PURDUE SL

Critical Design Review

Mission Statement

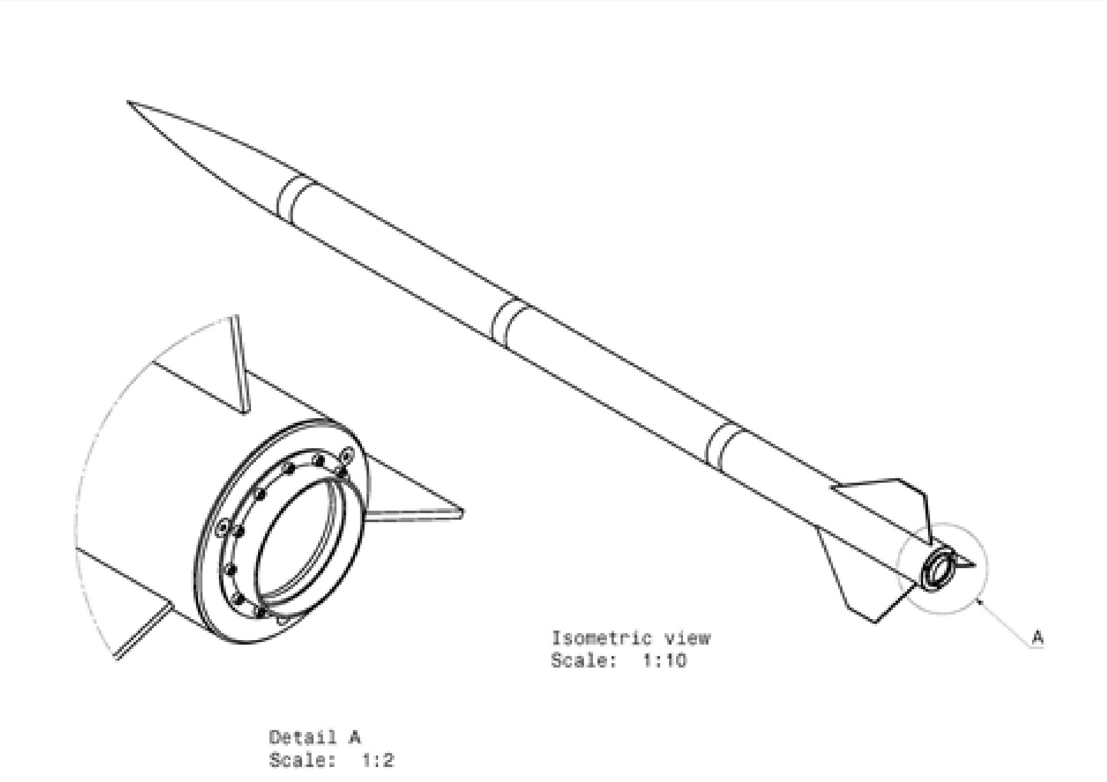
Our mission statement can be broken into two distinct goals:

- Design, build, test, and fly a student launch vehicle to an altitude of one statute mile
- Carry a camera system capable of detecting and differentiating tarps of three distinct color values

Launch Vehicle System Overview

The launch vehicle is consists of 5 distinct subsections:

- Nosecone
- Upper and middle airframe
- Avionics Bay
- Payload Bay
- Lower Airframe



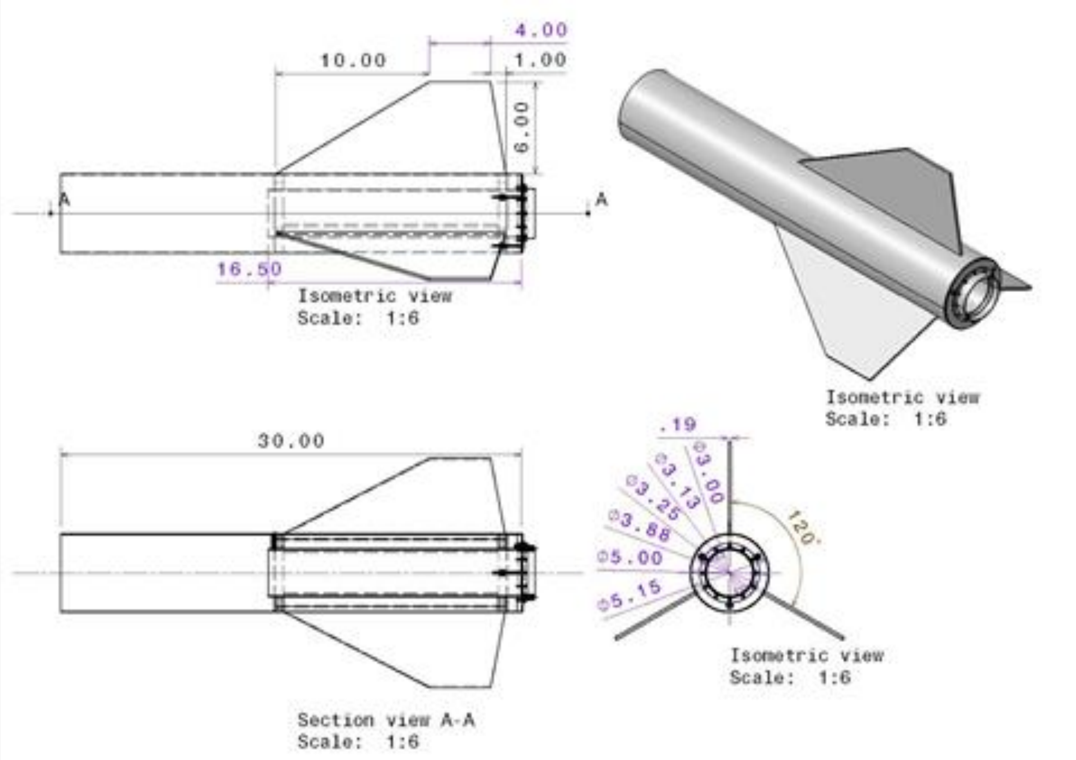
122" tall, 5.15" diameter

30 pound launch weight

Lower Airframe Subsystem

The lower airframe contains fins, motor mount assembly, thrust plate, and motor retainer

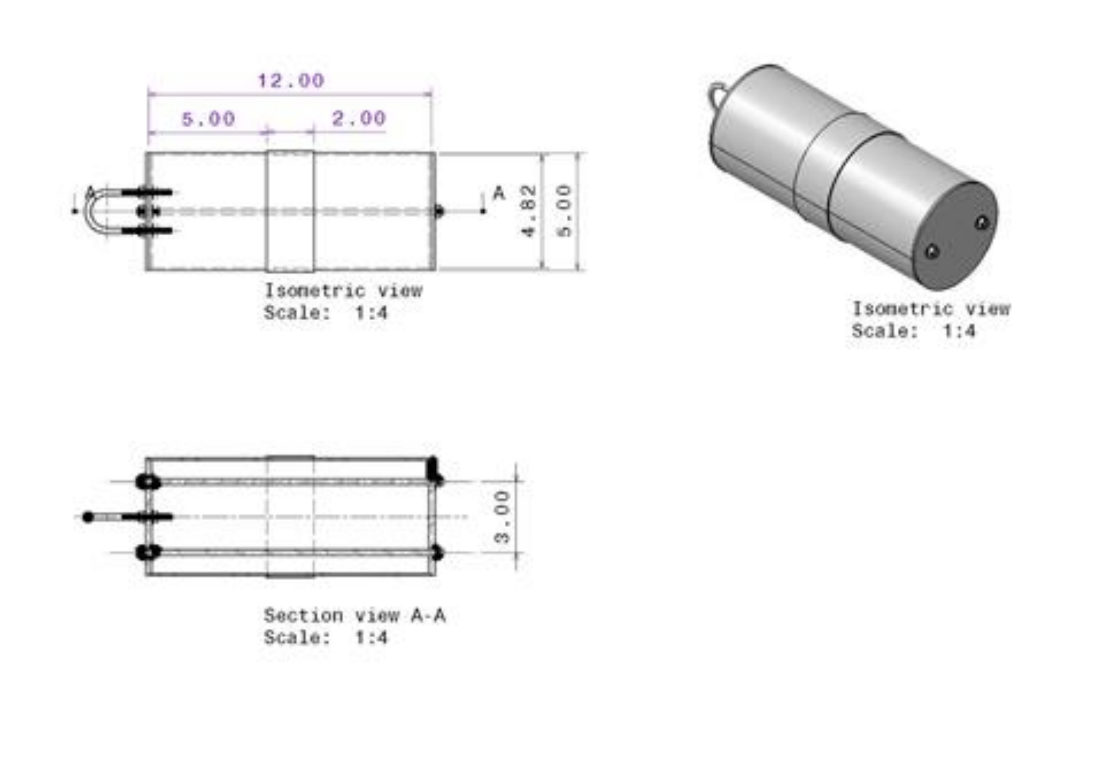
- Filament wound tubes
- G10 plate fiberglass fins and centering rings
- Utilizes interlocking TTW fins with plywood backed rings
- Bolted on thrust plate/retainer



Payload Bay Subsystem

The payload bay houses the camera system and interfaces with the mid and lower airframe

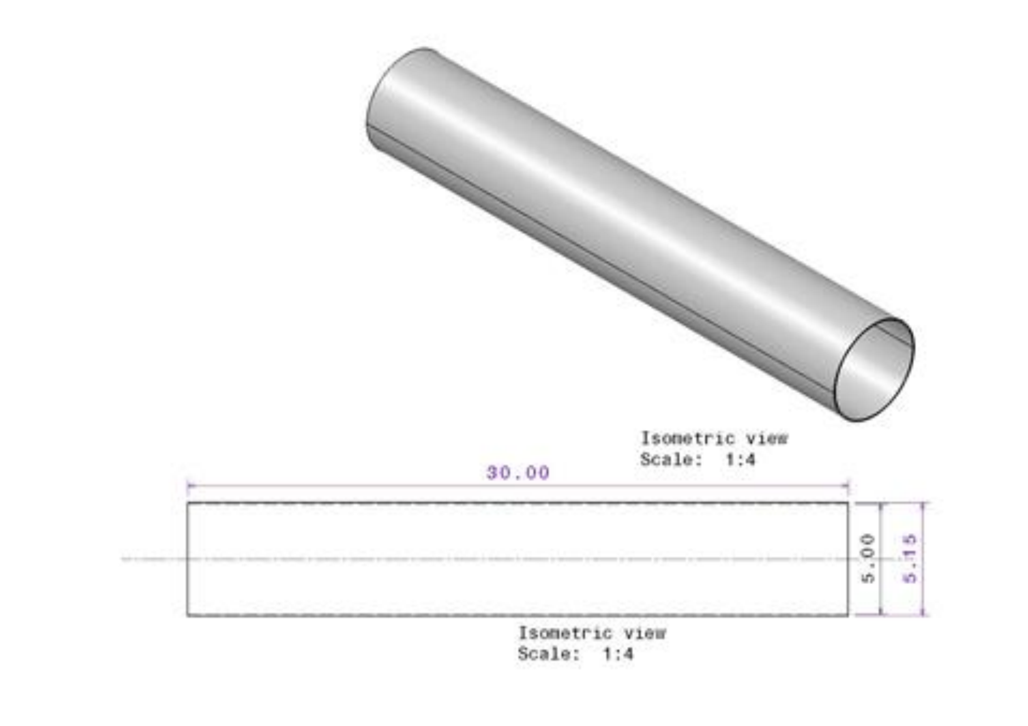
- Filament wound tubes
- Switch band for camera mounting and arming
- Aluminum bulkheads
- Stainless steel hardware



Mid And Upper Airframe Subsystem

The mid and upper airframes are identical sections of airframe tubing

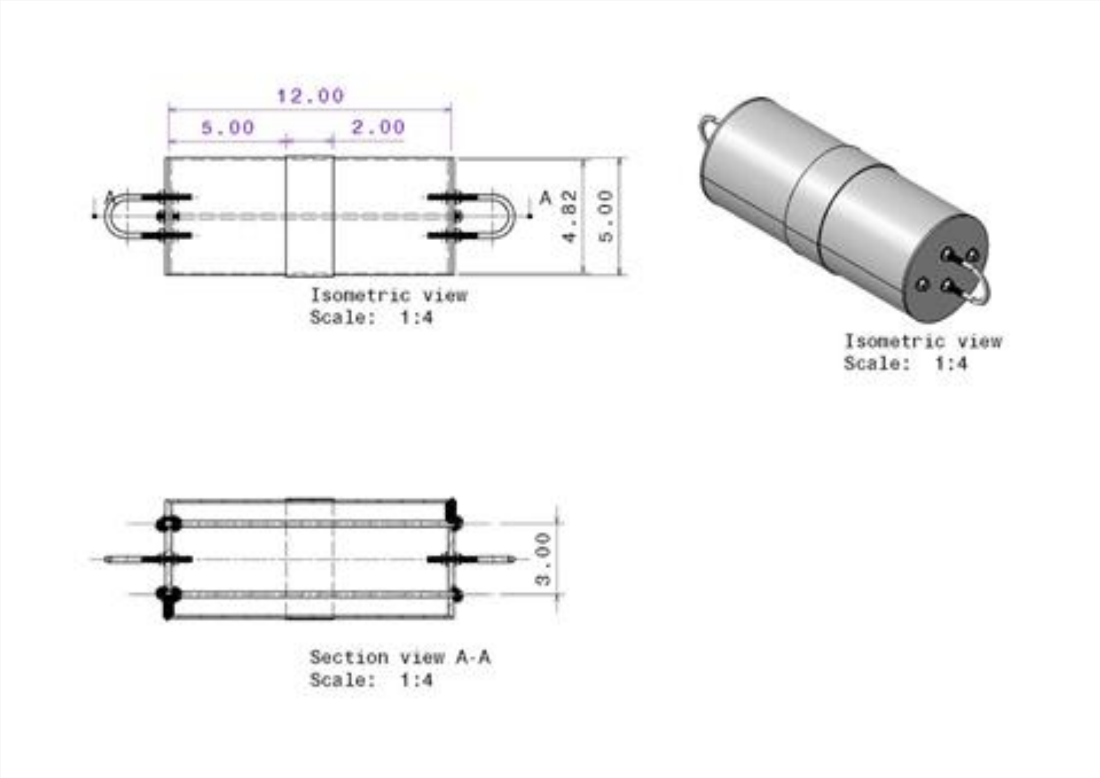
- Filament wound fiberglass
- 30” long each
- Mid airframe interfaces with the payload and avionics bays
- Upper airframe interfaces with the avionics bay and nosecor



Avionics Bay Subsystem

The payload bay houses the avionics and interfaces with the mid and upper airframe

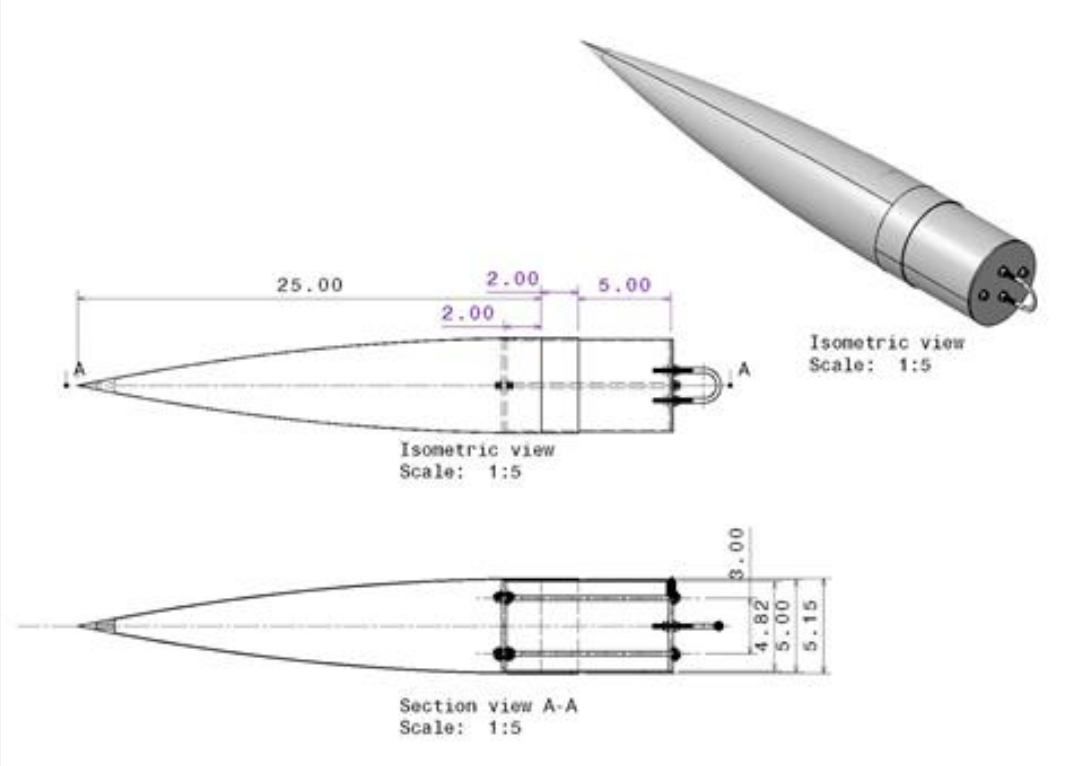
- Filament wound tubes
- Switch band for venting and arming
- Aluminum bulkheads
- Stainless steel hardware
- Identical to payload bay construction



Nosecone Subsystem

The nosecone reduces drag and interfaces with the upper airframe

- 25" long metal tipped filament wound cone and tubes
- Aluminum bulkheads
- Stainless steel hardware
- Removable auxiliary payload bay



Completeness And Manufacturability

- Nearly all components are commercially available but will need various holes
- Custom parts such as fins and rings will be supplied by a 3rd party contractor
- Building supplies will be bought with the materials or supplied by SEDS

Material Validation

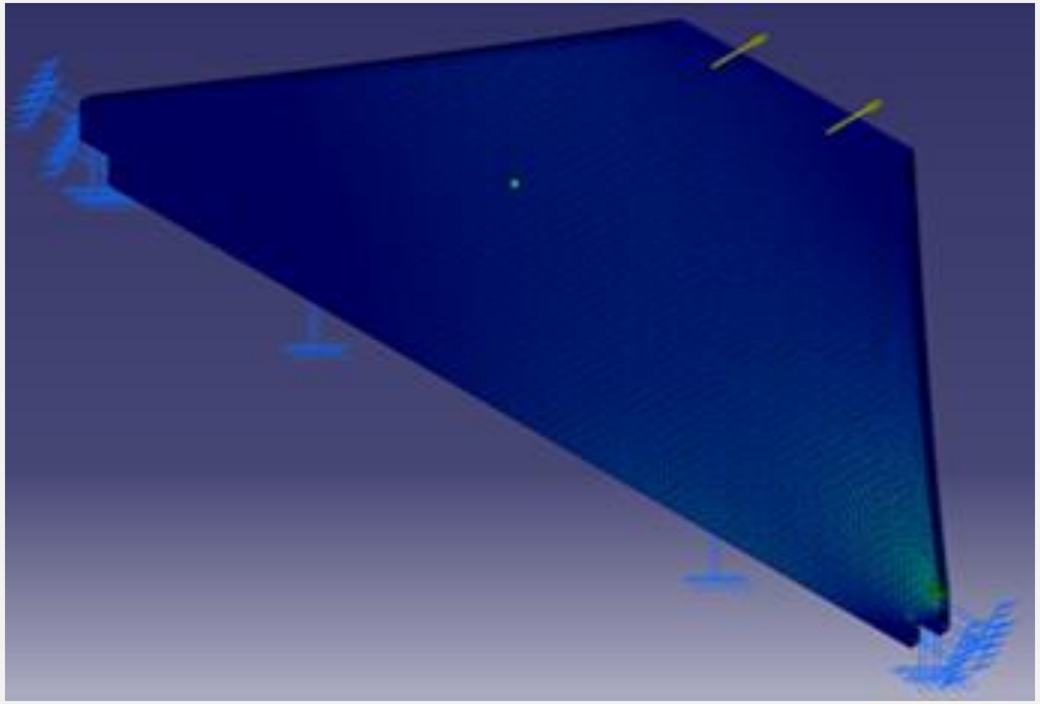
- All material validation was performed in CATIA V5 using a mesh size of 0.1" and sag of 0.01"
- Parts were assigned material characteristics and simulated using clamping and distributed forces
- If a part experienced a stress greater than the tensile yield point, the test is considered a failure

Aluminum yield strength: 40000 PSI

G10 fiberglass yield strength: 41000 PSI

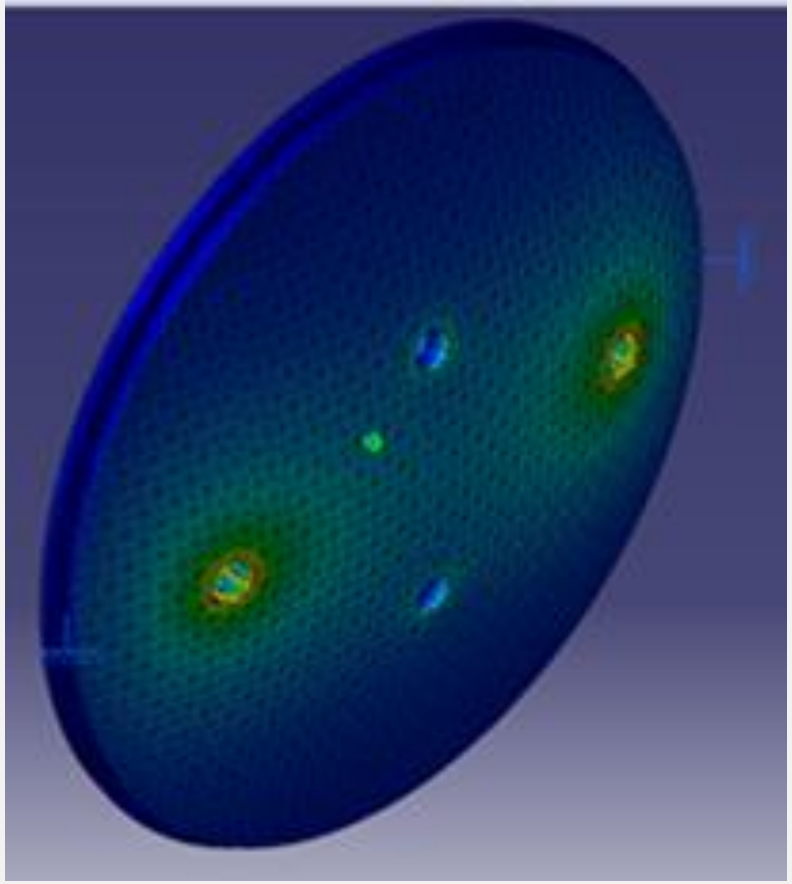
Fin Bending Analysis

Material: G10 fiberglass
Restraints: Clamped root and edges
Forces: 50 pounds laterally
Max. Displacement: 0.111”
Max. Stress: 3.73e+4 PSI



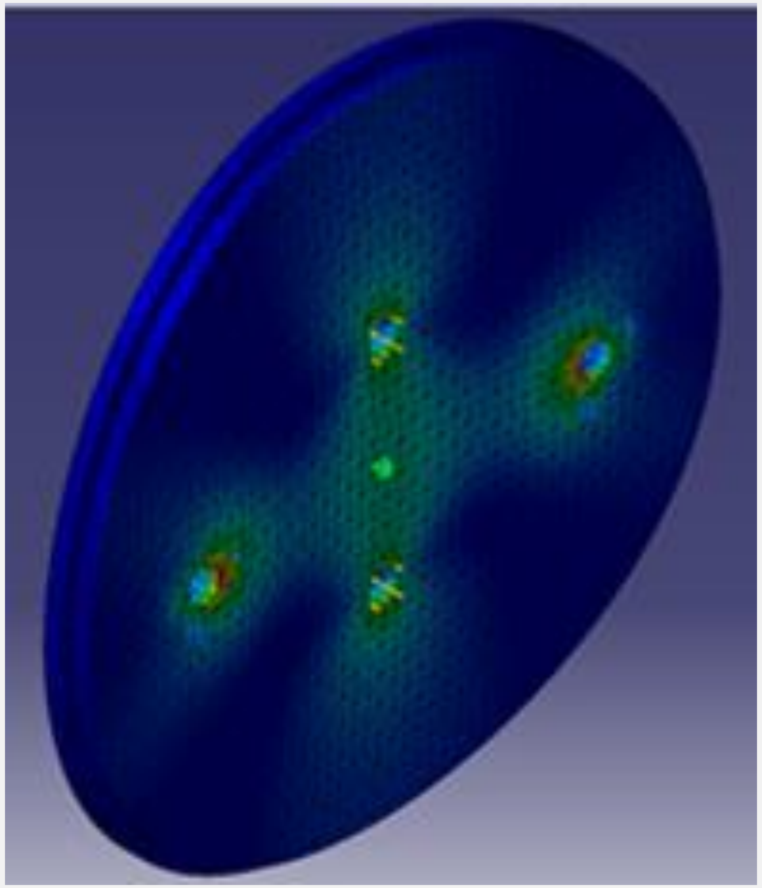
Bulkhead Pull Through Analysis

Material: 6061 T6 aluminum
Restraints: Clamped stepped perimeter
Forces: 1000 pounds inside the rod holes
Max. Displacement: 0.00468"
Max. Stress: 1.68e+4 PSI



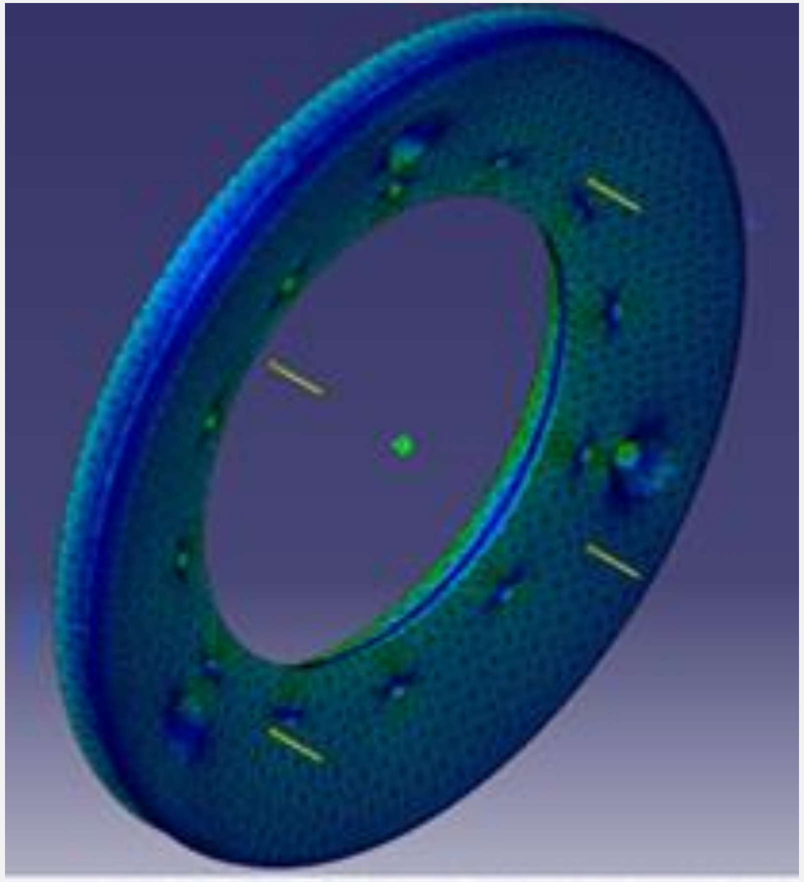
Reverse Bulkhead Pull Through Analysis

Material: 6061 T6 aluminum
Restraints: Clamped stepped perimeter
Forces: 1000 pounds inside the bolt holes
Max. Displacement: 0.00495”
Max. Stress: 2.04e+4 PSI



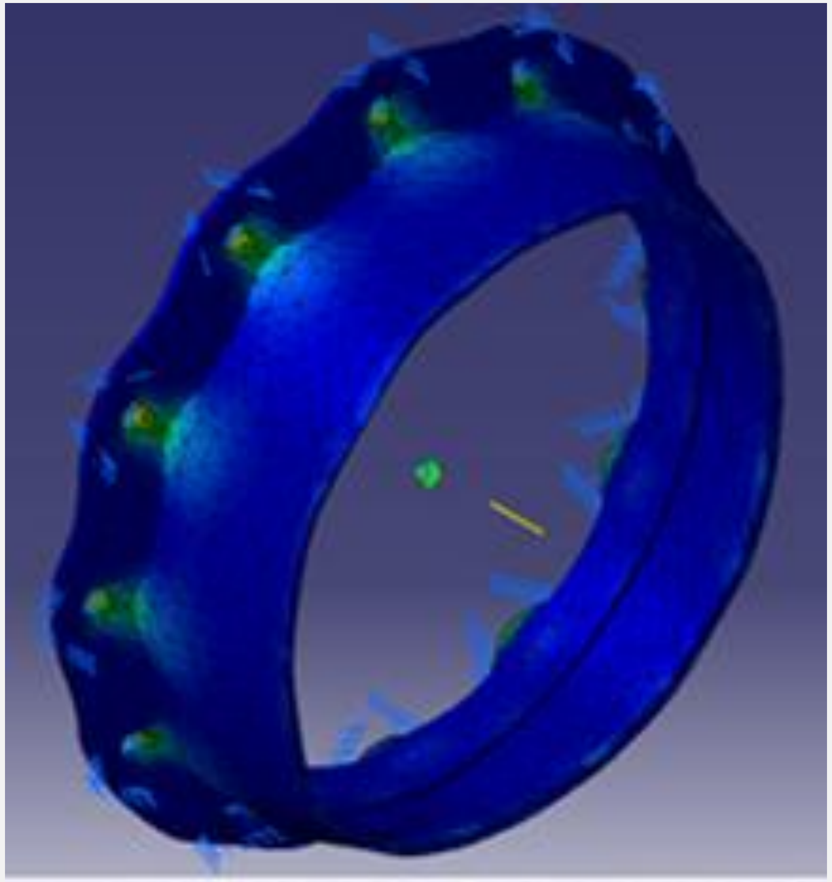
Thrust Plate Analysis

Material: 6061 T6 aluminum
Restraints: Clamped stepped perimeter
Forces: 1000 pounds on the face
Max. Displacement: 0.00302"
Max. Stress: 1.05e+4 PSI



Motor Retainer Analysis

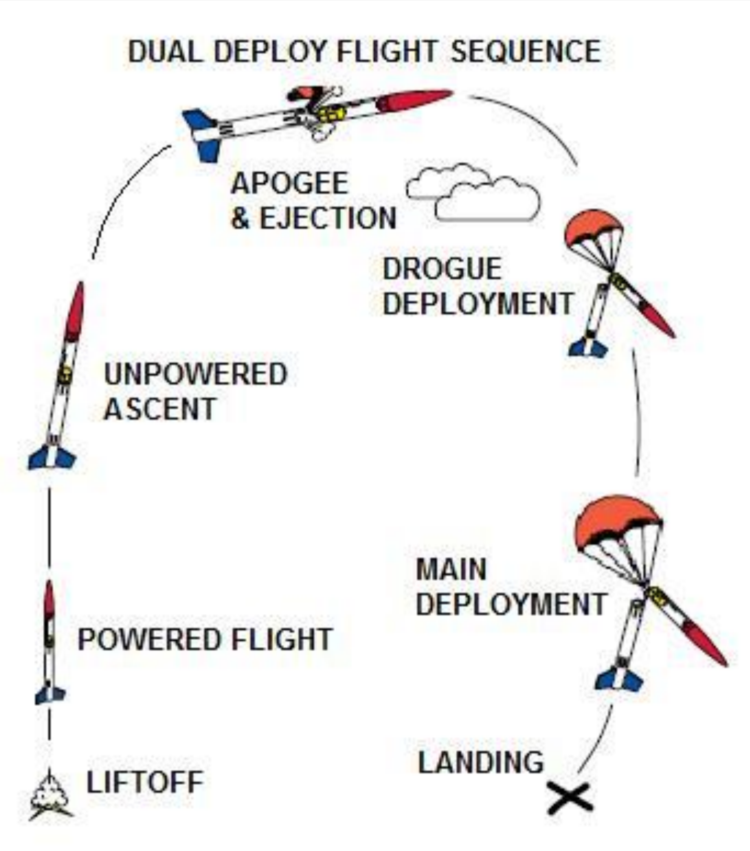
Material: 6061 T6 aluminum
Restraints: Clamped bolt holes
Forces: 1000 pounds on the inside face
Max. Displacement: 0.000477"
Max. Stress: 3.1e+4 PSI



Recovery System Overview

Standard dual deployment configuration:

- 24″ drogue parachute at apogee.
- 100″ main parachute at 700′ AGL.
- Kevlar Shock cord.
- Nomex heat shields.
- ¼″ SS connection points.
- Shear pinned to prevent separation



Main Parachute

Skyangle Cert-3 XLarge parachute:

- 100″ diameter
- 4x ⅝″ shroud lines rated at 2,250 pounds
- 0 porosity 1.9 ounce ripstop nylon
- Drag coefficient of 2.59
- Surface area of 89 square feet
- Rated for 32.6-70.6 pounds
- Estimated weight: 3.8125 pounds

Drogue Parachute

Skyangle Cert-3 Drogue parachute:

- 24" diameter
- 4x ⅝" shroud lines rated at 2,250 lbs
- 0 porosity 1.9 ounce ripstop nylon
- Drag coefficient of 1.16
- Surface area of 6.3 square feet
- Rated for 1.0-2.2 lbs
- Estimated weight: 0.375 lbs

Fireproofing

Nomex heat shield:

- Protects parachute from ejection gases
- 18”x18” square
- Slides directly over shock cord
- Burrito wrap parachute
- Estimated weight: 0.5 lbs

Tethers

Kevlar tether:
- ½" thickness
- 7,200 lbs. breaking strength
- Fireproof
- 3 sewn loops:
  - One on each end
  - One ⅓ the length from the top
- Estimated weight: 0.4 lbs each

Attachment Hardware

- Includes nuts, bolts, washers, u-bolts, and quick links
- Constructed from high tensile strength stainless steel (type 316 or 18-8)
- These alloys have exceptional strength, are corrosion resistant, and generally robust
- Will not oxidize in the presence of residue from black powder ejection charges
- Will maintain properties for many flights
- Estimated weight is approximately 1 lb.

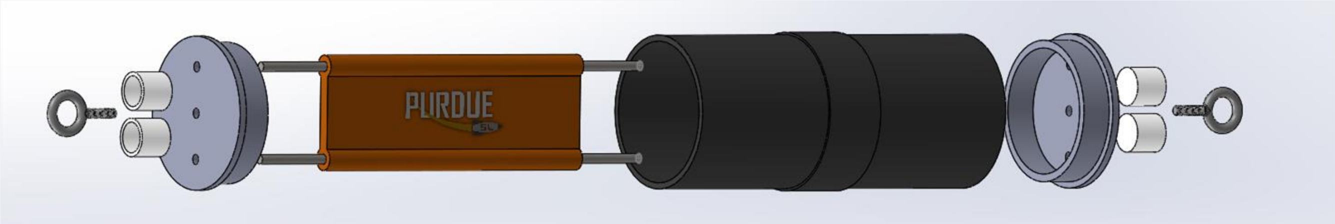
Bulkheads

- Constructed from 0.25" thick 6061 T-6 aluminum stock
- Contain four 0.25" holes:
  - Two holes 3" center to center to accept threaded rods and secure the bulkheads to the coupler tube, two holes 1.625" from center to center to accept the u bolt that attaches the rocket to recovery tether.
- Each bulkhead is estimated to weigh 0.45 lbs, 2.7 lbs total

Avionics System Overview

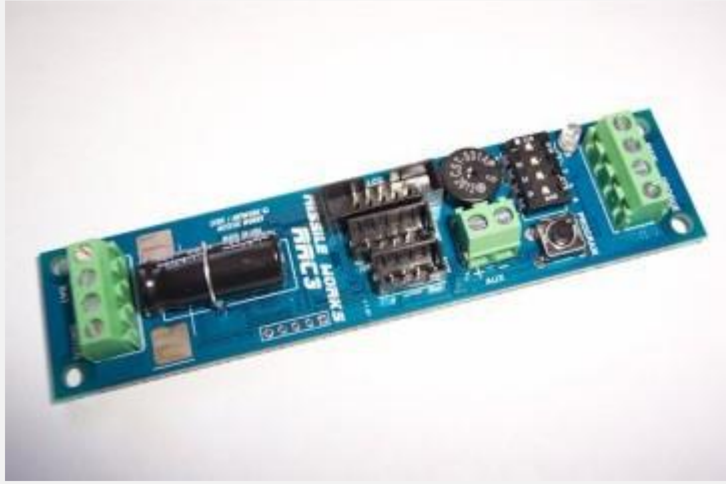
The Avionics Bay consists of:

- 2 Altimeters:
  - TeleMetrum and RRC3+ Sport
- 2 Batteries:
  3.7V LiPo and 9V alkaline
- 3D Printed Sled
- Stainless steel hardware
- Goex 4Fg Black Powder
- Capsules to hold Black Powder
- External Key Switches.



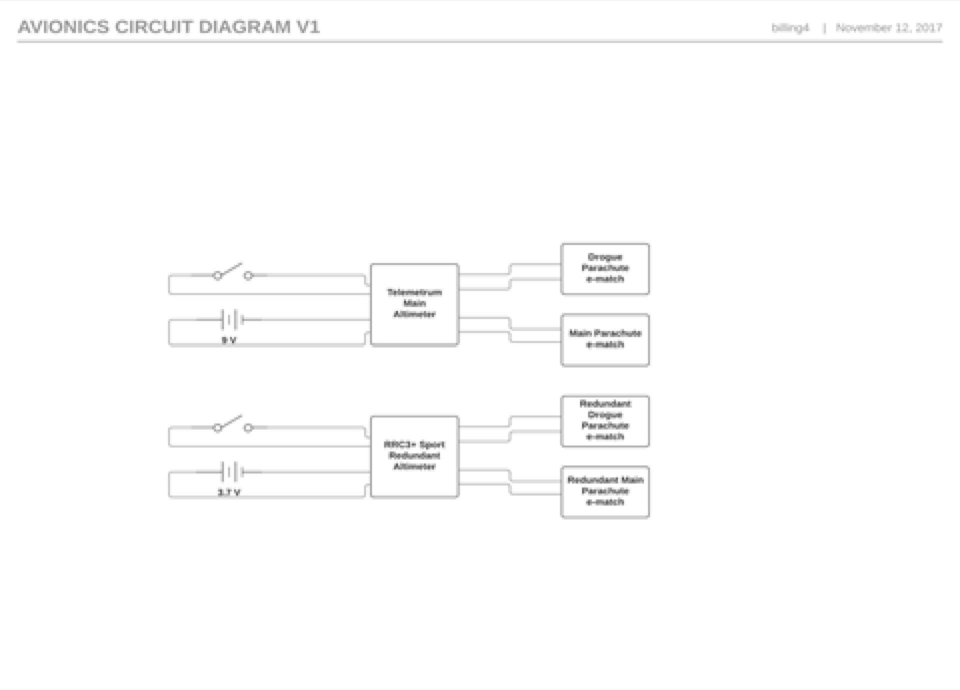
Chosen Altimeters

- Primary: Telemetrum
  - 3.7V LiPo Battery
- Secondary: RRC3+ Sport
  - 9V Battery
- Only need one GPS system for our launch vehicle



Electrical Schematics

- The electrical schematics shown are completely redundant systems.
- Each circuit has a battery, key switch, and pair of e-matches



Flight Prediction Overview

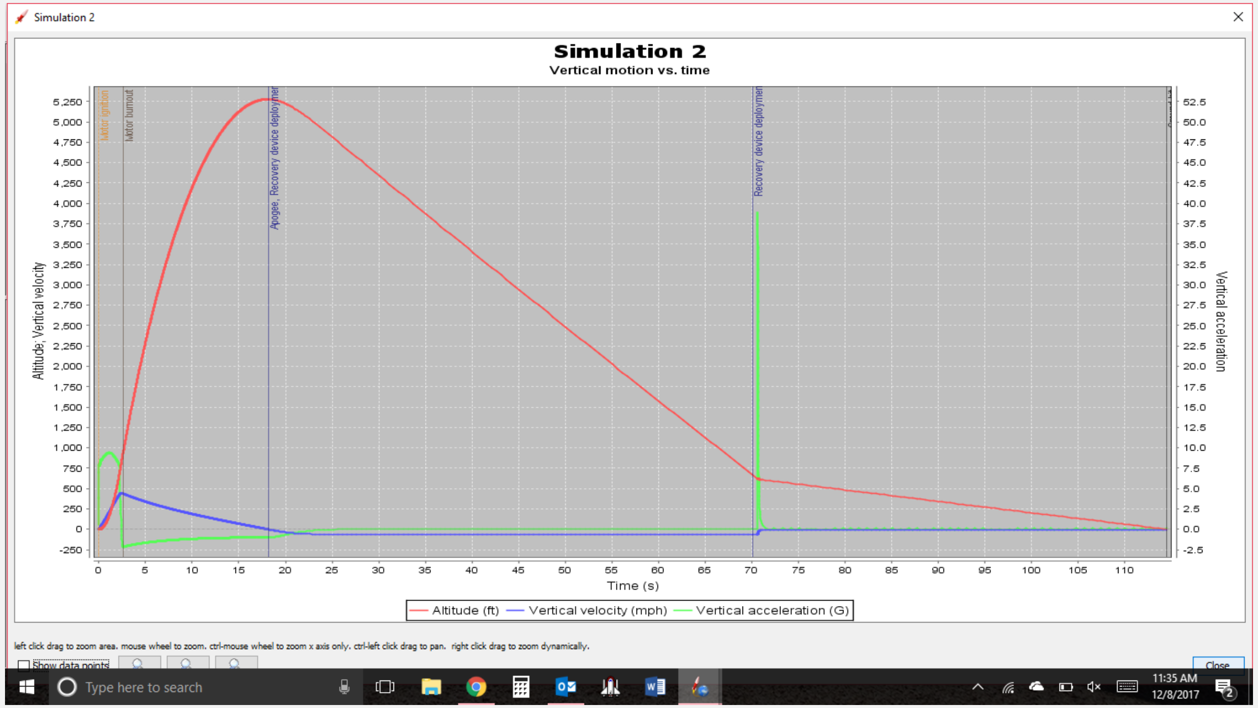
Flight predictions were created using OpenRocket 15.03 using the following settings:

- Extended barrowman calculation method
- 6DOF Runge Kutta 4 simulation method
- 0.02 second time step
- Spherical approximation geodedic calculations

Altitude Predictions

Openrocket predicts a maximum altitude of 5,281'

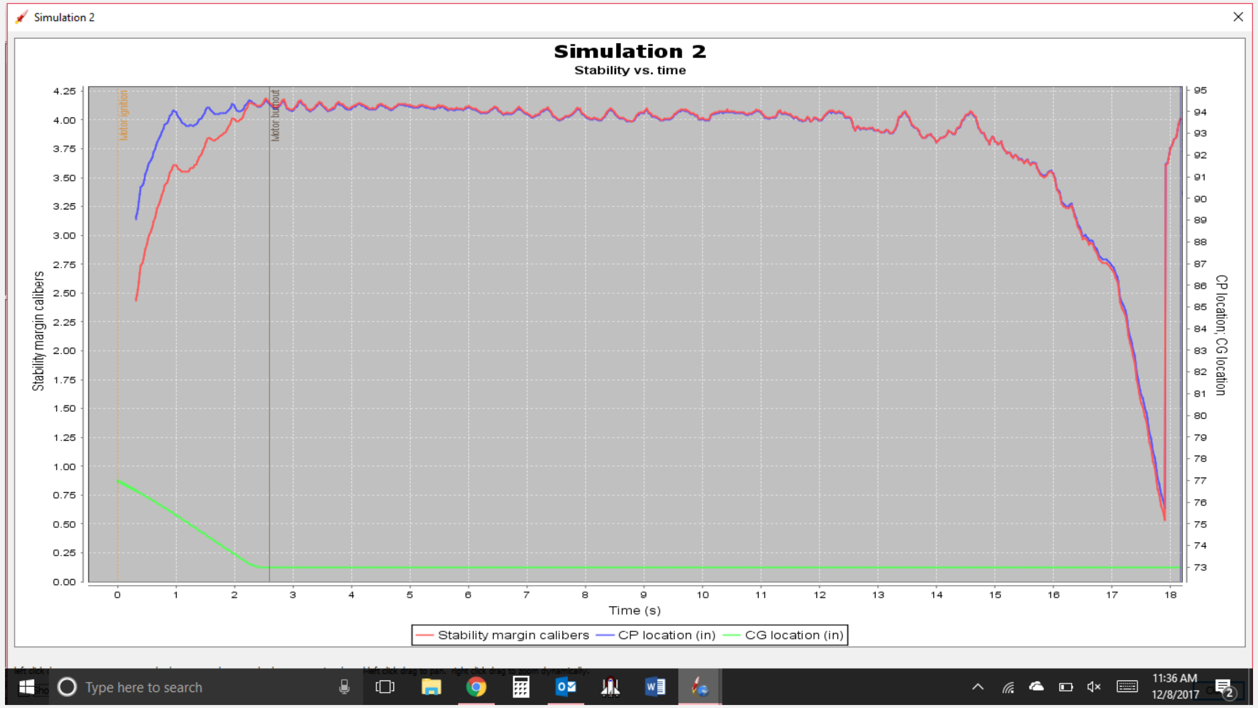
- Variable ballast
- 9.4G acceleration
- 0.58 Mach



Stability Predictions

After leaving the launch rail, the rocket will have the following stability characteristics:

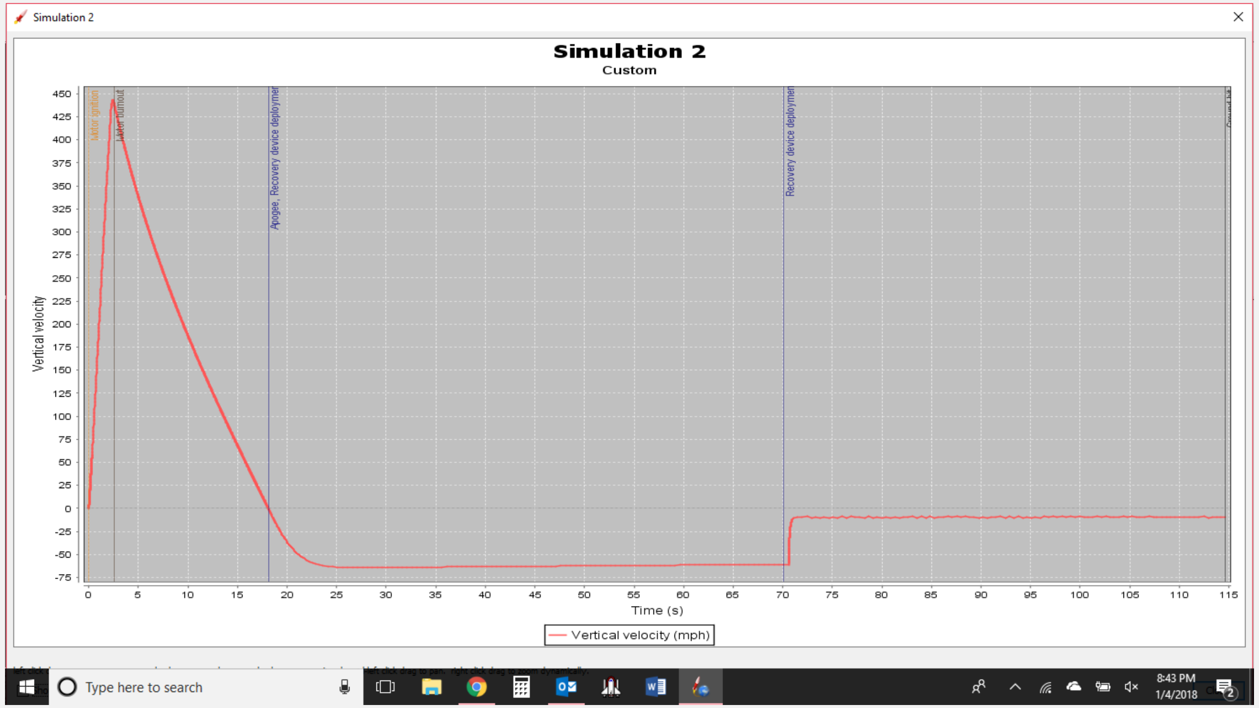
- 2.25 calibers stability
  - CP 88.5" from datum
  - CG 77" from datum
- Average stability of 4 calibers during flight



Landing Energy Predictions

The rocket is expected to have a touchdown speed of 9.2 MPH and a total energy of 96.5 ft. lbs.:

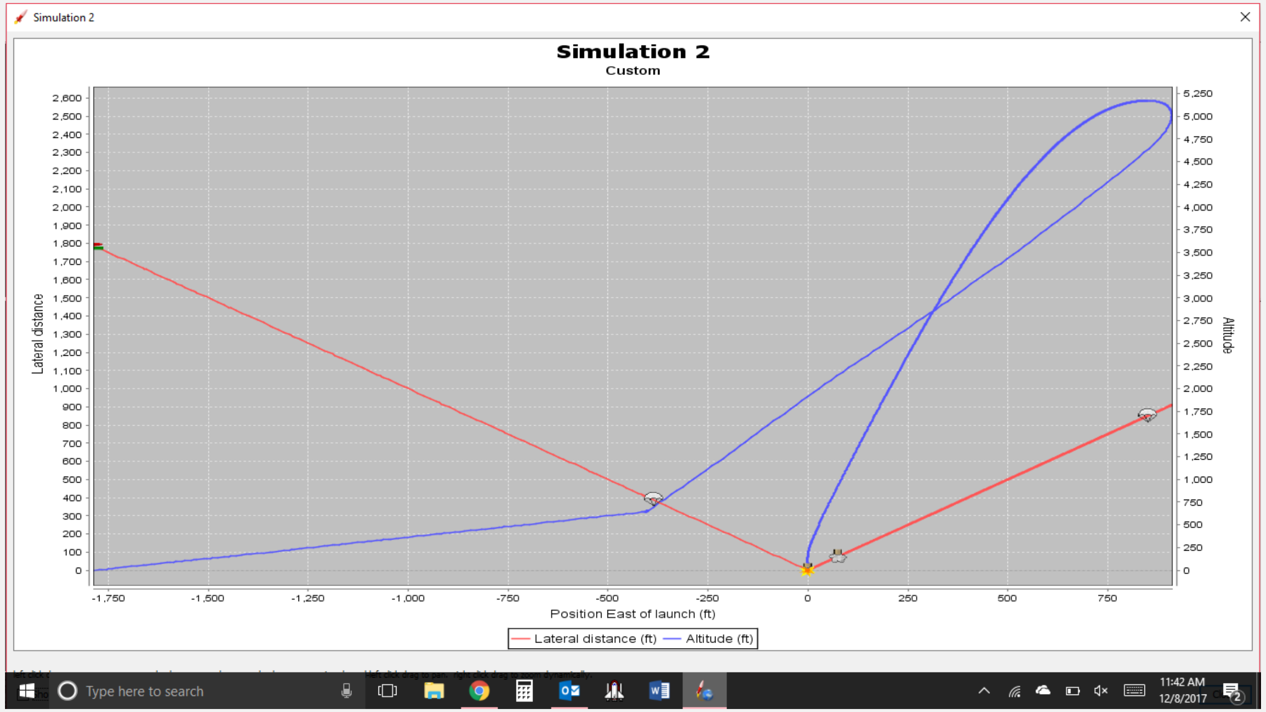
- Lower section: 54.6 ft. lbs.
- Mid section: 27.5 ft. lbs.
- Nosecone: 13.2 ft. lbs.



Drift Distance Predictions

Drift distances with varying wind, 10% turbulence, and 10% standard deviation are as follows:

- 0 MPH: 10’
- 5 MPH: 450’
- 10 MPH: 800’
- 15 MPH: 1300’
- 20 MPH: 1800’



Safety Overview

Goals of the safety team during work on the CDR:

- Enforce all safety plans and procedures set by the team
- Enforce all laws and regulations set for the team by authorities and governing bodies
- Create step-by-step guides for the team to use for various launch and recovery procedures which inform the team of potential hazards that may occur if proper procedures are not followed
- Greatly improve hazard analysis and contingency plan matrices in order to model as many risks presented by the project as possible

Recovery Preparation

Gives steps to follow for recovering the launch vehicle, including:

- General information: Tells what PPE to wear for recovery procedures, advises personnel on how to avoid injury during recovery, and reminds personnel to minimize pollution during recovery
- Preparation for retrieval: Discusses what to do before launch to make retrieval safer and easier
- During retrieval: Gives safe practices for retrieval, such as what to do if there is still fuel left in the rocket or if parts of the rocket fell off mid-flight
- After retrieval: Tells to check the rocket for damage and how to prepare the rocket for transportation from the launch site

Motor Preparation

Gives steps to follow to prepare the motor for flight, including:

- What motor will be used for this project and where instructions for using this motor may be found
- Hazards which can occur if the motor is not properly prepared
- PPE required to prepare the motor
- Guidelines for motor preparation to accompany manufacturer instructions on how to use the motor
- A reminder of the importance of closely following safety procedures and manufacturer instructions when preparing a motor

Launch Setup

Gives steps to follow for setting up the rocket on the launch pad, including:

- General information: Gives required PPE for launch setup procedures, preparations for emergencies, and a reminder to ensure conditions are good for launch and to have backup launch locations and launch dates
- Before setup: Gives reminders of what to consider when placing the launchpad, such as proximity of water sources, wildlife, and man-made structures as well as ground rigidity
- During setup: Gives procedures for safely setting up the launchpad and attaching the rocket to it and reminds team members to watch the launchpad constantly to ensure its configuration does not change

Igniter Installation

Gives steps to follow to prepare the motor for flight, including:

- What igniters will be used for this project and where instructions for using them may be found
- Hazards which can occur if the igniters are not properly prepared
- PPE required to work with the igniters
- Guidelines for igniter installation to accompany manufacturer instructions on how to use the igniters
- A reminder of the importance of closely following safety procedures and manufacturer instructions when installing the igniters

Troubleshooting

Gives steps to follow for dealing with various problems which may be encountered throughout the project, including:

- Construction problems such as machine failure
- Vehicle component problems such as rust or component expansion
- Ignition and launch problems such as a failed ignition
- Aerodynamic problems such as adverse effects from drag
- Avionics and payload problems such as loss of GPS signal
- Recovery problems such as a parachute deployment failure
- Personnel problems such as hypothermia or insufficient communication

Post Flight Inspection

Gives steps to follow for inspecting the rocket and launchpad after flight, including:

- General information: Gives PPE required for post-flight inspection and reminds that rocket components may be hot from fuel consumption or sharp due to damage suffered in flight
- Exterior rocket inspection: Tells how to handle unburned fuel left in the rocket and how to inspect the exterior of the rocket for damage
- Interior rocket inspection: Tells how to handle ejection charges left in the rocket and how to check the rocket interior for damage, then reminds personnel to recover flight footage and data then disarm electronics
- Pad inspection: Tells how to clean the launchpad and check for damage

Hazard Analysis and Contingency Plans

Category	Negligible	Minor	Moderate	Major	Disastrous
Remote	1	2	3	4	5
Unlikely	2	4	6	8	10
Possible	3	6	9	12	15
Likely	4	8	12	16	20
Very Likely	5	10	15	20	25

- The magnitude of a risk is still evaluated using cross-examination of hazard likelihood and hazard impact, using the table shown
- The amount of content describing project risks and their mitigations has been increased from approximately 6 pages in the PDR to 35 for the CDR
- More depth was added to each section, but Failure Modes and Effects Analysis changed the most. It is now organized by the area of interest which each hazard relates to, such as recovery, and is 15 pages longer

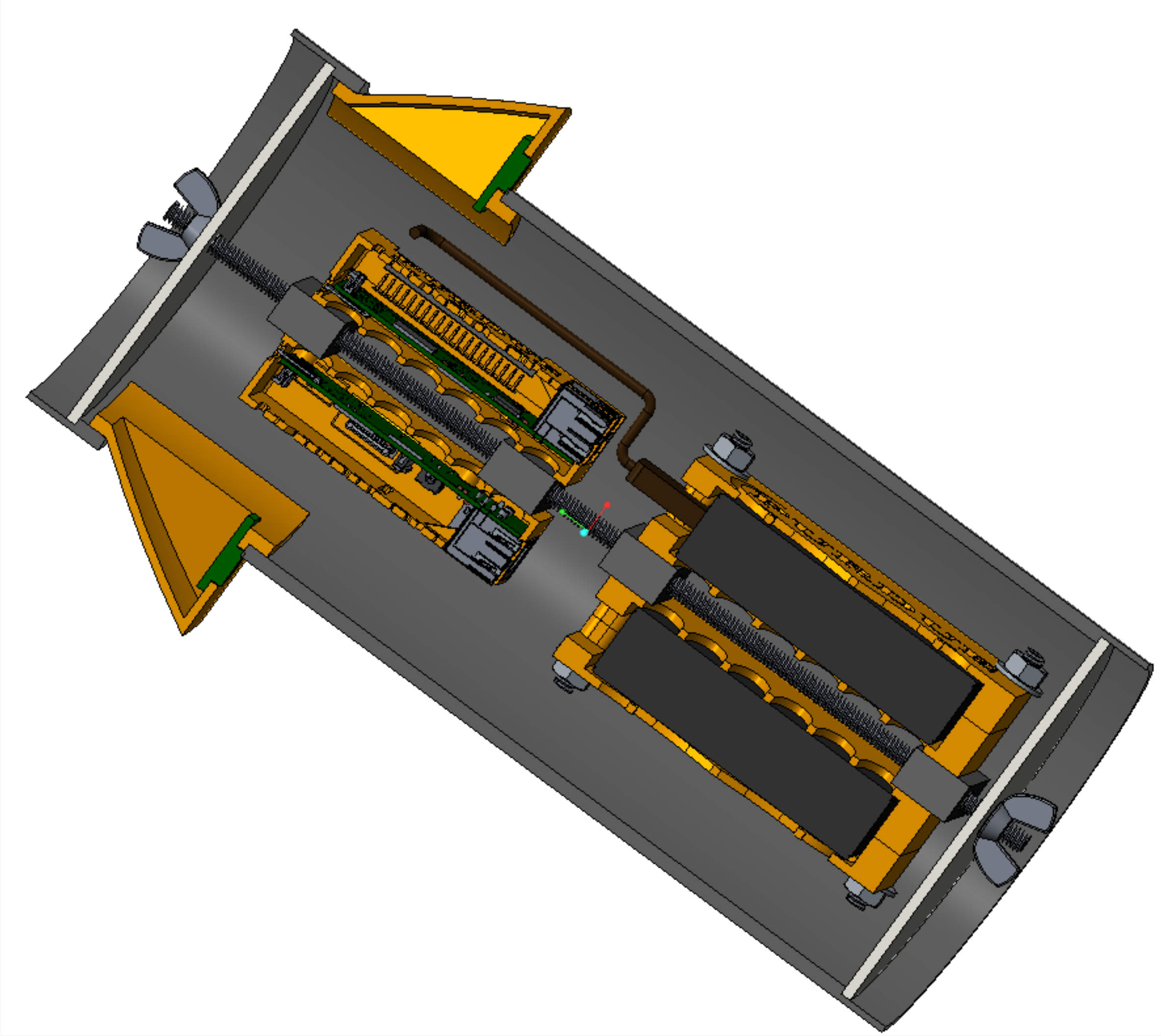
Payload System Overview

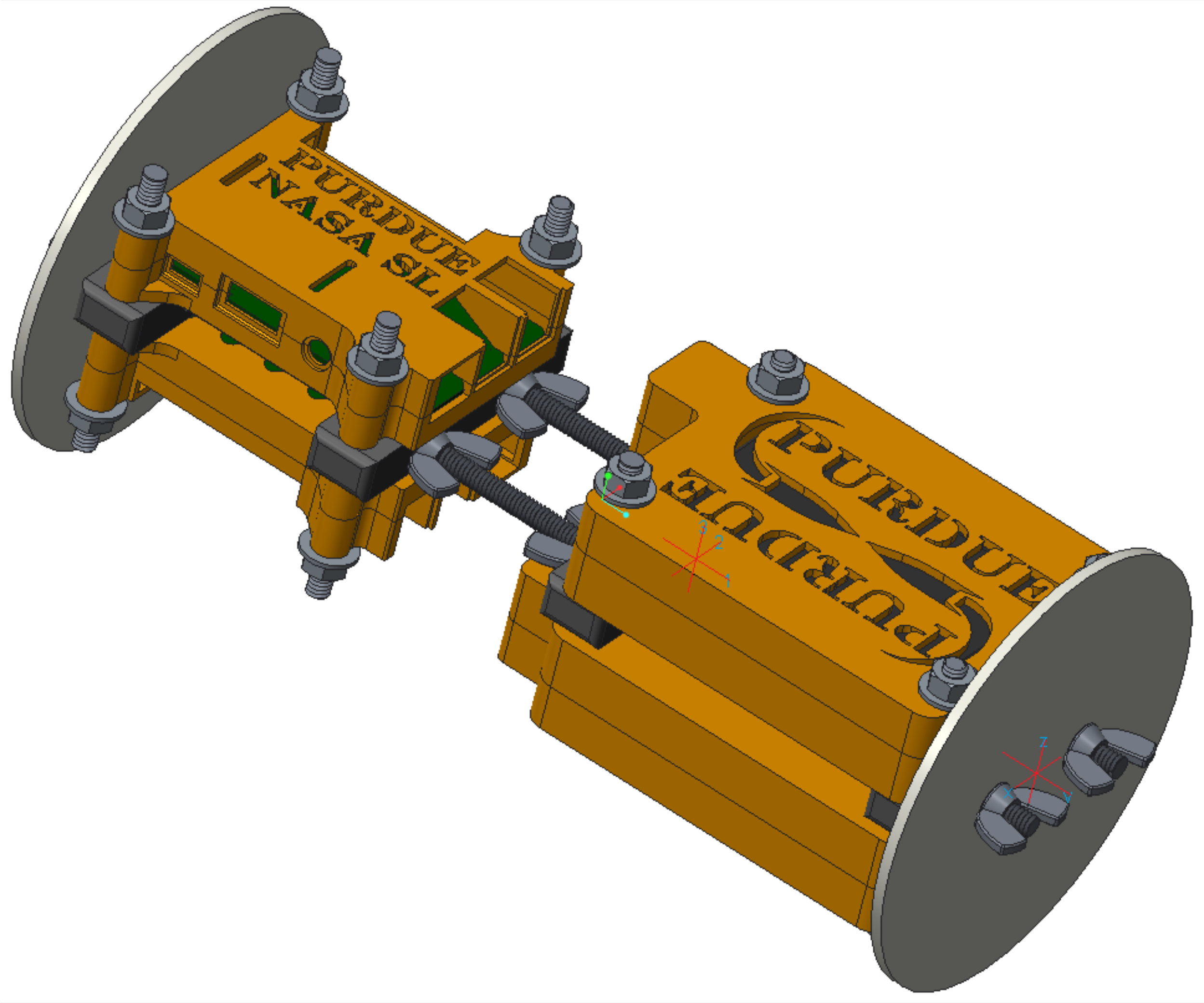
- Target Detection System
- Frame by frame image feed into system to be processed in real time
- Three adjacent tarps will be uniquely identified based on color by the system during flight
- System will be completely redundant for backup purposes

Payload Design: Requirements

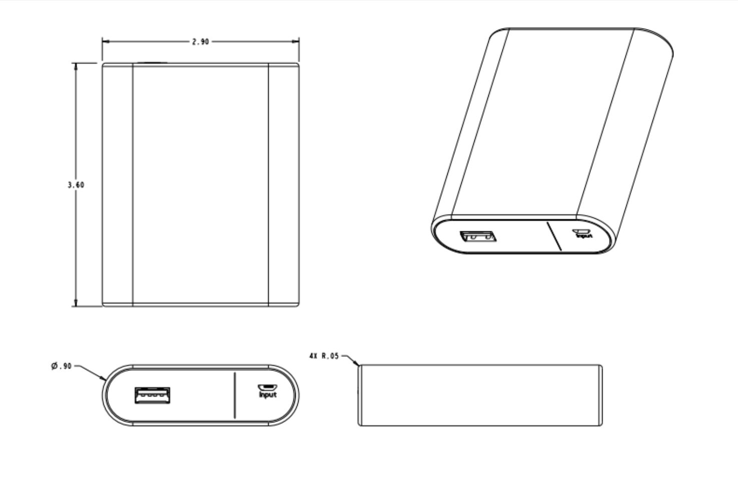
- Less than 2 lbs
- Dimensions:
  - 12” long & 4.815” diameter
- 2 hours of autonomous operation
- Independent from avionics bay
- Processing must be done in real time on board the launch vehicle.
- Full redundancy system
- Two externally mounted LED’s are to be used to indicate the cameras are actively recording
- Two externally mounted LED’s are to be used to indicate the batteries are actively supplying power
- An externally mounted switch is to be used to activate/deactivate both battery supplies
- Both onboard computers must be remotely accessible via WiFi to initiate/terminate the recording programs

Payload Design





Battery



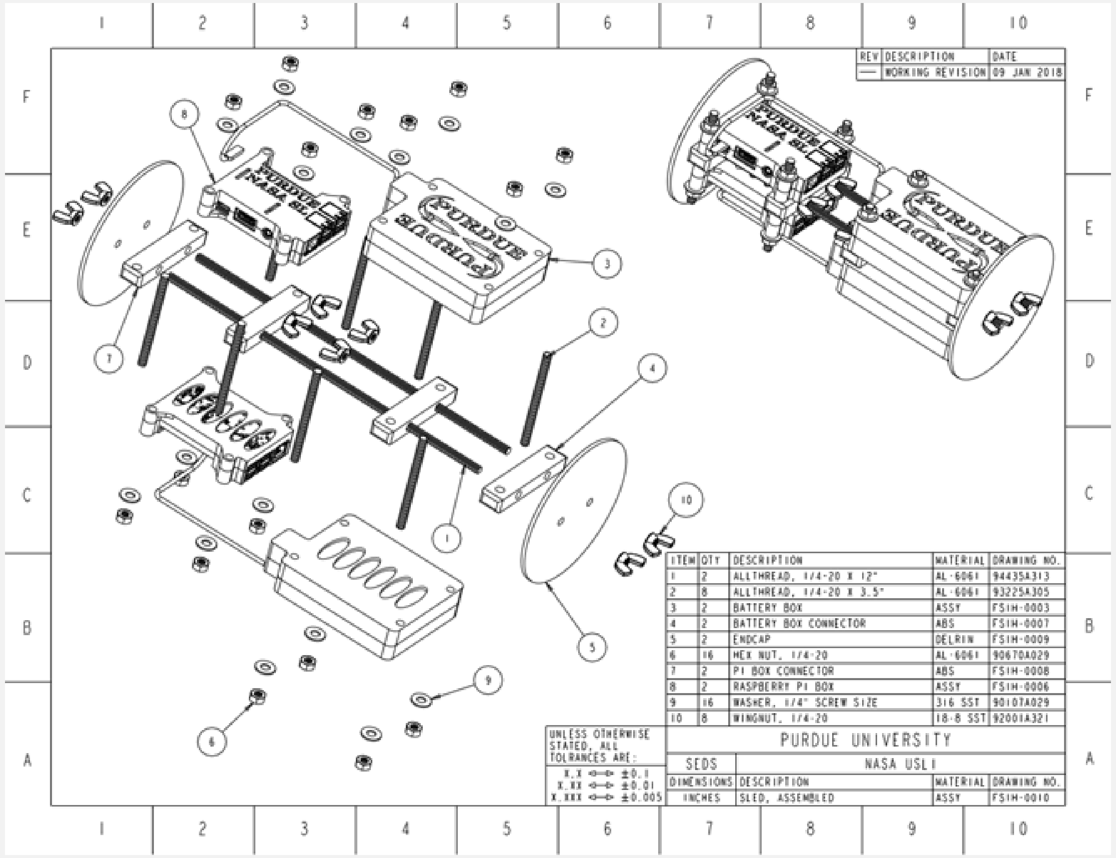
https://www.anker.com/products/variant/PowerCore-10000mAh/A1263011

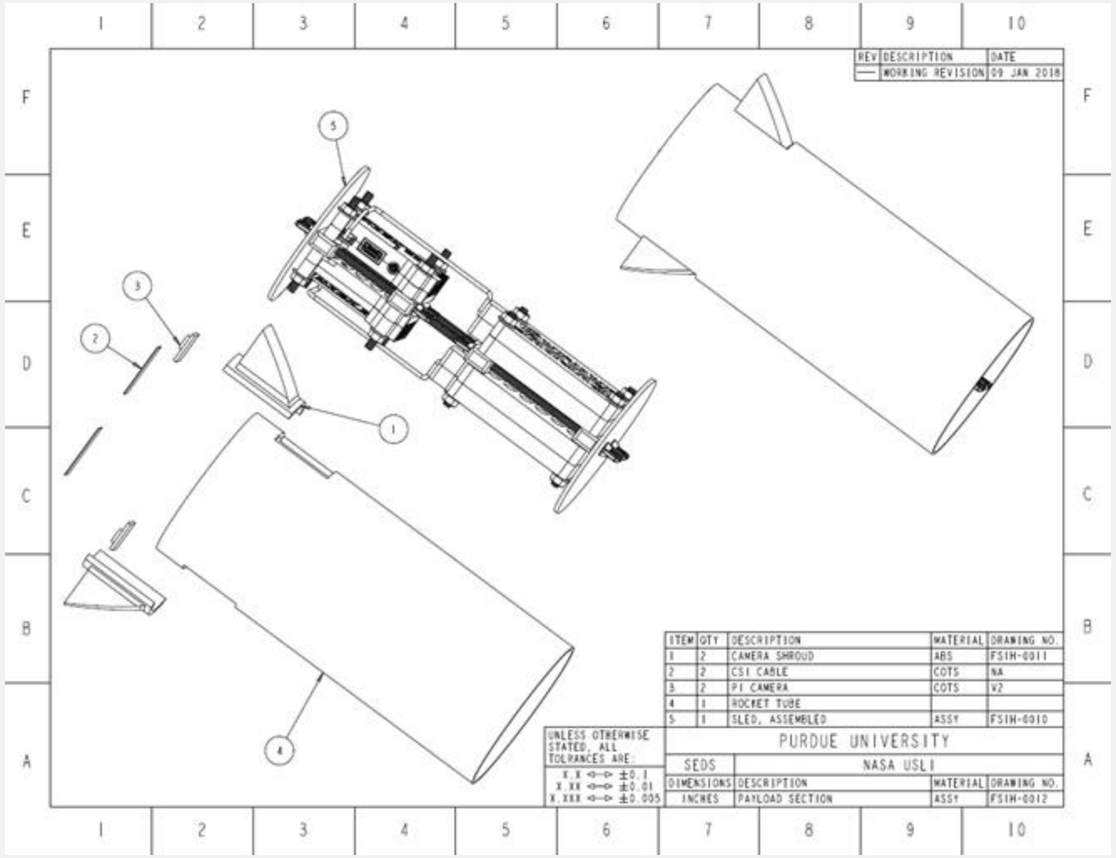
- Requirements:
  - Less than $30 per battery.
  - Less than one pound.
  - Less than four inches wide.
- Leading Choice: Anker PowerCore 10,000mAh:
  - Allows for even weight distribution.
  - Meets all requirements.
  - Provides significant power for dimensions and cost.

1	Battery (Supplier/Link)	mAh	L (in)	W (in)	T(in)	m(lb)	Price ($)	Amps (A)	Volts (V)
2	RAVPower Portable Charger with 2 ports (Amazon)	20100	6.81	3.19	0.87	0.84	49.99	2.4 per	5
3	RAVPower Portable Charger with 1 port (Amazon)	6700	3.54	1.57	0.98	0.26	13.99	2.4	N/A
4	Anker PowerCore Charger with 1 port (Amazon)	10000	3.6	2.3	0.9	0.4	25.99	2.4	5
5	Anker PowerCore 2-in-1 Portable/Wall Charger (Amazon)	5000	3.6	2.8	1.2	0.42	25.99	2.1	5
6	ROMOSS USB for Raspberry Pi (Adafruit)	10000	5.4	2.4	0.8	0.64	39.95	2	5 each

Depicted above is the subscale battery.
https://www.anker.com/products/variant/PowerCore-5000/A1109011

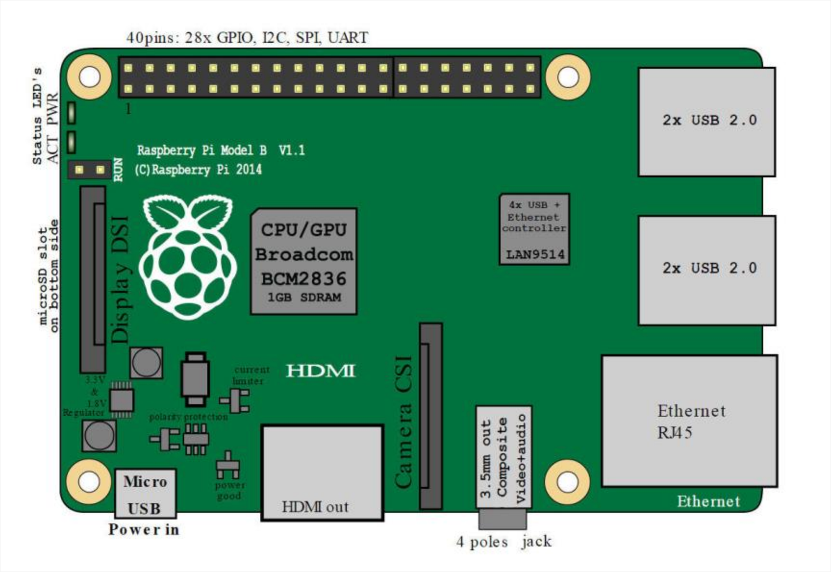
Payload Design Cont.

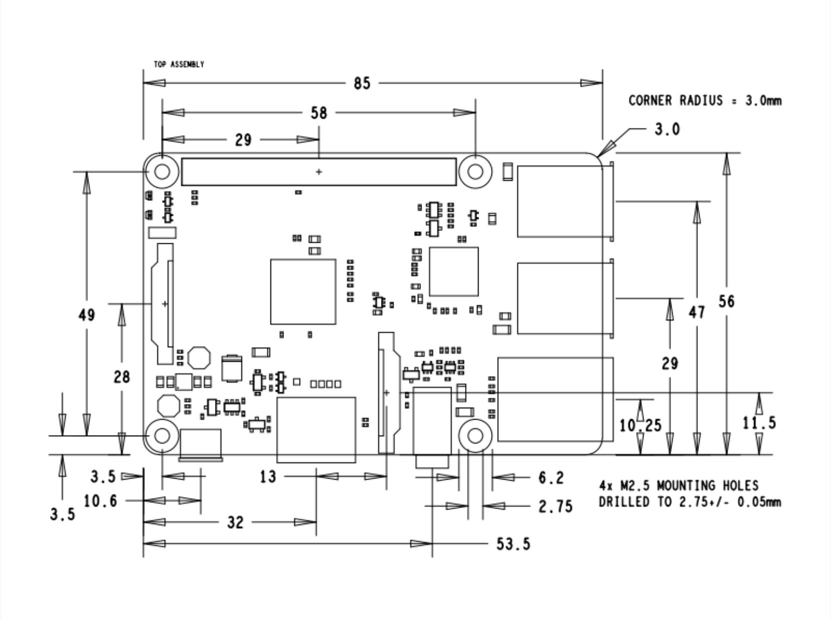




Computer

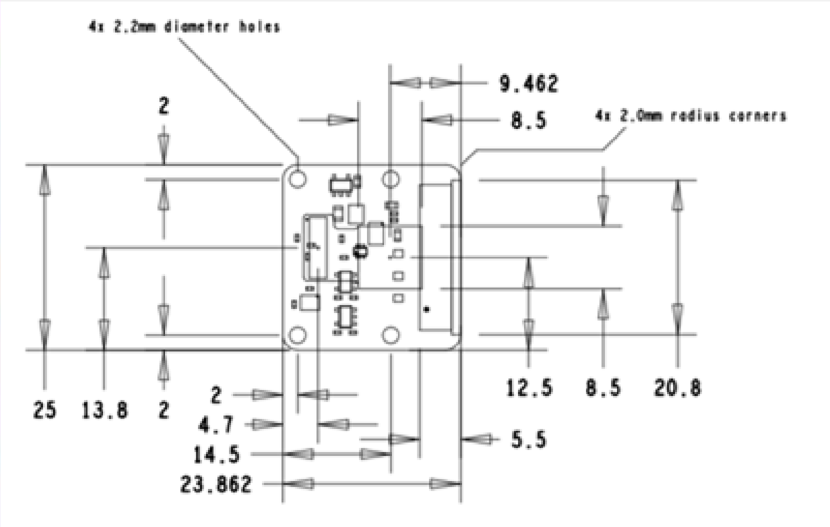
- Raspberry Pi Model 3B:
  - Cost: $35.
- Operating Requirements:
  - 4.75 - 5.25 Volts.
  - 5 Amps.
- Mass: 0.042 kg.
- Dimensions:
  - 85.6mm x 56.4mm x 17.0 mm.
- Processing Performance:
  - 1 GB SDRAM.
  - Quad Cortex A52 @ 1.2Ghz.





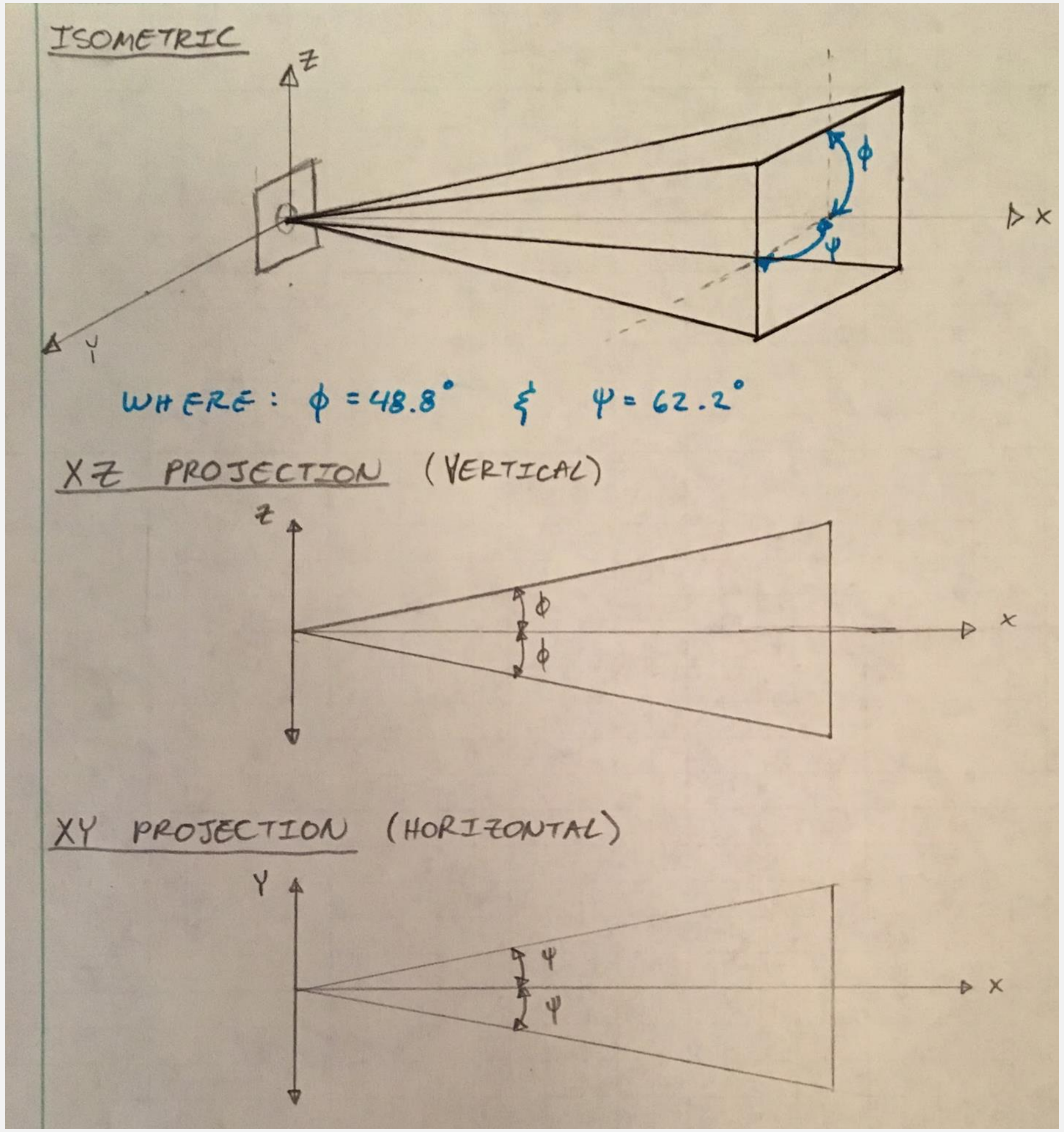
Camera

- Raspberry Pi Camera Module V2:
  - Cost: $25.99.
- Resolution:
  - 8 MP (3280 x 2464).
- Frame Rate:
  - 1080p @ 30 fps.
  - 720p @ 60 fps.
- Port: CSI.
- 79 degree field of view.
- Mass: 0.0031 kg.
- Dimensions:
  - 0.98" x 0.94" x 0.35".



Camera Properties

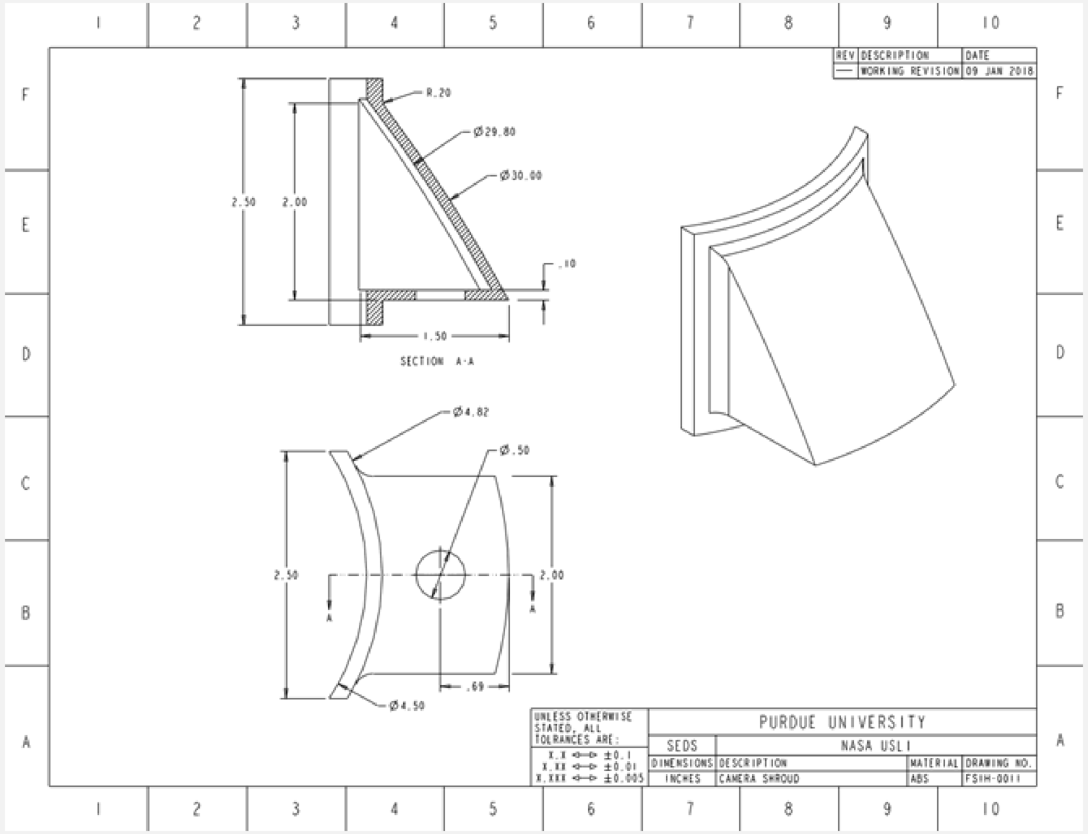
- Horizontal field of view
  - 62.2 degrees
- Vertical field of view
  - 48.8 degrees



Camera Positioning

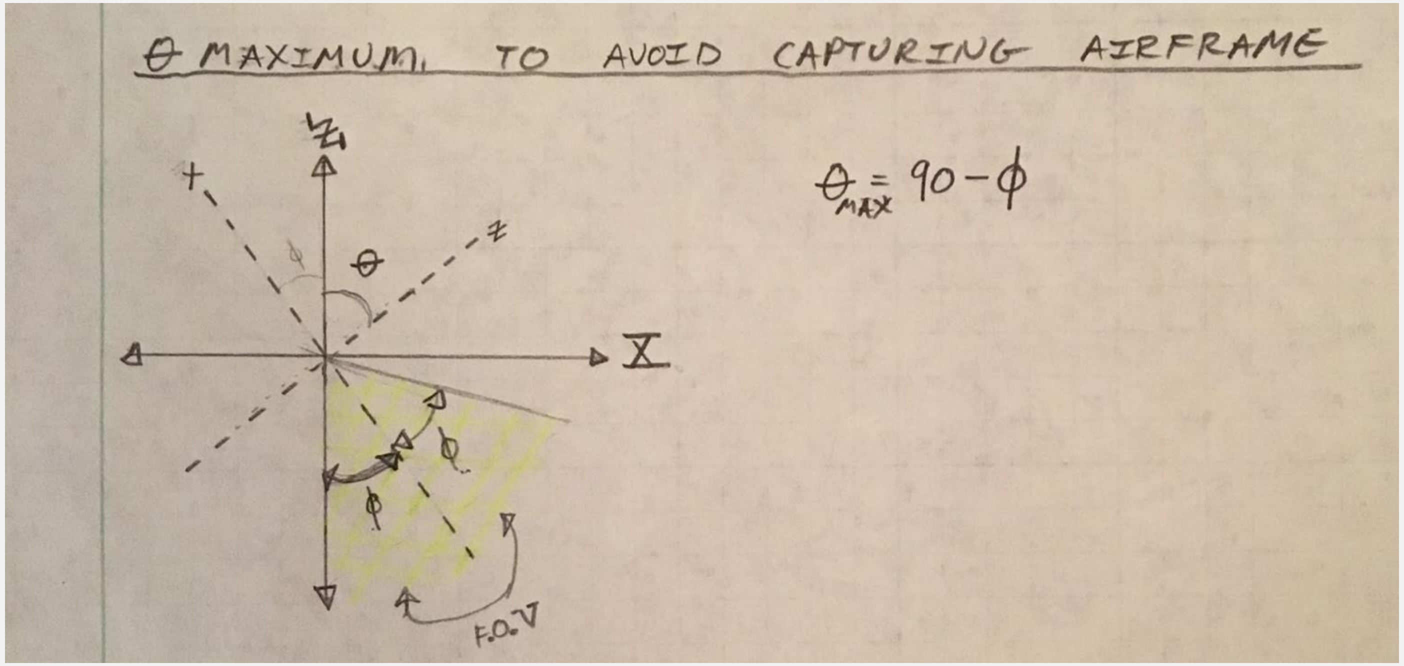
Objective:

- Minimize the amount of airframe entering camera's FOV
- Maximize opportunity for targets to within camera's FOV
- Minimize drag produced by camera being externally mounted



Camera Positioning Cont.

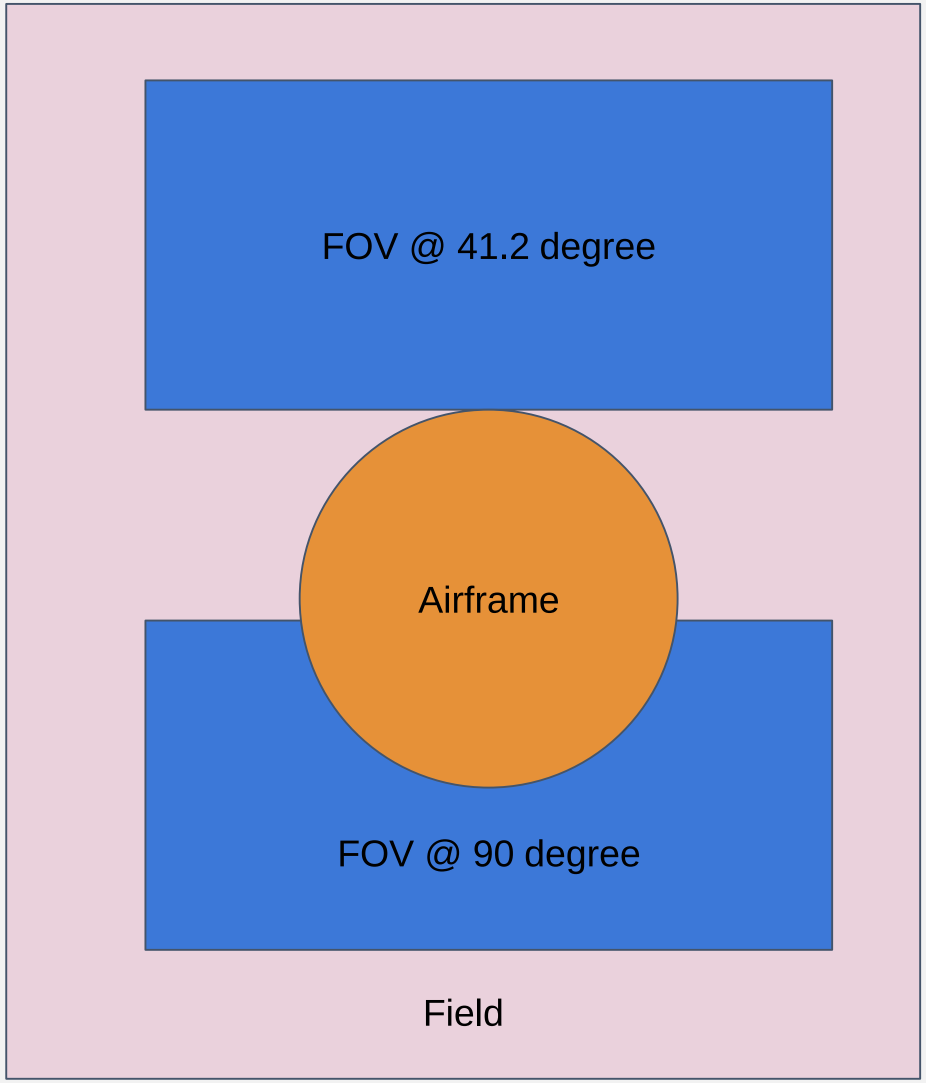
- Max angle to prevent interference of air frame
  - 41.2 degrees



Camera Positioning Cont.

Decided to mount camera perpendicular to airframe

- Jeopardize drag and increase interference of airframe entering FOV
- Maximize potential for targets to stay inside FOV
  - The airframe of the rocket introduces a blind spot
  - Gives the added ability to see “behind” the rocket



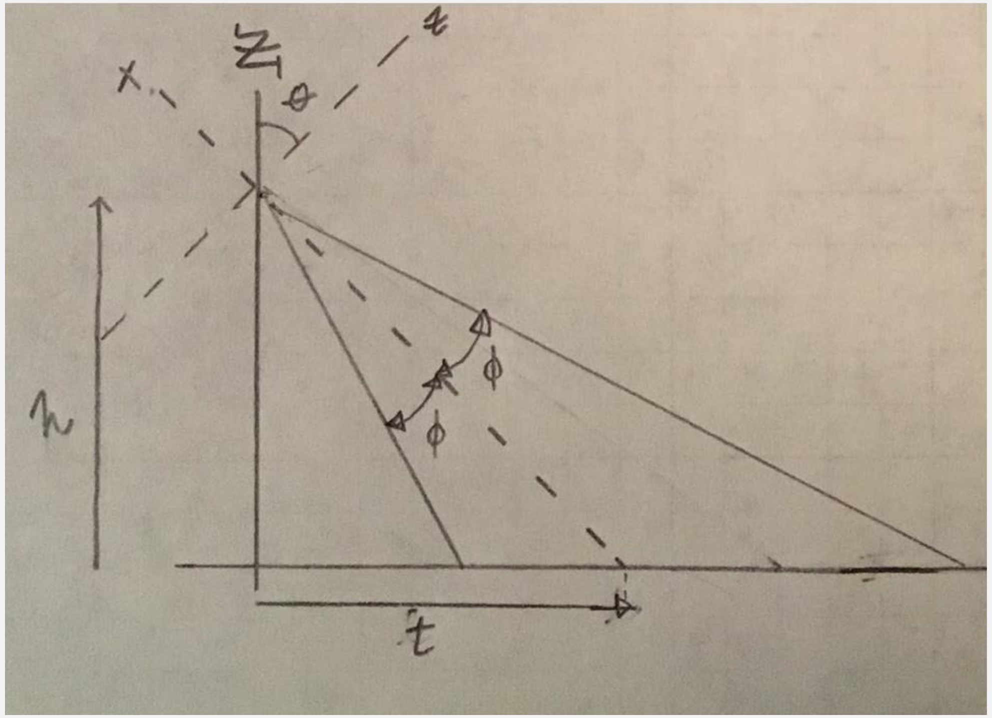
Camera Positioning Cont.

Assume:

- Perfectly vertical flight
- Max target distance 600 ft

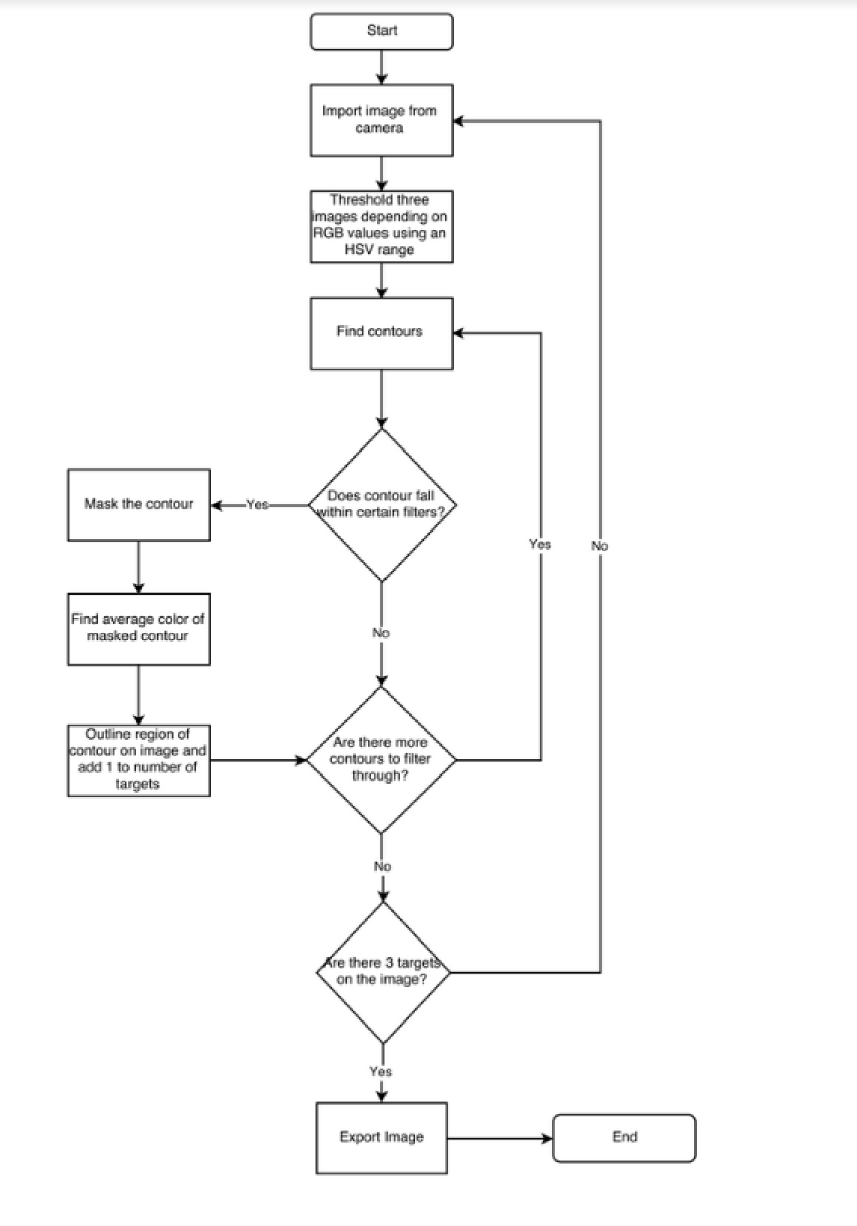
Results:

- Targets enter field of view
  - 525 ft
  - In range for 90% of flight
- Radius of FOV at apogee
  - 6031 ft



Software

- Running on Raspian OS
  - Easily interfaces with Pi Camera and Pi
- Python Script (3.0)
  - Import OpenCV libraries



Subscale Test Overview

Subscale Flight Recorded Results

Subscale Scaling Factors

Launch Conditions And Simulations

Recorded Vs. Predicted Data

Project Plan Overview

The scope of the project plan moving forward involved the following areas and tasks:

- Tests to prove design integrity
- Fundraising
- Full scale build and test launch
- Educational engagement

Tests To Prove Design Integrity

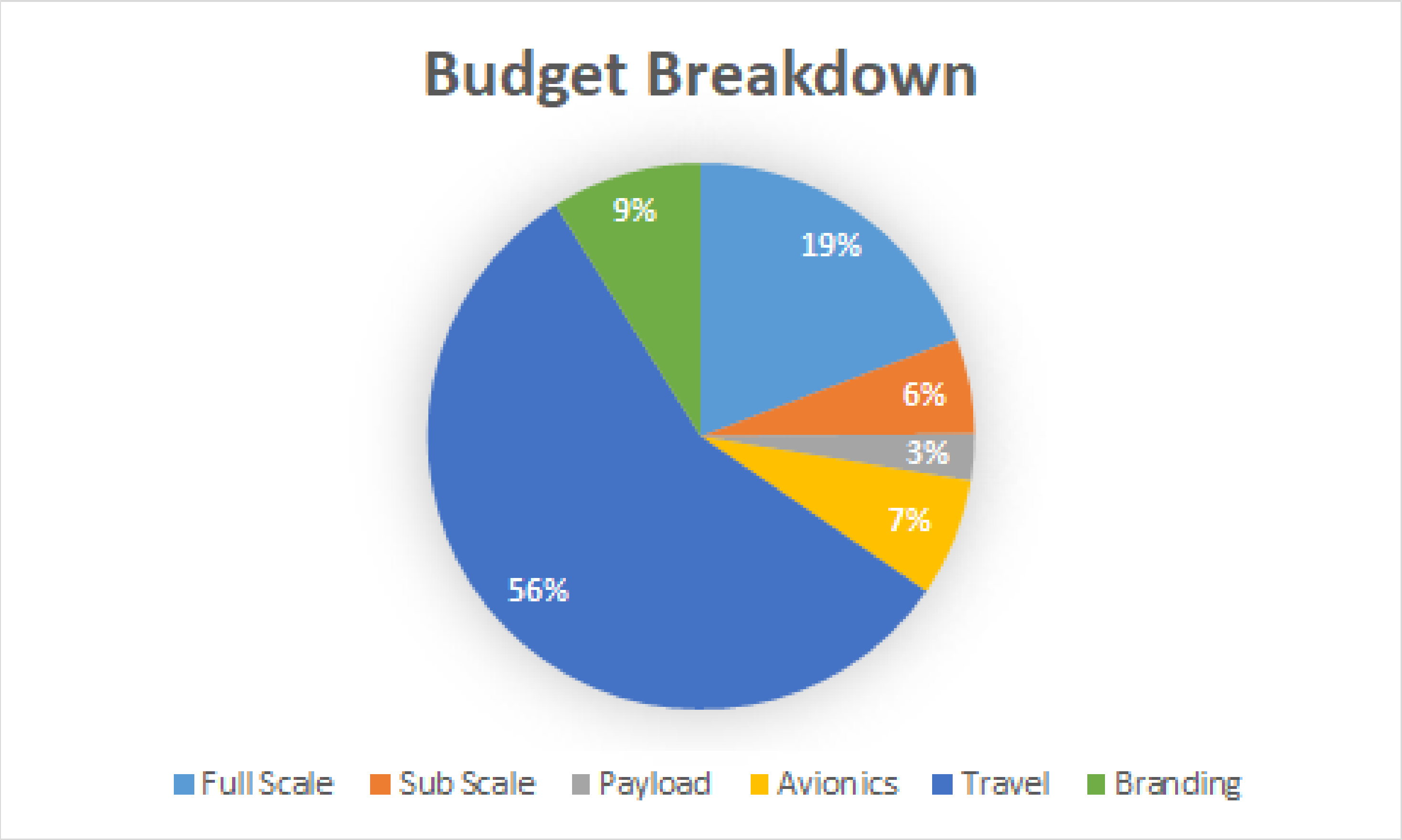
In order to prove the integrity of the design and all subsystems, the following tests will be performed:

- Avionics continuity testing
- Ejection charge testing
- Avionics/payload battery testing
- Camera testing
- Software testing

Budgeting

Total of ~$11,000

- Broken into 6 distinct sections
- Currently looking for means to low travel costs



Funding Plan

5 Forms of Funding:

1. Restaurant Fundraisers: $800 (across 3-4 fundraisers)
2. Grants (INSGC/Other): $5000+
3. Company Sponsorship: $1000-
4. Crowdfunding: $3500
5. SEDS Treasury: $700

Total: $11000 ($500 Margin)

Question And Answer Session