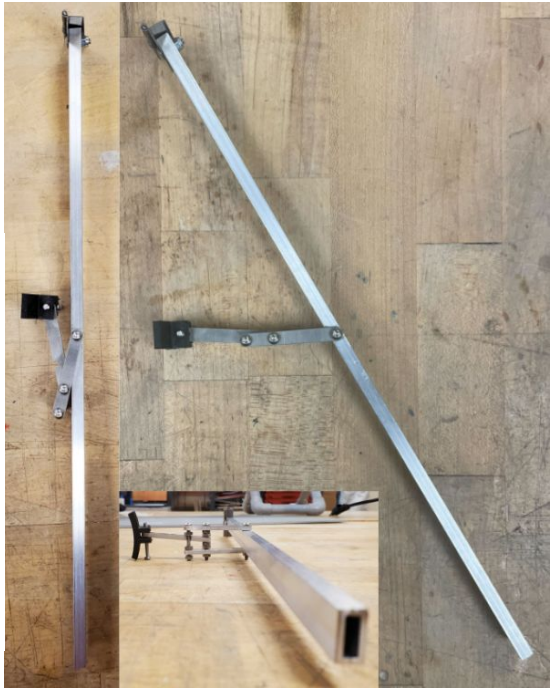




Leg Mechanism Fabrication

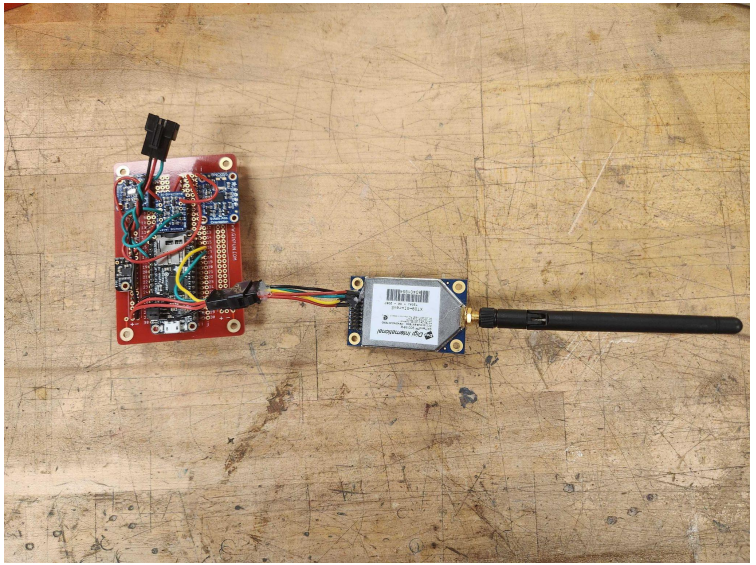
- All pieces assembled
  - Will be screwed into the upper bulkhead and bolted to the SAIL body
- 13” Legs
- 23.75° angle
- 15.05” span





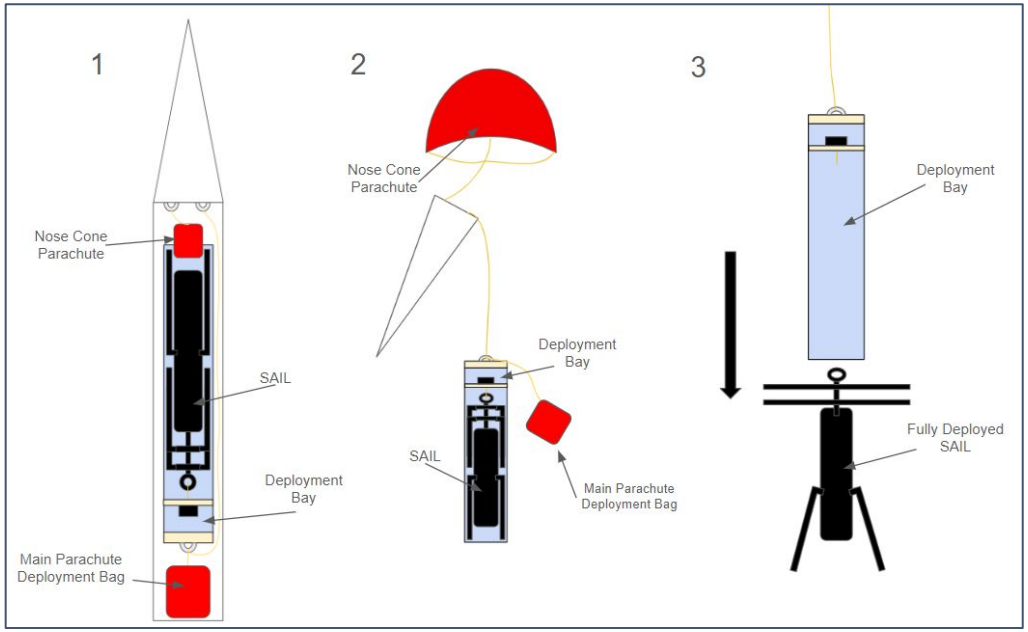
SAIL Electronics

- Adafruit Feather selected as the flight computer
- Powered by the electronic speed controllers BEC
- Communicates with ground station via XTend transceiver



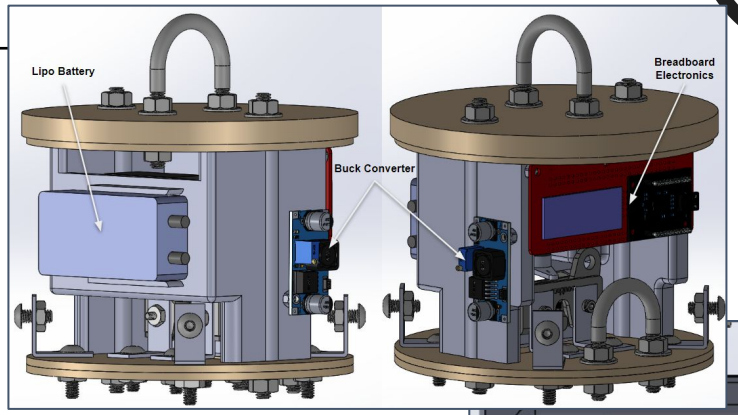
SAIL Deployment Overview

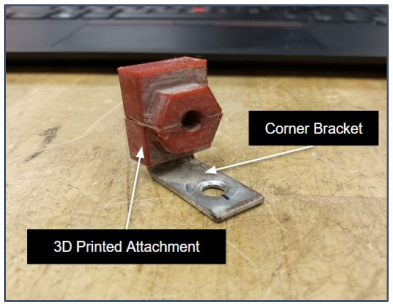
- SAIL rotated 180 degrees to save space in main/payload bay
- Deployment events otherwise unchanged from CDR
- Sequences of events verified at VDF with SAIL mass simulator under a parachute

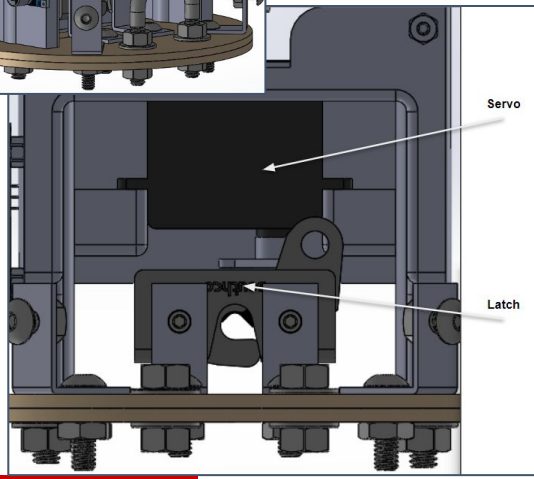


Deployment Bay Design

- Latch configuration unchanged since CDR
- Electronic sled redesigned to save on space and weight
- 3D printed attachment added for smoother mounting to Blue Tube



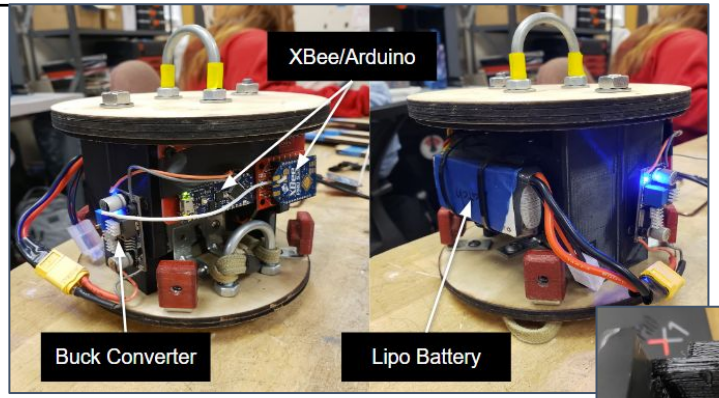


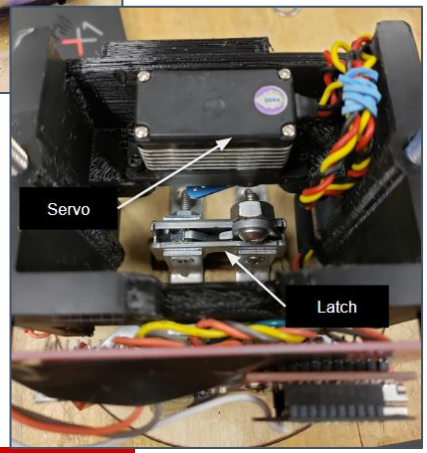


Deployment Bay Design

Deployment Bay Manufacturing

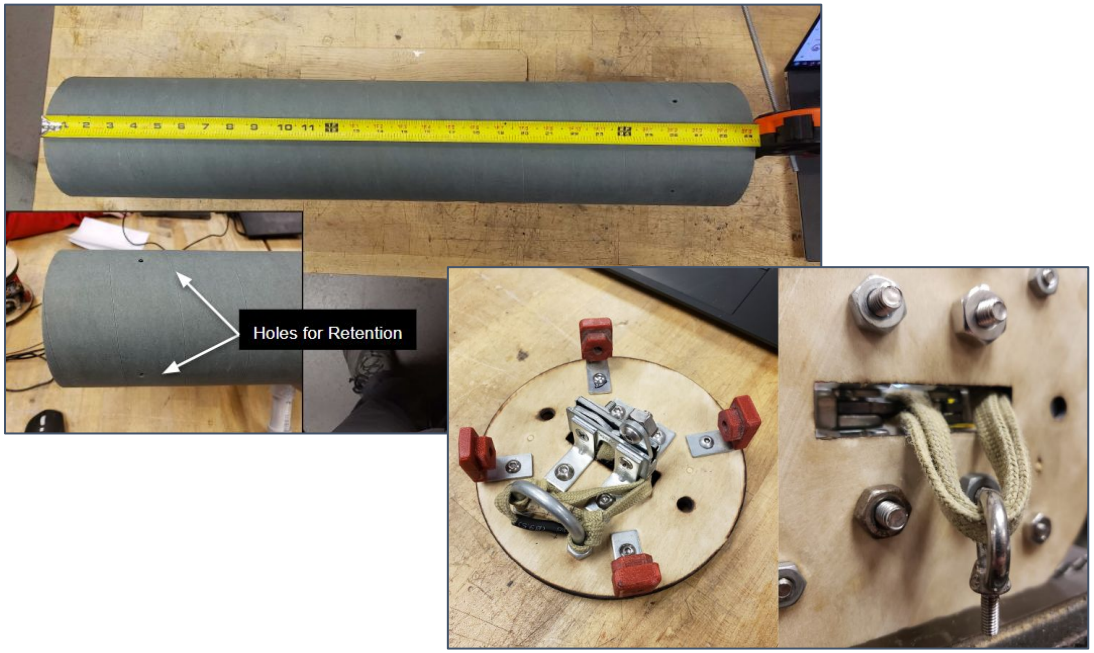
- Sled, bulkheads, and electronics put together with fasteners
- Servo positioned to allow arm to reach manual latch release
- Lipo + Servo secured further with zip ties for launch





Deployment Bay Manufacturing

- Blue Tube cut using miter saw
- Holes measured and drilled using a power drill
- Shock cord tied and cut to length for SAIL retention in deployment bay



Deployment Bay Manufacturing

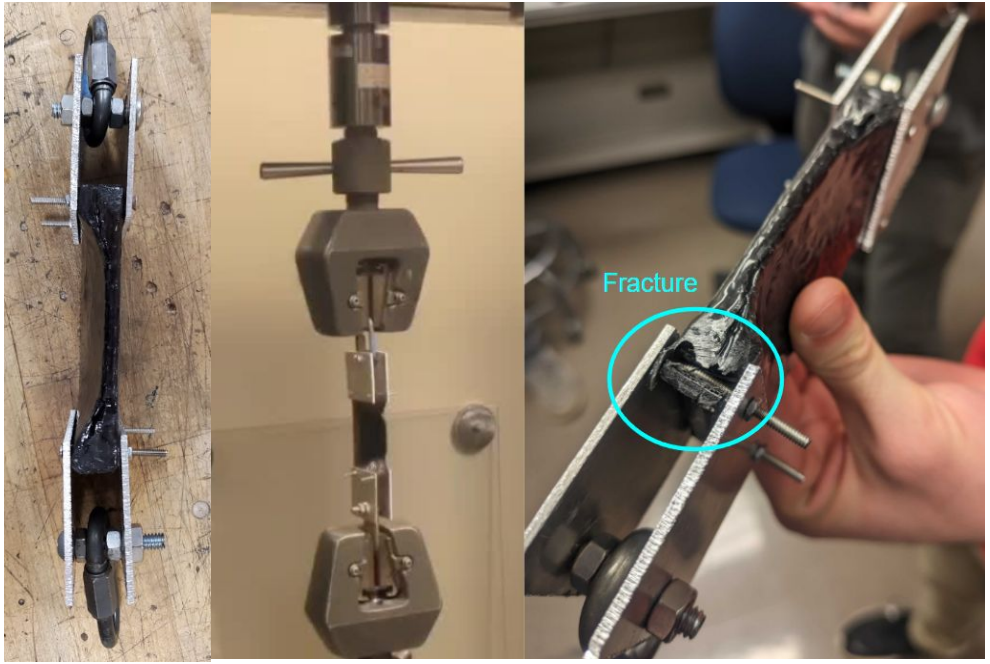
- Electronics bay secured to Blue Tube using corner brackets and screws
- Ready to insert in main/deployment bay

Payload Verification Testing

Blade Adhesion Test

- Fabricated a short test article
- Tested using the Instron tensile testing machine

- **Success Criteria:** withstand 300 lbs. of axial loading
- **Result:** withstood 517 lbs.
  - Fractured at mounting hole



Leg Bend Test

- Test will be conducted using incremental weights up until 50 lbs.
  - Measure new height of the assembly to determine deformation

Success Criteria: Landing legs do not bend further than the base of the SAIL body

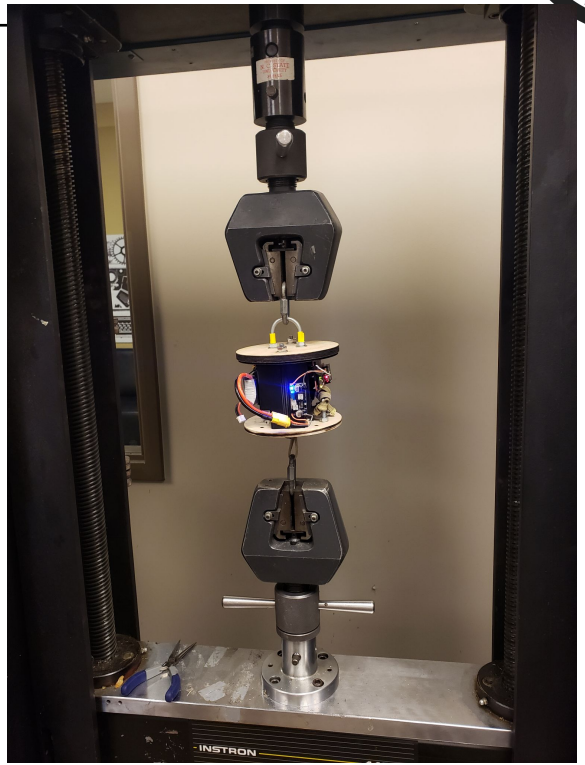
- Due to the fiberglass tube not arriving yet, this test has not been completed

RF Signal Test

- Performed at Launch Field (Bayboro, NC)
- Signal sent up until 2500 ft
- Servo received signal and turned, meeting the expected max drift distance
- **Success Criteria:** The servo turns for every distance that the release command is sent
- **Success Criteria:** The servo turns inside of the deployment bay for every distance the command is sent
- **Success Criteria:** The servo turns with at least 7.4V
- PF 2 Verified

Latch Tensile Test

- Tested in NCSU's Instron Tensile Testing Machine
- Latch withstood the max load of 100 lb
- Latch did not open under higher loads due to deflection.
- **Success Criteria:** The latch does not open and/or fracture under a load of 100 lb. without being opened manually
- **Success Criteria:** The servo turns the manual release under a load of 100 lb. and opens the latch
- PF 3 Verified



Thrust Test

- Test will be conducted using NCSU's thrust stand
- Rotor blades will be spun at increasing RPM while recording the thrust generated, creating a thrust curve

- **Success Criteria:** The SAIL generates 8 lbf of thrust.

- Due to changes in the gearbox design, the test has not been completed as of the submission of FRR. The test is currently planned for the week of March 4th.

Deployment Test

- Test will be conducted at NCSU.
- The completed SAIL will be released from the deployment bay at a height of 6 ft.

- **Success Criteria:** The rotor blades and landing legs deploy within 1 second of leaving the deployment bay.

- Due to a delay with receiving the fiberglass tube, the test has not been completed as of the submission of FRR. The test is currently planned for the week of March 11th.

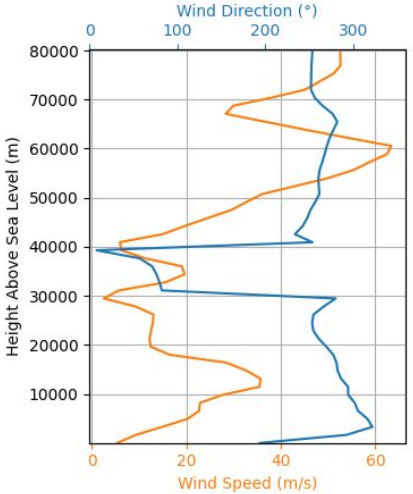
VDF Results

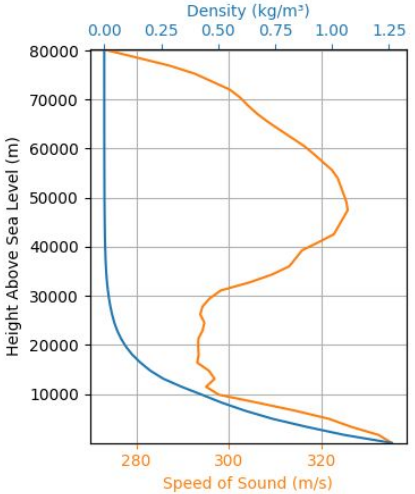
Flight Conditions

Time of Flight: **2/26/2023 1:00 PM**

Temperature: **60° F**

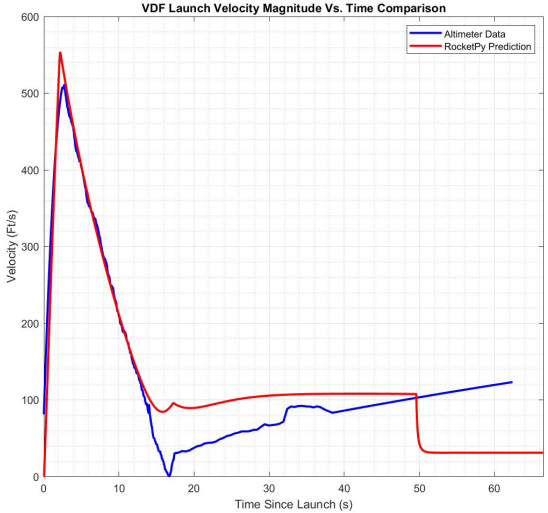
Wind Speed: **10 MPH**

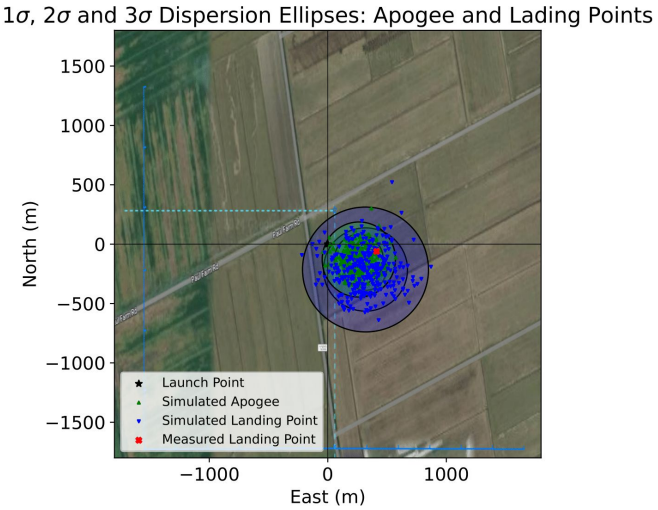


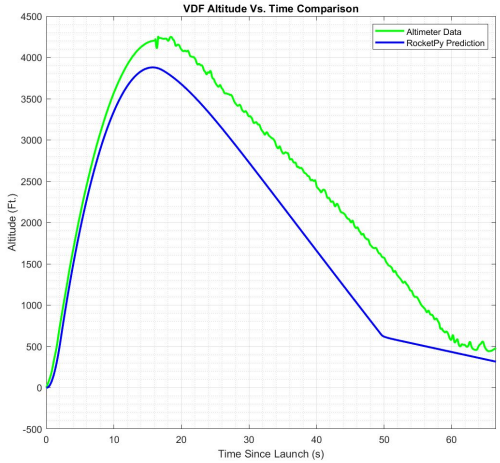


VDF Flight Data

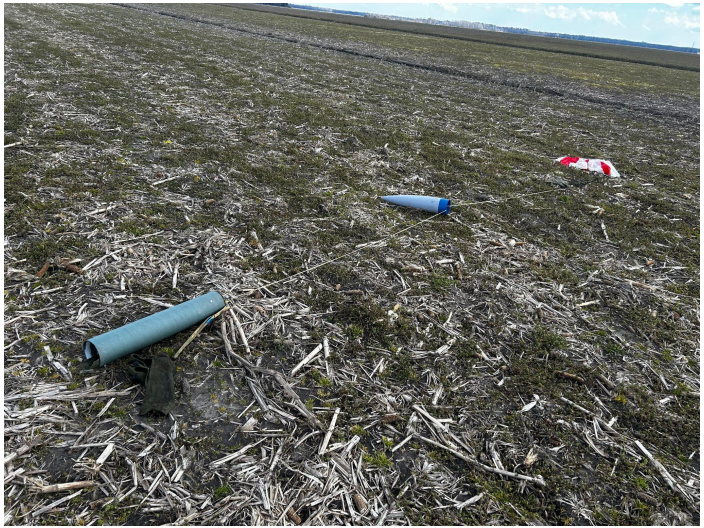
RocketPy Predicted	Altimiter Measure	Difference (ft.)	Difference (%)
3986 ft.	4204 ft.	218	5.32







Recovery Configuration



PDF Plans

- Was not completed with VDF
- Will be completed on March 23rd, 2024
  - All payload tests will be completed prior
- Paul Farm, Bayboro, NC
- Launch procedure same as VDF

Requirements Verification

Requirements Verification Status

- Requirements pertaining to subscale fabrication and flight, full scale design, and VDF have been verified. An example is provided below.
- Plans for verifications requiring payload to have been built/tested or launch day requirements are discussed in FRR.
- See section 6 of FRR 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.

Launch Vehicle Requirements

- *LVF 5* Rivets SHALL have a factor of safety greater than or equal to 2.
  - Verified by Fastener Shear Loading test (section 7.1.6, 7.1.7).
- *LVD 3* Bulkheads SHALL not fracture under tensile stress less than the maximum shock force.
  - Verified by Bulkhead Tensile Test (section 7.1.8, 7.1.9).
- *RF 3* Altimeter testing SHALL be successful and accurate before any vehicle launch.
  - Verified by Altimeter Test (section 7.1.4).

Payload Requirements

- *PF 2* The RF transmitter and receiver for release SHALL have an operational range of at least 2500 ft.
  - Verified by RF Signal Test (section 7.2.5).
- *PF 3* The SAIL deployment latch SHALL withstand up to 100 lb. of tensile force.
  - Verified by Latch Tensile Test (section 7.2.6).
- *PF 6* Adhesion methods used for propeller blade sections SHALL withstand at least 300 lb.
  - Verified by Blade Adhesion Test (section 7.2.3).

Questions?