Critical Design Review

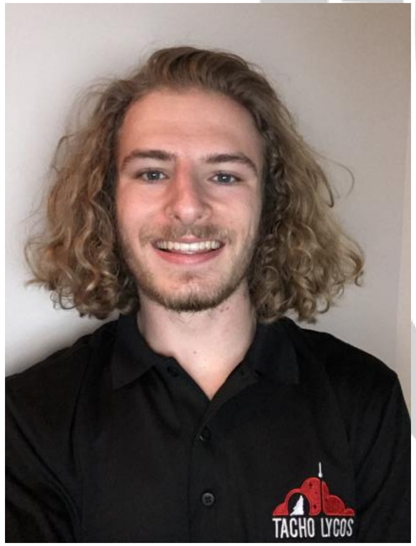
January 4, 2021

Evan Waldron
Team Lead

Alex Thomas
Structures Lead

Justin Parkan
Aerodynamics Lead

Robert Kempin
Recovery Lead



Evan Patterson
Payload Vehicle Lead

Daniel Jaramillo
Payload Integration Lead

Emma Jaynes
Payload Imaging Lead

Final Launch Vehicle Design

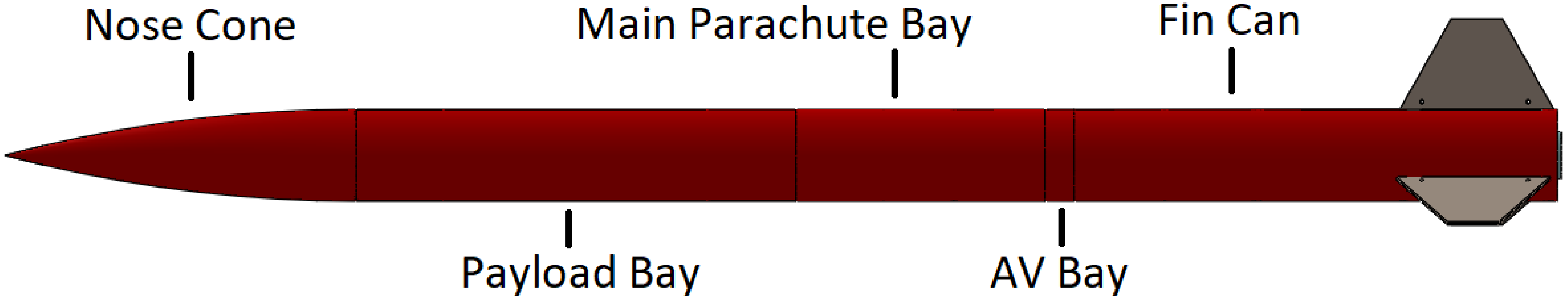
Material Selection

Airframe Sections

Fin Configuration

Launch Vehicle Dimensions

- Length: 106.25"
- Diameter: 6"
- Launch Weight: 45.4 lbs
- Empty Weight: 41.3 lbs



Material Selection

G12 Fiberglass

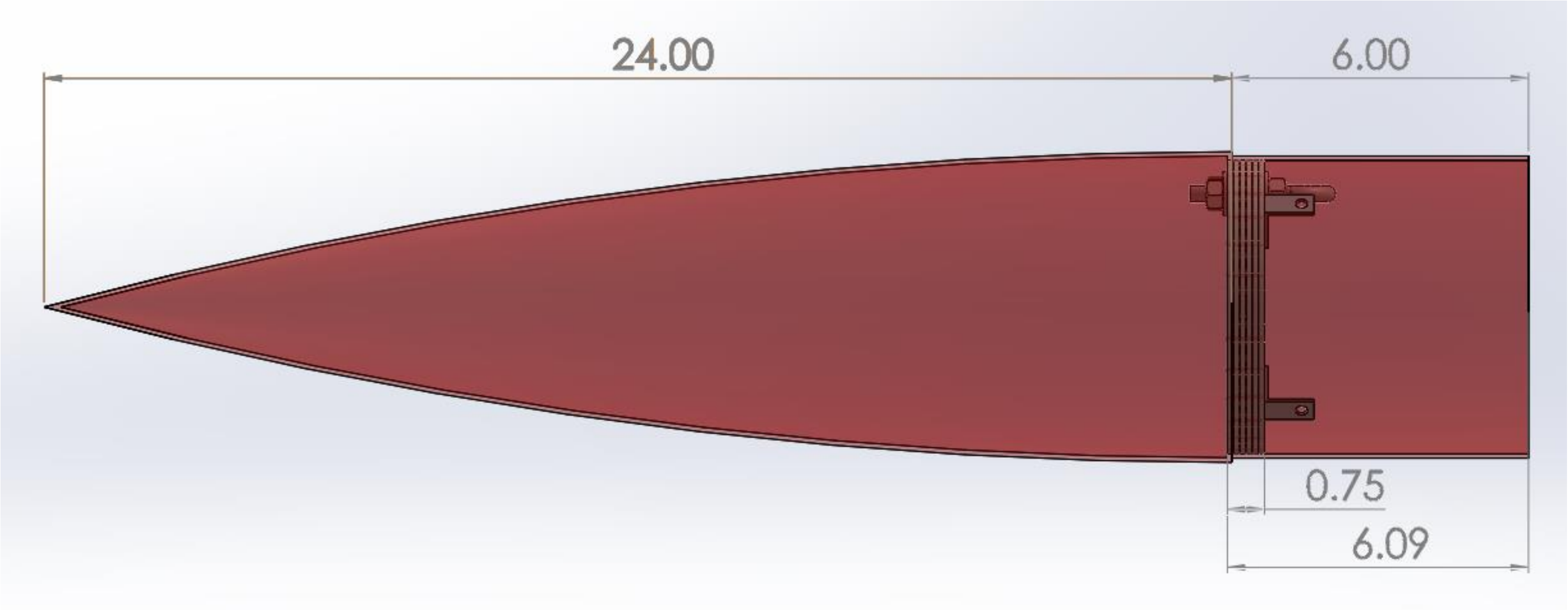
- Strong and durable
- Easily resists compressive loading and impact forces
- Moisture resistance is important for reusability of launch vehicle

Aircraft-grade Birch Plywood

- Lightweight and strong material
- 1/8" thick, two layers used for 1/4" fins
- Bulkhead thickness will vary from 1/2" to 3/4" depending on loading

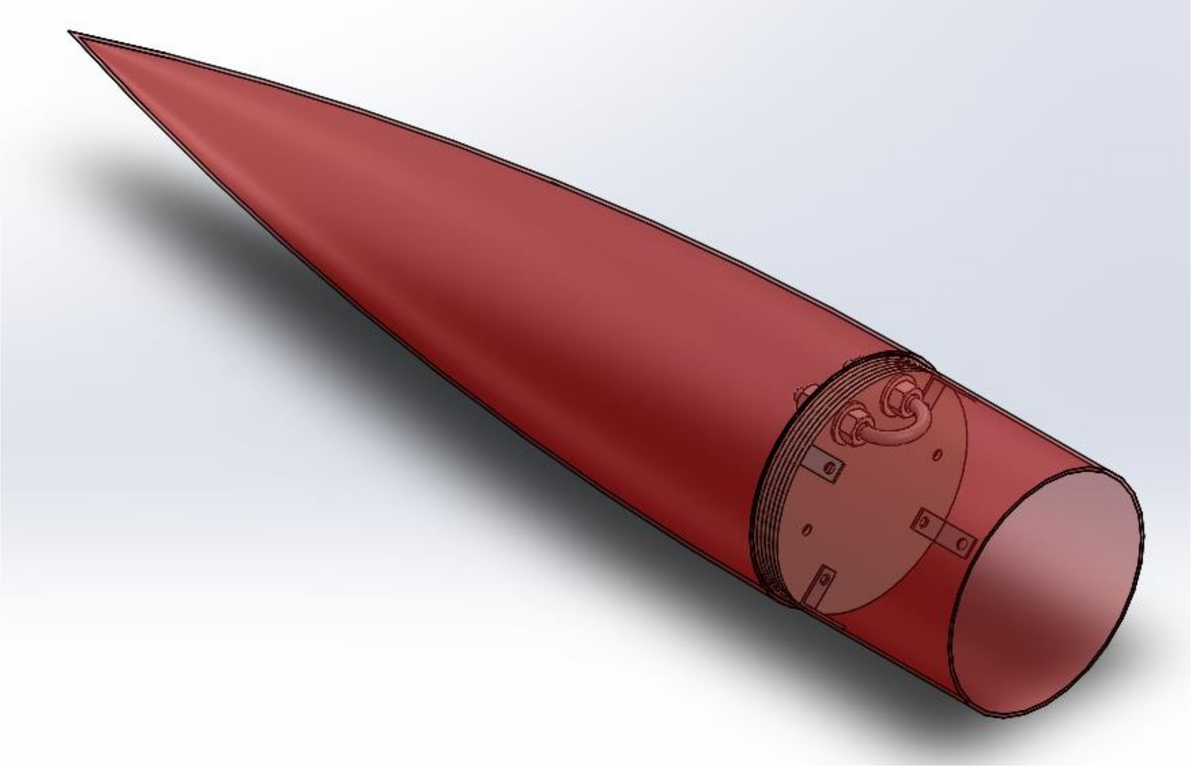
Nose Cone: 4:1 Ogive

- Commercially available for subscale and full scale
  - Ensures aerodynamic similarity
- Gives desired stability margin for launch vehicle



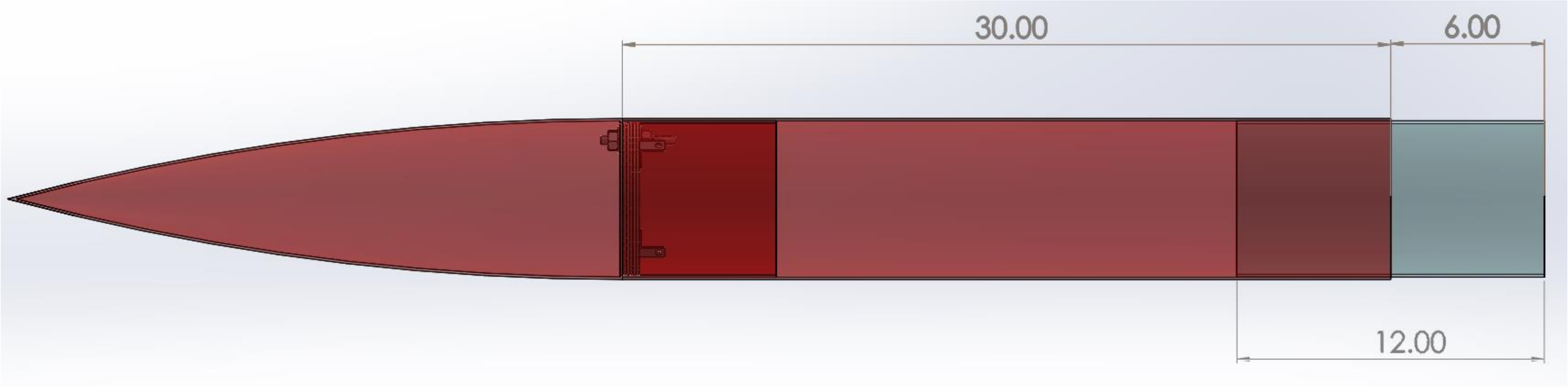
Removable Bulkhead

- Gives the option to add ballast to adjust stability as needed
- Gives space for payload integration electronics
- L-brackets will be used to mount bulkhead to nose cone



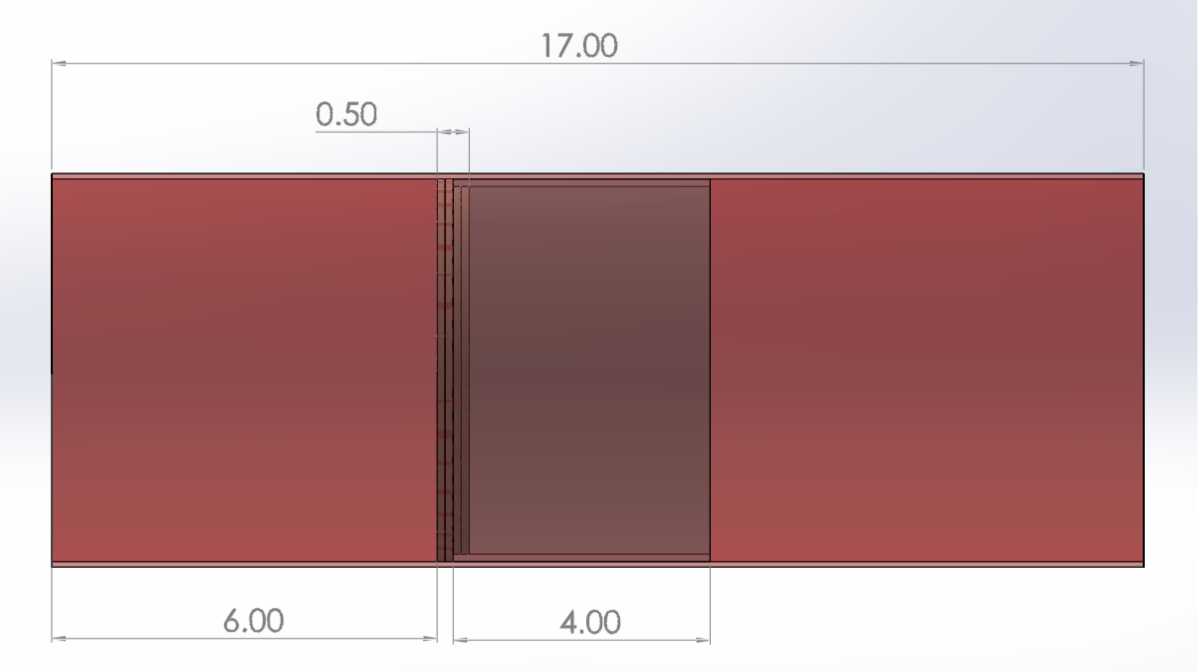
Payload Bay

- Located between nose cone and main parachute bay
- Forward location shifts CG forward for better stability
- Shear pins through body hold payload in place



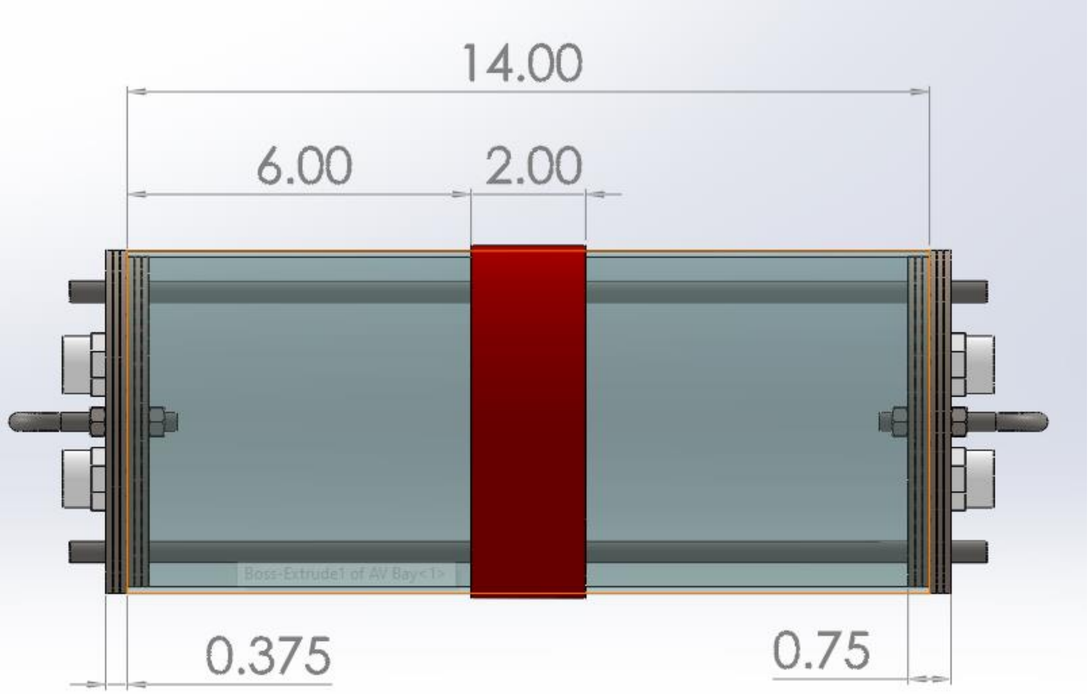
Main Parachute Bay

- Located between payload bay and AV Bay
- Main parachute packing volume: 5" D, 7" L
- Recovery material takes up 10" of main parachute bay length
- Contains piston used in main deployment



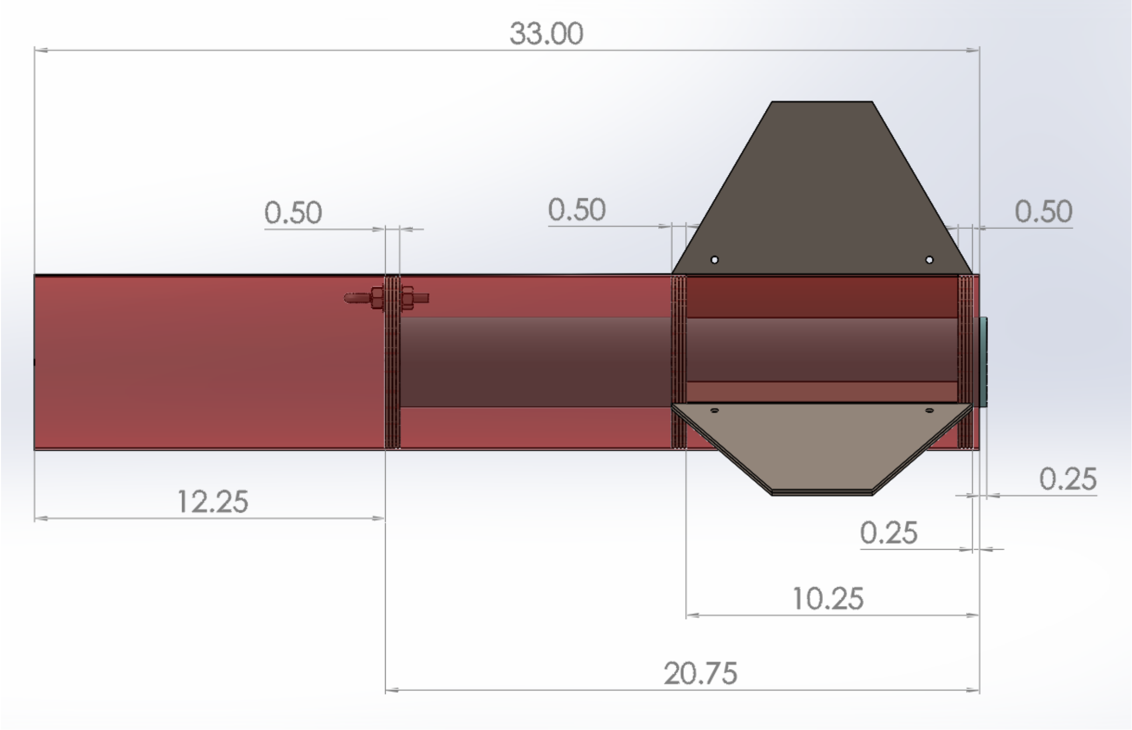
AV Bay

- Modular design allows for easily accessible AV sled
- Allows simultaneous assembly alongside launch vehicle
- Easy access to blast caps and U-bolts



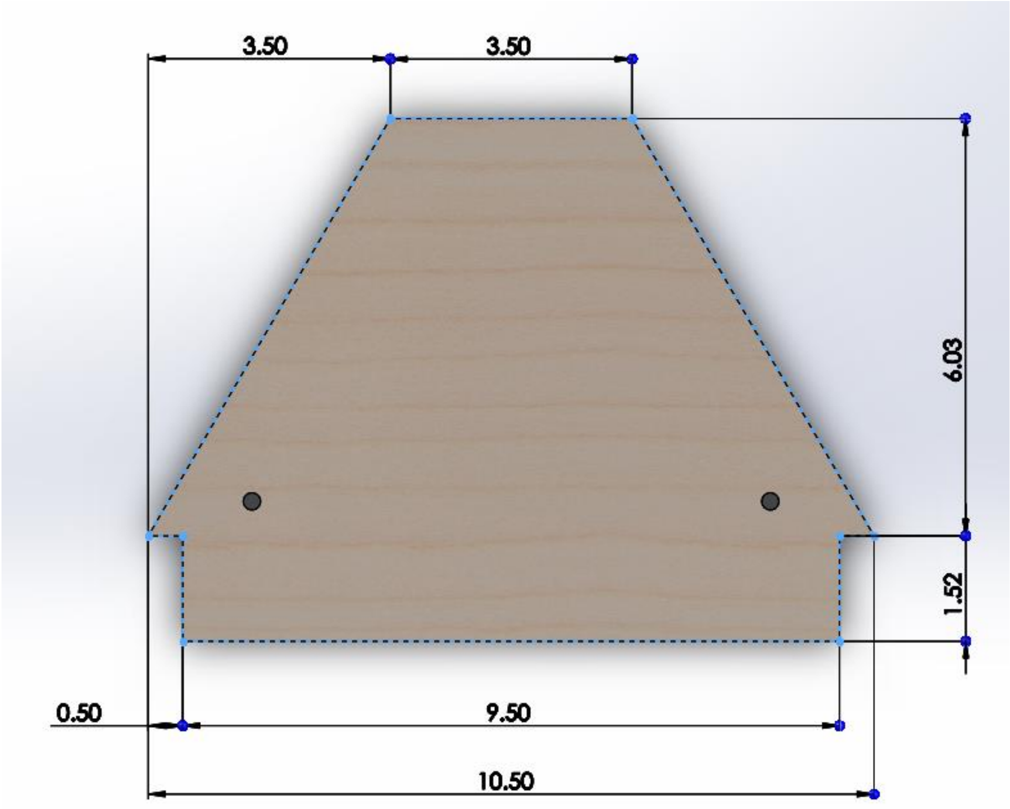
Fin Can

- Centering rings and engine block are used to align and secure motor tube
- Middle centering ring is additionally used to align and support fins
- 12.25" space forward of engine block is used to store drogue parachute



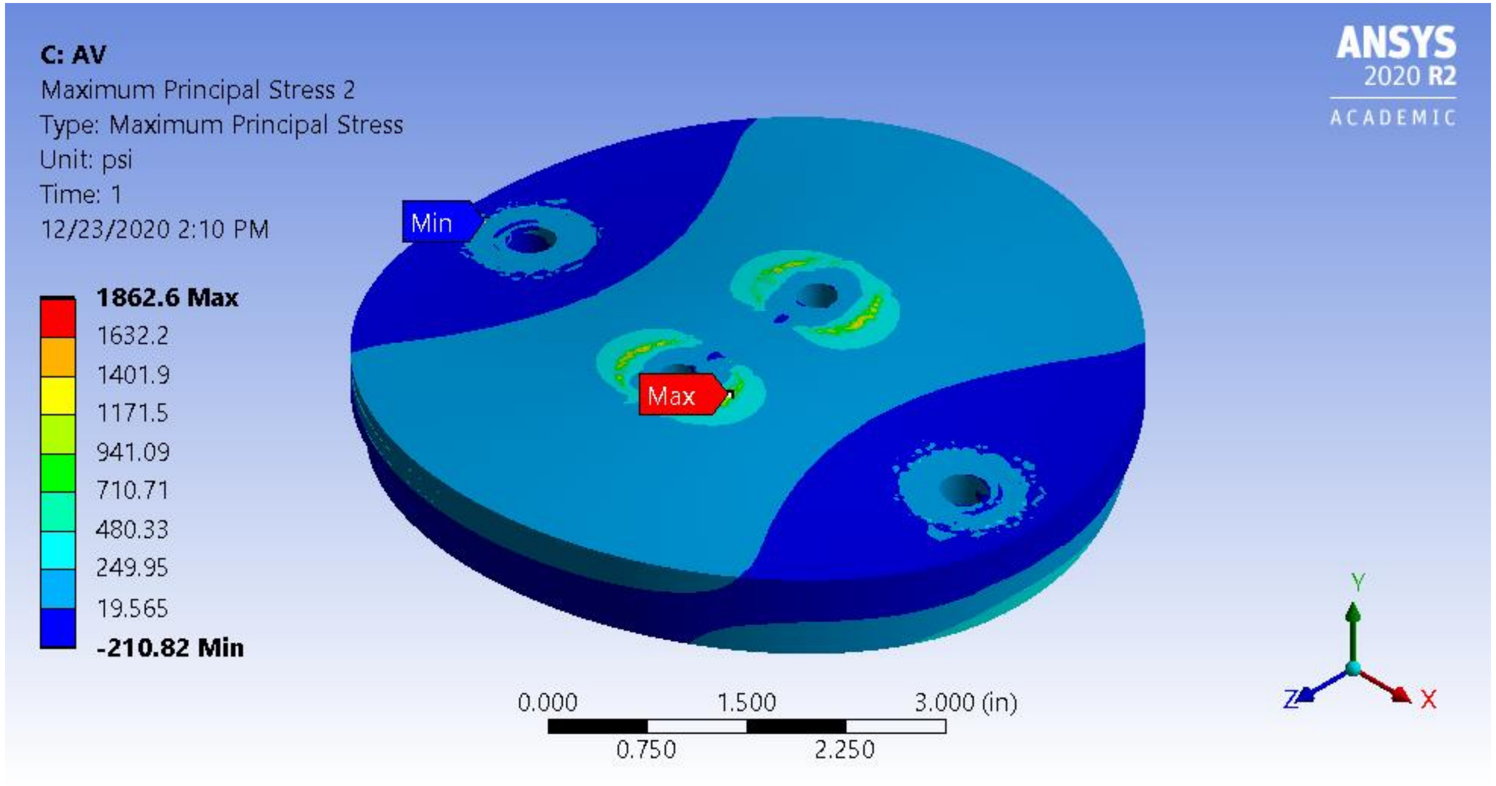
Three-Fin Configuration

- Primarily chosen for weight and drag reduction, as well as lower chance of weathercocking
- Leading-edge sweep reduces drag, pushes CP aft, increasing stability
- Trailing-edge sweep reduces drag, protects fins from damage on landing



Finite Element Analysis

- Used to determine the stress experienced by bulkheads under loading
- Helps verify that all bulkheads meet desired factor of safety



Recovery System Design

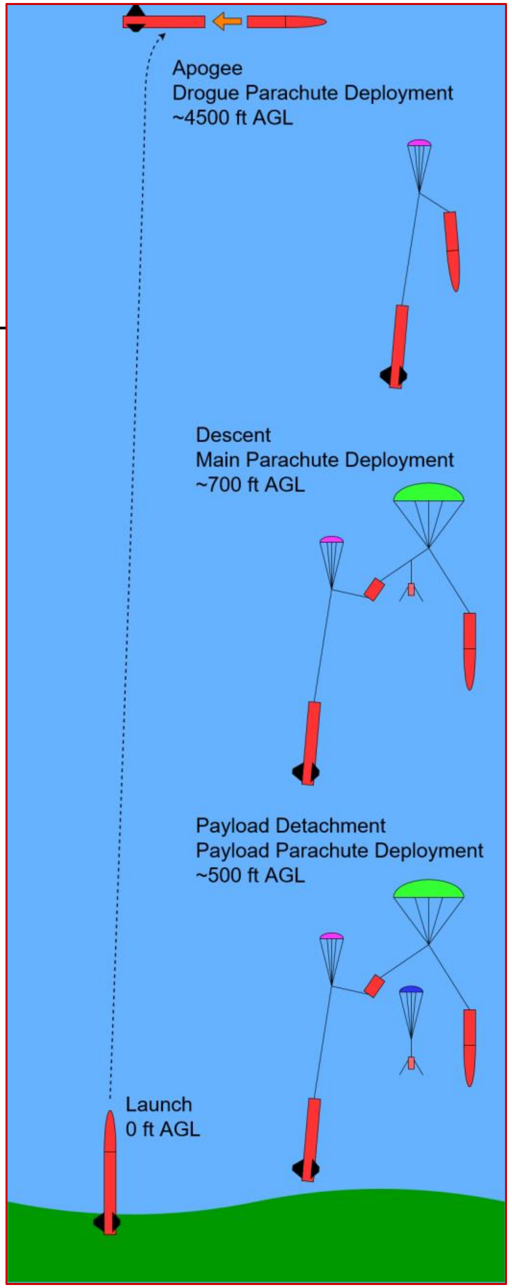
Parachute Selection

Recovery Harness

Avionics

Recovery Overview

- Drogue parachute deployment at apogee
    - Secondary at apogee + 1 sec
- Main parachute deployment at 700 ft
    - Secondary charge at 650 ft
- Payload parachute freed at 600 ft
- Payload parachute deployment at 500 ft

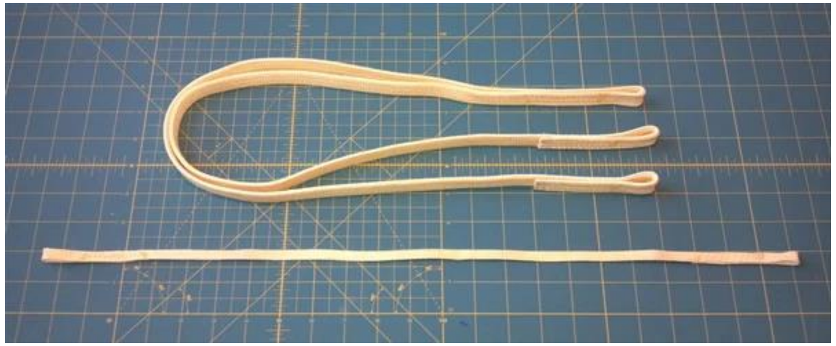


Parachutes

- Main Parachute: Fruity Chutes 120" Iris Ultra Compact
- Drogue Parachute: Fruity Chutes 18" Classic Elliptical
- Payload Parachute: Fruity Chutes 60" Iris Ultra Compact

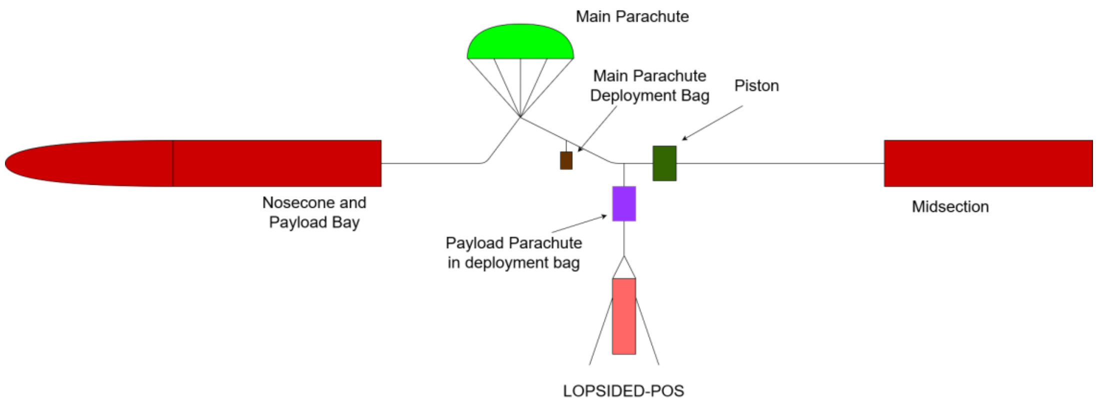
Recovery Harness

- Main and Drogue Shock Cord: 40 ft x 5/8" tubular Kevlar
- Payload Shock Cord: 15 ft x 5/8" tubular Kevlar
- Rated for 6600 lbf
- Main parachute attached 160" from nosecone bulkhead
- Drogue parachute attached 160" from aft AV bulkhead



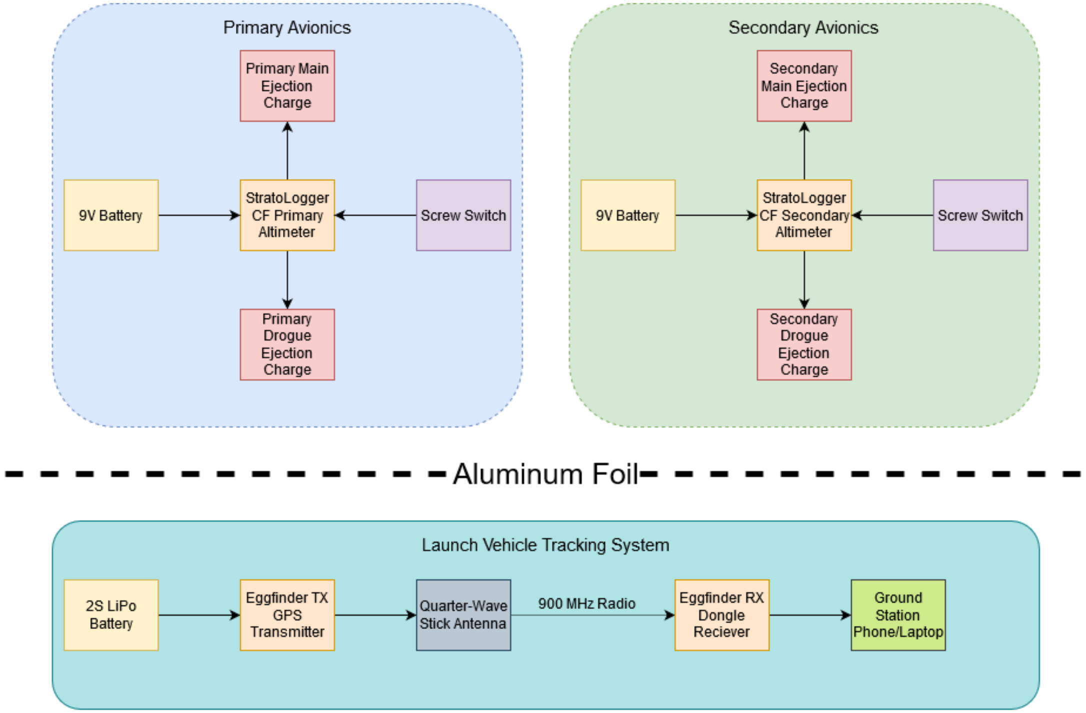
Main Recovery Harness Detail

- Payload deployment via main parachute recovery harness
- Piston ejection system used to protect payload during ejection
  - Allows smaller main ejection charges
  - Redundant Jolly Logic parachute retention system keeps payload parachute furled during main deployment



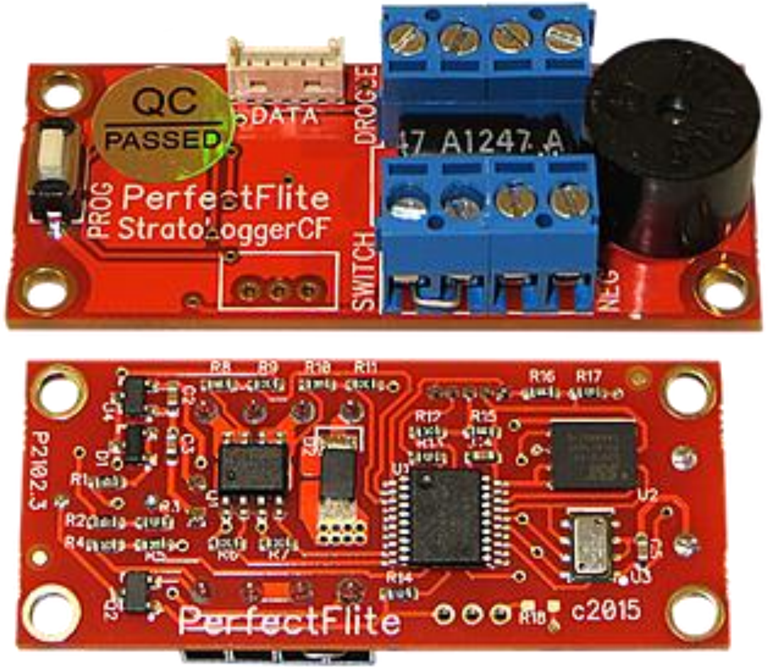
Recovery Avionics

- Two independent, redundant altimeter systems manage launch vehicle recovery
- Launch vehicle tracked via Eggfinder TX/RX GPS locator system
  - Frequency: 921 MHz, ID #8
- Payload parachute kept furled during main deployment by two cross-linked Jolly Logic parachute retention devices



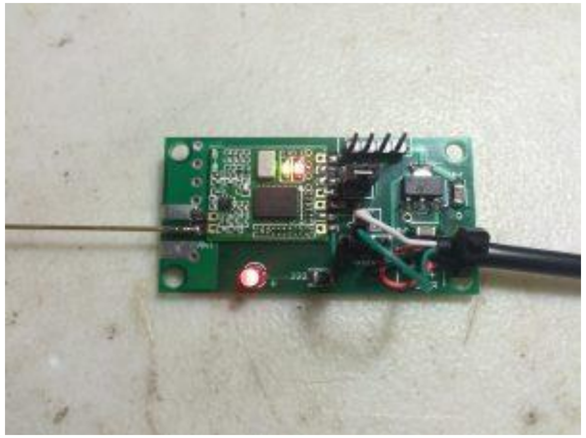
Altimeters

- All four flight altimeters will be StratoLogger CF altimeters
- Fully redundant launch vehicle recovery system
- Primary
  - Drogue: Apogee, 2.6 g charge
  - Main: 700 ft, 2.9 g charge
- Secondary
  - Drogue: Apogee + 1 sec, 3.1 g charge
  - Main: 650 ft, 3.4 g charge
- Payload Latch
- Payload Release



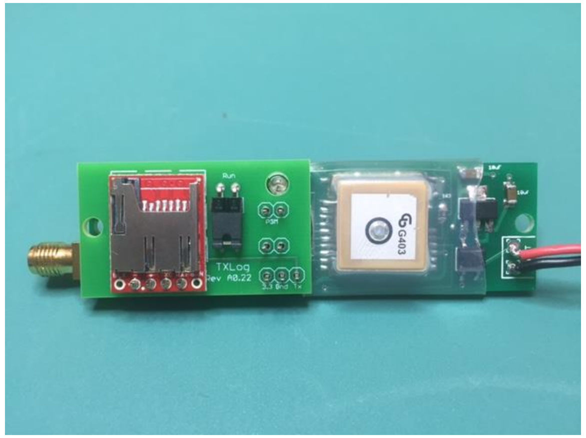
Eggfinder GPS Tracking System

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



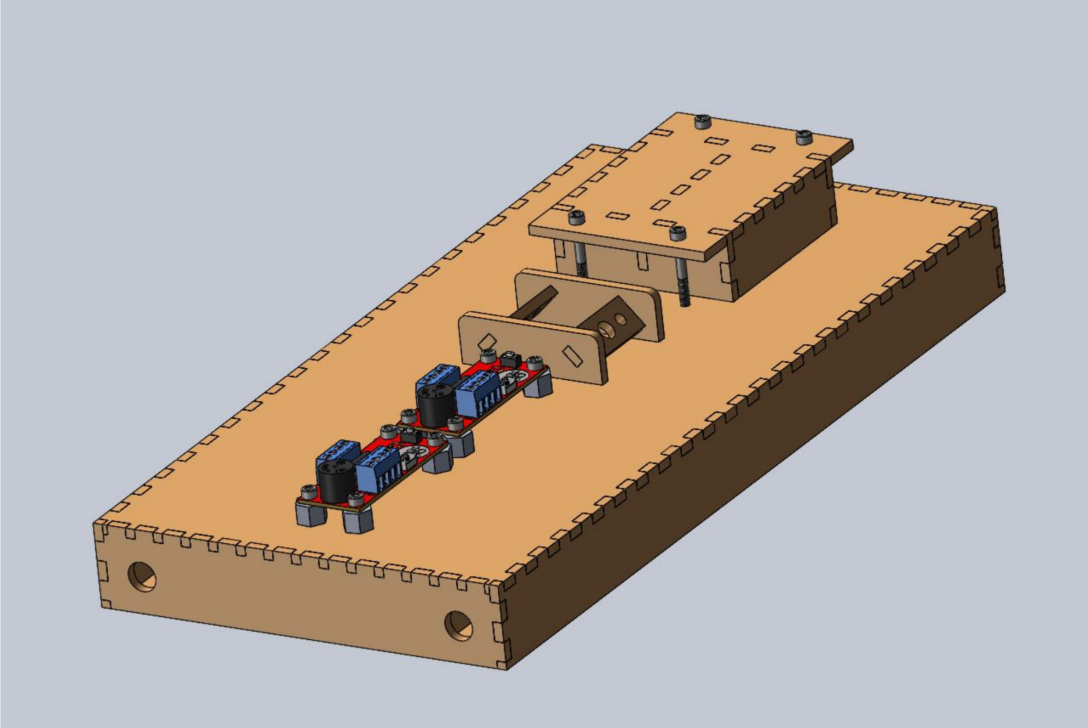
Eggfinder RX Receiver

Eggfinder TX Transmitter



Avionics Sled

- Material selection: Aircraft grade birch plywood
- Current Design:
    - Provides for internal wiring
    - Mounts altimeters, screw switches, launch vehicle tracker, and batteries



Mission Performance Predictions

Target Apogee

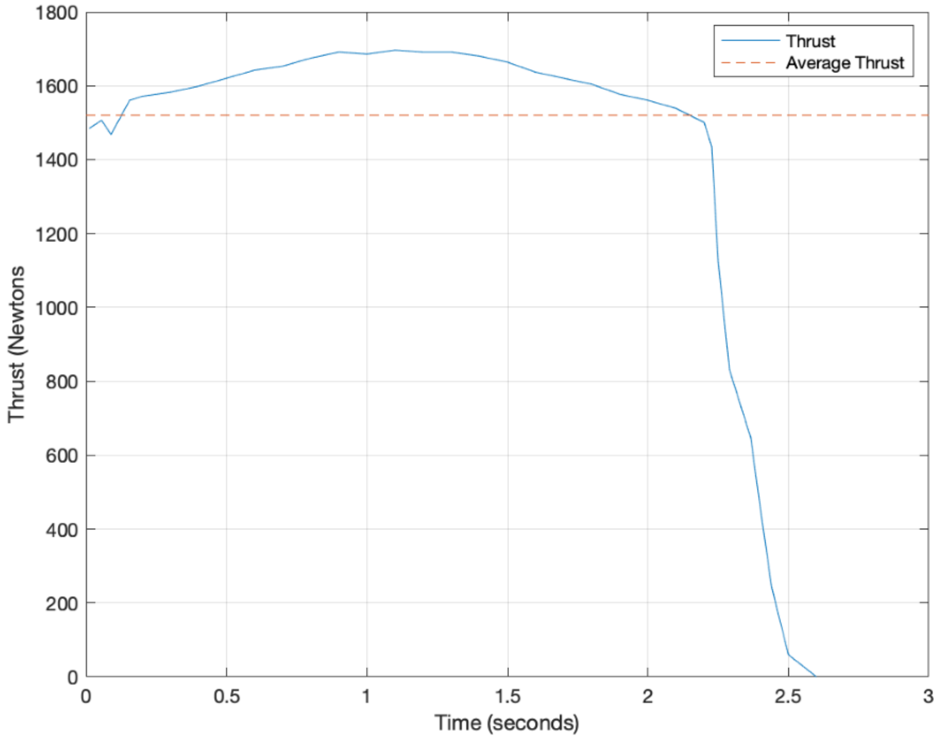
Stability Margin

Wind Drift

Recovery Forces

Motor Selection

- AeroTech L1520T
- Short burn time
- High Max and Average Thrust
- RMS 75/3840 Casing

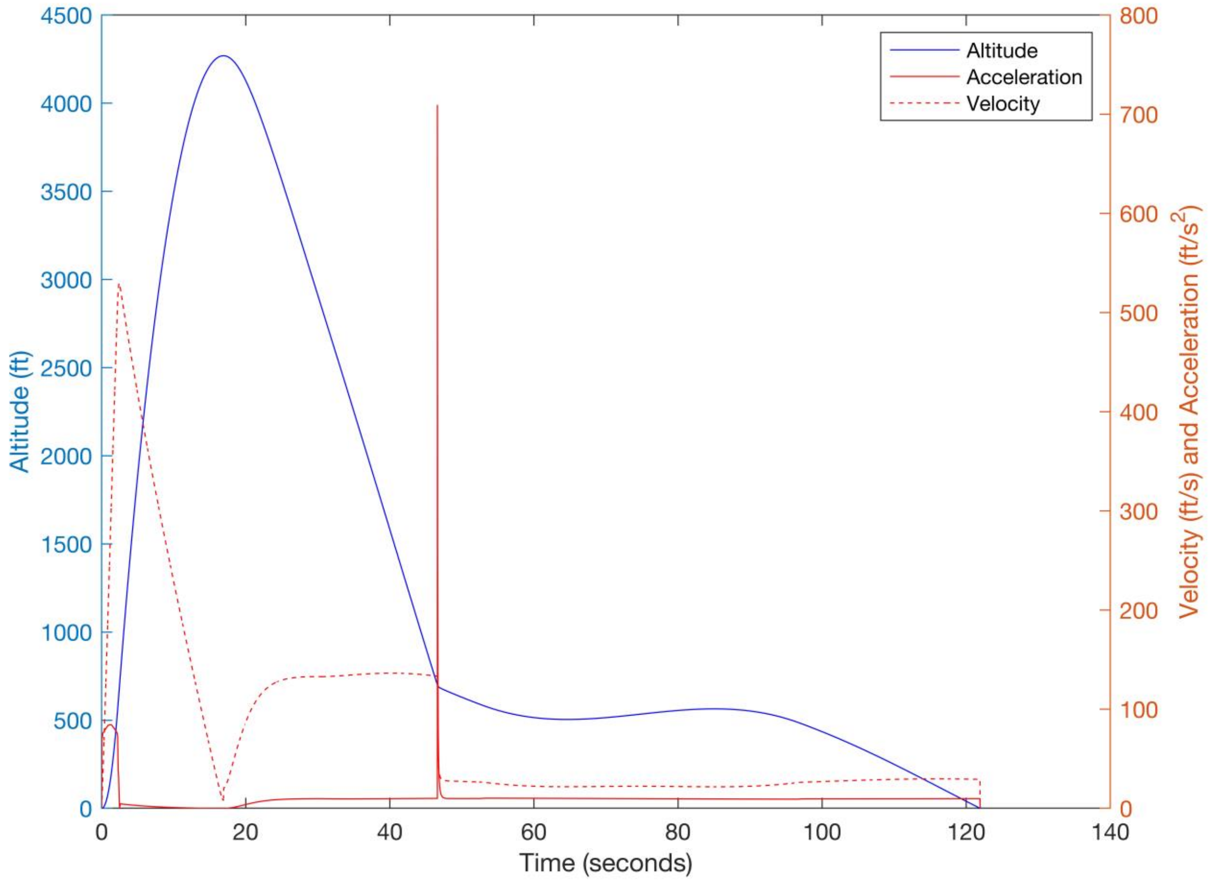


Target Altitude

4473 feet

Based on

- 3 - 14.9 MPH winds
- 5° cant of the launch rail
- 144" launch rail

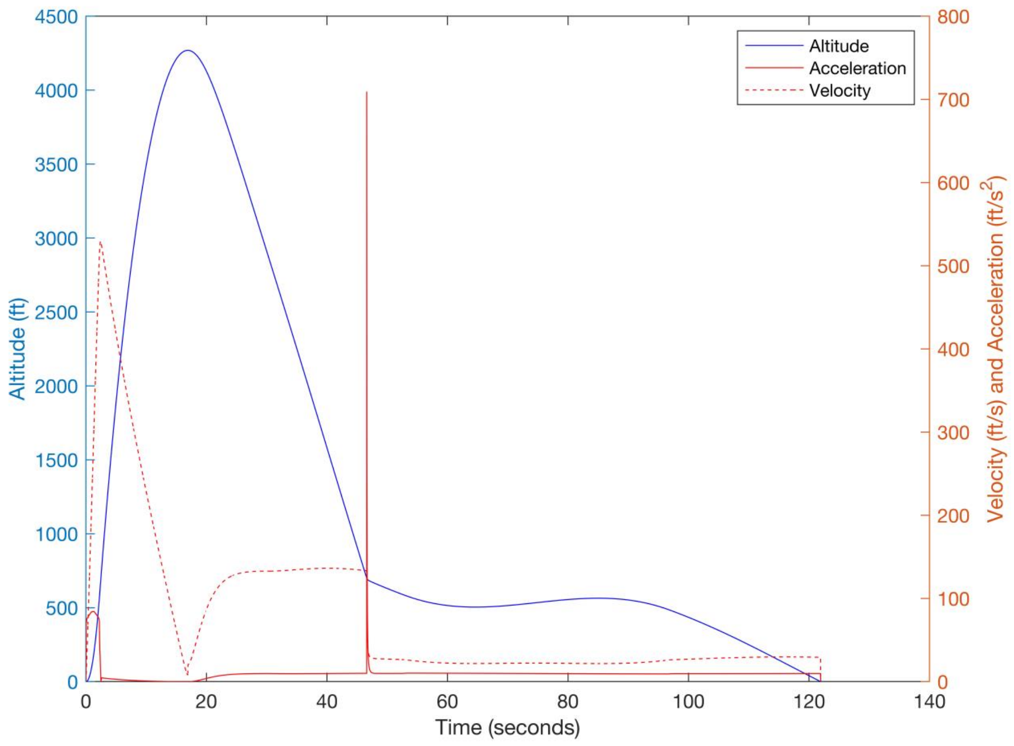


Predicted Apogee

<u>4293 feet</u>

<u>Reason</u>

- Weighing constructed parts rather than estimates
- Better accounting for small parts in simulations

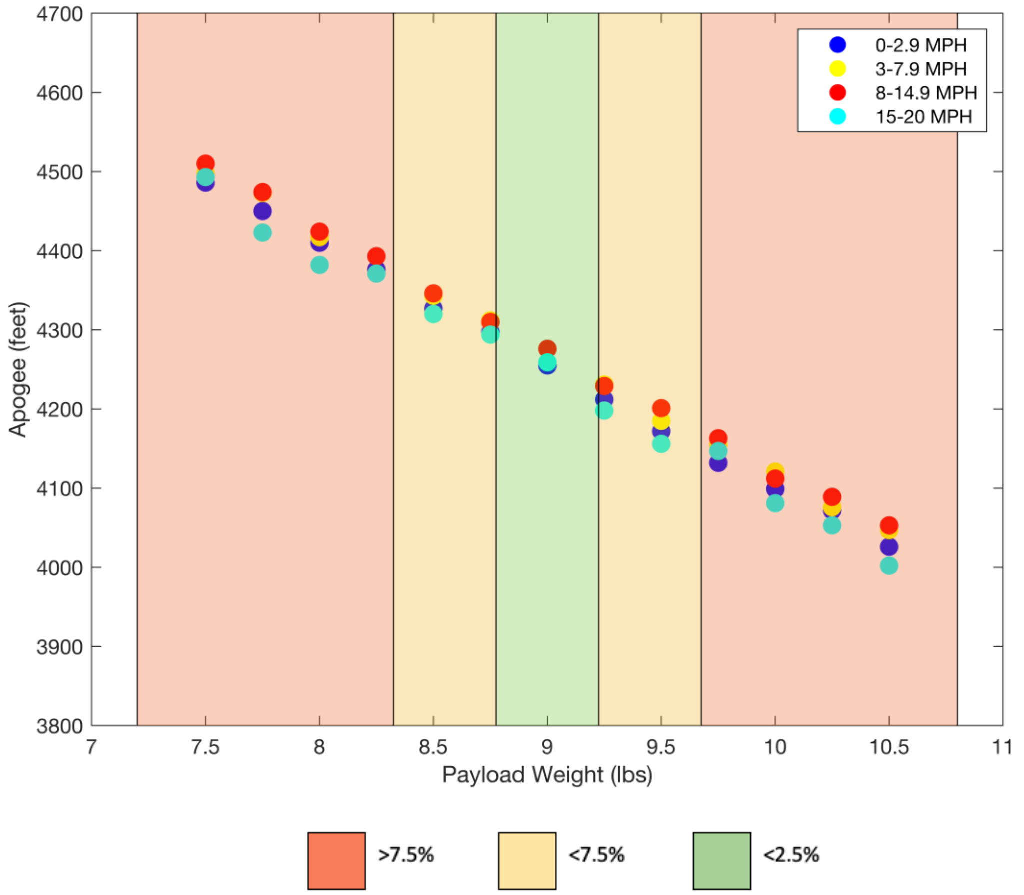


Other Key Flight Characteristics

- Velocity at Launch Rail Departure: 72.70 ft/s
- Peak Velocity: 532.67 ft/s
- Peak Mach: 0.471 Mach
- Peak Acceleration: 684.40 ft/s^2
- Thrust to Weight Ratio: 7.52

Apogee Uncertainty

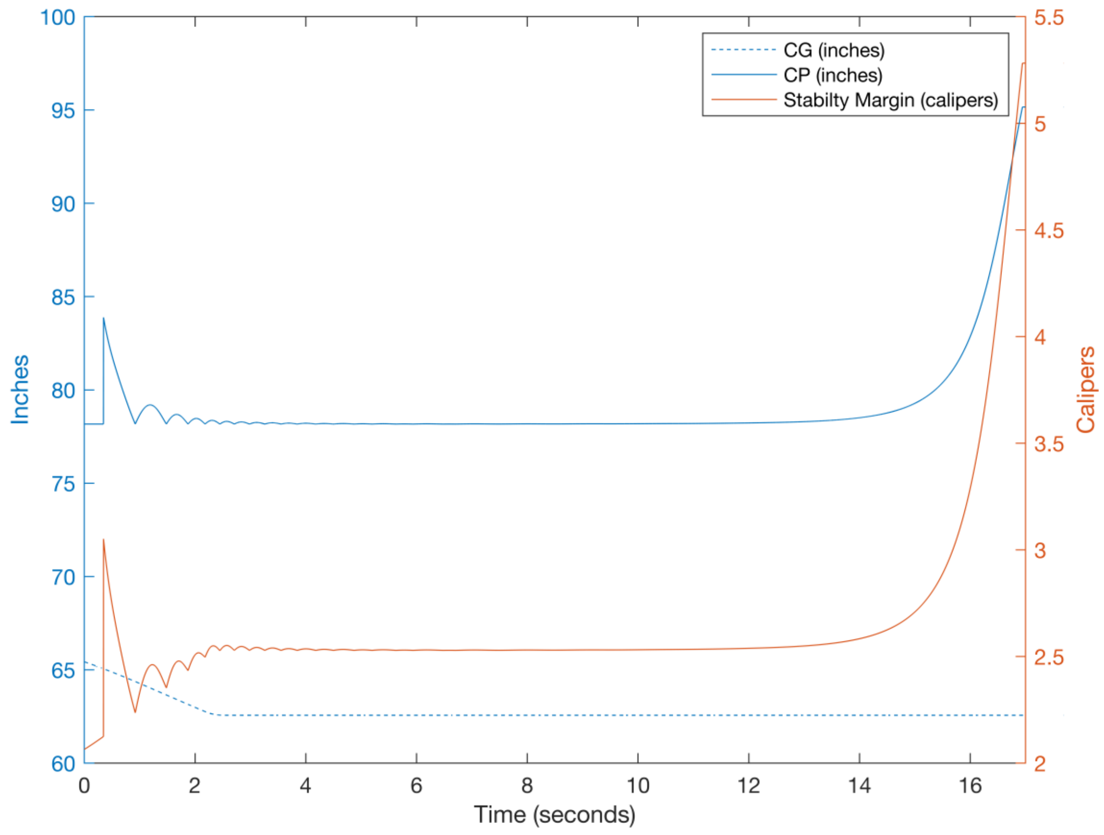
Uncertainty
- Wind Speed
- Payload Weight



Static Stability Margin of Launch Vehicle

- Initial: 2.07
- At departure of Launch Rail: 2.1

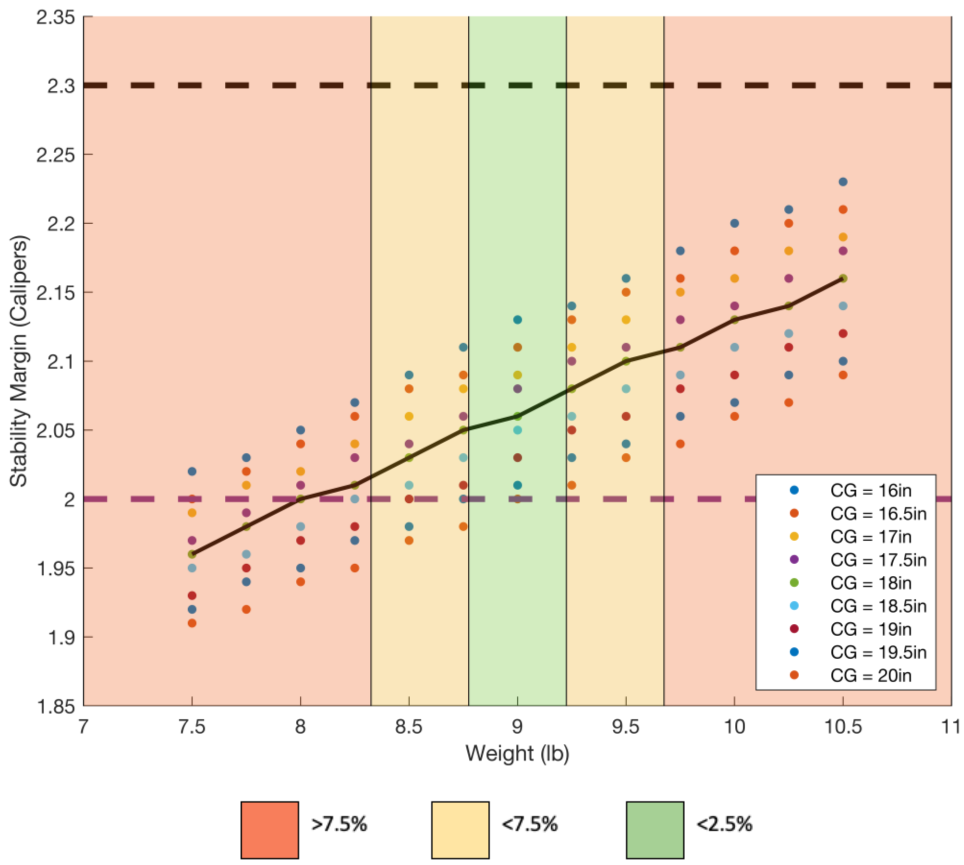
Computational Method	Static Margin (Calipers)
Barrowman's Method	2.20
RockSim	2.07



Stability Margin Uncertainty

Uncertainty

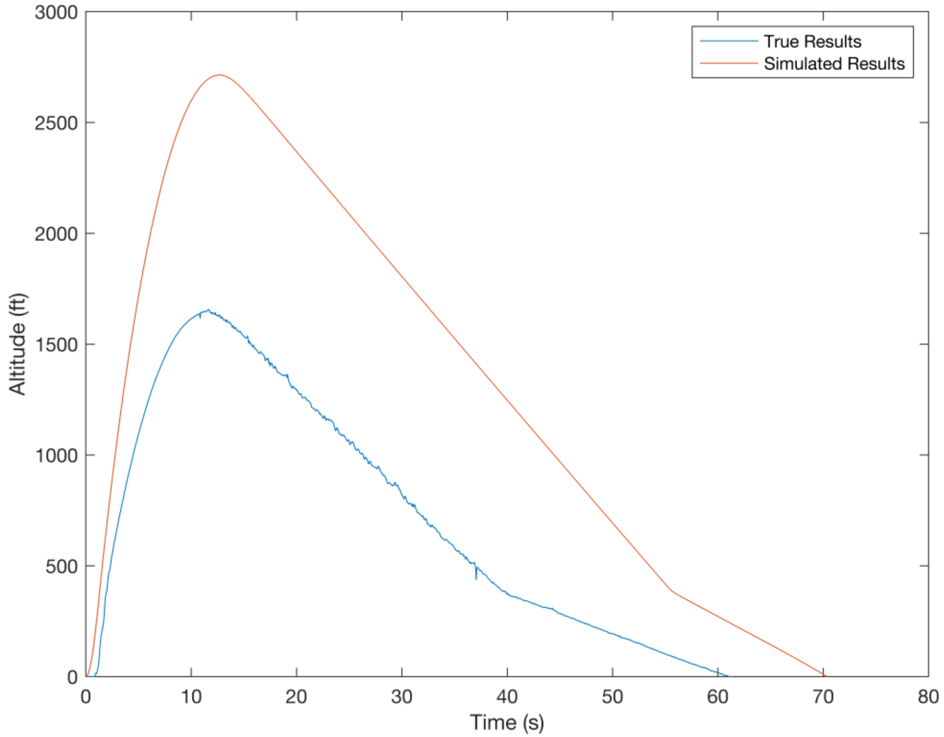
- Payload Weight
- Payload CG



Subscale Flight Results

Predicted Apogee: 2700 ft

Recorded Apogee: 1657 ft



Reason

- Underestimation of Weight
- Reduced Stability

Wind Drift

- Downrange movement due to field wind conditions
  - Descent Time: 85 s
  - Drift @ 20 mph: 2490.9 ft
  - Apogee assumed to be directly above launch pad

Speed	Apogee	Descent Time	Drift Distance
0 mph	4473 ft	85 s	0 ft
5 mph	4473 ft	85 s	622.7 ft
10 mph	4473 ft	85 s	1245.5 ft
15 mph	4473 ft	85 s	1868.2 ft
20 mph	4473 ft	85 s	2490.9 ft

Kinetic Energy Under Drogue

- Large kinetic energy under drogue resulting from rapid descent
- Critical importance of successful main parachute deployment

Section	Mass	Descent Velocity	Kinetic Energy
Nosecone and Midsection	0.9161 slugs	117.4 ft/s	6310.7 ft-lbf
Fin can	0.3686 slugs	117.4 ft/s	2539.3 ft-lbf

Kinetic Energy at Landing

- Consider three cases
  - Payload successfully deployed
  - Payload exits payload bay but remains attached to recovery harness
  - Payload fails to exit payload bay
- Worst case scenario: Payload remains in payload bay
  - Nosecone w/ Payload mass: 0.5704 slugs
  - Maximum section kinetic energy: 60.0 ft-lbf

Section	Mass	Descent Velocity (Payload attached)	Descent Velocity	Kinetic Energy (Payload attached)	Kinetic Energy
Nosecone	0.2907 slugs	14.5 ft/s	12.8 ft/s	30.6 ft-lbf	23.9 ft-lbf
Nosecone w/ Payload	0.5704 slugs	14.5 ft/s	N/A	60.0 ft-lbf	N/A
Payload	0.2797 slugs	14.5 ft/s	N/A	29.4 ft-lbf	N/A
Midsection	0.3457 slugs	14.5 ft/s	12.8 ft/s	36.4 ft-lbf	28.4 ft-lbf
Fin can	0.3686 slugs	14.5 ft/s	12.8 ft/s	38.8 ft-lbf	30.3 ft-lbf

Main Parachute Opening Shock

- Confirm that the recovery harness can withstand opening shock
  - Launch Vehicle mass load at main parachute deployment: 387.8 lbf
  - Kevlar shock cord rated for 6600 lbf
  - Shock Cord FS of ~17

Section	Mass	Opening Shock
Forward Section	0.5704 slugs	172.2 lbf
Midsection and Fin Can	0.7143 slugs	303.4 lbf

Payload Recovery Parameters

- Maximum Wind Drift: 2445.2 ft @ 20 mph
- Kinetic Energy at Landing: 25.0 ft-lbs.
- Velocity at Landing: 13.4 ft/s
- Descent Time: 100 s

Speed	Descent Time	Drift Distance
0 mph	100.2 s	0 ft
5 mph	100.2 s	611.3 ft
10 mph	100.2 s	1222.6 ft
15 mph	100.2 s	1833.9 ft
20 mph	100.2 s	2445.4 ft

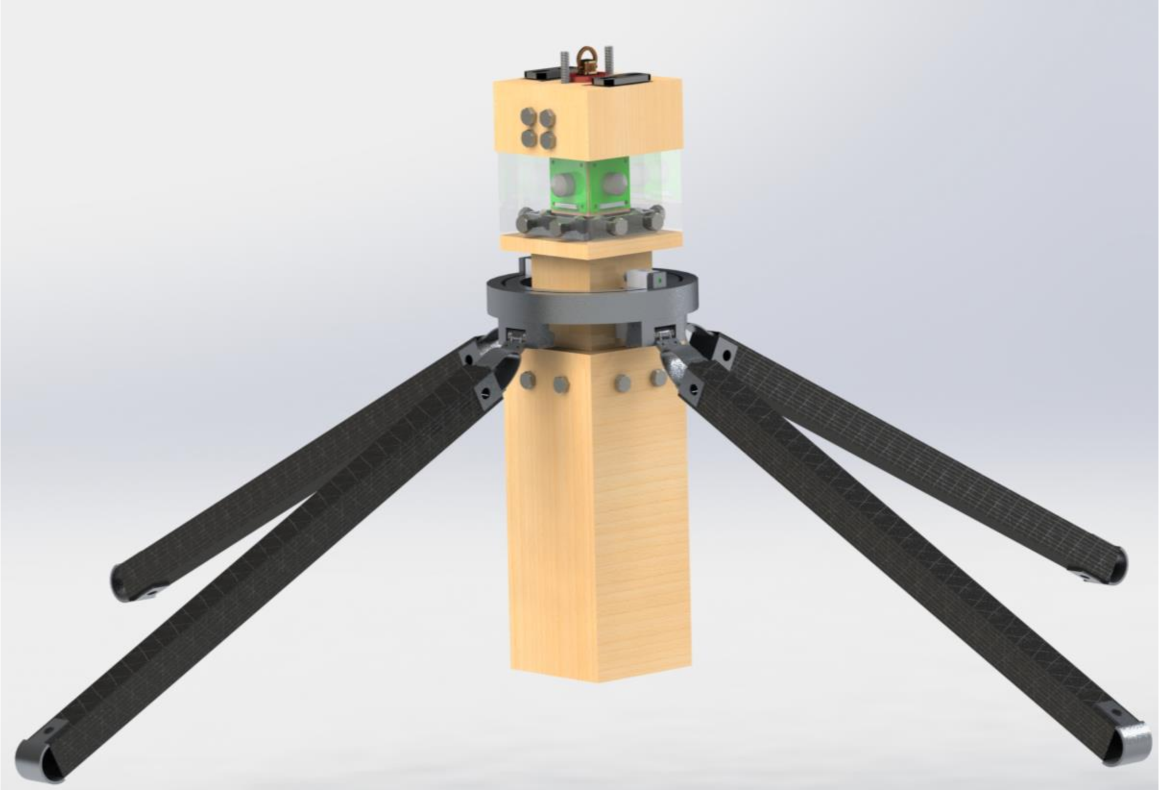
Payload Design

LOPSIDED

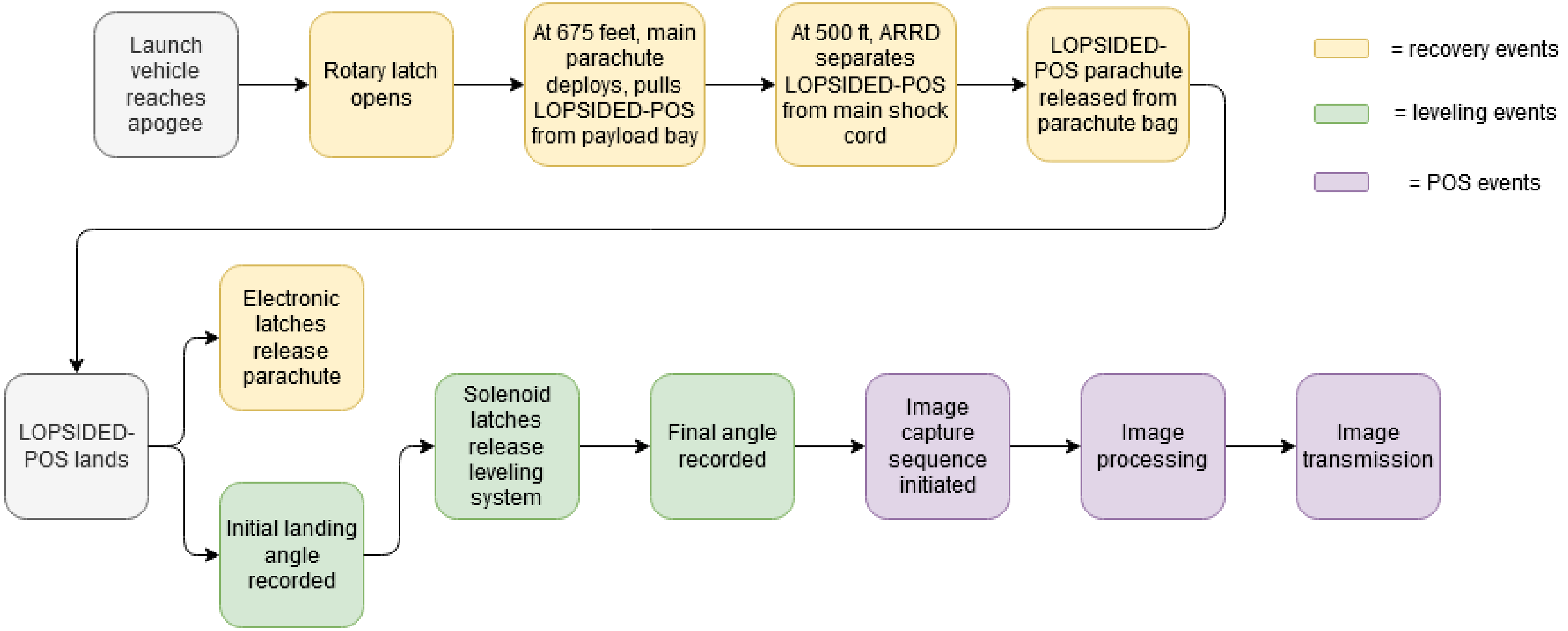
POS

LOPSIDED

- Lander for Observation of Planetary Surface Inclination, Details, and Environment Data
- Main Objectives:
  - House the Planetary Observation System (POS)
  - Land and take initial orientation measurement
  - Re-orient within 5° of vertical using levelling system
  - Record new orientation measurement

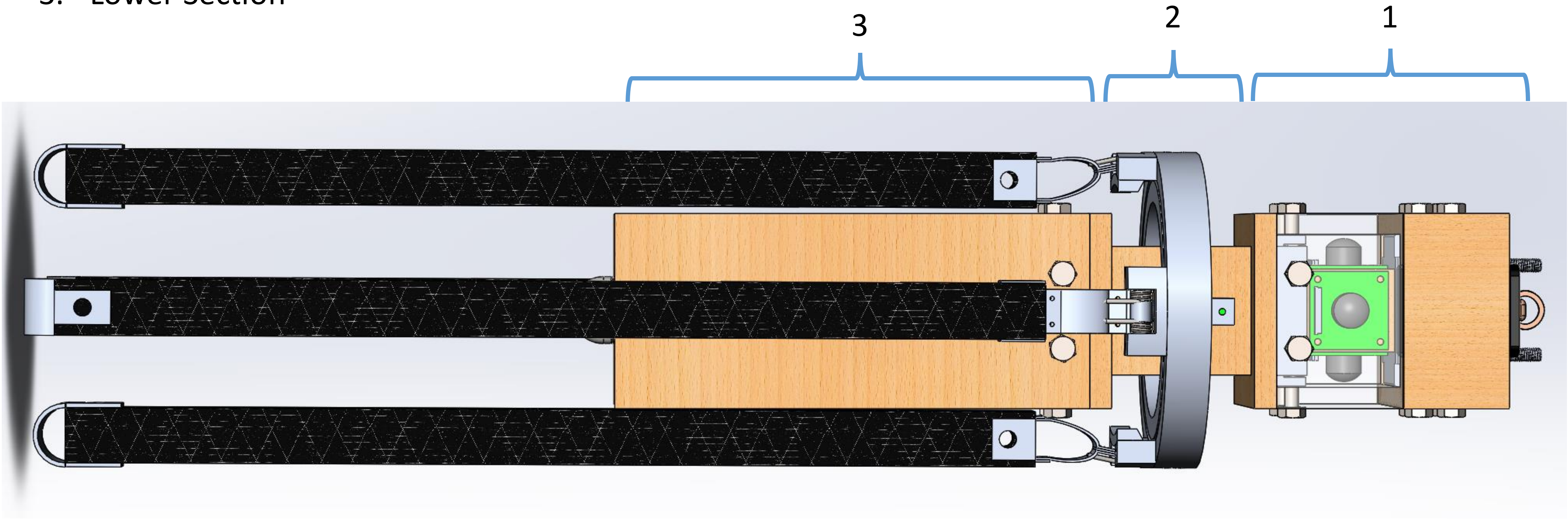


LOPSIDED-POS Sequence Flowchart



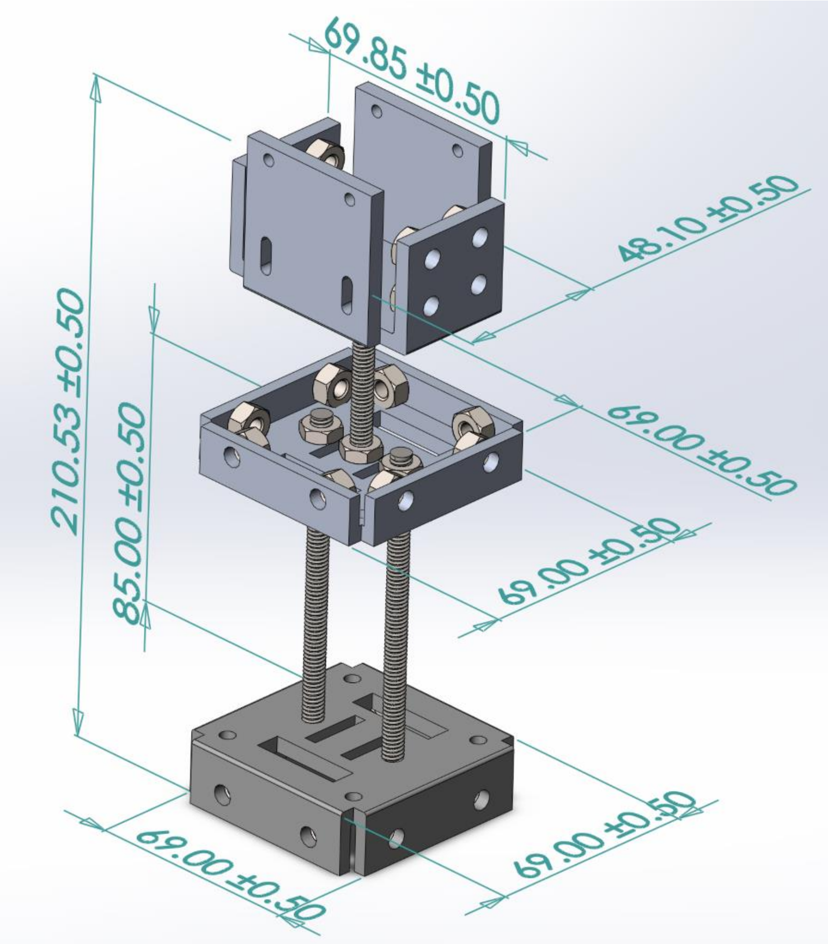
LOPSIDED Sections

1. Upper Section
2. Middle Section
3. Lower Section



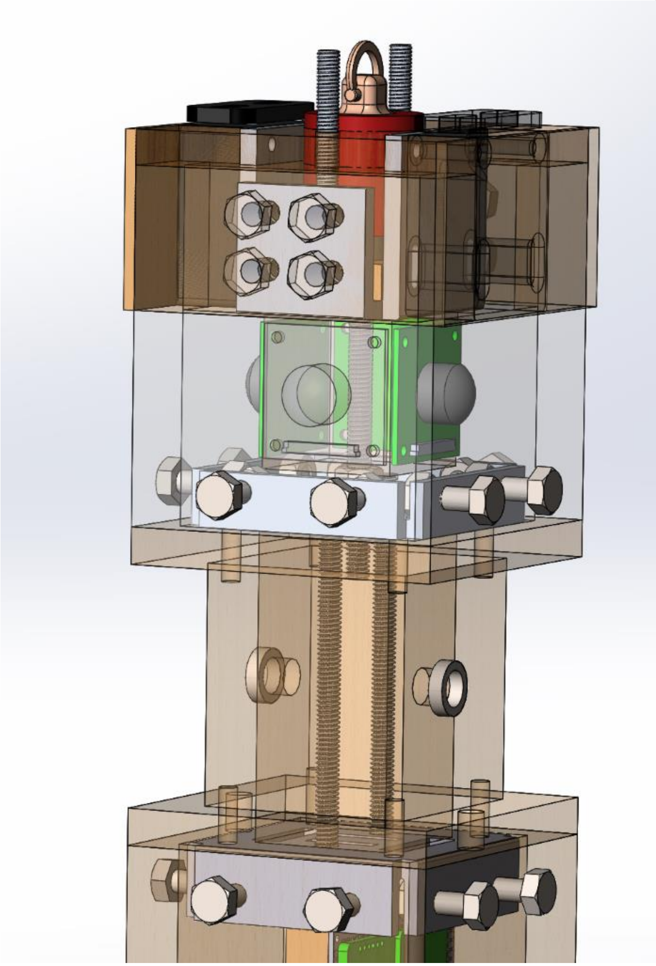
Structural Frame

- Used as an assembly structure
  - All three body parts will be mounted to it
  - Fits snugly between body sections
- Used to bear and distribute opening shock load

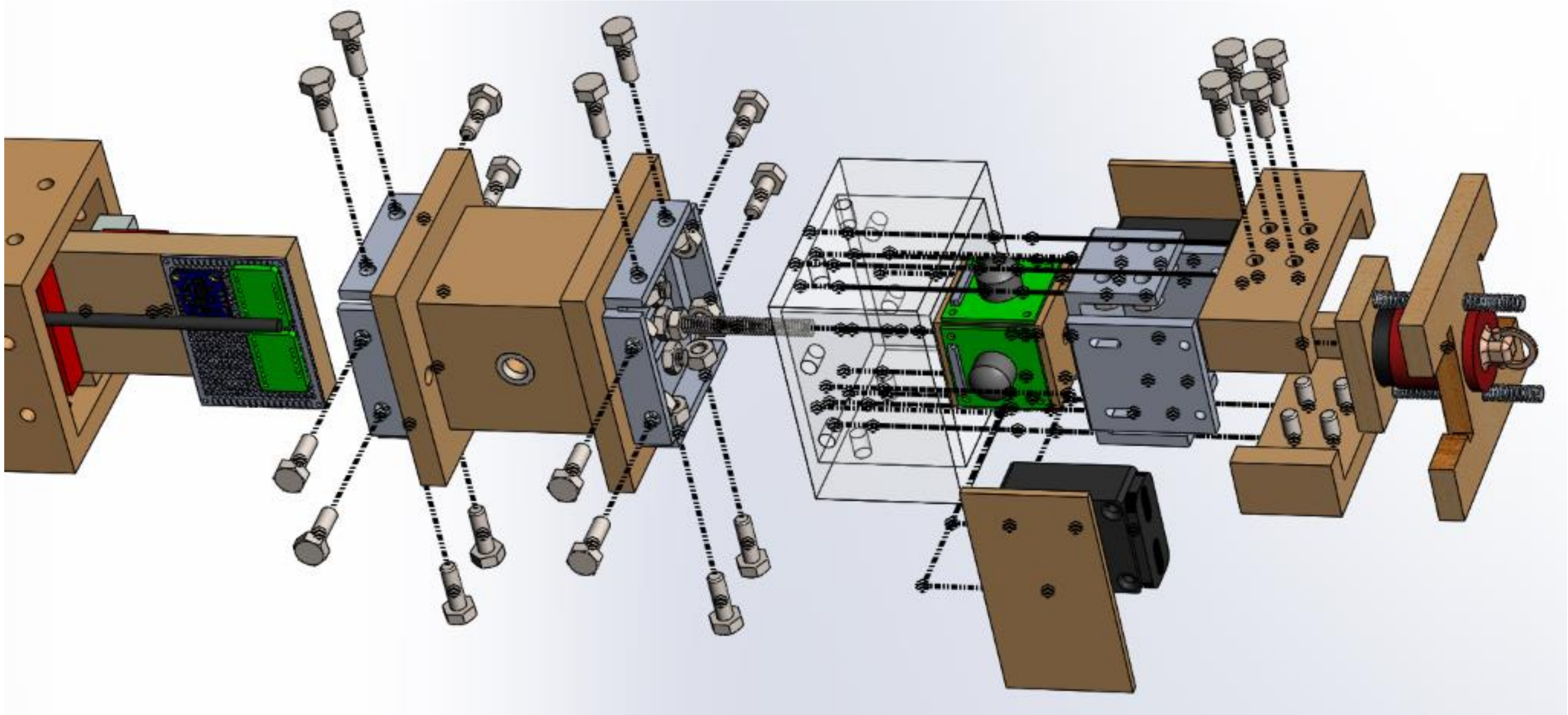


Structural Frame

- The ARRD and latches will be mounted on the upper section with the POS cameras beneath it and the wood panels on the side
- The middle piece will bolt onto the polycarbonate screen
- 2 bolts run between the middle and lower pieces that will hug the middle section.

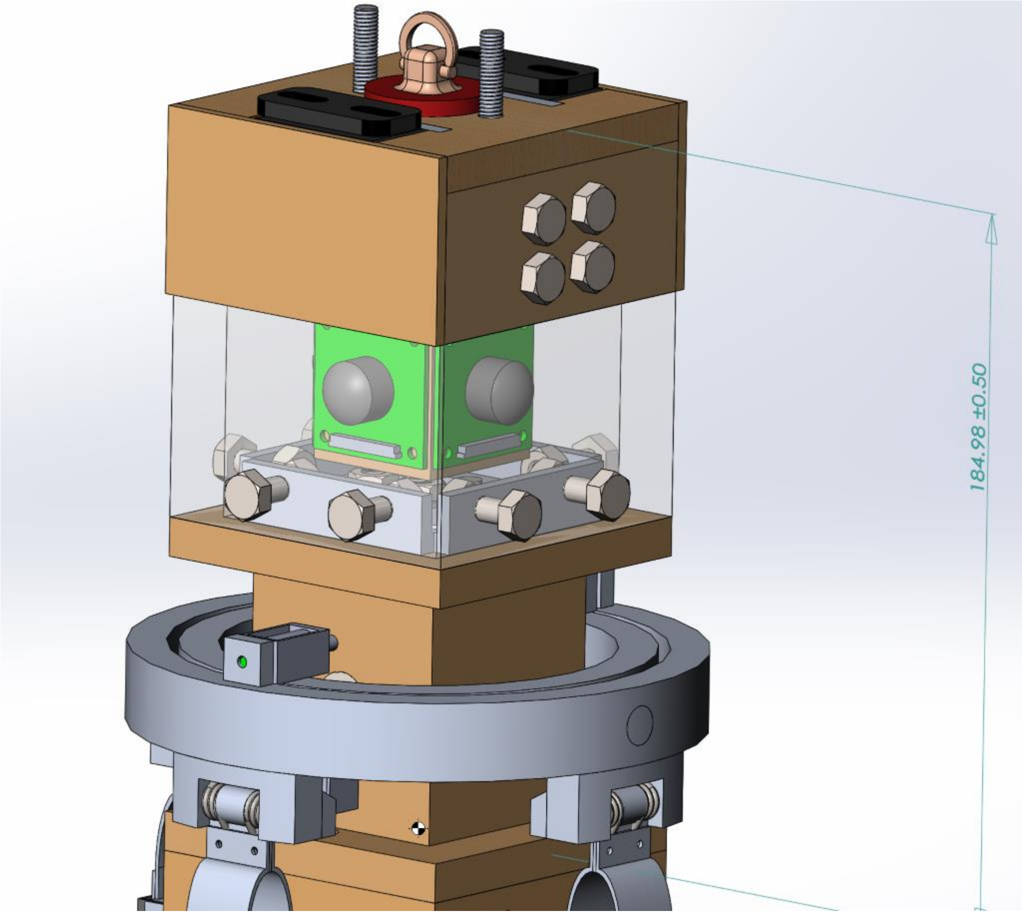


- Assembly



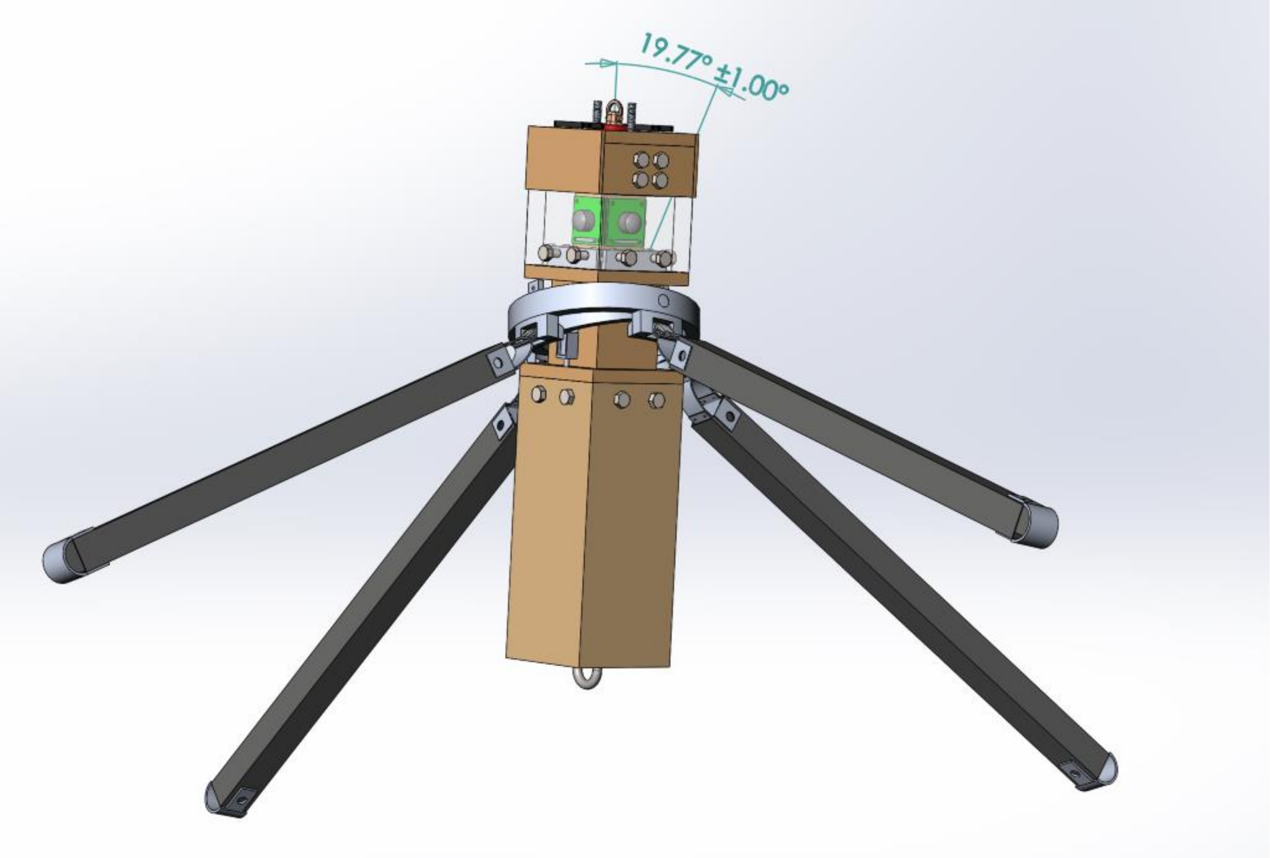
Levelling and Chassis Design

- 2-axis (both horizontal) gyroscopic levelling
  system driven by the force due to gravity
  - CG will be beneath the two axes
    - A ballast will be placed at the bottom of the chassis to achieve this
- The chassis will feature a cutout to increase the rings' range of tilt



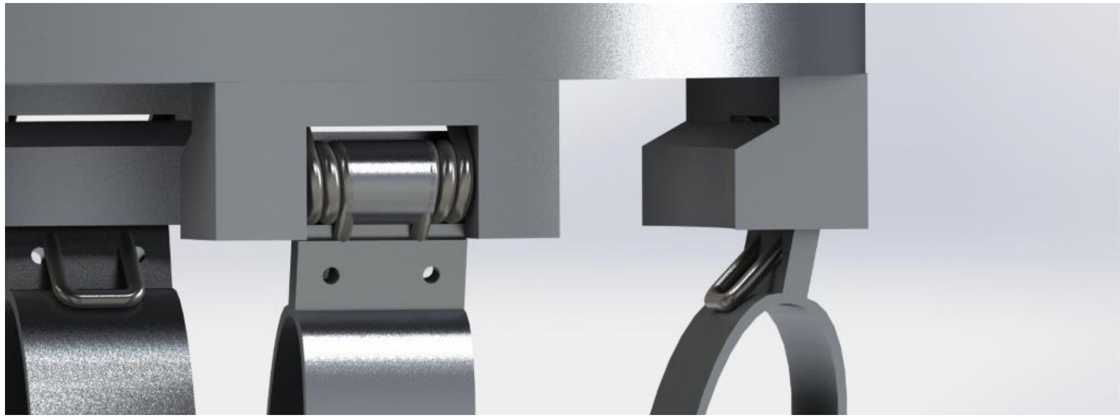
LOPSIDED Tilt Range

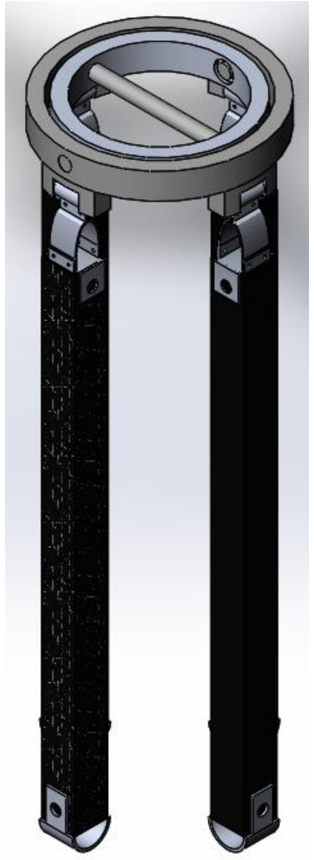
- Range depends on landing orientation
  - Tilt:
    - Min: 15°
    - Max: 20°
  - Grade:
    - Min: 20°
    - Max: 25°



Support and Levelling System

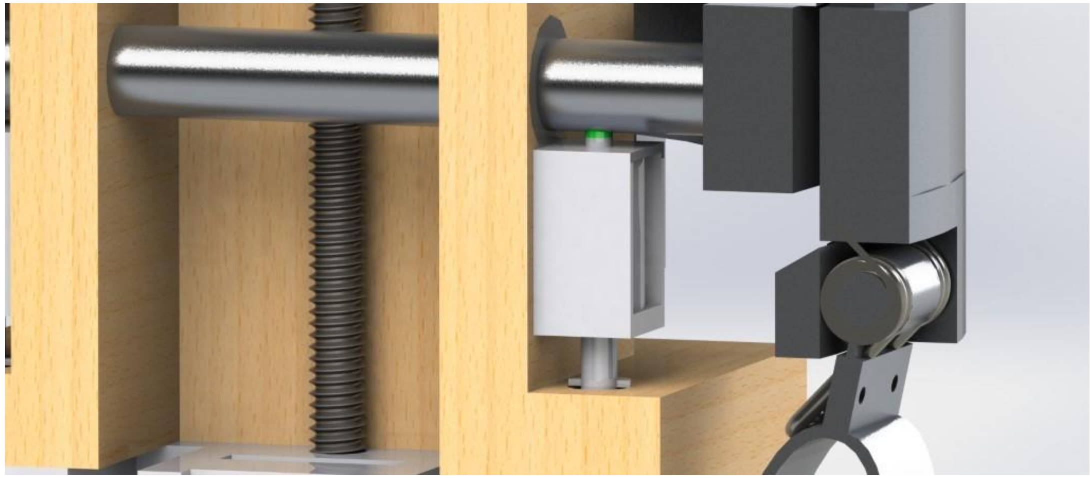
- Rods will connect to the rings via ball bearings
- Leg rotation driven by torsional springs, stopped by cable
- Materials: Aluminum and carbon fiber





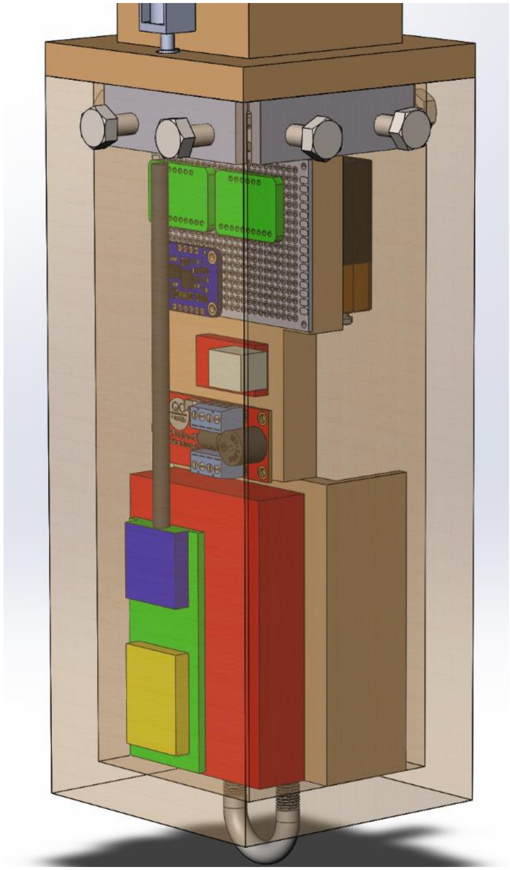
Levelling Locking

- Two axes need to be locked
  - Inner ring
  - Outer ring
- Two 5-volt solenoid locks for each axis



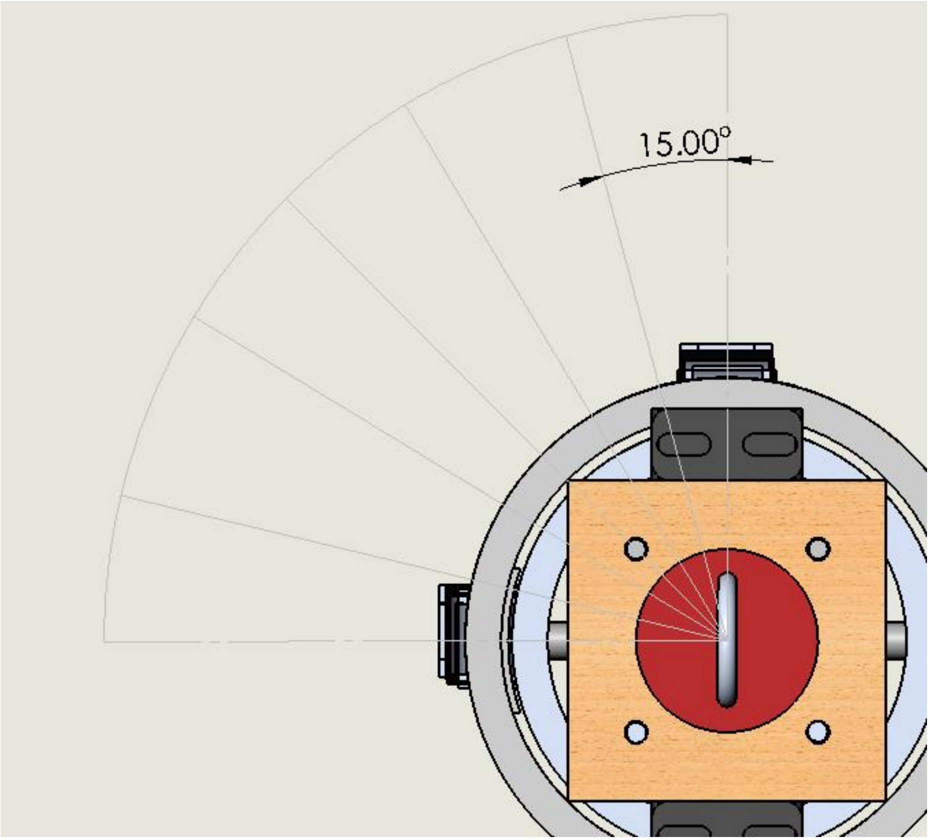
Electronics Section

- Lower Third Section of Chassis
- Contain LOPSIDED and POS electronics
- Contain ballast to lower CG
- All mounted on a sled for easy access



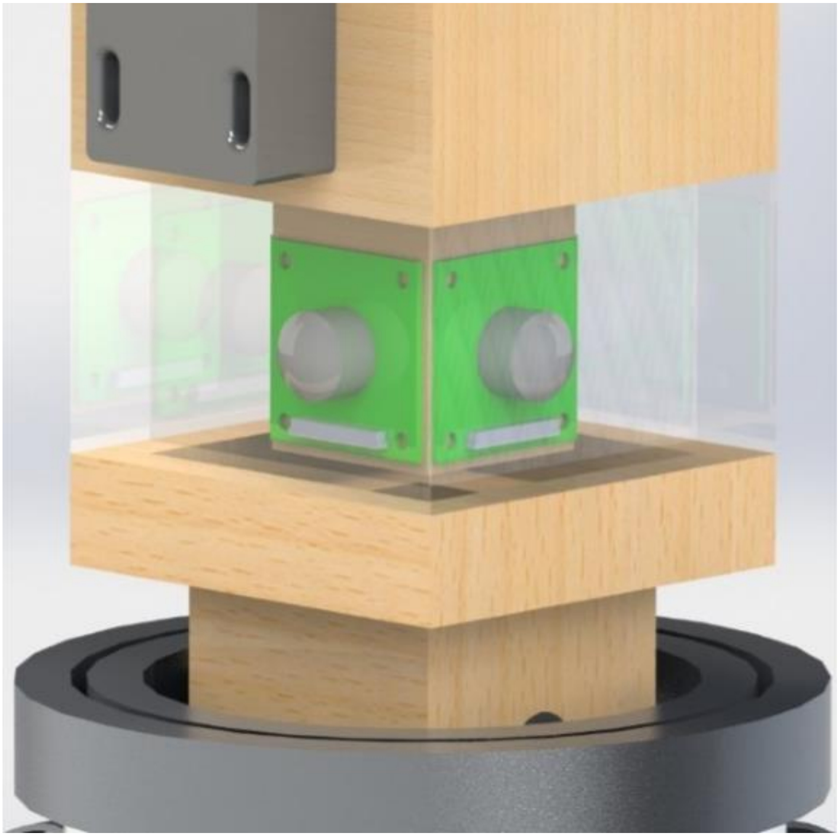
LOPSIDED Testing

- Tilt Range
  - Map max tilt angle around the body
- Load Bearing
  - Opening Shock
  - Landing



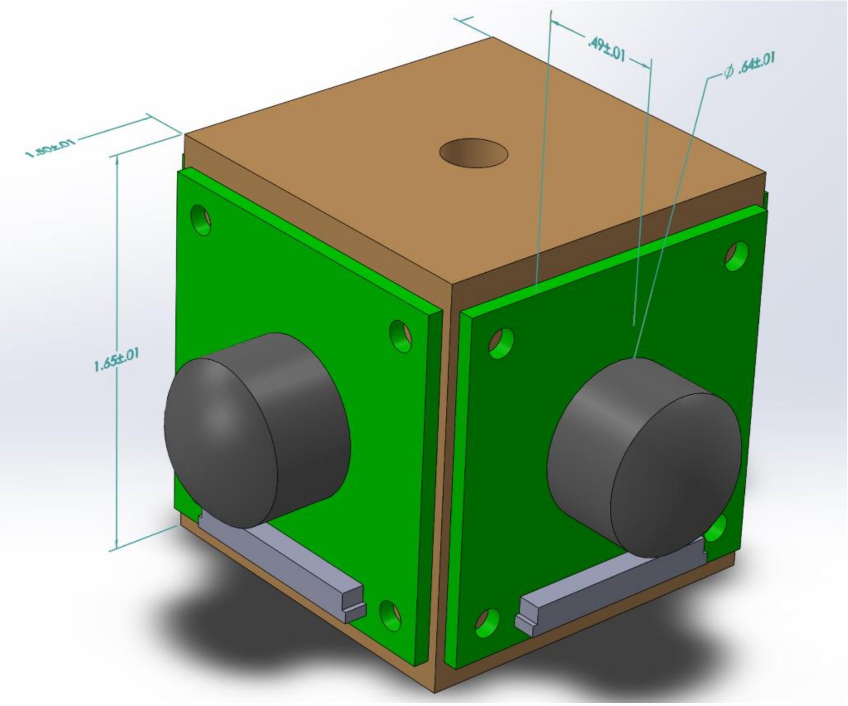
Planetary Observation System (POS)

- Payload must capture a 360° panoramic photograph of the landing site and transmit it back to the team
- Main Objectives:
  - After self-leveling is completed, initiate photo capture
  - Process images to generate 360-degree panoramas
  - Transmit images back to team ground station



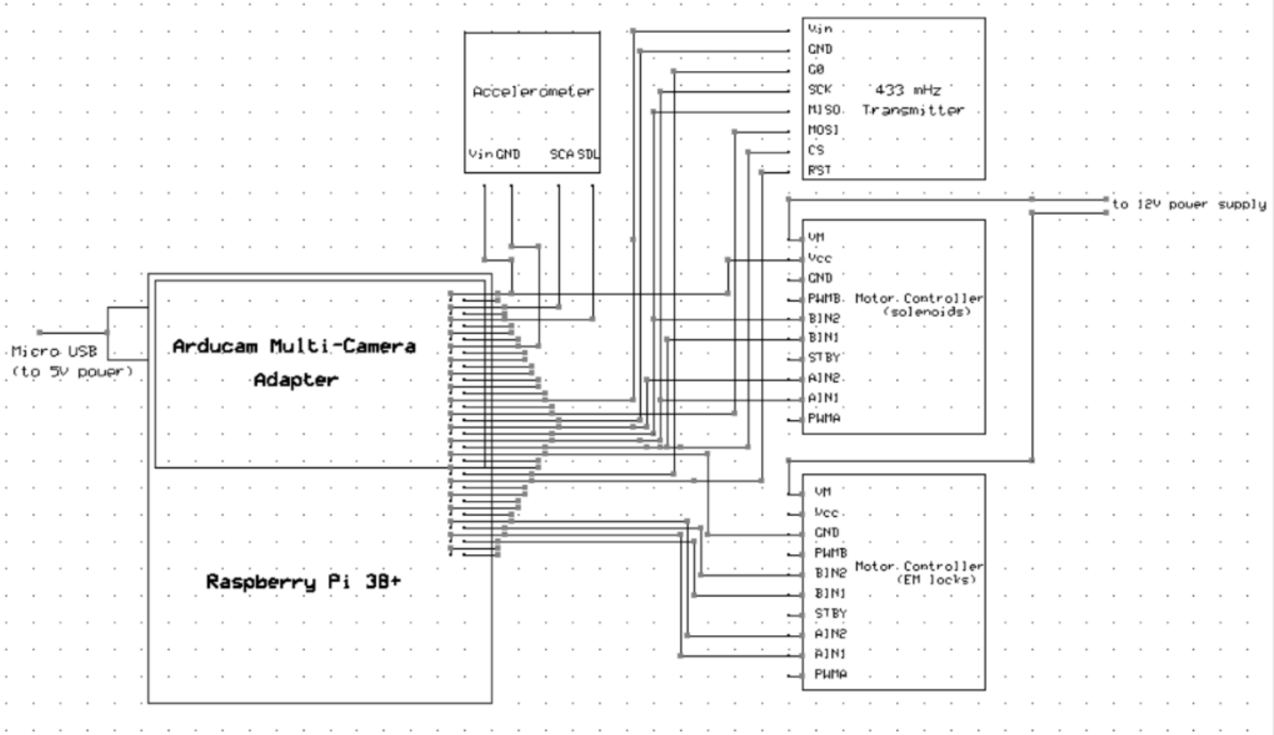
POS Imaging

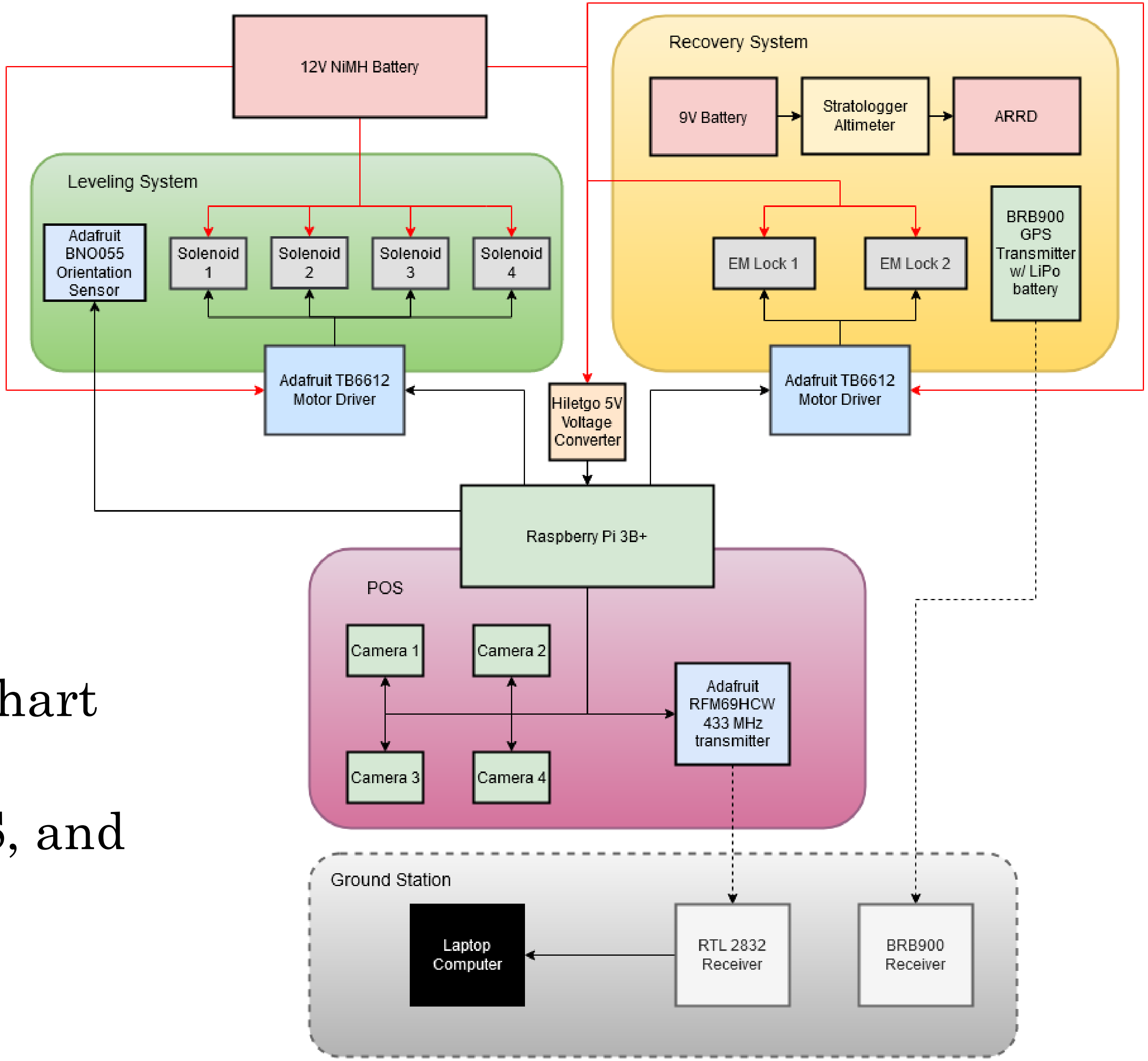
- Camera horizontal field of view (HFOV) = 194°
  - Capture 194° images and combine to form panorama
  - Four cameras can capture two 360° images
- Cameras housed in upper LOPSIDED section
  - Wooden mounting block
  - Polycarbonate walls
- 24" ribbon cables to connect modules to Raspberry Pi



LOPSIDED-POS Computing

- Raspberry Pi 3B+ used for components of all LOPSIDED-POS systems
- Pi will run Raspbian OS with Python
    - Python scripts used to initiate parachute release, leveling, image capture , and image transmission
    - Power from 12V battery via voltage regulator
- POS transmitter, orientation sensor, motor drivers, and cameras receive power directly from Pi





- LOPSIDED-POS electronics flow chart
- Electronics for LOPSIDED, POS, and recovery systems

POS Electronics

- Four Arducam Fisheye Camera Modules
  - Power supplied from Pi
- Arducam Multi-Camera Adapter Board
  - Attachment to Raspberry Pi
- Adafruit RFM69HCW Transmitter
  - 433 MHz
- Hiletgo Step Converter w/ USB
  - 12V DC to 5V DC for Raspberry Pi via USB
- SDR RTL 2832 Receiver
  - Connects to laptop computer via USB

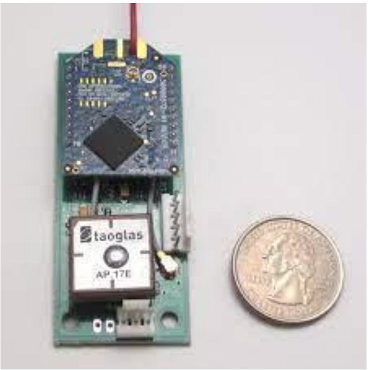



Leveling System Electronics

- Four Sparkfun 5V Solenoids
- LM2596 DC-DC Step-Down Converter
  - 12V DC to 5V DC for solenoids
- Adafruit BNO055 Orientation Sensor
  - Data used for leveling and POS
- Adafruit TB6612 Motor Driver
  - Can operate up to four solenoids (two simultaneously)
  - Accounts for voltage difference between solenoids and Raspberry Pi

Recovery Electronics

- StratologgerCF Altimeter
- 9V battery
  - Separate power supply for altimeter
- Two Dormakaba 3510LM 12V Electromechanical Locks
  - Powered directly from 12V battery
- Adafruit TB6612 Motor Driver
  - To operate electromechanical locks from Raspberry Pi
- BRB900 GPS Transmitter
  - 900 MHz
  - Equipped with separate LiPo battery for power

LOPSIDED-POS Power Requirements

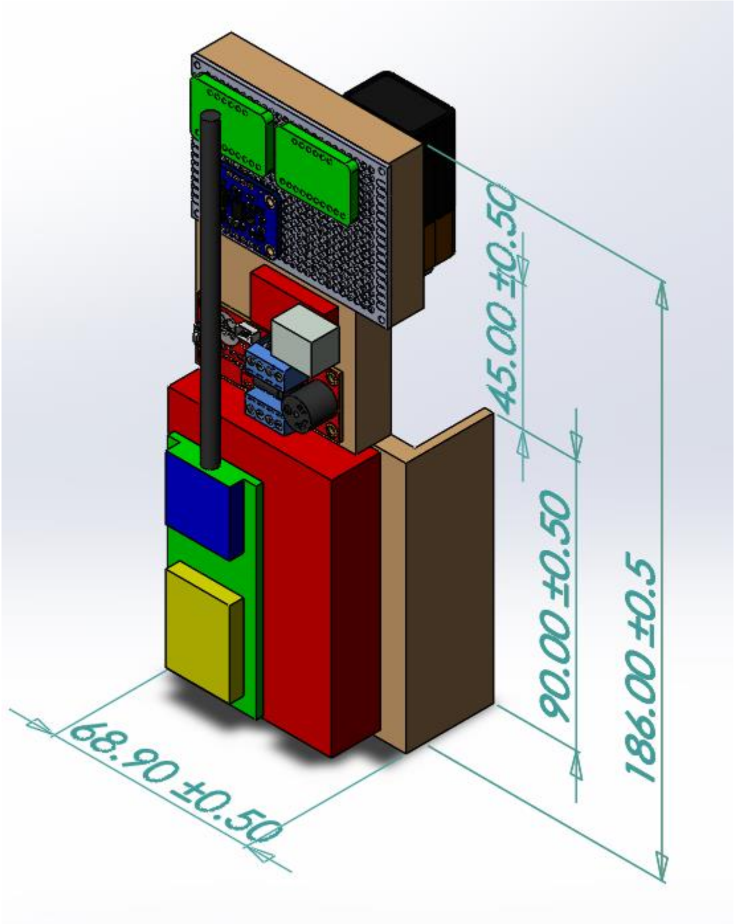
Component	Voltage (V)	Current (mA)	Active Time (s)	Capacity (mAh)
BRB900 Tracker	4.2	315	7200	630
3510LM EM Lock (x2)	12	500	4	1.11
StratoLogger Altimeter	9	1.5	7200	3.00
BNO055 Accelerometer	3.6	12.3	7200	24.6
Raspberry Pi	5	500	7200	1,000
Arducam Camera	5	250	15	1.75
RFM69HCW Transmitter	5	150	1200	50
Open Frame Solenoid SK-F0420 (x4)	12	250	4	1.11
Total	-	-	-	1,710

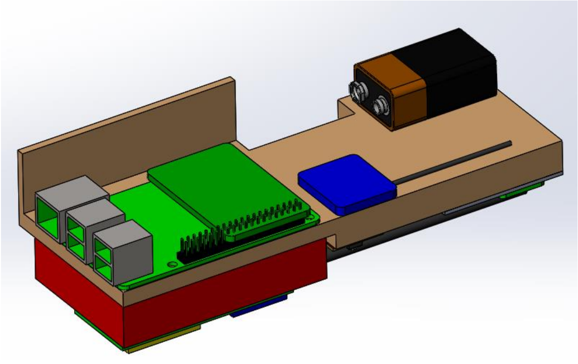
LOPSIDED-POS Battery Selection

- Battery for Altimeter: 9V Alkaline battery
- Battery for BRB900: Own LiPo single cell battery
- Other components: 1600 mAh NiMh 12V battery pack
    - Capacity required is 1,077 mAh for 2 hours of power

Electronics Sled

- Location of all payload electronics except solenoid latches, camera modules, and ground station hardware
- Removable from LOPSIDED for easy access
- Mounting via wood screws and hook and loop fasteners





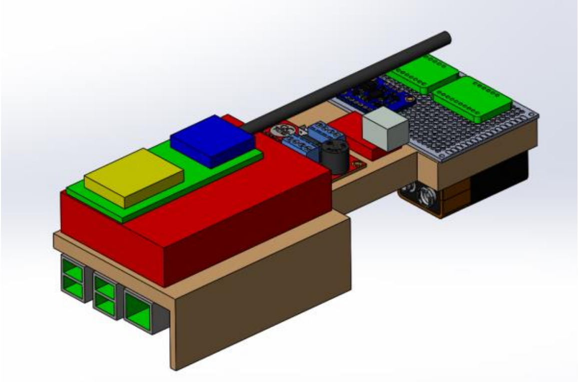
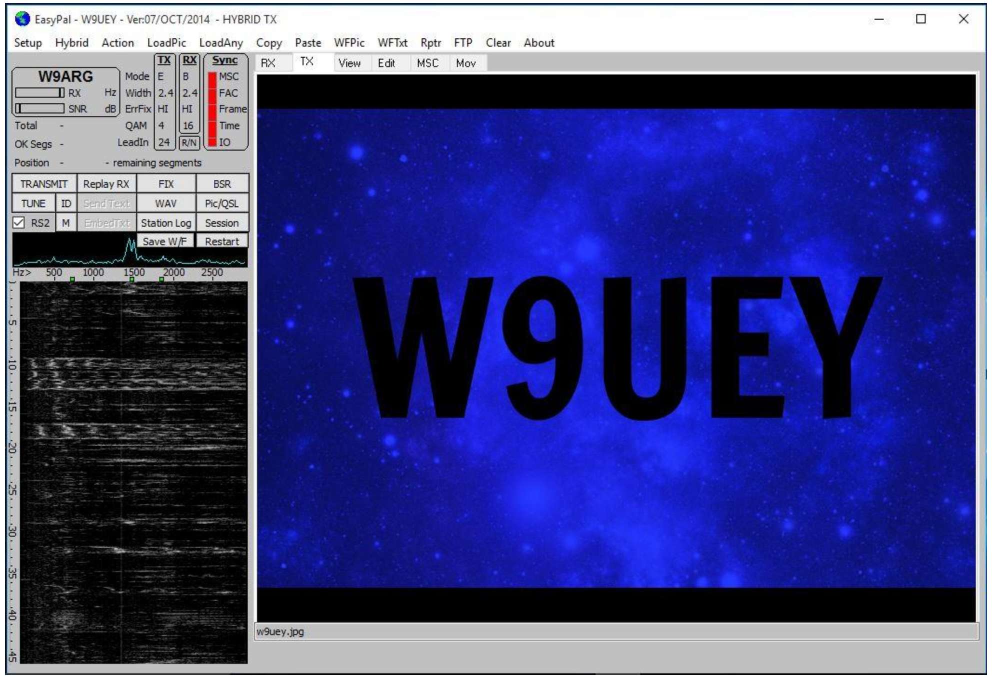


Image Transmission

- Digital Slow-Scan Television (DSSTV)
  - Transmission method that utilizes voice radio frequencies to send static images
  - Images are converted to audio (WAV) files, transmitted, and decoded using computer software
- Low-power compared to other methods
- DSSTV limits loss in image quality compared to analog SSTV
- Received images will be compiled into 360-degree panoramas using image software at the team's ground station

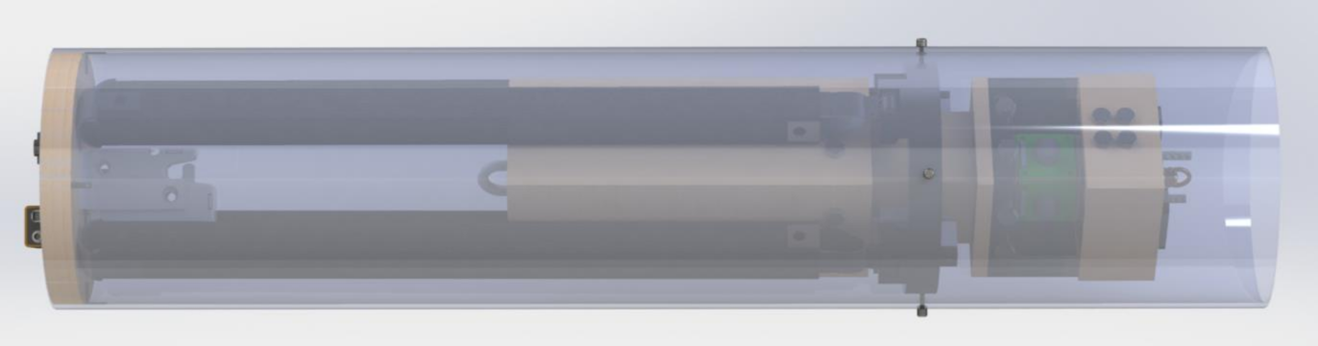


Subscale Payload Results

- Main objectives of subscale payload:
  - Test robustness and image quality of cameras by capturing images during and after launch
  - Gain experience working with Raspberry Pi/Python
- Due to the unintended disabling of the Raspberry Pi's CSI port, no images were able to be captured in flight
- Camera was still functional after flight, confirming that the camera modules are capable of withstanding flight forces

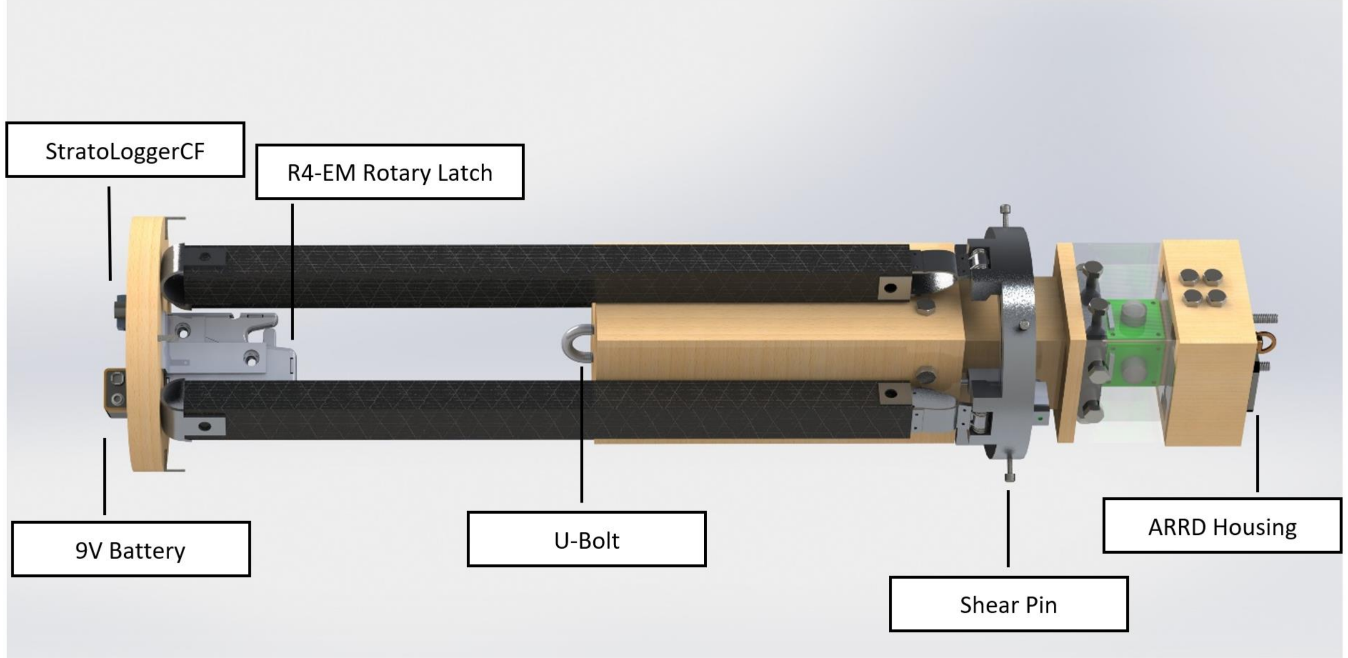
Payload Integration and Deployment

- Main Objectives:
  - Retain LOPSIDED throughout main-vehicle launch until deployment.
  - Release LOPSIDED while avoiding impacts that cause damages to electronics or leveling components.
  - Release parachute post-landing to avoid parachute pulling on LOPSIDED or covering of POS.



Final Integration Design

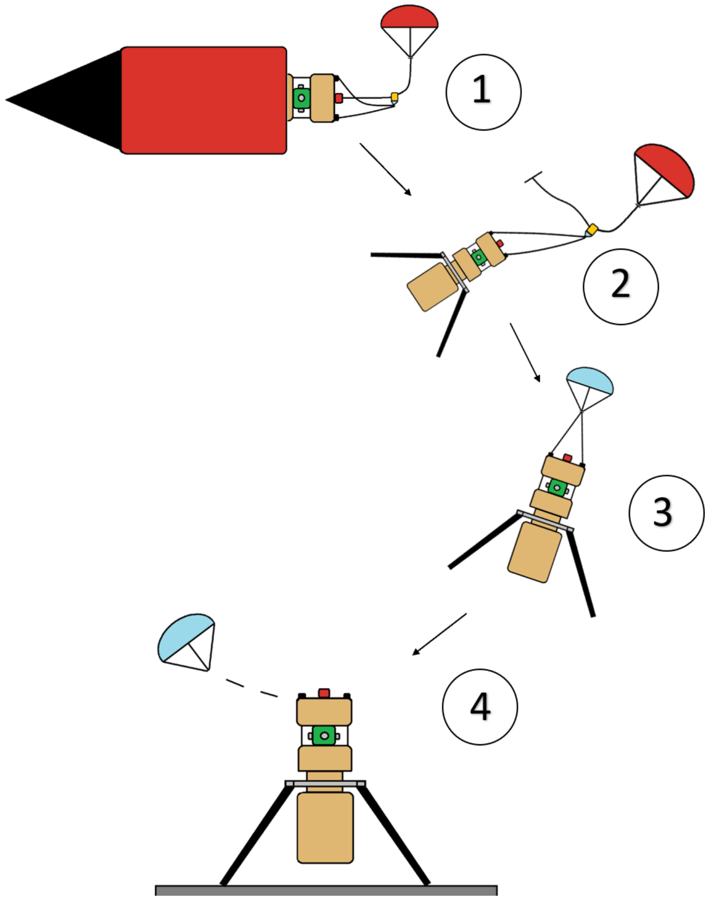
- Altimeter: StratoLogger CF
  - •Sends Signal at apogee (~4,500ft AGL)
- Shear Pin:
  - Breaking Load: 35lbf
- Rotary Latch: R4-EM series
  - •Holding Force: 1522 lbf
  - •Powered by small 12V alkaline battery
  - •Activated by altimeter
  - •Maximum load experienced: 360 lbf



Payload Deployment Sequence

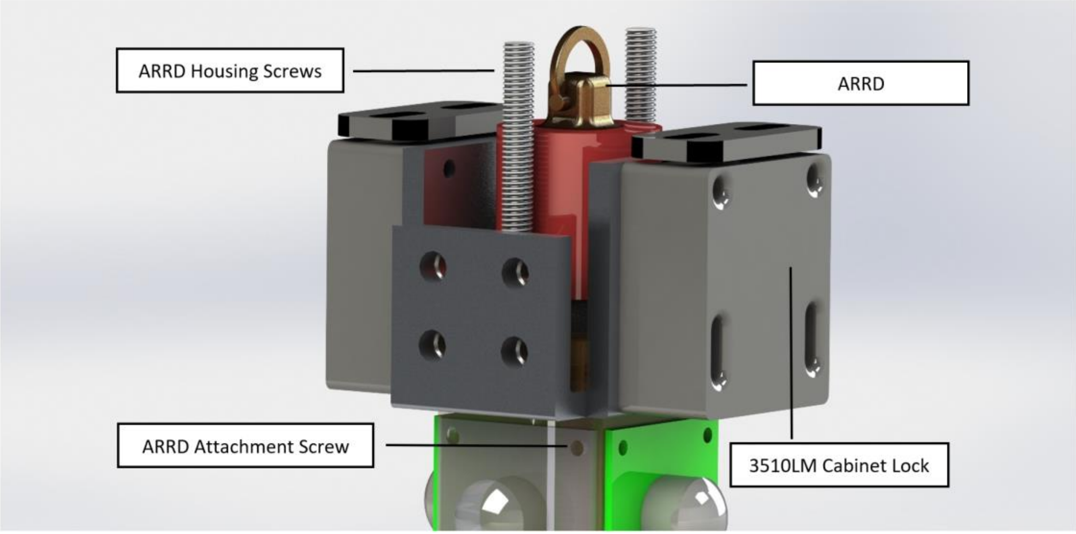
- Steps:

1. Payload is pulled by the main parachute deployment at ~675 ft AGL. Altimeter ignites at 500 ft AGL separating payload from main chord.
2. LOPSIDED exits and pulls the payload parachute from the bag attached to the main parachute chord.
3. Payload proceeds to fall under a parachute.
4. Accelerometer detects impact and activates the electromechanical locks to release parachute upon landing.



Final Payload Deployment Design

- Advanced Retention Release Device (ARRD)
  - Altimeter sends electric signal through e-match to ignite the ARRD's black powder
  - Activated at 500 ft AGL
  - Supports up to 2,000 lbf
  - ARRD is attached to LOPSIDED using the ARRD housing shown
- Electromechanical lock
  - Model: Dormakaba 3510LM Cabinet Lock
  - Holding Force: 250lbf
  - Dimensions: 1.65in x 1.65in x 0.79in



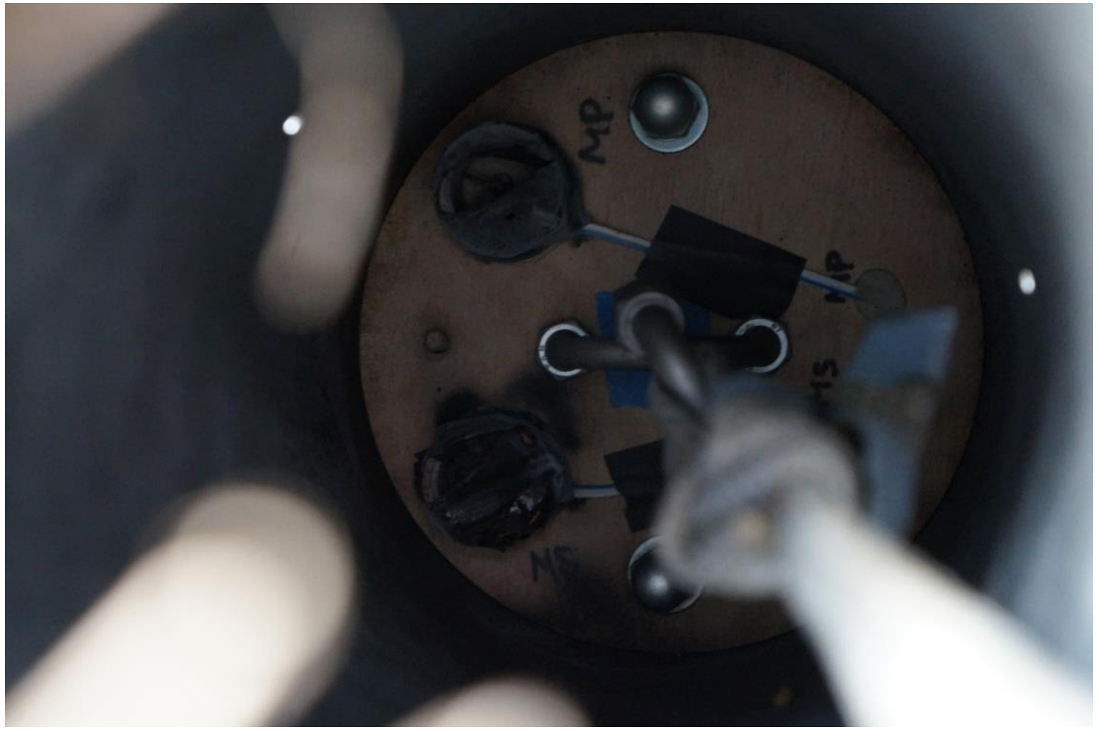
Launch Vehicle Interfaces

Internal Interfaces

External Ground Interfaces

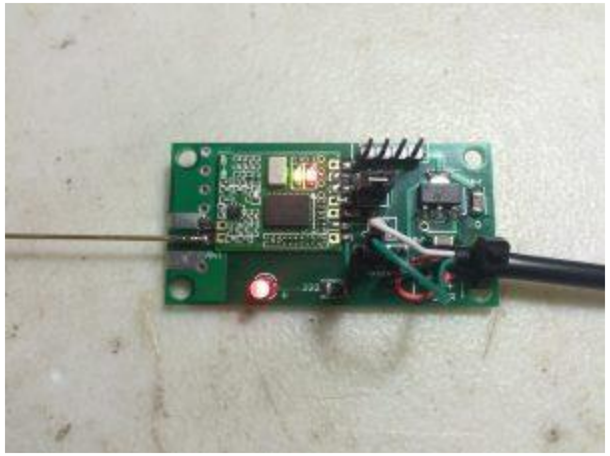
Internal Interfaces

- Recovery harnesses attached to bulkheads
  - AV Bay bulkheads hold black powder charges
- LOPSIDED deployed by main parachute recovery harness
- Separating sections secured by nylon shear pins



Ground Interfaces

- Launch buttons/rail
  - Buttons interface with 12-foot long 1515 rail
- EggFinder TX/RX
  - Launch vehicle tracker
- BigRedBee BRB 900
  - Payload tracker
- 433 MHz SSTV Transmitter
  - Payload imaging



Requirements Verification

Verification Status

Testing Plan

Status of Requirements Verification

- All requirements verified by analysis have been verified
  - Stability margin, rail exit velocity, kinetic energy, wind drift, etc.
- Demonstration and inspection requirements have verification plan detailed in the CDR document
  - 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 detailed on each requirement

NASA 2.4	The launch vehicle SHALL be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The structures and recovery leads design the launch vehicle such that it is capable of being recovered with minimal damage and launched again on the same day without repairs or modifications.	Inspection, Demonstration	Recovery; Structures	Not verified	The launch vehicle is designed to be recoverable and reusable. See section 3.4.1 for the final recovery design. This requirement will be verified by inspection of the launch vehicle following the VDF.

Testing Plan

- Used to quantifiably validate design performance
- Schedule and success criteria detailed in CDR document
- Examples:
  - Bulkhead tensile strength
  - Shear pin loading
  - Battery life

Payload Test Suite

- Five tests are planned to be conducted for various LOPSIDED-POS systems
- Includes tests for LOPSIDED, POS, and recovery and integration
- First test scheduled for 1/29/2020, last test scheduled for 2/16/2021
- Used to verify requirements NASA 2.7, 3.13, 3.13.2, 4.2, 4.3.3, 4.3.3.1, 4.3.3.2, .3.4, and TDR 4.6, 4.8, 4.14, 4.15, 4.16

Questions?