Flight Readiness Review (FRR)

UNIVERSITY OF NORTH DAKOTA
FROZEN FURY ROCKETRY TEAM

NASA SLI 2018

Presentation Outline

Launch Vehicle

Recovery

Full-Scale Flight Results

Payload

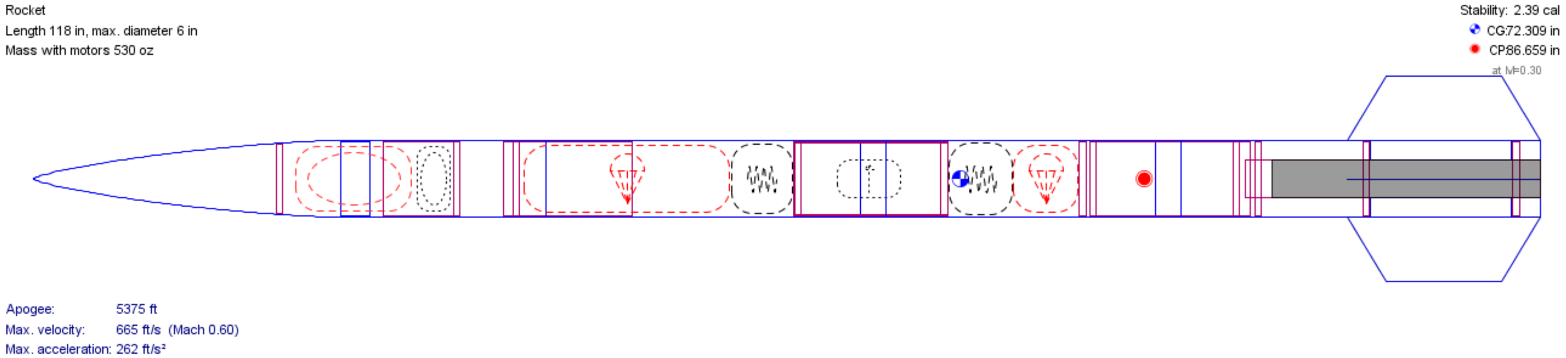
Safety

Educational Outreach

Launch Vehicle Design

The 2018 Launch Vehicle is comprised of 5 main sections

- Fin Can: Motor housing and stabilizing airframe
  - 4 fiberglass fins
  - AeroTech L1150R
- Avionics Bay: Data logger and camera housing
  - Student-designed Datalogger
  - Fredi WiFi camera
- Parachute Chambers: Stores recovery system
  - 24” Drogue
  - 120” Main
- Altimeter Bay: Altimeter and back-up altimeter housing
  - PerfectFlite SL100
- Payload Bay: Houses rover payload and Rover-Deployment System (RDS)

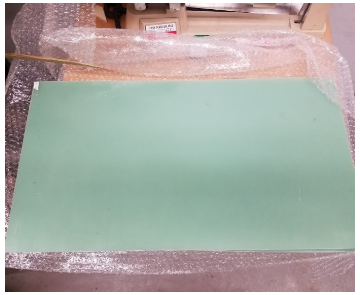


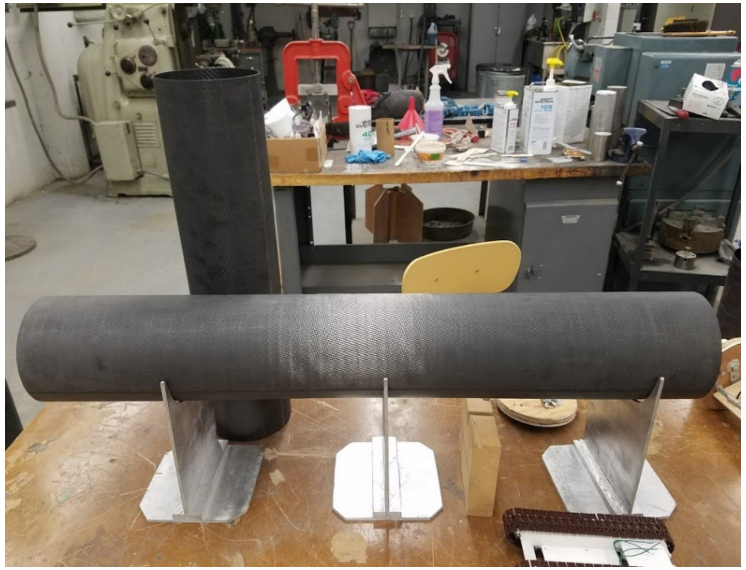
Launch Vehicle Dimensions

Mass of Launch Vehicle (Unloaded)	25.13 lbs.
Mass of Launch Vehicle (Loaded)	33.13 lbs.
Length of Launch Vehicle	118 in.
Diameter of Launch Vehicle	6 in.
Center of Pressure (CP)	86.65 in. from tip nose cone
Center of Gravity (CG)	72.30 in. from tip nose cone
Stability Margin	2.39
Apogee	5,375 ft
Max. Velocity	665 ft/s
Max. Acceleration	262 ft/s^2
Time to Apogee	18.4 seconds (s)
Altitude of Deployment of Drogue	5,375 ft. (Apogee)
Altitude of Deployment of Main Parachute	750 ft.
Ground Impact Velocity	17.6 ft/s

Airframe

- Body is made of rolled carbon fiber tubing
  - 6 inch diameter
  - 0.056 inch thick walls
- Fins are cut from G-10/FR4 fiber glass
  - 0.1 inch thick sheet
  - Tensile strength of 40,000PSI
  - Compressive strength of 35,000 PSI edgewise
- Both materials survived high impact test of 1.87 kJ (1378 ft-lbs) of impact energy with minor cosmetic damage.



Bulkhead

- All bulkheads are constructed out of half inch plywood
- Used to separate parachute chambers from other sections of the launch vehicle
- Must be able to withstand impulse of black powder charges
- Tested during charge tests of parachute chambers

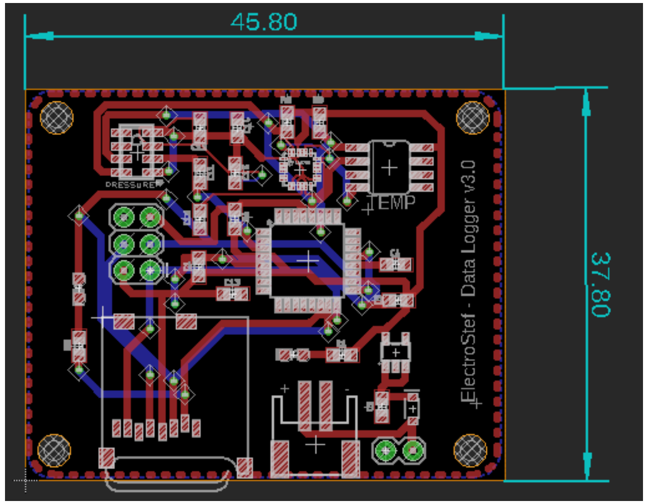
Flight Electronics

Avionics Bay

- Data logger: Designed by students and records temperature inside the housing, acceleration, magnetic heading, and angular frequency in degrees per second
- Camera: pinhole style surveillance camera used to record flight

Altimeter Bay

- Altimeter: PerfectFlite SL100 Stratologger monitors and records altitude and initiates the parachute charges



Motor Selection

AeroTech L1150

Average Thrust: 1150 N

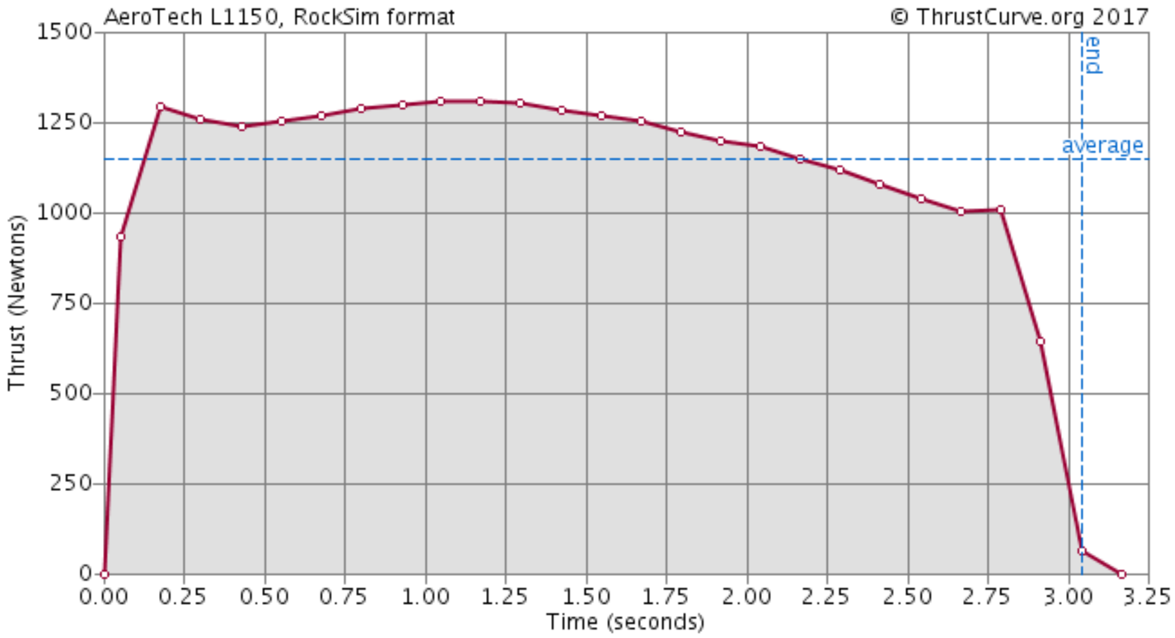
Max Thrust: 1346 N

Total Impulse: 3517 Ns

Burn Time: 3.1 s

Total Weight: 3674 g (8.10 lbs)

Prop. Weight: 1902 g (4.19 lbs)

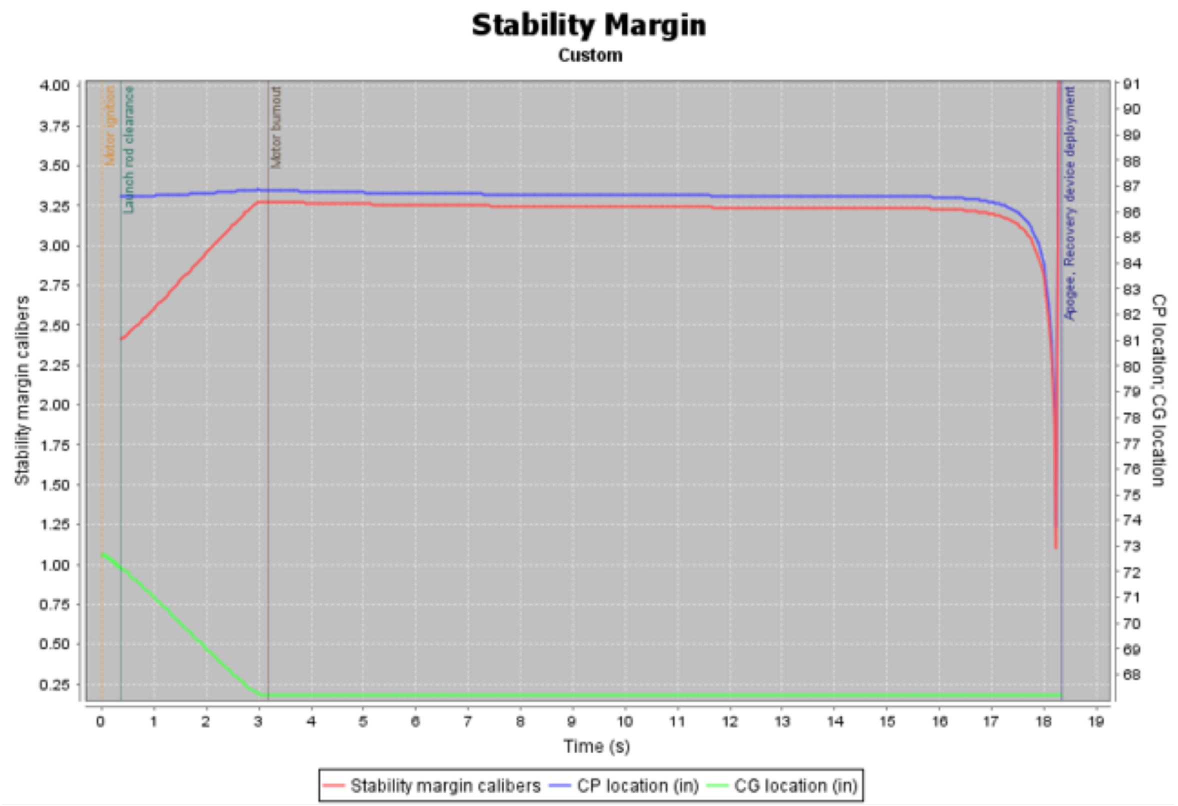


Stability Margin

- Stability margin: 2.49
- CP at rail exit: 3.3”
- CG at rail exit: 1”
- Thrust to weight ratio:

$$\frac{258.53\ lbs}{33.06\ lbs} = 7.82$$

- Exit Rail Velocity: 78.1 ft/s



Drift Predictions

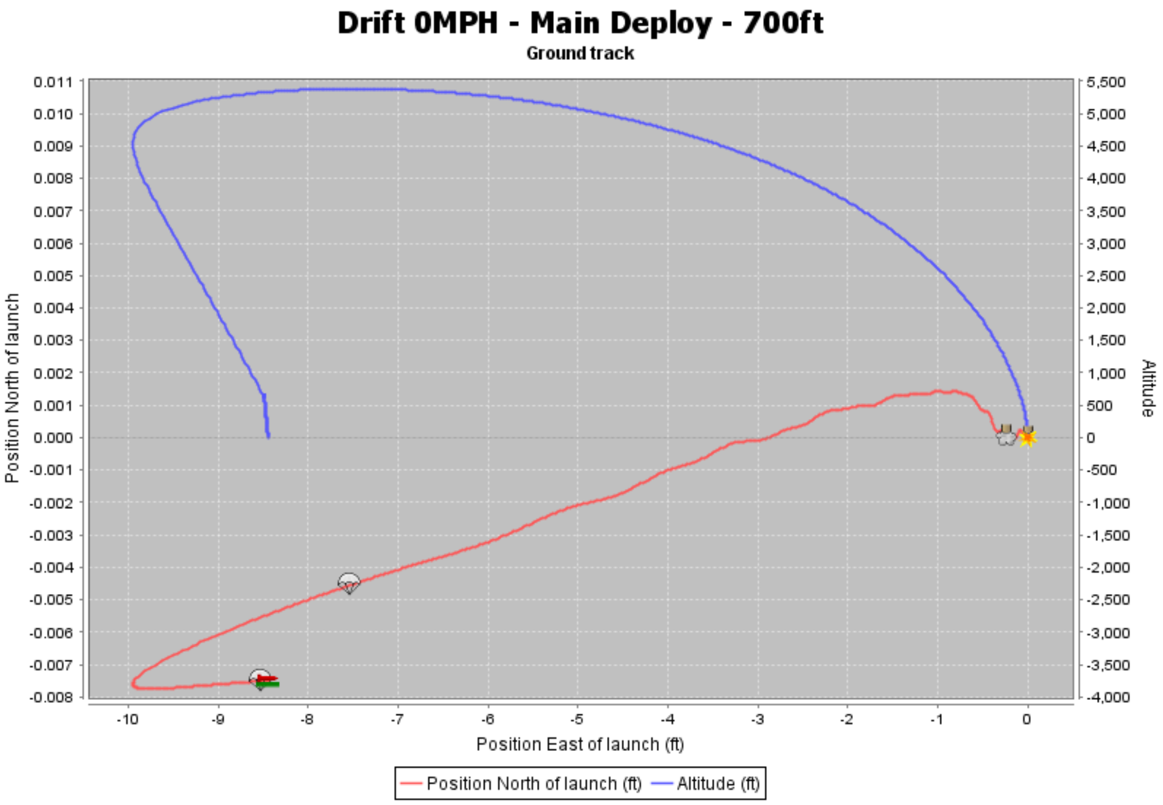
$$Descent\ Time * Wind\ Speed = Drift$$

Wind Speed (miles per hour)	Excel Calculations (ft)	OpenRocket Calculations (ft)
0	0	8.5
5	598.86	500
10	1198.54	1100
15	1797.40	1700
20	2396.261	2450

Two different calculations were conducted, one by hand using the given equation;
One automatically calculated by OpenRocket simulations

Discounting the no-wind calculation there is an average discrepancy of 88 feet between the simulations and hand calculations

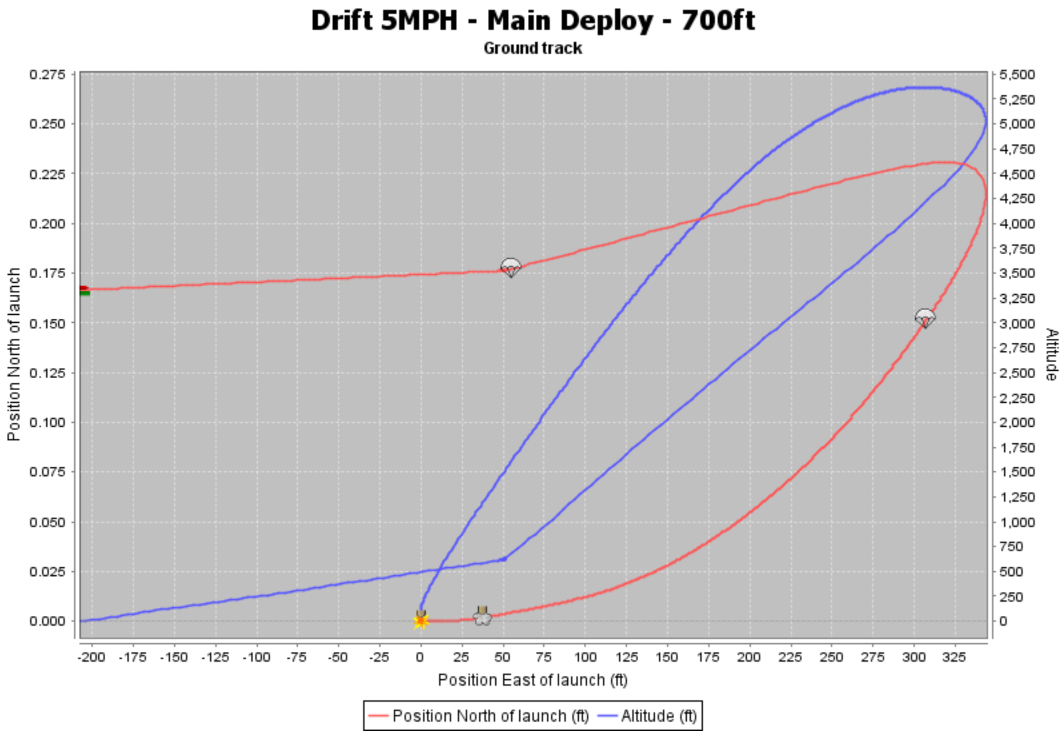
Simulation (0 mph)



- Apogee: 5375 feet

- Distance from launch (sim): 8'
- Distance from launch (hand): 0’
- Discrepancy: 8’

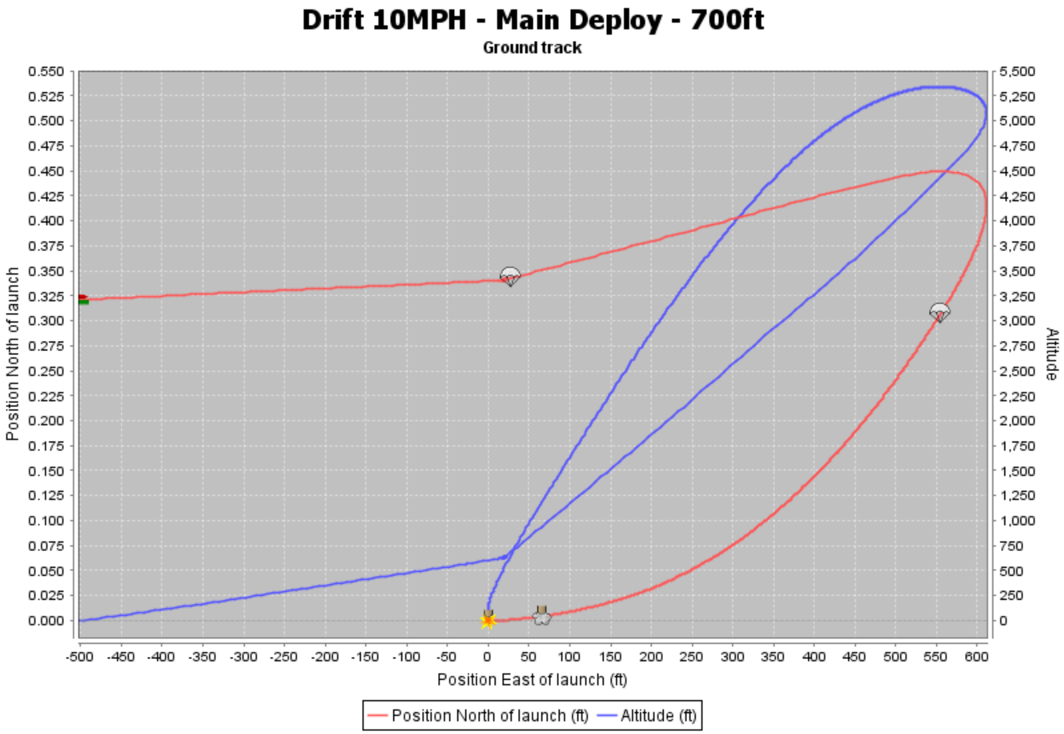
Simulation (5 mph)



- Apogee: 5375 feet

- Distance from launch (sim): 500'
- Distance from launch (hand): 599’
- Discrepancy: 99’

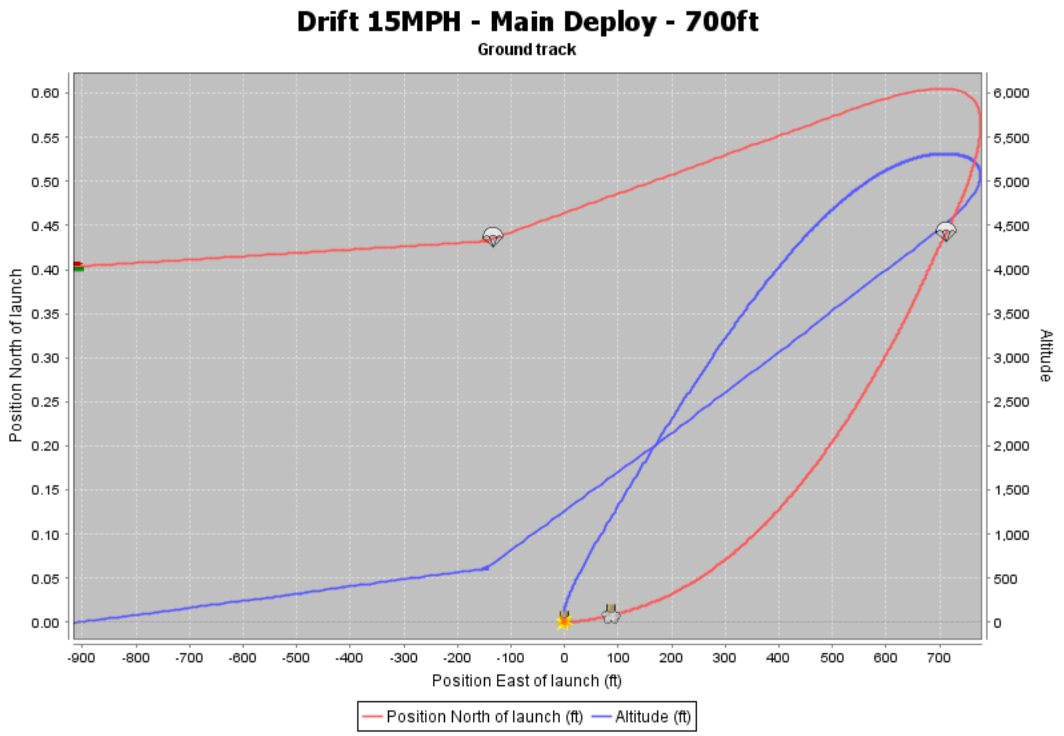
Simulation (10 mph)



- Apogee: 5375 feet

- Distance from launch (sim): 1100'
- Distance from launch (hand): 1199’
- Discrepancy: 99’

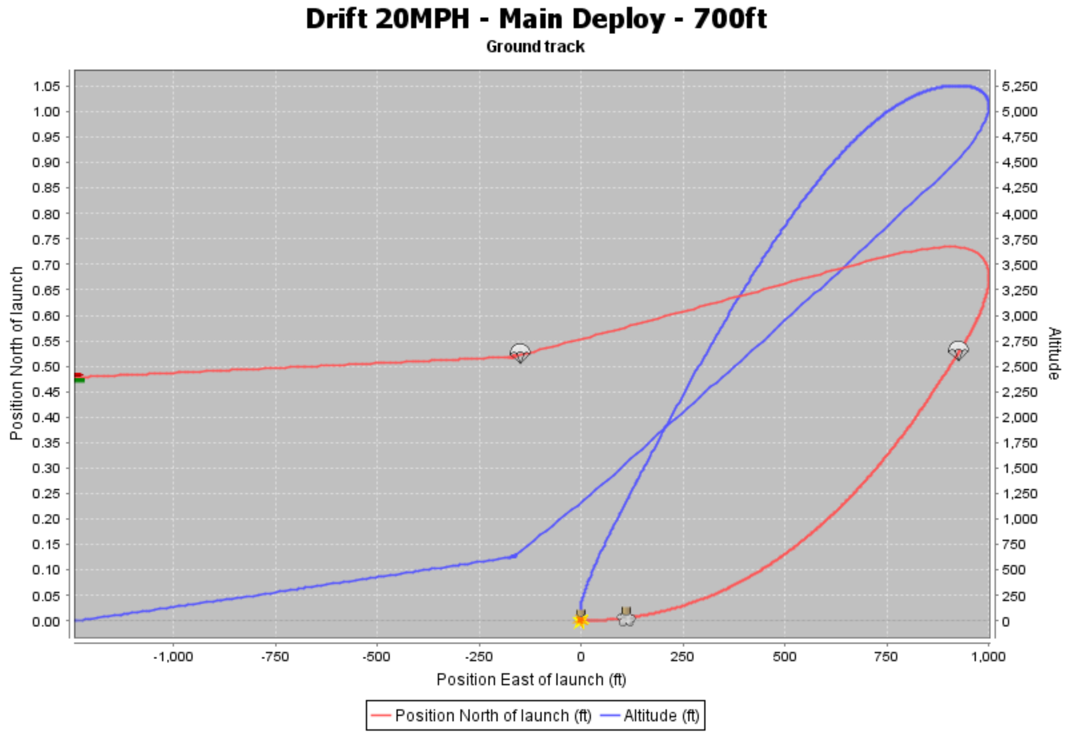
Simulation (15 mph)



- Apogee: 5375 feet

- Distance from launch (sim): 1700'
- Distance from launch (hand): 1797’
- Discrepancy: 97’

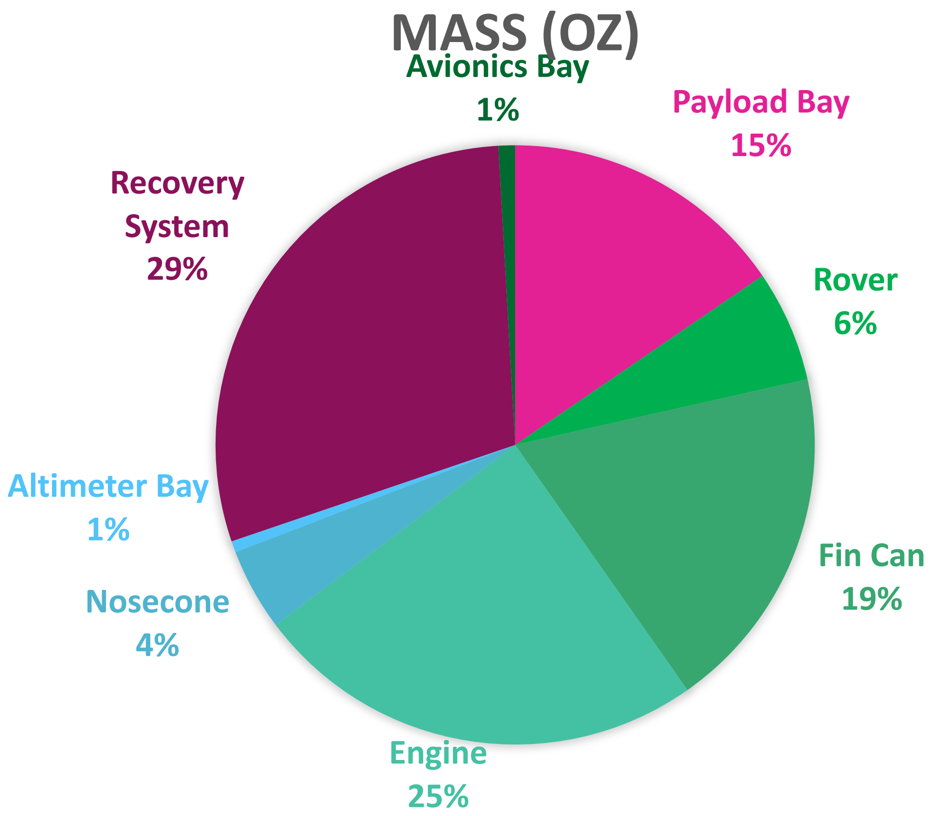
Simulation (20 mph)



- Apogee: 5375 feet

- Distance from launch (sim): 2450'
- Distance from launch (hand): 2396’
- Discrepancy: 54’

Mass Margin



Section	Mass (oz)
Payload Bay	82
Rover	32
Fin Can	99.6
Engine	130
Nosecone	23.5
Altimeter Bay	3.25
Recovery System	155.6
Avionics Bay	4.76

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Launch Vehicle

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Recovery Overview

Dual deployment
- 24-inch drogue parachute
- 120-inch main parachute

Drogue
- Deploys at apogee

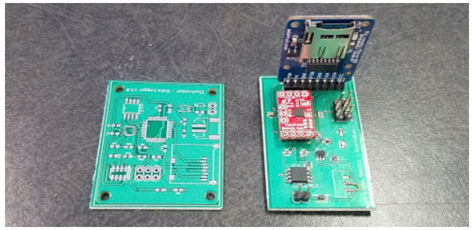
Main
- Deploys at 700 feet

Connection
- Shock cord uses 1-inch thick tubular nylon
- 144 inches total length
- Main stored in deployment bag
- Drogue uses circular parachute protector
- Shock cord connected to U-bolts affixed to bulkheads

Flight Computer Redundancy

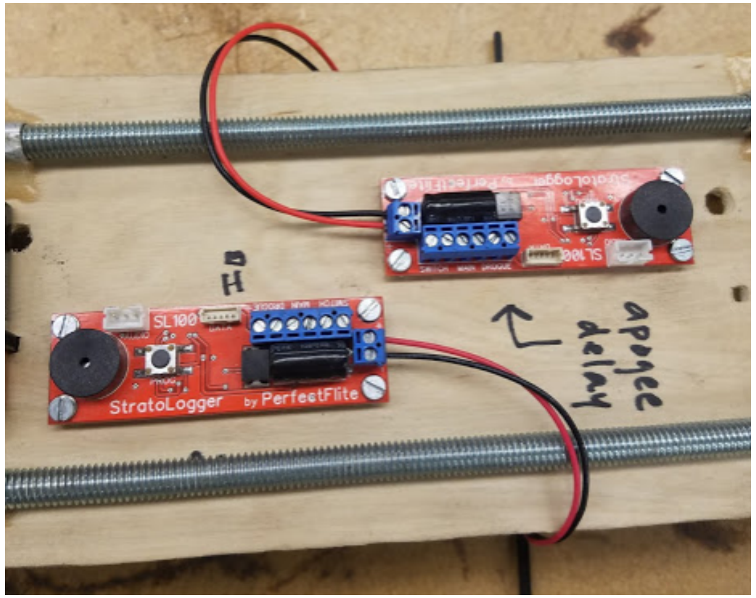
Two PerfectFlite SL100s are used in the altimeter bay

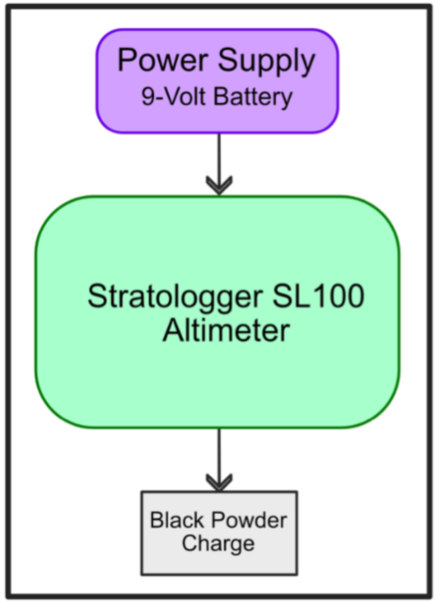
- Primary StratoLogger
- Secondary StratoLogger



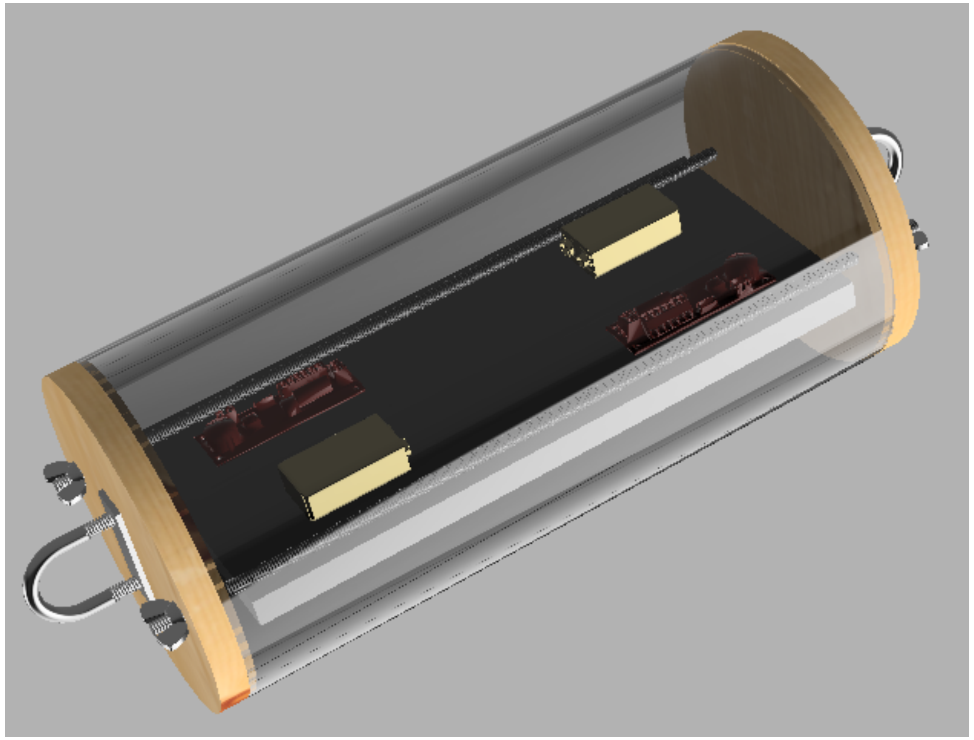
Datalogger in avionics bay

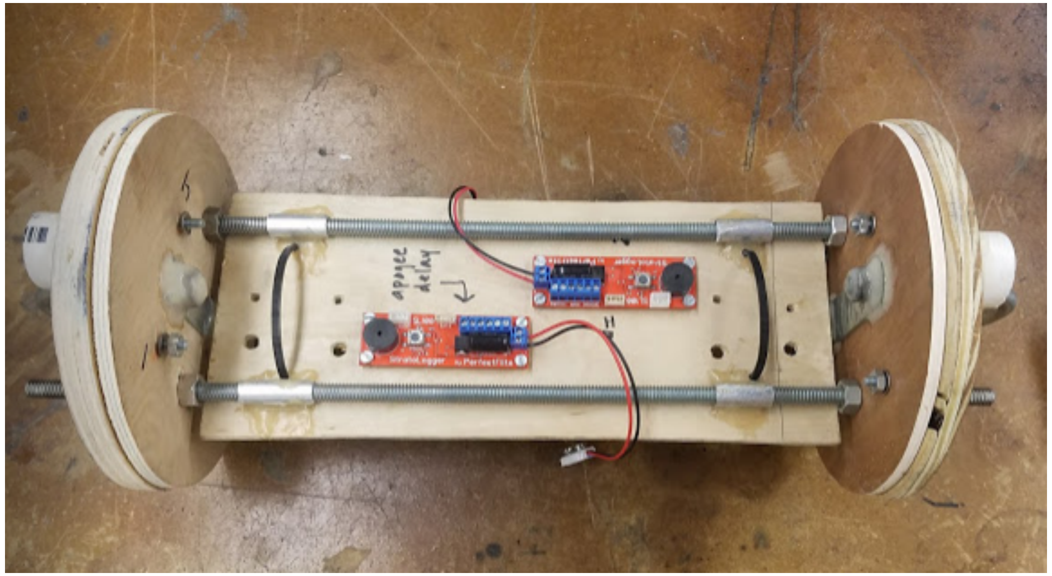
- Collects acceleration data
- Collects barometric altitude data
- Cross references StratoLogger data





Final Recovery Bay Configurations





Recovery Specification

Section	Mass (oz)	Mass (kg)	Velocity (m/s)	K.E. (Joules)	K.E. (ft-lbs)
Fore	227.4	6.45	5.24	88.59	**65.34**
Altimeter Bay	3.25	0.09	5.24	1.27	**0.93**
Aft	226.26	6.41	5.24	88.15	**65.01**

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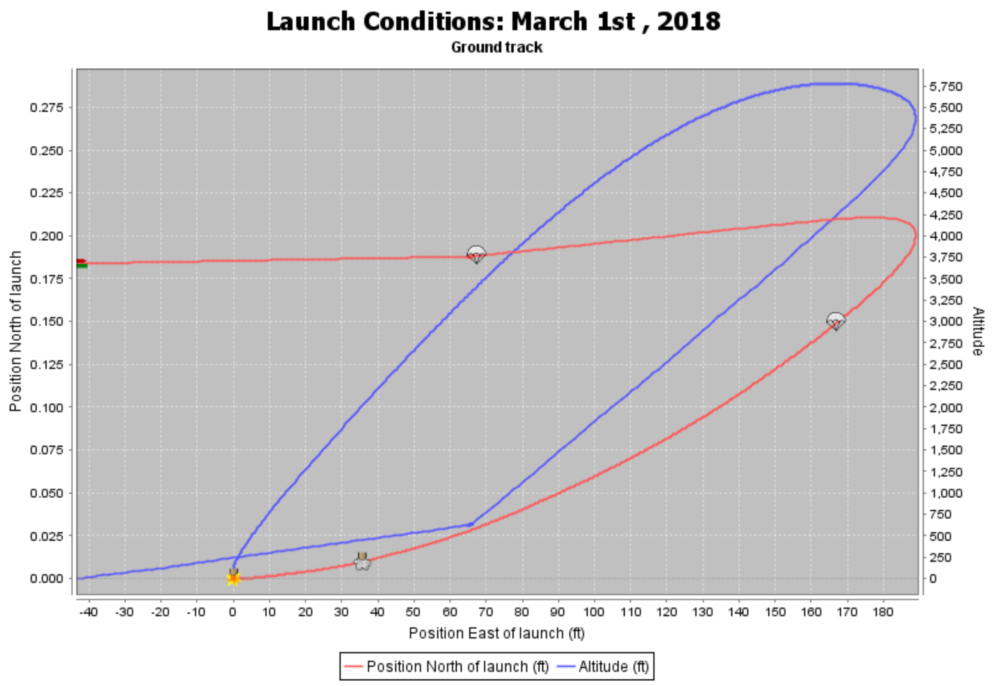
Full-Scale Test Flight

Test Launch used AeroTech L850W

- Simulated apogee 5777’

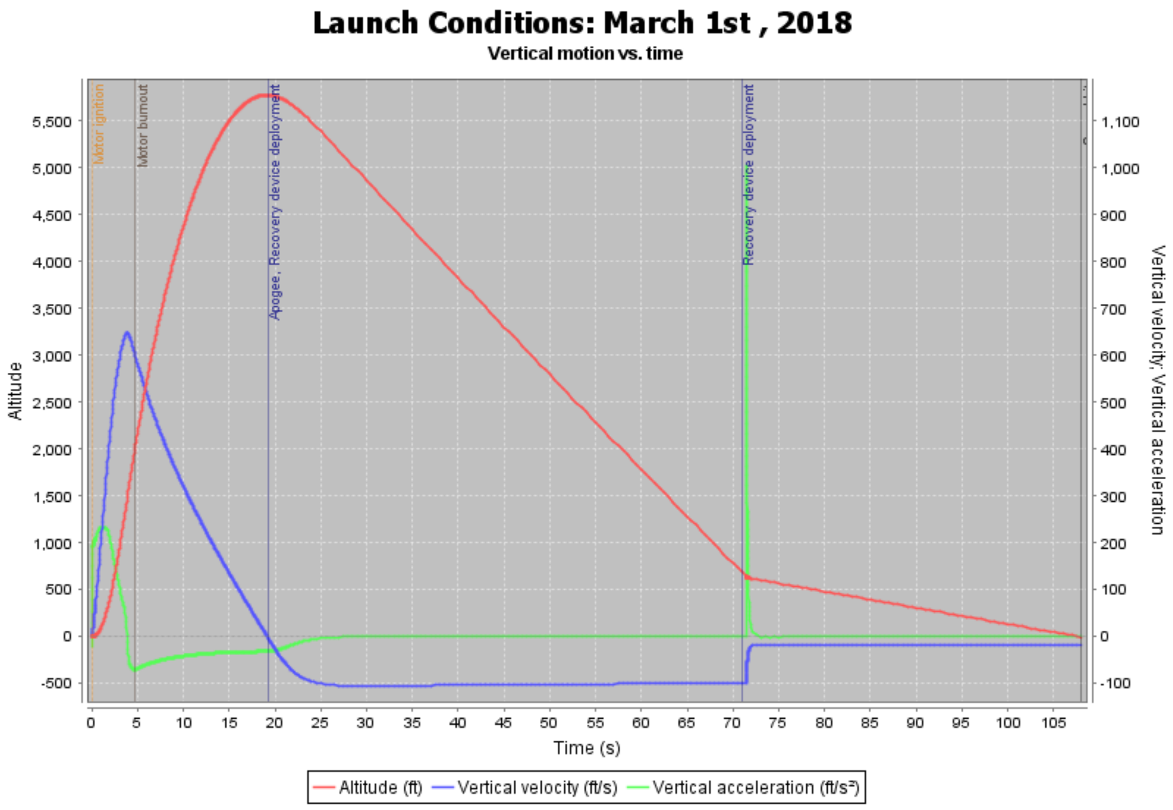
Differences between L850 and L1150

- 787 N vs 1100 N (average thrust)
- 4.7 sec vs 3.2 sec (thrust time)
- 3695 Ns vs 3489 Ns (total impulse)
- 3673 grams for both (total weight)

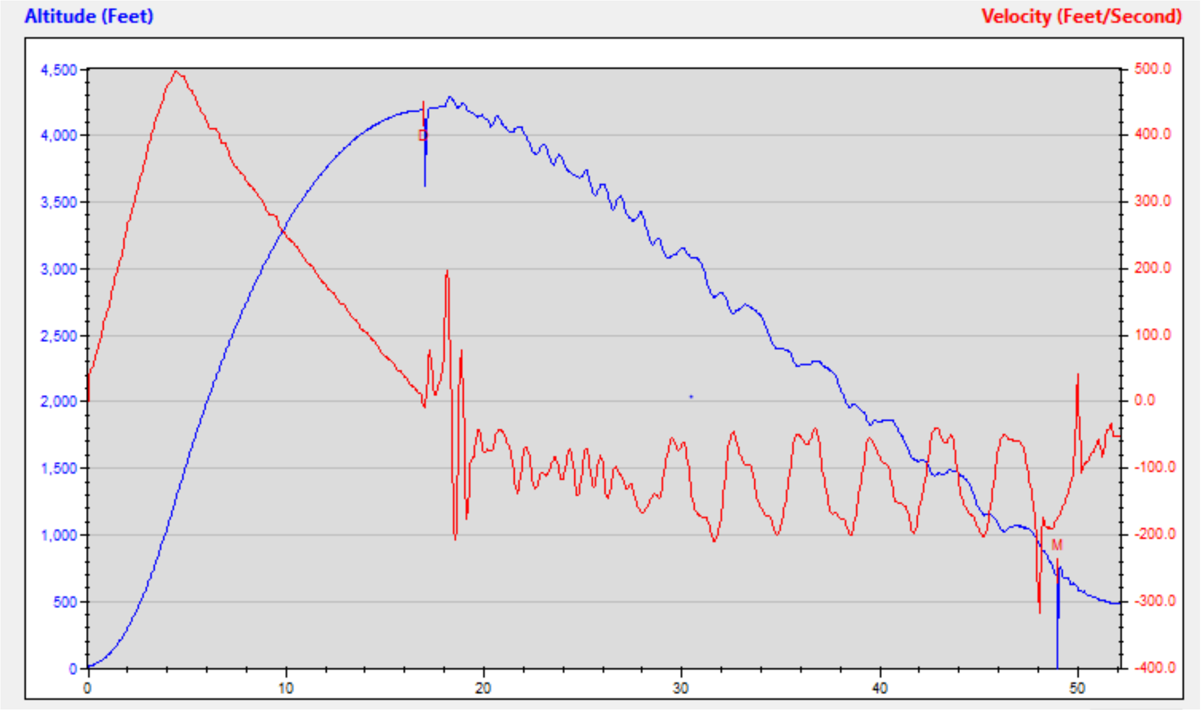


Simulated wind conditions of launch day

Full-Scale Test Flight



Simulated launch



Actual launch data

Full-Scale Test Flight Results

Failed Launch

- Carabiner attaching drogue airframe to altimeter failed to be attached
- Fore section and altimeter bay landed with main parachute
- Aft section impacted ground under the influence of only the drogue parachute
- Drogue-only simulation predicted a descent velocity of 68.9 ft/s
- Calculated impact kinetic energy of 1378 ft-lbs.

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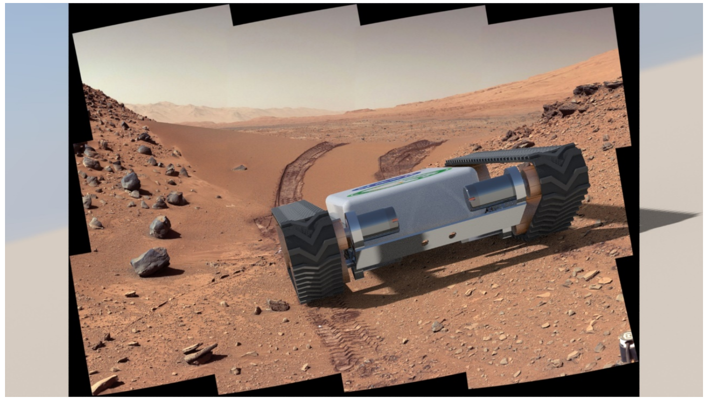
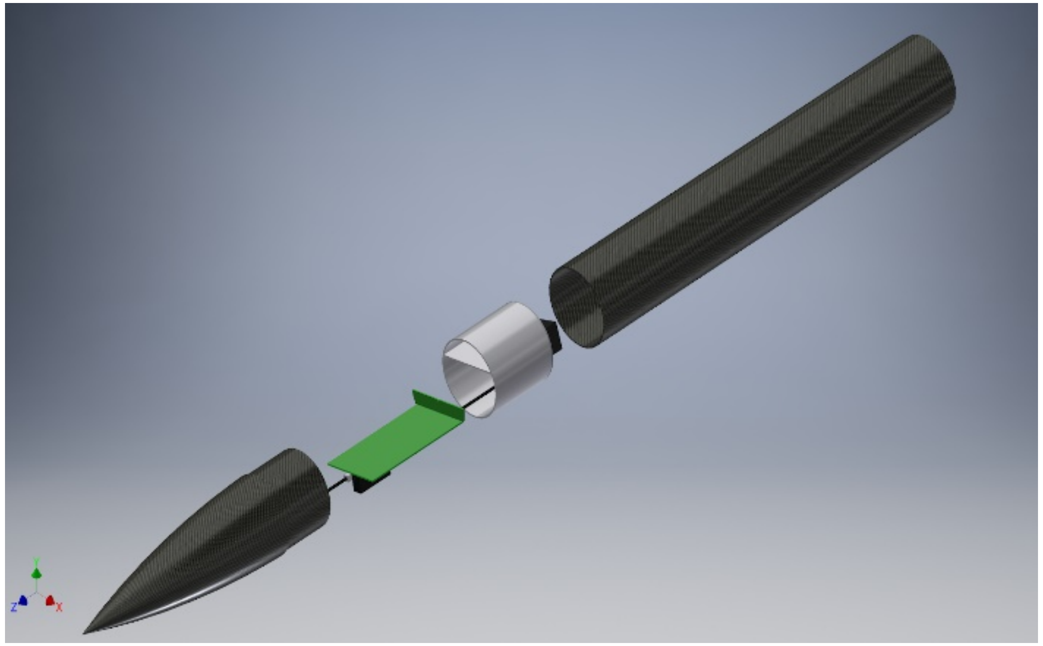
Payload Design Overview

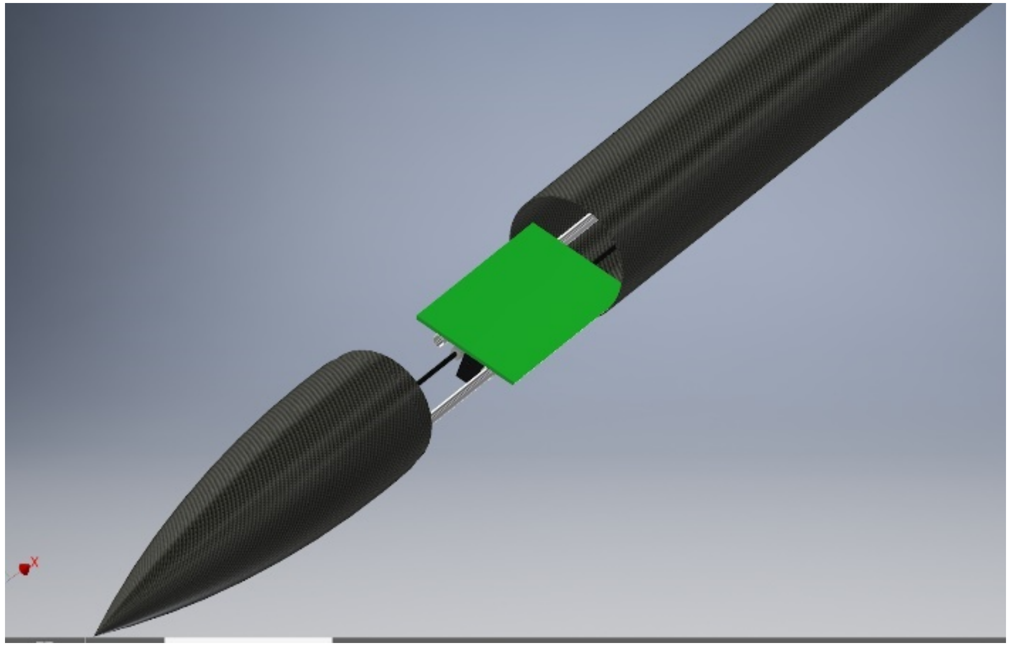
"Rover Deployment System" refers to all the subassemblies and subsystems of the entire experimental payload on the launch vehicle

"The rover" refers to only the subsystems/subassemblies onboard the autonomous rover



Rover Deployment System (RDS)

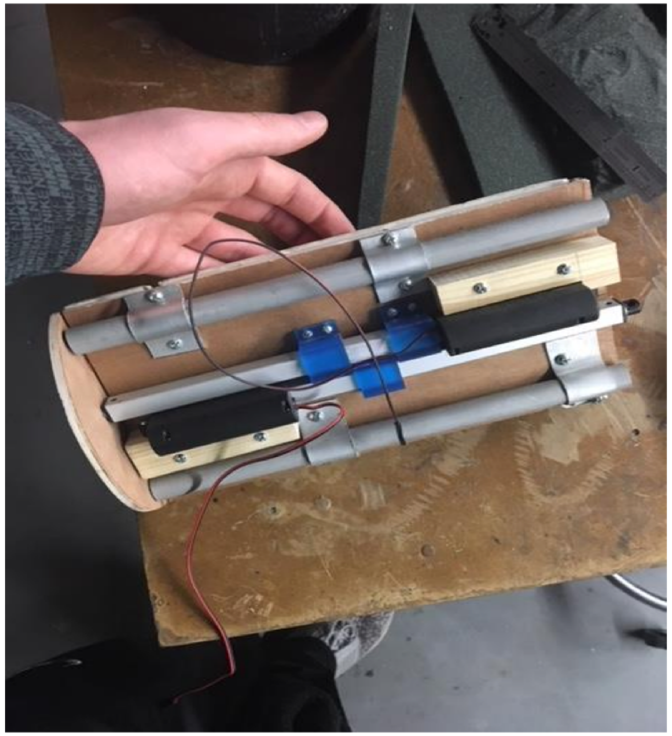


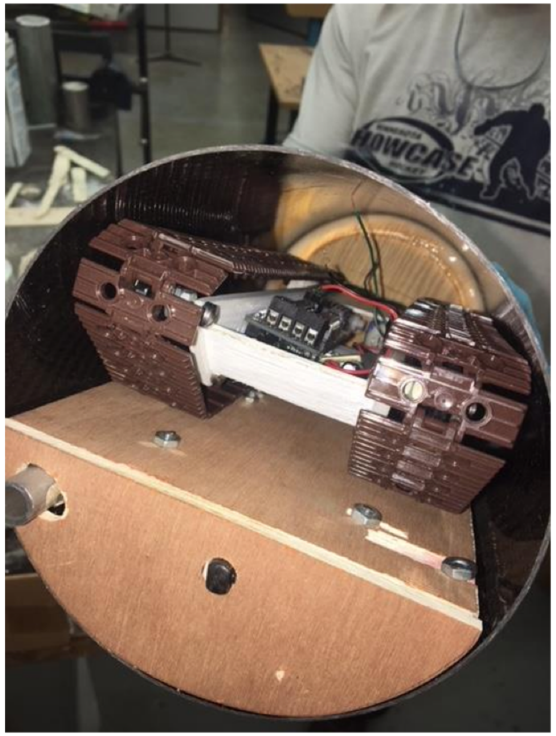


CAD Model of Rover Deployment System

RDS Continued

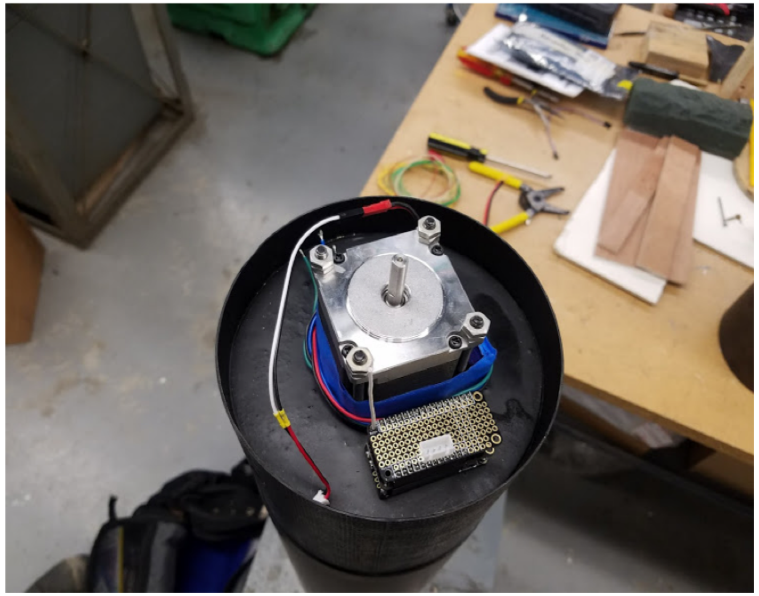
- The rover plate is made from of 3/16” plywood.
- Inside each pipe is another pipe, both of these pipes are made from aircraft aluminum.
- Linear actuator push on bulkheads and separate nose cone and airframe to expose rover plate.





RDS Continued

- Stepper motor is rotates coupler to correct orientation
- Stepper motor is part of the main parachute chamber
- Stepper motor attaches to bracket on coupler in order to rotate it



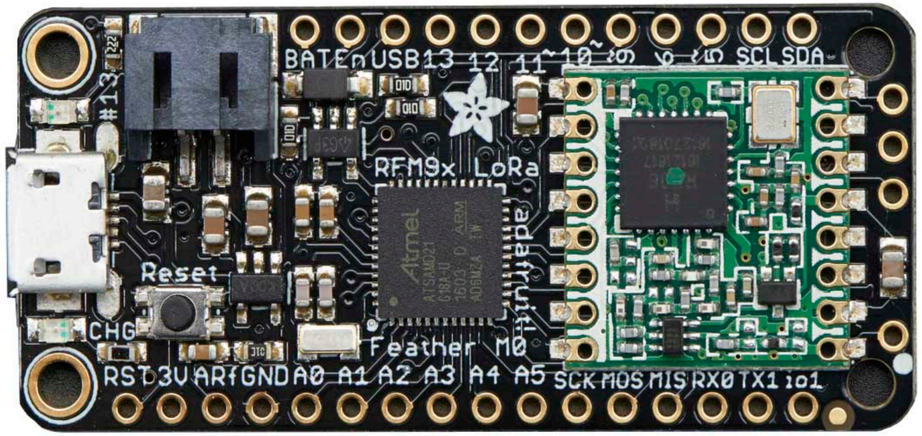
RDS – Radio Communications/Motor Controller

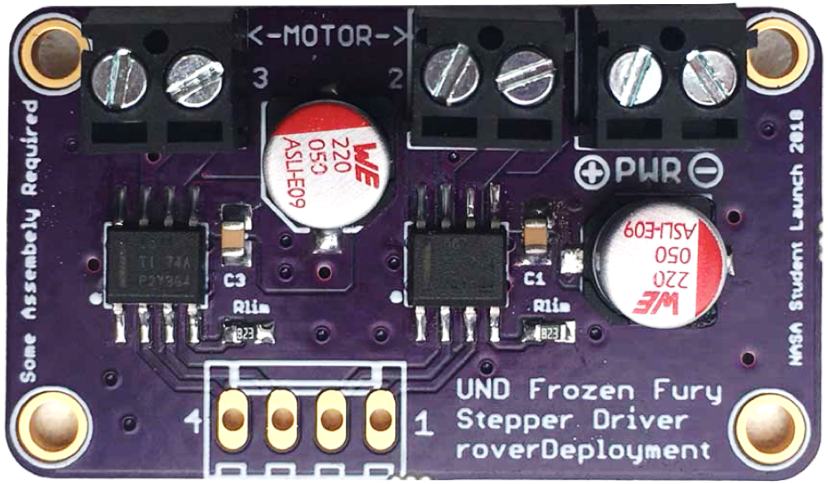
Radio Communication

- Transmission using LoRa spread spectrum modulation with a center frequency of 916Mhz and a bandwidth of 31.25 kHz
- Radio can transmit and receive modulated data packets with a max output power of 20dBm (100 mW).
- Will listen for unique package to before initiating rover deployment

Stepper motor controller

- The linear actuators run on 12V, but the stepper motor has a rated voltage of 3V,
- motor driver circuit board was developed to limit the current going to the stepper motor using dual H-Bridge motor drivers (Texas Instruments DRV8871).

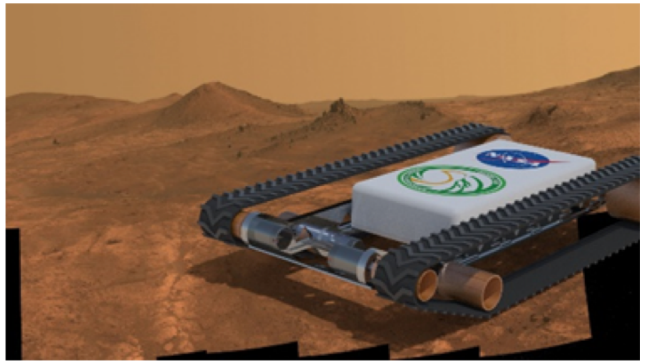


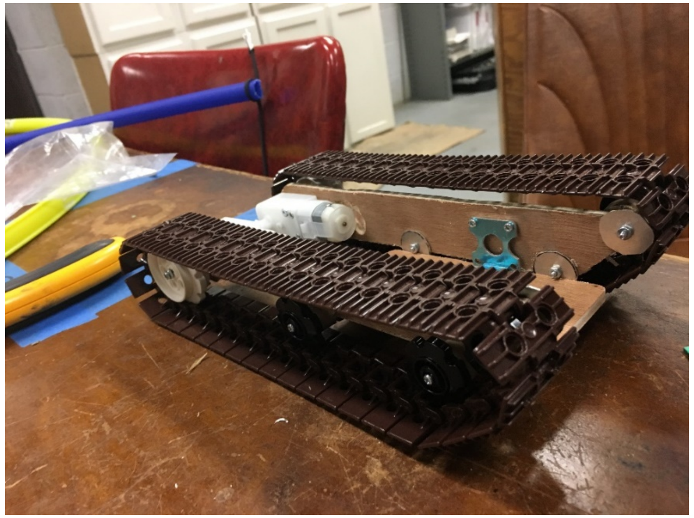


Rover Body

Prototyping
- Digital model (design and set dimensions)
- Wooden model (test dimensions in real world RDS)
- Light-grade plastic printed model (overall test of parts assembly)
- FormLabs engineer-grade resin/wood hybrid (strength testing)

Tracks
- Lego Technic mobility tracks and wheels
- All other parts manufactured in house

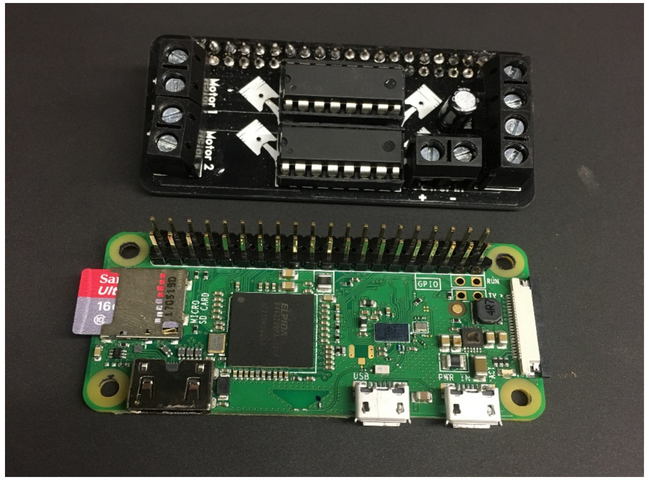




Rover Electronics

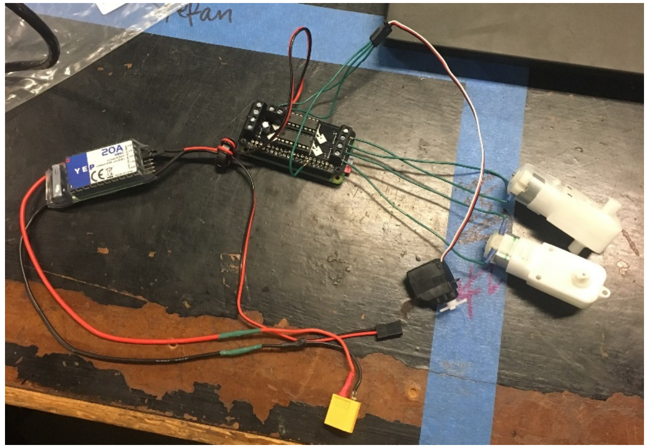
Computer

- Raspberry Pi ZeroW controls all electronics in rover
- MotoZero motor controller works with Pi to control DC motors



Motors

- 2 224:1 Gear DC motors drive treads
  - Can run on 3 to 6 volts
- 1 Fubata servo drives Solar Array Deployment (SAD) system



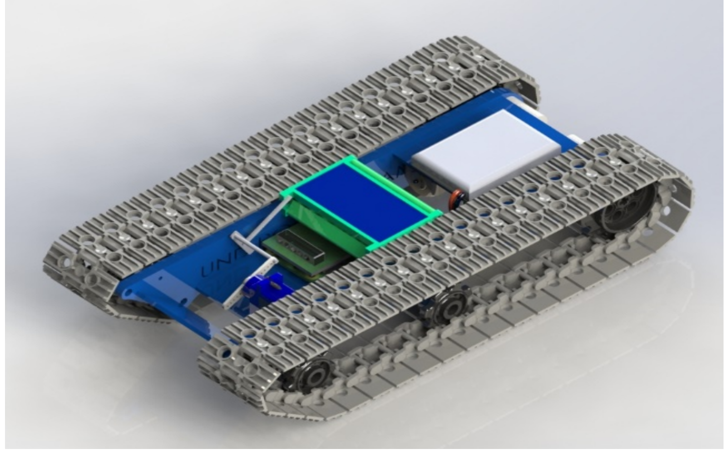
Power

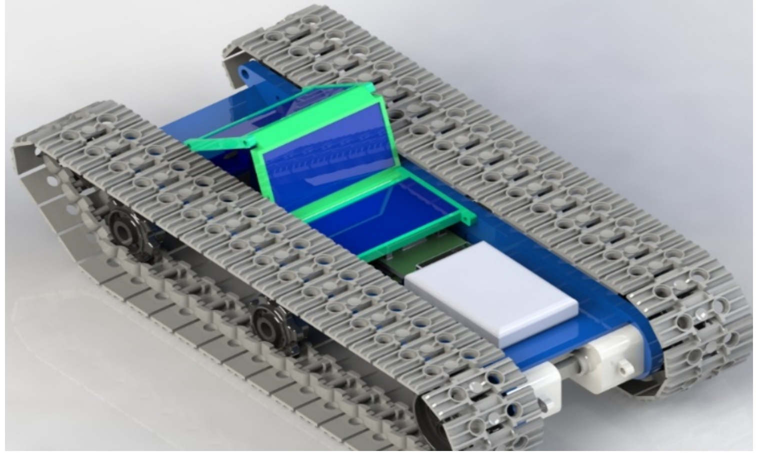
- 7.4 Recharable LiPo
- Stepped down to 5V by Turnigy voltage regulator

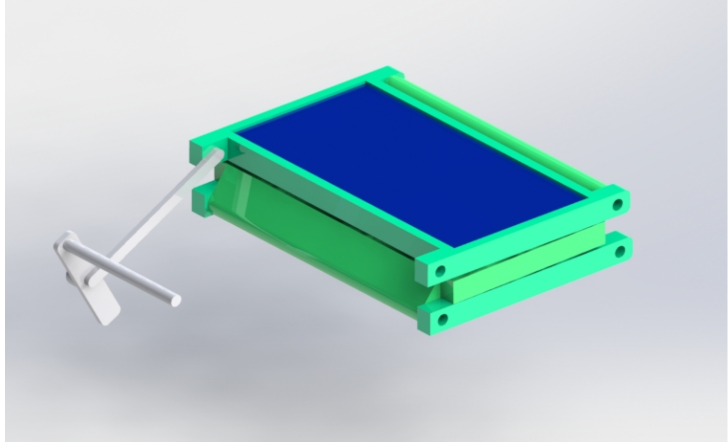
Solar Array Deployment (SAD)

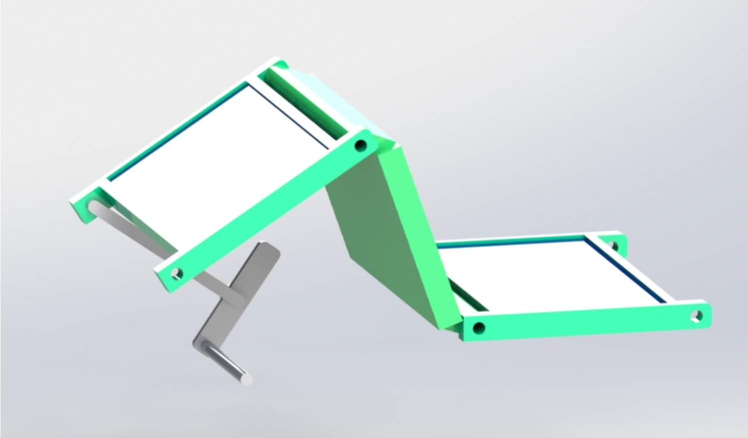
Deployment Operation

- Servo controlled by Pi will deploy panels after the rover has driven 5 feet
- 3 solar panels
- Accordion style fold, allows for increase in solar panel surface area when fully deployed but a tight package when in transport





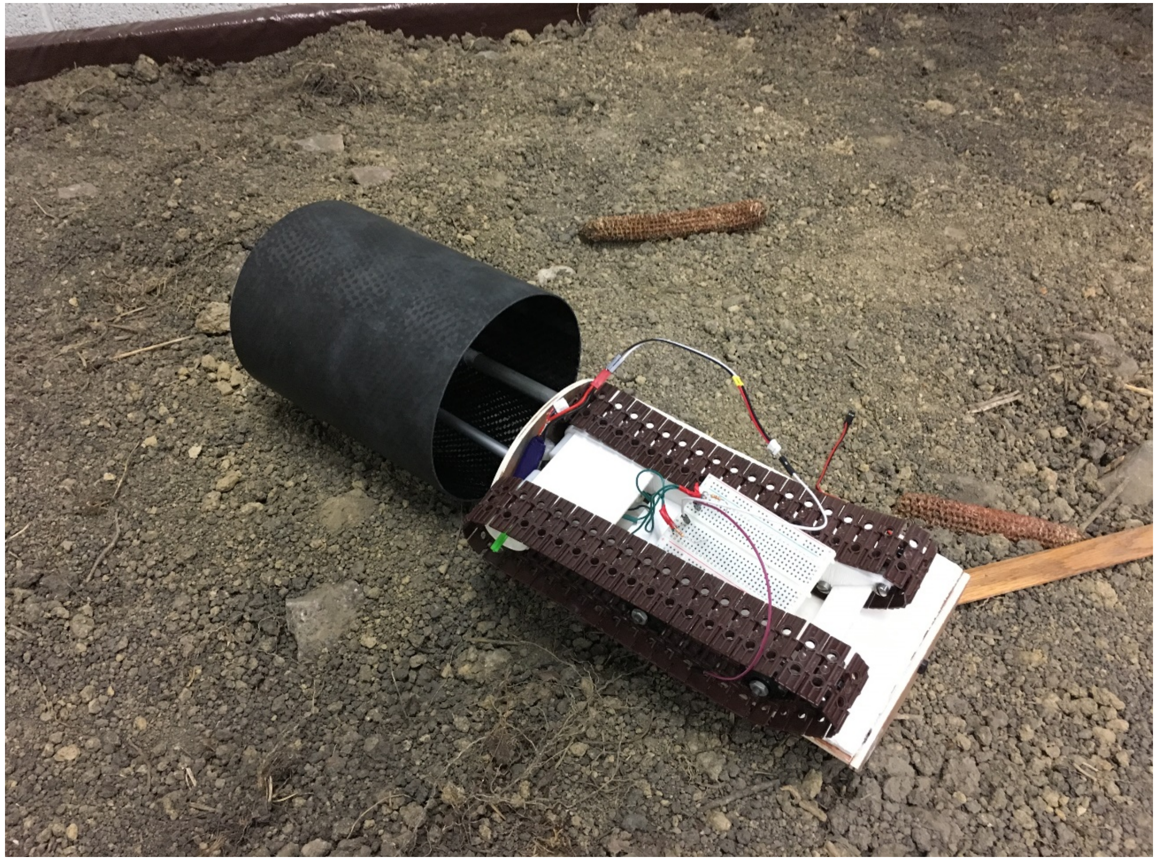




Rover Testing Results

Results

- Rover is able to navigate terrain similar to the terrain in Huntsville
- Grass has proven to be a problem. Getting stuck and jamming up the treads
- SAD system still has to be tested



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Launch Operations

Launch Site

- Launch site located 60 miles south of Grand Forks, ND
- Farm field 1500 feet from buildings or highway
- North Dakota topography is flat with no more than 2° slope

Launch

- Launch days have been reschedule due to winds, Frozen Fury will not be launched in winds over 15 mph
- Launch pad is cleared to NAR specified distances
- 10 second countdown is given as a group and all eyes must be on the rocket and held on the launch vehicle impact

Minimum Distance Table (L-Motor Highlighted)

Total Impulse (Newton-Seconds)	Motor	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 – 320.00	H or smaller	50	100	200
320.01 – 640.00	I	50	100	200
640.01 – 1,280.00	J	50	100	200
1,280.01 – 2,560.00	K	75	200	300
2,560.01— 5,120.00	**L**	**100**	**300**	**500**
5,120.01- 10,240.00	M	125	500	1000

High Power Rocket Safety Code – Minimum Distance Table (nar.org).

Safety Overview

Launch Site

- Launch site located 60 miles south of Grand Forks, ND
- Farm field 1500 feet from buildings or highway
- North Dakota topography is flat with no more than 2° slope

Motor

- Motor is assembled on site to reduce chance of early ignition during transport

Risk Assessment Matrix

To rank the probability and the severity of the hazards associated with building high-powered rockets we will use the following Risk Matrix.

Risk Assessment is used during all steps of the project:

- General Project Analysis
- Personal Hazard Analysis
- Environmental Concerns
- Failure Modes and Effects Analysis
    - General Failure Modes
    - Rover Subsystem
    - Deployment Subsystem

Frozen Fury Risk Matrix

Probability	**Consequence**		
	Severe (1)	Moderate (2)	Minimal (3)
High (A)	A1	A2	A3
Medium (B)	B1	B2	B3
Low (C)	C1	C2	C3

Risk Acceptance and Management Approval Level

Risk Level	Acceptance Level
High Risk	**Unacceptable**. Documented approval from the MSFC EMC or an equivalent level independent management committee.
Medium Risk	**Undesirable**. Documented approval from the facility/operation owner's Department/Laboratory/Office Manager or designee(s) or an equivalent level management committee.
Low Risk	**Acceptable**. Documented approval required from the supervisor directly responsible for operating the facility or performing the operation.

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Event	Date	Size (participants)	Percentage (to meet outreach minimum)
UND Aerospace 50th Birthday	02/03/2018	170	85%
Newfolden High School lab tour	02/14/2018	30	100%
Public Colloquium	02/26/2018	40	+20%
UND Robotics Competition	03/01/2018	15	+27.5%

Frozen Fury Outreach focused on the operations and uses for rocketry based missions. Included the break down of previous Frozen Fury launch vehicles and the purpose for each section.