Project Walker
Critical Design Review

Vehicle Design Characteristics

Mission Statement

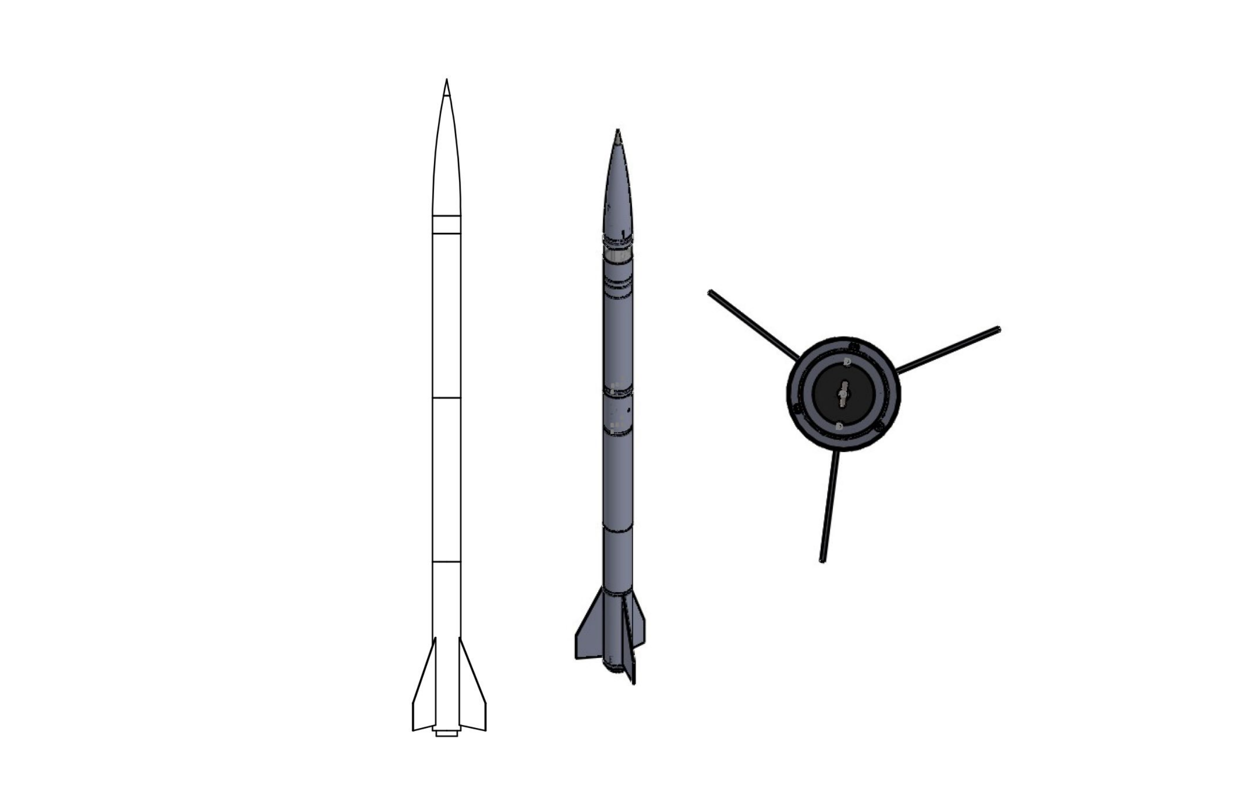
Our mission statement can be broken into two distinct goals:

- To design, build, test, and fly a student-crafted launch vehicle to a predetermined altitude
- To carry a payload consisting of a small rover capable of moving a set distance and collecting a soil sample

Launch Vehicle System Overview

The launch vehicle is consists of 5 distinct subsections:

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



120” Height

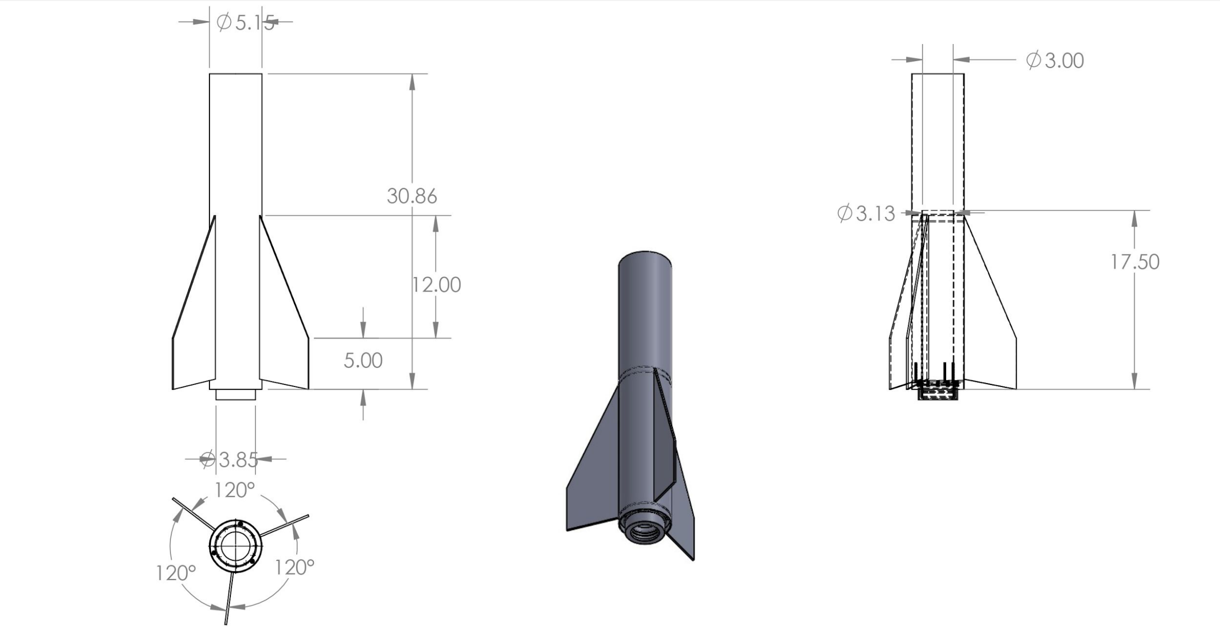
5.15” Outer Diameter

~37.5 lbs Launch Weight

Lower Airframe Subsystem

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

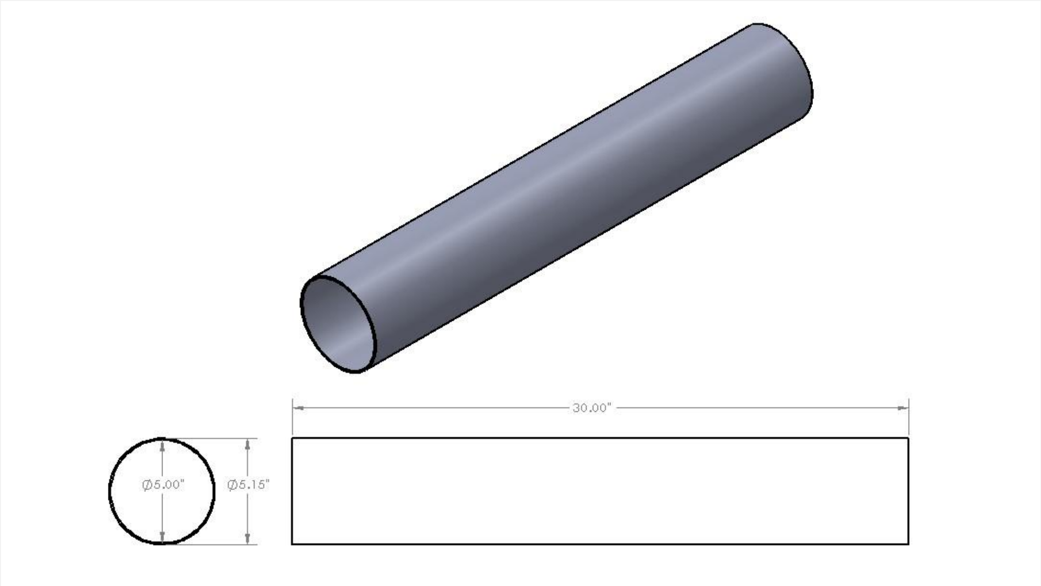
- Filament wound tubes
- G10 plate fiberglass fins and centering rings
- Utilizes interlocking TTW fins with plywood backed rings
- Bolted on thrust plate/retainer



Mid And Upper Airframe Subsystem

The mid and upper airframes are identical sections of airframe tubing

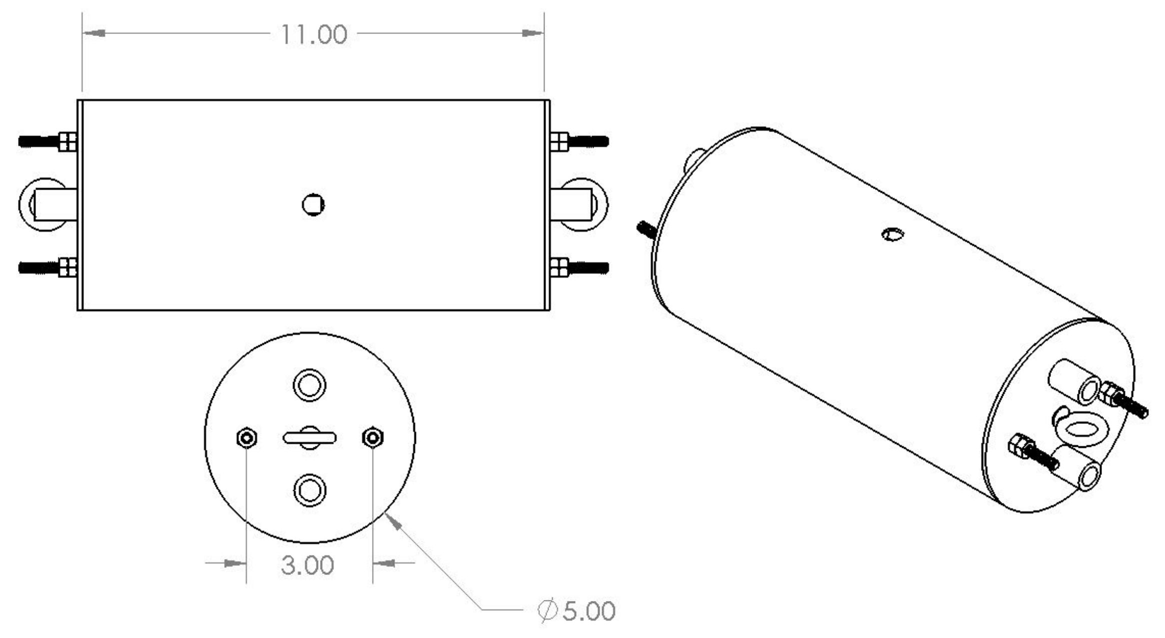
- Filament wound fiberglass
- 30” long each
- Mid airframe interfaces with the payload and avionics bays
- Upper airframe interfaces with the avionics bay and nose cone



Avionics Bay Subsystem

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

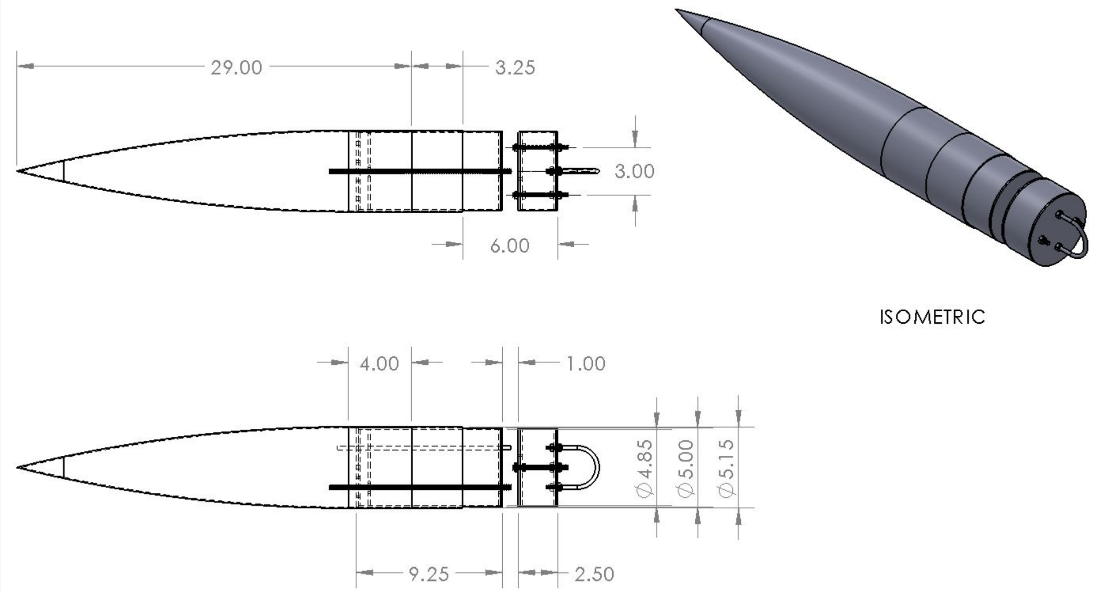
- Fiberglass Tubes
- Two independent switches
- Fiberglass Bulkheads
- Threaded Rods
- Stainless Steel Eye Bolts
- Charge Wells



Nose Cone / Payload Bay Subsystem

The payload bay houses the payload ejection system and housing for the rover

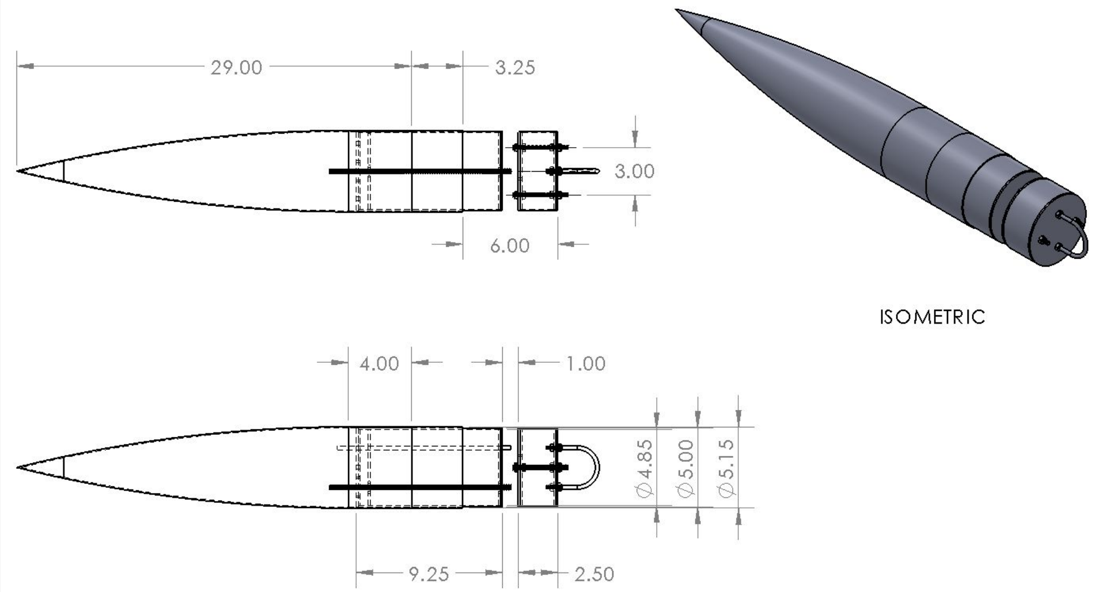
- Filament wound tubes
- ABS printed sled and rover parts
- Stepper motors, batteries, etc.
- Fiberglass bulkheads
- Stainless steel hardware



Nose Cone / Payload Bay Subsystem Cont.

The nose cone reduces drag and interfaces with the upper airframe

- 29" long metal tipped filament wound cone and tubes
- Fiberglass bulkheads
- Stainless steel hardware
- Installed payload bay



Completeness And Manufacturability

- Nearly all components are commercially available but will need various holes
- Fins will be cut locally with PSP-SL fin design
- Custom parts such as rings will be supplied by a 3rd party contractor
- Building supplies will be bought with the materials or supplied by SEDS

Material Validation

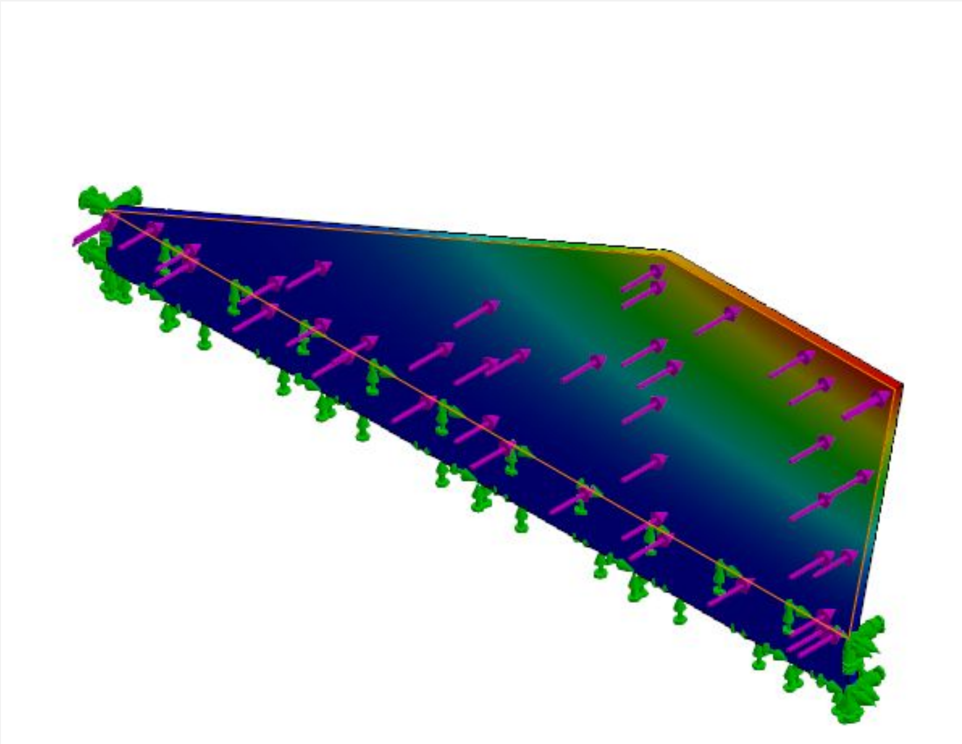
- All material validation was performed in SolidWorks 2017 using a mesh size of 0.1” and sag of 0.01”
- Parts were assigned material characteristics and simulated using clamping and distributed forces
- If a part experienced a stress greater than the tensile yield point, the test is considered a failure

Aluminum yield strength: 40000 PSI

G10 fiberglass yield strength: 41000 PSI

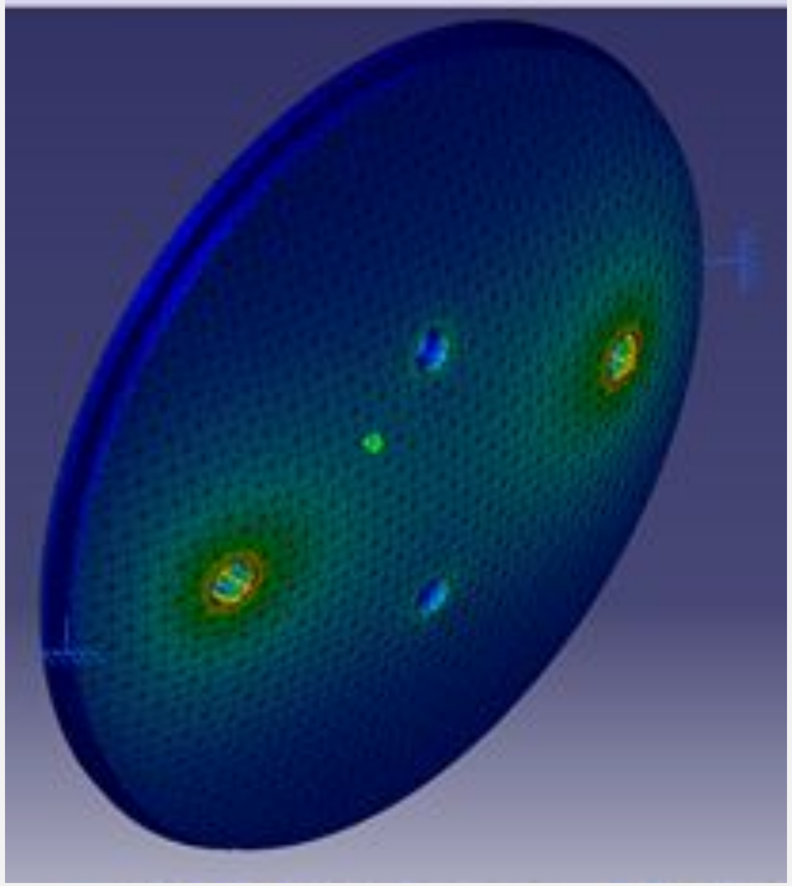
Fin Bending Analysis

Material: 1020 Steel (due to SolidWorks constraints)
Restraints: Clamped root and edges
Forces: 50 pounds laterally
Max. Displacement: 0.005”
Max. Stress: 2119 PSI



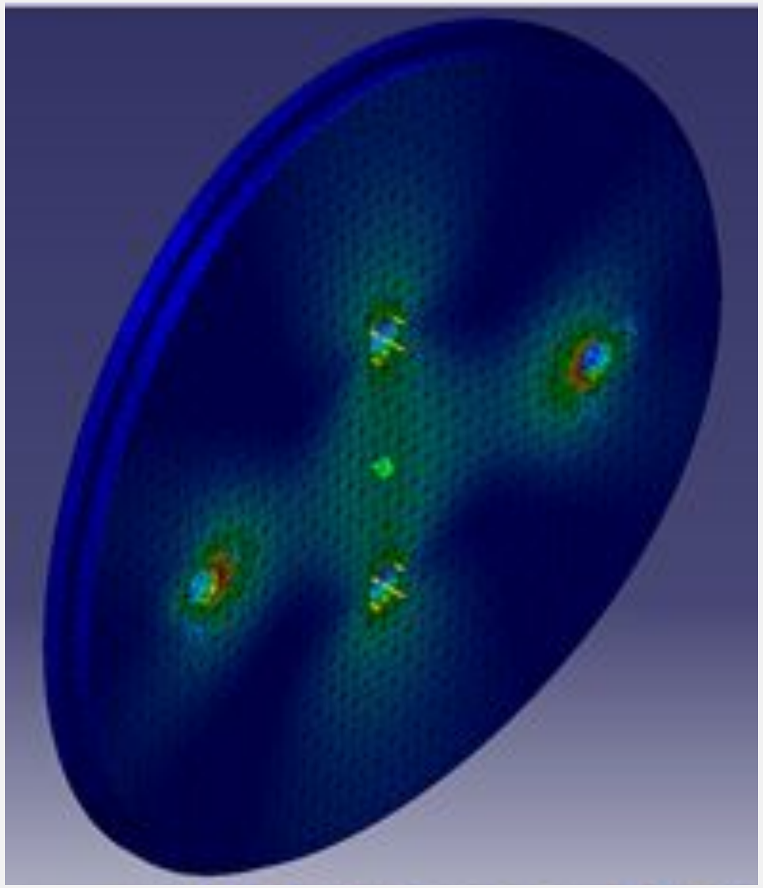
Bulkhead Pull Through Analysis

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



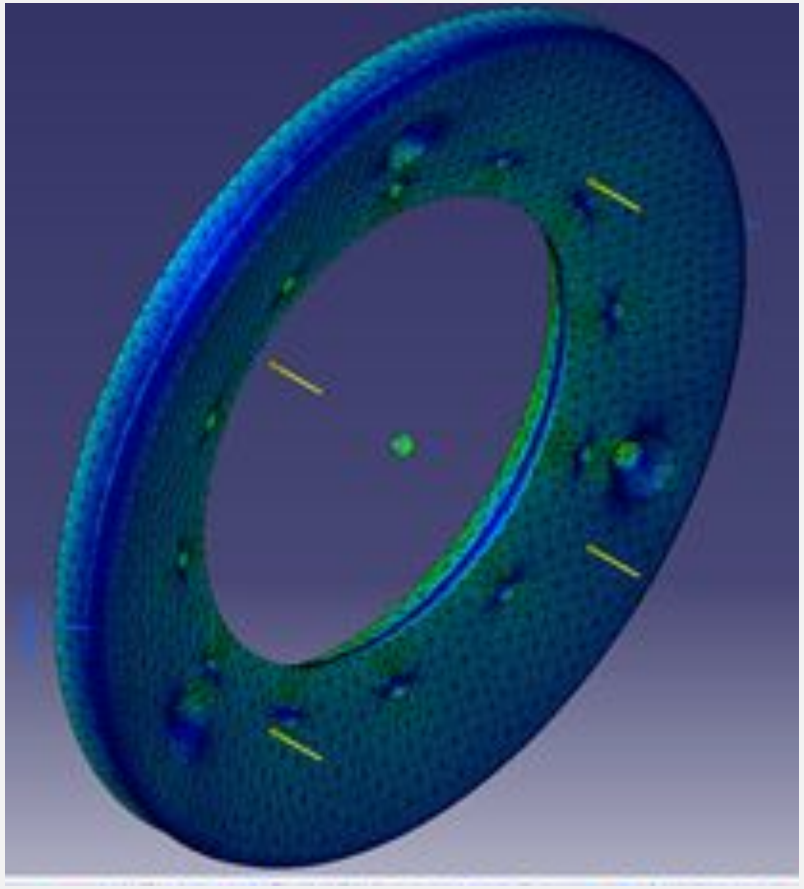
Reverse Bulkhead Pull Through Analysis

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



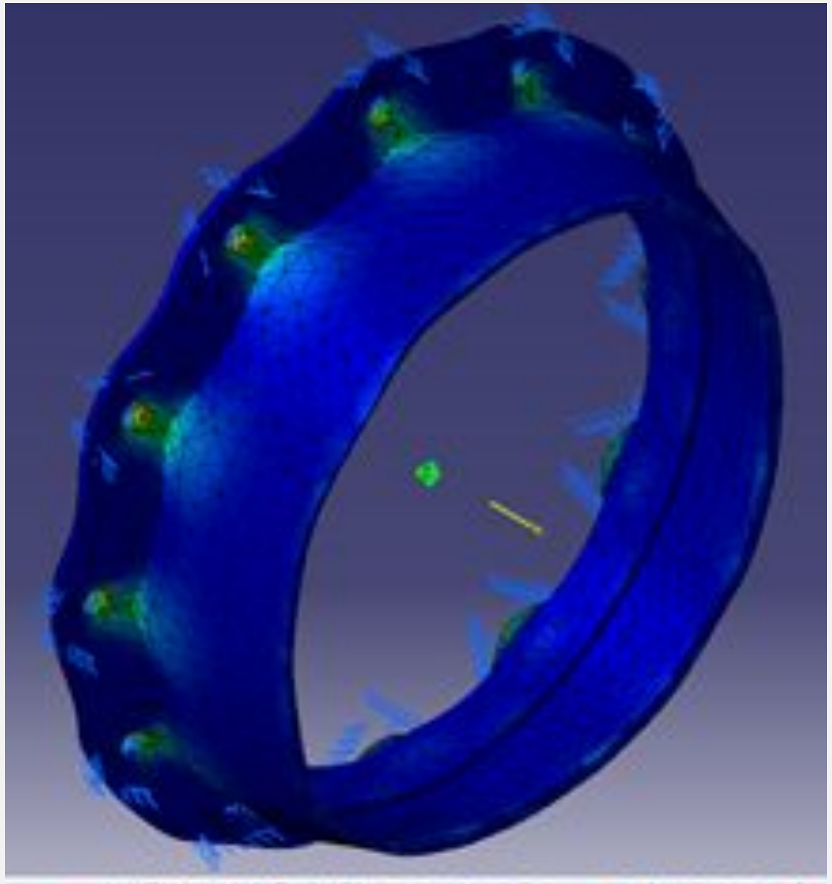
Thrust Plate Analysis

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

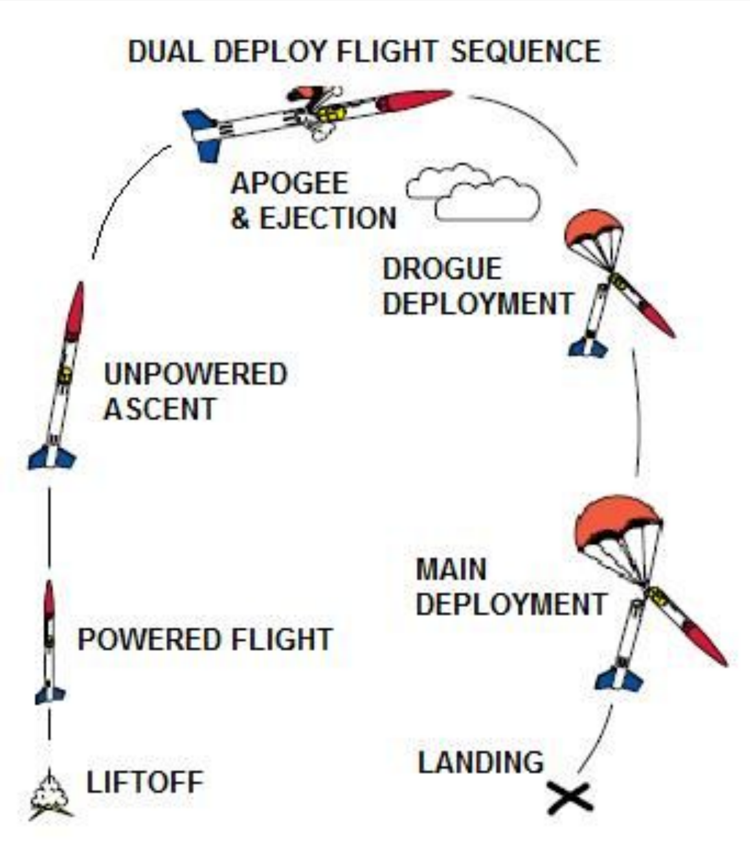


Recovery System Information

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
- 4 x 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
- 18x18" 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.

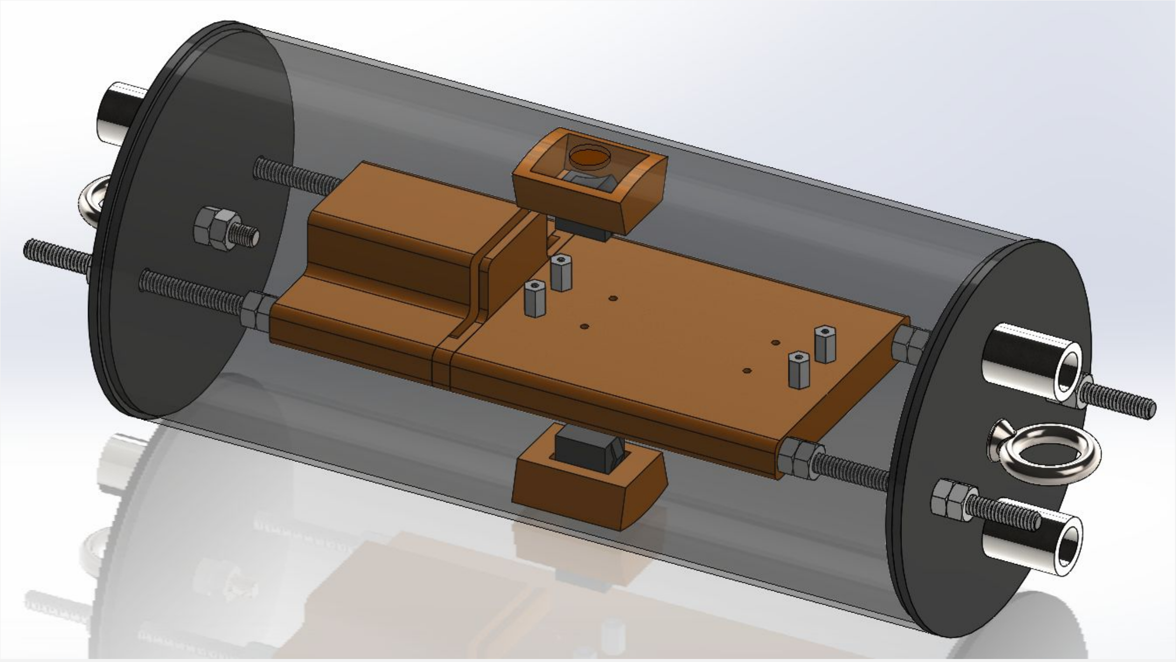
Bulkheads

- Constructed from 0.25” thick G10 fiberglass
- Contain 5 - 0.25” holes:
  - Two holes 3” center to center to accept threaded rods and secure the bulkheads to the coupler tube
  - One hole 1.625” that attaches the rocket to recovery tether.
  - Two holes will be for attaching charge wells
- Each bulkhead is estimated to weigh 0.25 lbs, 1.5 lbs total

Avionics System Overview

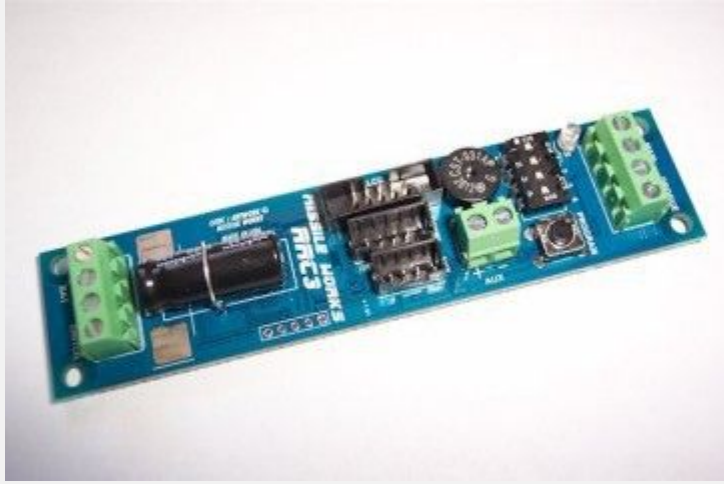
The Avionics Bay consists of:

- 2 Altimeters:
  - TeleMetrum and RRC3+ Sport
- 2 Batteries:
  - 3.7V LiPo and 9V Alkaline
- 3D printed sled and Battery Housing
- Stainless Steel Hardware
- Black Powder
- Independent Rocker Switches



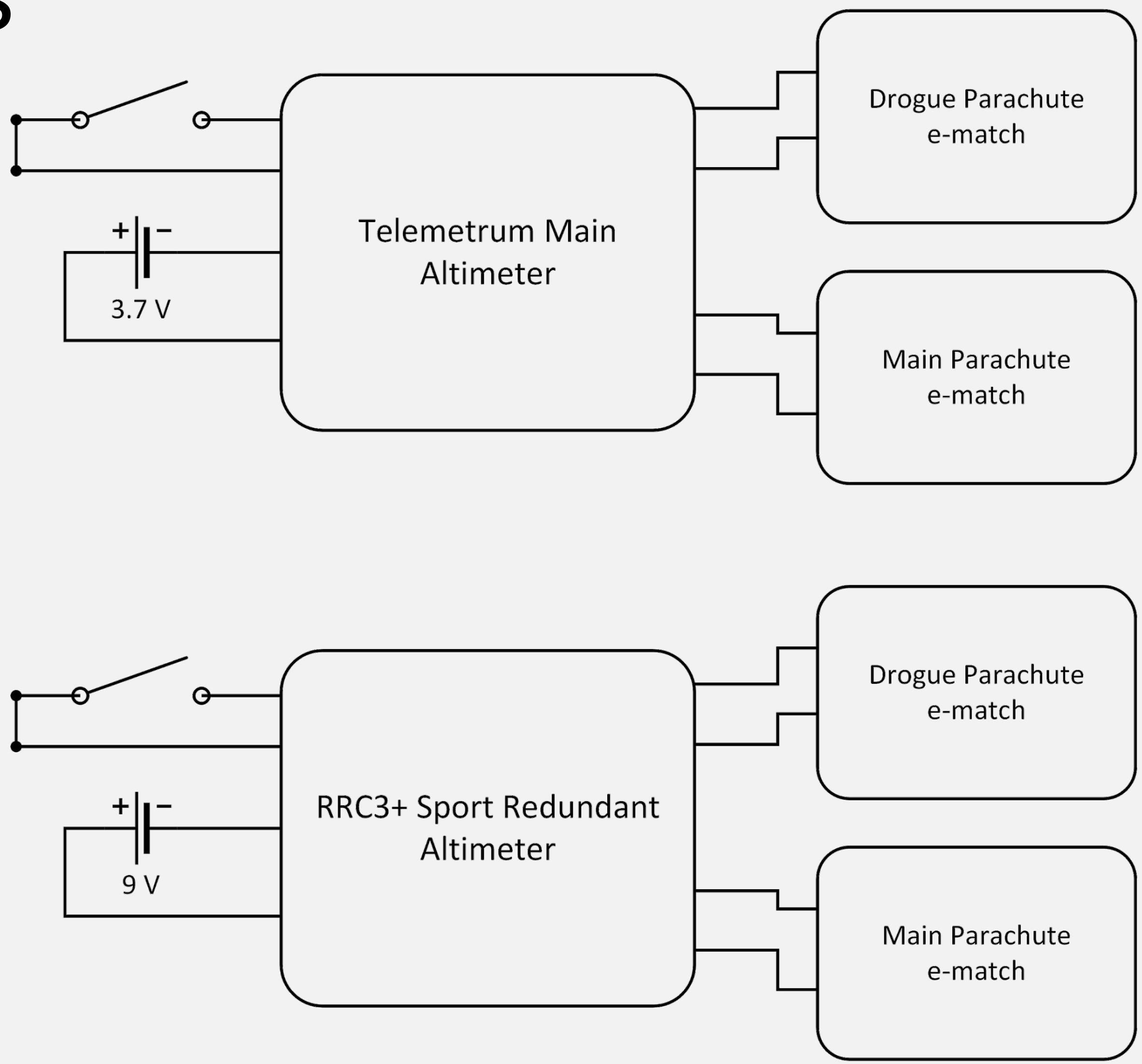
Chosen Altimeters

- 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, rocker switch, and pair of e-matches



Flight Prediction Overview

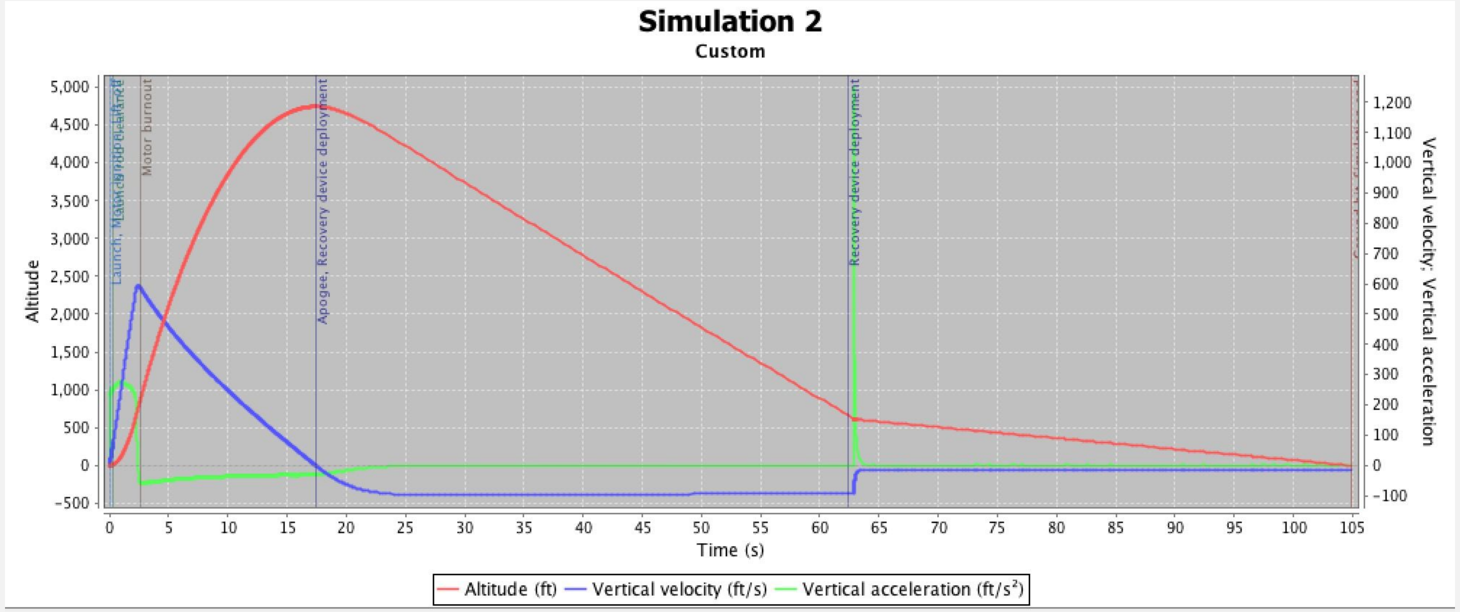
Flight predictions were created using OpenRocket 15.03 using the following settings:

- 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 4,850’

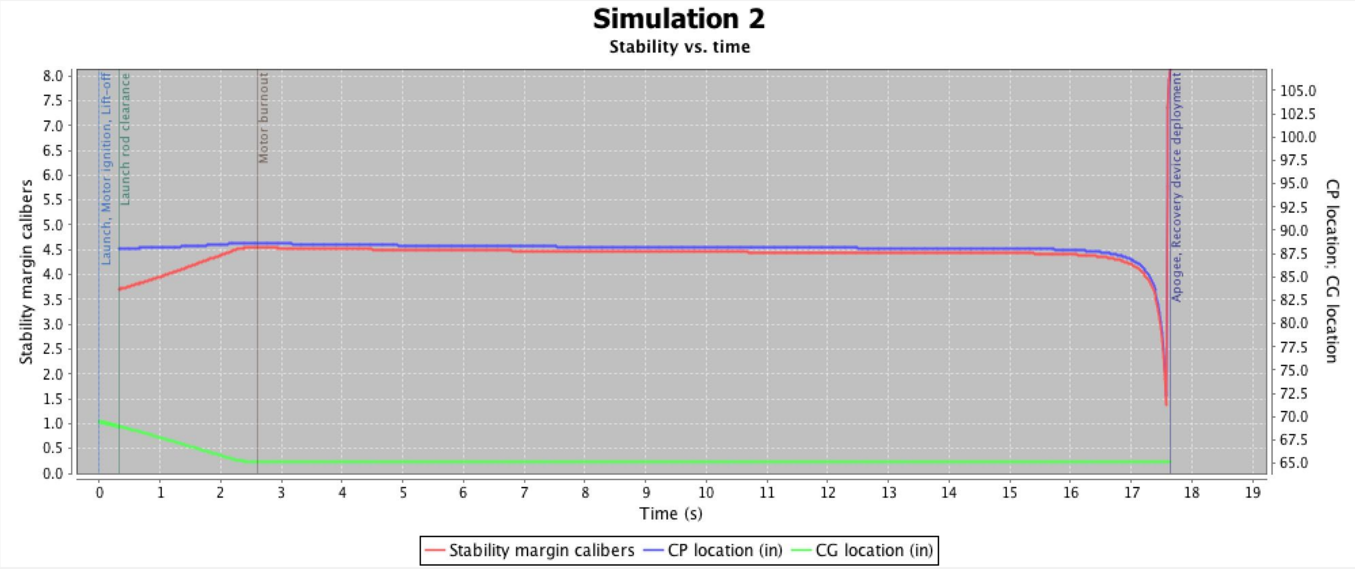
- Variable ballast
- ~9G acceleration
- 0.54 Mach



Stability Predictions

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

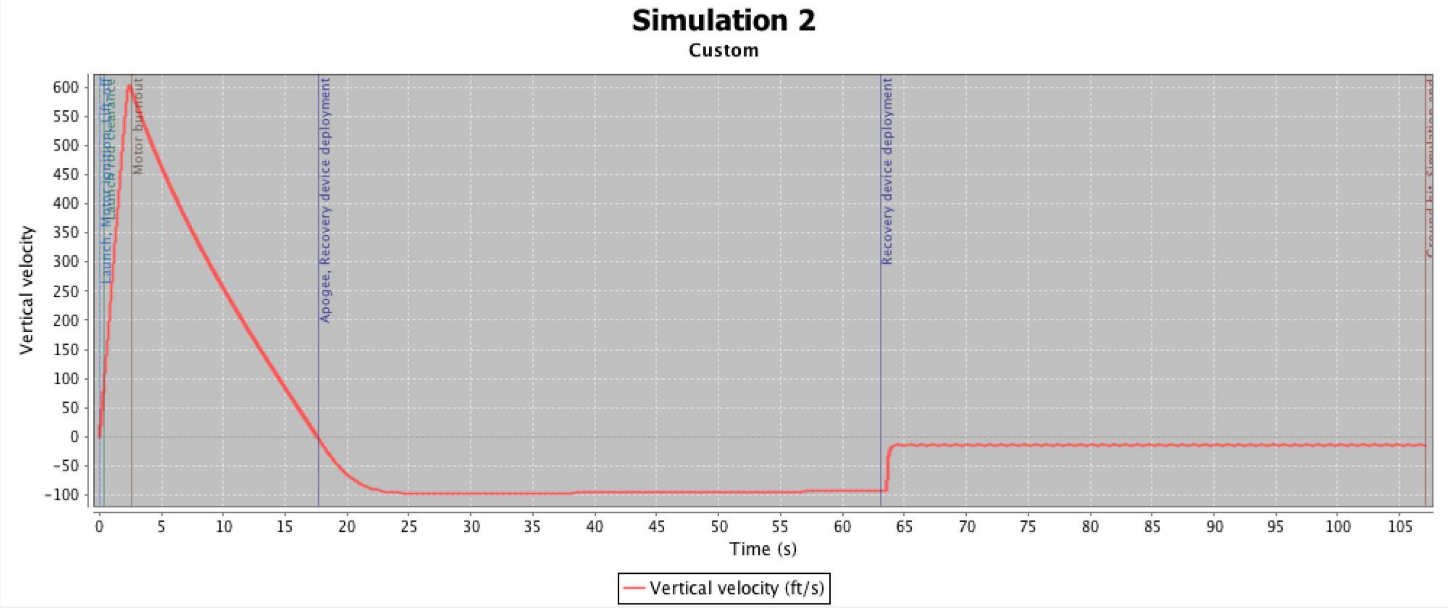
- 3.64 calibers stability
  - CP 88.221” from datum
  - CG 69.471” from datum
- Average stability of 4.5 calibers during flight



Landing Energy Predictions

The rocket is expected to have a touchdown speed of 15.2 ft/s and a total energy of 127.9 ft. lbs.:

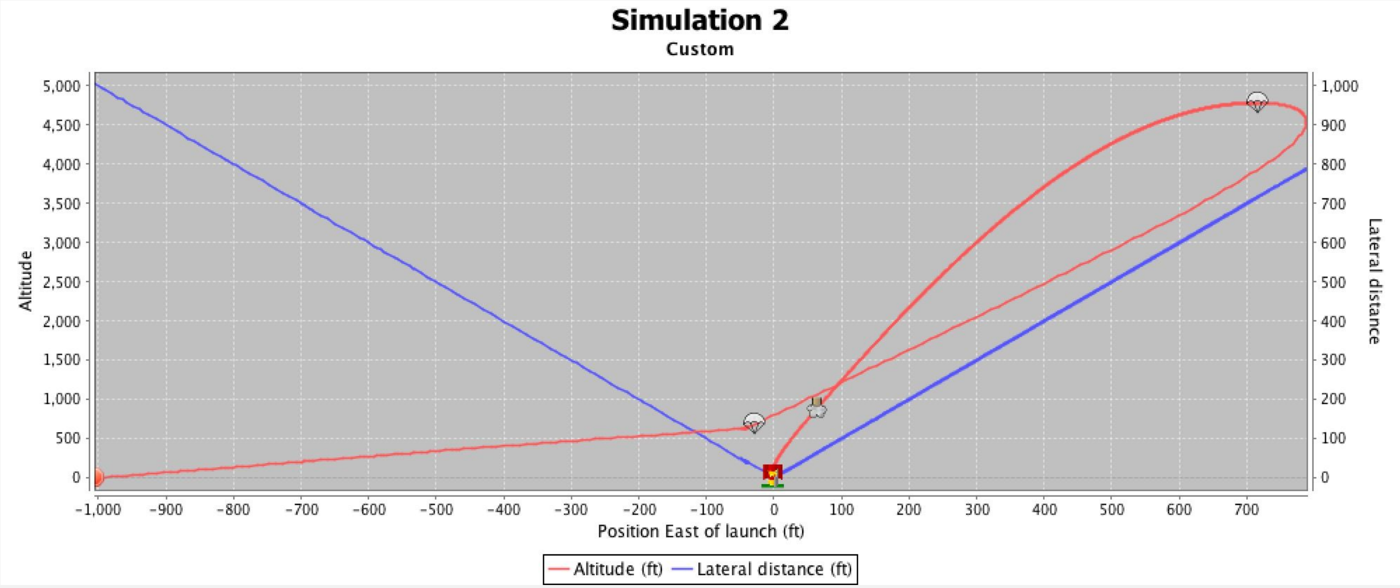
- Lower section: 50.67 ft. lbs.
- Mid section: 32.3 ft. lbs.
- Nosecone: 44.9 ft. lbs.



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: 1000’
- 20 MPH: 1450’



Safety

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 to include more hazards and to include new risks after mitigation
- More depth was added to each section with risk after mitigation

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

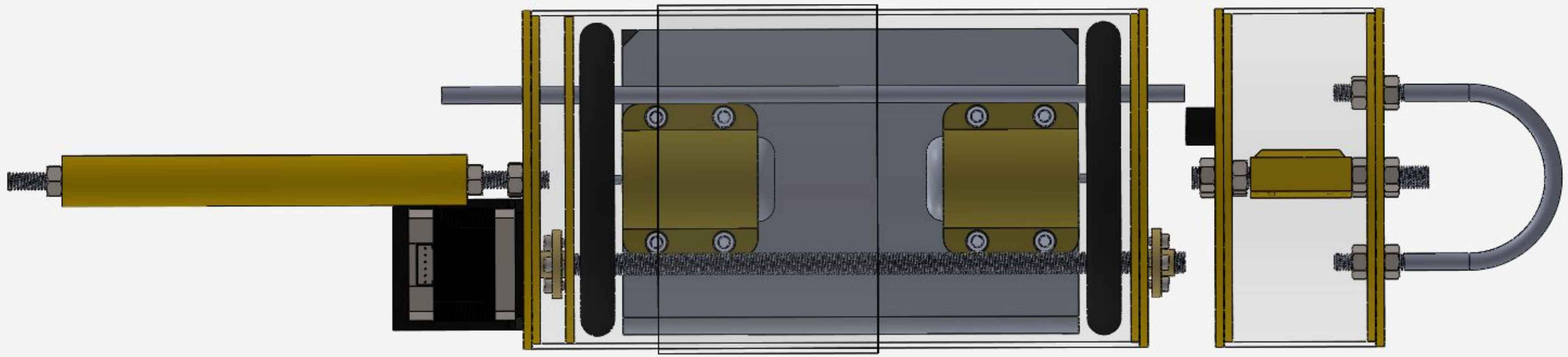
Payload

Payload Design

- Mission
  - Deploy an autonomous rover.
    - Drives 20 feet from rocket.
    - Collects and stores 10 mL soil sample.
- Requirements
  - Less than 8 lbs.
  - Dimensions:
    - 12” long & 4.815” diameter.
  - 3 hours of battery life.
  - Rover can autonomously navigate and avoid obstacles.
  - Rover must stay inside of payload bay until landing.

- Key components
  - 2 x Wheels
  - 1 x LIDAR sensors
  - 1 x 2C LiPO battery
  - 1 x Motor Driver
  - 2 x Brushed DC Motors
  - 1 x 3-Axis Accelerometer
  - 1 x Arduino Pro Mini
  - 1 x Soil Collection System
  - 2 x XBee Wireless Radios

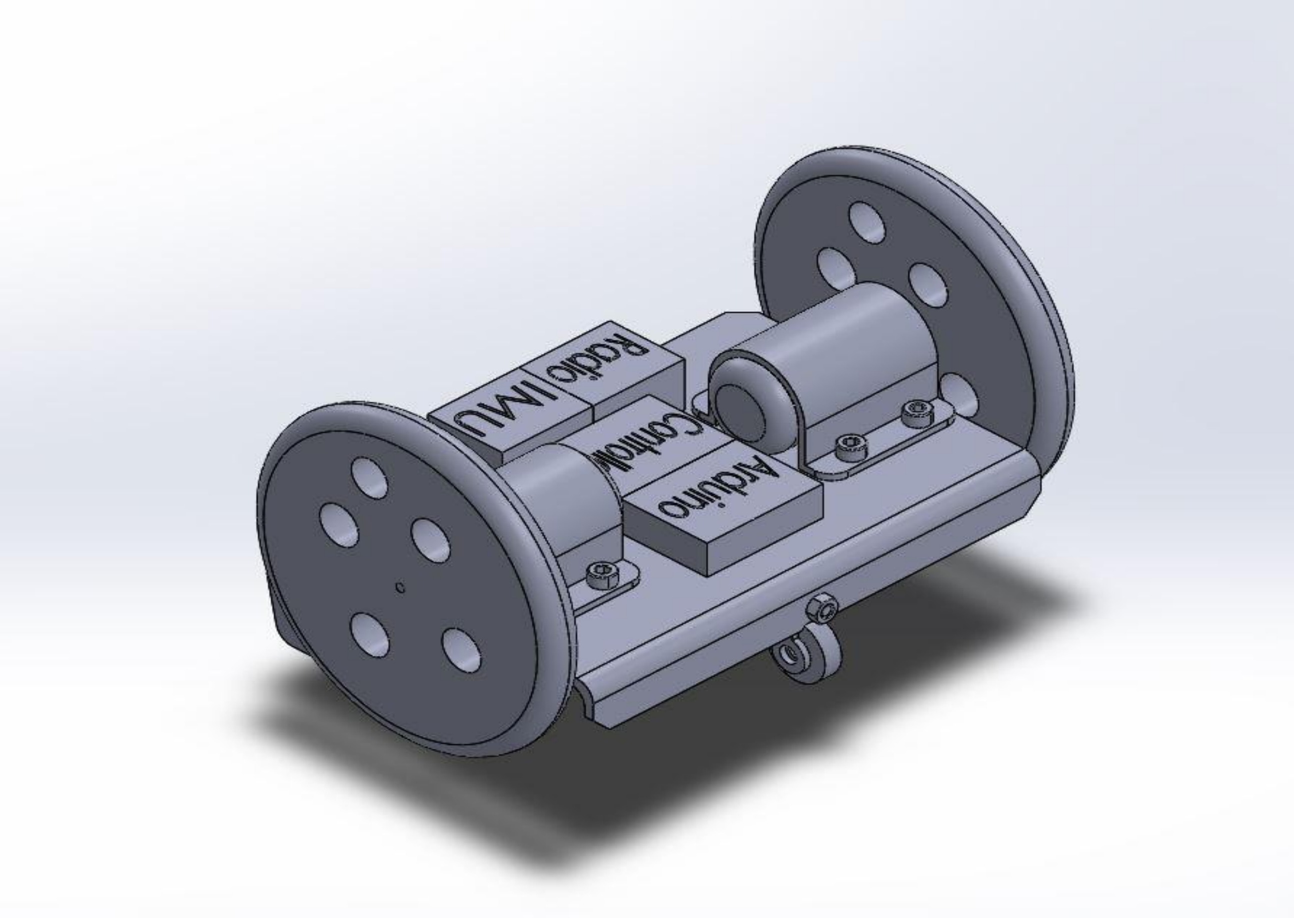
Payload Bay

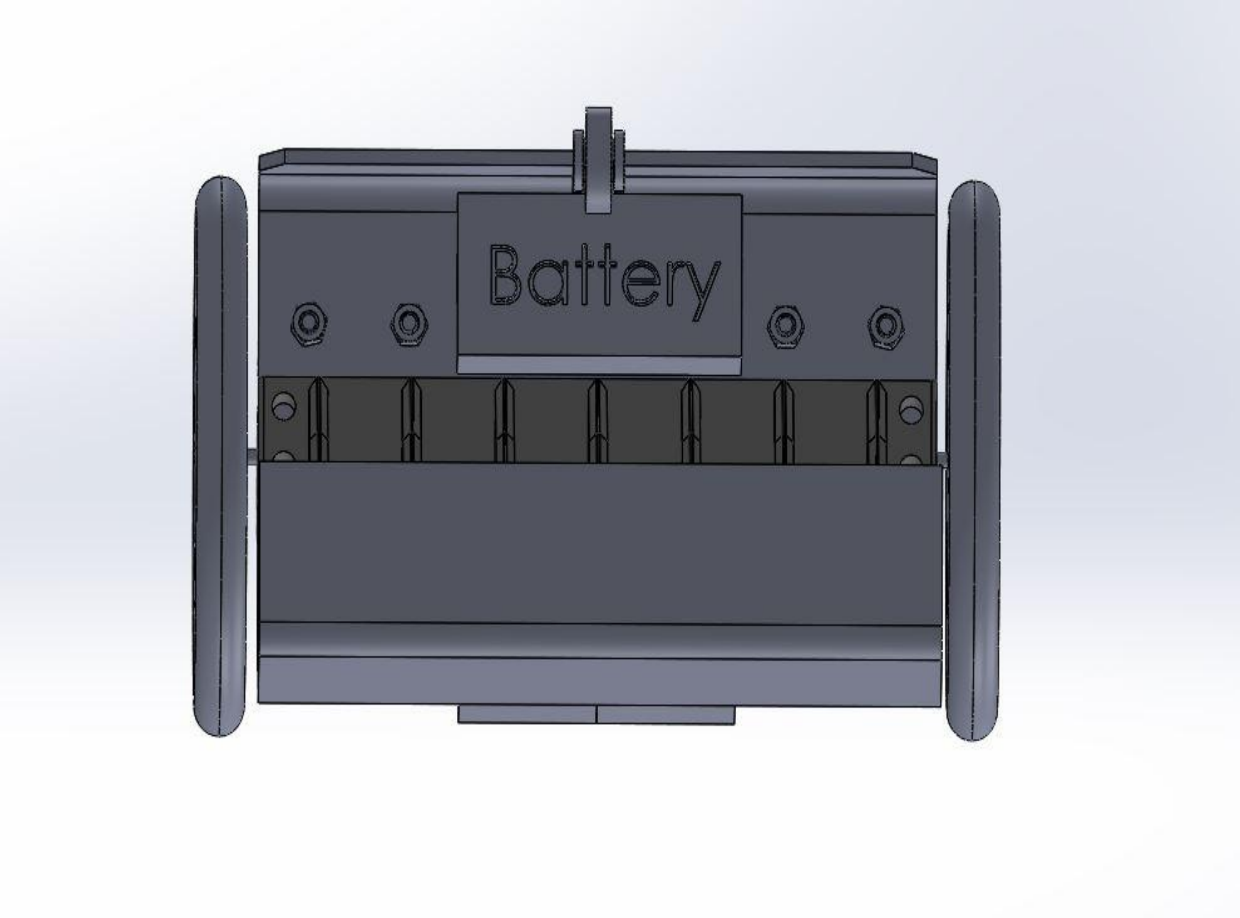


Rover Design

- Chassis
  - Sheet metal
  - Aluminum 6061
  - 6.75” by 4.625”
- Motors/Wheels
  - Brushed DC Motors
    - Placed on top of chassis on either side
  - Large wheels for traction and stability
  - All other rover components under axle to lower center of mass and maintain rover orientation
- Electronics
  - Arduino placed on top of chassis
  - Easy to access
  - Sensors placed on front for unobstructed view
- Soil Retention System
  - Back of rover
- Batteries
  - Under the rover to lower center of mass
- Front support wheel increases stability

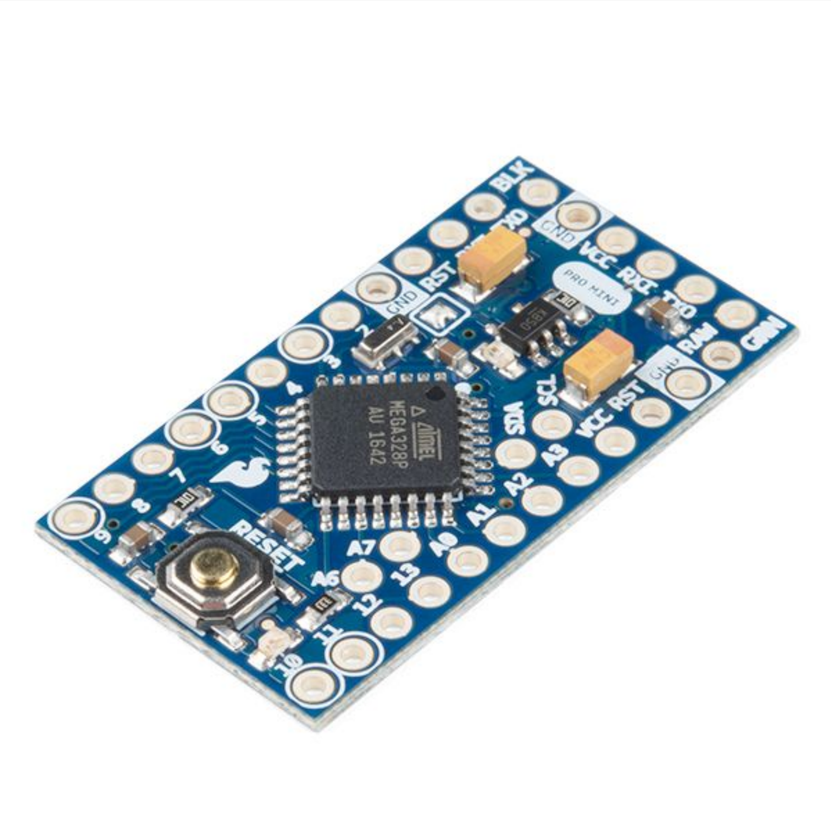
Rover Design





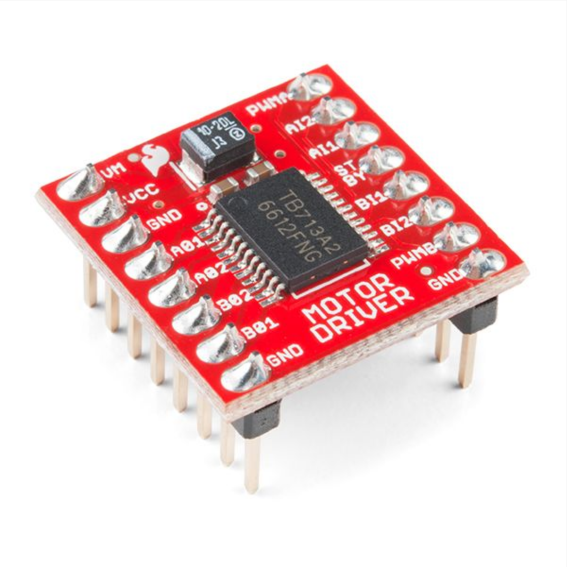
Control Unit

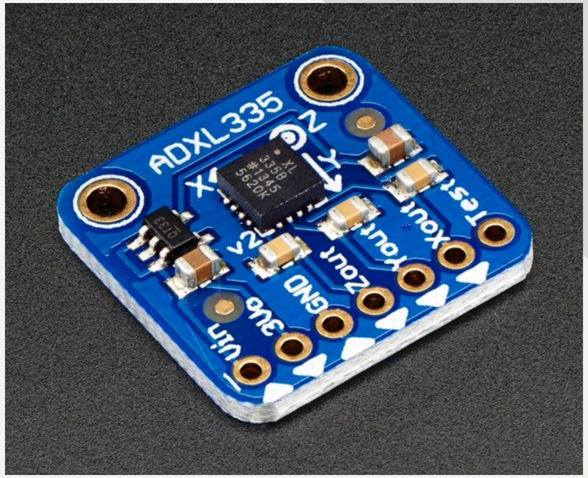
- Arduino Pro Mini 328 - 5V/16MHz:
  - Cost: $9.95.
- I/O Pins:
  - 14 Digital input/output.
  - 8 Analog.
  - 6 PWM.
- Mass: < 2g.
- Dimensions:
  - 1.3x0.7”.
- Processing Performance:
  - ATmega 328 @ 16 MHz.

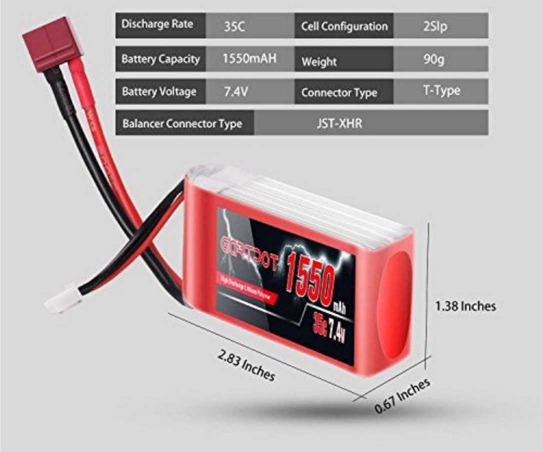


Electrical Design

- Arduino Pro Mini
- TB6612FNG Motor Driver
- ADXL335 3-axis accelerometer
- 2-Cell LiPO Battery

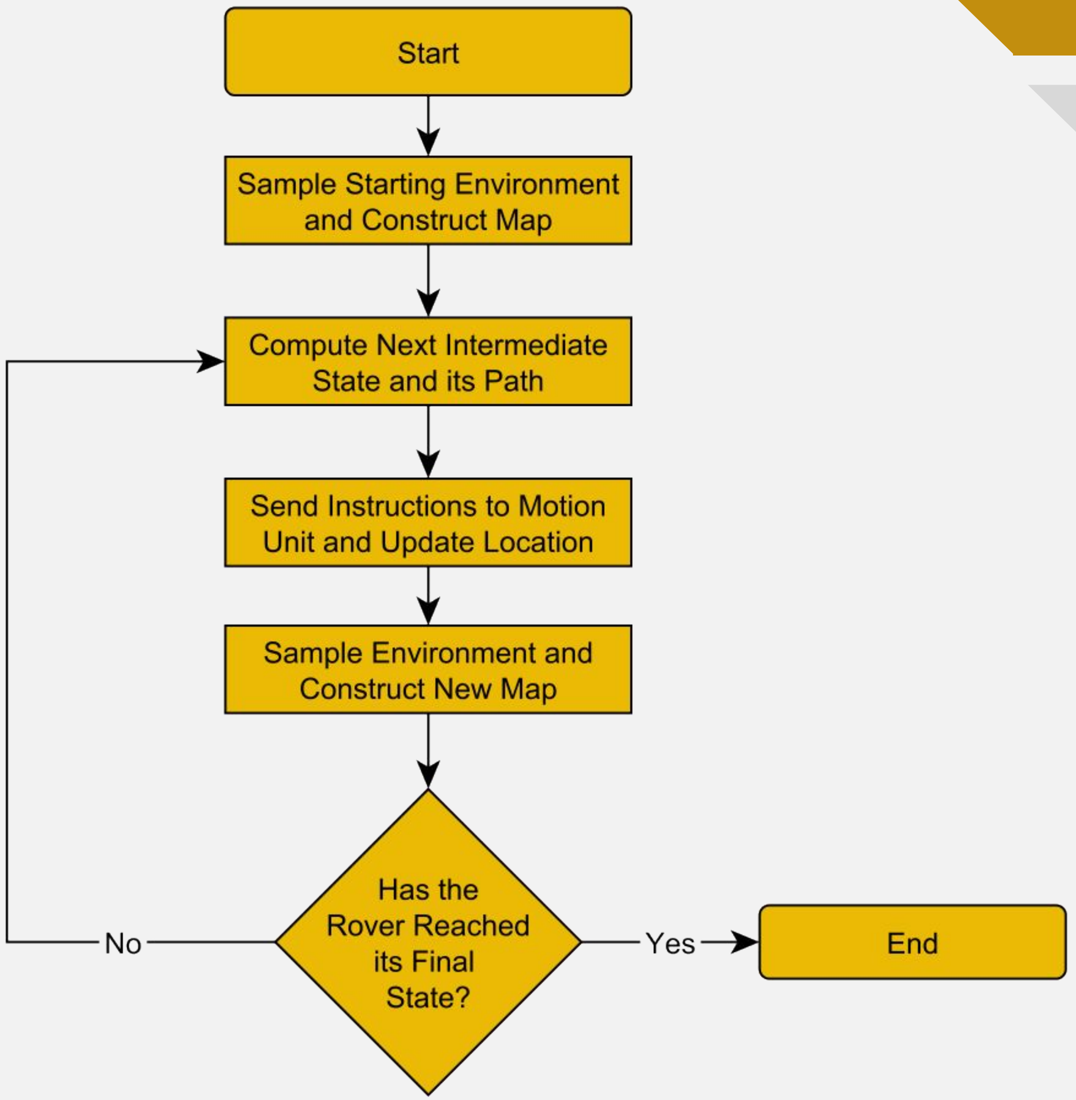




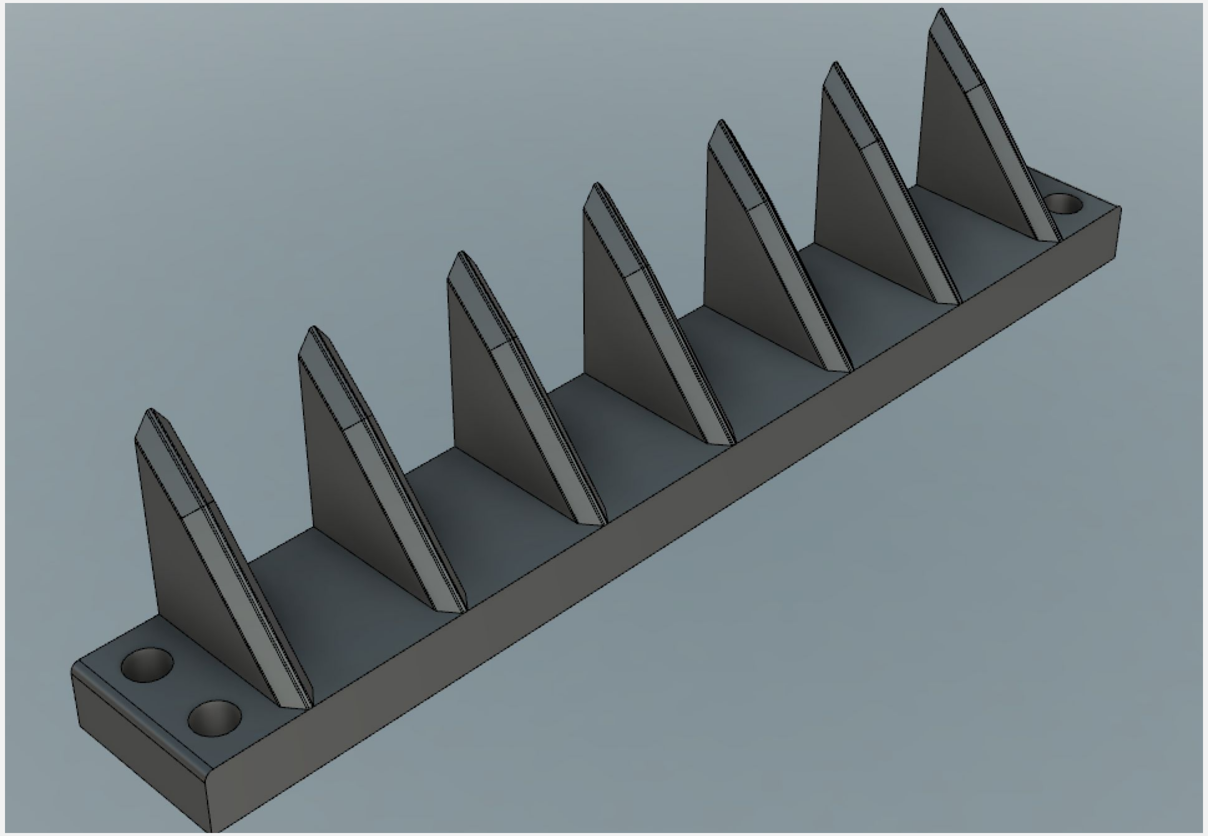


Software

- Software Development:
  - Arduino IDE.
- Coding Language:
  - C/C++.
- Algorithms:
  - Object detection:
    - Landmark extraction.
    - Landmark avoidance.
  - State estimation:
    - Position relative to rocket.

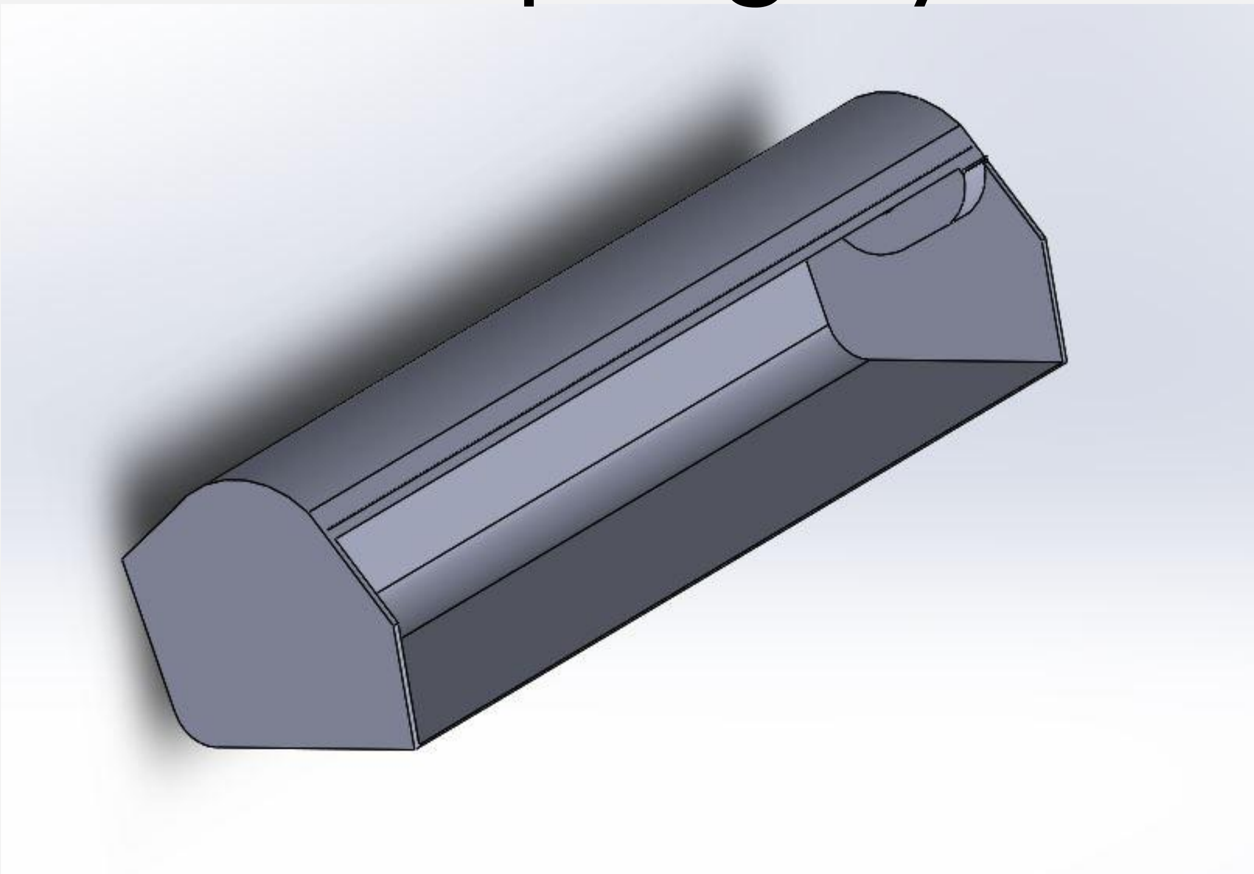


Soil Sampling System—Procurement



- "The Rake"
  - Attached at rear of rover chassis
  - Driven into soil for well agitated sample
  - Provides rover with counter-torque
  - 6.75" x1" Base Plate
  - 1.5" Tall Spikes
  - ABS Plastic

Soil Sampling System—Retention

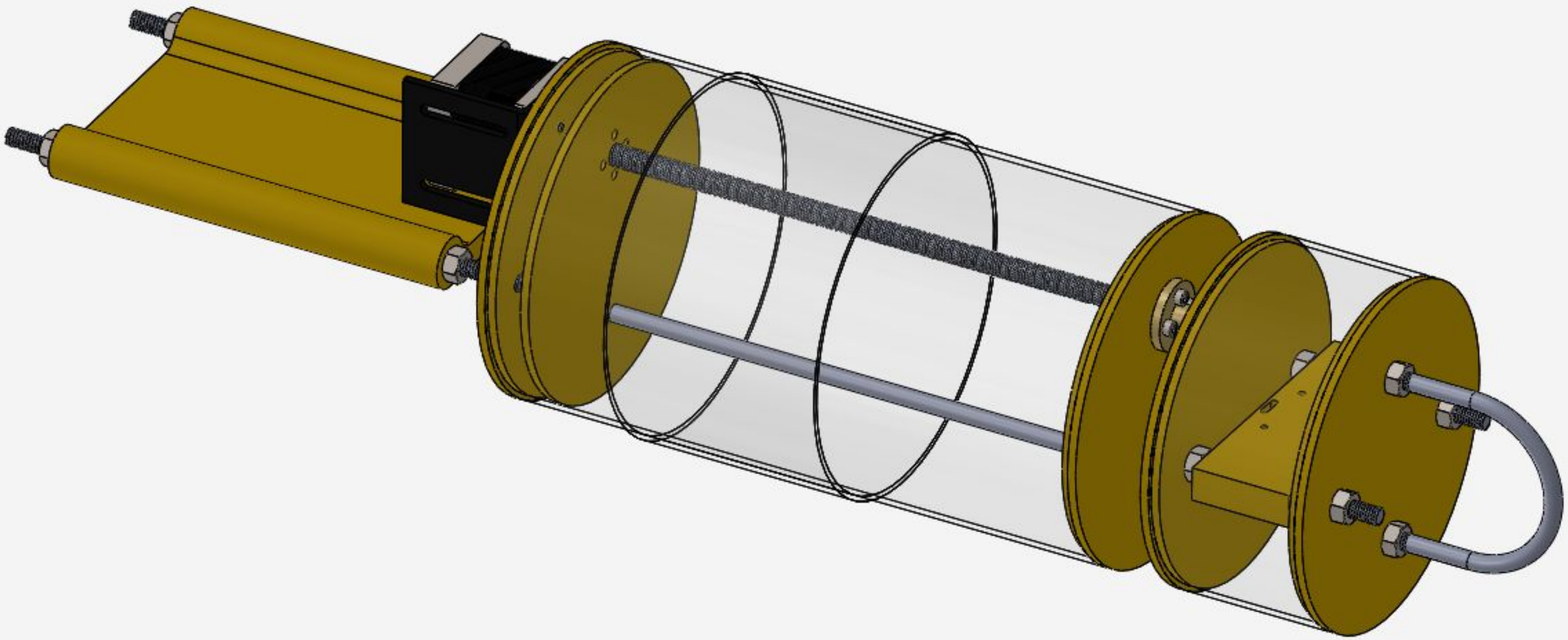


- "The Excavator"
  - Follows behind procurement apparatus
  - Aims to collect minimum 20ml soil sample
  - Rotated 90° via servo
    - Open position for collection
    - Closed position seals around procurement apparatus
  - 6.75" Width

Deployment

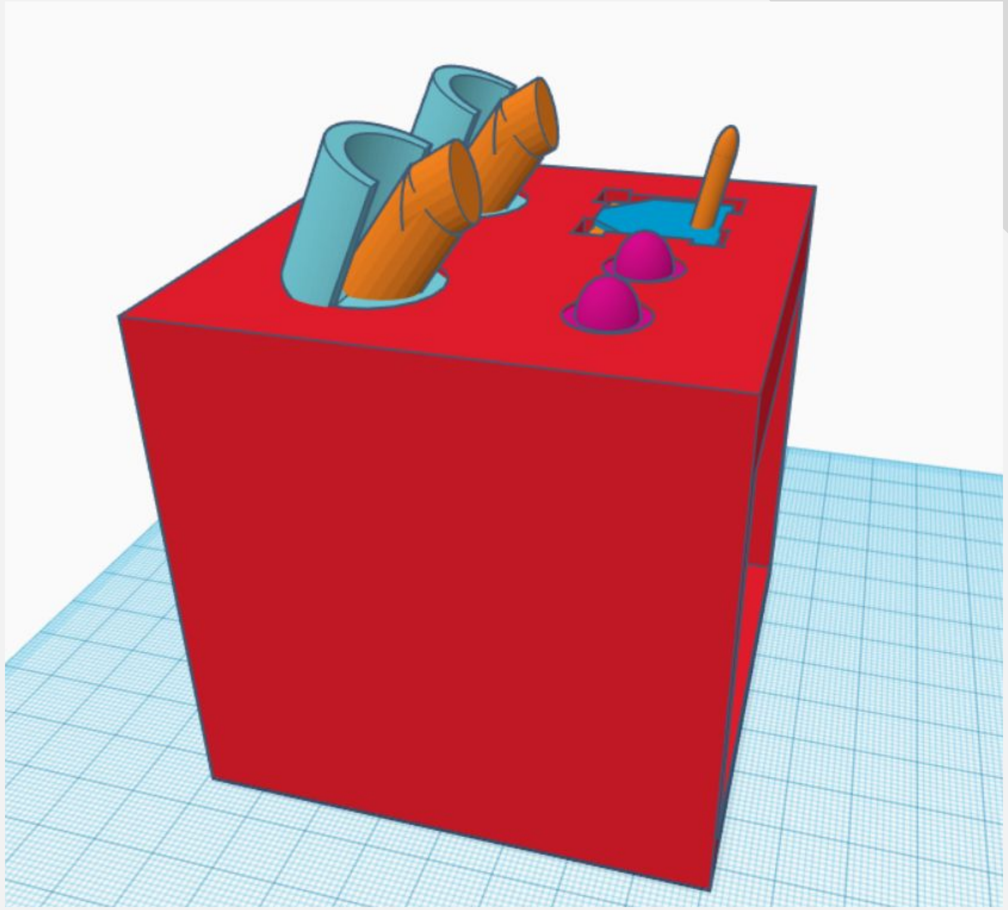
- Initiated by signal sent remotely
- Triggers black-powder charge, separating payload bay and nose cone from rocket upper airframe
- Linear actuator pushes rover out of payload bay
- Rover components are placed so the rover naturally stays upright

Deployment

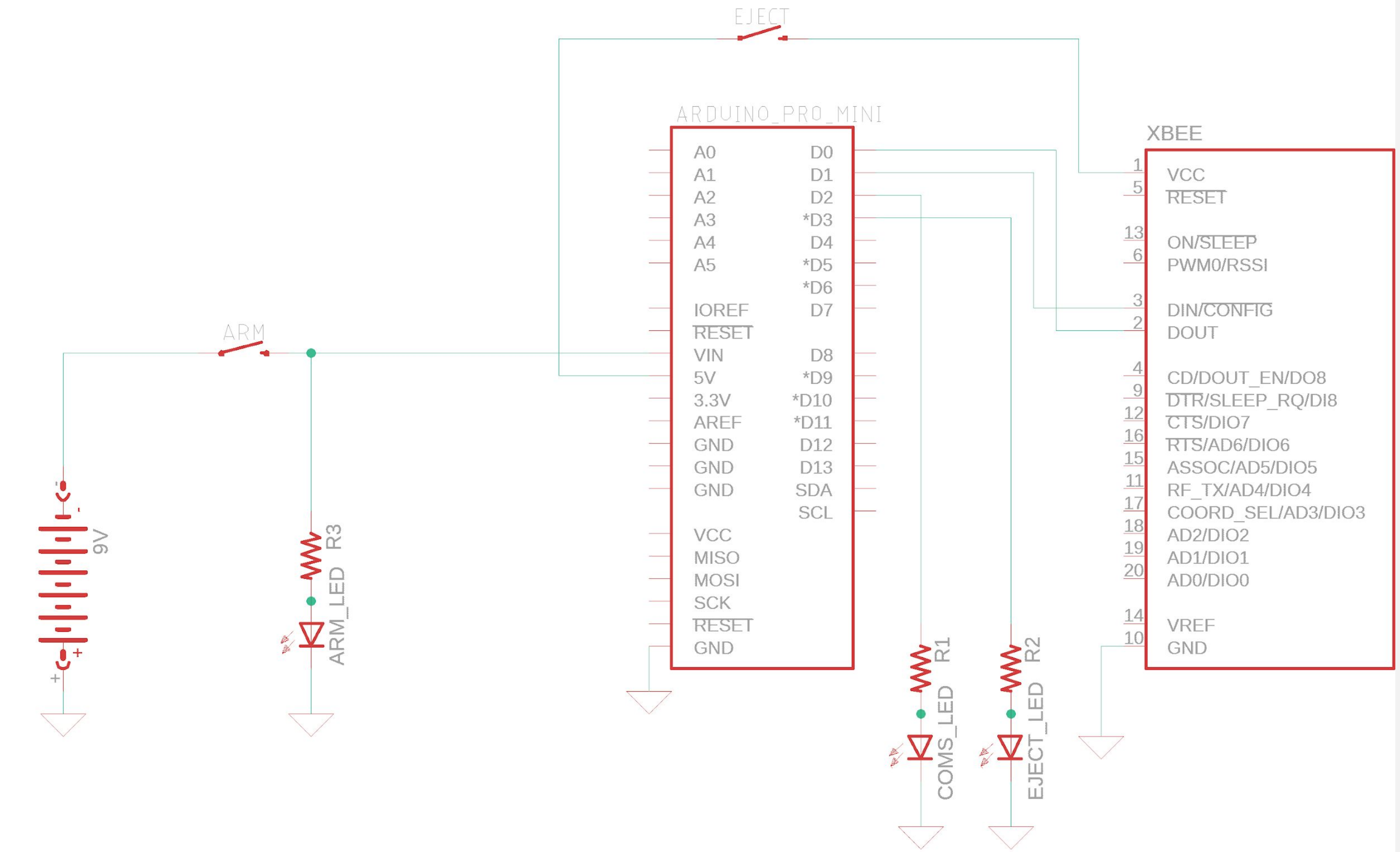


Deployment - Base Station

- Payload must be deployed remotely
- Portable XBee-based controller
- Built-in safety features



Deployment - Base Station



Subscale Launch

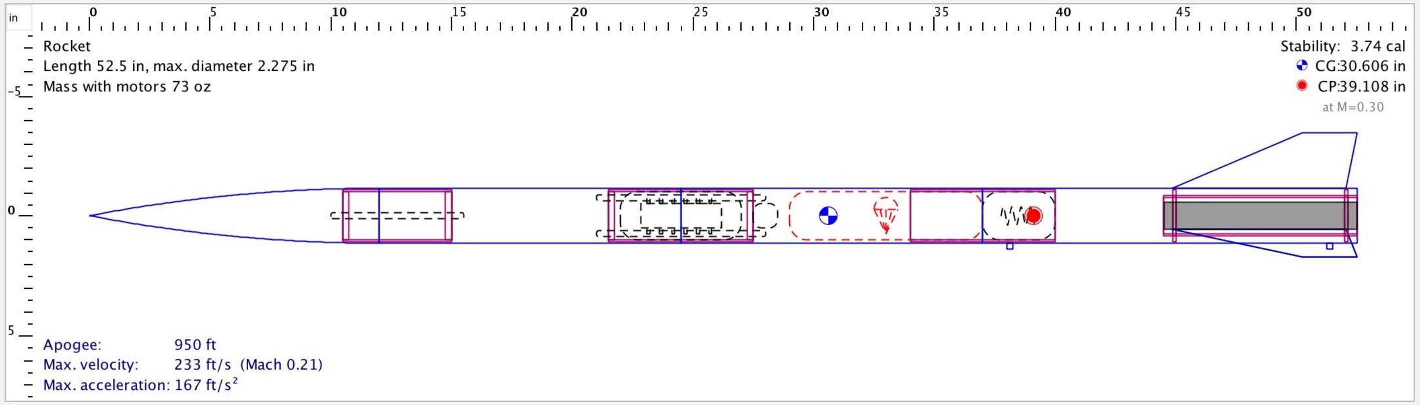
Subscale Test Overview

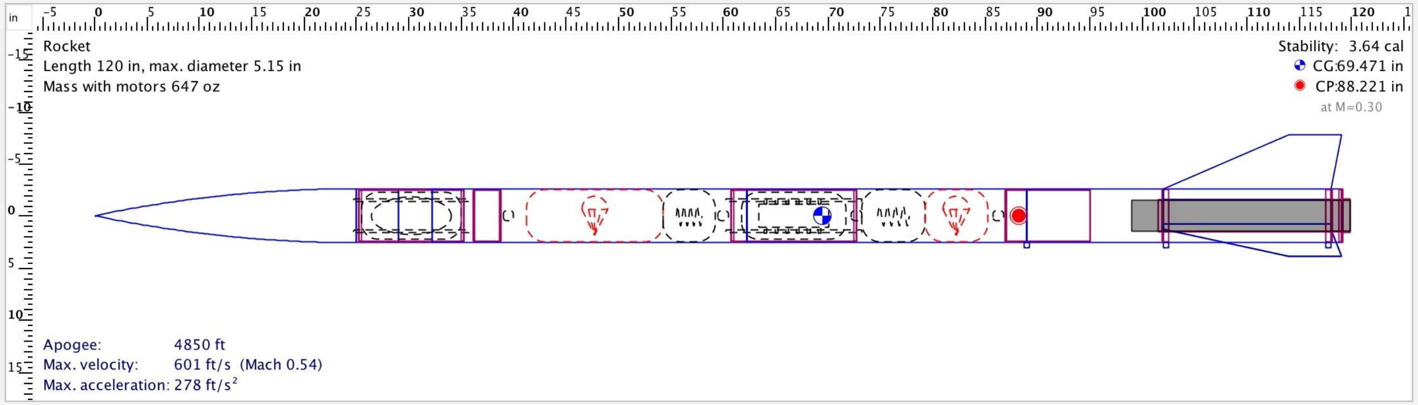
- Build/launch/recover subscale version of competition vehicle
  - Must share geometry
  - Utilize similar avionics and payload system

- Subscale vehicle experienced unplanned rapid disassembly
  - Drogue parachute did not deploy
  - Main chute did deploy
  - Bulkheads and couplers ripped apart
  - Avionics data is unrecoverable

Subscale Scaling Factors

- Need to maintain consistent geometry ratios
- Use motor that would produce similar Reynolds numbers
  - Cesaroni H-115
- 3:5 size ratio (subscale : fullscale)





Subscale Launch Conditions

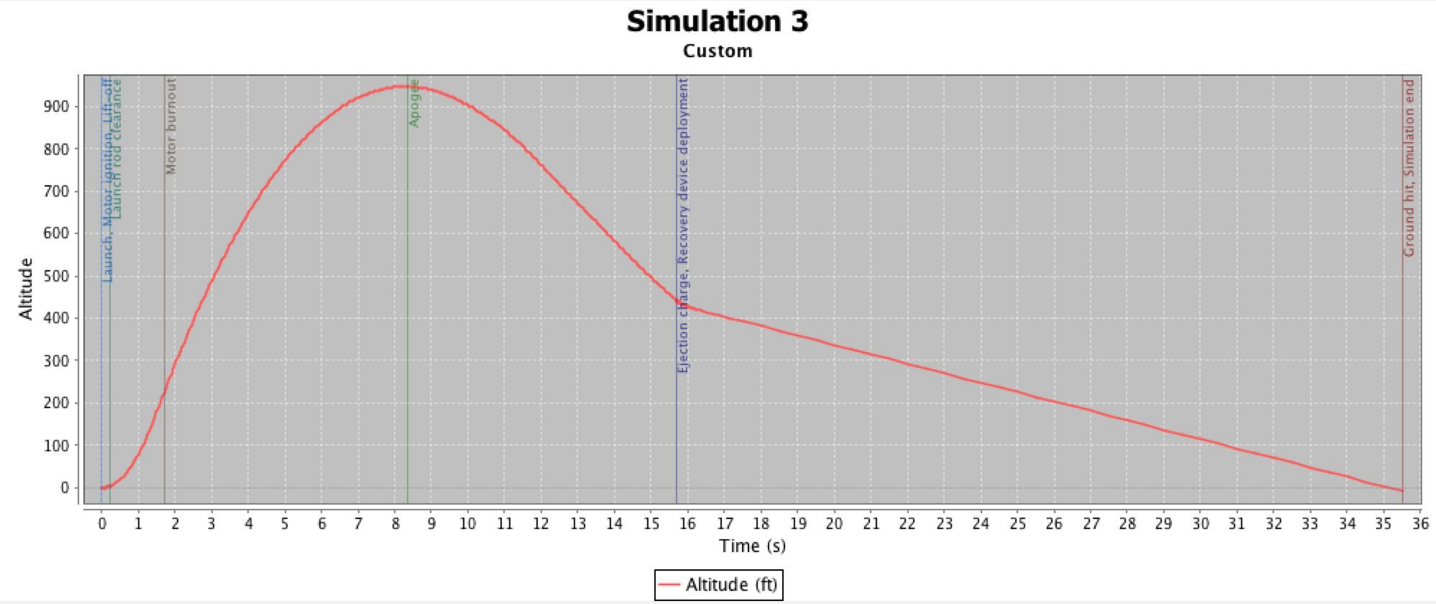
- Overcast, mostly cloudy
- ~14 mph wind from West
- ~27-29 deg. Fahrenheit
- ~72% Humidity
- Overall no extreme weather
- Flight conducted on Purdue's Beck Center Fields

Subscale Flight Recorded Results

- Two altimeters were flown for redundancy:
  - MissileWorks RRC3+ Sport (Primary)
  - JollyLogic AltimeterOne (Secondary)
- MissileWorks RRC3+ Sport max altitude: 895 ft
- JollyLogic AltimeterOne max altitude: 884 ft

Recorded Vs. Predicted Data

- Through simulations an altitude of 950 ft was predicted
- Between the two altimeters, the average altitude was 889.5 ft
- The main reason for this was due to imperfections in the fin mounting, that have been fixed for full scale



Continuation of Project Plan

Project Plan Overview

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

- Further Avionics Testing (Battery Drain, Vacuum Chamber)
- Payload Testing (Rover, Ejection, etc.)
- Fundraising (SkipAMeal, Purdue AAE Department)
- Full scale build and test launch (IRI Launch Feb. 10th)
- Educational engagement

Tests To Prove Design Integrity

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

- Avionics Continuity Testing
- Avionics Battery Power Drain Testing
- Altimeter Ejection System Testing (Vacuum Chamber)
- Parachute Drop Testing
- Payload LIDAR Object Detection Test
- Payload Ejection Distance Testing
- Payload Rover Mobility Testing
- Payload Soil Collection Volume Testing
- Payload Communication Distance Testing

Derived Requirements and Verification Plans

Avionics Test: Derived Requirements

1. Altimeter Continuity Testing: Each altimeter will have be tested for proper continuity via audible beeping
2. Altimeter Battery Drain Test: Each altimeter battery will be tested for battery life duration thus lasting ~3 hours, calculations shall also be conducted
3. Altimeter Ejection System Test: Each altimeter will have simulated apogee and ~700’ AGL pressures via vacuum chamber and will ignite e-matches
4. Parachute Drop Test: Parachutes will be tested for proper folding and proper opening with ~40 lbs of weight

Avionics Test: Verification Plan

1. Altimeter Continuity Testing: Continuity will be verified via audible inspection of altimeters as well as referring to altimeter manuals
2. Altimeter Battery Drain Test: Battery life will be verified via calculations, research, and testing
3. Altimeter Ejection System Test: Ejection will be verified via several redundant tests
4. Parachute Drop Test: Parachute opening will be verified via several measurements of time from drop to open

Payload Test Derived Requirements

1. The separation between the payload bay and rocket should be at least 3 meters.
2. The wireless communication system for transmitting the deployment signal to the rover should send, receive, and parse signals over distances up to 3000 feet.
3. The rover shall be capable of reorienting itself from all possible initial orientations after deployment.
4. The rover shall be capable of moving away from the rocket over varying terrain.
5. The rover shall consistently acquire and contain 20 mL of soil upon execution of its soil collection routine.
6. The payload system’s weight shall not exceed 8 lbs.
7. The battery shall provide power to the system for at least 6 hours.
8. Range-finding measurements taken by the LIDAR sensor on-board the payload must be accurate to within an inch.

Payload Test Verification Plan

1. Ejection separation test: assure that the payload bay will successfully separate at least 3 meters.
2. Radio communication distance test: establish that Xbee radio is able to communicate from at least 3000 feet away.
3. Rover orientation test: determine that the rover will be in the correct orientation after deployment.
4. Rover mobility test: certify that the rover will be orient itself in any configuration to allow movement in any direction.
5. Soil collection test: ensure that the rover collects at least 20 mL.
6. Rover net weight test: make sure that the rocket is not too top heavy.
7. Battery drain test: confirm that the battery will be able to last for the duration of the launch.
8. LIDAR Range Test: guarantee that the rover will be able to detect obstacles.

Funding and Educational Engagement

Changes Since PDR

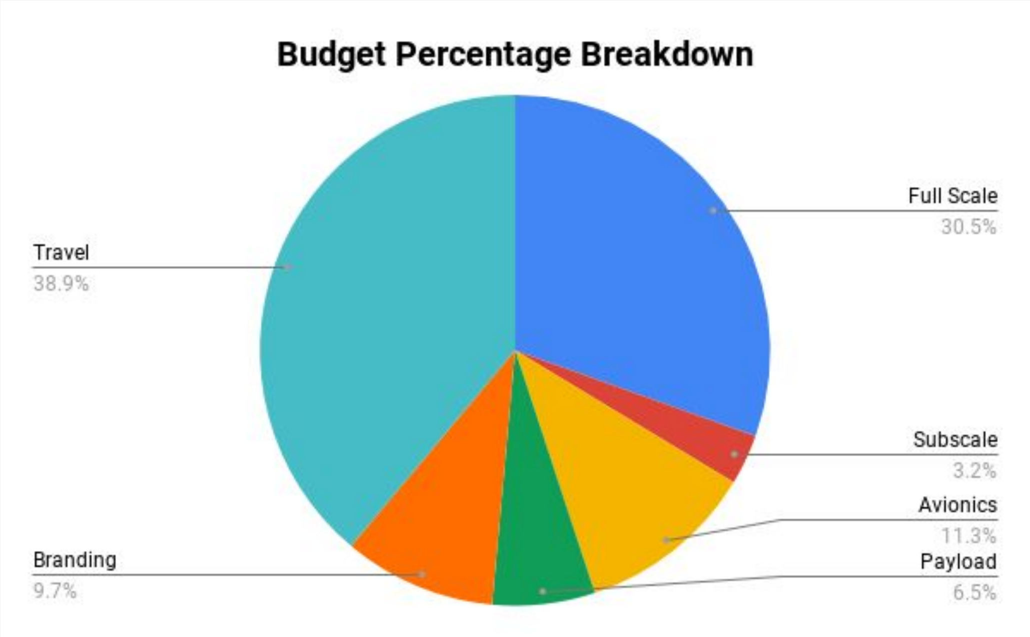
- Total budget has been changed
  - Reflected in how funds are allocated
  - Line item budget updated

- Material procurement methods have been finalized
  - Full scale used from last year
  - Almost all parts have been purchased
  - Decreased overall budget

Budgeting

Total of ~$6000

- Broken into 6 distinct sections
- Two options for travel
- Most sections have been completely funded



Section	Status	Cost
Full Scale	Paid	$1888.89
Subscale	Paid	$197.93
Avionics	Paid	$701
Payload	Unpaid	$403 (estimate)
Branding	Paid	$600 (estimate)
Travel	Unpaid	$2412 (estimate)

Funding Plan

<u>4 Forms of Funding:</u>

1. Restaurant Fundraisers: $600 (across 3 fundraisers)
2. Grants (INSGC/Other): $4000
3. Crowdfunding: $1000
4. SEDS Treasury: $700

Total: $6300 ($300 Margin)

- Future teams will have an opportunity for a company sponsorship, although not this year.
- Funding plan is redundant in case we do not meet certain quotas.

Question And Answer Session