Mars Rover CDR

Rensselaer Rocket Society
Team Number: 1200

Presentation Outline

Acronyms

ARD	Arduino
PLA	Polylactic Acid
CONOPS	Concept of Operations
CAD	Computer Aided Design
TTA	Time to Apogee
NAR	National Association of Rocketry
HPR	High Power Rocketry
TPU	Thermoplastic Polyurethane

Systems Overview

Mission Summary

1. Rocket and rover must launch to at least 1000 feet and deploy Mars Rover
2. Rover must be able to overcome cut corn stalks which can be as tall as one foot
3. Rover must be fully contained in the rocket before being deployed
4. Rover must return to the ground safely
5. Rover must be designed to withstand the forces associated with rocket ejection and landing
6. Rover must detach parachutes after landing
7. Rover must travel 3 feet
8. Travel must be done within 10 minutes (time starts at time of landing)
9. Rover must collect between 5 and 25 grams of dirt
10. Dirt collection must be done within 5 minutes
11. Rover must take a picture and transmit to a hand held receiver

Rocket

Requirements:

1. Motor clusters are not allowed.
2. Staging is not allowed.
3. Total installed impulse shall not exceed 2,560 Newton-seconds or a K motor.
4. All parts of the rocket must safely return under a recovery system.
5. The rocket airframe, nose cone, fins, bulk plates, and centering rings cannot be made of any types of metal. Composite materials are allowed.
6. If the rocket with the rover exceeds 12 pounds, rail buttons for 1515 and extreme rails must be used.
7. If the rocket is more than 6 inches in diameter, rail buttons for 1515 and extreme rails must be used.
8. If the rocket is over 35 pounds or greater than 8 inches in diameter, unistrut rail buttons must be used and will be launched at the away cell.
9. The rocket must reach at least 1000 feet.
10. The rocket must use a commercial altimeter for measuring the peak altitude.
11. The average thrust to weight ratio must be greater than 5:1.
12. Average thrust is per the motor designation. For example a J240 has an average thrust of 240 newton-seconds.
13. The rocket must use a motor retainer. Friction fit is not allowed.
14. All common rules must be followed.

Rover

Requirements:

1. Rover cannot weigh more than 2 kg.
2. Rover must be contained completely inside the rocket during launch.
3. The rover recovery system must be secured so no part of the rover free falls.
4. No pyrotechnics are allowed in the Mars rover.
5. The rover shall take a picture of the site where the soil was collected.
6. Each image must be in color and have a resolution of at least 640x480
7. At landing, the rover must autonomously release the recovery system. The recovery system can be used as the first marker.
8. Rover shall meet all operational requirements described.
9. The rover must travel 3 feet within 10 minutes autonomously after detaching parachute.
10. Mission must be completed in 5 minutes after commanding.
11. No flying rovers.

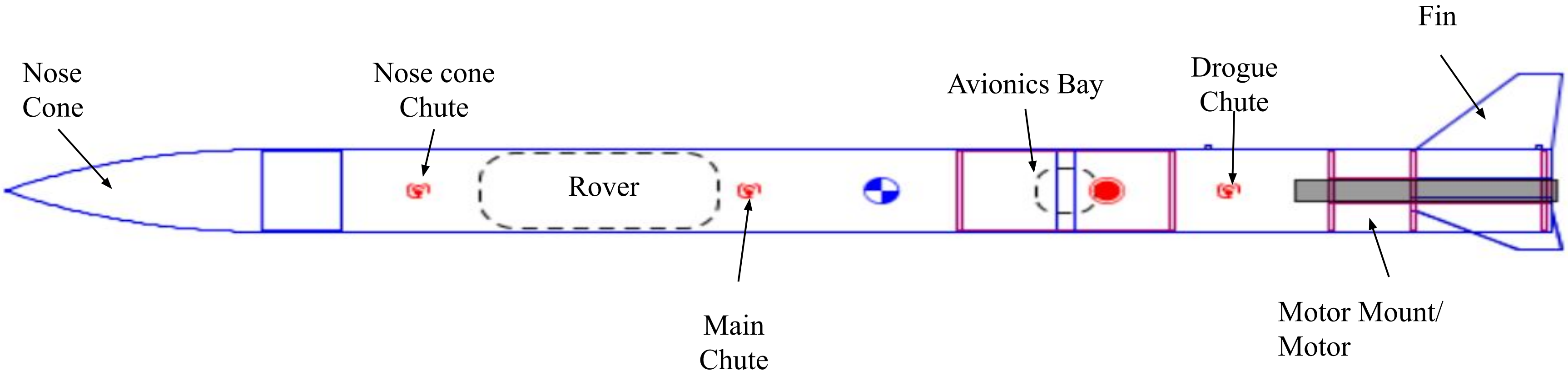
Controller

Requirements:

1. Controller must be hand held
2. Controller must communicate with the rover via radio signals. WiFi, bluetooth, or XBEE radio are allowed. XBEE radios must have their PAN/NET ID set to team number
3. Controller must send a single command for each action required
4. Laptop cannot be used

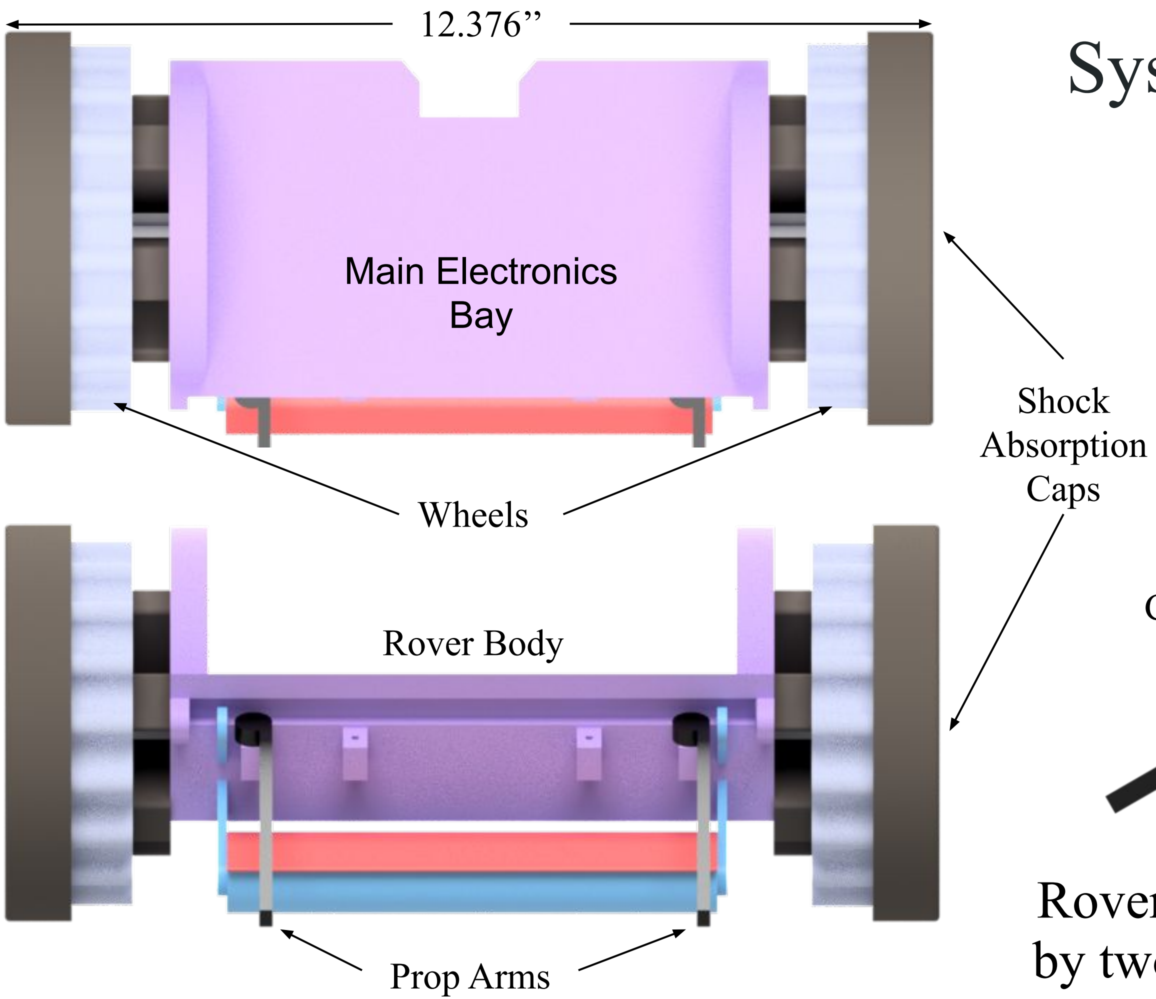
System Level Design, Rocket

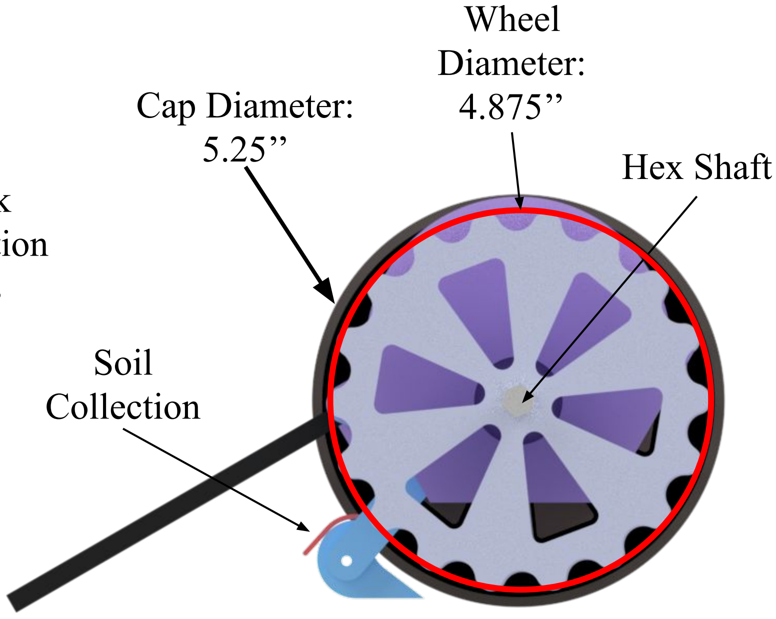
Length: 78.481 in.   Diameter: 5.540 in.   3 Fins



Rocket is 5.5” cardboard tubing with a J500 motor

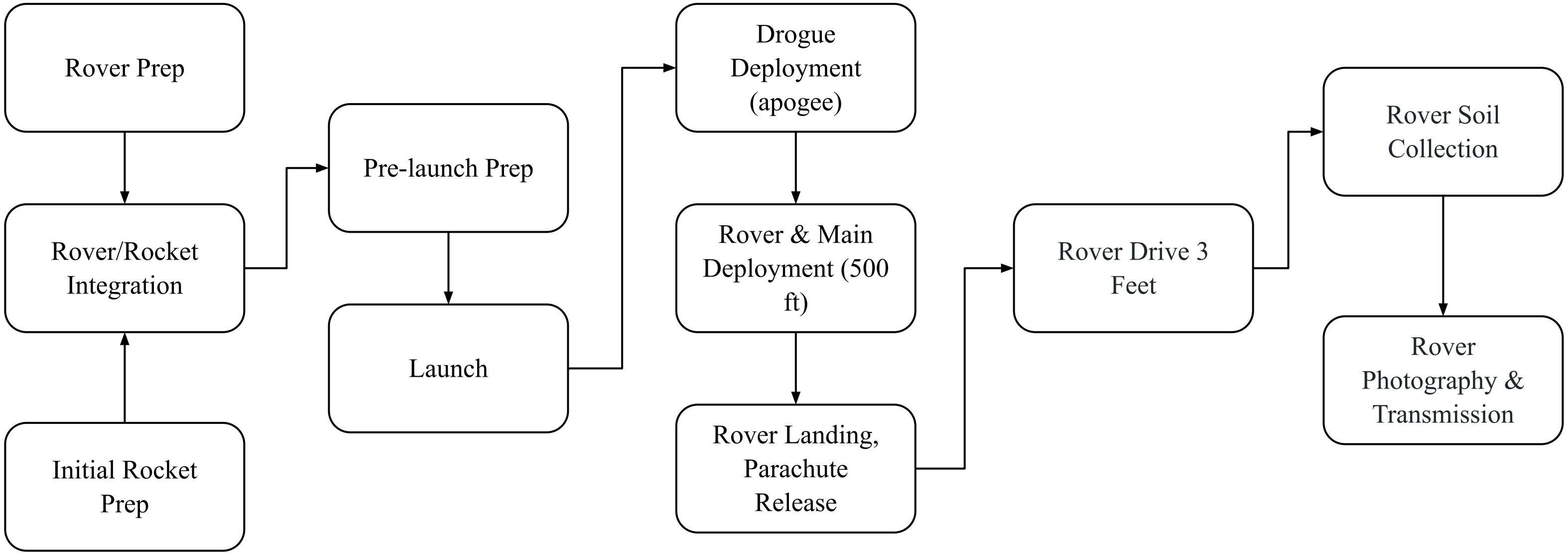
System Level Design, Rover





Rover uses a single drive axle run by two separate continuous servos

System Concept of Operations



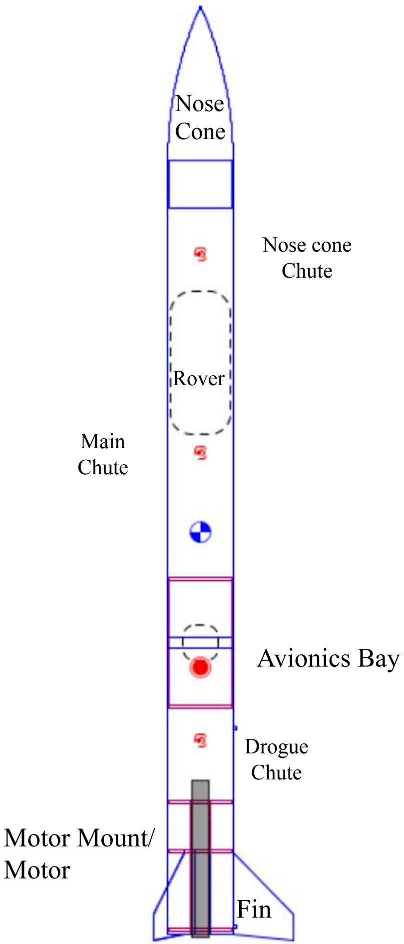
Rocket Design

Changes Made to the Rocket

- Main and nose cone parachutes will now be deployed at an altitude of 550 feet as opposed to the previous 500 feet
- Secondary charge will now go off at 500 feet instead of 450 feet
- Remeasured parachute shroud line values

Overview

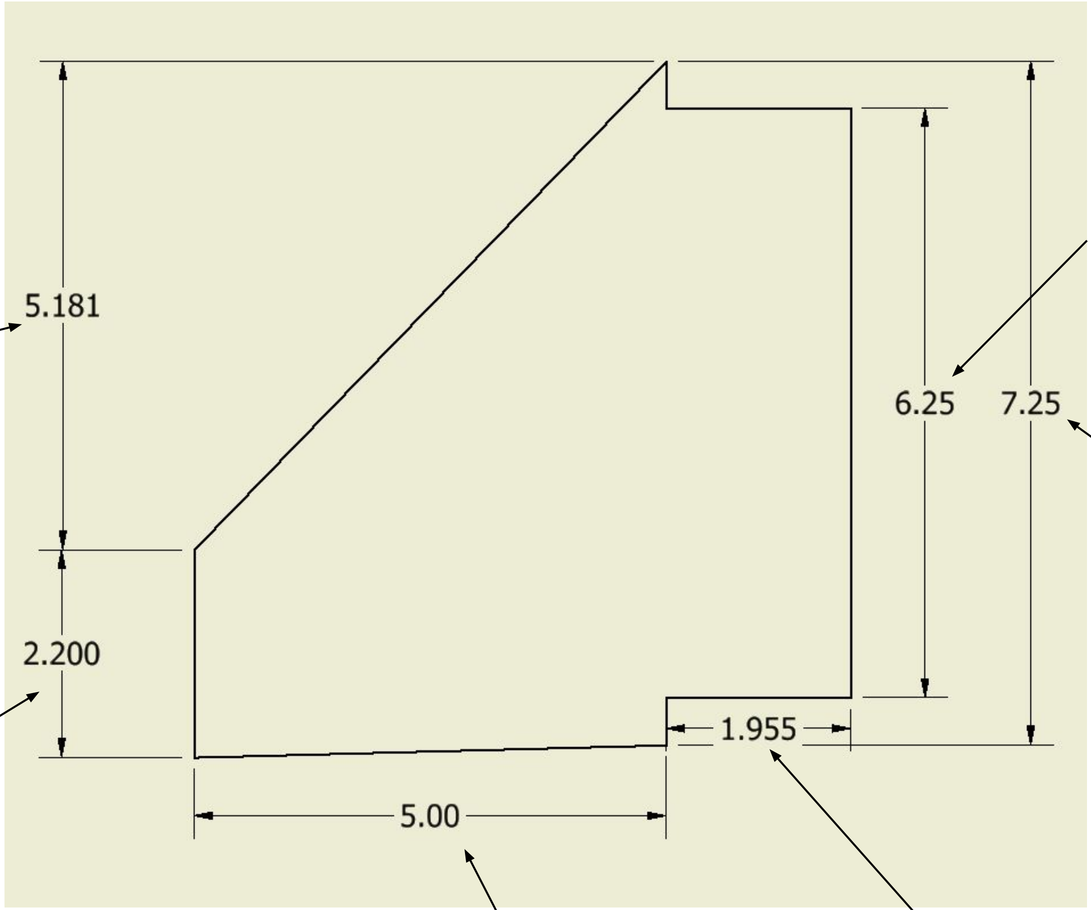
- Length: 78.481 in
- Airframe Diameter: 5.540 in
- Stability: 2.05 cal
- Number of Fins: 3
    - Dimensions:
        - Shape: Trapezoidal
        - Tip chord: 2.2 in
        - Root chord: 7.25 in
        - Sweep length: 5.181 in
        - Mass: 284 g
        - Material: Plywood
        - Fin Tab Length: 7.1 in
        - Fin Tab Height: 1.955 in
        - Fin Position: 0 in from bottom



Airframe

- Lengths of various sections of airframe
  - Booster Airframe: 24 in
  - Switch Band: 1 in
  - Payload Bay: 32 in
- Airframe Diameter: 5.54 in. outer, 5.38 in. inner
- Airframe Materials
  - LOC Precision Tubing, cardboard, 2-56 nylon shear pins
- Nose Cone
  - Length: 13 in
  - Diameter: 5.38 in
  - Shape: Tangent ogive
  - Material: Polystyrene

Fins



All dimensions are in inches

Masses, CGs, and CPs

- Mass:
  - With J500 (Primary) Motor: 15.611 lbs (7.081 kg)
  - With J570 (Backup) Motor: 16.125 lbs (7.314 kg)
- Center of Gravity:
  - With J500 (Primary) Motor: 44.193 in from nose tip
  - With J500 (Primary) Motor: 44.722 in from nose tip
- Center of Pressure:
  - With J500 (Primary) Motor: 55.558 in from nose tip
  - With J500 (Primary) Motor: 55.558 in from nose tip

Motor Mount and Retention

- Motor Mount
  - 38mm diameter
  - 11 in length
  - Steel Z-clips will be used to retain the motor
- Three identical centering rings are placed around the motor for retention
  - First centering ring is ¼” from bottom of motor mount
  - Second is 6.9” from bottom of motor mount
  - Third is 11” from bottom of motor mount
- Forwardmost centering ring connected to avionics bay
  - Connection via 25’ shock cord
  - Drogue chute attached to this shock cord

Materials

- Airframe- Brown Kraft Paper
- Nose Cone- Polypropylene Plastic
- Fins, Centering Rings, Bulkheads- ¼ in Baltic Birch Plywood
- Rail Buttons- 2 1-piece nylon buttons for 1515 rail. Each secured with an 8-32 machine screw through the airframe
- Adhesives- Wood Glue and JB Weld epoxy

Rocket Recovery System

Parachute Selection

- Dual deploy
  - Parachutes are protected by 18in square Nomex Blanket

	Parachute (Within 53” body tube) - Main Parachute	Parachute (Within 24” body tube) - Drogue Chute	Parachute (Attached to Nose Cone) - Nose Cone Chute	Rover Parachute
Canopy	Diameter- 53 in Material- Ripstop nylon	Diameter- 24 in Material- Ripstop nylon	Diameter- 24 in Material- Ripstop nylon	Diameter- 44 in Material- Ripstop nylon
Shroud Lines	Lines- 3 Line Length- 60 in Material- ⅜” tubular nylon	Lines- 4 Line Length- 30 in Material- ⅜” tubular nylon	Lines- 8 Line Length- 11.8 in Material - 1/8” tubular nylon	Lines- 3 Line Length- 44 in Material - ⅜” tubular nylon

Parachute- Descent Rates

Part	Drogue Descent Rate (ft/s)	Main Descent Rate (ft/s)	Total Drift Distance (ft)
Rocket Body	66.11	15.90	972.04
Nose Cone	66.11	17.06	929.29
Rover	66.11	17.07	928.78

	Drogue Descent Velocity (ft/s)	Main Descent Velocity (ft/s)	Total Descent Time (sec)	Drift Distance (ft)
BOTR 2020 Rocket (Rover)	66.10825719	15.8990184	48.60216406	972.0432812
BOTR 2020 Rover	66.10825719	17.07336104	46.43906953	928.7813906
BOTR 2020 Nose Cone (Rover)	66.10825719	17.05841531	46.46472793	929.2945585

Calculated using Air Drag Formula

$$D = \frac{1}{2} C_d \rho v^2 A$$

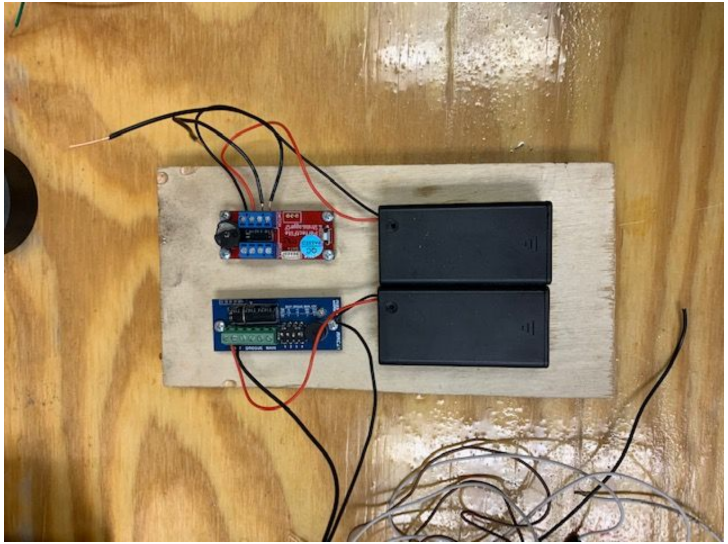
Harness

- Shock cords
  - 5/8” tubular nylon - 1500 lb test - 25’
- Linkages
  - ¼” quick links - 1400 lb test
    - Each main parachute attachment
    - End of harnesses

- Attachment points, eyebolts, fender washers, etc. and their mounting methods
  - ¼”-20 forged eye bolts - 500 lb test
    - Each end of electronics bay
  - Nose cone parachute is directly attached to slots in nose cone
  - Main parachute will quick link to the recovery harness
    - Tied to the forward eyebolt of the electronics bay
  - Drogue will quick link to the recovery harness
    - Tied to the aft eyebolt of the electronics bay

Electronics

- 1 Stratologger CF Altimeter will be used as primary (scoring)
- 1 RRC2+ Altimeter will be used as backup
- Motor ejection
    - J500 - 14 second delay, drilled to 10 seconds
    - J570 - 10 second delay



Altimeter

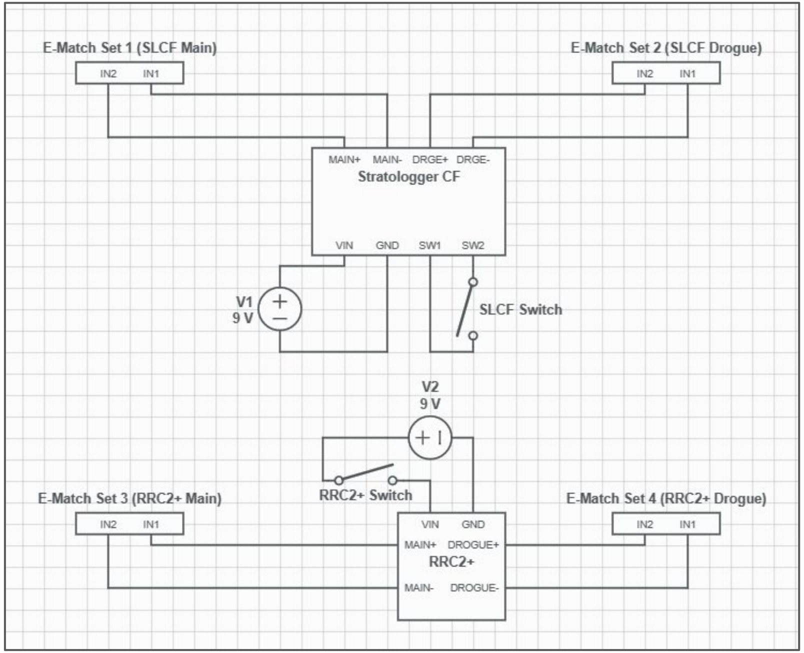


Figure 1 - Wiring Diagram of Altimeter

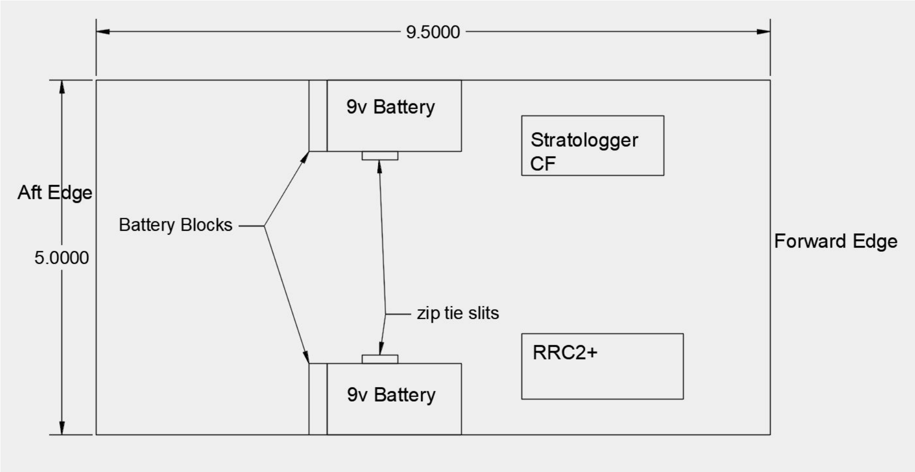


Figure 2 - Physical Layout of Altimeter Mounting and Power Distribution

Deployment Method

- Ejection Charge - Black Powder
  - Main Primary - 3.10 g
  - Main Backup - 3.50 g
  - Drogue Primary - 1.25 g
  - Drogue Backup - 1.50 g
  - Motor - 1.50 g
- Pressurized Volume:
  - Main: 431in^3
  - Drouge 159 in^3
- Each section will be secured with shear pins
  - Shear Pins: 3 2-56 nylon screws
    - Three at each section
    - Each less than 50 lbs shear strength
    - Sep. strength at 10 PSI is greater than 200 lbs

Ejection Charge Safety and Arming Procedures

Ejection Charge Installation - After all other prep phases but prior to check-in

1. Measure an appropriate mass of 4f BP into a charge well (Each well is labeled)
2. Install 2 redundant E-Matches into charge well
3. Plug E-Matches into appropriate labeled terminal block
4. Seal the charge well with tape
5. Repeat for each charge

Arming on the pad - Prior to inserting motor igniter

6. Turn switch to power on backup altimeter
7. Verify that backup altimeter is powered on and functioning correctly
8. Turn switch to power on primary altimeter
9. Verify that primary altimeter is powered on and functioning correctly

General Safety Considerations

- BP will be stored in a climate-controlled environment away from any potential sources of ignition
- All ejection charge installation shall only be performed by properly certified personnel over the age of 18
- After ejection charges have been installed, no personnel will pass the rocket in such a location as to be in the path of any section of the rocket should the charges be inadvertently activated
- Altimeters will only be armed when the rocket is vertical on the launch pad

Disarming After a Scrub

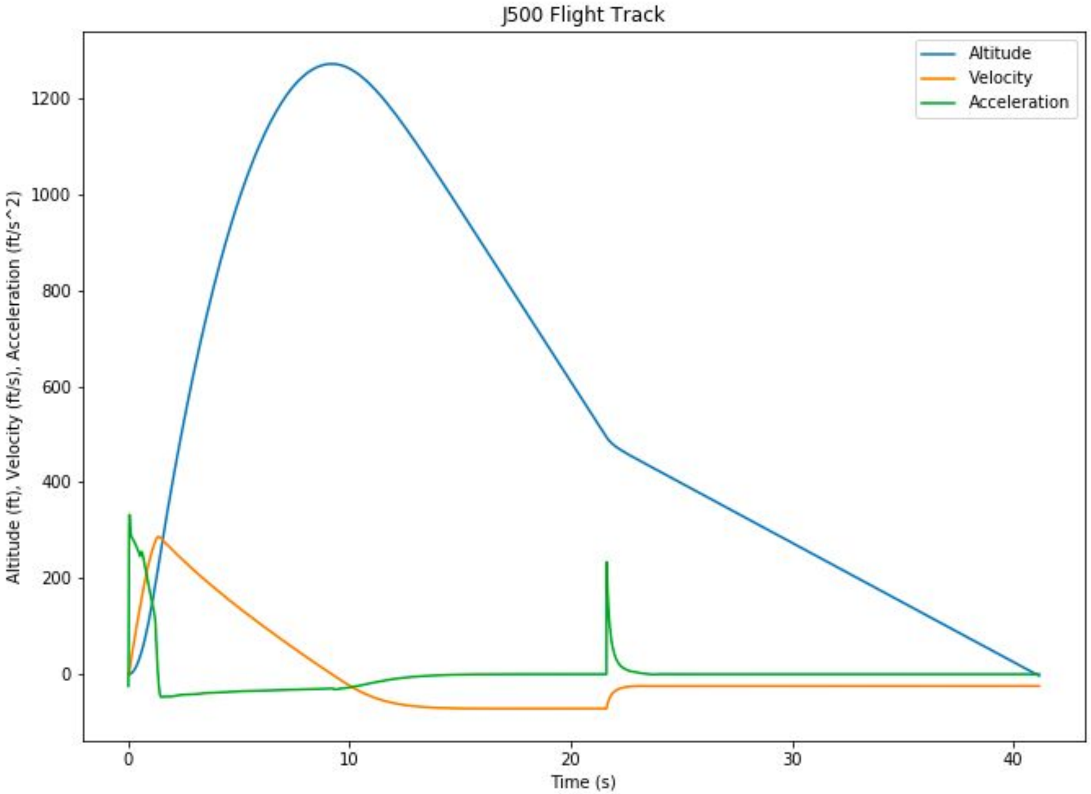
- Turn off all altimeters, verify all altimeters are powered off
- Remove electronics bay and pour out each ejection charge

Rocket Motor Selection

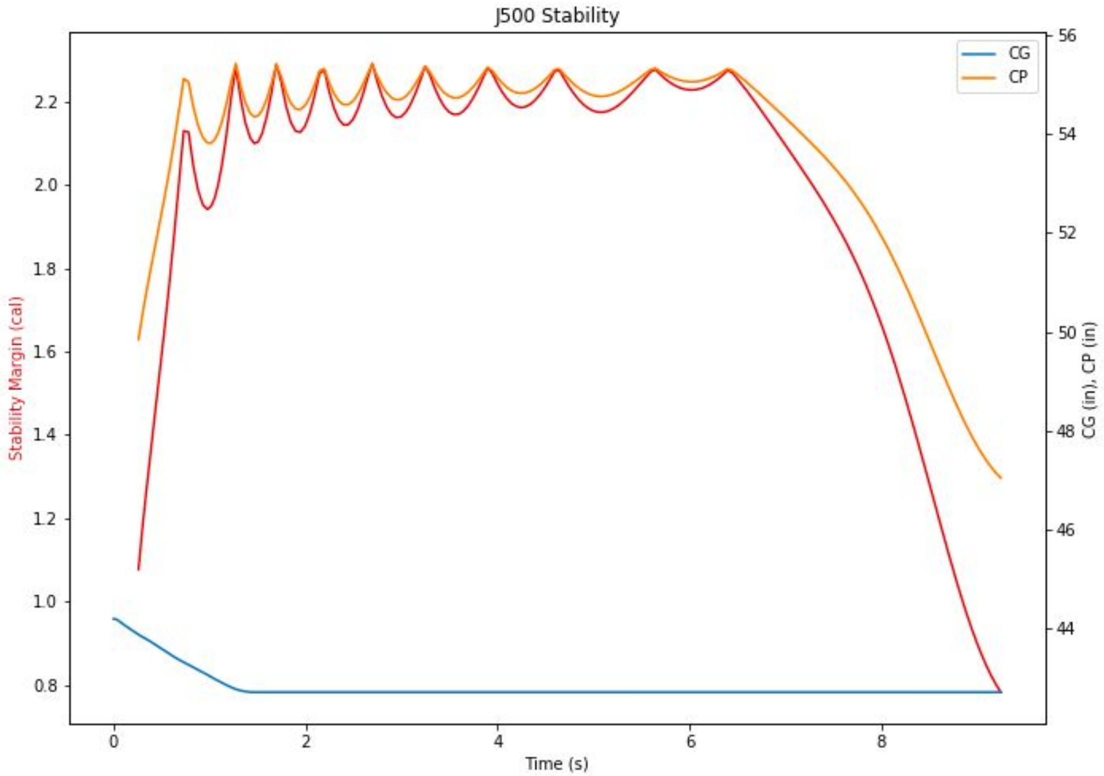
J500

- Manufacturer: Aerotech Consumer Aerospace
- Certifying Organization: Tripoli Rocket Association
- Casing: 38/720
- Total Impulse: 723 Ns
- As certified Thrust to Weight Ratio: 7.76:1
- Expected Apogee: 1284 ft
- Expected Max Velocity: 288 ft/s
- Expected Max Acceleration: 332 ft/s2
- Expected Minimum stability: 2.05 Caliper
- Time to Apogee: 10.96s

Simulations



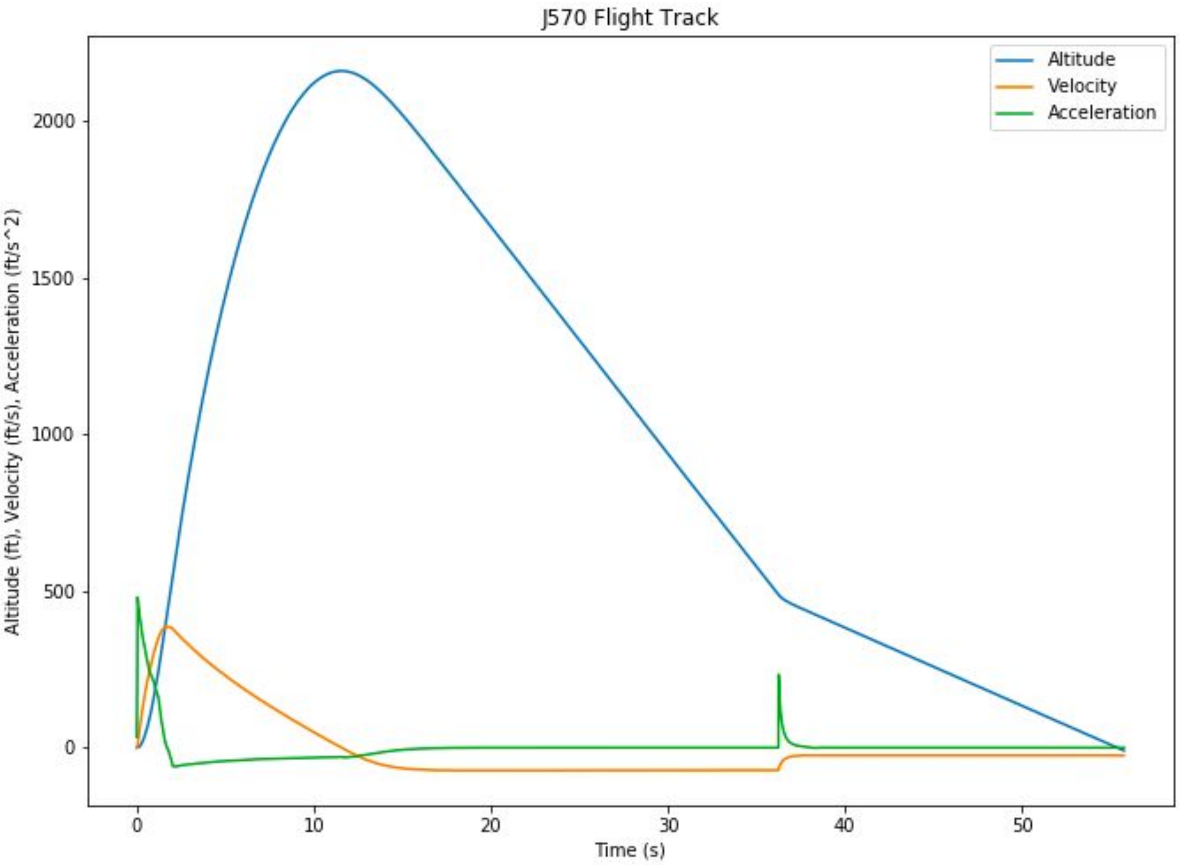
Stability Graphs



J570

- Manufacturer: Aerotech Consumer Aerospace
- Certifying Organization: Tripoli Rocket Association
- Casing: 38/1080
- Total Impulse: 973.1 Ns
- As certified Thrust to Weight Ratio: 8.58:1
- Expected Apogee: 2178 ft
- Expected Max Velocity: 388 ft/s
- Expected Max Acceleration: 478 ft/s2
- Expected Minimum stability: 1.96 Caliper
- Time to Apogee: 11.50s

Simulations



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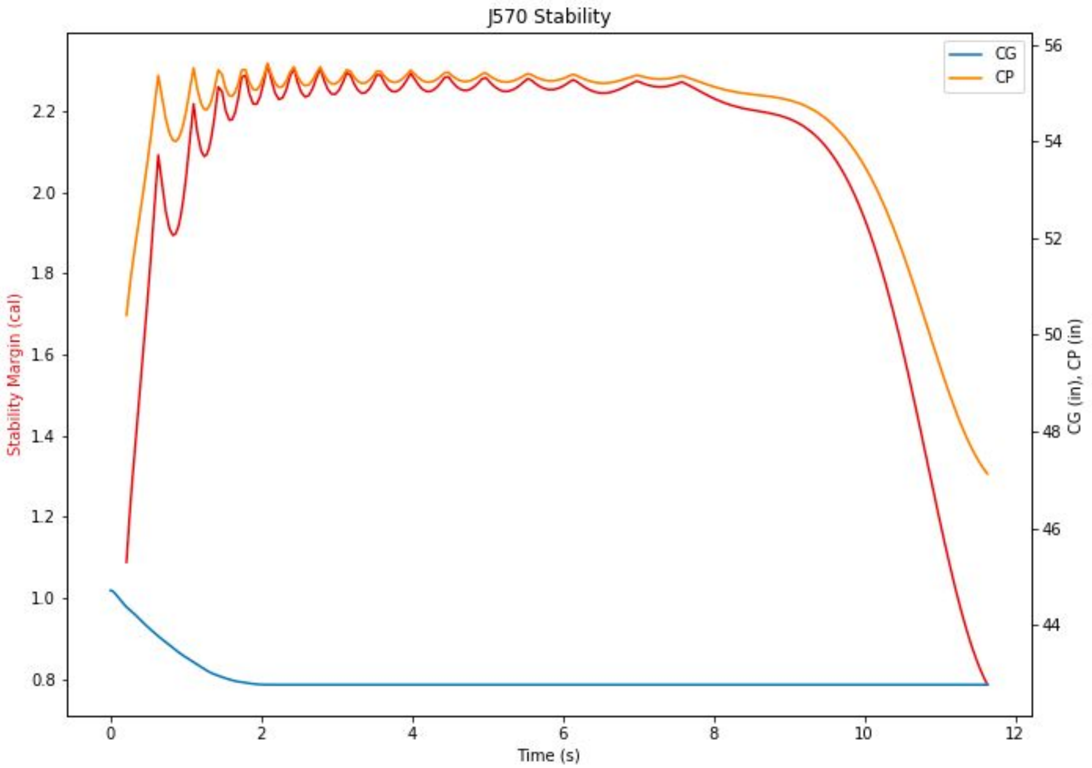
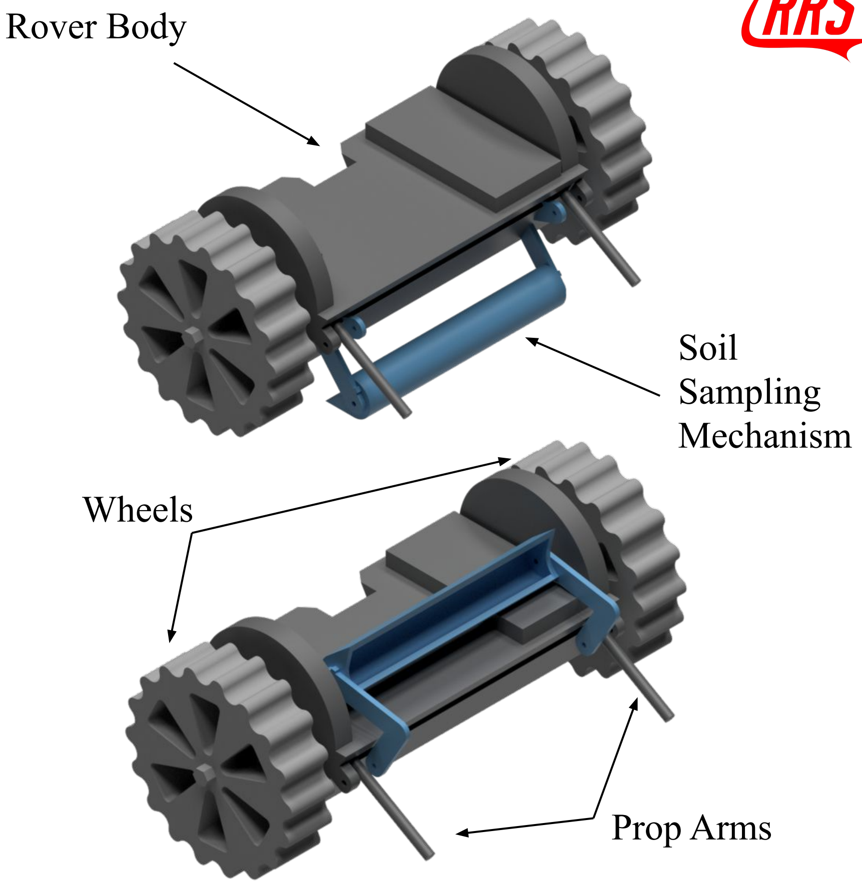


Rover Design

Rover Design Overview

- Dimensions:
  - Half hexagon prism design
  - Dimensions:
    - Total Length: 12.376”
    - Body Length: 8”
    - Wheel Outer Diameter: 4.875”
- Major Components
  - Drive shaft
  - Wheels
  - Soil Collection “Scooper”



Mechanical Design

Chassis Structure:

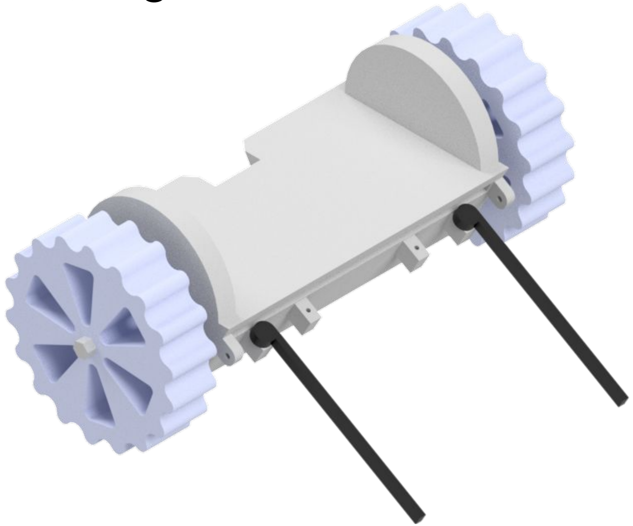
- PLA 3D printed body with TPU 3D printed wheels
- Axle: ⅜ inch aluminum hex shaft
- One support structure with one large hex shafts to connect the wheels and motors

Component placement:

- Legs attached via servo horn to two servo motors bolted to the back face of the rover
- Batteries fastened within slot/cavity in the bottom of the rover body
- Camera, arduino, sensors, and antenna bolted onto the top face
- One wheel on either side mounted onto the hex shaft running through the center

Structure

- Dual motor drive train for higher power
- Slot in bottom for mounting batteries and motors
- Retractable propping arms on back to ensure the body doesn't spin
- Wide base, large wheels for extra mobility in rough terrain



Materials
PLA (gyroid infill)
TPU (gyroid infill)
Aluminum

Properties
Length: 4.665 in
Width: 10 in
Height: 3.897 in

Material Selection

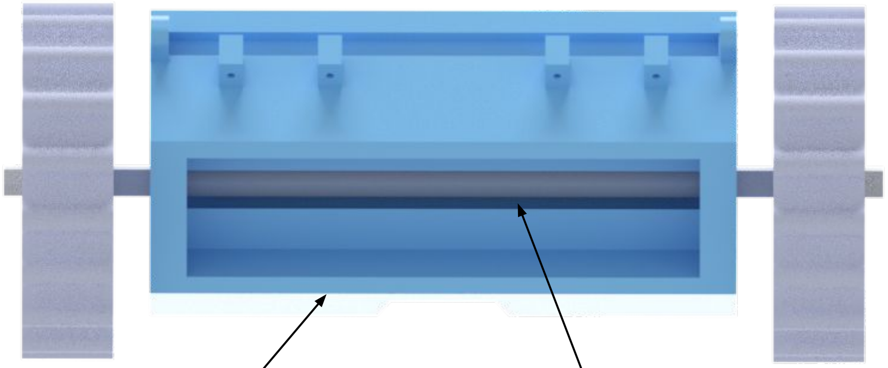
- Materials Utilized
  - Rover body: PLA 15% infill
  - Locomotion components:
    - Aluminum 6061 Hex Shaft
    - PLA Shock Absorption Caps
  - Soil sampling components:
    - PLA Scooper
    - PLA Scooper Deploy Arms
    - PLA Soil Sample Lid

PLA

Rover Locomotion

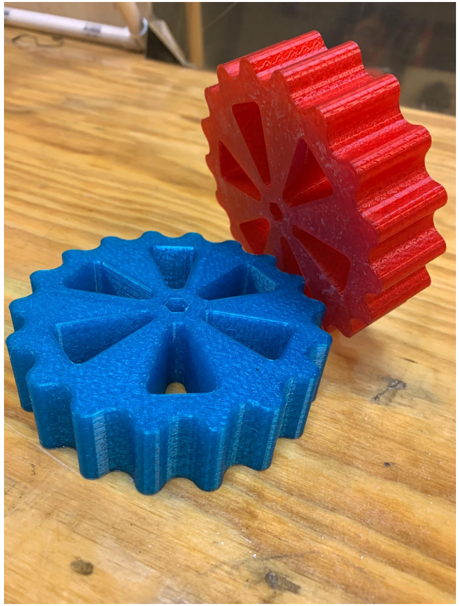
- The drivetrain consists of:
  - Custom wheels are mounted on a singular ⅜" hex shaft that runs through the center of the rover body
    - Belt driven by two continuous servos on either side
  - A cavity in the bottom of the rover body allows for access to the hex shaft and the battery mount

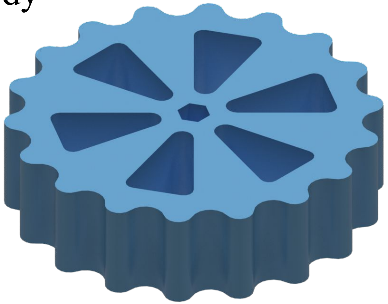
Bottom/Back View of Rover



Wheel Design

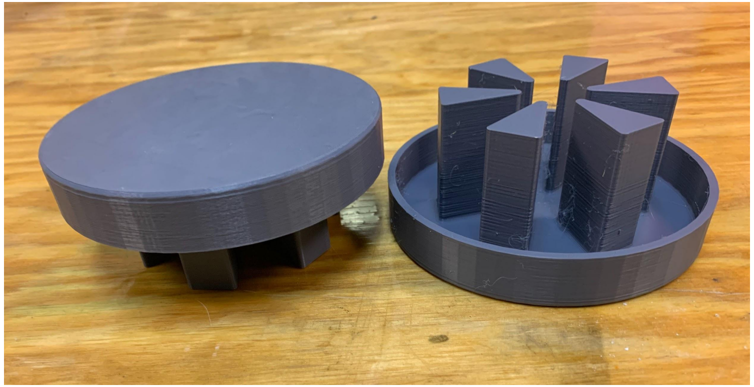
- Custom designed TPU wheels
  - Deforms to absorb impact energy and isolate more delicate electronics
  - Tread design for high traction
  - Strong enough to not deform under driving loads
- Design Parameters
  - Infill: 15%
  - Outer Diameter: 4.875”
  - Inner rubber “hub” for ⅜” hex shaft
  - Holes in sides, to direct thrust directly into the body
  - Unpoppable





Shock Absorption Caps

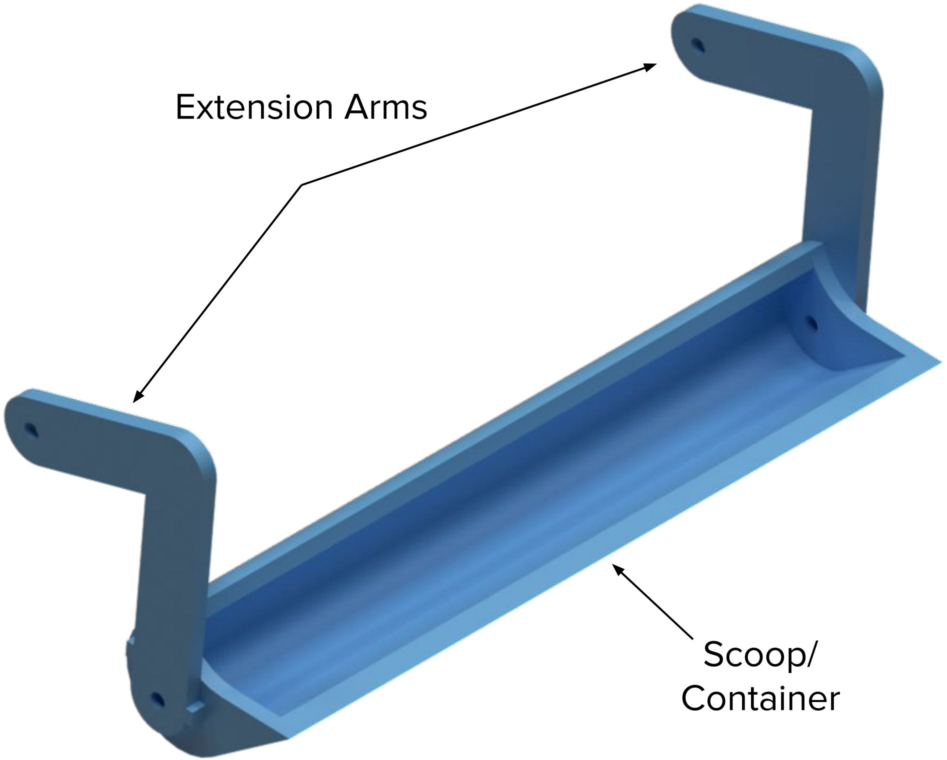
- 3D printed cylindrical wheel caps
  - Transfers the force of the ejection charge over a larger volume on the rover body
  - Reduces friction between wheels and the interior of the rocket body upon deployment
- Design Parameters
  - Infill: 15%
  - Outer Diameter: 5.25”
  - Fits over the hex shaft in order to avoid unnecessary stresses on the drivetrain
  - Extrusions interface with holes in the wheels in order to make direct contact with the side face of the rover



Soil Collection Mechanism

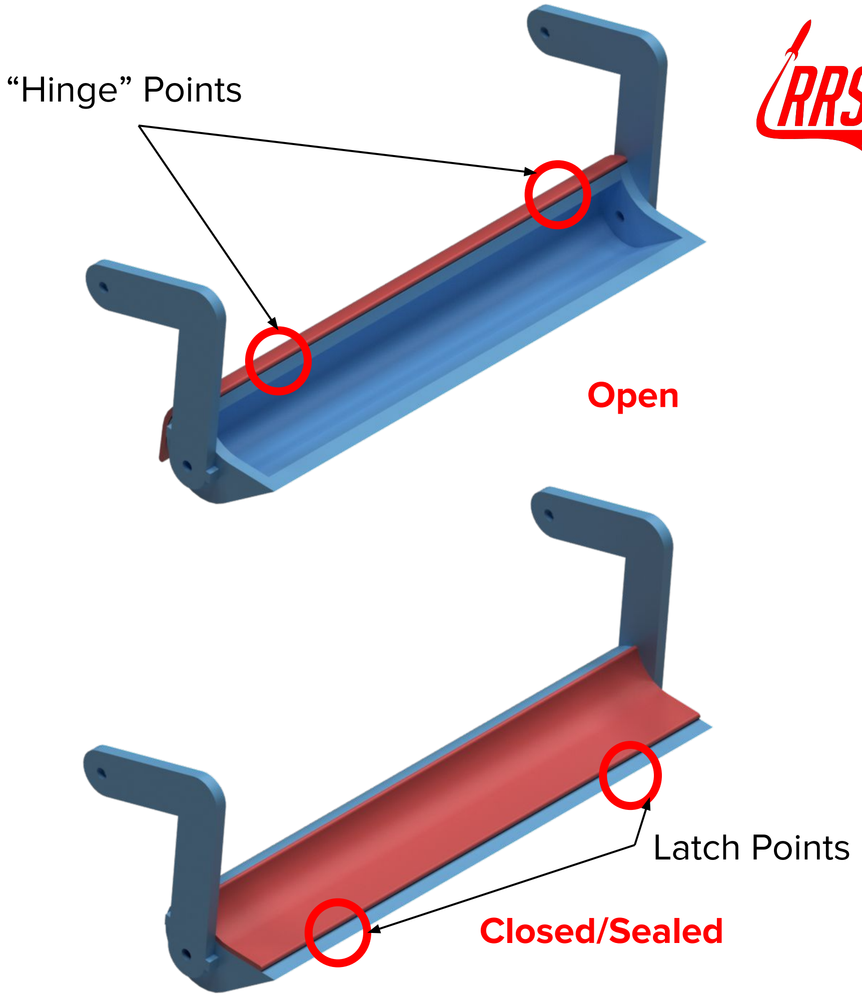
Soil Collection "Scooper"

- The soil collection is a passive, J-shaped scoop
- Spring loaded with rubber bands
- Deploy via nichrome wire melting the securing rubber bands
- The leading edge of the scoop directly leads into a partially enclosed cavity
- This scoop/cavity is itself the removable container



Soil Storage

- Free Moving Lid
  - PLA semicircular extrusion
  - Attached to top of scoop via wires/rubber bands at "hinge points"
  - Rubber bands hold it in place on back of scoop until soil is collected
  - Lid is flipped over top and latched with the same rubber bands to the other side



Rover Descent

Rover Descent Control

- Nichrome wire shorting will be used to deploy and release the parachute based on altimeter and gyroscope readings
- Rover descent rate: 17.07 ft/s

	Drogue Descent Velocity (ft/s)	Main Descent Velocity (ft/s)	Total Descent Time (sec)	Drift Distance (ft)
BOTR 2020 Rocket (Rover)	66.10825719	15.8990184	48.60216406	972.0432812
BOTR 2020 Rover	66.10825719	17.07336104	46.43906953	928.7813906
BOTR 2020 Nose Cone (Rover)	66.10825719	17.05841531	46.46472793	929.2945585

Calculated using Air Drag Formula

$$D = \frac{1}{2} C_d \rho v^2 A$$

Rover Mass

Rover Component	Material	Mass (g)	Uncertainty (g)
Rover Body	PLA (15% infill)	125.34 (spec)	+/- 0.3
Soil Scooper	PLA (15% infill)	5.71 (spec)	+/- 0.1
ATmega2560 microcontroller	-------------	34.90 (spec)	+/- 0.1
MPU6050	-------------	1.80 (spec)	+/- 0.1
Digi XBee 1mW Wire Antenna - Series 1	-------------	4.00 (spec)	+/- 0.1
7.2v 2200 mAh NiMH Battery Pack	-------------	226.80 (spec)	+/- 0.1
OV7670 300KP VGA Camera Module	-------------	9.07 (spec)	+/- 0.1
9v Alkaline Battery	-------------	45.33 (spec)	+/- 0.1

Rover Mass Count.

Rover Component	Material	Mass (g)	Uncertainty (g)
Scooper Lid	PLA (15% infill)	1.32 (spec)	+/- 0.1
Wheel x2	TPU (15% infill)	85.14 g [42.57 x2] (spec)	+/- 0.1
Mounting and Connecting	Nichrome wires, Electrical wires	50.00 (estimate)	+/- 0.1
Rover Locomotion - Hex Shaft	Aluminium	64.64 g (spec)	+/- 0.3
Shock Absorber Cap x2	PLA (15% infill)	70.10 g [35.05 x2] (spec)	+/- 0.1
Prop Arm x2	PLA (15% infill)	1.52 g [0.762 x2]	+/- 0.1
Soil Scooper Arm x2	PLA (15% infill)	1.37 [0.683 x2] (spec)	+/- 0.1
Servos x4 (Drive x2, Soil x2)	---------------	368.00 [92.00 x4] (spec)	+/- 0.1

Rover Mass Calculations

Example:

Rover Body = 41.121 in^3 = 673.852 cm^3

PLA Density = 1.24 g/cm^3

Rover Body Mass = 1.24 x 673.852 =
835.576 g

Infill = 15 %

True Rover Body Mass = 835.576 x 0.15 =
125.336 g

Total Rover Mass (g) = 1095 g => 1.095 kg

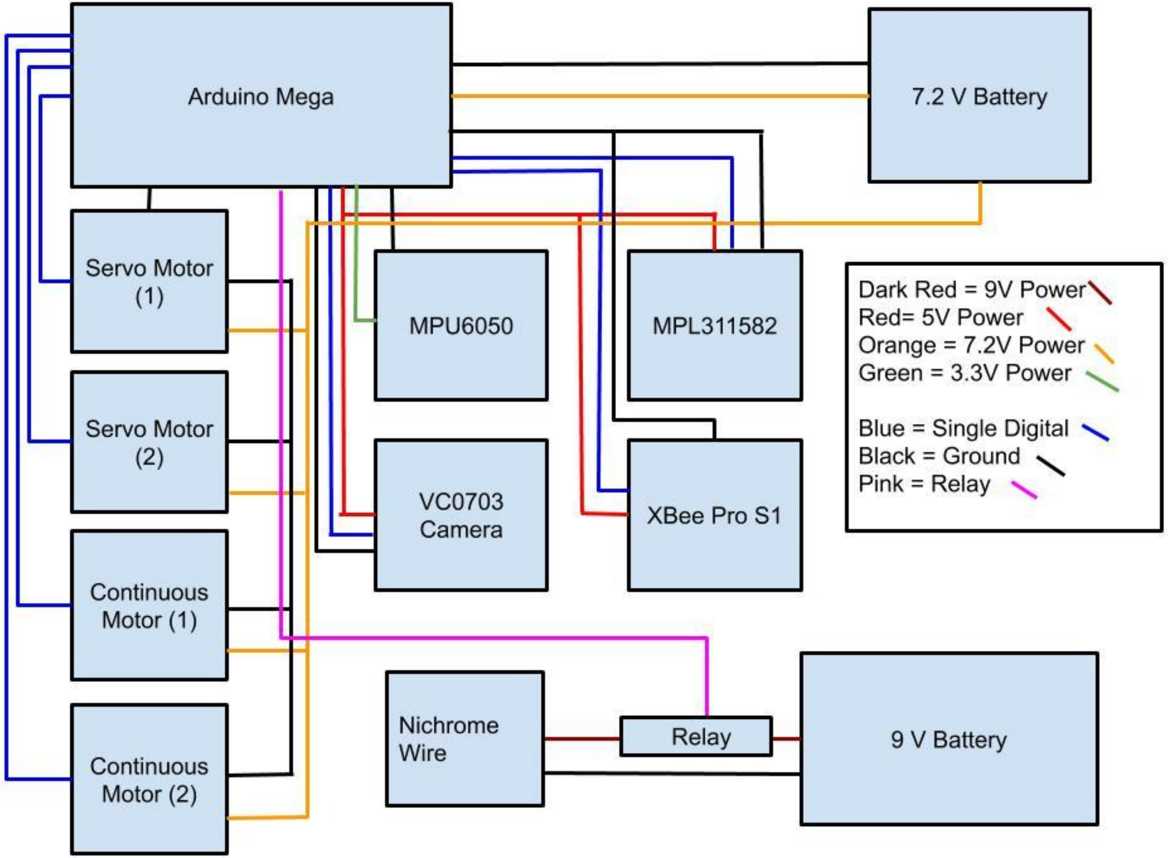
Margin = 102.8 g (8.58 %)

Uncertainty = 100 g

- Mounting and Connecting usage
- Soldering, Epoxy, Screws

Rover Electronics

Wiring Diagram



Rover Control Module

Choice:

Arduino Mega 2560

Specifications

- ATmega2560 microcontroller
- Flash Memory: 256 KB
- 5V Operating Voltage
- 37g weight
- 16 MHz clocking speed
- Boot time: 8 - 10 seconds
- Compact, light, and powerful

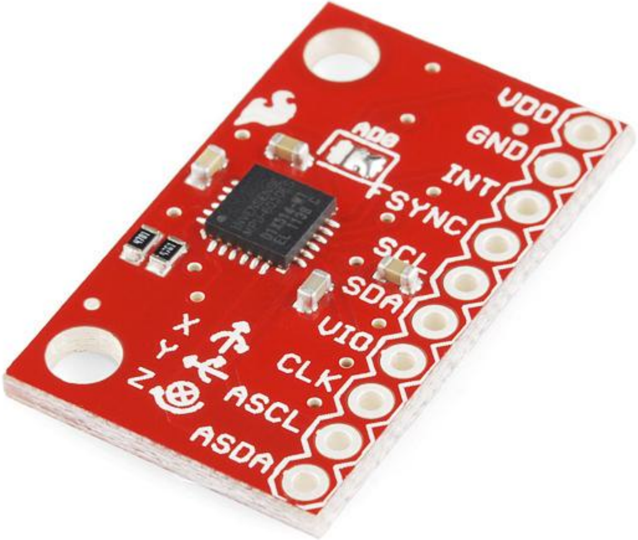
Sensors - Accelerometer

<u>Choice:</u>

Sparkfun MPU6050 (Accel + Gyro)

<u>Specifications</u>

- Arduino communication via I^2C
- Tri-Axis gyro with a full scale range of ±500 dps
- Tri-Axis accelerometer with a programmable full scale range of ±2, ±4, ±8, ±16, g
- Digital thermometer



Sensors - Altimeter

<u>Choice:</u>

Sparkfun MPL3115A2 (Barometer)

<u>Specifications</u>

- Arduino communication via I^2C
- Resolution down to 1 foot
- 32 sample FIFO

Sensors - Camera

<u>Choice:</u>

DigiKey UCAM-III Serial Camera Module

<u>Specifications</u>

- Arduino serial communication
- Takes compressed 640x480 JPEG pictures
- 56 degree lens with adjustable focus
- 3.68Mbps TTL data transfer rate

Rover Power

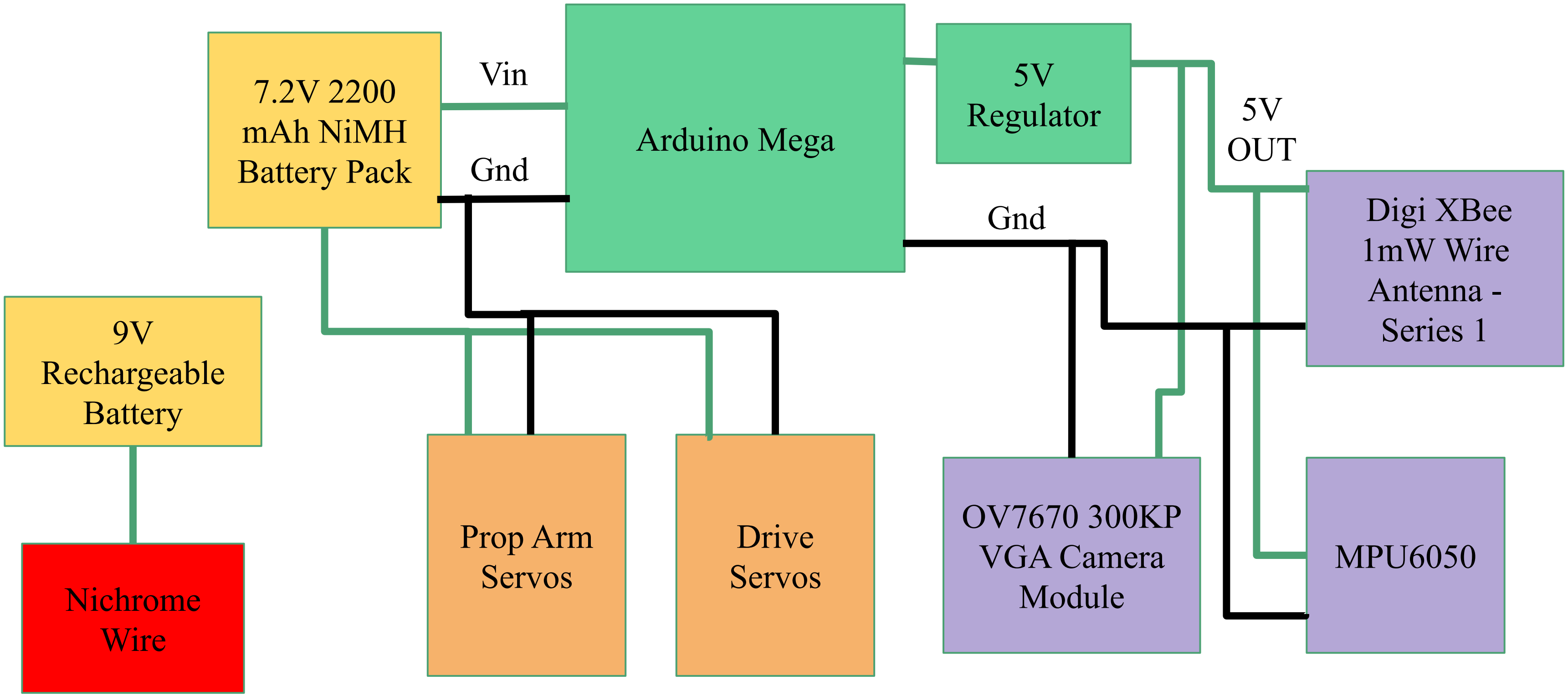
<u>Choices:</u>

7.2V 2200 mAh NiMH battery pack
9V Alkaline battery

<u>Specifications</u>

- More durable/reliable than other options(eg. solar panels)
- Ability to place cell anywhere on rover body
- Mounted in plastic recession in bottom of rover
- Incorporated fuse in case of short circuit

Power Distribution Diagram



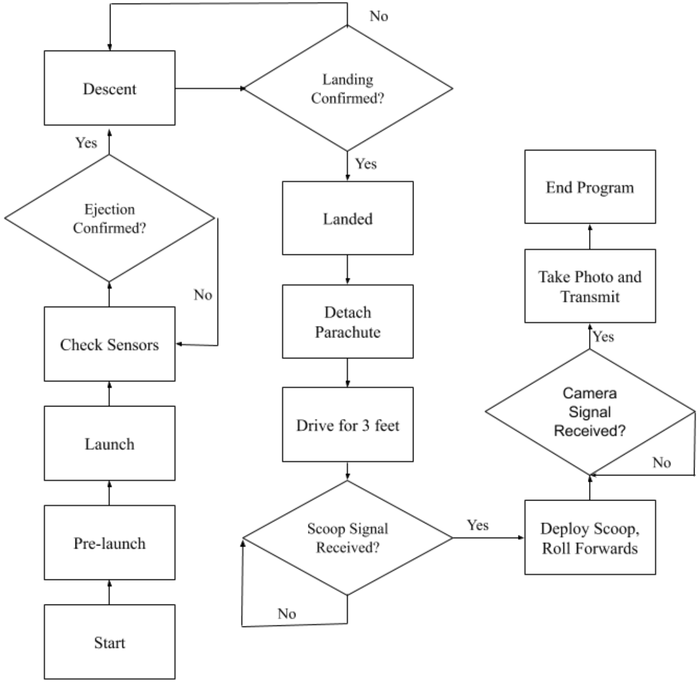
Power Budget

NiMH Battery:

Batteries	Capacity (WH)			
7.2 V Battery	15.84			
Power Consumers:	Current (mA)	Quantity	Voltage	Power draw (W)
Arduino Mega	0.2	1	7.2	1.44
Positional Servos	0.018	2	7.2	0.2592
Continuous Servos	0.02	2	7.2	0.288
XBee	0.045	1	5	0.225
Camera	0.45	1	5	2.25
Accelerometer	0.004	1	5	0.02
				4.4822
			Expected functional time (Hours):	3.53397885

Rover Software Design

- Software environment: Arduino C
- IDE: Arduino Development Environment



Software Development Plan

- Modular development using object oriented design
  - Classes are forward defined in separate files
  - Forward declaration allows us to set expected functionality of these objects while being able to experiment with different implementations
- Github is used for code collaboration
  - With separate files, programmers can simultaneously work on the code base
- Arduino Development Environment for integrated libraries and hardware flashing
- Unit testing of individual modules

Rover Payload Integration

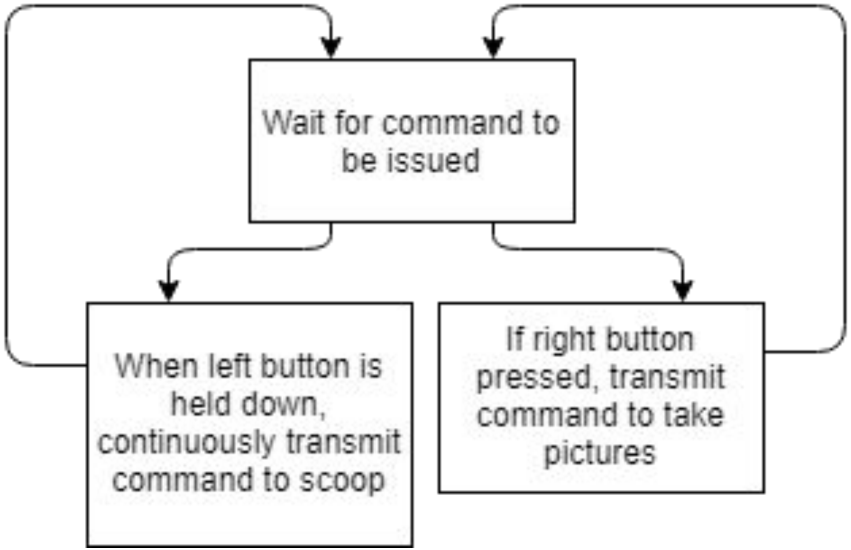
- Charges will be fired with e-matches
- Shear pins rated at 50 lbs of strength are used to secure the nose cone to the body tube. When the charges are fired, the shear pins will break allowing for the payload to be pushed out of the rocket.
- In the order it is placed within the rocket
  - Electronics bay with ejection charges
  - Main Body parachute (60”)
  - Rover (with 44” parachute)
  - Nose Cone parachute (24”)
  - Nose cone secured with shear pins

Hand Controllers

- **Arduino Based Custom Controller**
  - Commercial
  - Radio Type: XBEE
  - User Interface: Buttons
  - Accommodations for a gloved hand: Buttons are easy to press

Hand Controller Software

- Software environment: C++
- IDE: Sketch



Logistics

Flight Operations

Rover Prep:

- Fold prop arms and soil scoop into positions
- Check for loose electrical connections
- Turn rover on
- Slide rover into rover bay

Rocket Prep

- Fold and protect parachutes
- Insert drogue parachute
- Assemble avionics bay and main body
- Attach electronics bay (to booster w/ shear pins, to payload w/ 8-32 machine screws)
- Ejection charge prep
- Build motor (per instructions - set ejection charge to TTA + 2 seconds)
- Install motor, motor retention (NOT igniter)
- Insert Main body parachute and rover
- Insert nose cone parachute
- Attach nose cone w/ shear pins

Flight Operations

Launch:

- RSO check-in
- Upright on the pad
- Powerup electronics
- Install igniter
- Retreat to safe distance, continuity check
- Verify rover is operational
- Launch

Recovery and Safing:

- Power off all altimeters and rover components
- Check to make sure ejection charges have fired
- Field pack parachutes, return to prep area
- Clean motor casing
- Check rocket for damage

Program Budget

Rover Component	Cost
Chassis	$19.36
Servos	$111.60
Electrical components	$32.90
Total	**$271.85**

Rover Component	Cost
Wheels and axle	$7.99
Camera	$100

Rocket Component	Cost
Airframe Tubing	$158.69
Couplers	$10.81
Quick links	$9
Motors	$437.94
Electrical Connectors	$16.18
Total	**$632.62**

- No additional service costs
- Travel expenses: $900
- Total: $1,804.47