Critical Design Review

January 21, 2022

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Removal of Lander

- The lander solution (BS2) has been eliminated from the design
- The lander was always a backup idea, and after the subscale's success in getting images for APPA (BS1), it was decided it would be best to remove the lander from the design plans
- No lander allows for time and money to spent on APPA to help ensure that it will work
- Also, without a lander the main parachute can be deployed higher which helps get better images sooner in the descent

Launch Vehicle Design

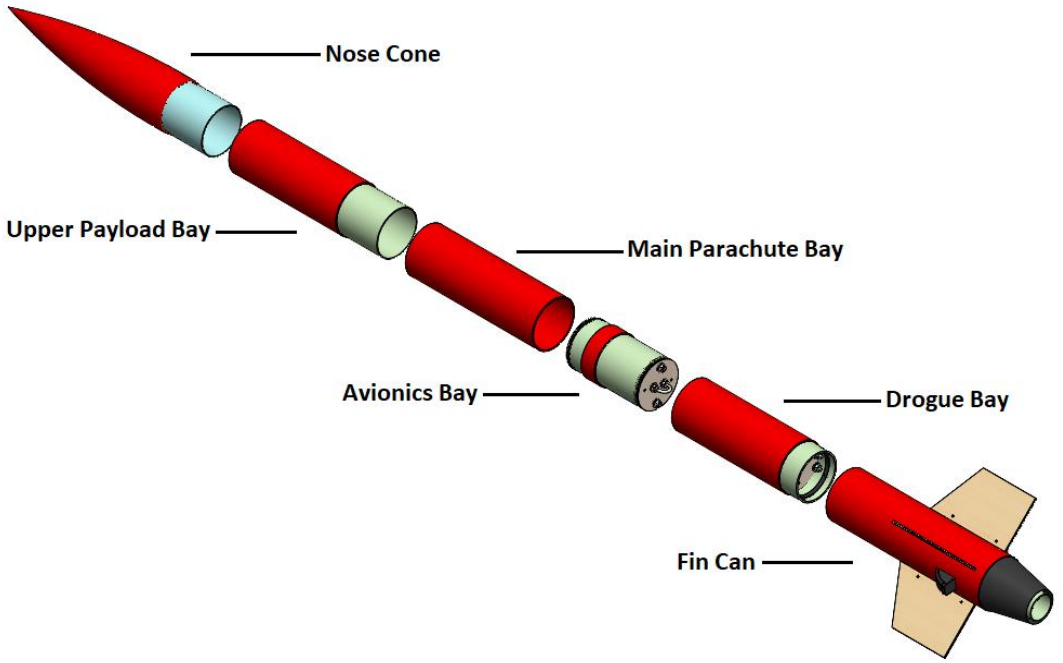
Material Selection

Airframe Sections

Fin Configuration

Launch Vehicle Dimensions

- Length: 109"
- Diameter: 6"
- Launch Weight: 37.41 lb
- Burnout Weight: 32.8 lb



Launch Vehicle Dimensions

Material Selection

G12 Fiberglass

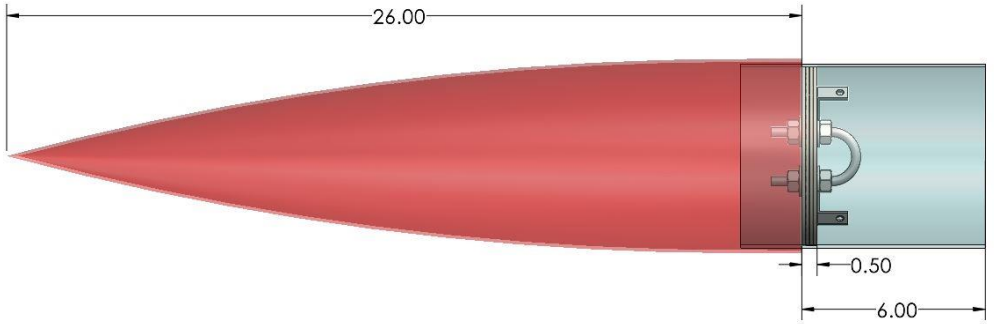
- Fiber-reinforced plastic composite
- Highly durable and damage resistant
- Easily resists compressive loading and impact forces
- Water resistant

Aircraft Grade Birch Plywood

- Lightweight and sturdy material
- 1/8" layer thickness
- 2 layers will be used to create ¼" thick fins
- Bulkhead thickness will vary from ½" to ¾" thickness depending on expected loading

Nose Cone: 4:1 Ogive

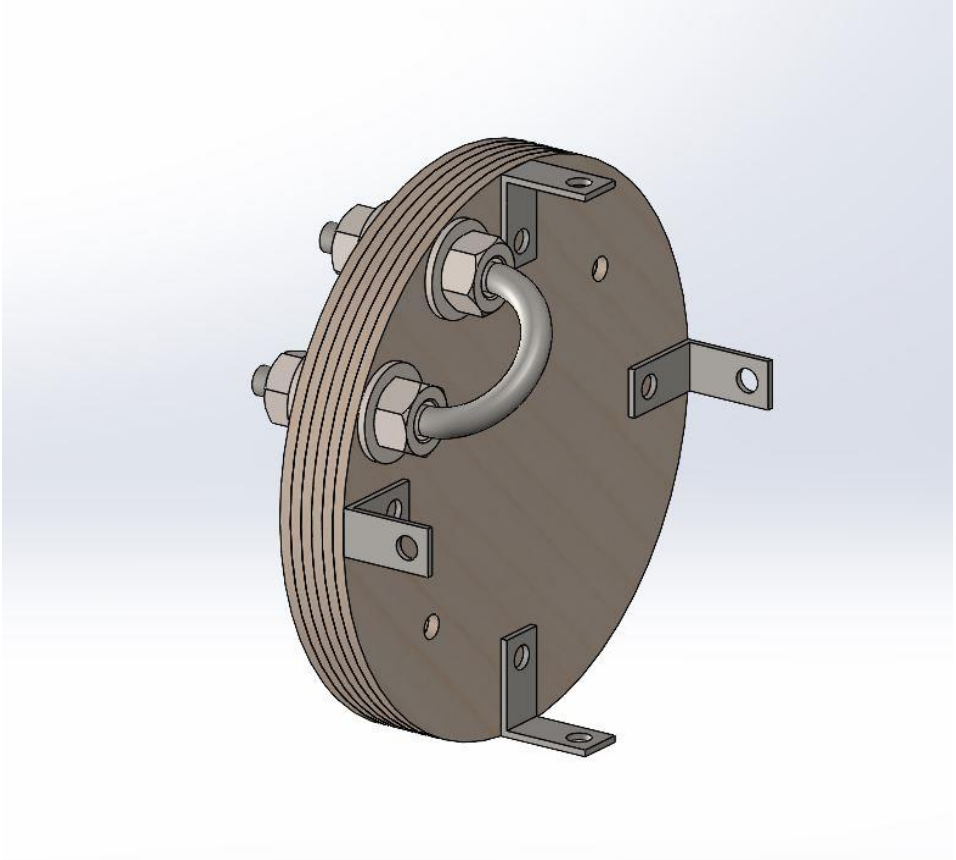
- Ogive
  - Commercially available in size for both subscale and full scale
  - 4:1 Ogive gives a desirable stability margin of 2.2 in RockSim simulations



Nose Cone Dimensions

Removable Nosecone Bulkhead

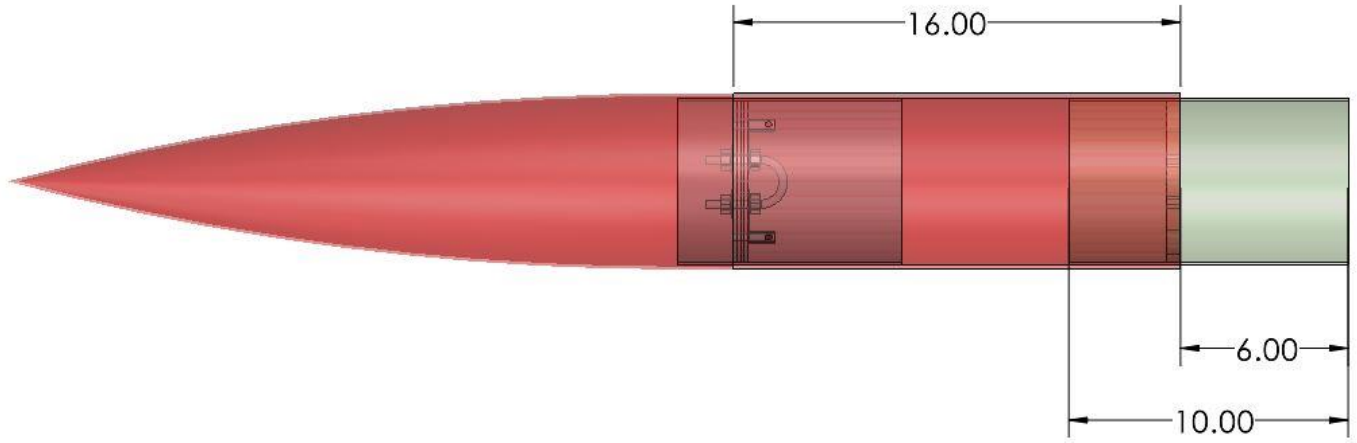
- Stress concentration at the bolted connections
- Allows for accessibility to adjust ballast on the forward side



Removable Bulkhead

Upper Payload Bay

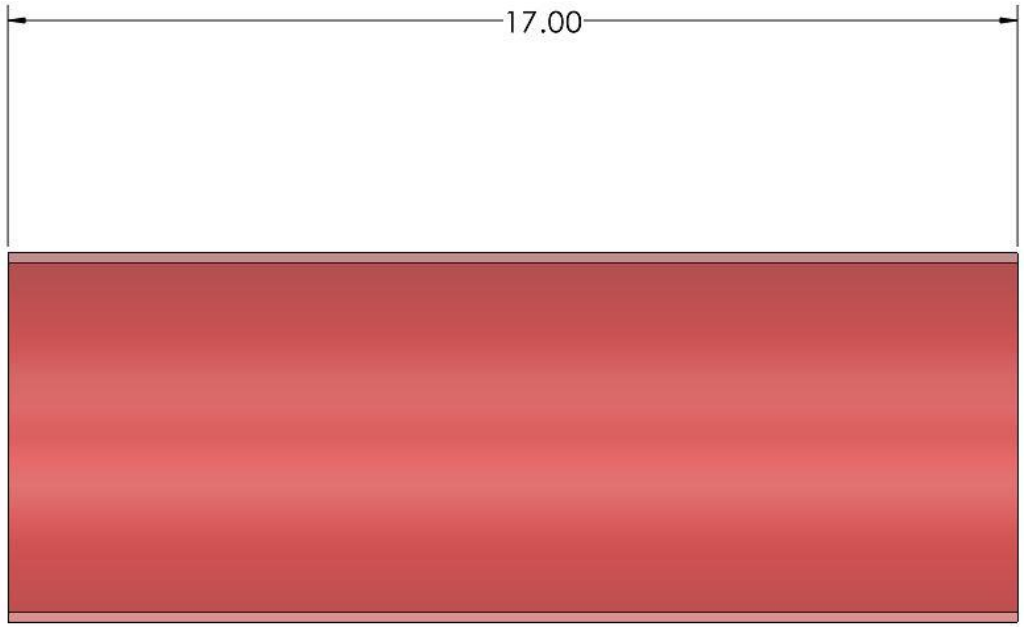
- Located between the nose cone and main parachute bay
- Forward location shifts the CG forward, improving the stability



Upper Payload Bay Dimensions

Main Parachute Bay

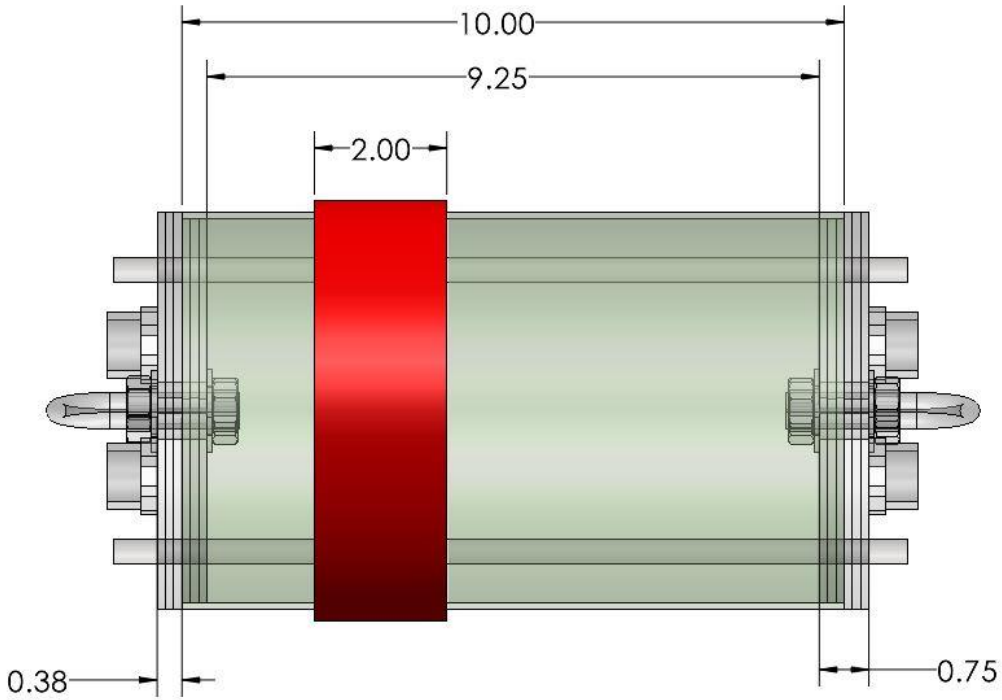
- Located between the upper payload bay and avionics bay
  - Shear pin connection to upper payload bay
  - Bolted connection to avionics bay
- Drogue and Main parachute packing volume: 47.87 in^3
- Recovery harness takes up 37.5 in^3 of main parachute bay



Main Parachute Bay Dimensions

Avionics Bay

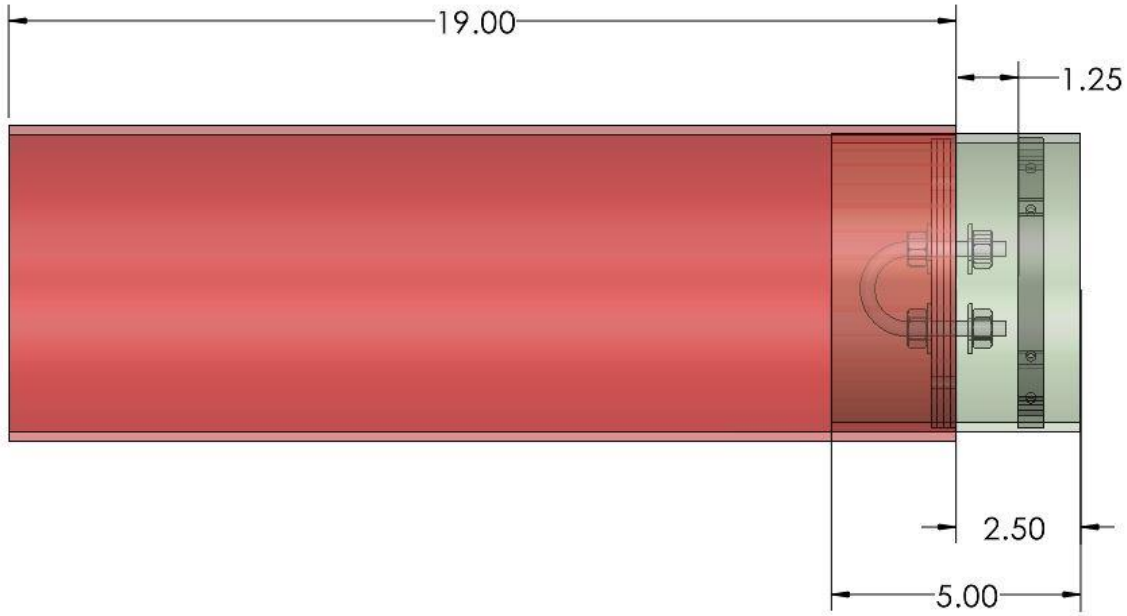
- Between the main parachute bay and drogue parachute bay
- Modular, 2 bulkhead design allows for accessibility to the avionics sled
- Allows for simultaneous assembly alongside launch vehicle
- Easily accessible blast caps and U-bolts



Avionics Bay Dimensions

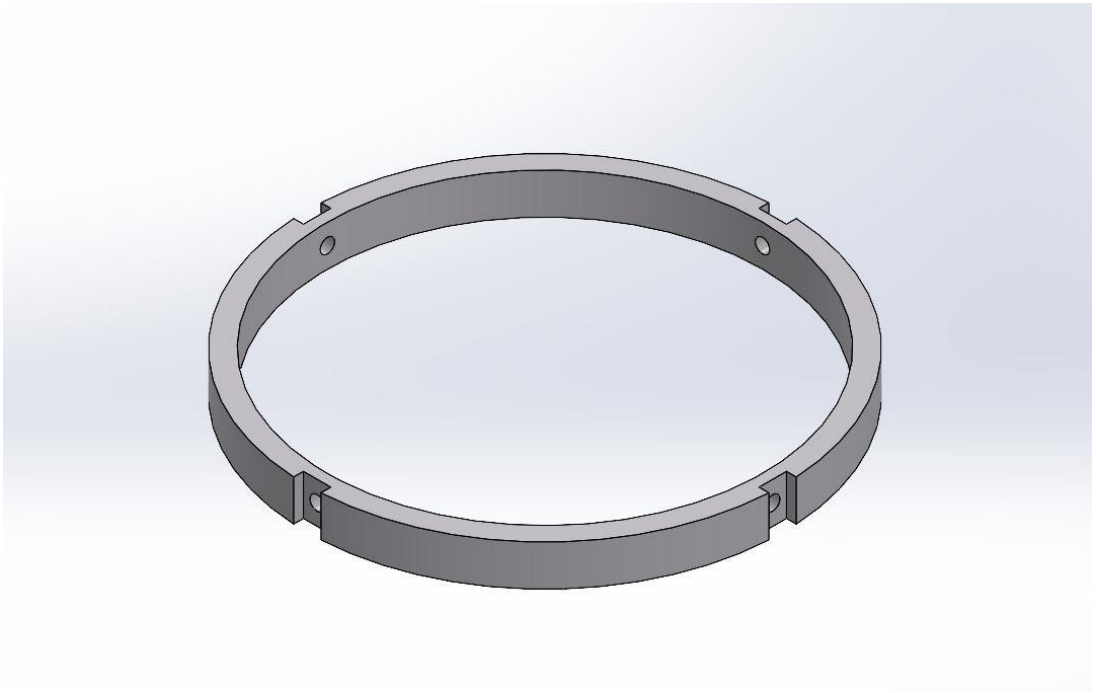
Drogue Parachute Bay

- Between the avionics bay and the fin can
  - Shear pin connection to avionics bay
  - Bolted connection to the fin can using a 3D printed centering ring
- Forward compartment used to store fin cans recovery harness
- The main and drogue parachutes take up 46.2 in^3
- The shock cord will take up 9.375 in^3

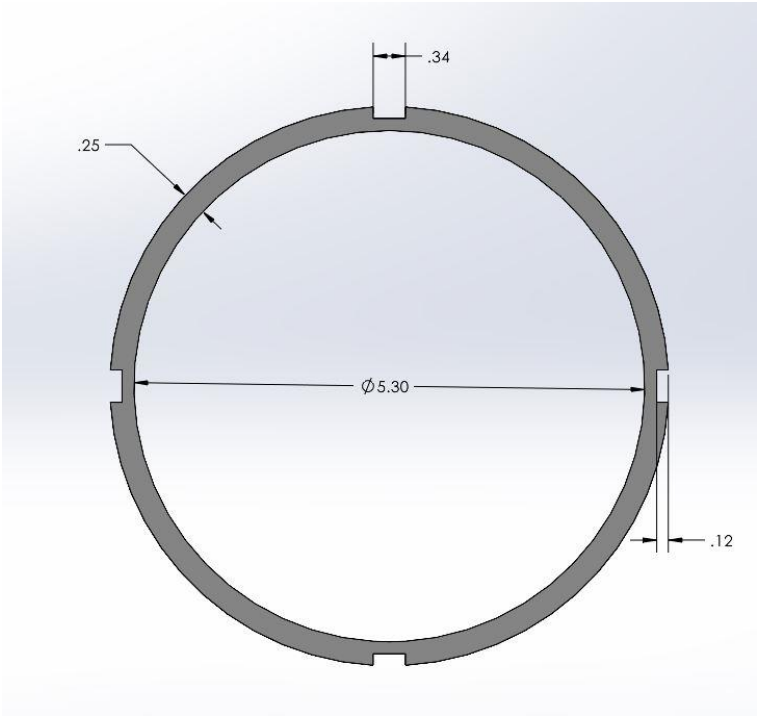


Drogue Parachute Bay Dimensions

Nut Centering Ring



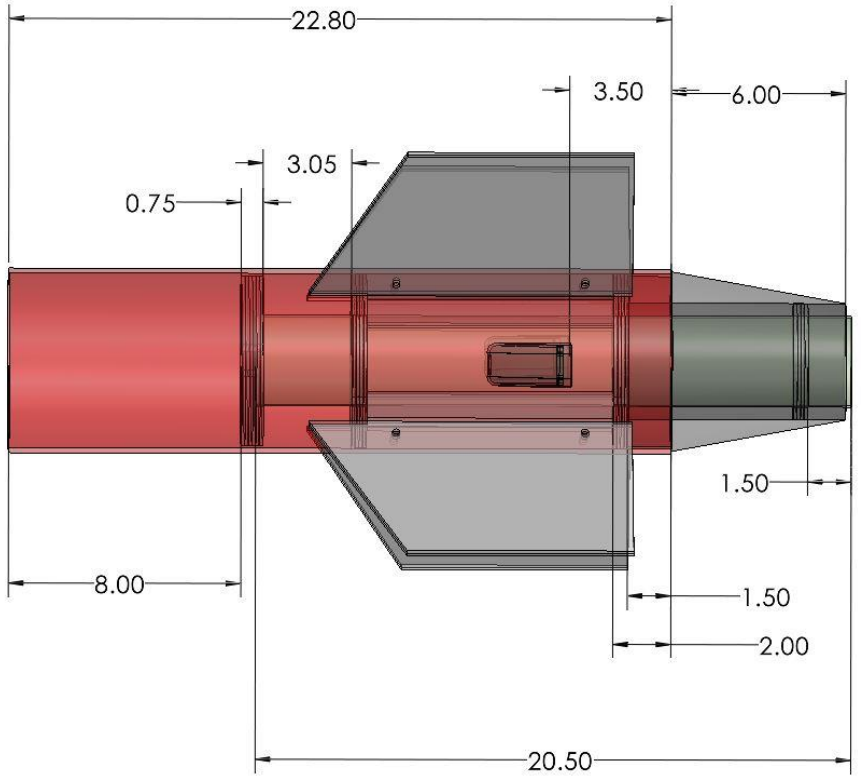
Nut Centering Ring Orthogonal View



Nut Centering Ring Dimensions

Fin Can

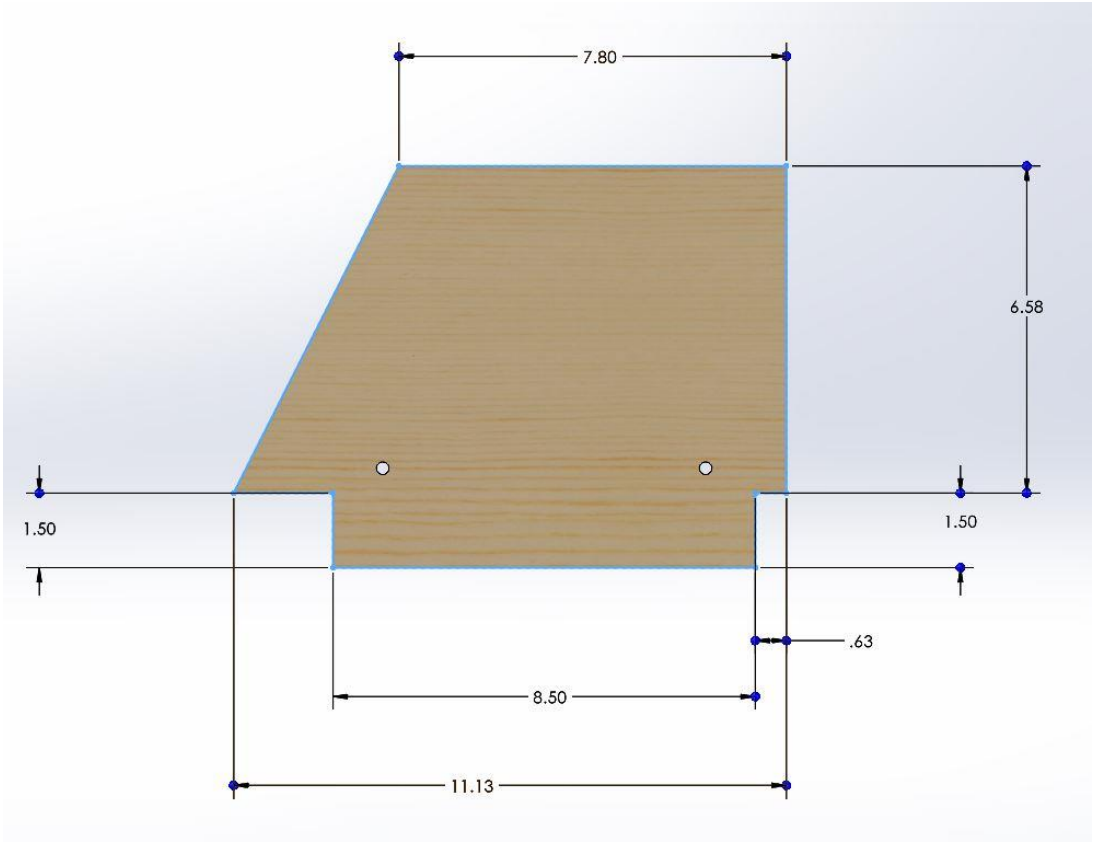
- Engine block and three centering rings are used to align and secure the motor tube
- 6" conical tail cone used to reduce turbulent airflow
- Symmetrical camera housings located between fins
- Forward compartment used to house the lower payload sled



Fin Can Dimensions

Four Fin Configuration

- Four fin configuration primarily chosen for camera housing symmetry to balance aerodynamic forces
- Leading-edge sweep reduces drag, pushes CP aftwards, and increases stability



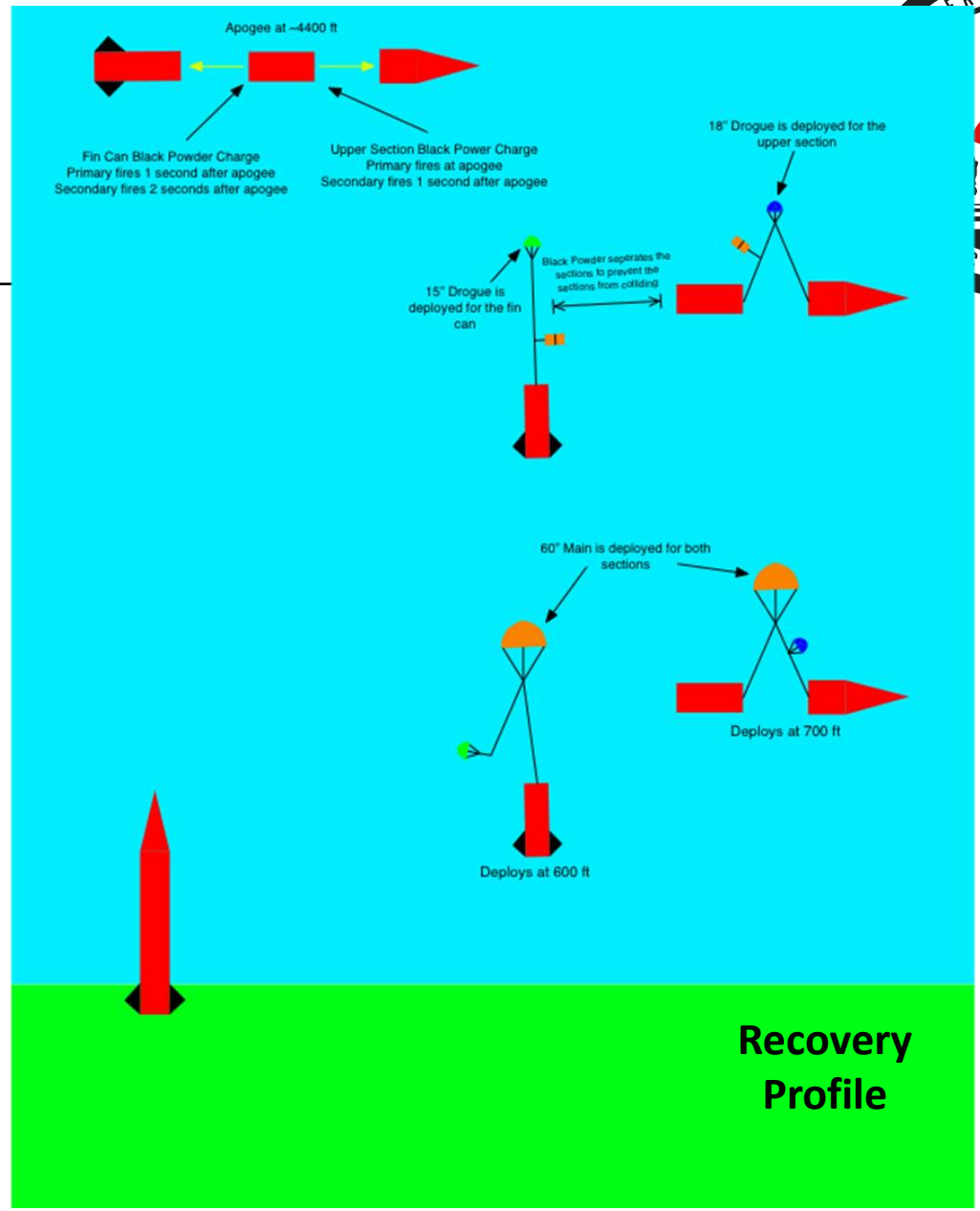
Fin Dimensions

Recovery System Design

Parachute Size

Recovery Overview

- Drogue for upper section deploys at Apogee
  - Secondary is approximately 1 sec after apogee
- Drogue for Fin Can deploys 1 second after apogee
  - Secondary is approximately 2 seconds after apogee
- Main deploys for fin can 600 feet
- Main for upper section is 700 feet
  - Both mains are deployed using Jolly Logic Parachute releases
- Objective is the safe recovery of all parts of the launch vehicle and payload



Parachutes

Upper Section

- Main Parachute: Fruity Chutes 60” Iris UltraCompact
- Drogue Parachute: Fruity Chutes 18” Classical Elliptical

Fin Can

- Main Parachute: Fruity Chutes 60” Iris UltraCompact
- Drogue Parachute: Fruity Chutes 15” Classical Elliptical

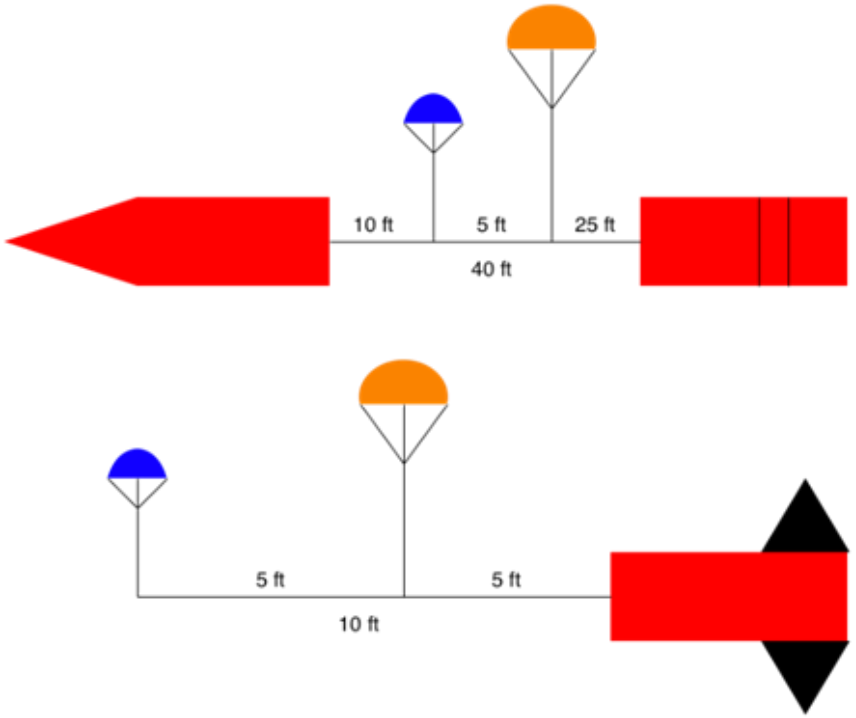
Compact Elliptical Parachute

Recovery Harness

- Main: 5/8 in x 40 ft tubular Kevlar
- Drogue: 5/8 x 10 ft tubular Kevlar
- Rated for 6600 lbf

5/8 in tubular Kevlar

Main Recovery Harness Lengths

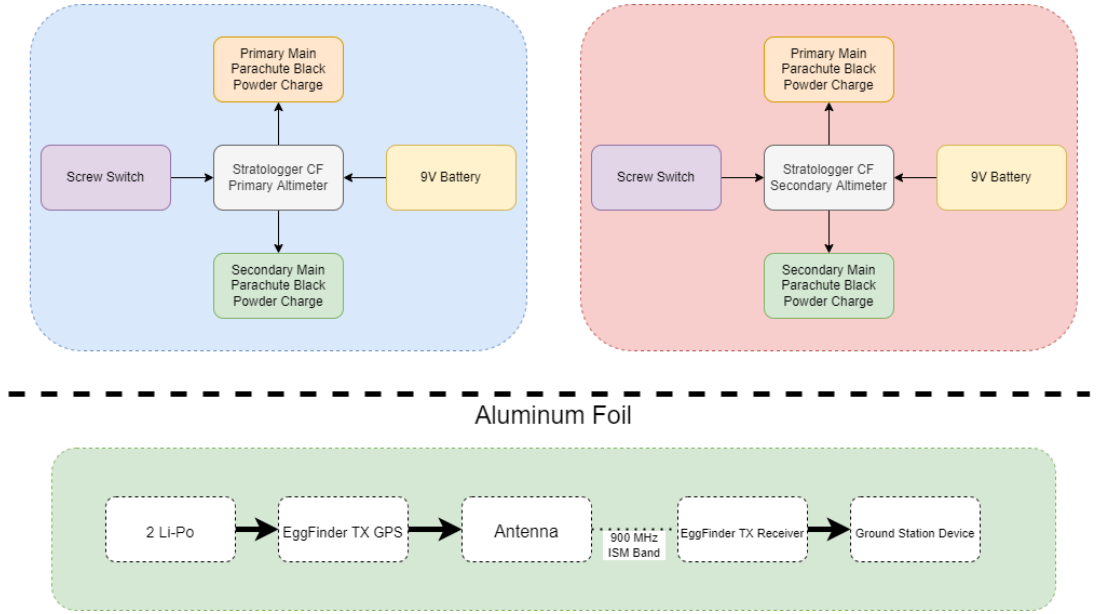


Loop placements on the recovery Harness

- The upper section uses a 40 foot length with loops 10 feet and 15 feet from the nose cone bulkhead
- Fin Can will have a 10 ft shock cord with the drogue connected at the end and the main connected 5 feet from the fin can bulkhead

Recovery Avionics

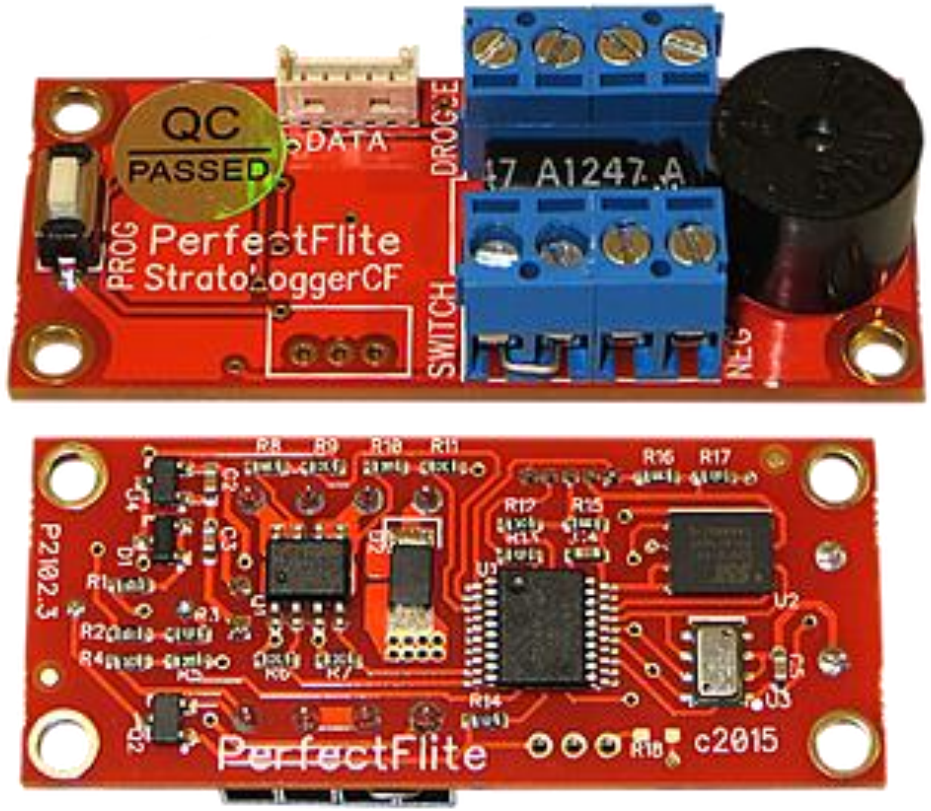
- Fully Independent Sections that will deploy the recovery system
- Upper Section and Fin Can will be tracked via Eggfinder TX/RX GPS Locator systems
  - Frequency 921 MHZ, ID #8 and #9
- Main parachute for both sections will deploy via Jolly Logic Parachute releases



Avionics Schematic

Altimeters

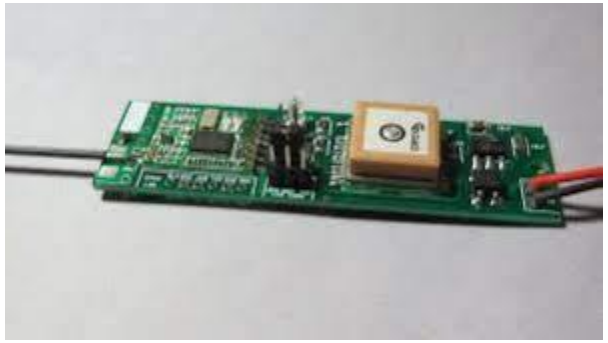
- The three altimeters will be StratoLogger CF altimeters
- The launch vehicle recovery system will be fully redundant
- Primary Altimeter
  - Drogue: Apogee + 1 , 4.6 g charge
  - Main: Apogee, 5.5 g charge
- Secondary Altimeter
  - Drogue: Apogee + 2 sec, 5.1 g charge
  - Main: Apogee + 1, 6.0 g charge



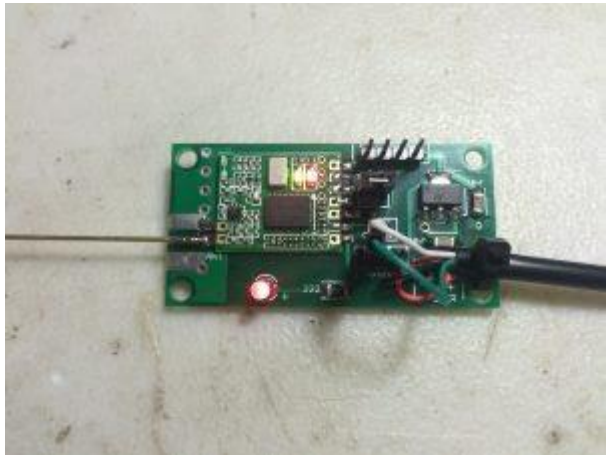
StratoLoger CF Altimeters

Trackers

- Transmitter Operating Frequency: 921 MHz, device ID #8 and #9
- Transmitter Operating Power: 100 mW
- Bluetooth link between receiver and Android phone
- Rocket Locater App used to plot location information



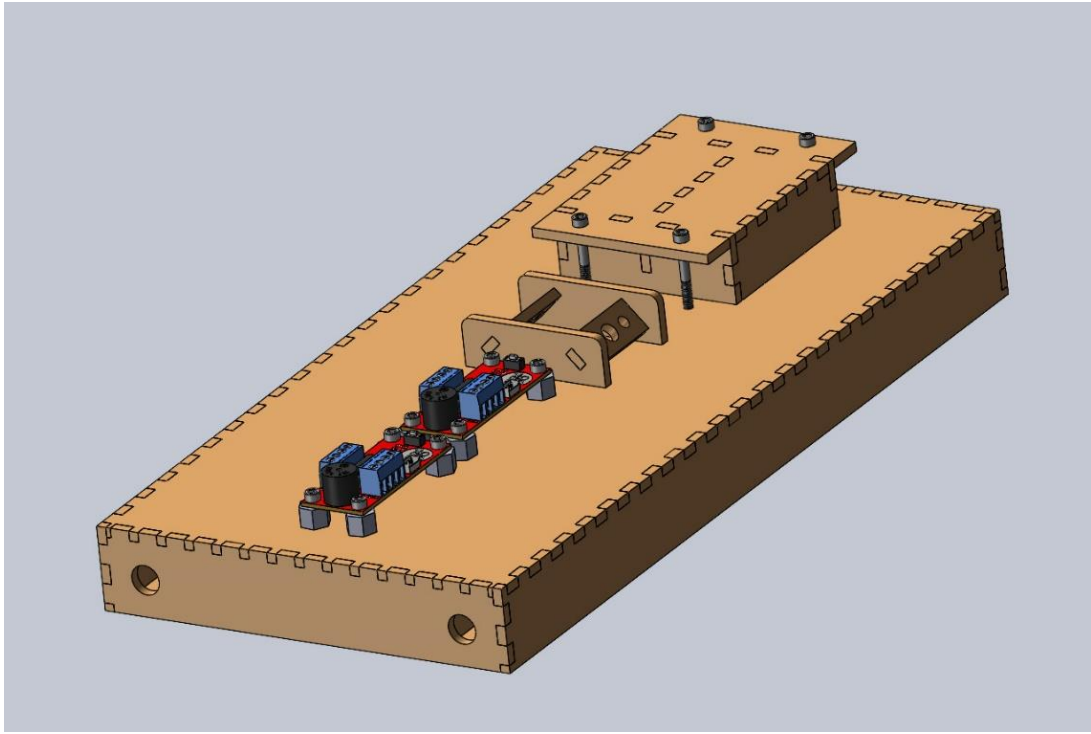
Eggfinder Transmitter



Eggfinder Receiver

Avionics Sled

- Material selection: Aircraft grade plywood
- Will be laser cut with a jigsaw pattern
- Top side: the altimeters and screw switches
- Bottom side: Eggfinder Tracker
- The wires will be held inside the sled and there will be a layer of aluminum foil to prevent interference between the layers



Avionics Sled

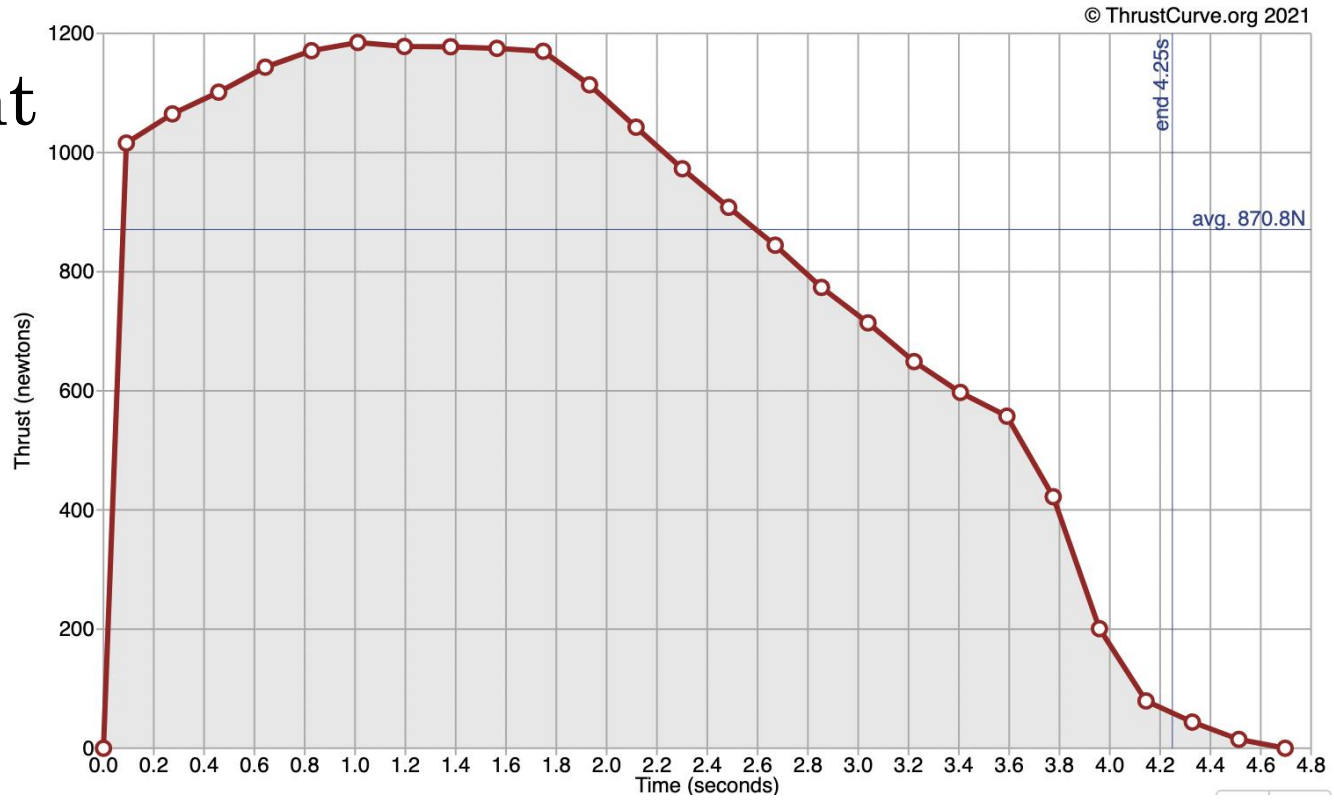
Mission Performance Predictions

Predicted Launch Values

- Static Stability Margin: 2.2 calibers
- Thrust to Weight ratio: 6
- Rail Exit Velocity: 64.77 fps
- Max Velocity: 572 fps
- Max Acceleration: 201 ft/s^2

Motor Selection

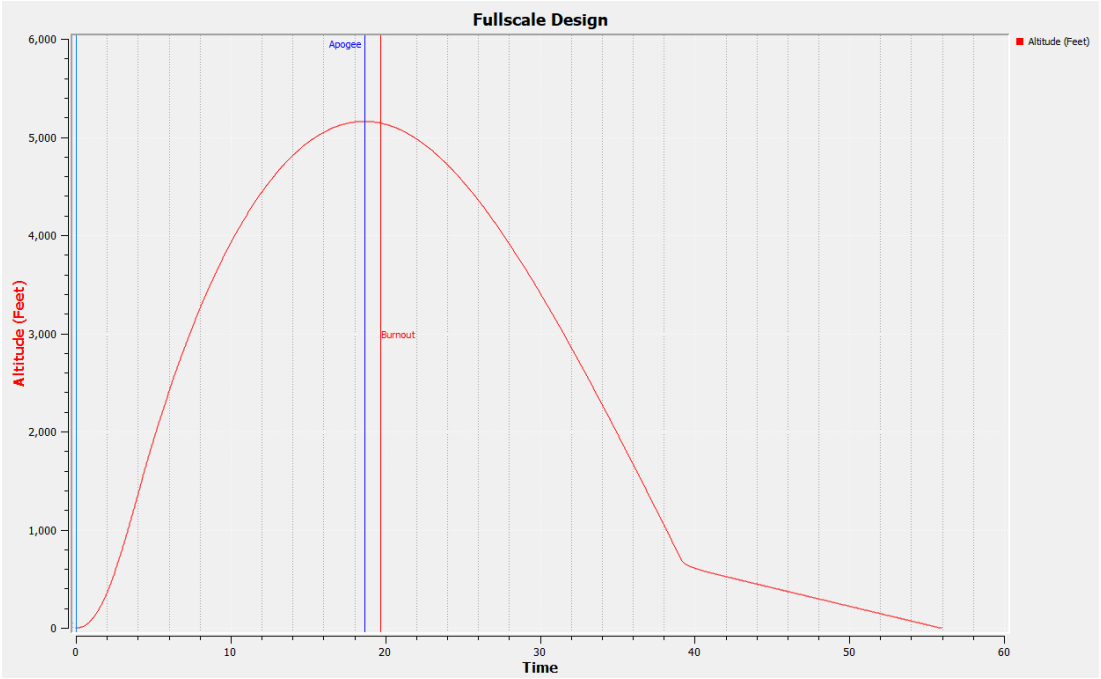
- Aerotech L850W
- Loss of lander weight meant motor downsizing
- Lowest impulse that still met apogee goals
- RMS 75/3840



Motor Curve

Apogee

- Predicted to be 4,400 feet
- Based on
  - RockSim model (4,412 feet) with
    - 5-15 MPH winds
    - 5° cant
    - 144" launch rail
  - Hand Calculations (4,493 feet)
- Apogee reduces recovery problems



RockSim Altitude Profile

Revisited RockSim Apogee Study

Year/Scale	RockSim Apogee (ft)	Actual Apogee (ft)	Percent Error
2020 Fullscale	3500	3000	14.29%
2020 Subscale	2700	1650	38.89%
2019 Fullscale	4173	3373	19.17%
2019 Subscale	1366	1161	15.01%

RockSim Apogee Table

- Use of RockSim was scrutinized to ensure proper use, no significant sources of error were detected
- Subscale flight metrics were used in RockSim
  - Predicted apogee was worse than the pre-flight simulations
- Correction is still in use for altitude prediction

Ballast Apogee Study

- How ballast weight effects apogee
- A result of the removal of lander
- 3 lb of ballast is ideal

Lander Weight (lb)	Predicted Apogee (ft)
2.0	4590
2.2	4565
2.4	4523
2.6	4496
2.8	4457
3.0	4399
3.2	4344

Ballast Study Table

Updated Fin Stability Margin Study

- Study was repeated to account for the change in design.
- Goal was to ensure that the method could adjust stability margin with new design.
- Study confirmed a fin span of around 6.58 and that the method could be used to reliably change stability margin.

Fin Span (in)	Stability Margin (Calibers)
6.0	1.75
6.2	1.94
6.4	2.14
6.6	2.21
6.8	2.4
7.0	2.52

Fin Stability Table

Wind Drift and Descent Time

Calculated based on constant wind down range.

Maximum Wind Drift
- Upper Section: 2381.2 ft
- Fin Can: 2422.5 ft

Descent Time
- Upper Section: 81.2 s
- Fin Can: 82.6 s

Drift and Descent time

Upper Section

MPH	Apogee	Descent Time	Wind Drift
0	4400 ft	81.2 s	0 ft
5	4400 ft	81.2 s	595.3 ft
10	4400 ft	81.2 s	1190.6 ft
15	4400 ft	81.2 s	1785.9 ft
20	4400 ft	81.2 s	2381.2 ft

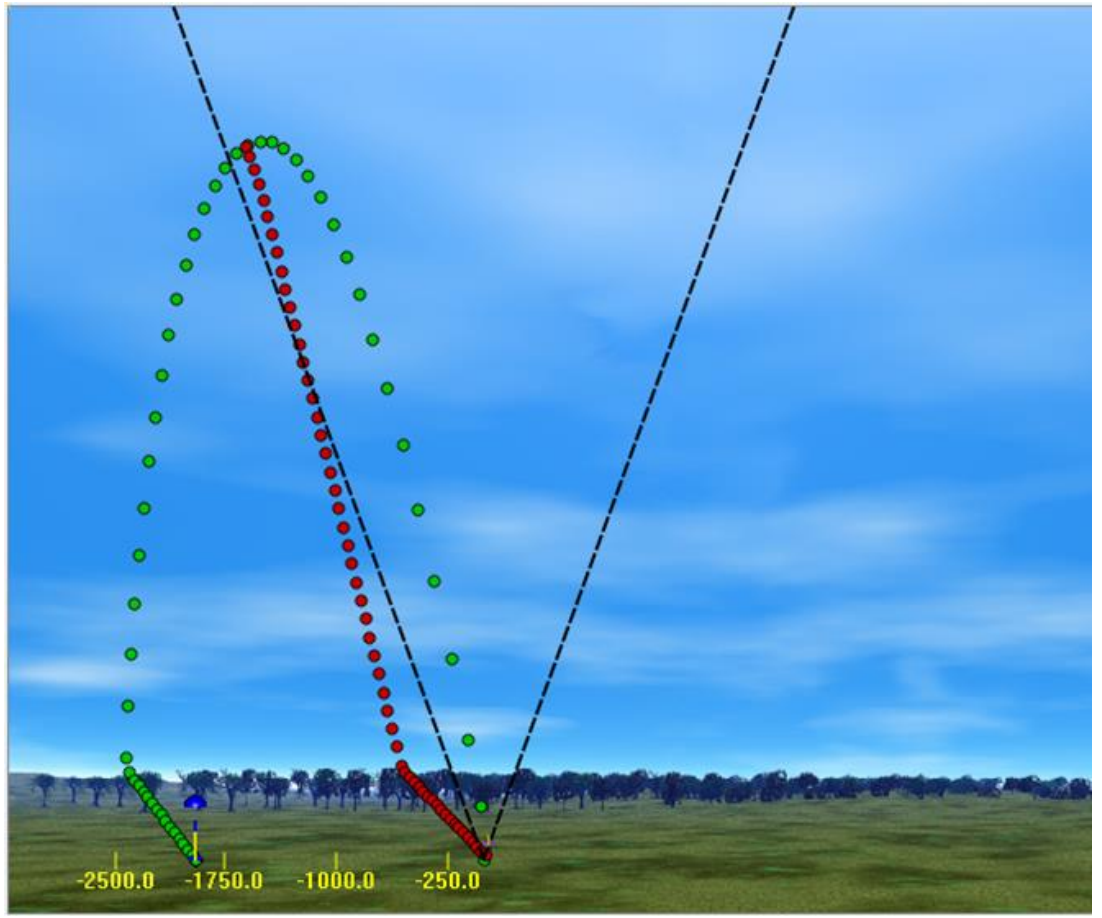
Fin Can

MPH	Apogee	Descent Time	Wind Drift
0	4400 ft	82.6 s	0 ft
5	4400 ft	82.6 s	605.6 ft
10	4400 ft	82.6 s	1211.3 ft
15	4400 ft	82.6 s	1816.9 ft
20	4400 ft	82.6 s	2422.5 ft

Alternative calculation

	Upper Section		Fin Can	
MPH	Wind Drift	Descent Time	Wind Drift	Descent Time
0	0 ft	56 s	0 ft	78 s
5	677 ft	56 s	40 ft	78 s
10	1245 ft	55 s	40 ft	77 s
15	1654 ft	54 s	30 ft	77 s
20	1950 ft	54 s	20 ft	76 s

By using RockSim, the calculations can consider weather cocking into the wind and drifting back towards the rail.



Kinetic Energy

Body Section Kinetic Energy at Landing

Section	Mass	Maximum Descent Velocity
Nosecone	.3755 slugs	20.0 ft/s
Midsection	.2353 slugs	25.2 ft/s
Fin Can	.4230 slugs	18.8 ft/s

This table displays the maximum descent velocity each section can reach in order to obtain a kinetic energy below the maximum.

Section	Mass	Descent Velocity	Kinetic Energy
Nosecone	.3755 slugs	19.74 ft/s	73.2 ft-lbf
Midsection	.2353 slugs	19.74 ft/s	45.8 ft-lbf
Fin Can	.4230 slugs	16.43 ft/s	57.1 ft-lbf

Given the selected main parachutes of 60” Fruity Chute Iris Ultra Compact, the max kinetic energy felt is 73.2 ft-lbf by the nose cone at landing

Opening Shock

Making sure the recovery harness will withstand main deployment shock

- Kevlar Rated at 6600 lbf
- Max loading: 186.849 lbf
  - Factor of Safety: 35
  - This is the combination of both tethered sections when main is deployed

Section	Mass	Opening Shock
Nose cone and Payload bay	.3755 slugs	114.867 lbf
Midsection	.2353 slugs	71.9822 lbf
Upper Section	.6108 slugs	186.849 lbf
Fin Can	.4230 slugs	139.721 lbf

Main Deployment Opening Shock

Subscale Launch Results

Launch Day Conditions

- 55° F
- 5-10 mph winds
- Mostly clear skies
  - Clear during launch

Tragedy Launch Photo

Final Measurements

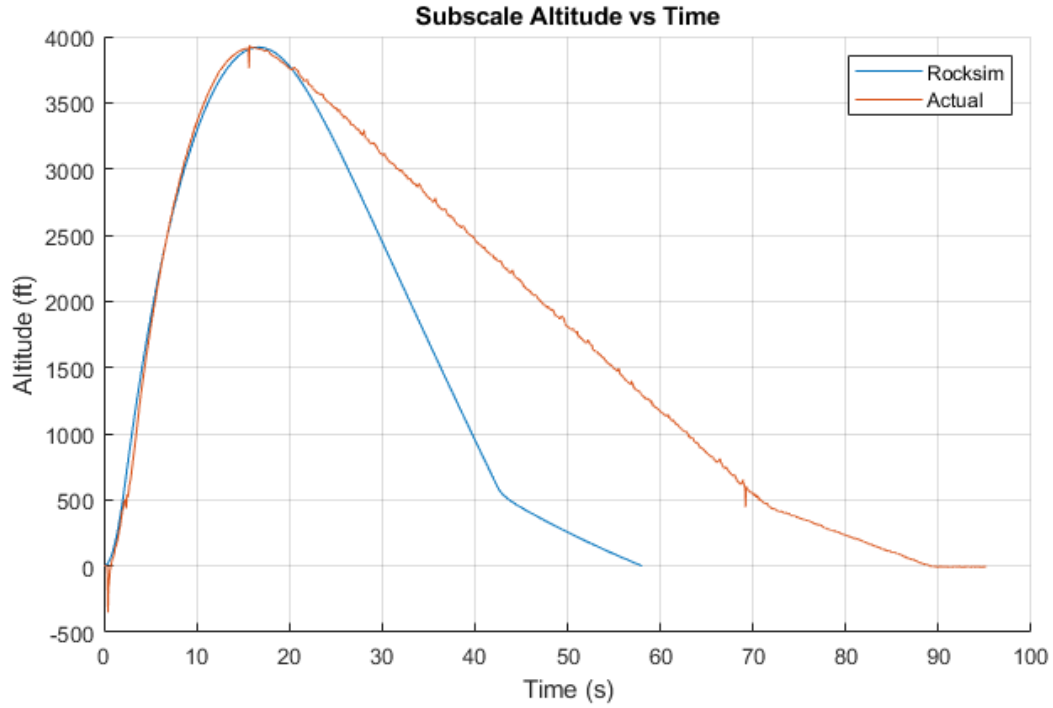
- Final weight was lower than predicted weight.
- Likely due to how RockSim estimates motor mass.
- Actual stability margin was good, not too high or low.

	Weight (lb)	Stability Margin
Predicted	18	2.18
Actual	16.6	2.245

Subscale Weight Table

Altitude Results

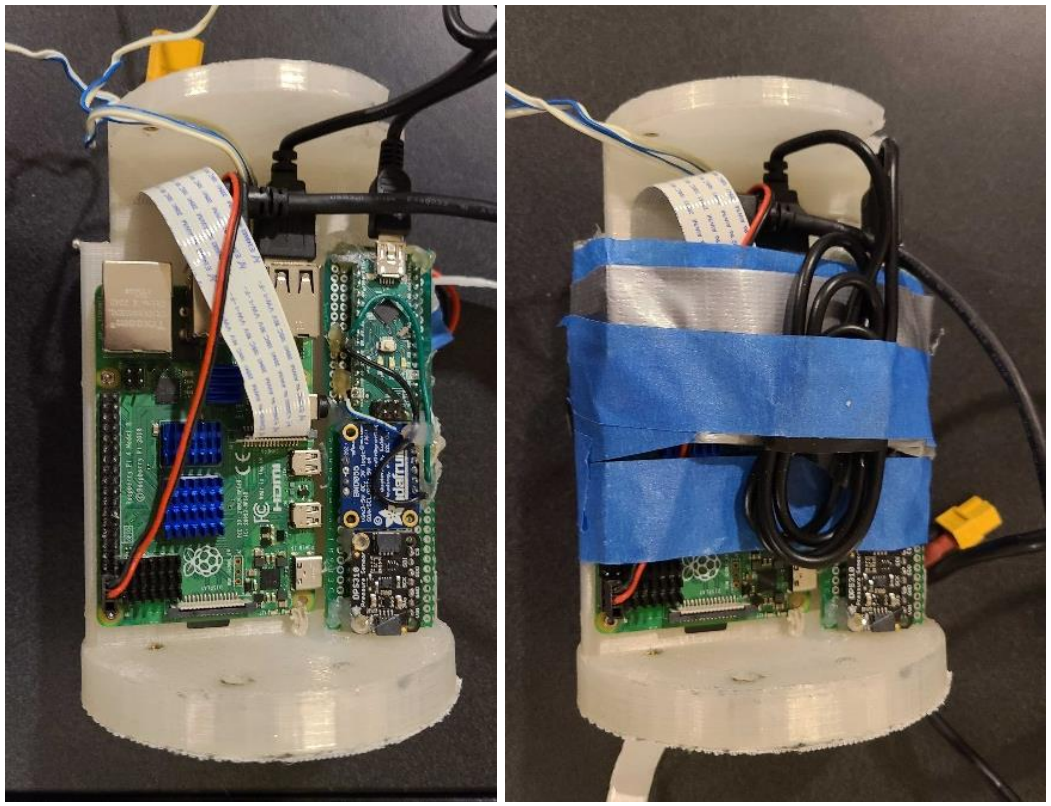
- Predicted apogee was 3924 ft and actual apogee was 3919 ft, for a difference of **5 ft**.
- Helps justify use of RockSim apogee correction
- Slight cocking in flight
- Discrepancy in landing time
  - Possibly weight, wind, or parachute related



Subscale Altitude Graph

Subscale Electronics Sled

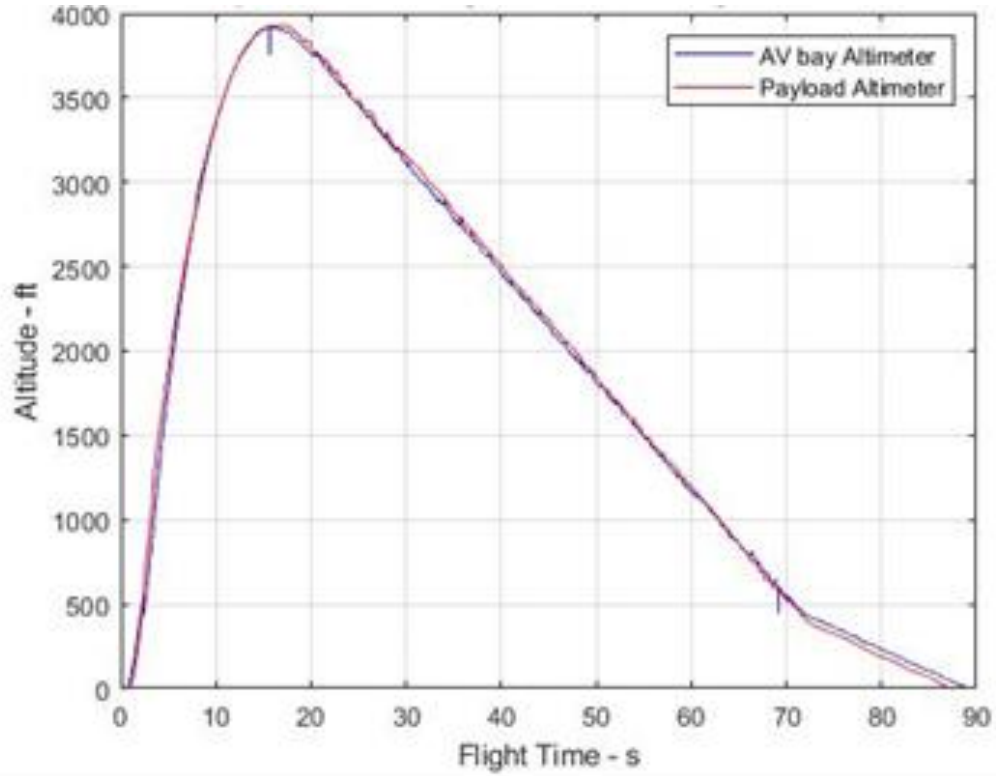
- Very similar to plan for full-scale sled
- Consisted of Raspberry Pi, DPS310 altimeter BNO055 IMU, and Arduino Nano
- Tape, hot glue, nuts, bolts, and zip ties were used to secure electronics to sled
- Velcro used to retain sled in lower payload compartment



Subscale Payload Sled

Payload Sensor Data

- Successfully recorded:
  - Pressure measurements for altitude
  - Orientation
  - Acceleration
- IMU data not fully post-processed yet
- Recorded altitude was compared with AV altimeter data



Subscale Payload Altitude Graph

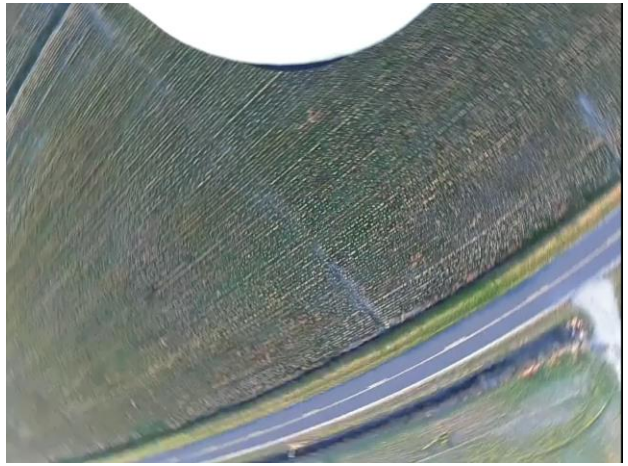
Subscale Camera Housing

- Camera housings designed and 3D printed similarly to the full-scale models
  - Epoxied onto launch vehicle
  - Aluminum foil tape used to secure cables

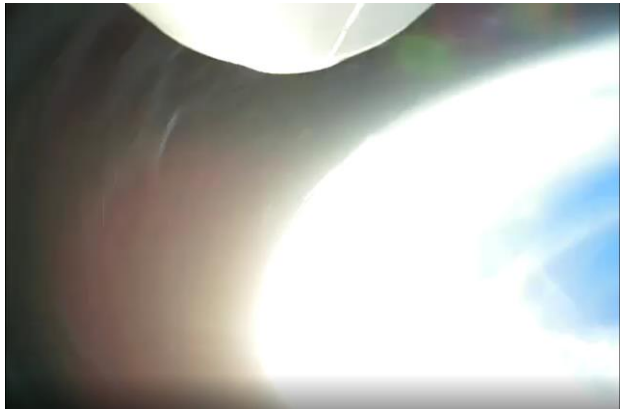
Camera Housing Integration

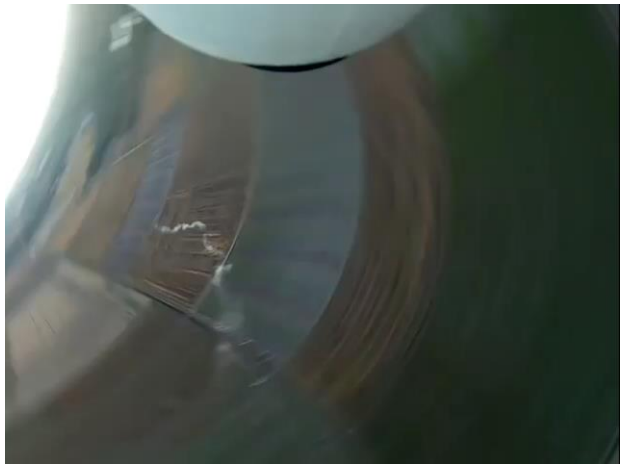
Cameras / Imaging

Picture of Ascent



Picture During Main

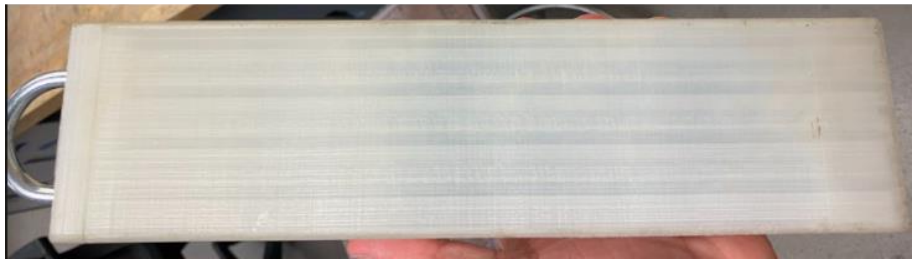




Images taken During Drogue

Dummy Weight

- Used to simulate the weight of a lander
- ~5.4 lb.
- Attached to shock cord and deployed from launch vehicle with parachutes
- Caused instability during descent

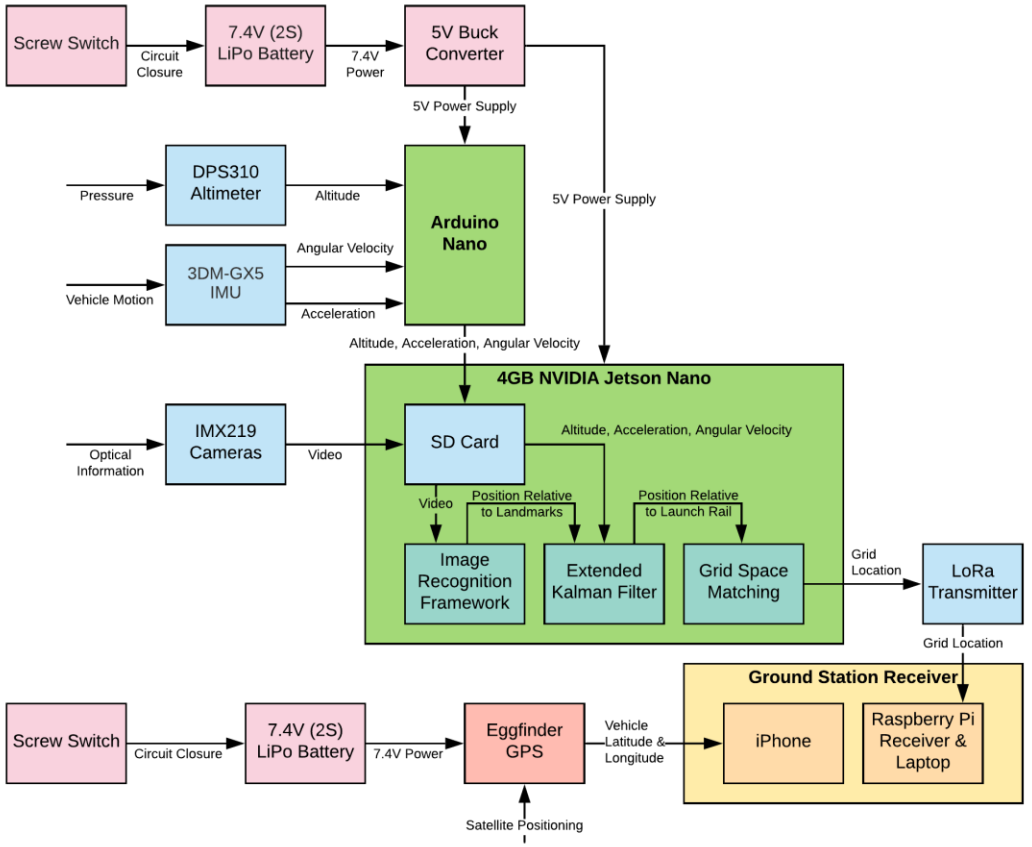


Lander Dummy Weight

Payload

Baseline Solution 1: APPA

- APPA: Aerial Photographing and Positioning Apparatus
- Method of determining location based on flight data
- Consists of electronics sled in lower payload bay coupled with cameras and camera housings mounted on the fin can



APPA Functional Diagram

APPA: Data Synthesis

- Goal: Track the vehicle through use of a Kalman filter
- Means: Record state information via sensors
  - IMU / Altimeter – direct
  - Images – computer vison

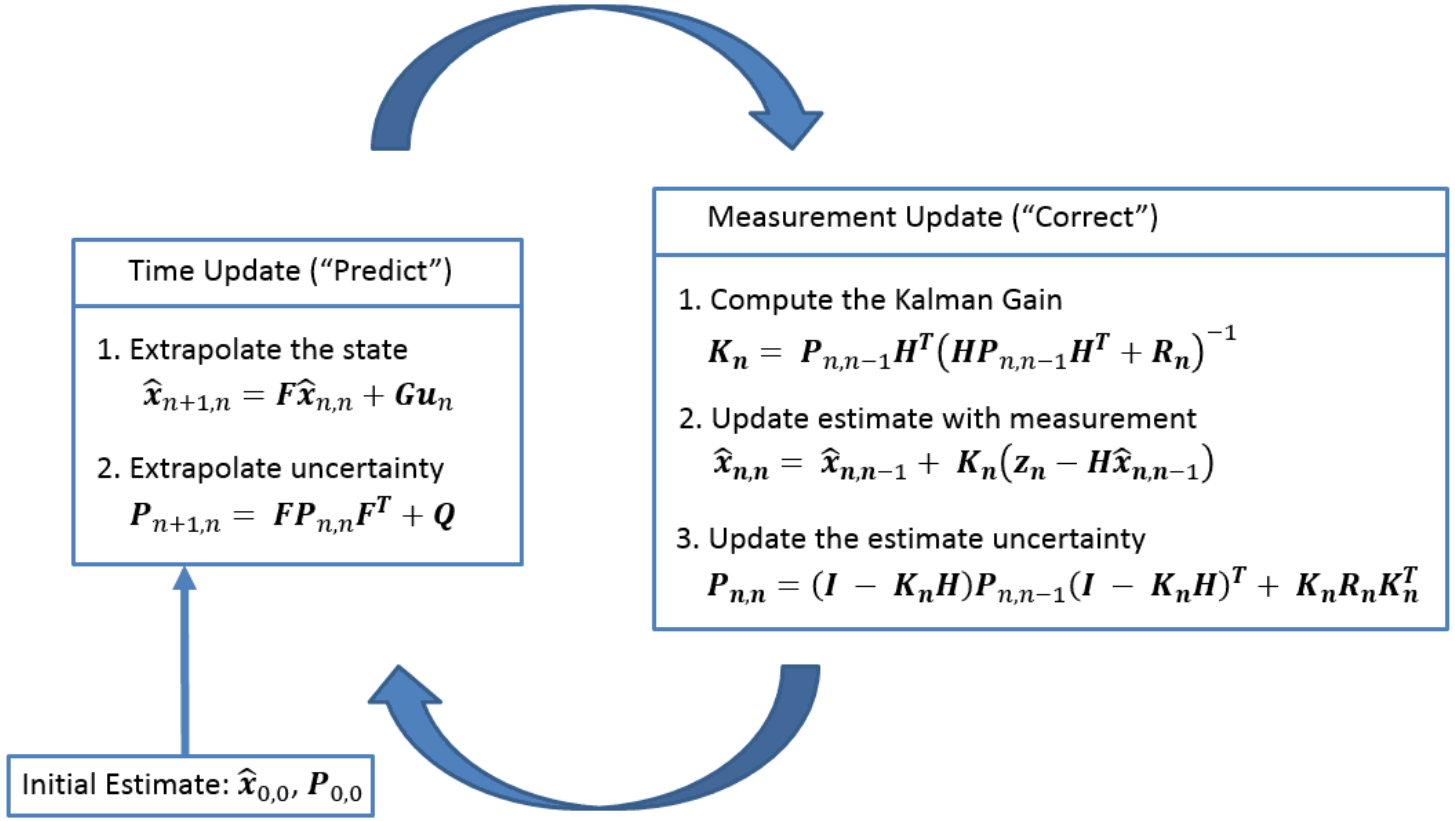


Image Credit: www.kalmanfilter.net

APPA: Electronic Components

- Nvidia Jetson
  Primary Processor
- Arduino Nano
  Secondary Processor
- Adafruit DPS310
  Barometric Altimeter

Jetson

Arduino

Altimeter

APPA: Electronic Components

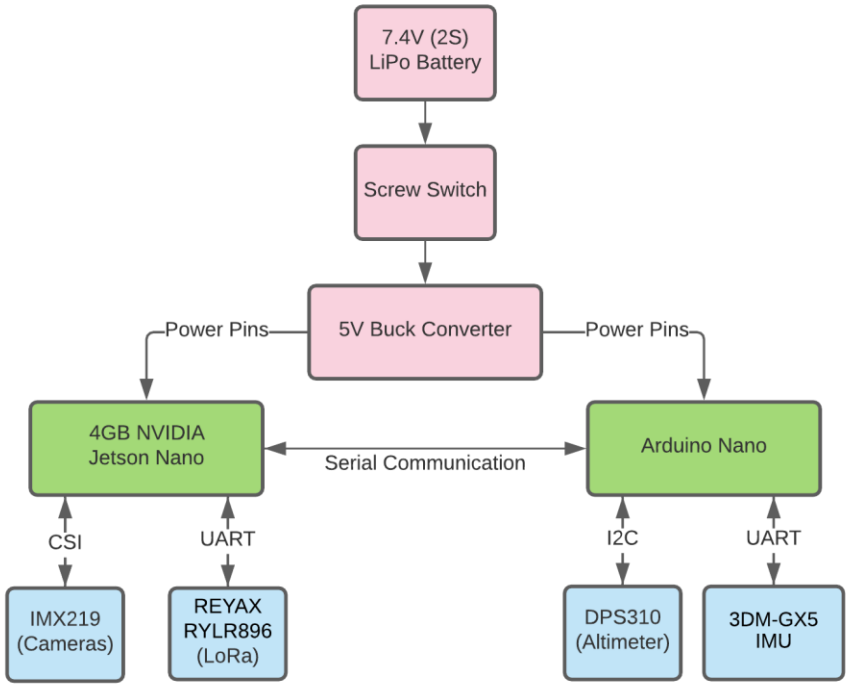
- 7.4 V, 5000 mAh LiPo chosen for voltage and battery life requirement

- IMU is now the **3DM-CX5-IMU**

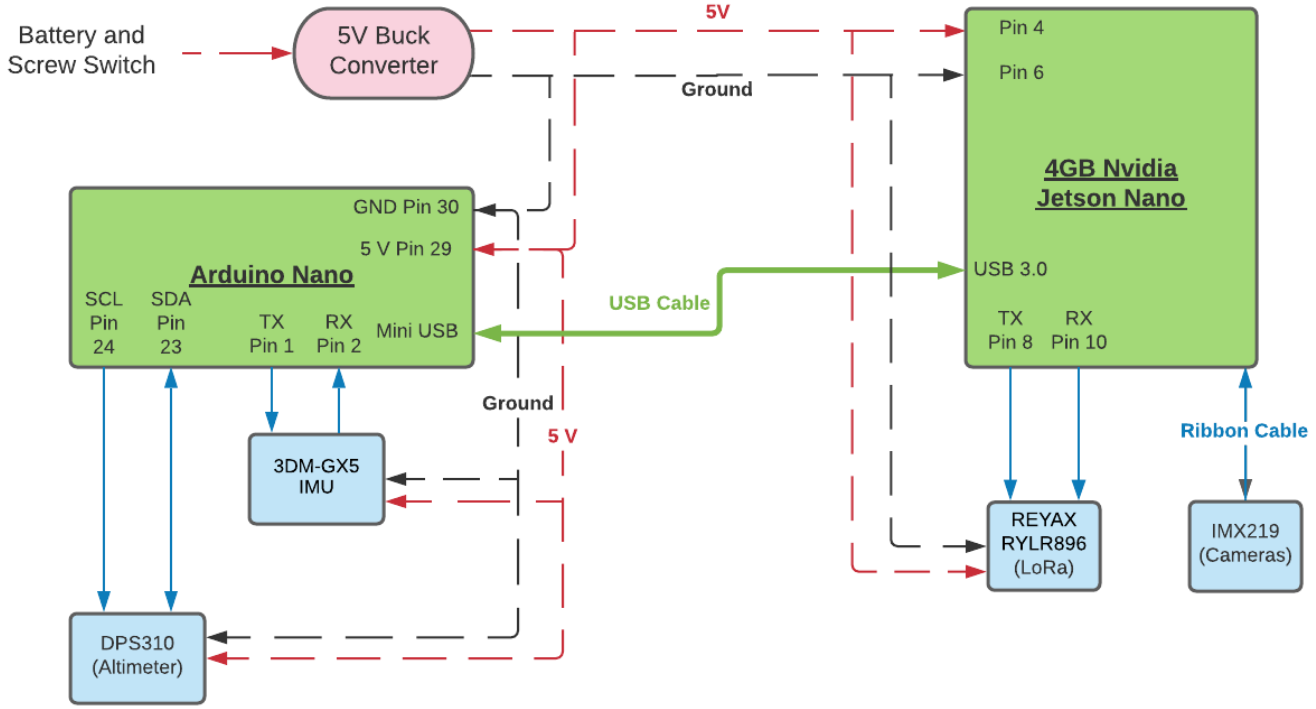
- Cameras:

IMX-219-160

APPA: Electronic Connectivity



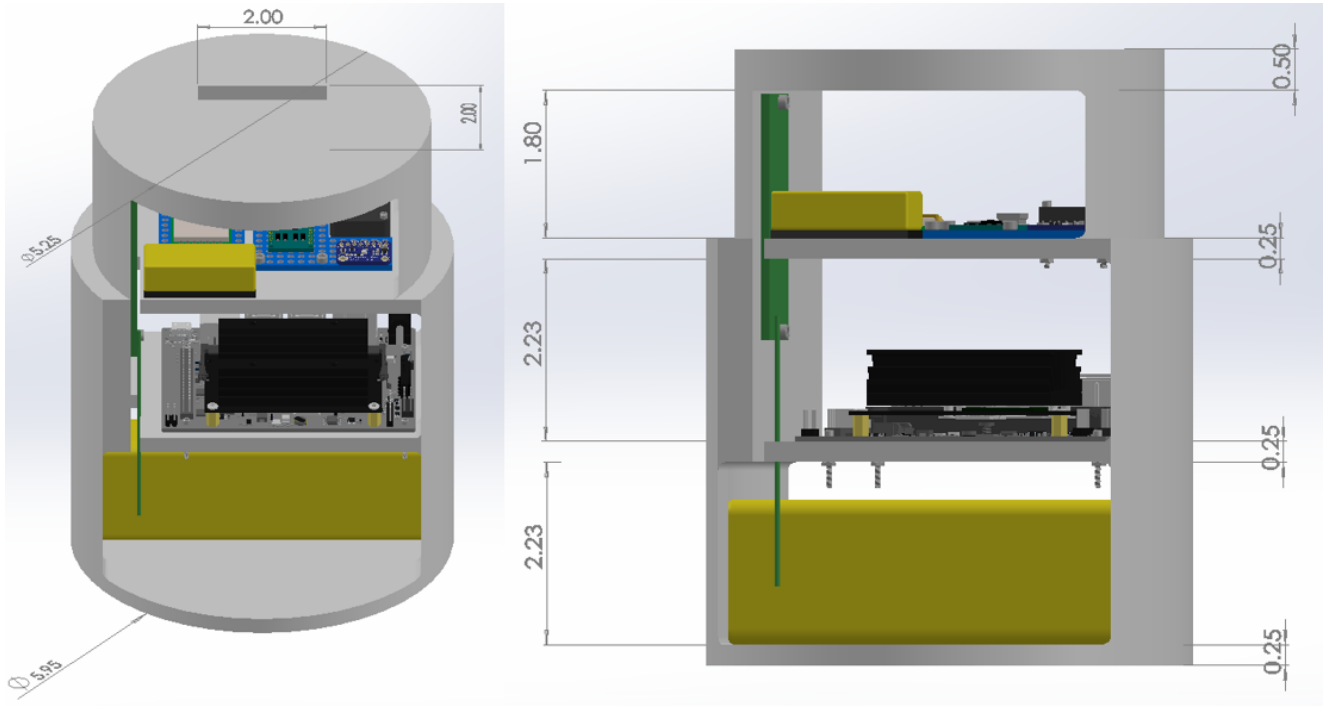
APPA Electronics Schematic



APPA Wiring Diagram

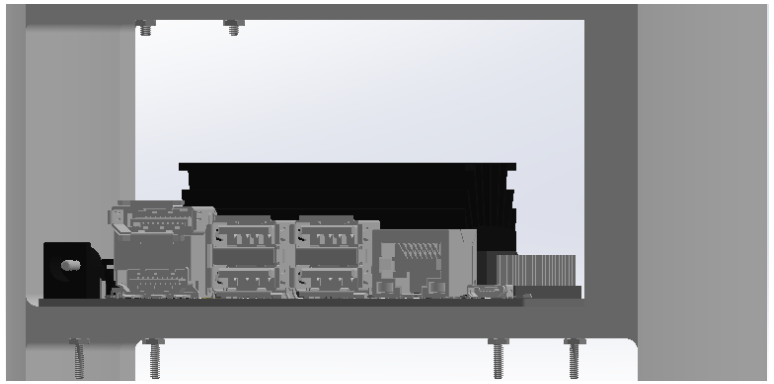
APPA Sled Design

- Houses APPA electronics and fin can recovery GPS
  - LoRa and GPS will be covered in aluminum foil
- Sized to fit lower payload compartment
  - Designed to interface with structural elements
- Three internal platforms to attach components
  - NVIDIA Jetson Nano in central location on sled

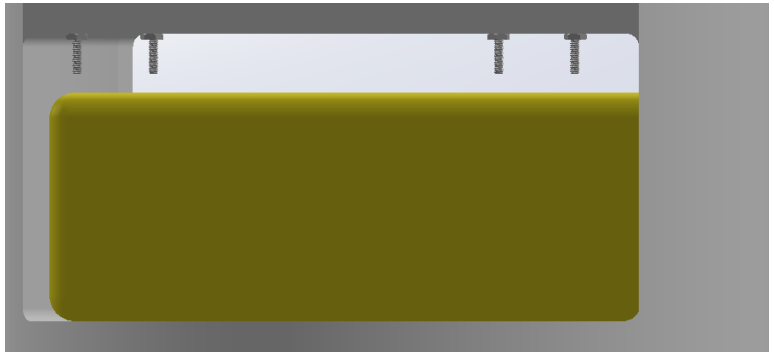


APPA Sled

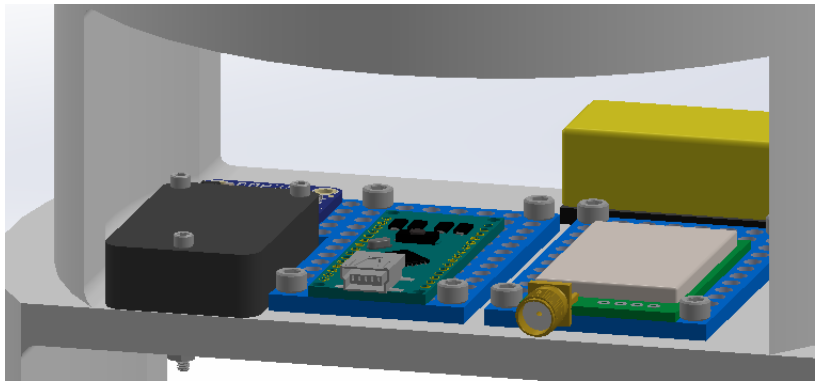
APPA Sled-Electronics Connections



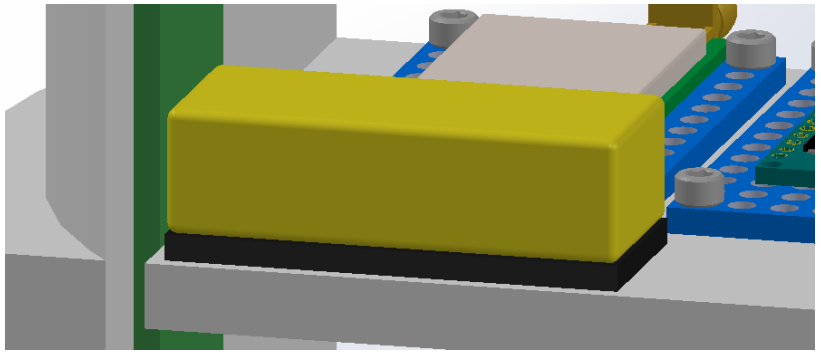
NVIDIA Jetson Nano: secured with four nuts and bolts in pre-cut holes



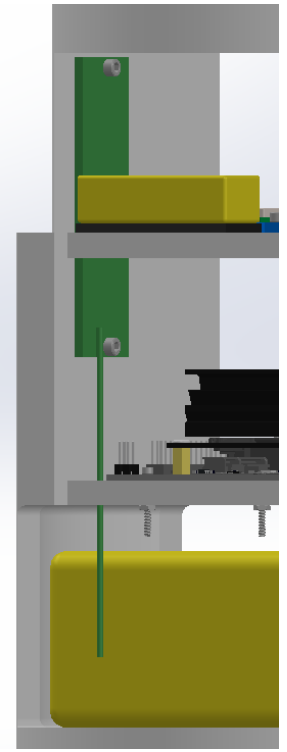
APPA LiPo: three zip ties and close interactions with sled wall



IMU: three nuts and bolts; **Other APPA electronics:** perf boards, bolts, threaded inserts



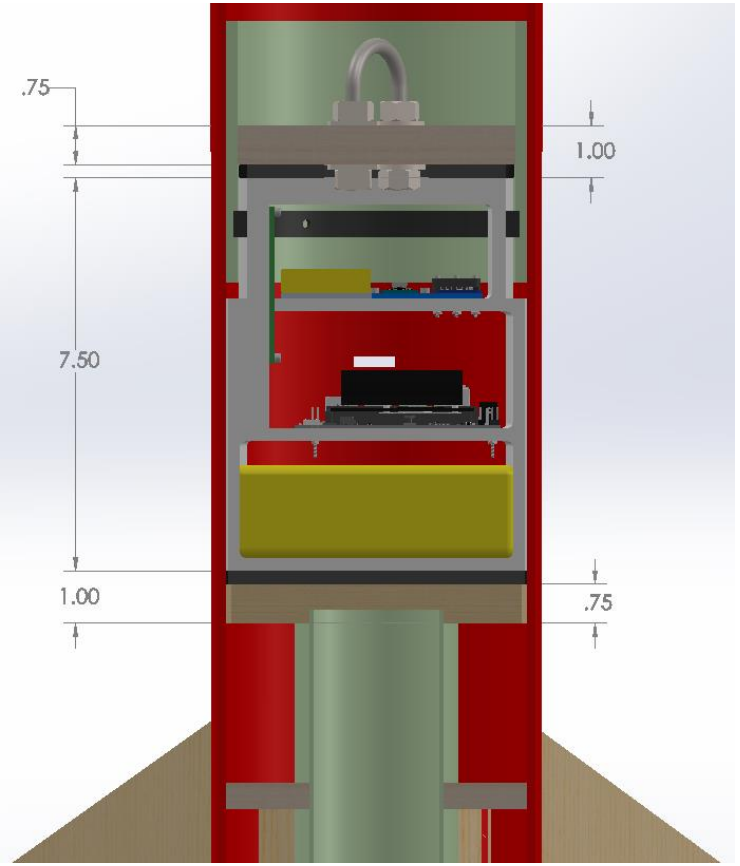
Recovery Battery: secured with two zip ties and industrial strength Velcro



Recovery GPS: secured with bolts and threaded inserts

APPA Sled Integration

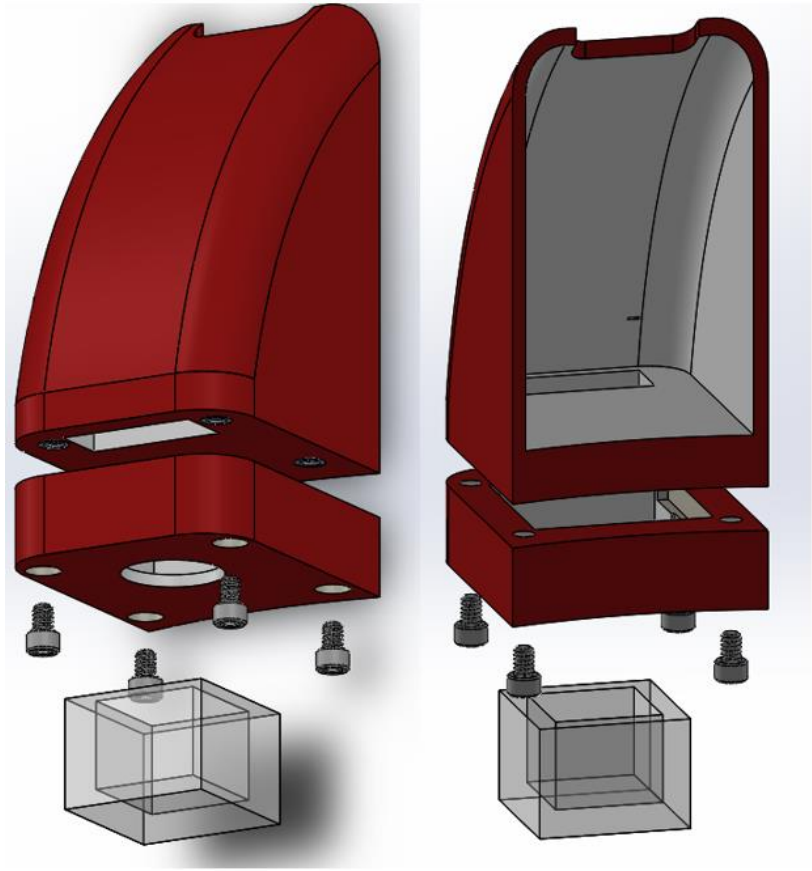
- Sled contained in lower payload compartment between bulkheads
  - Sled attaches to bulkheads with Velcro to resist rotation
- Interfaces with structural elements
  - Coupler, centering ring, and U-bolt
- Camera ribbon cable exit ports located near NVIDIA Jetson Nano
- Four 0.2256” diameter sampling holes in section for altimeters
- Two access ports for screw switches
  - One for recovery system and one for APPA



APPA Sled Retention Section View

Camera Housings

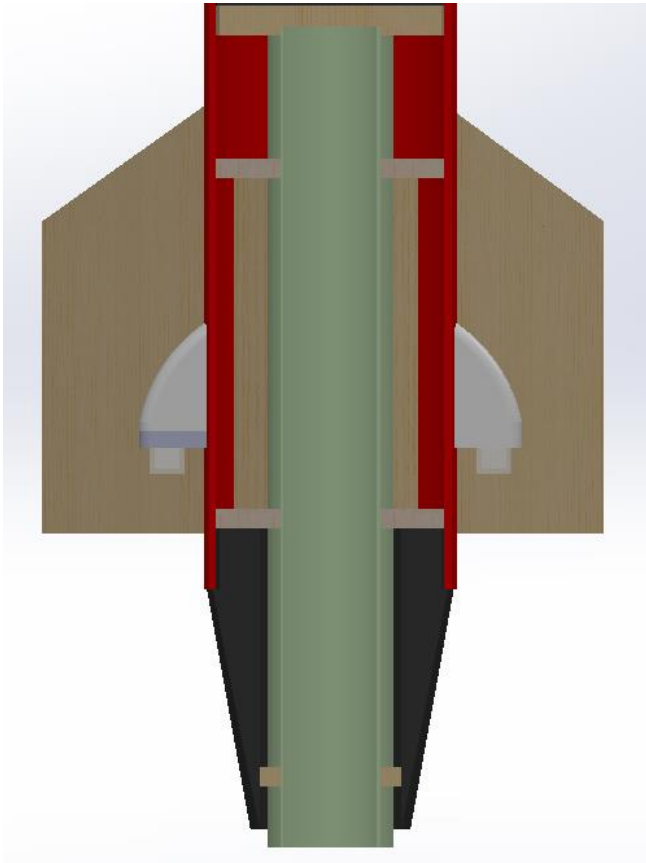
- Cameras will be secured in housings
  - Printed in PLA, coated in a composite layup of epoxy and carbon fiber
- Covers allow for easy installation and removal of cameras
  - Covers will be bolted into threaded inserts soldered into the housings
- Plexiglass box will be epoxied to the cover to surround the camera lens
  - Protects cameras from water and impact damage



Camera Housing Assembly

Camera Integration

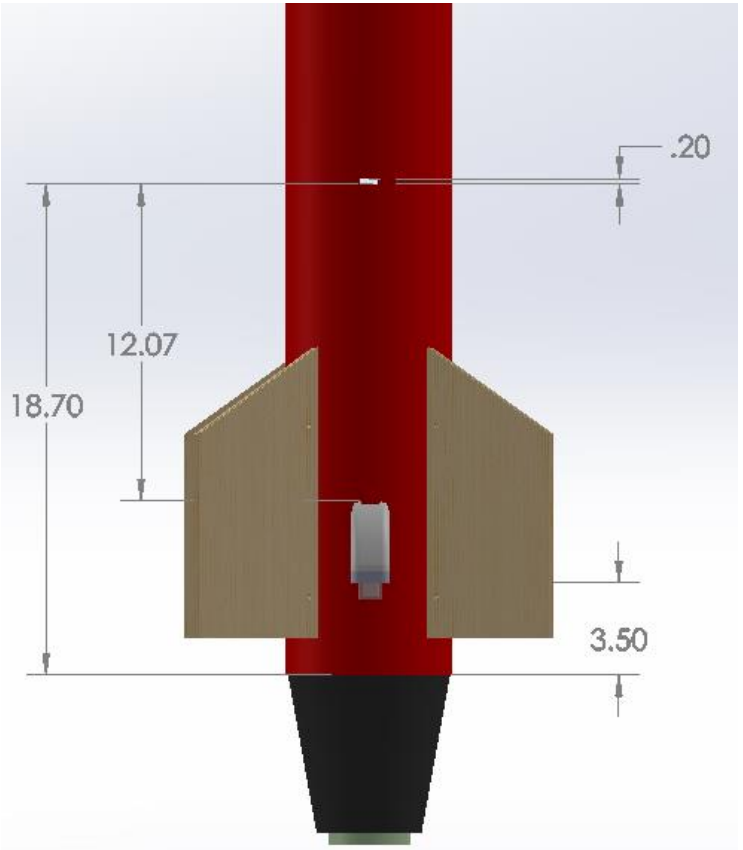
- Two housings will be epoxied to the launch vehicle to house each camera
  - Mounted symmetrically on opposite sides of the fin can
  - Mounted between fins to limit aerodynamic impacts over fins
- Camera lenses oriented straight down with respect to the vehicle
  - Mounted on fin can because it is a relatively stable section on descent due to its weighting



Camera Housing Integration Section View

Camera Electronics Integration

- Camera ribbon cables exit top of housings and extend up the vehicle
  - Travel 12.07 inches up the fin can to enter lower payload compartment
- Ribbon cables will be secured to body tube with aluminum foil tape
  - Aluminum foil tape is waterproof and provide air leak protection
  - Successfully secured cables to the launch vehicle on subscale flight
  - Masking tape will protect vehicle paint



Camera Electronics Integration

APPA System Weight

Lower Payload Compartment Weight

Item	Weight (lb)
Centering Ring	.017
U-Bolt Nuts	.010
APPA Sled	.330
4GB Jetson Nano	.532
Arduino Nano	.020
REYAX RYLR896 LoRa	.015
DPS310 altimeter	.022
3DM-GX5-IMU	.036
APPA System Battery	.563
Cables and Buck Converter	.100
Perf Board	.010
Velcro	.092
Small Nuts and Bolts	.010
Eggfinder GPS	.044
Eggfinder GPS Battery	.049
Total	**1.833**

Camera Housing Assembly Weight

Item	Weight (lb)
Camera Housing Bodies	.020
Camera Housing Covers	.010
IMX219 Cameras	.018
Bolts	.005
Heat Set Threaded Inserts	.005
Plexiglass Boxes	.018
Total	**.076**

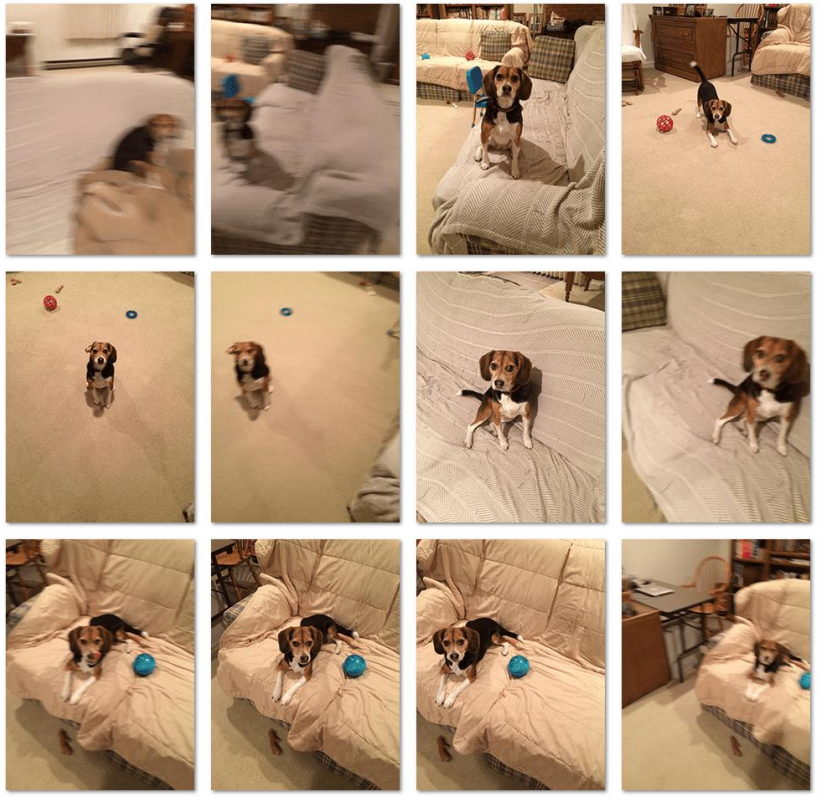
Image Processing

- Our solution utilizes image recognition and other forms of image processing
- CNN will be built in Python utilizing OpenCV, TensorFlow, and Keras
- NASNetLarge architecture
- Corner detection to aid in triangle similarity calculations
- Processing done on NVIDIA Jetson Nano
- Testing will need to be done to ensure it works

Jetson Nano

CNN Testing

- Run training images of landmarks through CNN
- Changing the sample size of the training data
- Blur and rotate images



CNN Training Visualization

Triangle Similarity Testing

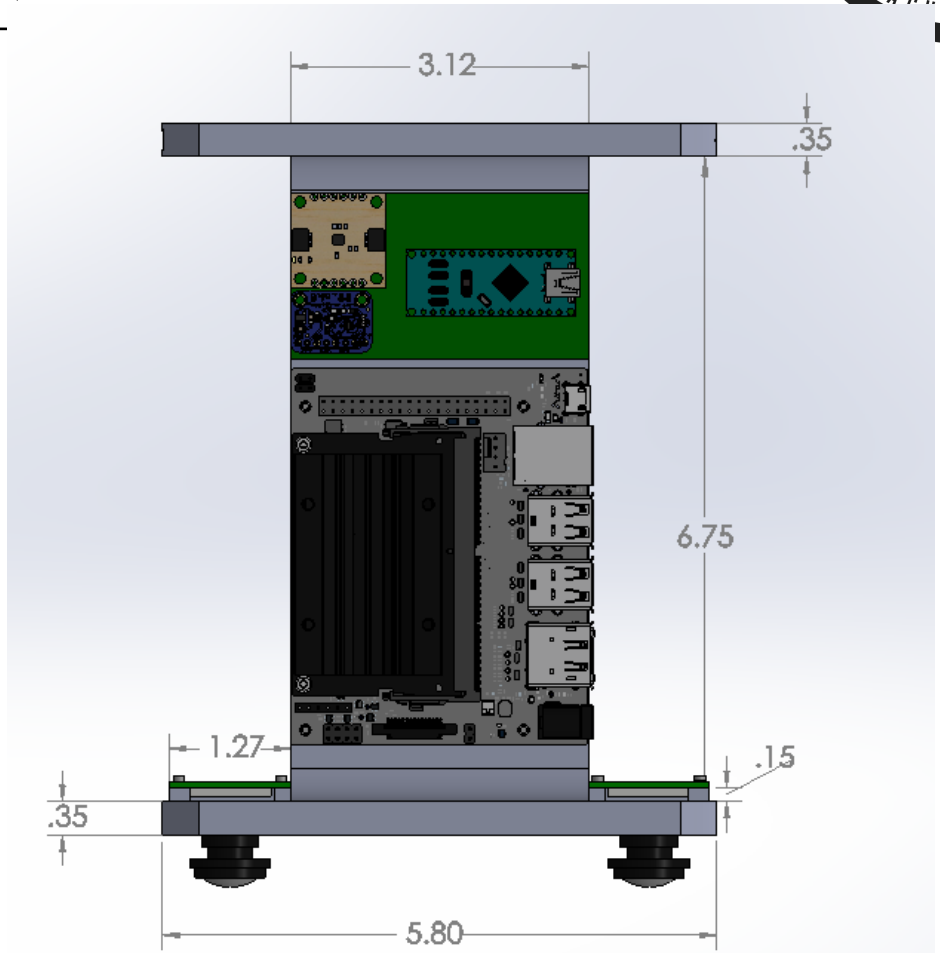
- Use a variety of images with different objects
- Dimensions and distance must be known
- Test with blurry and rotated images as well

$$D = \frac{F * W}{P}$$

Triangle Similarity Testing Visualization

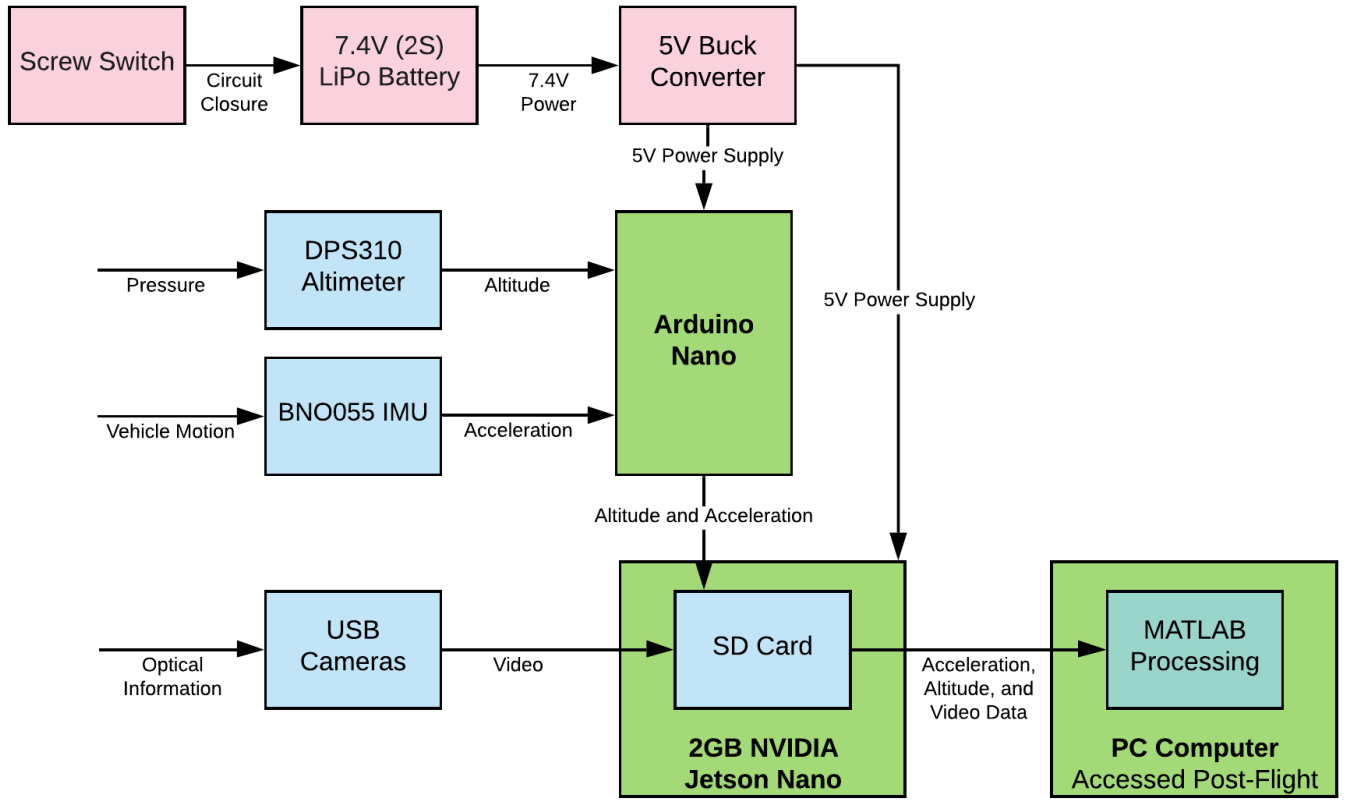
Means of Obtaining Meaningful Observations (MOMO)

- Experimental Payload: Does not help calculate the launch vehicle's location
- Located in Upper Payload Bay
- Will take photos of drogue deployment and behavior during launch vehicle descent
- Will have IMU and Altimeter for more data collection



MOMO Payload Sled

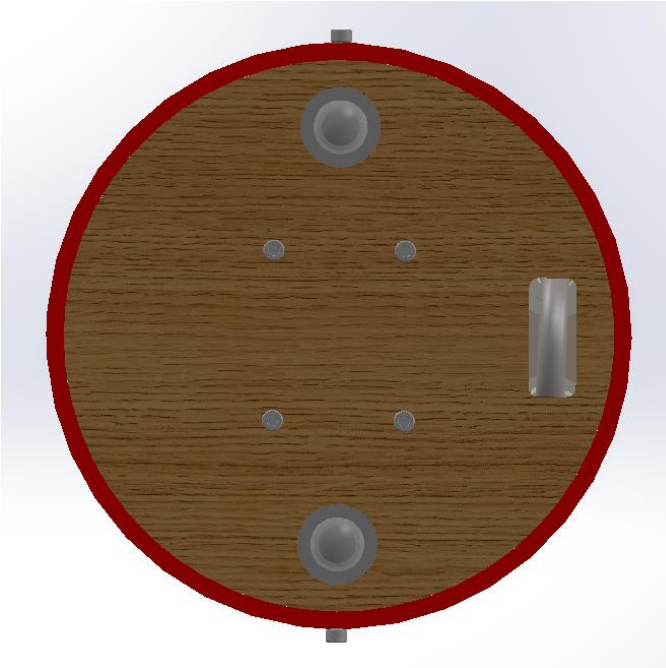
MOMO Functional Diagram



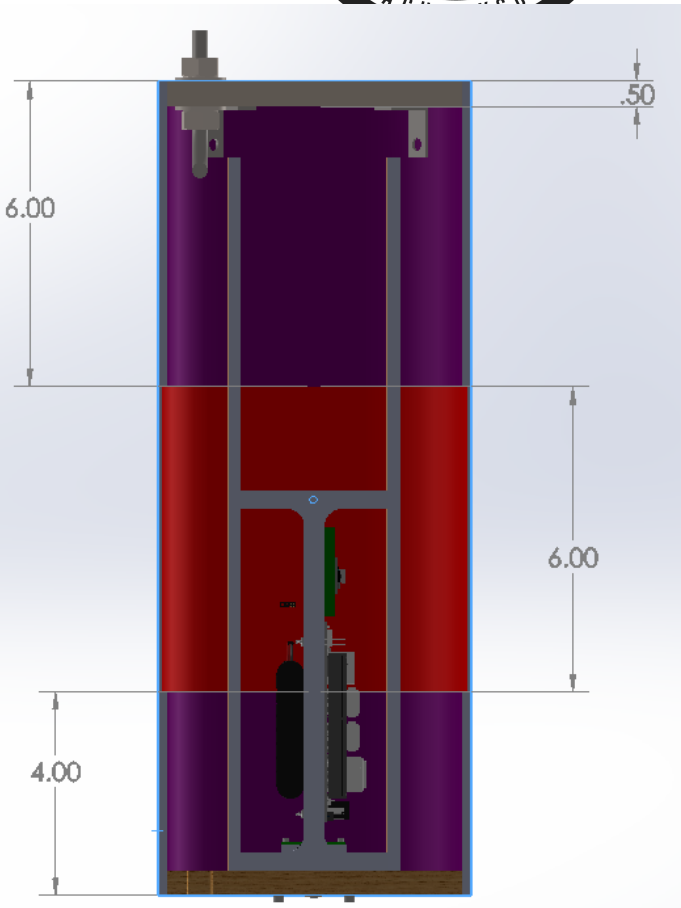
MOMO Functional Diagram

MOMO Retention

- Bottom of the sled will be bolted to the bulkhead using 4 bolts and threaded inserts
- Top sides of the sled will be bolted to the sides of the launch vehicle
- The bolts will be 6-32 threads with a diameter of .138 inches which match the threaded inserts
- 2 plywood supports will be UPB to separate shock cord from sled and for symmetry



MOMO Cameras in Bulkhead



MOMO Sled in UPB

Requirements Verification

Verification Status

Testing Plan

Status of Requirements Verification

- All requirements verified by analysis have been verified
  - Kinetic energy, launch vehicle max speed, APPA not rotating, APPA and MOMO's electronics max temperature, etc.

- Demonstration, inspection, and testing requirements have verification plan detailed in CDR
  - Varies for each requirement, requires launch vehicle or payload to be constructed

- See testing plan for requirements verified by test

Verification Plan Example

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

Recovery Team Derived Requirements						
ID	**Description**	**Justification**	**Success Criteria**	**Verification Method**	**Status**	**Status Description**
Functional Requirements						
RF 1	The descent velocity under drogue SHALL be less than 100 ft/s.	Having a decent velocity higher than 100 ft/s can lead to large main parachute shock.	The chosen parachute will have a terminal velocity of less than 100 ft/s with the given mass of the rocket.	Analysis	Verified	The drogue parachute selected has a descent velocity of 81.2 ft/s.

Testing Plan

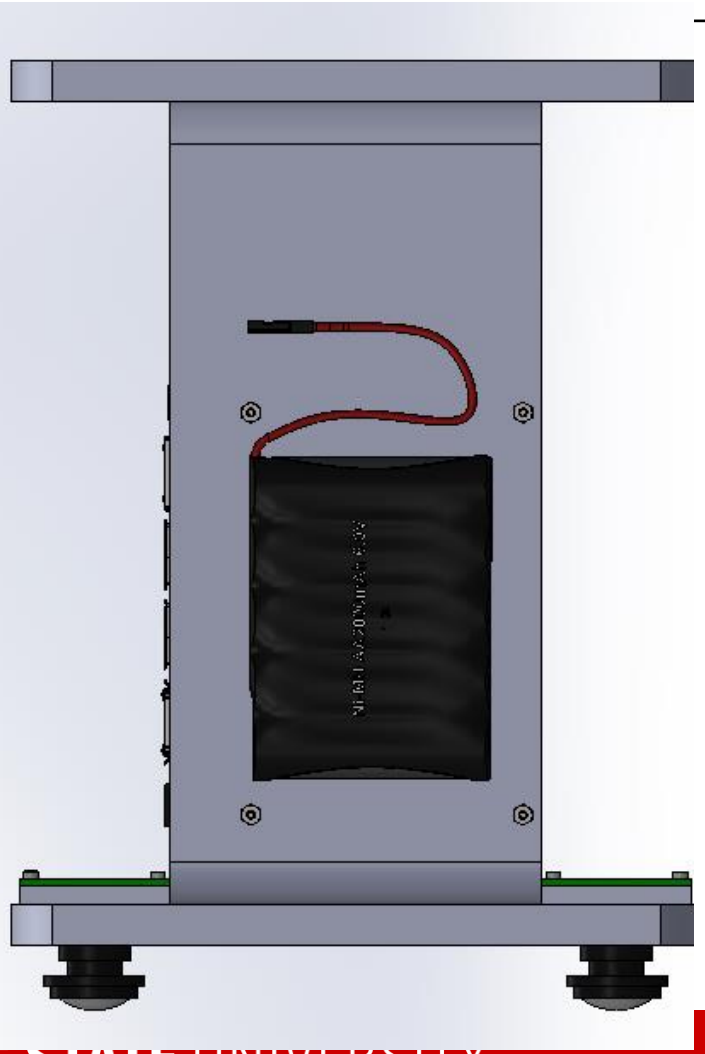
- Testing plans are included to validate components
- Section 6.1 in the CDR has success criteria and dates for all tests
- Examples
  - Nose Cone Bulkhead Tensile Loading Testing
  - Full-scale Ejection Test
  - Image Processing test
  - APPA Battery Capacity Test

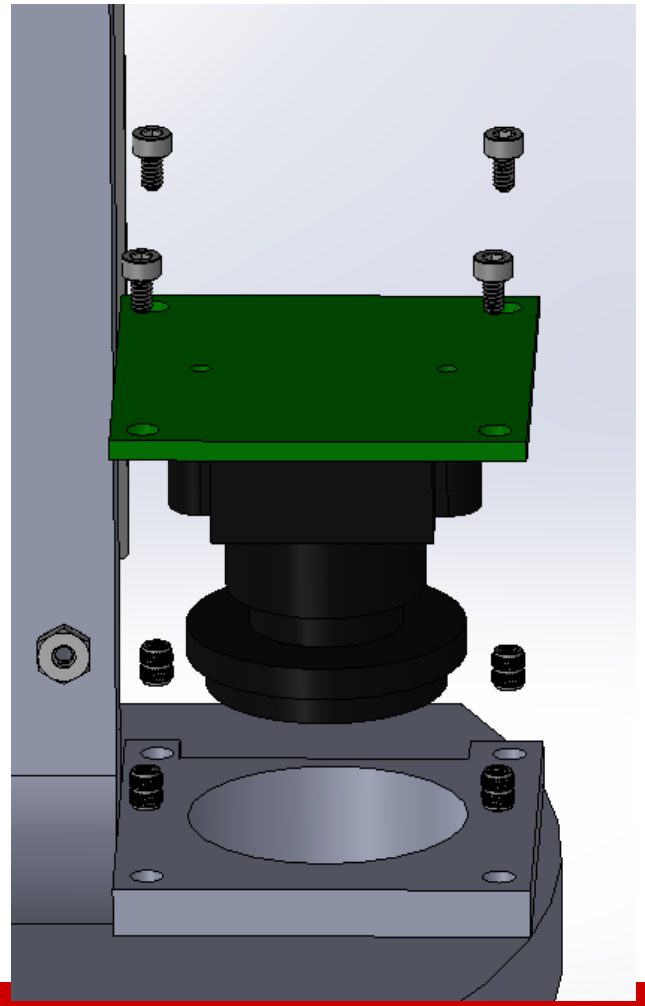
Subsystem Test Suites

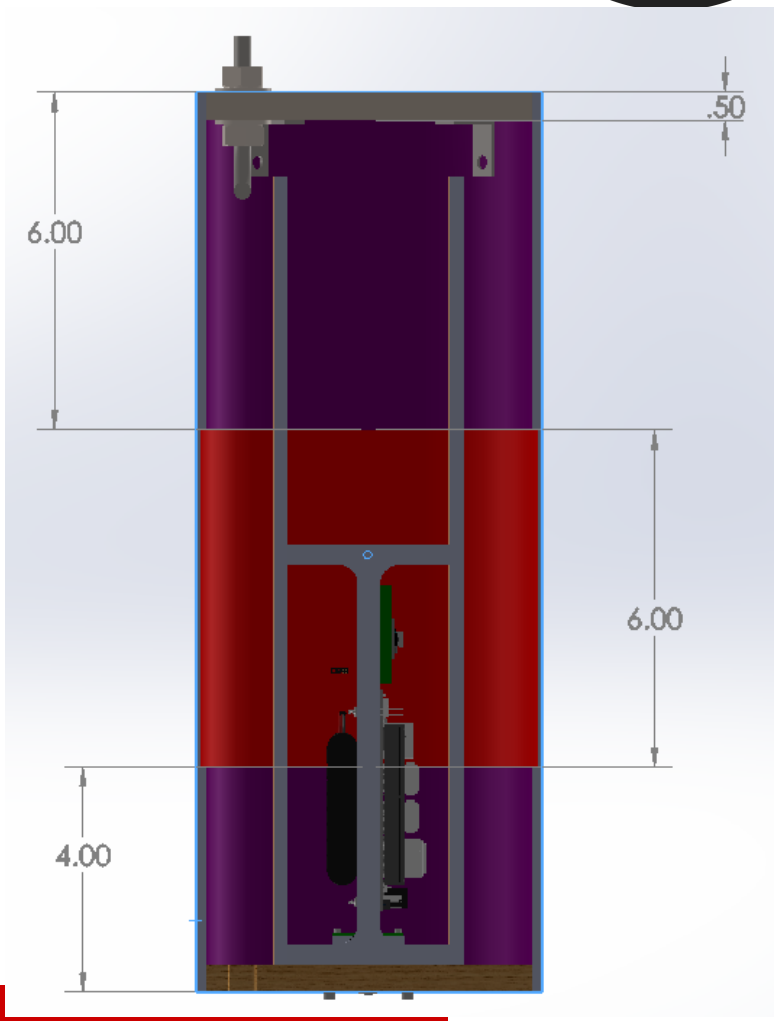
	Launch Vehicle Tests	Recovery Tests	Payload Tests
Tests	6.1.1.1 – 6.1.1.5	6.1.2.1 – 6.1.2.5	6.1.3.1 – 6.1.3.15
Completed Tests	N/A	6.1.2.1	6.1.3.1 – 6.1.3.3
Requirements Verified	LVD 1, LVD 5	NASA 2.7, NASA 3.2, NASA 3.12	PF1, PF2, PF3, PF4, PF5, PF6, PF7, PF8, PF9, PF11, PF12, PD1, PD2, PD5, PD6, PD6, PD10, PD11,
Start Date	1/24/22	11/18/21	11/20/21
Completion Date	1/27/22	2/2/22	2/25/22

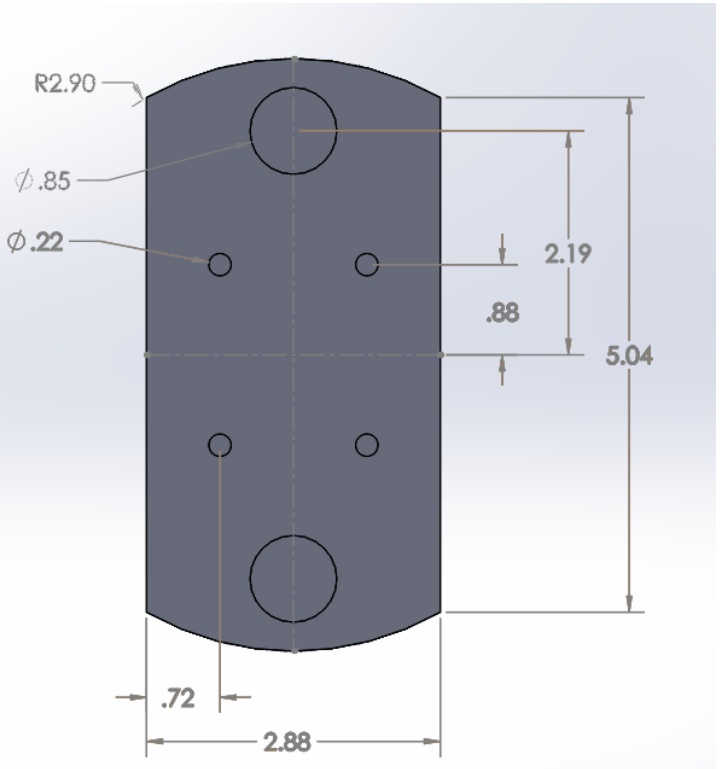
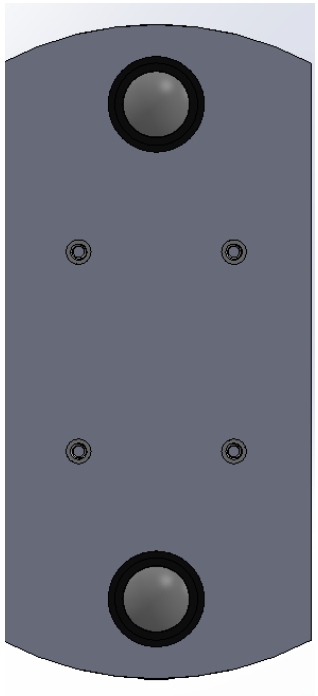
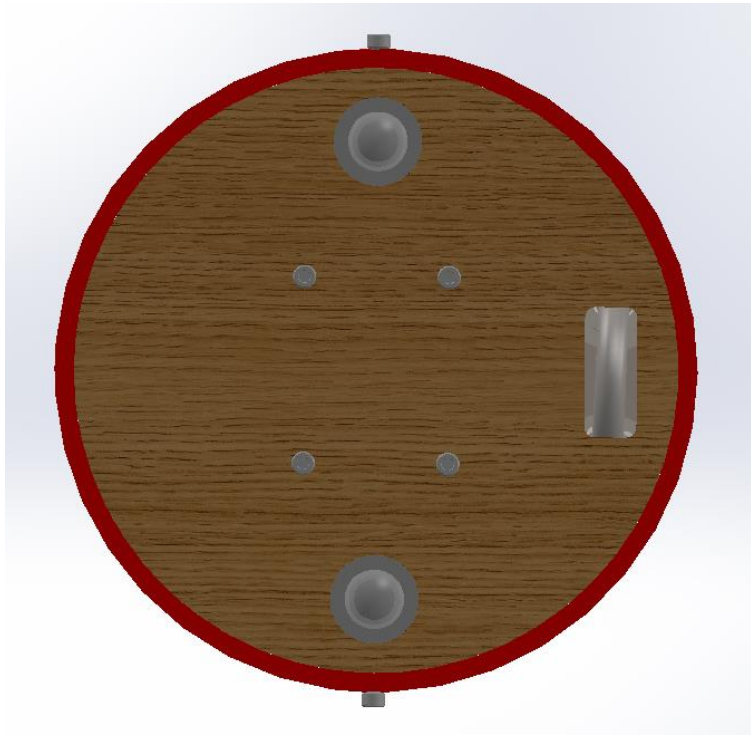
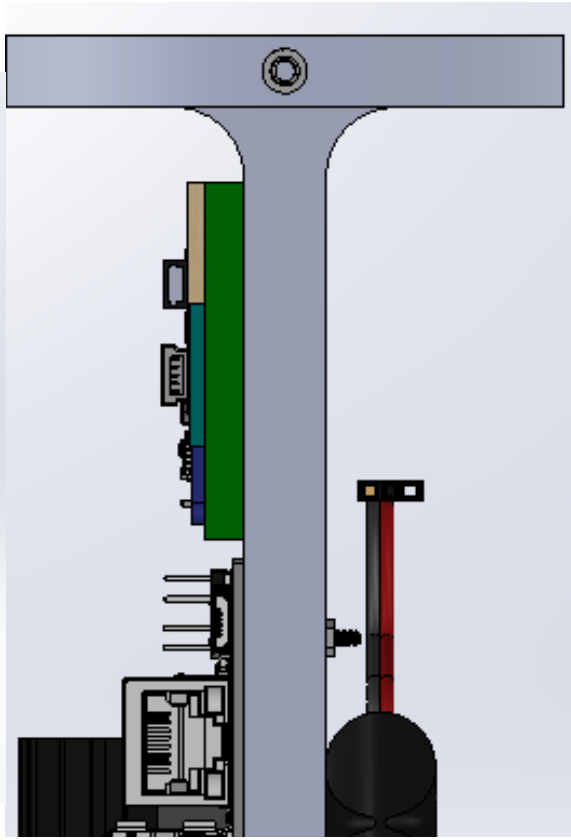
Questions?

Extra MOMO Images





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