Critical Design Review

January 9, 2023

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Launch Vehicle Design

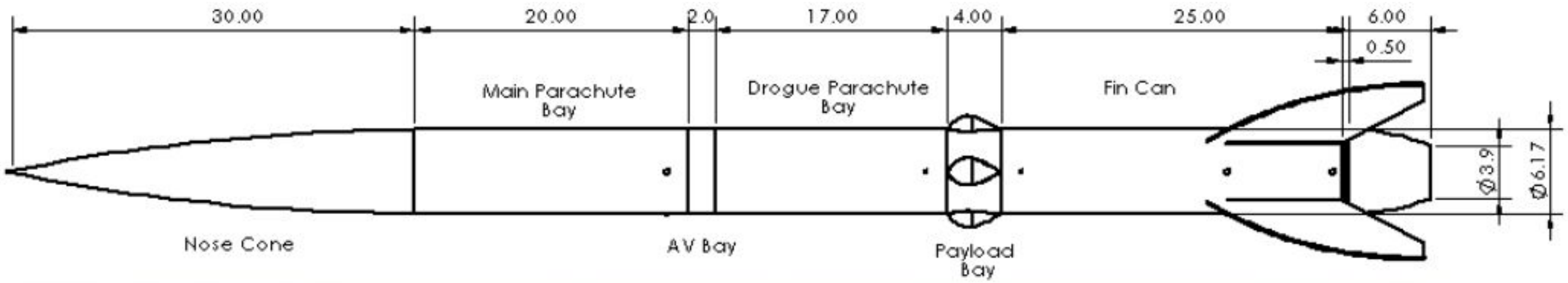
Material Selection

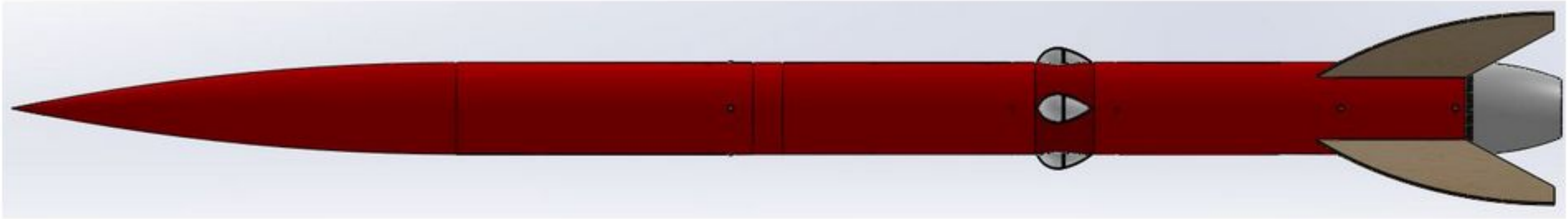
Airframe Sections

Fin Configuration

Launch Vehicle Dimensions

- Length: 104.5 in.
- Diameter: 6.17 in.
- Launch Weight: 40.71 lb.
- Burnout Weight: 36.62 lb.

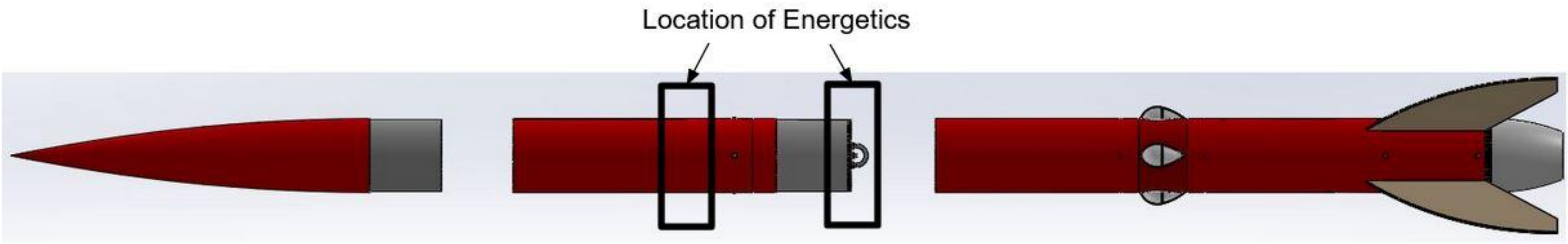




Separation Points

2 Separation Points:

- Nose cone - Main parachute bay
- AV bay - Drogue parachute bay



Material Selection

G12 Fiberglass

- Fiber-reinforced composite
- Highly durable and damage resistant
- Easily resists compressive loading and impact forces
- Water resistant

Aircraft Grade Birch Plywood

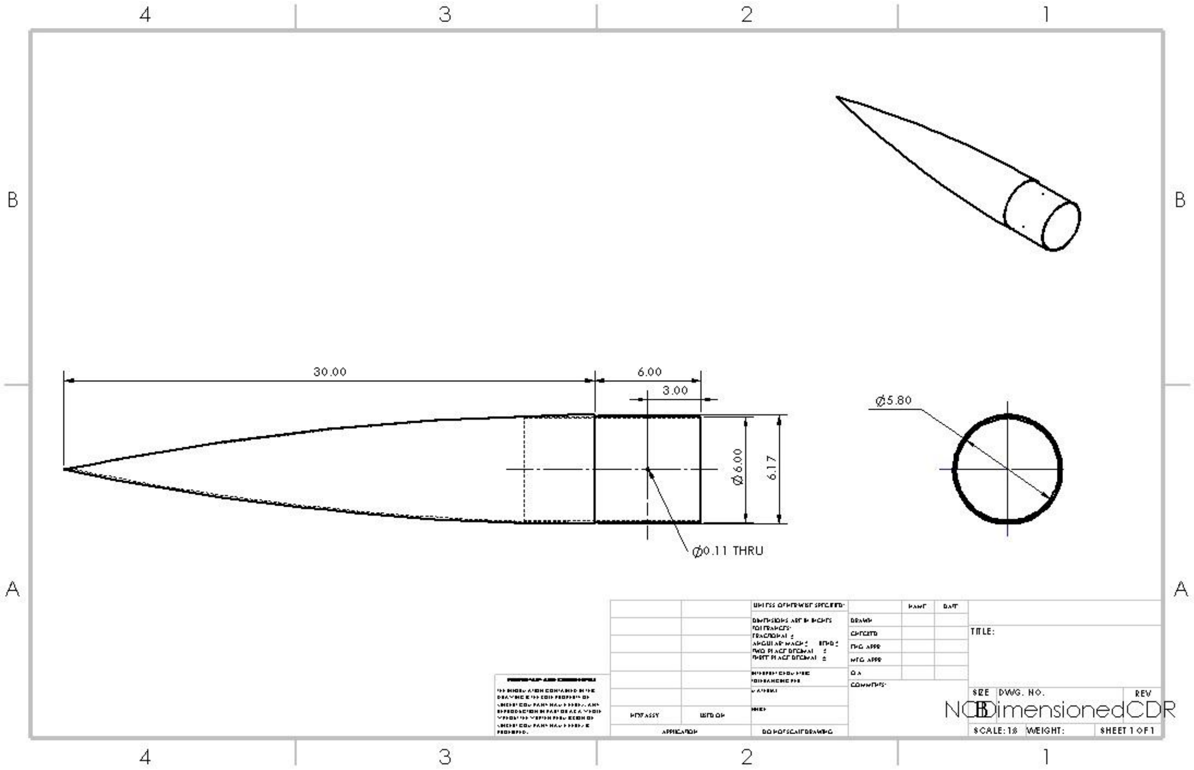
- Lightweight and sturdy material
- 1/8'' layer thickness
- Bulkhead thickness will vary from 1/2'' to 3/4'' thickness

Carbon Fiber Composite

- Balsa wood core with Carbon Fiber wrap
- Approximate 30% weight savings over plywood fins

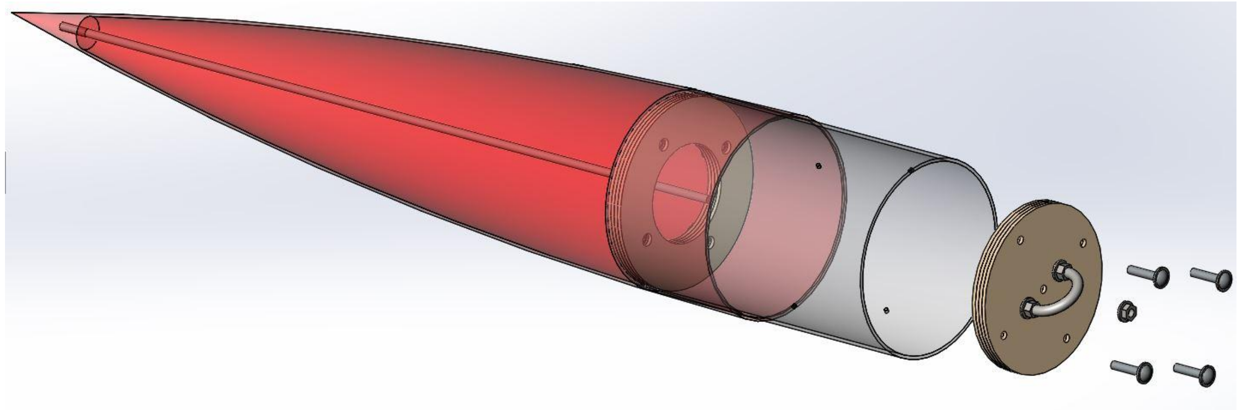
Nose Cone: 5:1 Ogive

- 5:1 Ogive
  - Provides good aerodynamic performance
  - 30 in. long with a 6 in. shoulder
  - Removable bulkhead mounted at the forward end of the shoulder
  - Threaded rod runs entire length for bulkhead support and ballast connection



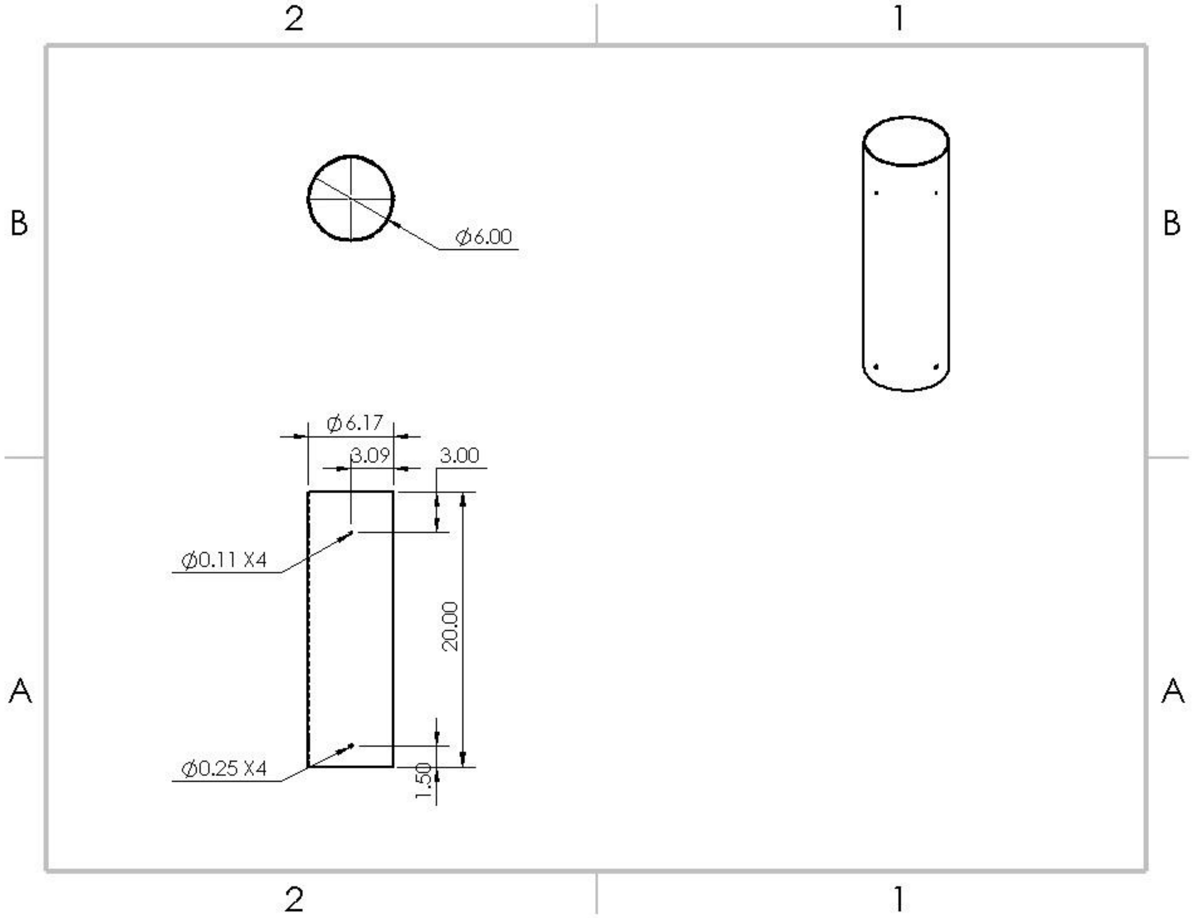
Removable Nosecone Bulkhead

- Allows for accessibility to adjust ballast on the forward side
- Permanently epoxied centering ring
- Bulkhead is secured to centering ring with 4 bolts
- stress concentrations expected around bolted connections



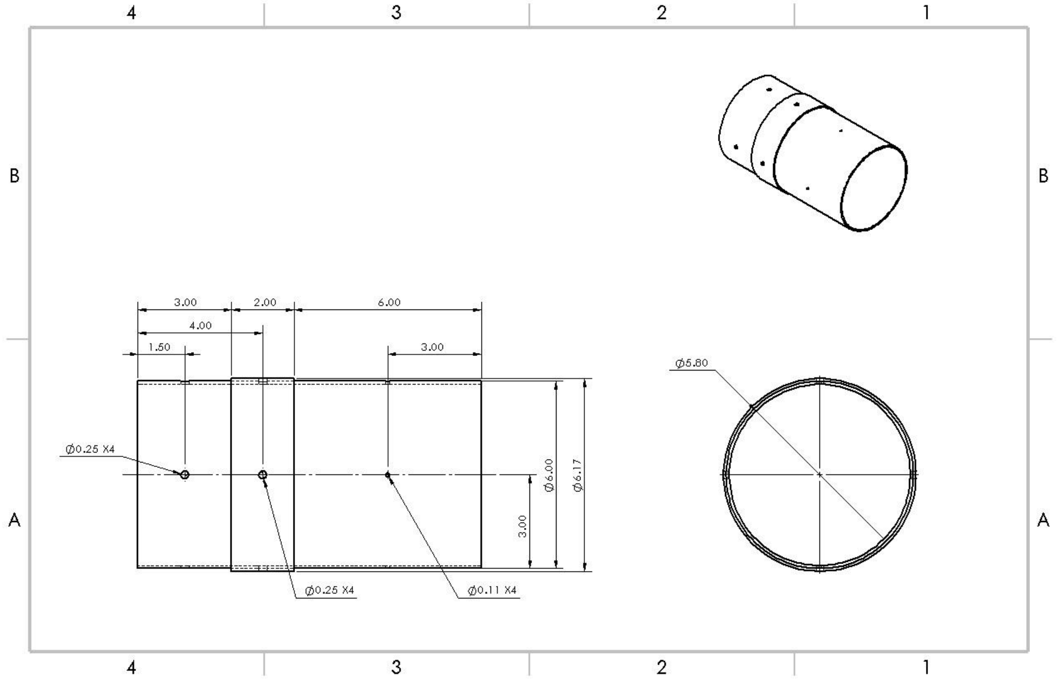
Main Parachute Bay

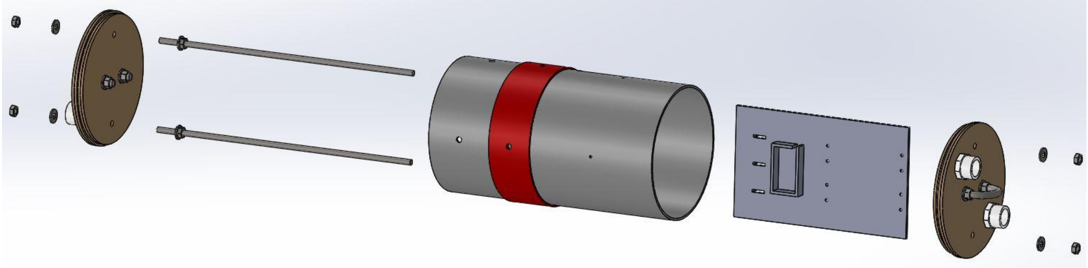
- 20 in. long
- Shear pin connection to nose cone
- Rivet connection to AV bay.



Avionics Bay

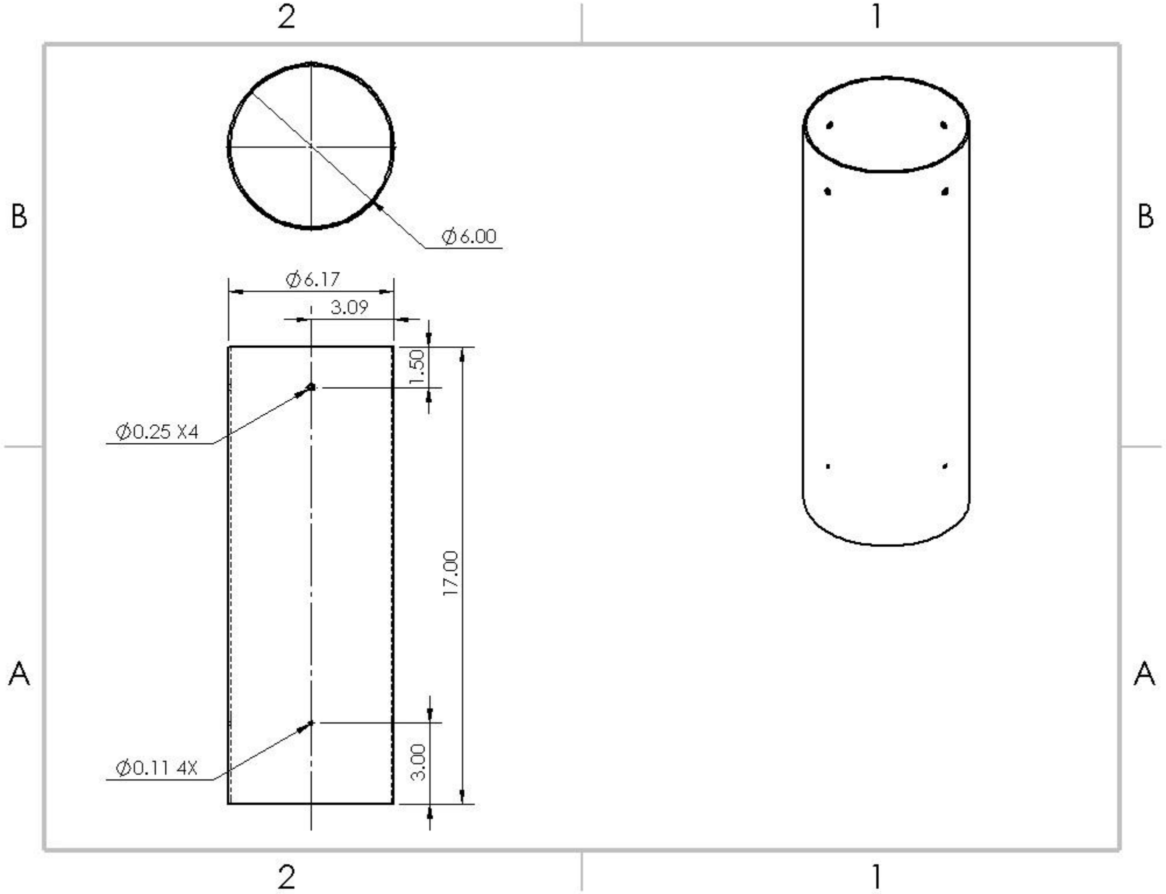
- 11 in. long coupler with 2 in. exposed airframe band
- Modular 2 bulkhead design
- Houses all recovery electronics





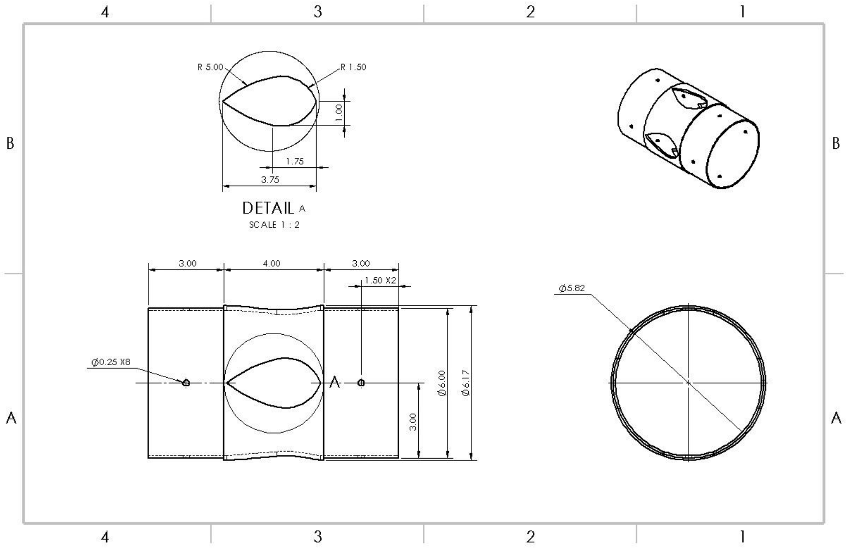
Drogue Parachute Bay

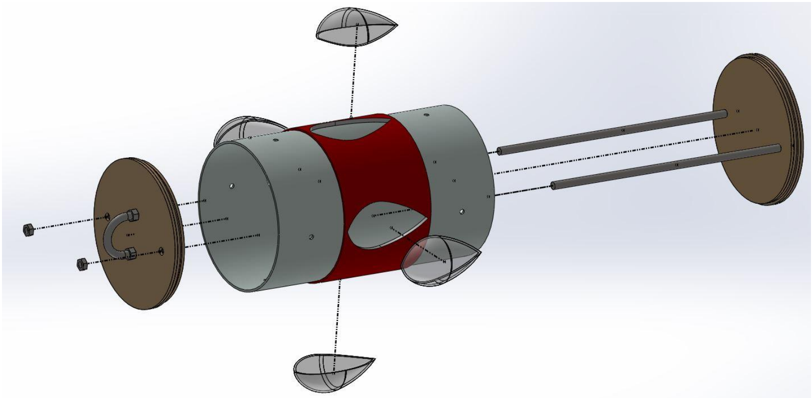
- 17 in. Length
- Shear pin connection to AV bay
- Rivet connection to payload bay



Payload Bay

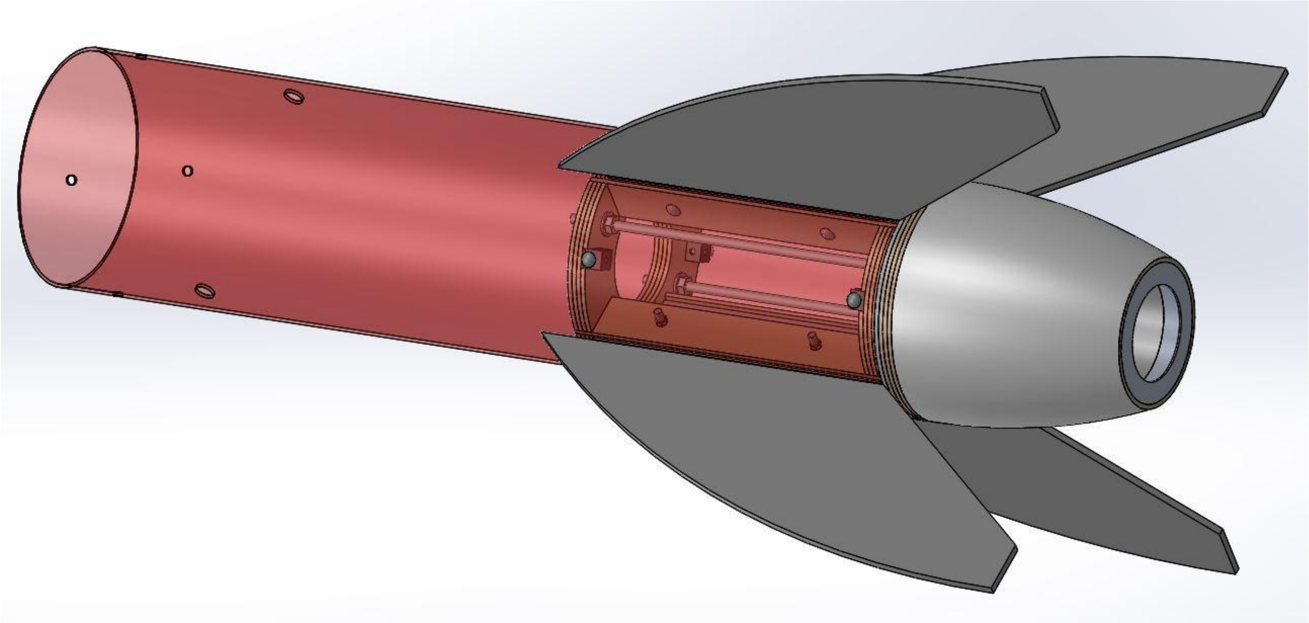
- 11 in. long coupler, 4 in. airframe band
- Modular 2-bulkhead design functions similar to AV Bay.
- Rivet connection to the drogue parachute bay and the fin can





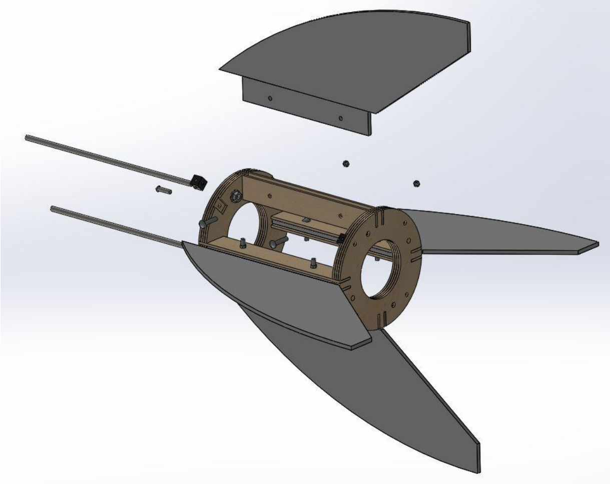
Fin Can

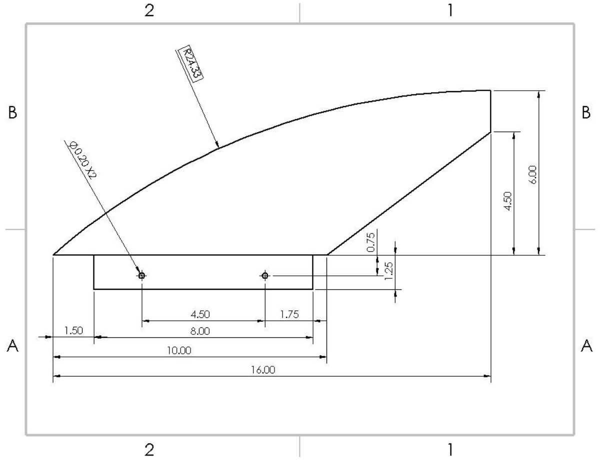
- Removable Fin System
- Overall length is 31 in. including tailcone
  - 25 in. airframe section
- Forward centering ring was removed



Four Fin Removable Configuration

- Fins are bolted to runners that span the centering rings
- Thrust plate ensures motor force is directly transferred to the airframe
- Swept wing design moves a portion of the surface area well behind the fin can which aids in moving the center of pressure farther aft.





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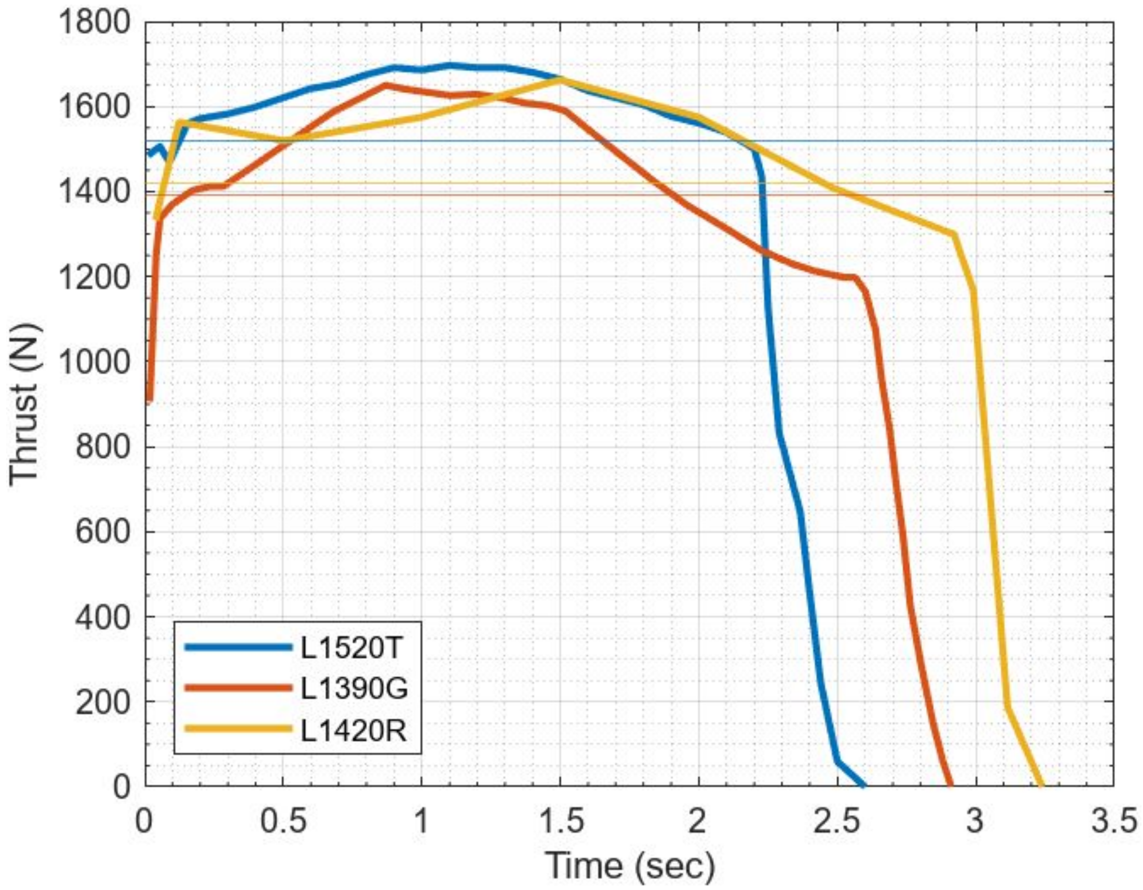
Mission Performance Predictions

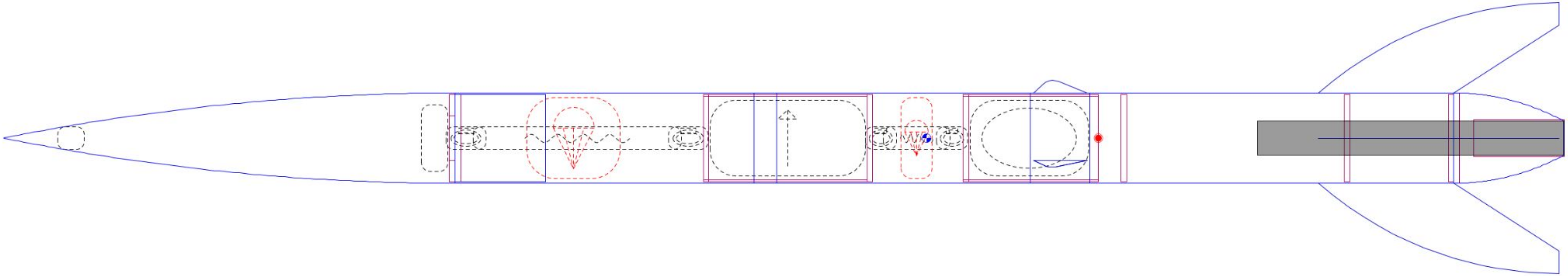
Motor Selection

- Selected the Aerotech L1520T
  - 75 mm Diameter
  - 1,854 g of Blue Thunder Propellent
  - 2.4 s burn time
  - 1,567 N Average burn time
  - 3,715 Ns of Impulse



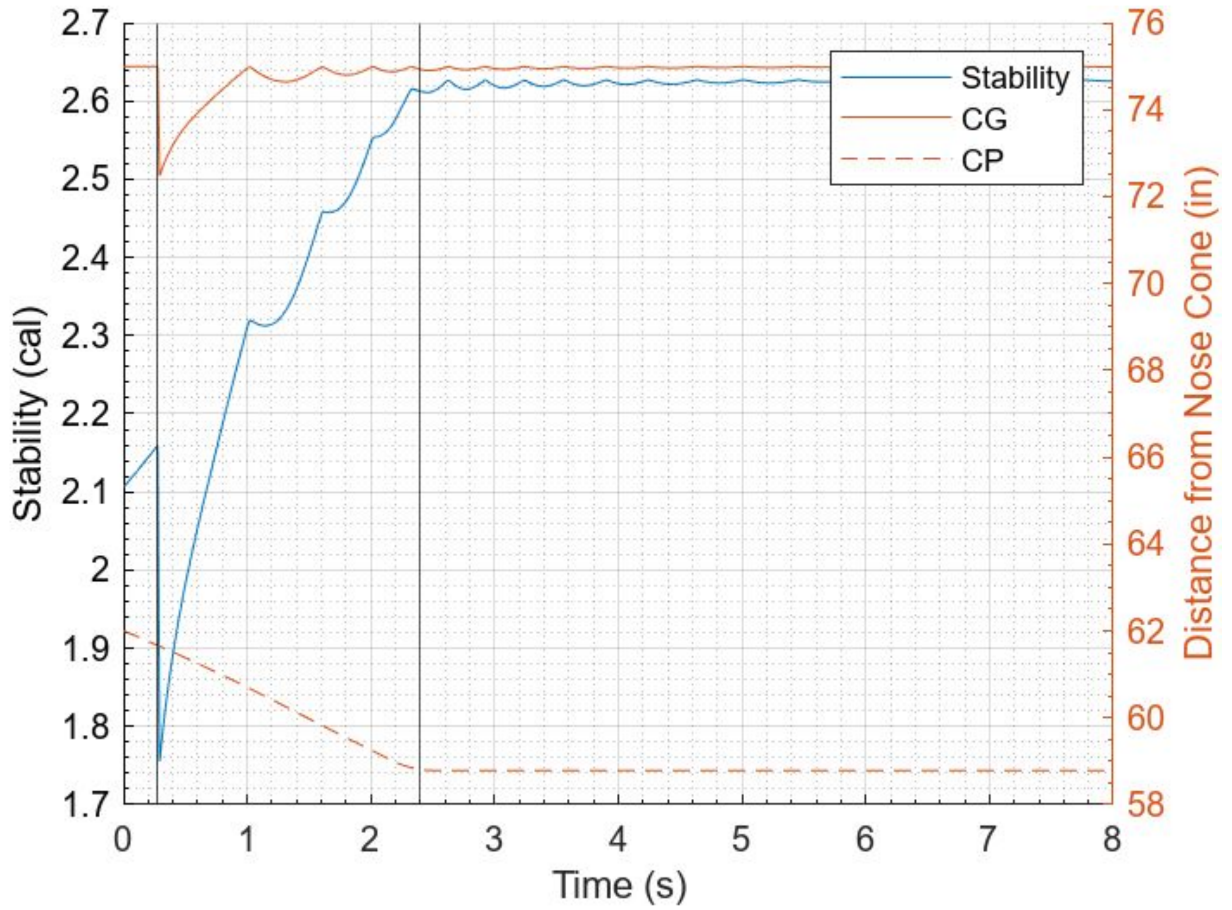
Flight Stability Simulation

- RockSim Simulation
  - CP at 75 in.
  - CG at 62 in.



Flight Stability Simulation cont.

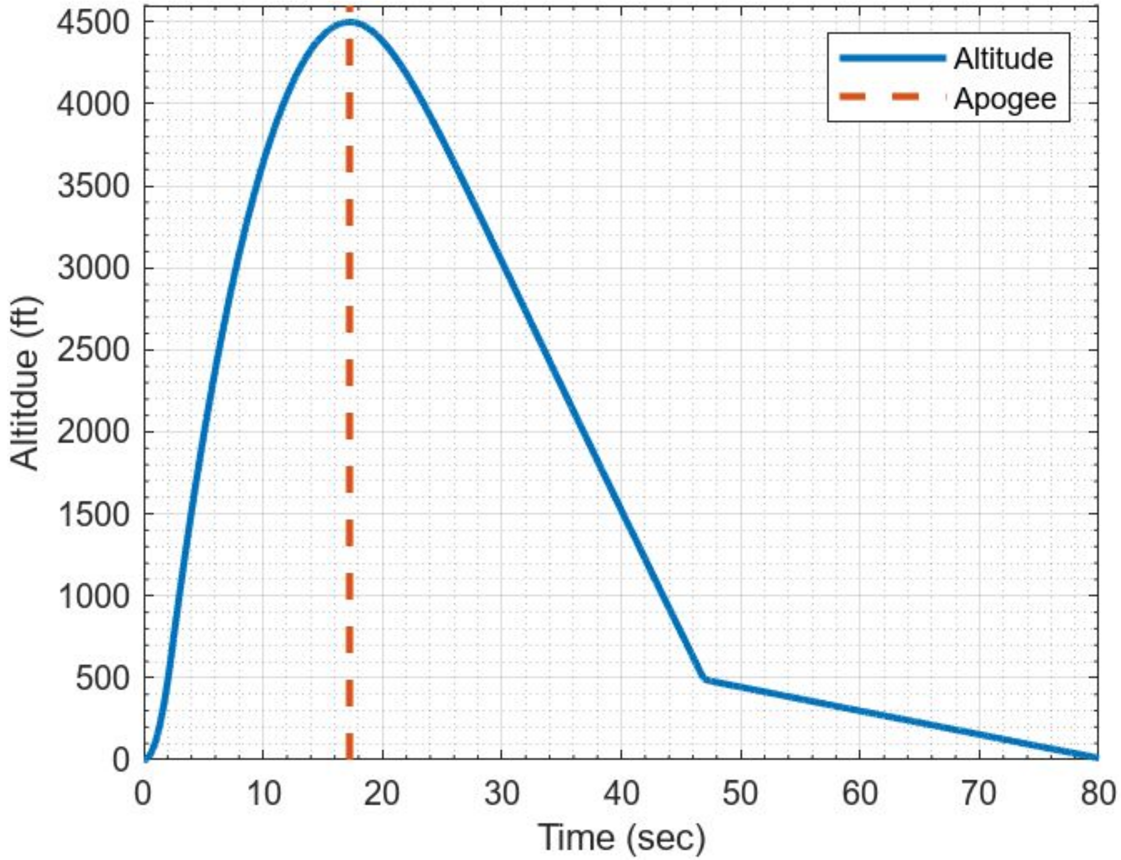
- Stability Simulation Results
  - 2.10 cal Static Stability
  - 2.16 cal at Rail Exit
  - 2.62 cal at Motor Burnout



Predicted Launch Values

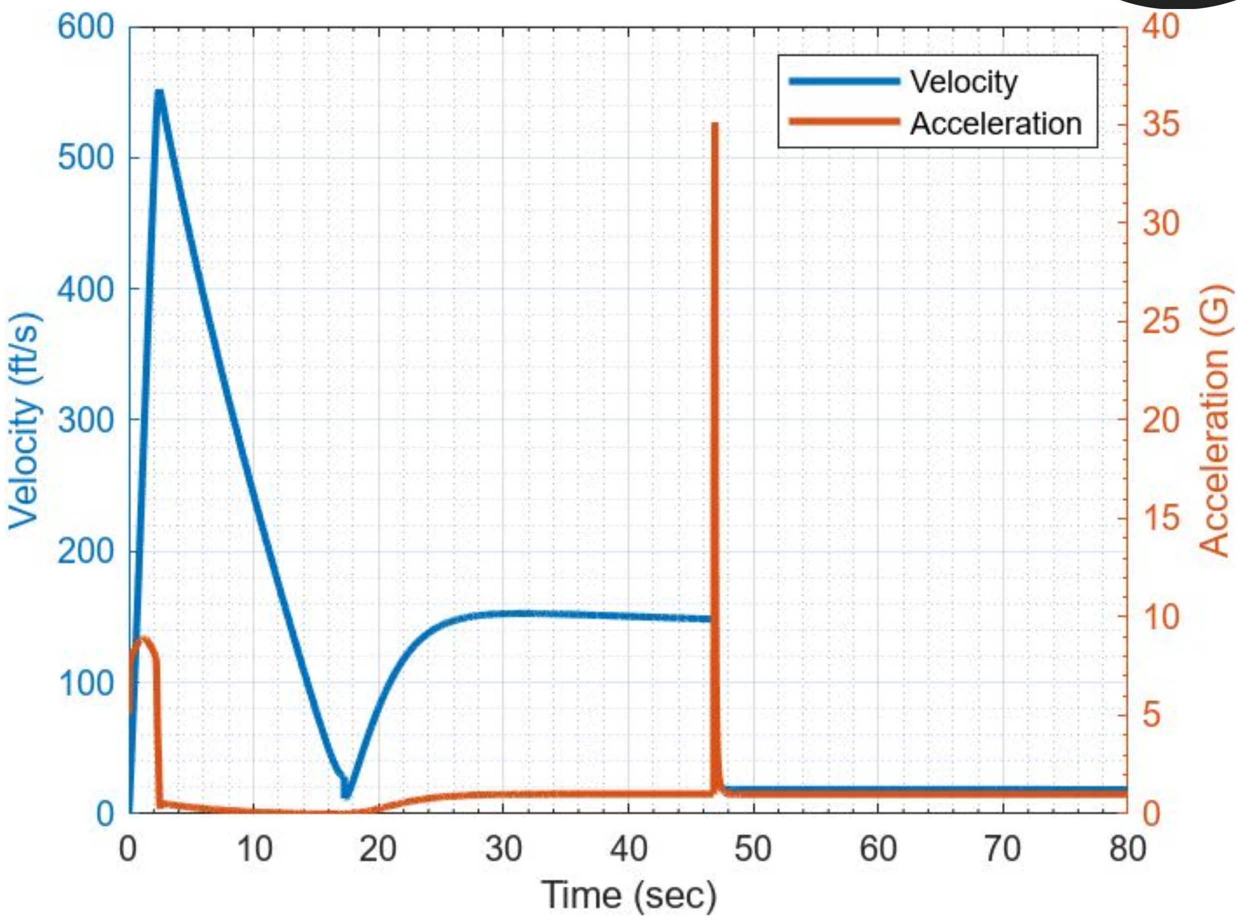
- Flight Simulation Results
  - 4,500 ft AGL
  - Apogee at 17.24 sec

Parameter	Assumption	Justification
Launch Rail Angle	5°	Handbook 1.12
Launch Rail Length	144 in.	Handbook 1.12
Wind Speed	10 mph.	Median Flight Condition
Launch Direction	Into Wind	Standard Procedure



Flight Performance

- Thrust to Weight Ratio
  - 8.35
- Rail Exit Speed
  - 60 ft/s
- Motor Burnout Speed
  - 552 ft/s

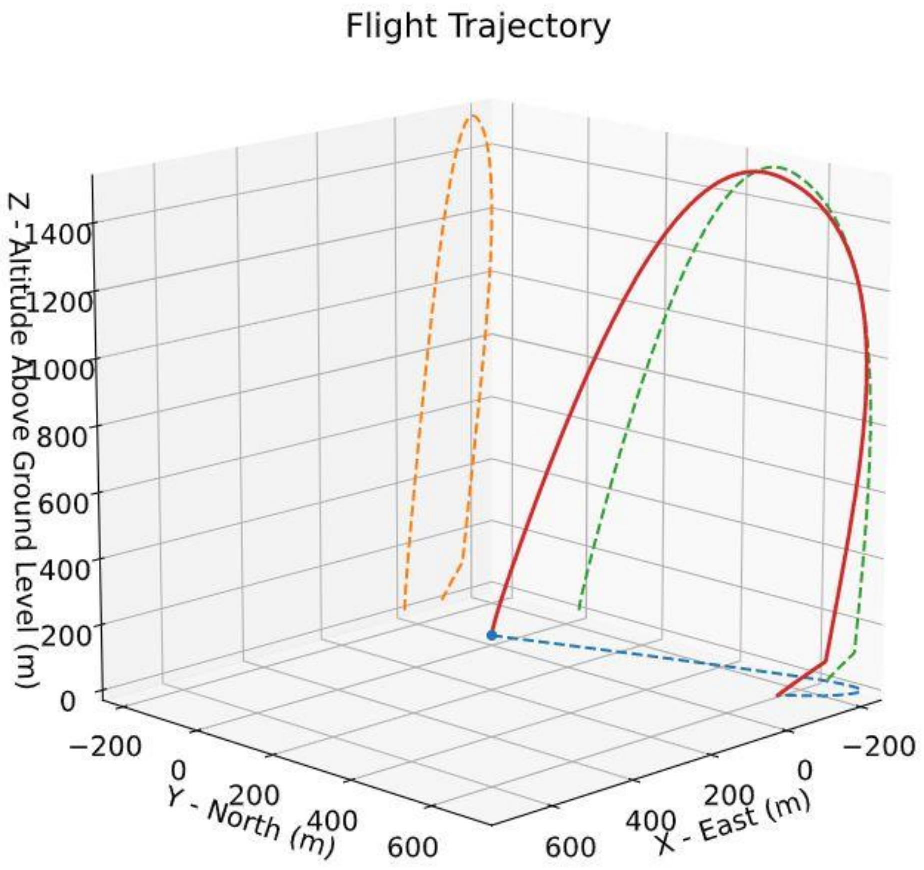


Mass Statement and Margin

Avionics Bay		Drogue Parachute Bay		Payload bay	
Component	**Weight (lb)**	**Component**	**Weight (lb)**	**Component**	**Weight (lb)**
Sled	0.18	Airframe	2.24	Airframe	0.52
Bulkheads	0.8	Drogue Parachute	0.07	Coupler	1.33
Threaded Rods, U-bolts	0.55	Shock Cord	0.45	Payload with Bulkheads	4
Airframe	0.26	Quick Links	0.14	U-Bolt	0.15
Coupler	1.46	Nomex	0.140625	Quick Link	0.07
Total	**3.25**		**3.04**		**6.07**
Nose Cone		**Main Parachute bay**		**Fin Can**	
Component	**Weight (lb)**	**Component**	**Weight (lb)**	**Component**	**Weight (lb)**
Nose Cone	4.6	Airframe	2.64	Airframe	3.3
Coupler	1.2	Main Parachute	1.375	Motor Tube	0.3
Bulkhead	0.34375	Shock Cord	0.45	Fins	0.75
Centering Ring	0.25	Quick Links	0.14	Thrust Plate, Tailcone, and Retainer	0.5
Threaded Rod	0.232	Deployment Bag	0.25	Motor Casing, Propellant	10
Ballast	0.75			Centering Rings	0.625
U Bolt and Quick Links	0.22			Threaded Rods, Misc. Hardware	0.42
Total	**7.60**		**4.86**		**15.90**
Total Vehicle Weight (lb)	**40.71**				

RocketPy

- Open Source Python Library
- Six-degrees of freedom simulation
- Advanced Weather Profiles
- Trajectory Optimization
- Monte Carlo Dispersion Analysis



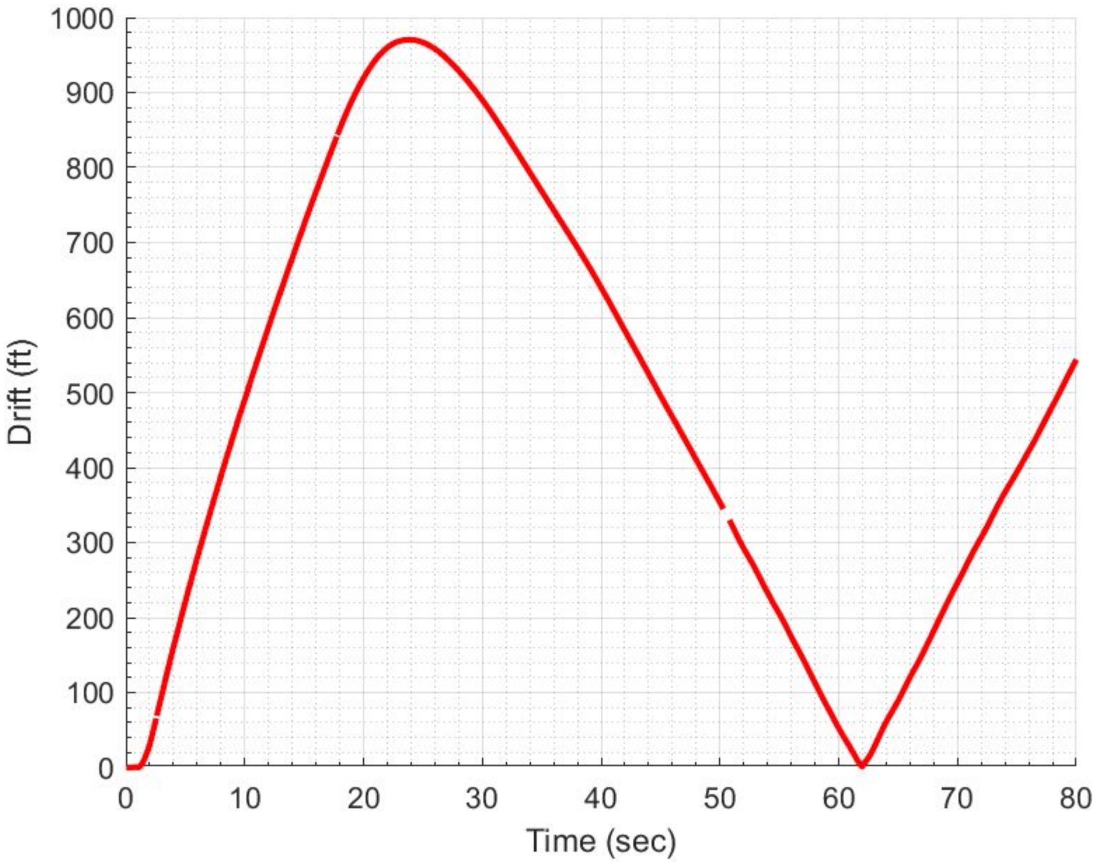
Wind Drift and Descent Time

- Drift distance is total downrange movement based on wind conditions
- Based on descent time of 79.5 seconds
- Maximum drift expected to be 2332 feet
- Apogee is estimated to be directly above launchpad

Wind Velocity	Drift Distance
0 mph	0 feet
5 mph	583 feet
10 mph	1166 feet
15 mph	1749 feet
20 mph	2332 feet

Alternative Wind Drift and Descent Time Calculations

- Using RockSim we can simulate the entire flight path of the vehicle
  - Total descent time is 68.38 seconds
  - Total drift distance is about 530 feet



Kinetic Energy Upon Landing

- Highest impact force felt by fin can section
- Highest force is still below 65 ft-lbf to get bonus points

Section	Mass of Section	Velocity Under Main Parachute	Impact Energy
Nose Cone	.207 slugs	6.11 ft/s	4.247 ft-lbf
Main Parachute Bay And Avionics Bay	.220 slugs	9.16 ft/s	9.230 ft-lbf
Drogue Parachute Bay, Payload Bay, and Fin Can	.6014 slugs	13.61 ft/s	55.69 ft-lbf

Opening Shock

- Kevlar Rated at 6600 lbf
- Max loading: 244.1 lbf
    - Factor of Safety: 27

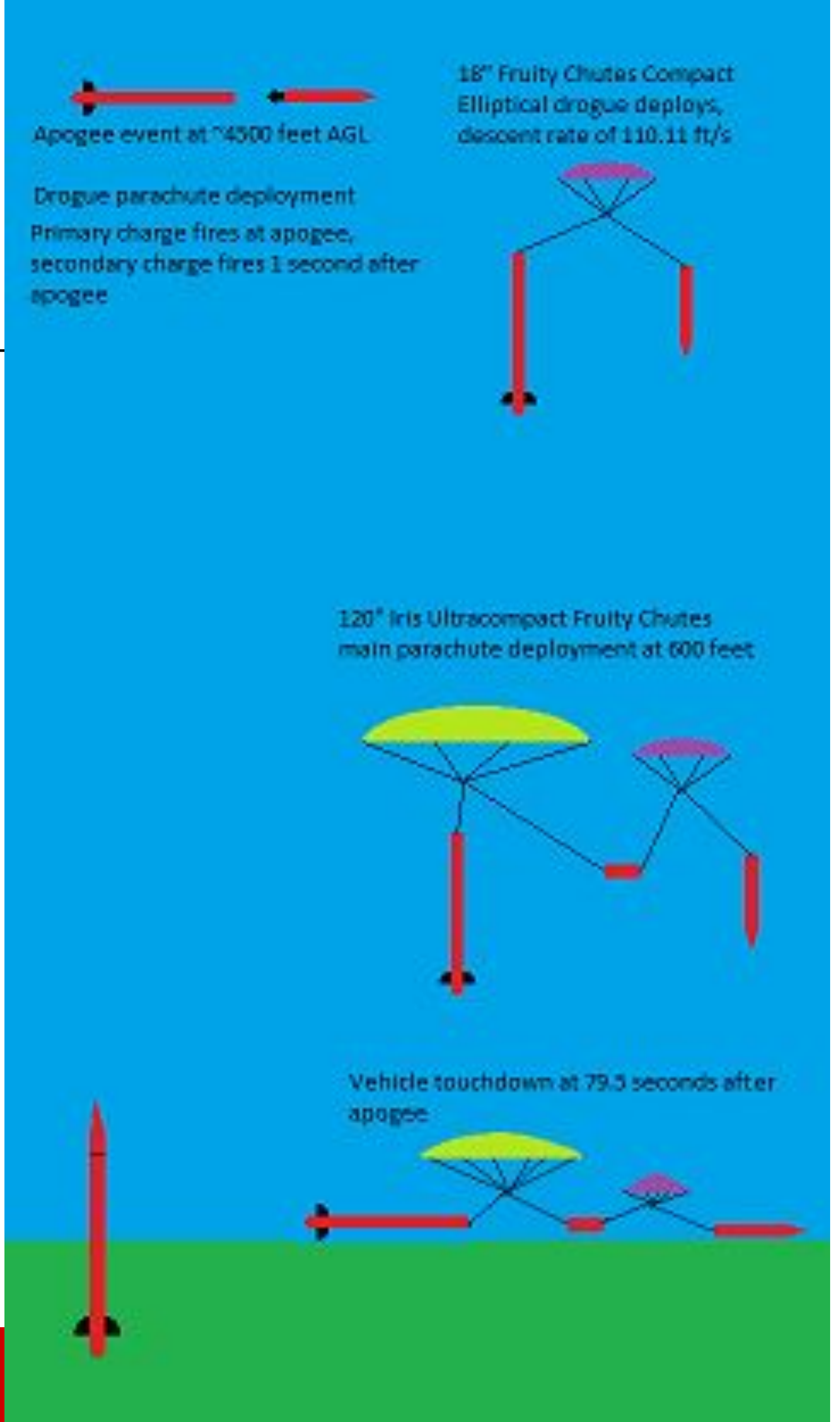
Launch Vehicle Body Section	Body Section Mass	Main Parachute Opening Shock
Full Launch Vehicle	1.255 slugs	370.54 ft-lbs
Nose Cone	.207 slugs	61.117 ft-lbs
Main Parachute Bay and Avionics Vay	.225 slugs	66.431 ft-lbs
Drogue Parachute Bay, Payload Bay and, Fin Can	.602 slugs	177.740 ft-lbs

Recovery System Design

Parachute Size

Recovery Overview

- Recovery components consist of:
  - 2 RRC3 “Sport” altimeters
  - 1 Eggtimer Quasar GPS
  - 1 Eggfinder LCD Display
  - 1 18” Drogue Parachute
  - 1 120” Main Parachute
  - 2 20’ Kevlar shock cords
  - 4 ejection charges of FFF Black Powder.



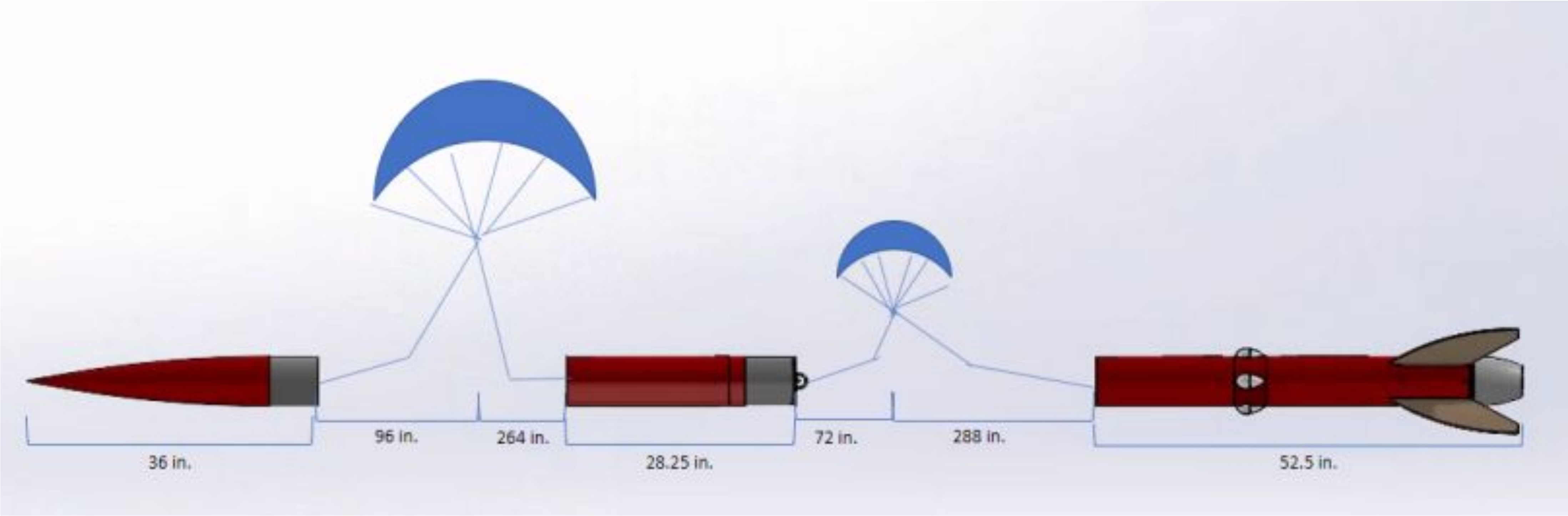
Parachutes

- Drogue Parachute: Fruity Chutes 18” Compact Elliptical
- Main Parachute: Fruity Chutes 120” Iris Ultracompact
- Nomex cloth wrapped for protection against ejection charges

Recovery Harness

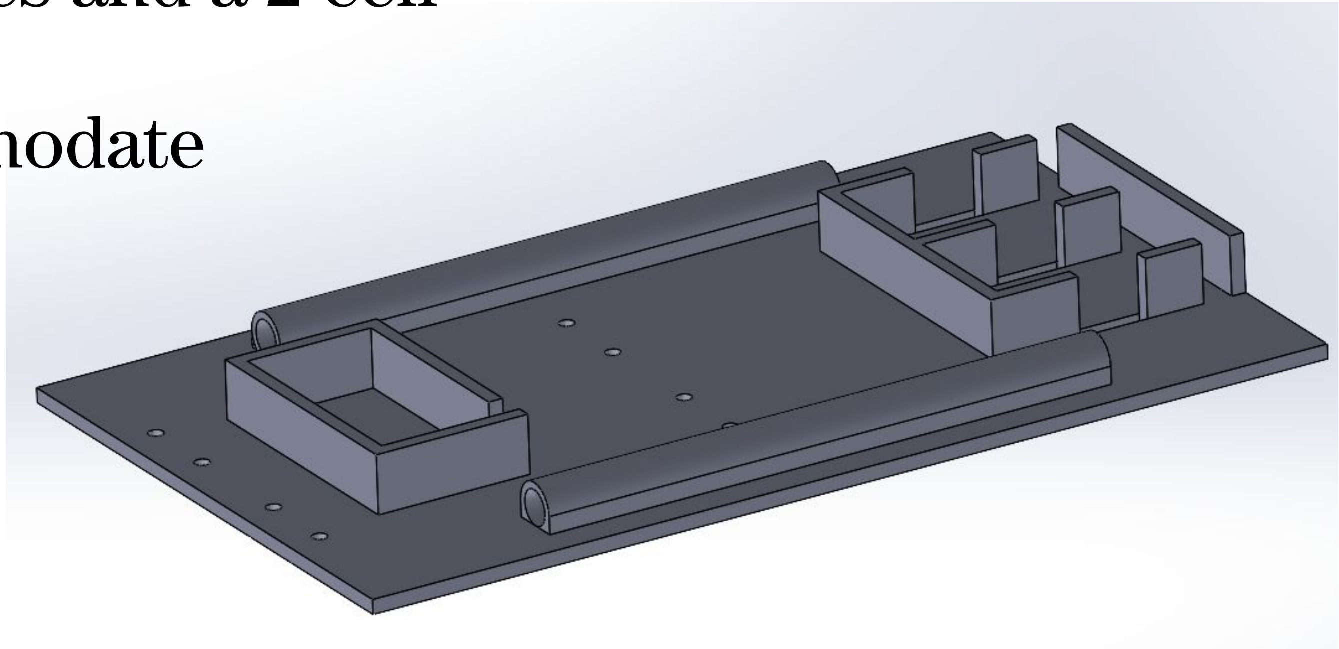
For each parachute there will be a 40 ft long ⅝ inch thick Kevlar shock cord attaching the parachutes to U-bolts on bulkheads connected to the launch vehicle.

Main Recovery Harness Lengths



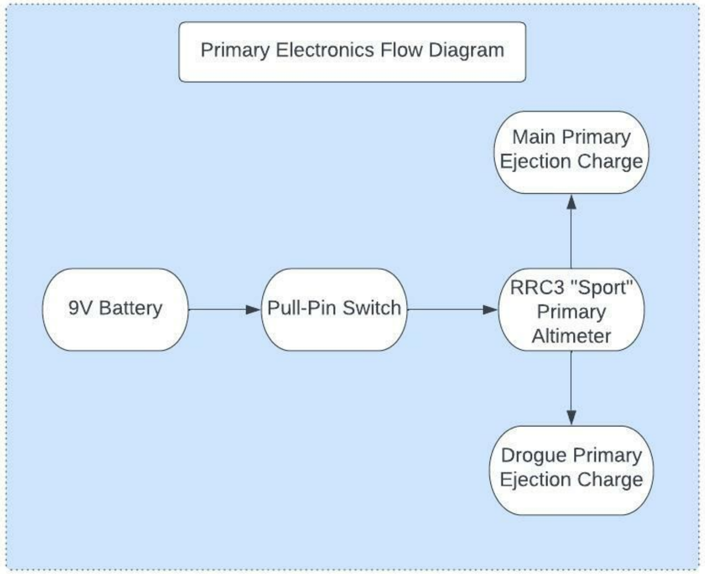
Avionics Sled

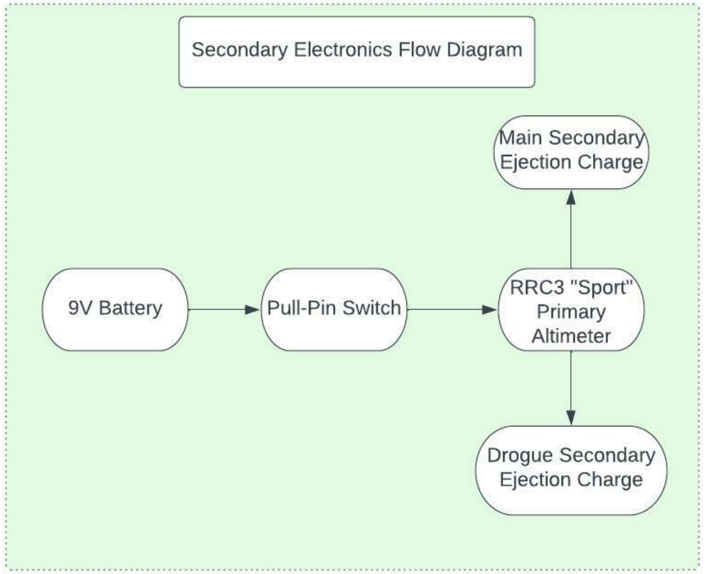
- 3D printed using PETG Plastic
- Separate slots for 2 9V batteries and a 2 cell LiPo battery
- Pre-allocated holes to accommodate altimeters
- Mounting space for GPS
- Mounting space for 2 pull pin switches by Lab Rat Rocketry

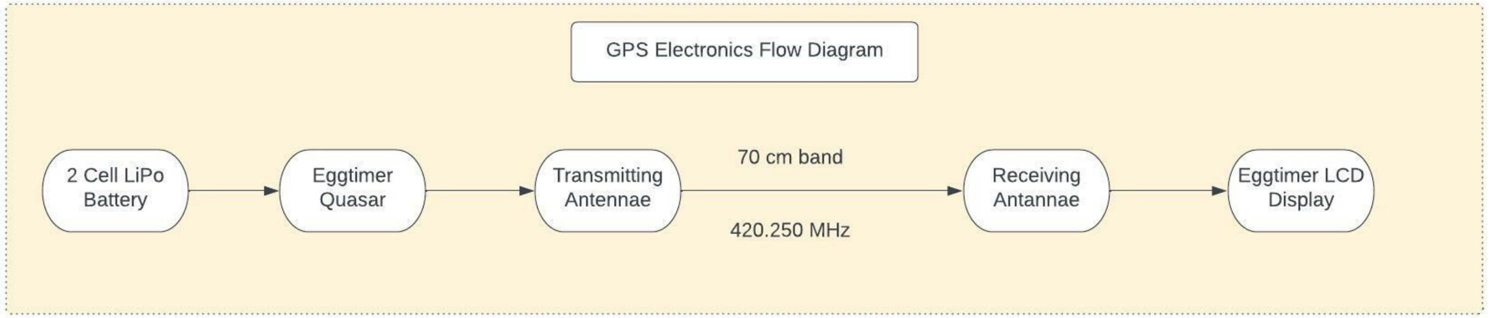


Avionics Sled

Recovery Avionics





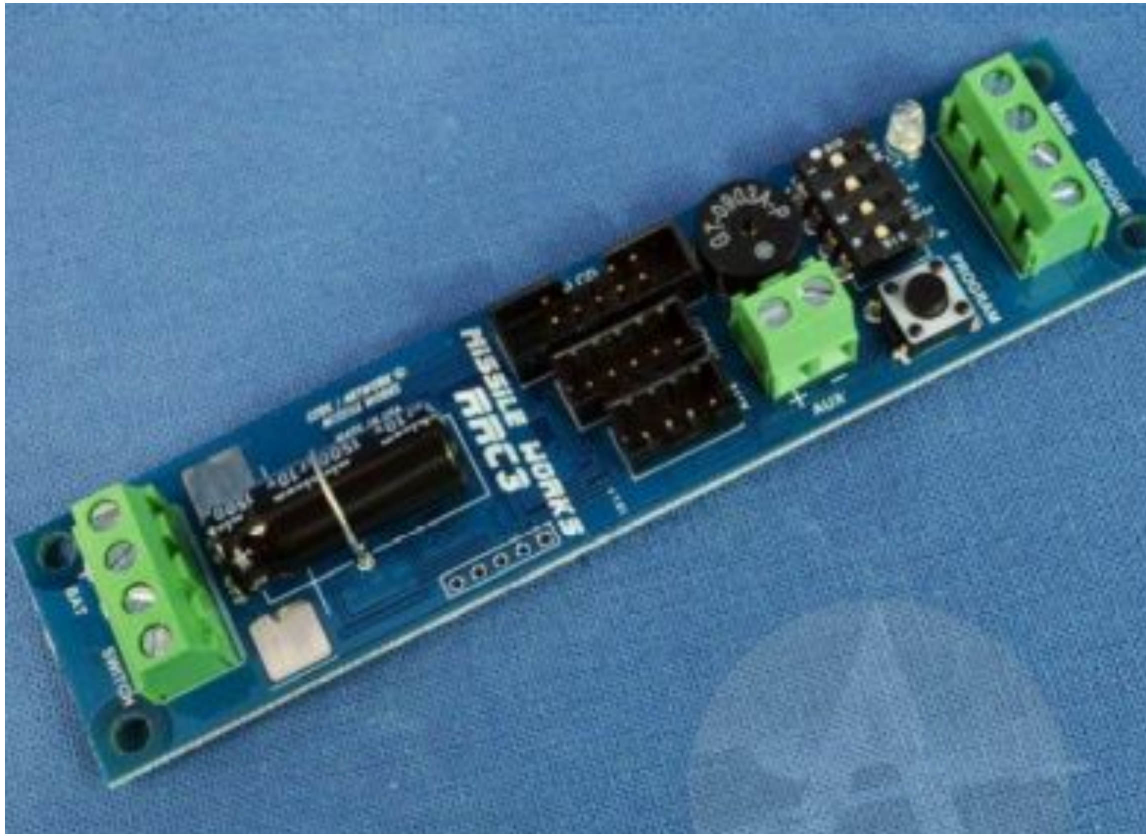


Altimeters

- Selected RRC3 “Sport” Altimeter from MissileWorks

- Primary:
  - Drogue at apogee
  - Main at 600 feet AGL

- Secondary:
  - Drogue at 1 second after apogee
  - Main at 500 feet AGL



Tracker

- Eggtimer Quasar dual altimeter and GPS.
  - 70 cm bandwidth transmission (420.250 MHz)
  - Altimeter functionality will not be utilized
  - It will be paired with the handheld Eggfinder LCD Receiver

Payload

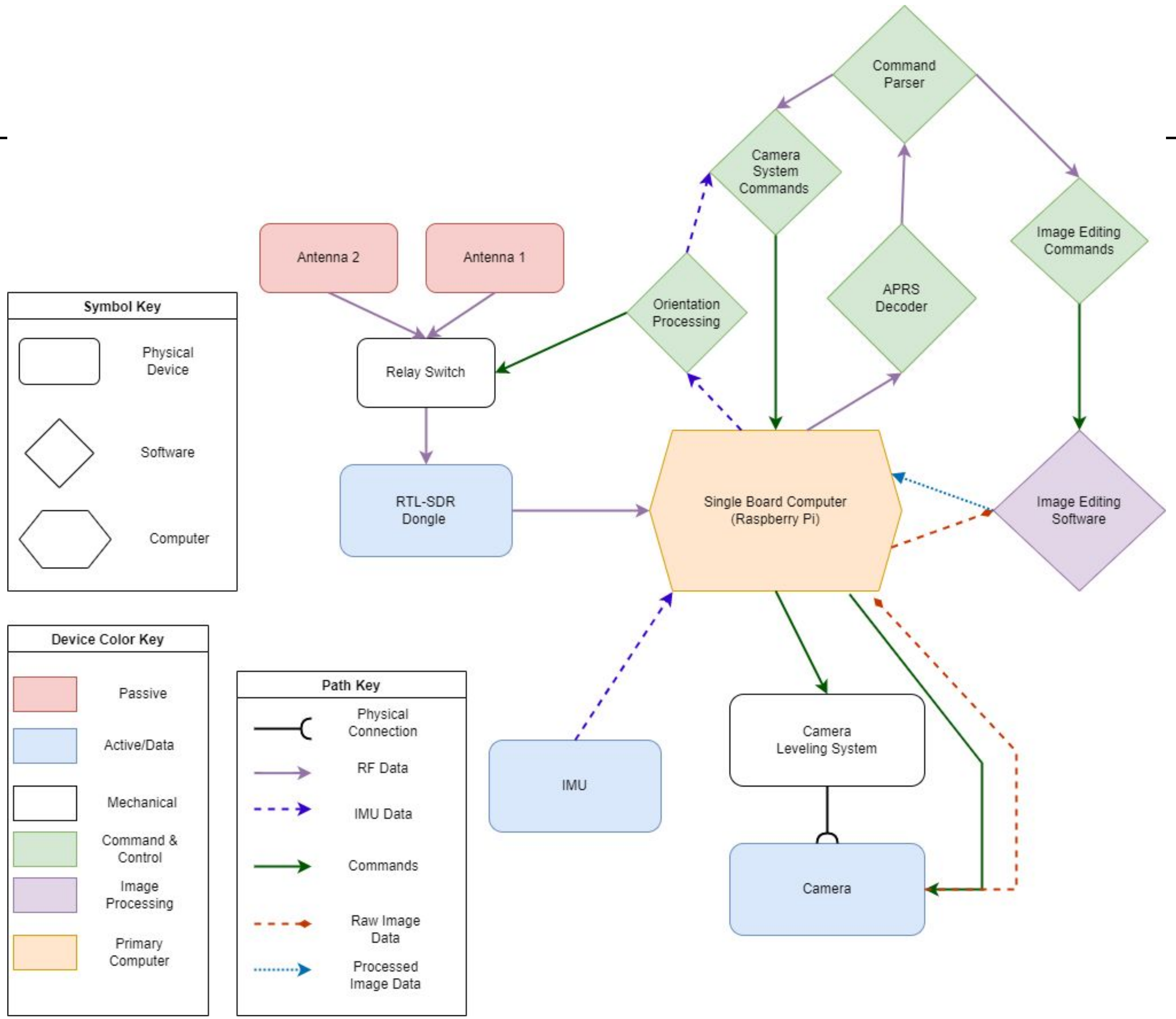
SOCS - Surrounding Optics and Camera System

System Overview

- SOCS consists of two subsystems and a central computer
  - RAFCO subsystem
  - Camera subsystem

  Raspberry Pi single board computer
- SOCS receives APRS commands using the RAFCO subsystem, processes these commands, and then instructs the camera subsystem to fulfill these commands

System Flow Chart

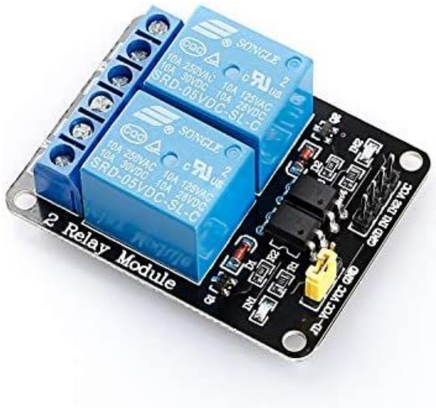


Changes Since PDR

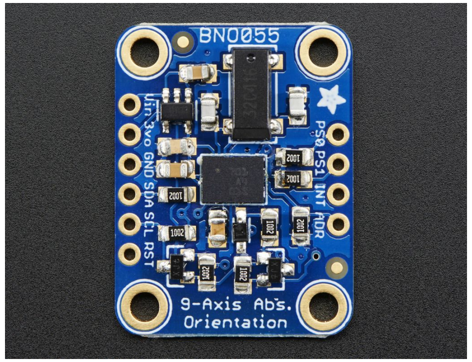
Change	Reason for Change
Addition of a logic-level shifter IC between the Raspberry Pi and the servos	Pi GPIO pins can only output a maximum of 3.3V, while the servos require 5V. This IC shifts the signals from 3.3V to 5V.
Antenna mounting along the launch vehicle no longer has a portion running along the fins	Antenna was ran along the fins in order to ensure that the antenna would fit entirely along the body of the launch vehicle. The aft section of the launch vehicle is long enough to lay the antenna along without bending it, with several inches of margin. Thus, it is not necessary to curve the antenna.
Added bracket for servo mounting to camera mount	Bracket needed to ensure that servo body remains fixed while head rotates
Changed camera from the Arducam IMX219 to the Smraza camera module 5	The Smraza modules offer similar performance at a smaller size, allowing for smaller camera housings. These cameras are also already in club possession.
Added supports to the camera mount for the camera housing	Provides extra rigidity and prevents camera housing deformation

RAFCO Subsystem Selected Components

- Dual two-meter dipole antennas
  - Easy to fabricate and easily integrates into hardware
  - One on each side of the launch vehicle to ensure signal reception
- SainSmart 2-Channel Relay
  - known ability to interface with the Raspberry Pi, well documented, commercially available
- BNO055 IMU
  - Large amount of measurements in a small package, previous club use, owned by club
- Nooelec NESDR Smart RTL-SDR Dongle
  - Compact, rugged, well documented use with Raspberry Pi



SainSmart 2-Channel Relay

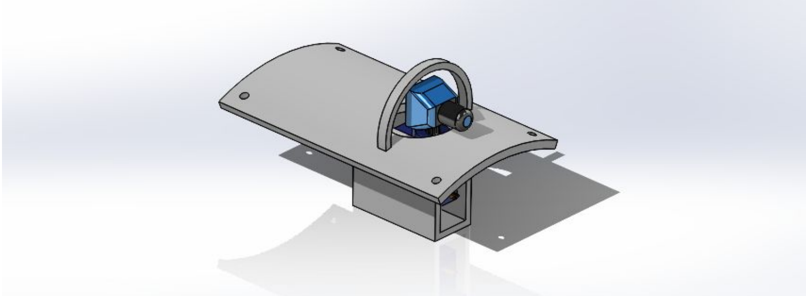


BNO055 IMU

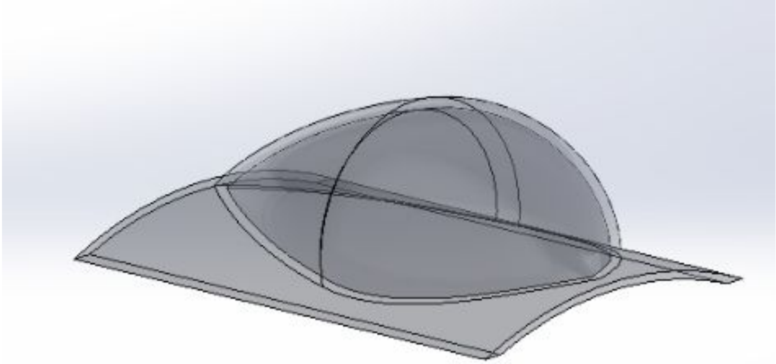
Nooelec NESDR Smart RTL-SDR Dongle

Camera Subsystem Selected Components

- Camera - Smraza Pi Camera Module (1)
    - FOV 160°
    - 25mm x 25mm
- Servo - Feetech FS90R Servo (2)
    - Compatible with 3.3V and 5V inputs
    - Continuous rotation
- Unit Mount - Custom, 3D-Printed (3)
    - PET-G and PLA
- Housing - Custom, Vacuum-Formed (4)
    - PET-G



CAD model of the camera unit mount. (3)



CAD model of the camera housing. (4)

RAFCO Subsystem Operations

- IMU Determines Launch and landing
- After landing, IMU is used to determine orientation
- Orientation is used to select upright antenna through relay
  - This routine runs continuously after landing to account for any changes in orientation
  - If landing is not detected after expected flight time + 5%, routine runs automatically
- Landing detection also activates RAFCO processing
- Analogue data is converted to digital data through the RTL-SDR dongle
- Direwolf acts as a software Terminal Node Controller, and feeds data into a TCP port on the Pi
- Pi then decodes APRS commands using a python script.

Camera Subsystem Operations

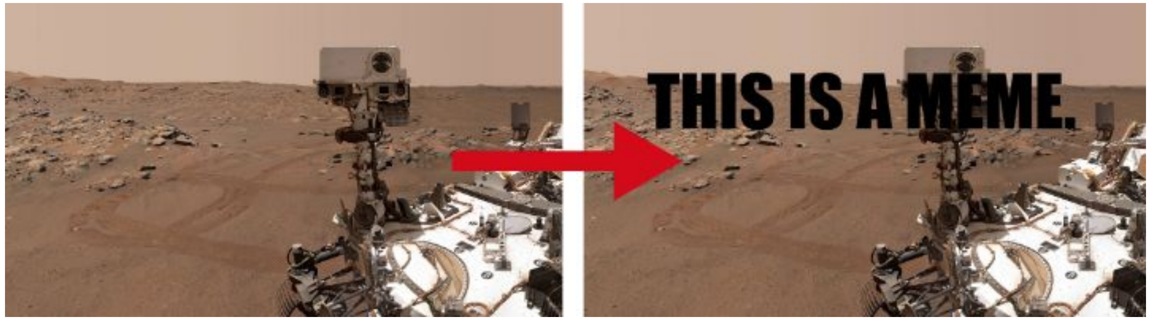
1. Receive and interpret APRS commands
2. Execute while loop
    a. Switch case between commands

        ~~XX4XXX~~ C3 A1 D4 C3 F6 C3 F6 B2 B2 C3

        ↑ loop variable = 13

    b. Close and save each image between successive commands

    c. Upon receipt of F6, randomly choose between image filters



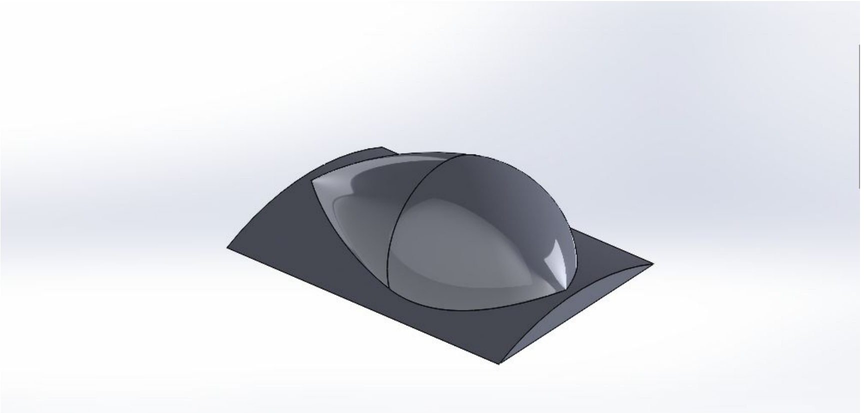
Example transformation using the meme() function for command F6.

Payload Manufacturing

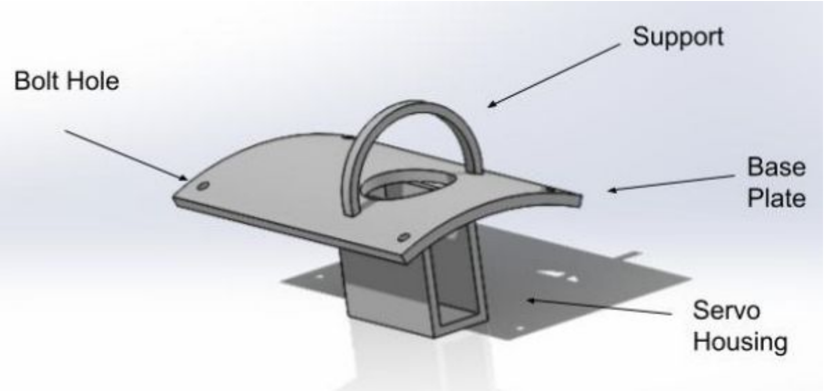
- Terminal blocks removed and replaced with jumper wires
  - JST-SM connectors used as removable connection
- Jumper wires are attached to large header which connects to Pi
- No daughter board exists for the logic-level shifter
  - Depending on component availability, a breakout for the through-hole version is to be made on stripboard, while a commercial breakout board for the SMT version can be purchased
  - Through-hole is preferred due to ease of use and lack of need for special parts

Payload Manufacturing Cont.

- Camera Housings vacuum formed using PETG
  - PETG: Thin, transparent → clear view
  - Formed with positive 3D-printed mold
- Camera unit mount 3D printed using PLA
  - Arch support prevents housing deformation
- The Payload sled 3D printed using PLA
  - Electronics secured with screws, velcro, and glue



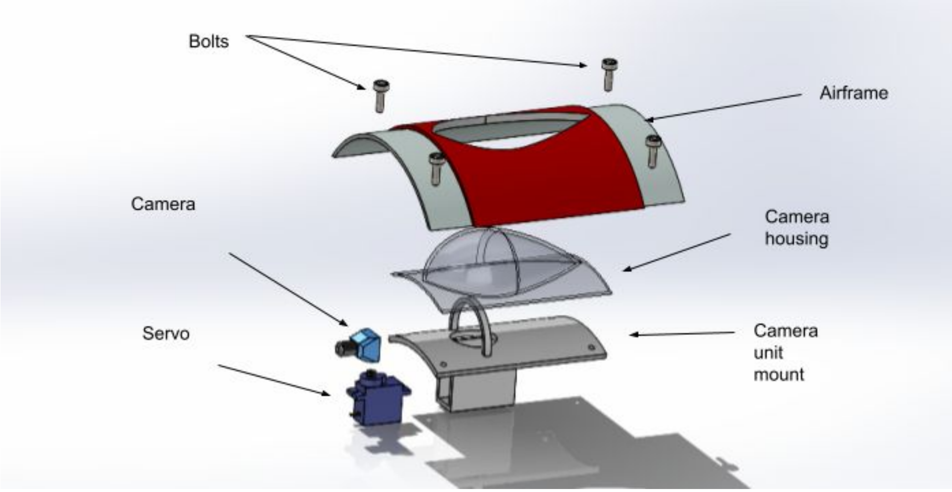
CAD Model of the camera housing mold.



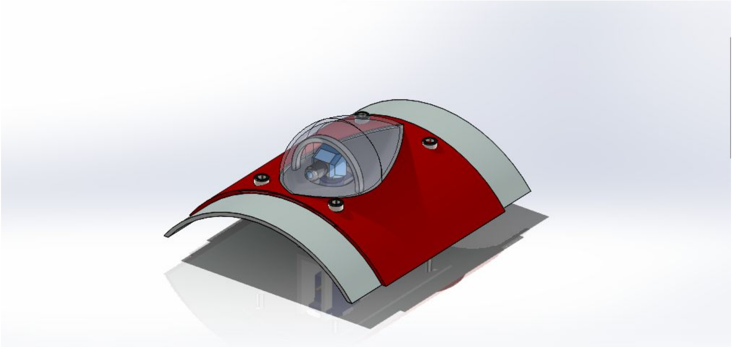
CAD Model of the camera unit mount.

Camera Subsystem Integration

- Order of Assembly
  1. Camera unit mount
  2. Camera housing
  3. Airframe
- Bolted together with 4, 6-32 bolts.
- Servo will be secured inside the camera unit mount
- Camera will see through the camera housing
- The camera itself is attached to the rotating part of the servo.



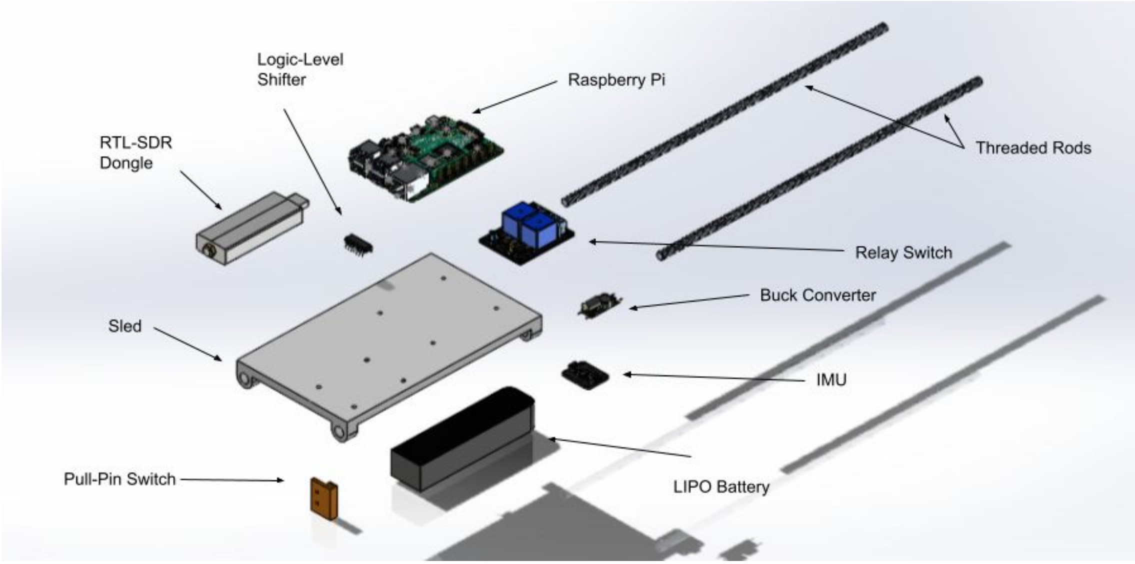
Exploded view of the payload assembly.



Assembled view of the payload.

Payload Retention

- The payload sled is held in place by 2, ¼-20 in threaded rods which run the length of the payload.
- 2 bulkheads at the end, the forward one will have a U-bolt attached to it, and the aft will have 2 holes so that the antenna can be connected to the electronics inside the bay.
- The antenna will be secured flat along the outside of the launch vehicle using non-conductive electrical tape.



Exploded view of the payload sled

Subscale Launch Results

Launch Day Conditions

- High of 58° F
- 2-4 MPH Winds
- Mostly clear skies
  - Very clear at launch

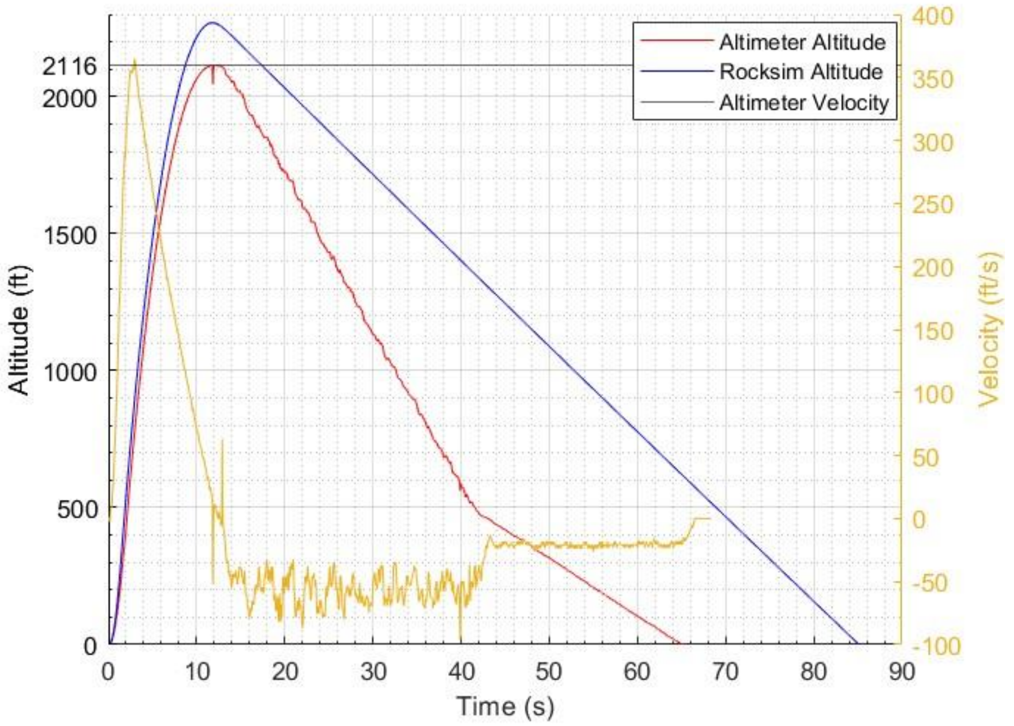
Final Measurements

- Final weight was a bit less than predicted weight.
- Actual stability margin was also decreased because of aft CG shift
  - Mass decrease in payload significantly
  - Antenna system weight

	Weight	Stabilit y	CG
Predict ed	14.2	2.15	40.4
Actual	10.25	1.92	41.3

Altitude Results

- Predicted: 2269ft
- Actual: 2116ft
  - 153 ft difference



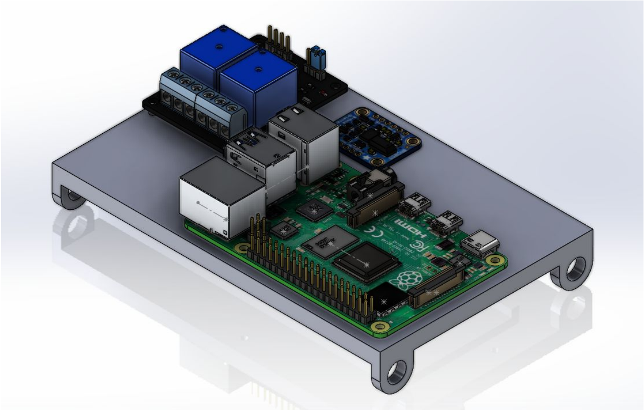
Subscale Altitude Graph

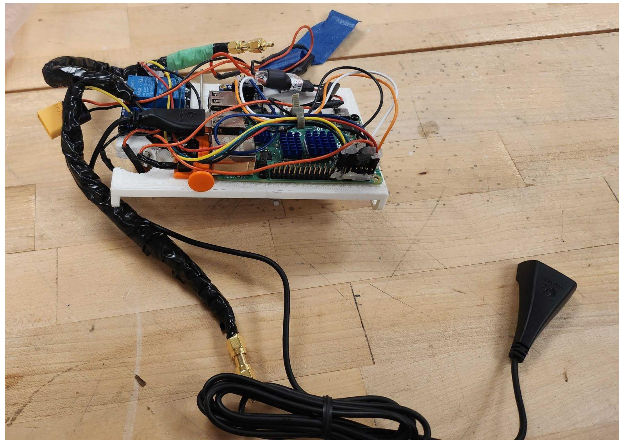
Subscale Payload Structure

- Four 3D Printed PLA Camera Housings were used
- Used Epoxy to create fillets for the housings
- Camera housings were ⅔ the size of full scale

Subscale Payload Sled

- RAFCO System Component Testing
- IMU for orientation
- 70 CM antennas for testing
- Antennas operational prior to launch





Subscale Payload Sled

Subscale Payload Results

- During the flight, terminal blocks sheared electrical connections to the antennas off
- Unknown if data was received at all due to payload shutdown before log file could be saved
- Highlighted need for system stability
  - Terminal blocks replaced with soldered connections
  - Data saving tests to be performed on competition payload

Requirements Verification

Verification Status

Testing Plan

Status of Requirements Verification

- All requirements verified by analysis have been verified
  - Stability margin, kinetic energy at rail exit, rail exit velocity, wind drift etc.
- Verification plans for demonstration, inspection, and testing requirements are detailed in CDR
  - Varies for each requirement, requires launch vehicle or payload to be constructed
- See testing plan in section 6 for testing requirements verification

Verification Plan Example

- Specifics of verification are detailed for each requirement in the format displayed below

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The aerodynamics lead designs the launch vehicle such that it has a minimum static stability margin of 2.0 at the point of rail exit.	Analysis	Aerodynamics	Verified	See section 3.7.4 regarding the projected static stability margin at rail exit.

Testing Plan

- Testing plans are included to validate components
- Section 6.1 in the CDR has success criteria and dates for all tests
- Examples:
    - Composite Fin Structural Test
    - Nose Cone Bulkhead Tensile Test
    - Rivet Shear Loading Test
    - Camera System Integration Test
    - APRS Reception and Decoding Test
    - 2-Meter Dipole SWR Test

Subsystem Test Suites

	Launch Vehicle Tests	Payload Tests
Tests	6.1.1.1 – 6.1.1.11	6.1.2.1 – 6.1.2.10
Completed Tests	N/A	N/A
Requirements Verified	NASA 2.18, NASA 2.18.1, NASA 2.19.1, NASA 2.23.8, NASA 2.23.9, NASA 3.2, NASA 3.4, NASA 3.5, NASA 3.6, LVD 1	NASA 2.18, PF 1, PF 3, PF 4, PD 3, PD 4
Start Date	1/20/23	1/14/23
Completion Date	2/28/23	3/10/23

Questions?