PURDUE SL

Project Walker
Flight Readiness Review

Mission Statement

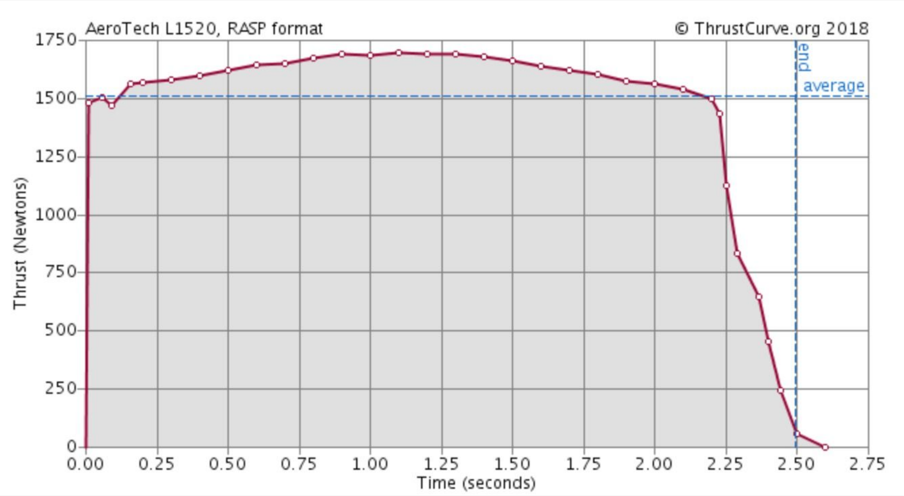
Our mission statement can be broken into two distinct goals:

- 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

Vehicle Design Characteristics

Launch Vehicle System Overview

- Launch Day Motor : AeroTech L1520 Blue Thunder
- Total Impulse: 3,716 N-sec
- Burn Time: 2.4 sec
- Peak Thrust: 1,779 N
- Propellant Weight: 1.854 kg
- Loaded Weight: 3.651 kg
- Thrust-to-Weight Ratios:
    - Ideal (40.5 lbs): 8.9
    - Current (43.5 lbs): 9.2

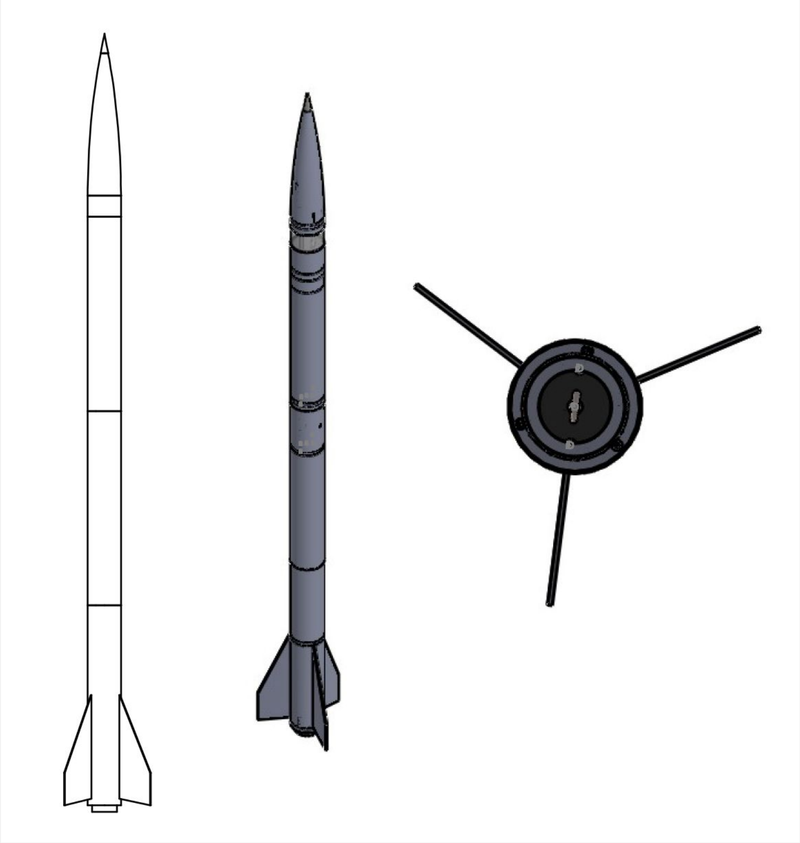


Launch Vehicle System Overview Cont.

The launch vehicle consists of 5 distinct subsections:

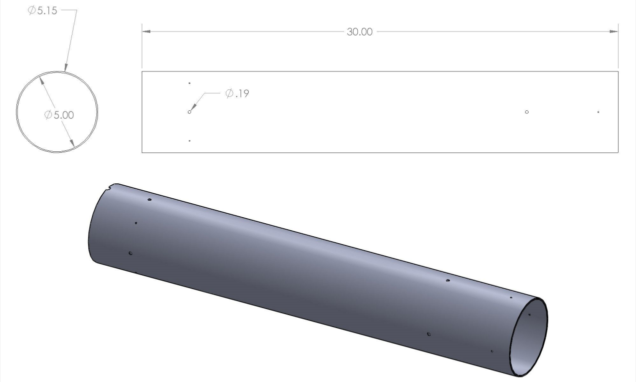
- Nosecone
- Payload Bay
- Upper and middle airframe
- Avionics Bay
- Lower Airframe

- 120” Height
- 5.15” Outer Diameter
- 43.5 lbs Launch Weight (current)
- 41.5 lbs → Ideal Launch Weight

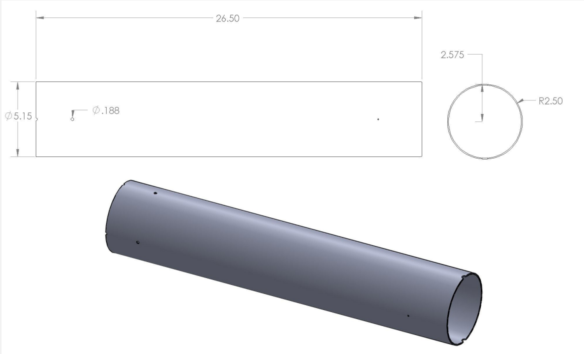


Lower , Mid, and Upper Airframe Subsystems

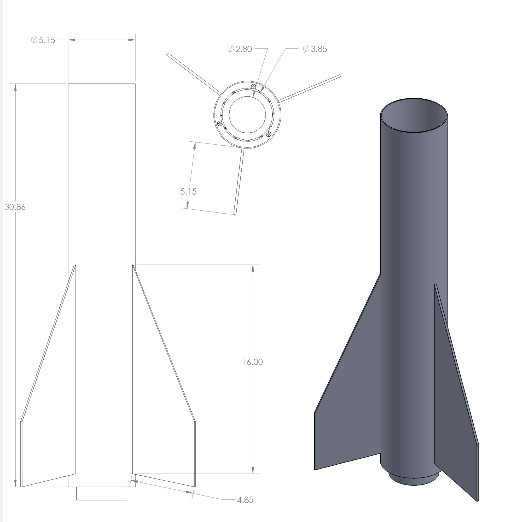
The Upper Airframe contains the main parachute and recovery gear.



The Mid Airframe contains the drogue parachute and recovery gear.



The Lower Airframe contains the fins, motor mount assembly, thrust plate, and motor retainer.

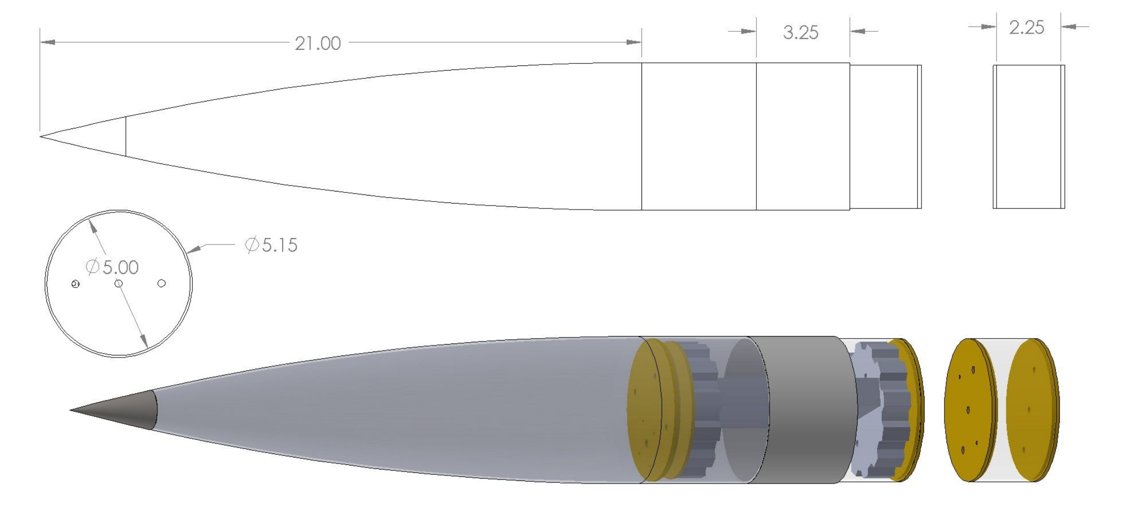


Nose Cone / Payload Bay Subsystem

The Nose Cone reduces drag and interfaces with the Payload Bay; the two are one large subsystem

The Payload Bay houses the payload ejection system and housing for the rover

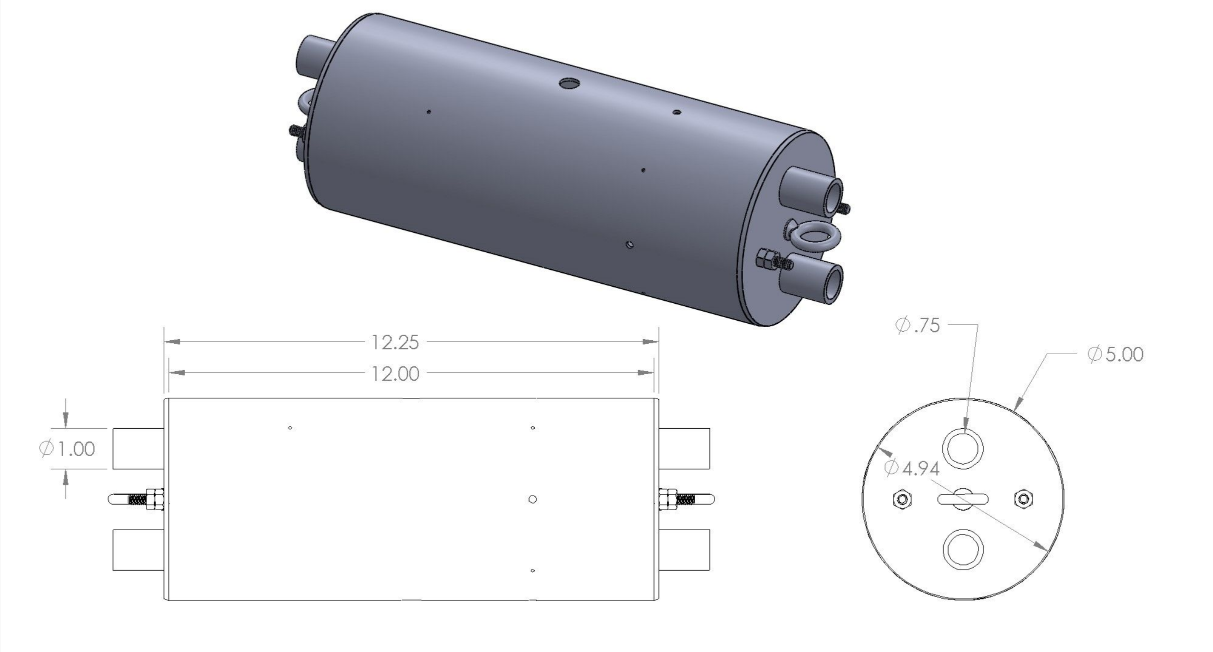
- ABS printed sled and rover parts
- Stepper motors, batteries, etc.
- Stainless steel hardware



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



Material Validation

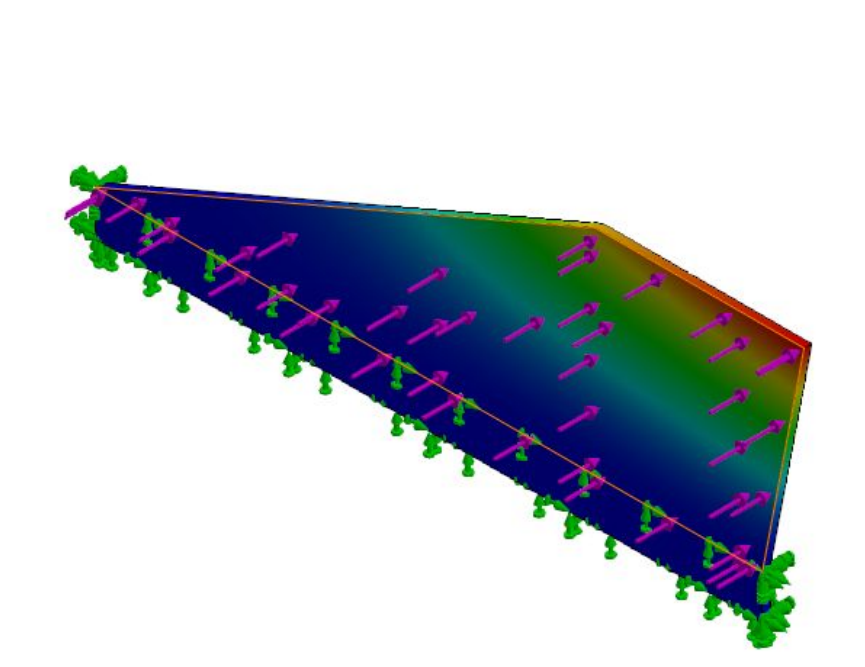
- All material validation was performed in SolidWorks 2018
- Parts were assigned material characteristics and simulated using clamping and distributed forces
- If a part experienced a stress greater than the tensile yield point, the test is considered a failure

Young's Modulus	1.2×10^{10} Pa
Poisson's Ratio	0.118
Yield Strength	6.5×10^{7} Pa

Numbers courtesy of http://www.dielectriccorp.com/downloads/thermosets/glass-epoxy.pdf, http://www.matweb.com/search/datasheet_print.aspx?matguid=8337b2d050d44da1b8a9a5e61b0d5f85, and http://www.fastenercomponents.com/news/fr-4-g10/

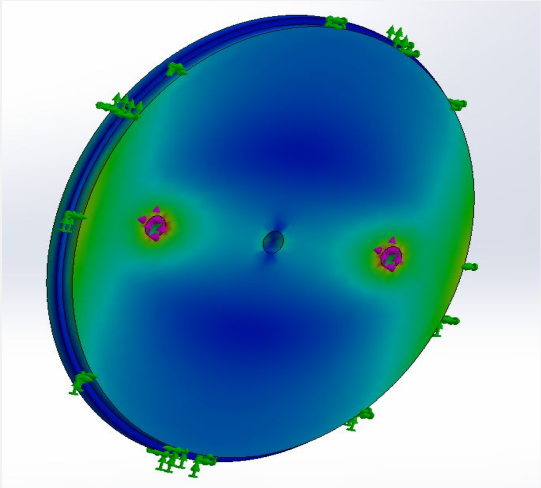
Fin Bending Analysis

Restraints: Clamped root and edges
Forces: 50 pounds laterally
Max. Displacement: 0.0846”
Max. Stress: 2110 PSI

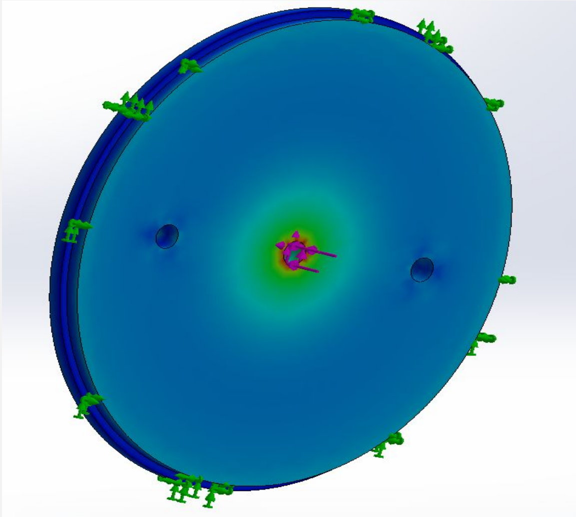


Bulkhead Pull Through Analysis

Forward Pull Through:
Restraints: Clamped stepped perimeter
Forces: 1000 pounds inside the rod holes
Max. Displacement: 0.02922”
Max. Stress: 2.153e+4 PSI



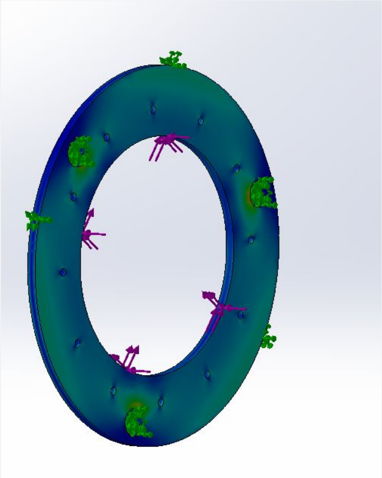
Reverse Pull Through:
Restraints: Clamped stepped perimeter
Forces: 1000 pounds inside the bolt holes
Max. Displacement: 0.0577”
Max. Stress: 2.689e+4 PSI



Thrust Plate & Motor Retainer Analysis

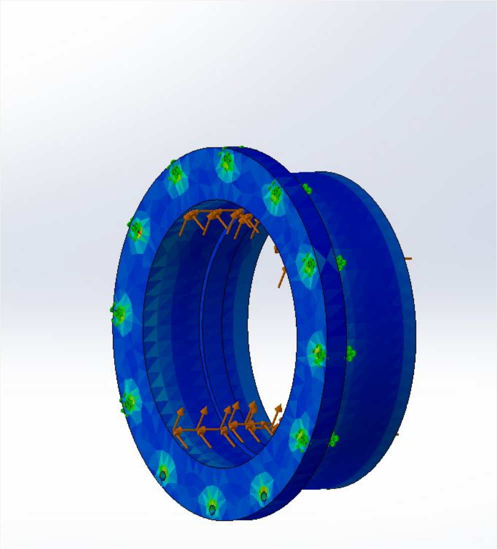
Thrust Plate:

Restraints: Clamped stepped perimeter
Forces: 1000 pounds on the face
Max. Displacement: 0.009142"
Max. Stress: 3.3e+4 PSI



Motor Retainer:

Restraints: Clamped bolt holes
Forces: 1000 pounds on the inside face
Max. Displacement: 0.001773"
Max. Stress: 3.989e+4 PSI

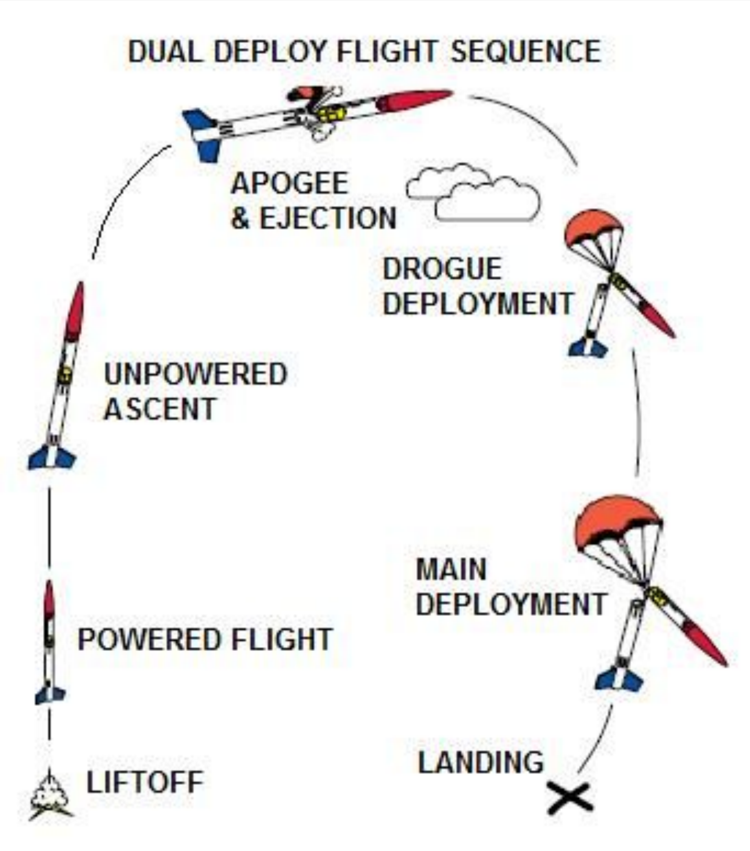


Recovery System Information

Recovery System Overview

Standard dual deployment configuration:

- 24″ drogue parachute at apogee
- 100″ main parachute at 700-900′ 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

Tether / Shock Chord

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, and welded eye bolts
- 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.

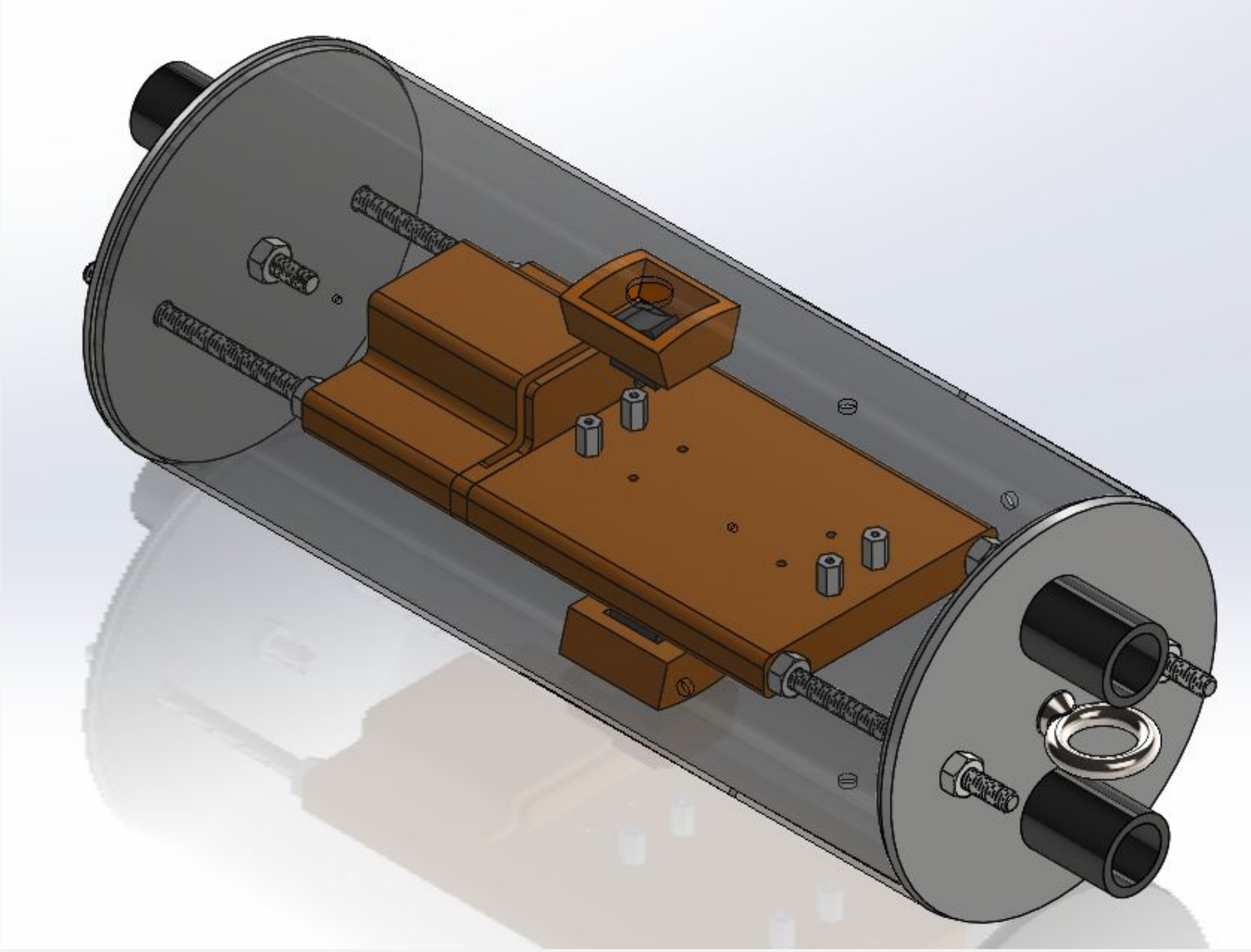
Bulkheads

- Constructed from 0.25" thick G10 fiberglass
- Contain four holes of 0.25" diameter:
  - Two holes 3" center to center to accept threaded rods and secure the bulkheads to the coupler tube
  - Two holes will be for attaching charge wells
- One hole 1.625" that attaches the rocket to recovery tether.
- Each bulkhead is estimated to weigh 0.25 lbs, 2.25 lbs total (9 bulk plates)

Avionics System Overview

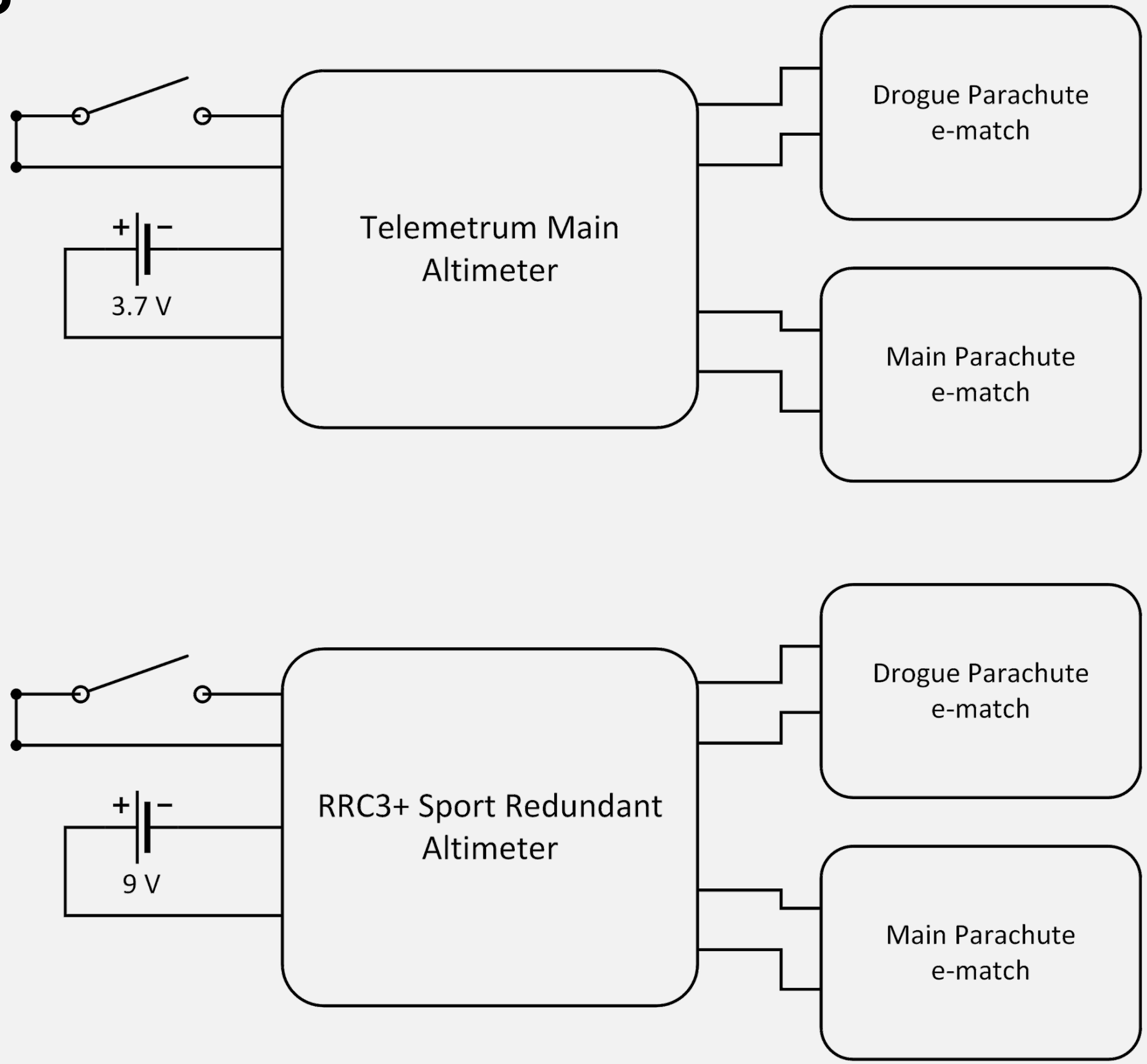
The Avionics Bay consists of:

- 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



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

Initial 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

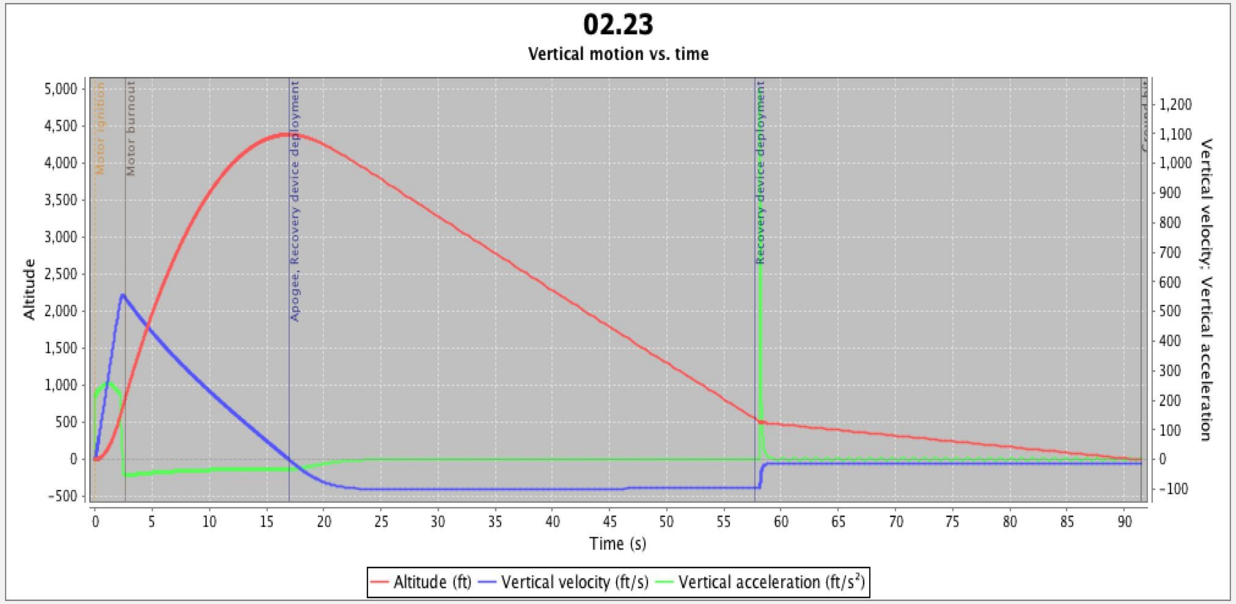
Secondary flight predictions were created using RASAero

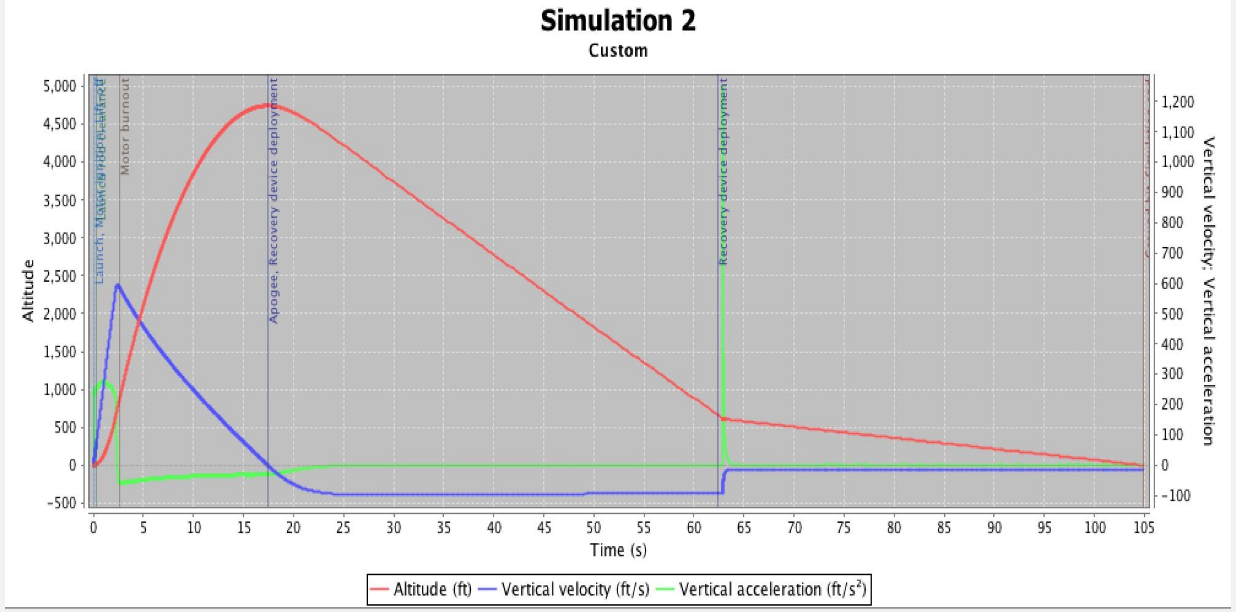
Verification calculations were also done by hand

Altitude Predictions

Openrocket predicts the maximum altitudes of:

- 4,387’ AGL for current 43.5 lb rocket (02.23)
- 4,876’ AGL for ideal 40.5 lb rocket (goal for April) (Sim 2)
- Variable ballast (No additional ballast post VDF)

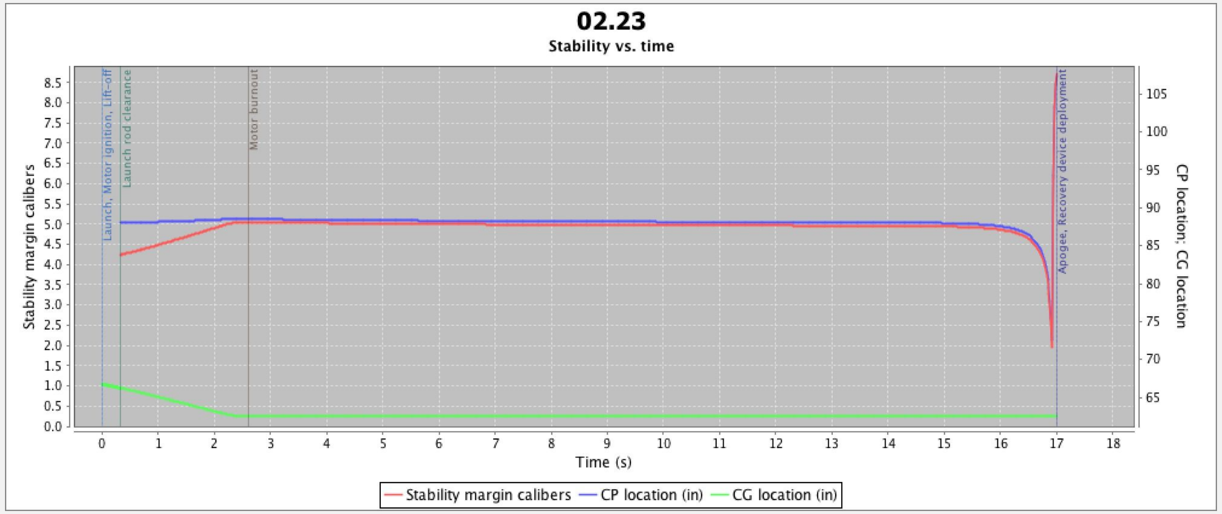


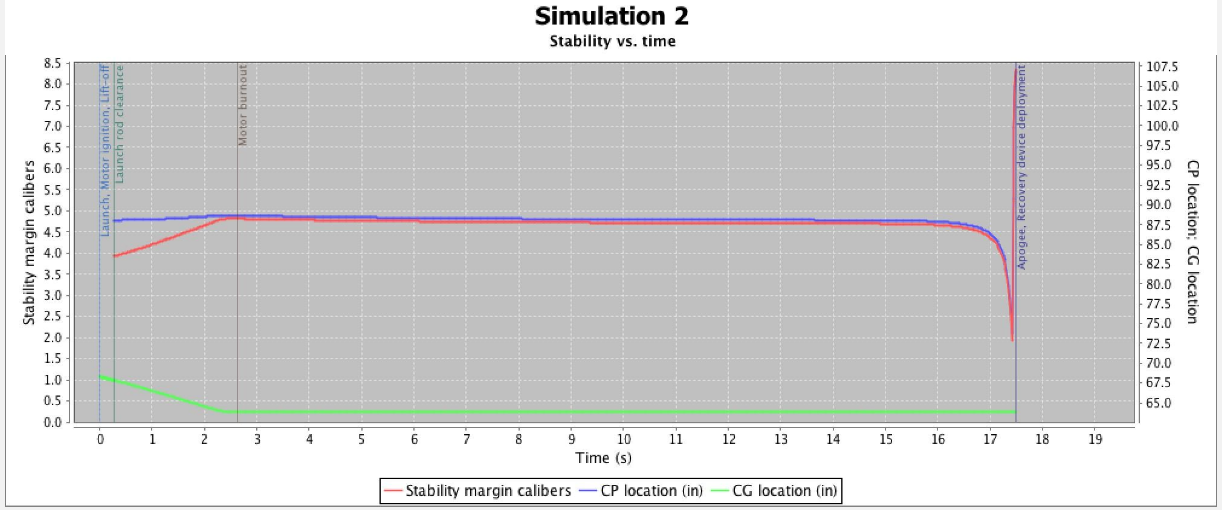


Stability Predictions

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

- 4.17 calibers stability (43.5 lb)
  - CP 88.221” from datum
  - CG 66.733” from datum
- 3.87 calibers stability (40.5 lb)
  - CP 88.221” from datum
  - CG 68.268” from datum

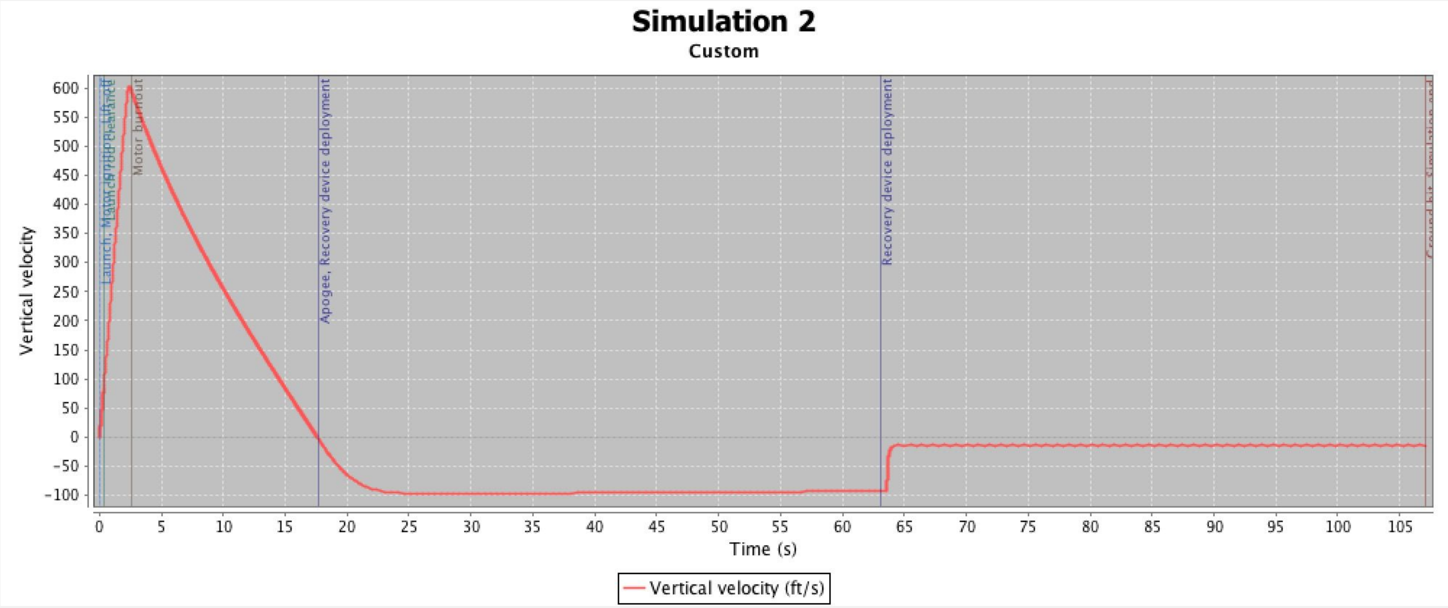




Landing Energy Predictions

The rocket is expected to have a touchdown speed of 14.3 ft/s and a total energy of 105 ft. lbs.

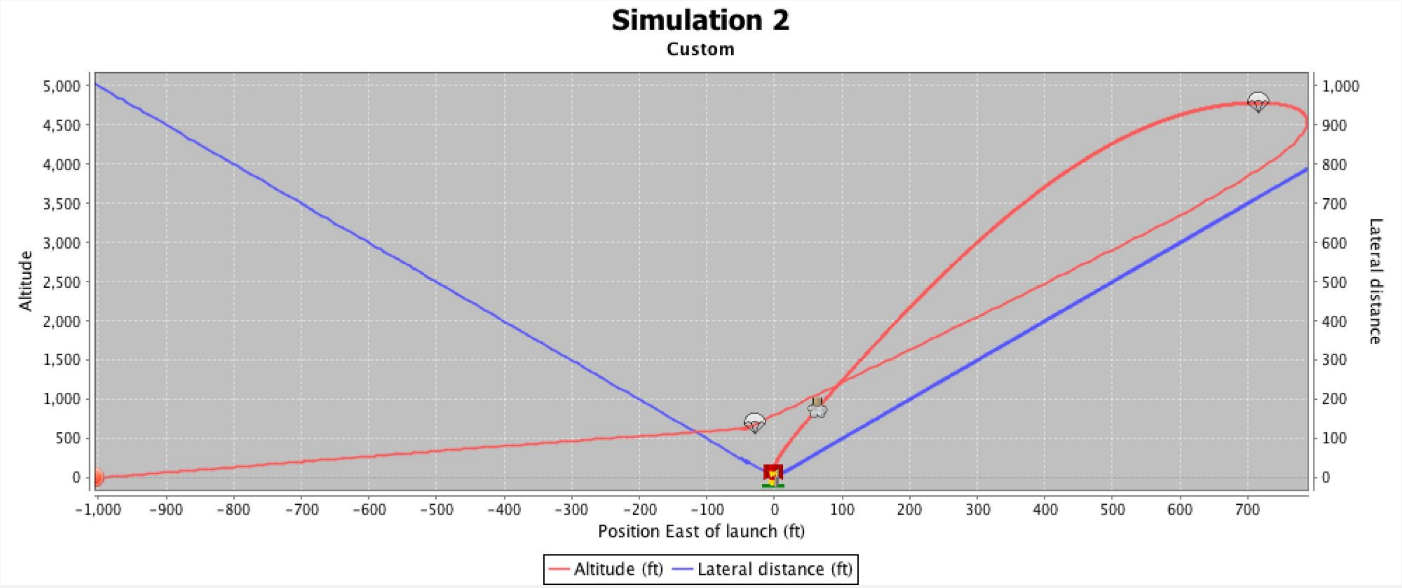
- Lower section: 57 ft. lbs.
- Middle Section: 10 ft. lbs.
- Upper Section: 38 ft. lbs.



Drift Distance Predictions

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

- 0 MPH: ~15’
- 5 MPH: 650’
- 10 MPH: 1100’
- 15 MPH: 1700’
- 20 MPH: 2400’



Drift Distance Prediction - Hand Calc.

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

- 0 MPH: 0 ft
- 5 MPH: 498 ft
- 10 MPH: 996 ft
- 15 MPH: 1494 ft
- 20 MPH: 1992 ft

These were calculated using the following formulas:

$$v = \sqrt{\frac{2 * W}{Cd * \rho * A}} \qquad t = \frac{h}{v} \qquad d_{drift} = t * v_{wind}$$

Safety

Safety Overview

Goals of the safety team during work on the FRR:

- Enforce all safety plans and procedures set by the team
- Enforce all laws and regulations set for the team by authorities and governing bodies
- Update 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

Safety and Environment

Updated the Personnel Hazard Analysis, the Failure Modes and Effects Analysis (**FMEA**), and the Environmental Hazard Analysis to include:

- Finalized hazard descriptions, causes, and effects for the rocket the team has built.
- A completed list of mitigations addressing the hazards and/or their causes
- A completed list of verifications for the identified mitigations

Focused primarily on FMEA to include more failures and superior verifications

Launch Operations Procedures

Updated **checklists** and procedures for the following:

- Recovery preparation
- Motor preparation
- Setup on launch pad
- Igniter installation
- Launch procedure
- Troubleshooting
- Post-flight inspection

Focused primarily on checklists and integrated most procedures directly in checklists

Launch Operations Procedures

Specifically demarcated steps related to safety to include:

- Warnings of hazards that can result from missing a step
- PPE required for a step in the procedure
- Required personnel to complete a step or to witness and sign off verification of a step

Organized in chronological order with some procedures built in to checklist in order to maintain the proper order

Payload

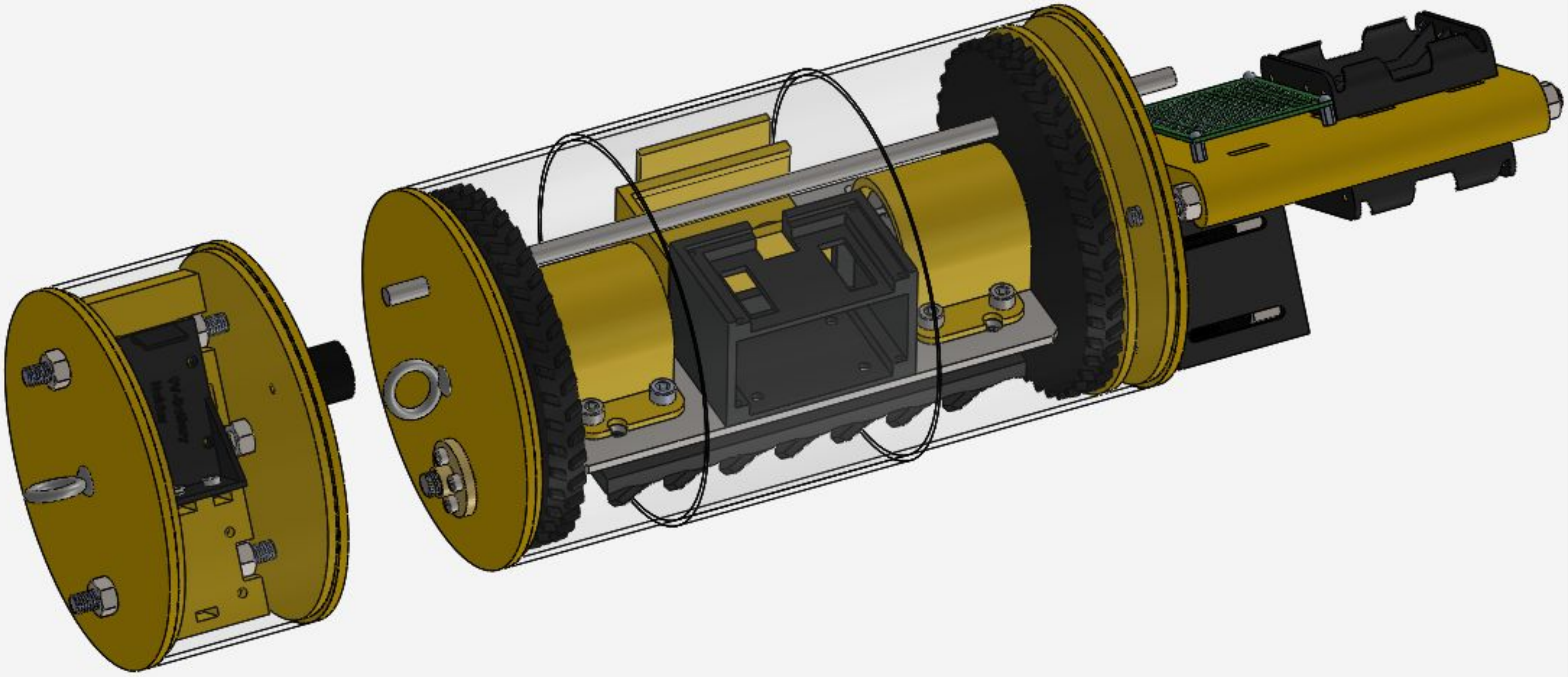
Payload Design

- 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 sensor
  - 1 x 2C LiPO battery
  - 1 x Motor Driver
  - 2 x Brushed DC Motors
  - 1 x 3-Axis Accelerometer with Gyroscope
  - 1 x Arduino Pro Mini
  - 1 x Soil Collection System
  - 3 x XBee Wireless Radios

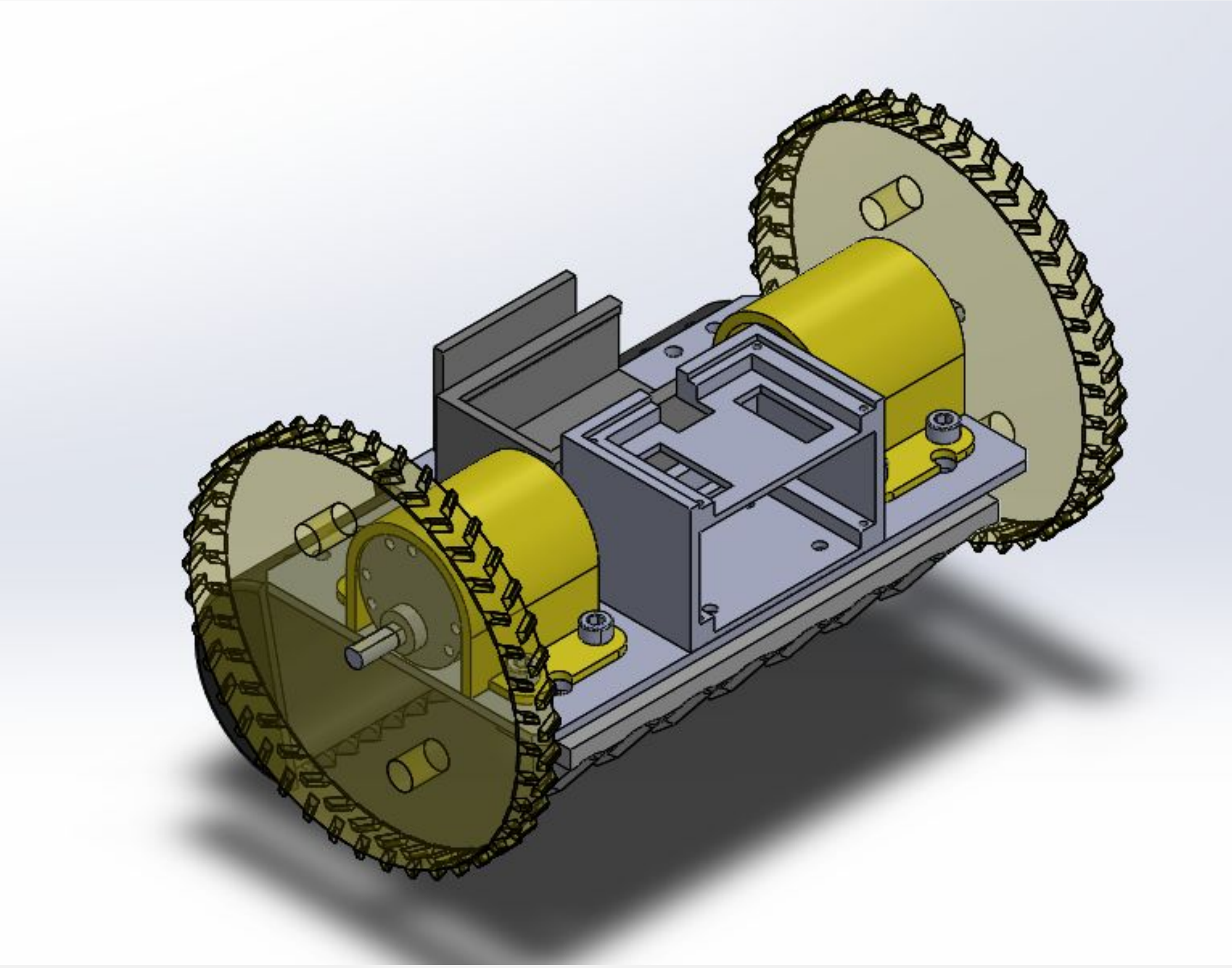
Payload Bay

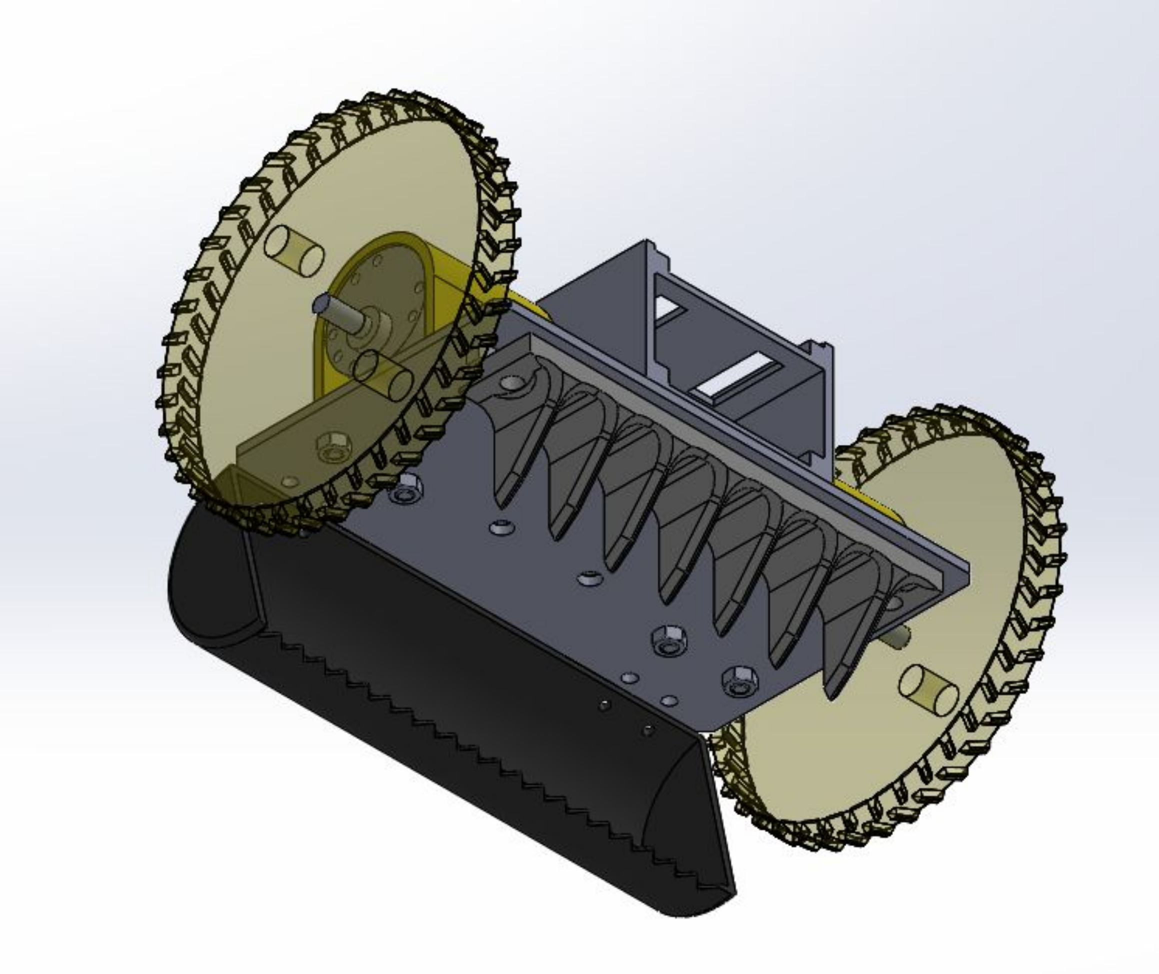


Rover Design

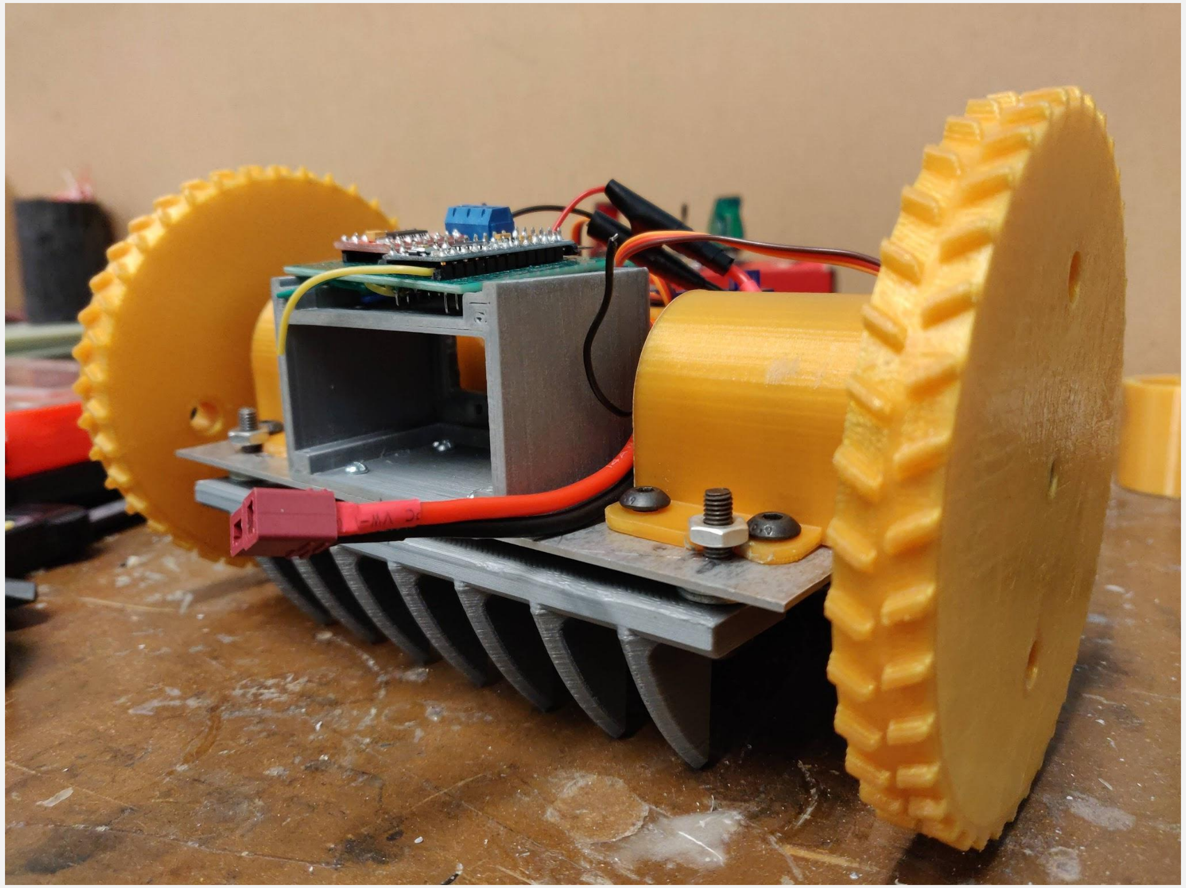
- Chassis
  - Sheet metal Aluminum 6061
  - 6.75” by 4.1875”
  - Low to ground to collect efficiently collect soil
- Motors/Wheels
  - Brushed DC Geared Motors- On top of chassis, either side
  - Large wheels for traction and stability
  - Components positioned under axle to provide low center of mass
- Batteries
  - On top of chassis in middle front
- Electronics
  - Arduino placed on top of chassis for ease of access
  - Sensors placed on front for unobstructed view
- Soil Retention System
  - Rake - Under chassis, front
    - Sharp pointed teeth to loosen soil
  - Scoop - Under chassis, back
    - Curved with teeth to collect loosened soil
- All non-electronic components are 3D printed

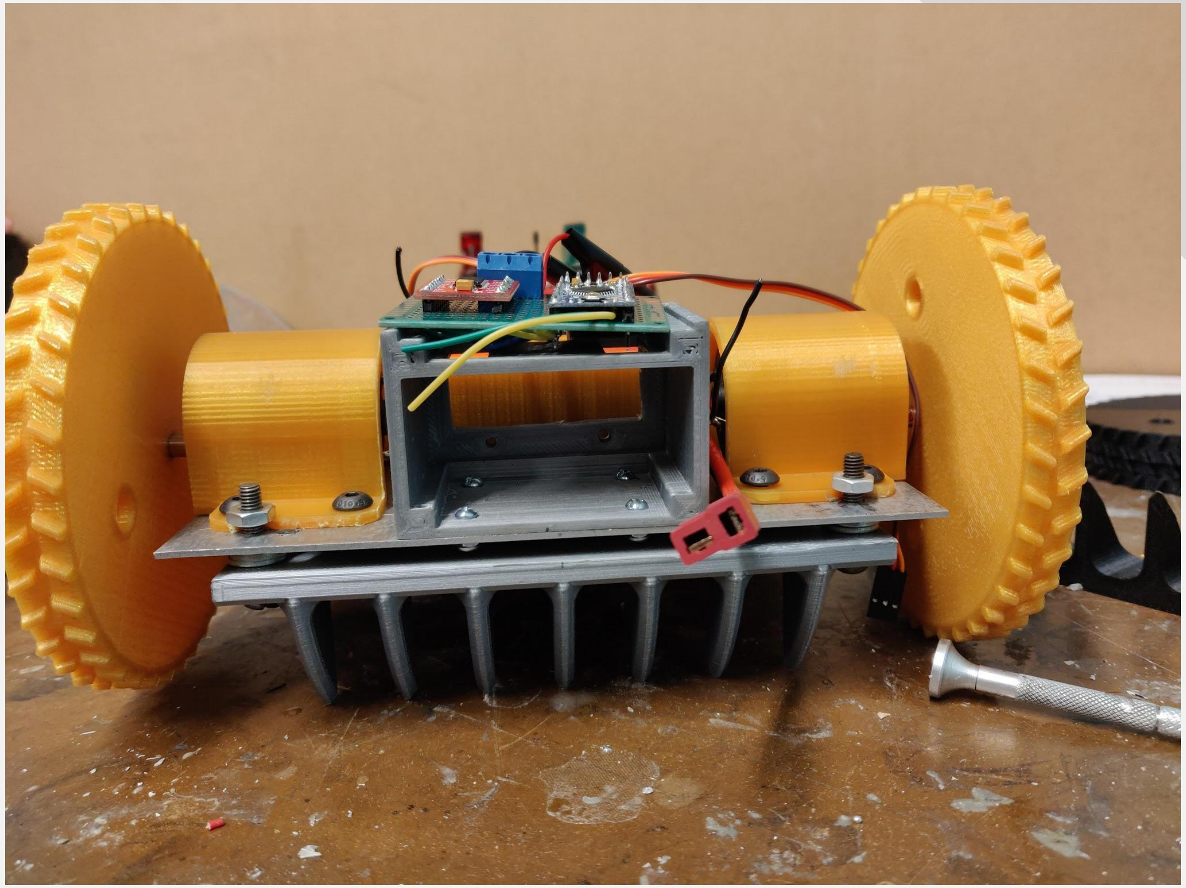
Rover Design





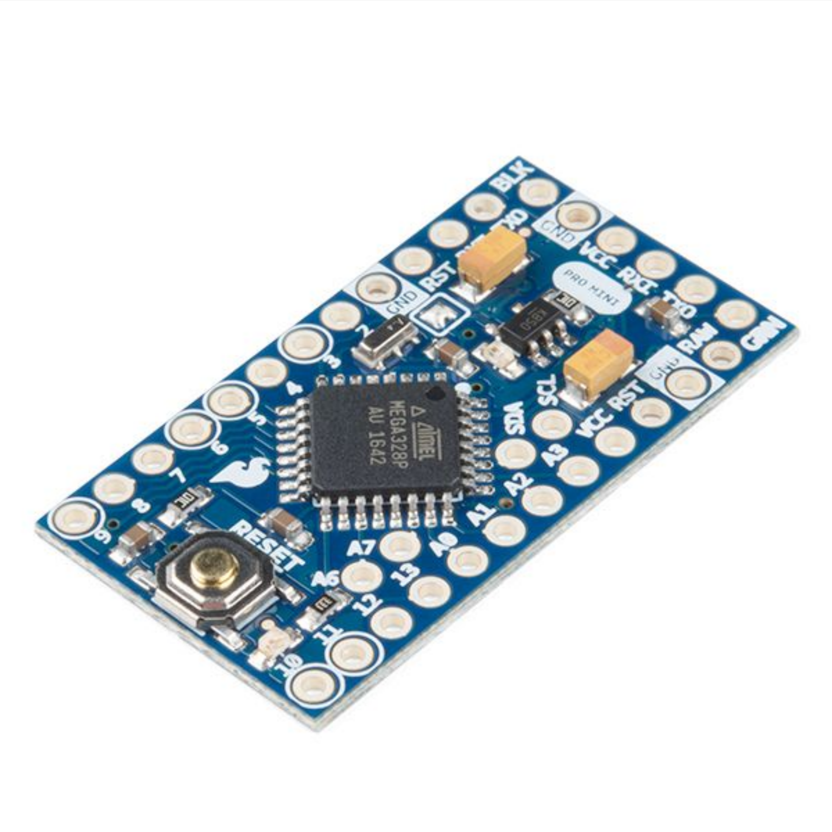
Rover Design





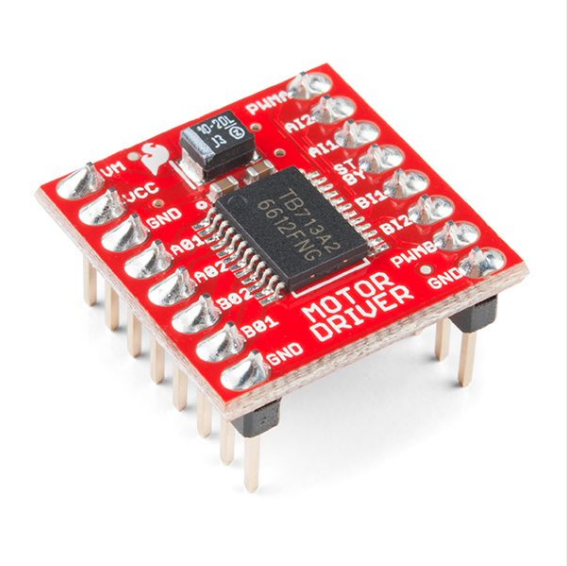
Control Unit

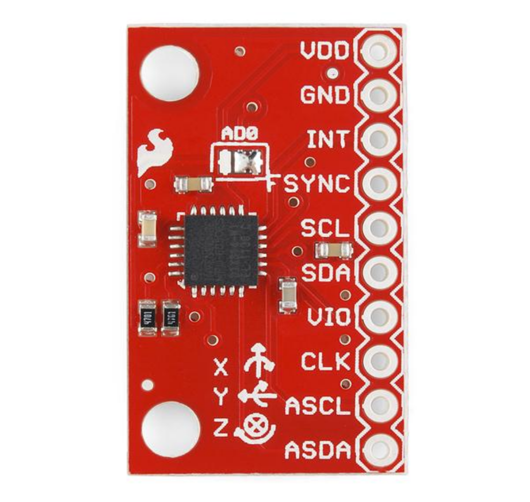
- Arduino Pro Mini 328 - 5V/16MHz:
  - Cost: $9.95.
- I/O Pins:
  - 14 Digital input/output.
  - 8 Analog.
  - 6 PWM.
- Mass: < 2g.
- Dimensions:
  - 1.3x0.7”.
- Processing Performance:
  - ATmega 328 @ 16 MHz.



Electrical Design

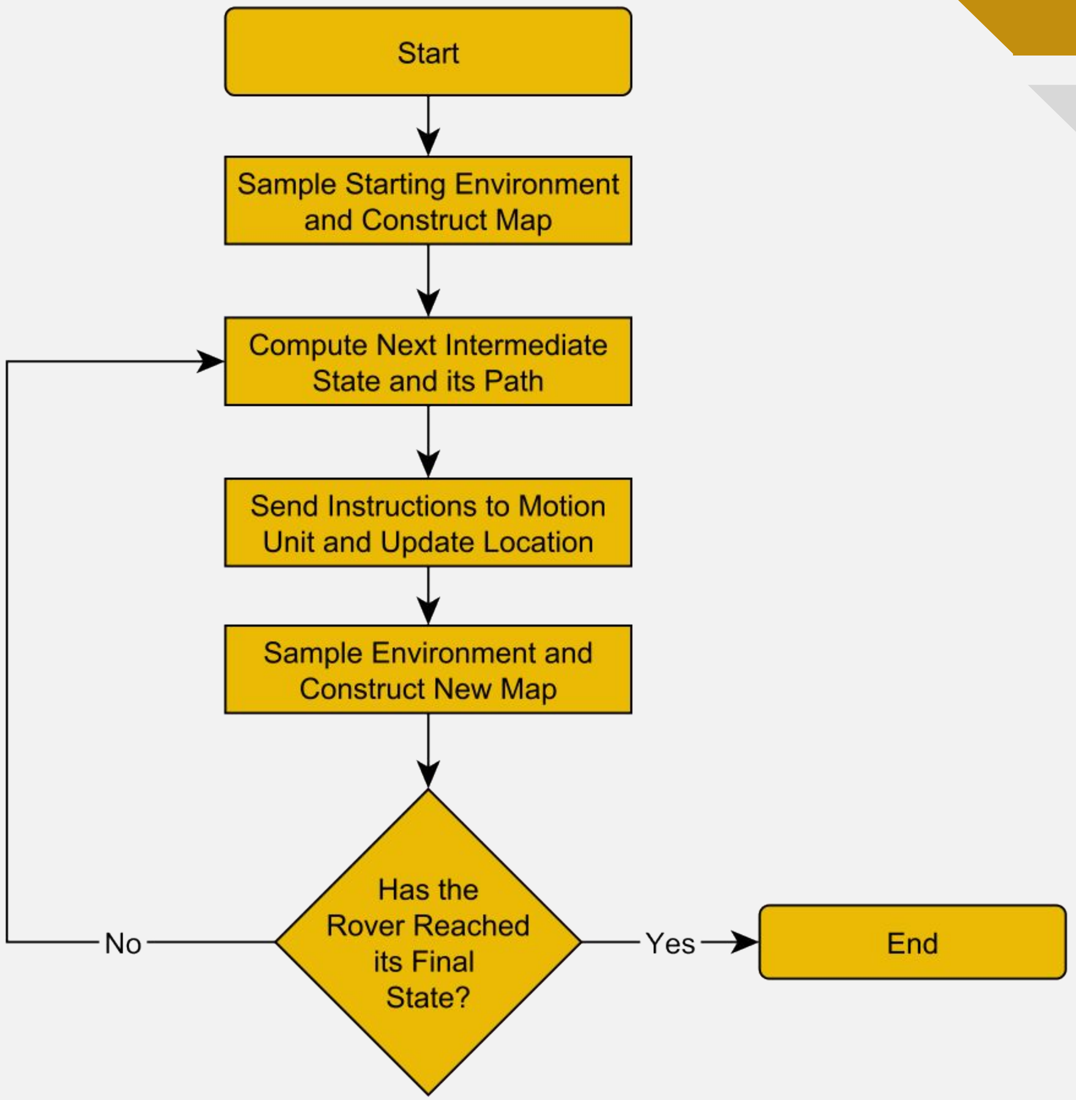
- Arduino Pro Mini
- TB6612FNG Motor Driver
- MPU-6050 3-axis accelerometer and gyroscope
- 2-Cell LiPO Battery





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"
  - Now attached at front of rover chassis
  - Drives into soil for well agitated sample
  - Provides sampling scoop with a driving torque
  - 5.875" x 1" Base Plate
  - 1.378" Tall Spikes
  - PLA Plastic

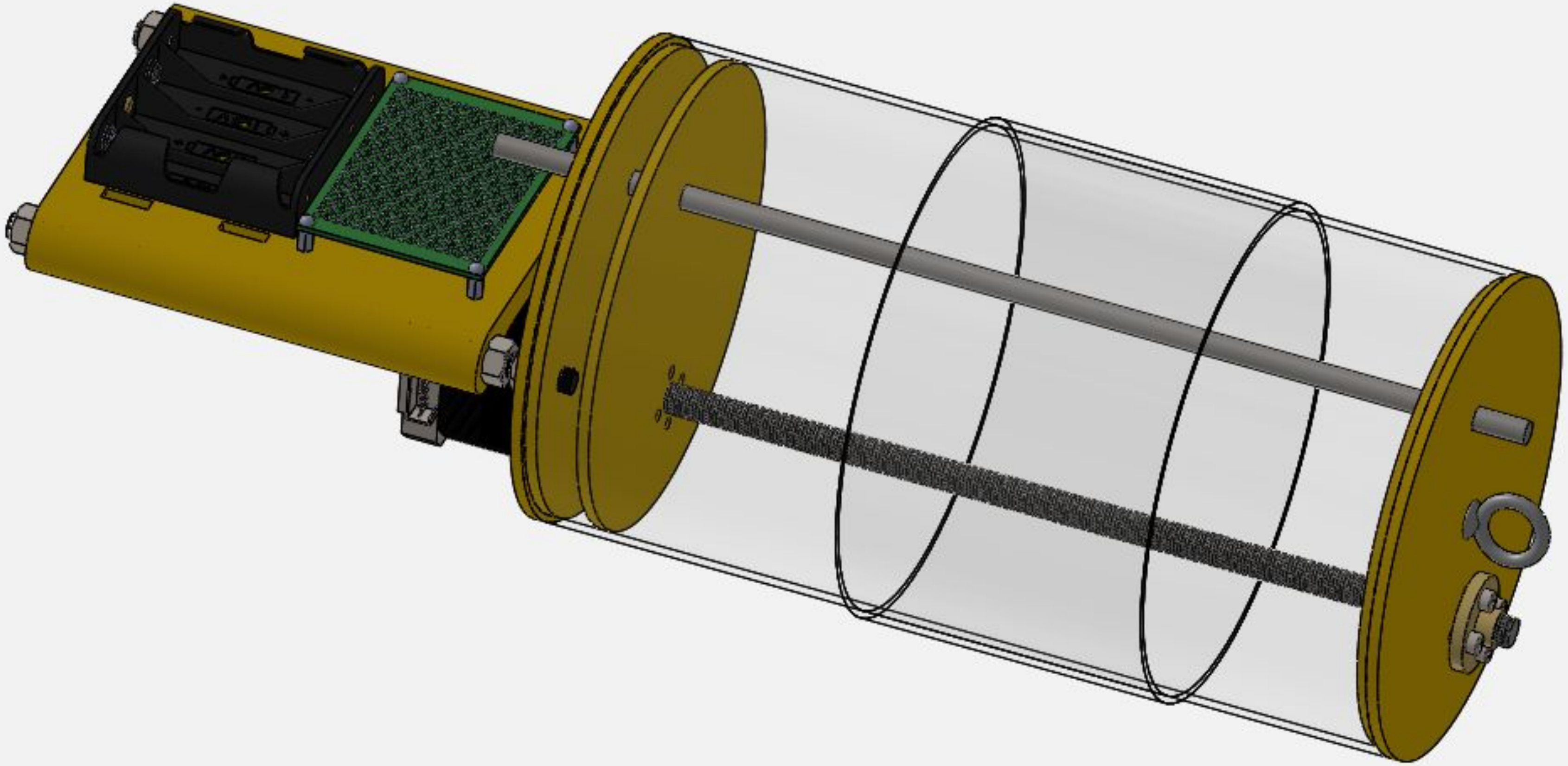
Soil Sampling System—Retention

- "The Scoop"
  - Now semicircular in shape, as the rake has been moved
  - 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
  - PLA Plastic

Retention and Deployment

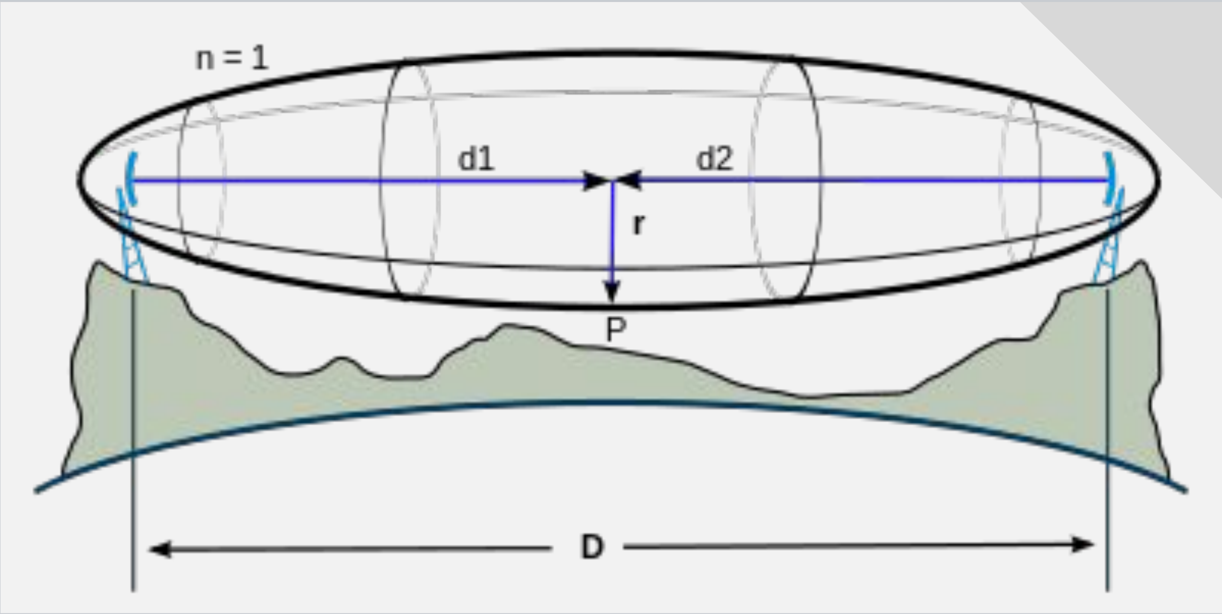
- Initiated by signal sent remotely
- Triggers black-powder charge, separating payload bay and nose cone from rocket upper airframe
- Linear actuator pushes rover out of payload bay
- Rover components are placed so the rover naturally stays upright

Retention and Deployment



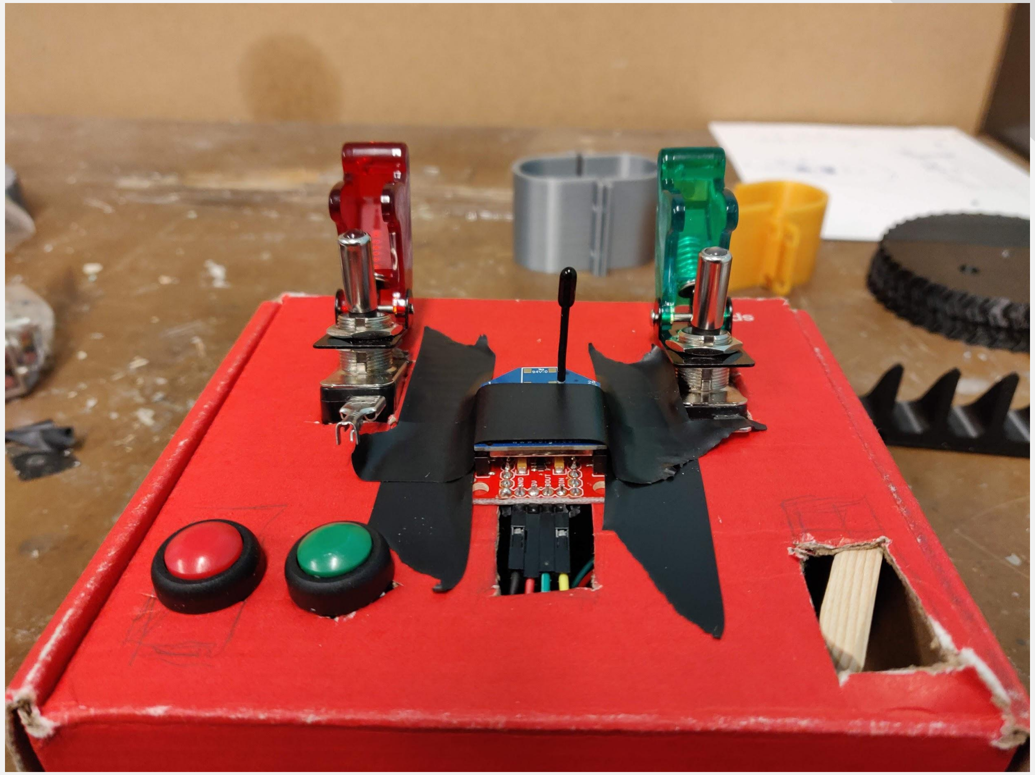
Deployment- XBee Tower

- Calculation of Fresnel Zone
- Separate XBee from Base Station
- Telescoping pole with XBee for height
- CAT5 cable to connect XBee from Base Station



Deployment - Base Station

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



Full Scale Demonstration Flight

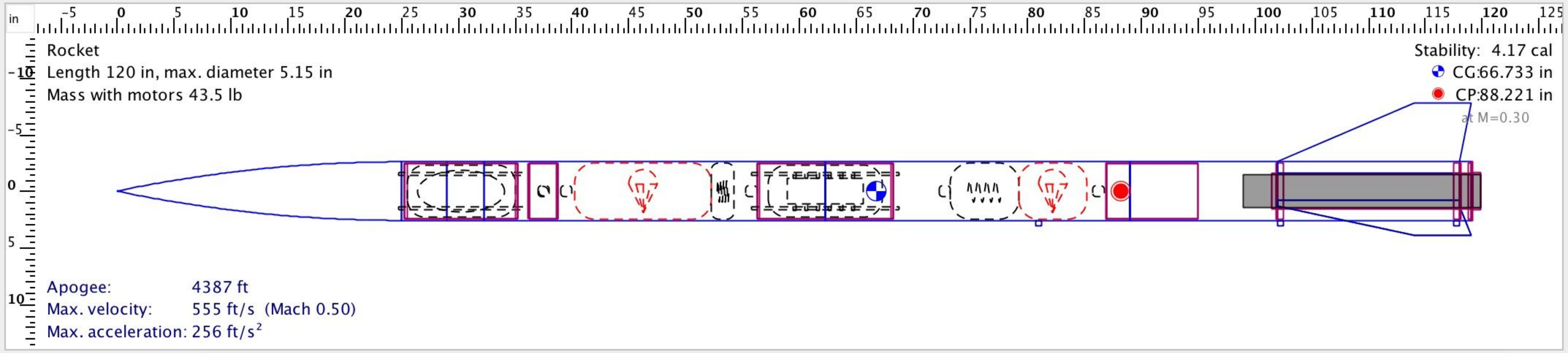
Full Scale Test Overview

- Build/launch/recover our competition vehicle
  - Must share geometry as the subscale
  - Utilize the same avionics and payload system

- Full scale vehicle successfully launched
  - Drogue chute successfully deployed at apogee
  - Main chute successfully deployed at ~900’ AGL
  - Main chute successfully opened at ~750’ AGL
  - All hardware remained undamaged
  - Both altimeters received accurate data and were unharmed

Full Scale Geometry and Motor

- We maintained similar geometry to our simulation and subscale rockets
- We conducted both Vehicle Demonstration Flight (VDF) and Payload Demonstration Flight (PDF) with the Aerotech L1520 motor



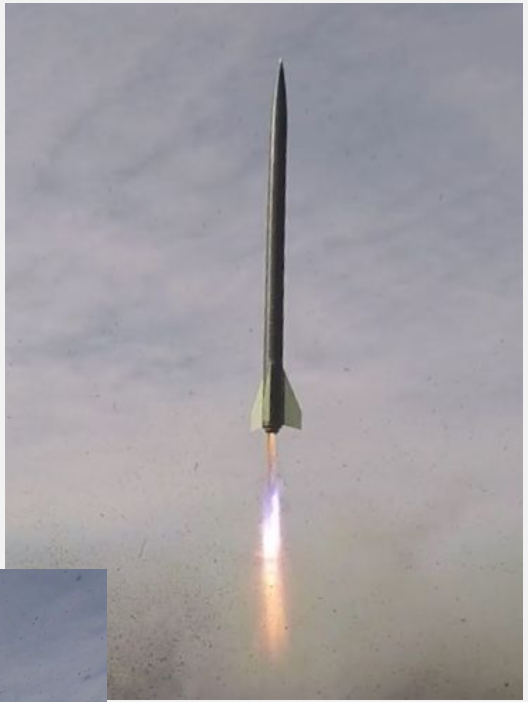
Full Scale Launch Conditions

- Sunny, Partial Clouds
- ~5-10 mph wind from NW
- ~17-30 deg. Fahrenheit
- Overall no extreme weather
- Flight conducted on Indiana Rocketry Inc. Tab, IN field

Full Scale Flight Recorded Results

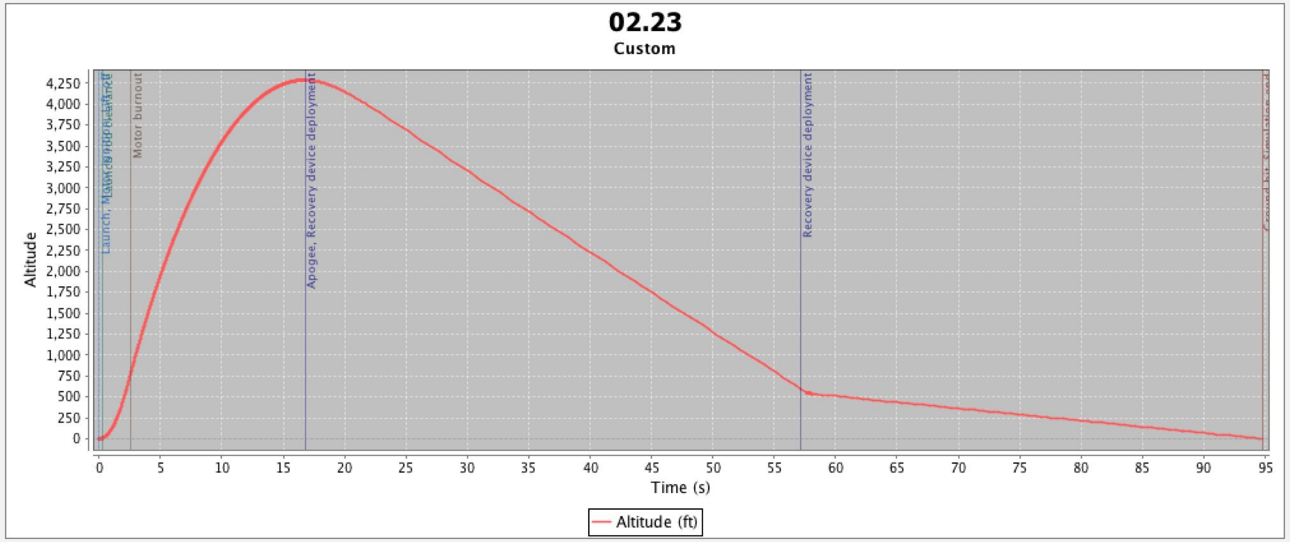
- Two altimeters were flown for redundancy:
  - MissileWorks RRC3+ Sport (Primary)(DD)
  - Altus Metrum TeleMetrum (Secondary)(DD)

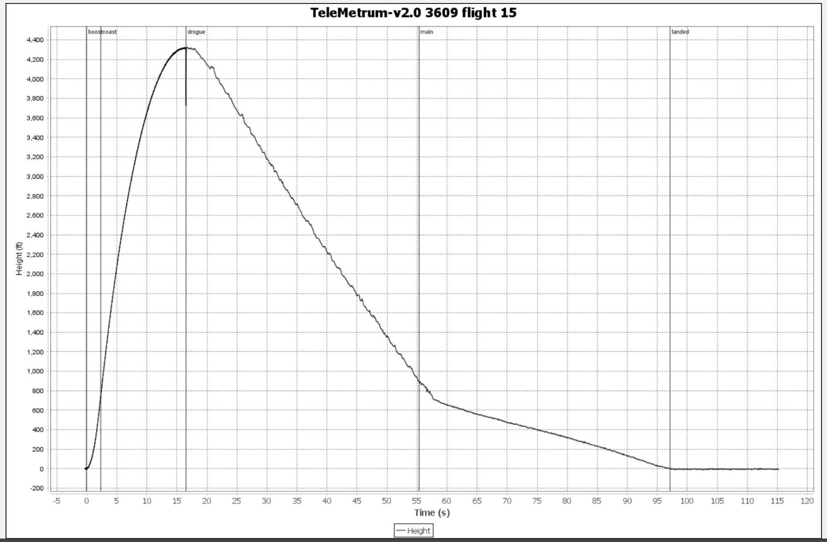
- MissileWorks RRC3+ Sport max altitude: 4,263 ft
- Altus Metrum TeleMetrum max altitude: 4,321.5 ft



Recorded Vs. Predicted Data

- Through simulations an altitude of 4287 ft was predicted
  - With current vehicle properties
- Between the two altimeters, the average altitude was 4,292 ft
- The main reason for imperfections is our rocket being to heavy





Demonstration Flight Summary

- 5th Time's the Charm left the pad about 2:04 pm CST
- Flew WSW until apogee, where drogue deployed
- Proceeded to fall under drogue until 900 ft AGL, where main was deployed
- Approximately 750 ft AGL, main opened
- When main opened, the forces broke the payload active retention system
- Rocket landed softly, payload bay (nosecone, rover,payload coupler and all electronics) fell from ~730 ft

Demonstration Flight Summary

- If payload bay was fixed to the rest of the rocket, there would have been no separation
- From our understanding:
  - VDF was successful
  - PDF was unsuccessful
- Either way our plan is to launch between 03/17 and 03/24
- FRR Addendum is currently being written
- Payload team is making the following design changes:
  - Adjusting position of main parachute
  - Changing to 4x 4-40 shear pins
  - Additional shock cord as added safety measure

Project Plan - Avionics Testing

Avionics Tests

The following tests were completed to ensure all avionics systems were fully functional:

- Parachute Drop Test
- Altimeter Ejection Vacuum Test
- Altimeter Ejection Black Powder Test
- Battery Drain Test
- Altimeter Continuity Test

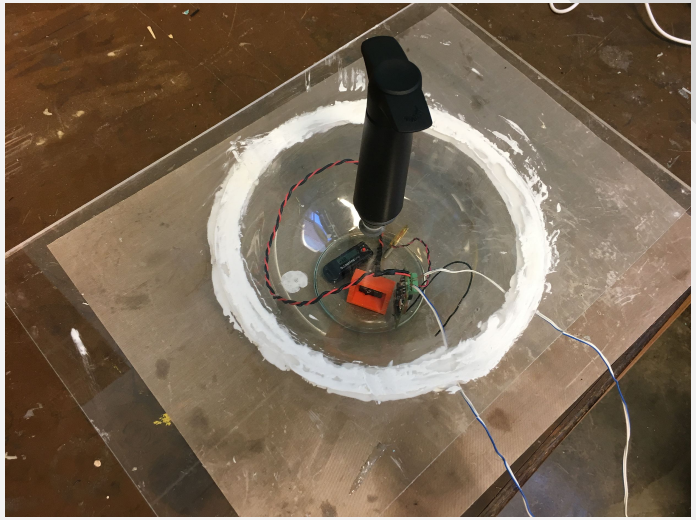
Parachute Drop Test

Derived Requirement: Both parachutes need to be able to open within a consistent time frame after being ejected.
Verification: After each trial the parachute was dropped, the amount of time it took for it to come to a fully opened state was measured. The parachute passed this test if the times measured in three trials were all within one second of each other.
Results: Drogue - the range of times to open is 0.37 sec
The drogue parachute **passed** the test.
Main parachute - **test unproven***

***Note:** The tallest parking garage publicly available to us to perform this test was not tall enough to allow the main flight parachute to completely open during its descent (it is too large). Therefore, this test must be classified as unproven. However, the main test parachute passed this test, and the main flight parachute was observed to open about one-third of the way in 1.26 seconds. There is reasonable confidence with the additional approval and guidance of a Level 3 Certified mentor that the main flight parachute is likely to open within a consistent time frame after being ejected.

Altimeter Ejection Vacuum Test

Derived Requirement: Both altimeters need to be able to consistently ignite both ejection charges at the appropriate times.
Verification: The Telemetrum altimeter passed this test if the magnitude of the difference between the apogee altitude and the altitude the drogue e-match ignited at was less than 700 feet and the altitude the main e-match ignited at was between 650 and 750 feet for all three trials. The RRC3+ Sport altimeter passed this test if the drogue delay was between 0.75 and 1.75 seconds and the altitude the main e-match ignited at was between 650 and 750 feet for all three trials.
Results: The Telemetrum **passed** the test.
The RRC3+ Sport **passed** the test.



Altimeter Ejection Black Powder Test

Derived Requirement: Both black powder canisters (one on either side of the avionics bay) need to be able to achieve successful separation of the avionics bay from the corresponding airframe, as well as full ejection of the corresponding parachute.
Verification: Each black powder canister passed this test if its ignition resulted in at least six feet of separation of the avionics bay from the corresponding airframe, as well as full ejection of the corresponding parachute, for at least one amount of black powder equal to or greater than four grams for the upper airframe and three grams for the lower airframe.
Results: The black powder ejection charges on the both the upper and mid airframe side of the avionics bay **passed** the test.

- The ideal amount of black powder for the drogue deploy is **3 g** primary, **4 g** backup
- The ideal amount of black powder for the main deploy is **4 g** primary, **5 g** backup

Battery Drain Test

Derived Requirement: Each battery of both the 3.7V LiPo and 9V variety needs to be able to supply power to its corresponding altimeter (drawing about 50 mAh of power) for the required amount of time (one hour).

Verification: Each battery passed this test if, connected to its corresponding altimeter, the battery was able to keep it powered on for an hour.

Results: The 9V battery **passed** the test.
The 3.7V LiPo battery **passed** the test.

Altimeter Continuity Test

Derived Requirement: Both altimeters need to be able to consistently achieve continuity for a dual deploy configuration.

Verification: Each altimeter passed this test if it emitted three beeps (or *dits* for the Telemetrum) every five seconds after the initialization routine for all three trials, indicating successful continuity for a dual deploy configuration.

Results: The Telemetrum **passed** the test.
The RRC3+ Sport **passed** the test

Project Plan - Payload Testing

Payload Test Derived Requirements

1. The separation between the payload bay and rocket should be at least 3 feet.
2. The wireless communication system for transmitting the deployment signal to the rover should send, receive, and parse signals over distances up to 2500 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 3 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

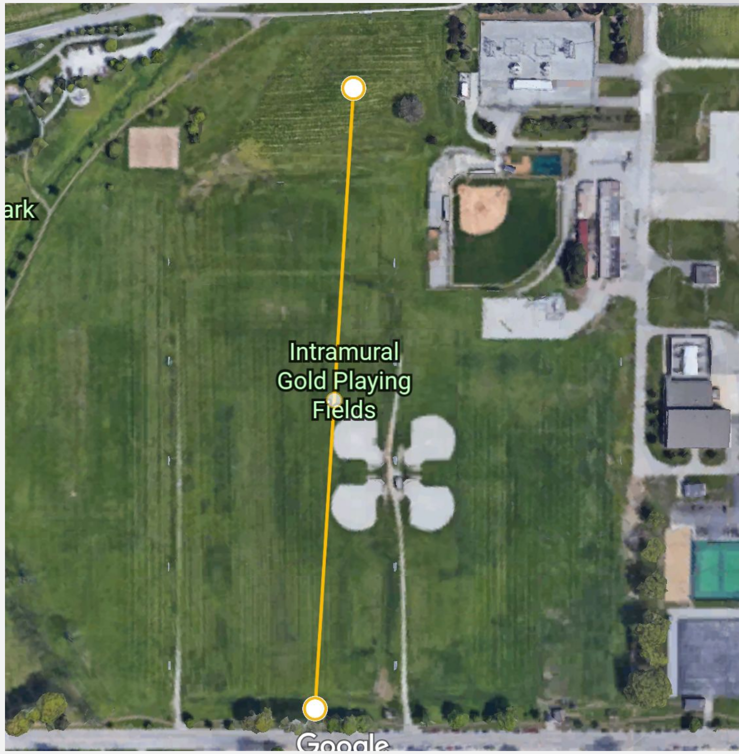
1. Ejection separation test: assure that the payload bay will successfully separate at least 3 feet.
2. Radio communication distance test: establish that Xbee radio is able to communicate from at least 2500 feet away.
3. Rover orientation test: determine that the rover will be in the correct orientation 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.

Ejection Separation Test

- **Requirement:** The separation between the payload bay and rocket should be at least 3 feet.
- **Verification plan:**
    a. Place rocket with payload bay in post-launch configuration
    b. Manually trigger black powder charge
    c. Measure separation of payload bay from upper airframe
- **Results:**
    a. ~30 feet of separation due to backup 3g charge igniting with 2g primary charge
    b. Plan to test again with new shear pin configuration

Radio Communication Test

- **Requirement:** The wireless communication system for transmitting the deployment signal to the rover should send, receive, and parse signals over distances up to 2500 feet.
- **Verification plan:**
  - Build test circuit to identify successful communication between XBee radios
  - Simulate launch scenario with test circuit over varying distances
- **Results:**
  - Preliminary tests indicated effect of elevation of transmitter XBee (~1250 feet)
  - Tests are planned to confirm range of 2500 feet



Funding and Educational Engagement

Changes Since CDR

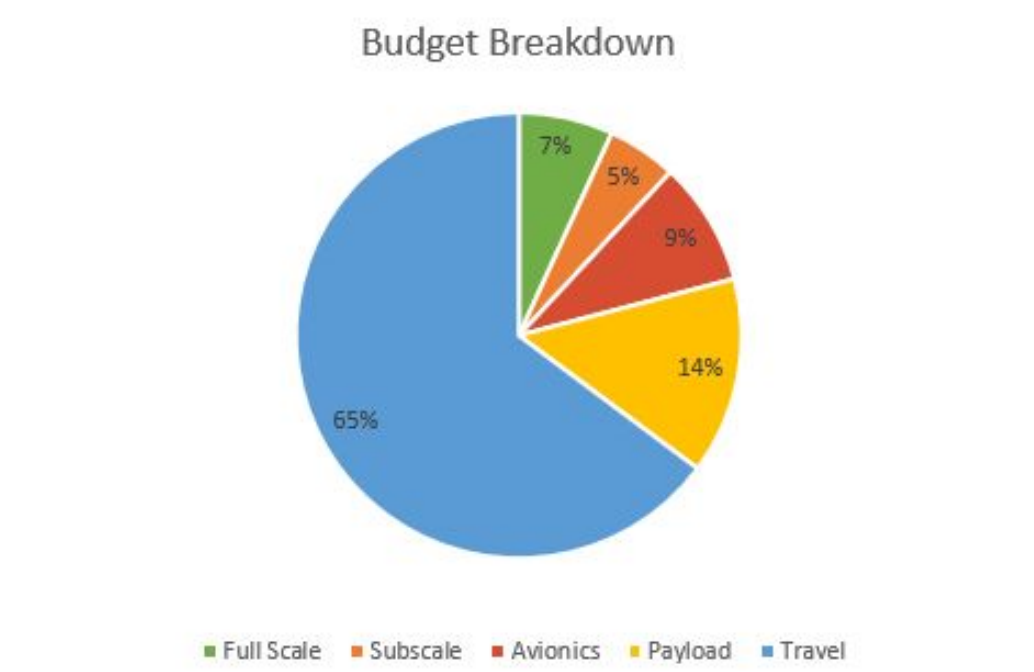
- Total budget has changed
  - Reflected in how funds are allocated
  - Line item budget updated
  - Budget not finalized due to potential future purchases, specifically for the payload team.

- Discounts now considered in budget
  - Budget grand total now considers donations, previous purchases, and price cuts.
  - Brings down overall budget dramatically

Budgeting

- Total before discounts: $7016.47
- Total after discounts: $3925.13

Section	Pre-discount Cost	Post-discount Cost
Full Scale	$2340.69	$269.35
Subscale	$197.93	$197.93
Avionics	$823.48	$353.48
Payload	$560.37	$560.37
Branding	$550	$0
Travel	$2544	$2544



- Discount sources
  - Previously purchased parts
  - Donated parts (SEDS, IRI)
  - Borrowed parts

Funding Plan

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

1. Restaurant Fundraisers: $600 (across 3 fundraisers)
2. Grants (AAE): $1600
3. Crowdfunding: $800
4. Levy Restaurants: $300
5. SEDS Treasury: $1000

Total: $4300 ($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.
- Concerns about potential future costs - $300 will be used up

Educational Outreach Plan

- We had 12 team members volunteer at Purdue Space Day
  - Charlie Walker was the guest Astronaut
  - About ~1,000 grade school students attended
- Our team was spread wide
  - Group Leads
  - Activity Leads
  - Safety Leads

PSP-SL Social

- Team photo, Subteam photos, Team Lead photos

- Rocket Fair
  - Creating poster that has an even distribution of a the team information
  - Creating rocket stand
  - Gathering CAD, Checklists, Procedures, etc. for a team summary binder

Next Steps

Next Steps

- Work on getting Full scale rocket painted
- Work on getting poster together for presentation
  - Construction, payload, Outreach, Funding
- Build and test Texas Rover II
- Payload Demonstration re-flight
- Ensuring the launch week team is fully prepared to set up the launch vehicle at the pad
- Prepare team for the rocket fair

PURDUE SL

Question And Answer Session