MIT Rocket Team

Project Raziel: PDR

November 18, 2016

About the Team

80 Undergraduates

Build engineering expertise

Educational outreach

Projects

- Certifications
- Competitions

Team organization

Each subsystem is assigned to a subteam:

- Structures
- Recovery
- Payload
- Avionics
- Propulsion
- Ground Support Equipment (GSE)

System engineering is handled by the body of subteam leads and Exec

About this PDR

Goals:

- Define Raziel in sufficient depth for a design review
- Feedback on each subsystem within its level of maturity
- Feedback on a systems level

Spaceport America Cup (SAC)

Experimental Sounding Rocket Association (ESRA)

8.8 lbs (4kg) of payload in CubeSat geometry

10,000 feet target altitude

Student-built hardware emphasis

Target Altitude (AGL)	10,000 feet	30,000 feet
COTS Solid or Hybrid		
SRAD Solid	Team’s entry	
SRAD Hybrid or Liquid		

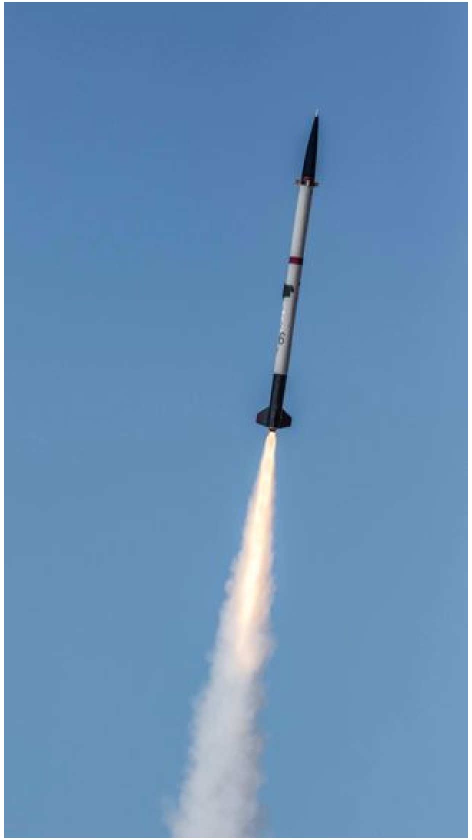
Carryover from 2015-2016

Project Raziel has significant carryover from the 2015-2016 rocket, Therion (pictured)

- Tube diameter
- Motor Impulse & target altitude
- Recovery Scheme
- Rocket Layout
- Pyxida flight computer

Result: subsystems are at different levels of maturity

Action: Flight Test sooner



Upcoming flight test

Flight Test 1 - Recovery Subsystem, Lander Recovery - December 3

Success: Full development Phase in January, February

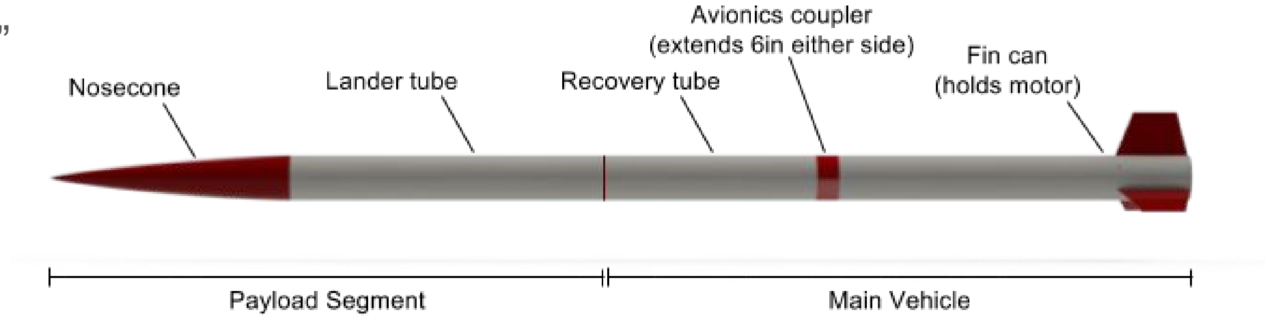
Failure: Fly again in January/February

Continue development of Payload

Systems Overview

Vehicle Overview

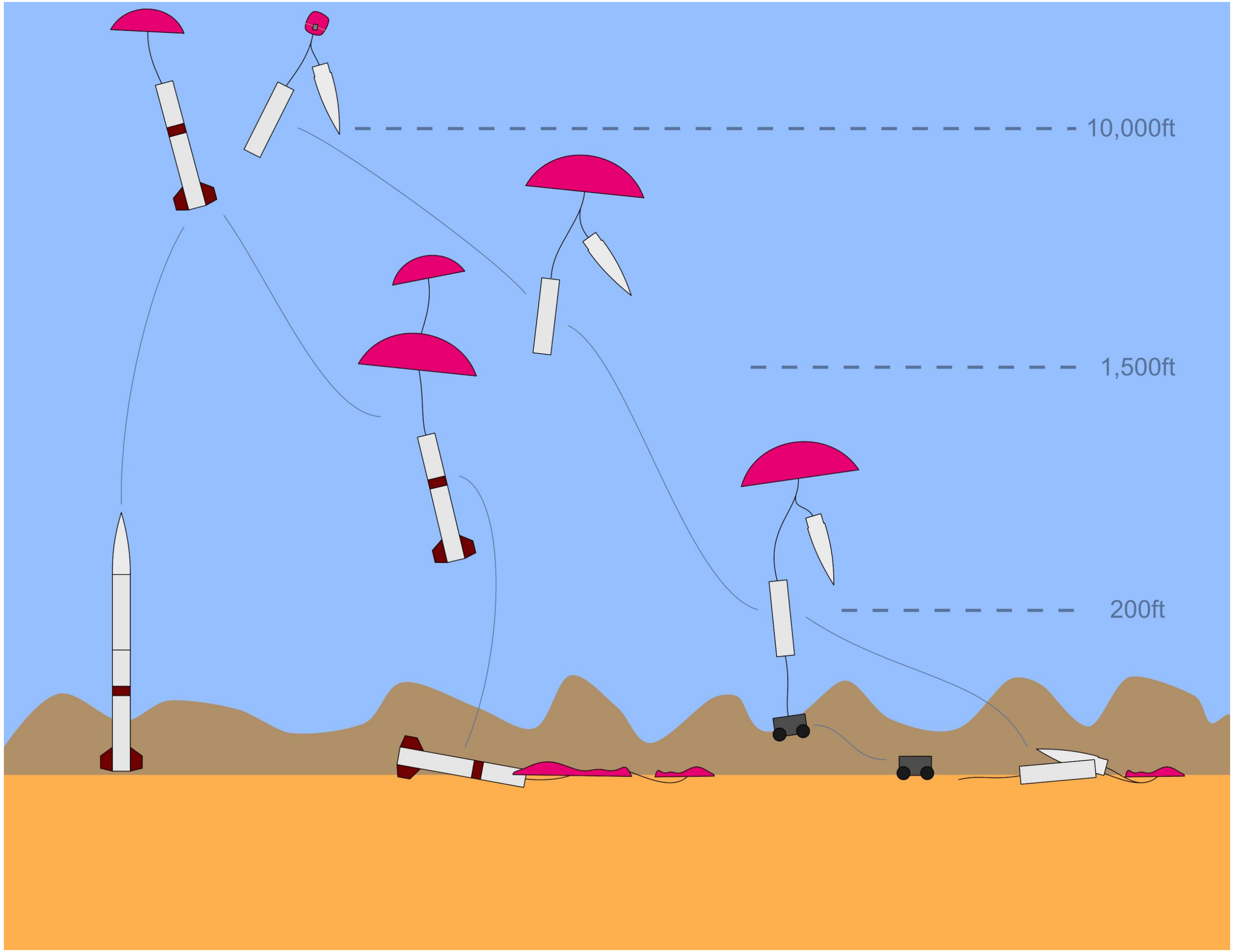
Length: 13' 8"



Mass allocations (excluding propellant):

Subsystem	Structures	Propulsion	Avionics	Recovery	Payload	Total
Therion Allocation (kg)	7.0	3.4	0.6	10.0	4.5	25.5
Therion Usage (kg)	6.7	3.3	0.7	5.7	9.1	25.5
Raziel Allocation (kg)	7.0	5.5	1.0	7.0	5.5	26.0

CONOPS



Flight Parameters

Using Cesaroni Technologies (CTI) M3400:

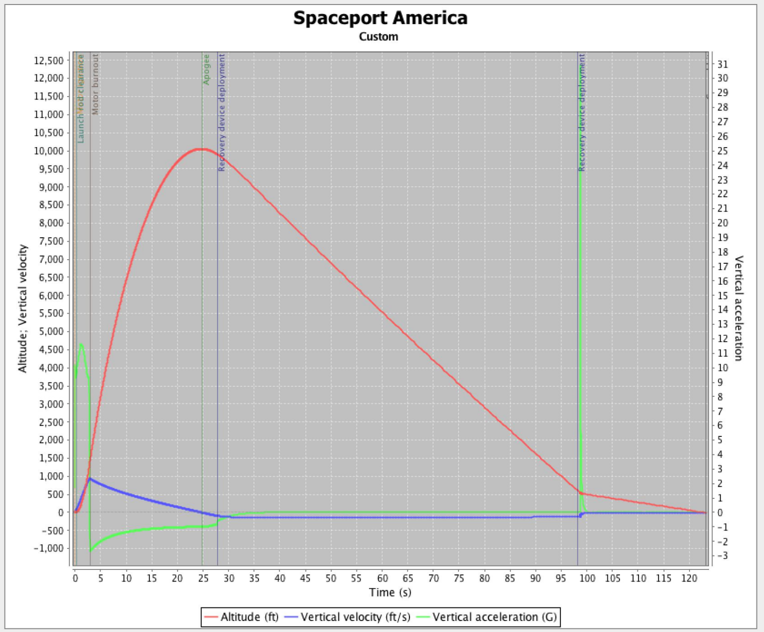
Max Velocity: M 0.9 @ 1500 feet

Descent Velocity targets: ~100 ft/s, <30 ft/s

Rail exit velocity: 89 ft/s → 3+ calibers off the rail

Interpolating for custom prop:

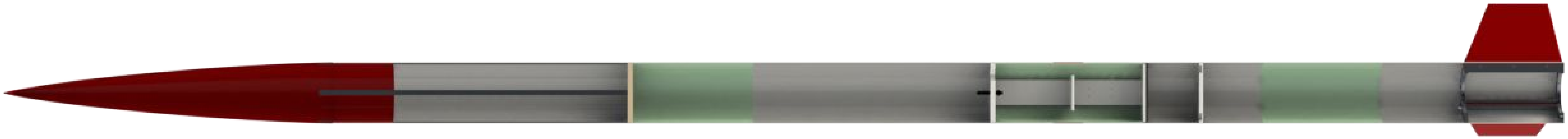
Max Acceleration: ~12 G's, design to 15 G's



Risk Matrix

Risk	20%					
	10%					
	5%					
	1%					
	0.1%					
		1	2	3	4	5
		Impact				
Description		Mission not compromised or minor loss of data	Damage to subsystem, substantial loss of data	Loss of subsystem, loss of critical data	Total loss of vehicle, miss major milestone due to schedule slip, loss of all data	Loss of mission, injury to team members, external parties adversely affected

Structures



Requirements - ESRA

Withstand loads

Coupling tubes extend 6”

Closed-eye, forged steel eye bolts

Airframe vented

2+ rail guides for standard rails

- Must bear rocket weight

Stable

Requirements - Internal

Ballast location

Av bay reachable on launchpad

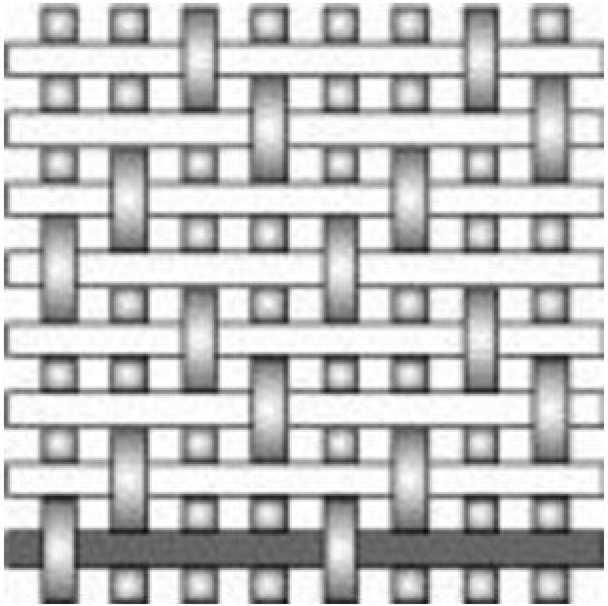
Subsystems accessible within 5 minutes

Removable fins

Fabric

9oz, 8-harness satin weave S-glass:

- High strength to weight ratio
- Radio transparent
- Satin weave for unusual shapes
- 9oz fabric is tightly woven
- Fewer plies?



4-harness satin weave

Current Layup Process

5’ long, 6” OD aluminum tube mandrel

2’ long, 5.85” OD aluminum coupler mandrel

Mylar

10-ply E-glass with epoxy

- 3:4 epoxy:fiberglass
- 0-90 plies

Perforated release film

Future Layup Process

Vacuum

- Interface with ventilation

Oven (max 300F)

- Space heater
- Arduino for temperature control

Oven-safe epoxy

S-glass

Easier to release from mandrel

Higher glass transition temperature

Nose Cone Shape

Von Karman

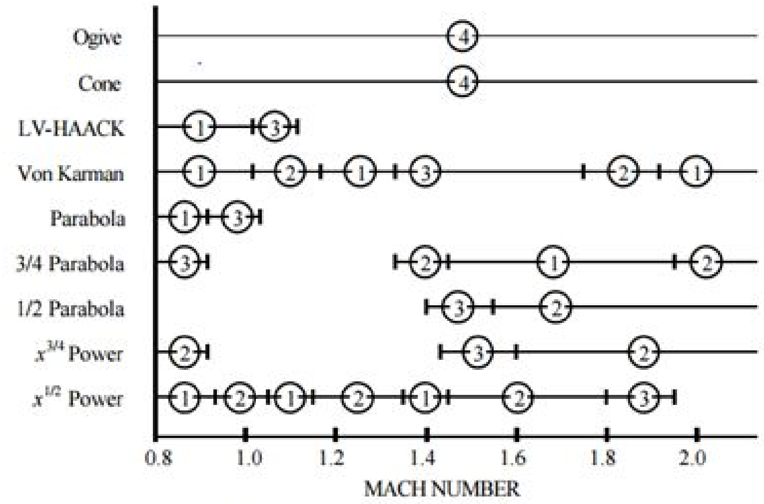
- Lowest drag for speed

5.5:1 fineness ratio

- Increased fineness ratio has minimal effect

No blunting

- High fineness ratio



Comparison of drag characteristics of various nose shapes in the transonic-to-low Mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4).

Nose Cone Layup

Fiberglass mold is inexact > route MDF mold

Five plies on each mold half

Bolt together

Strips on inside, outside to attach

Test

Avionics Bay

¼" polycarbonate

Stepped bulkheads for seal

Shelf to separate CO_2 canister

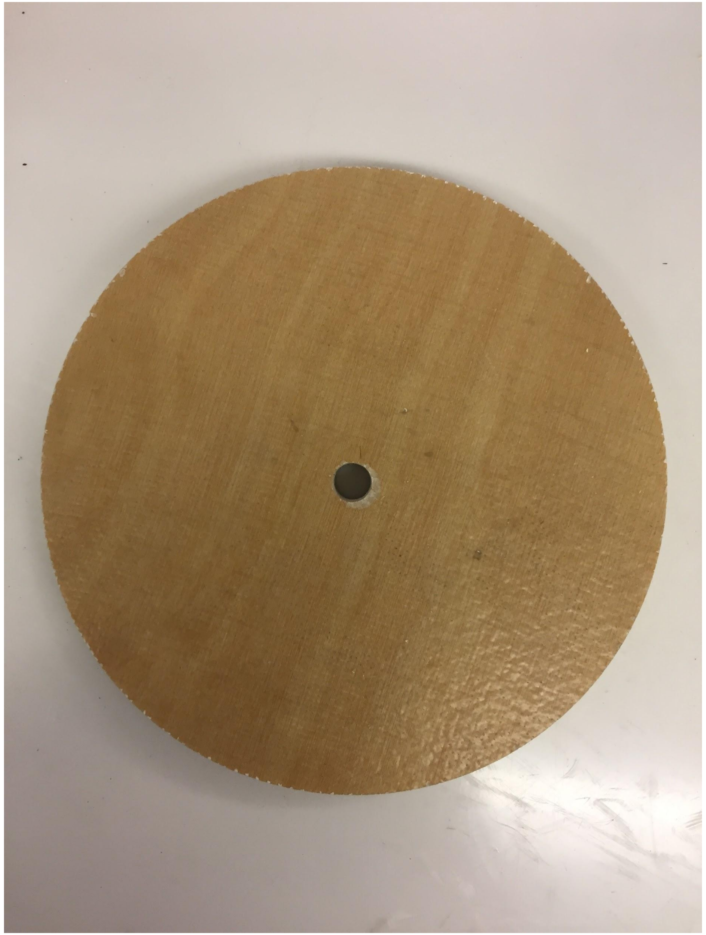
Mounts for avionics

Bulkheads

Payload/recovery: plywood, 2-ply fiberglass sandwich panel

Avionics: polycarbonate

Can withstand flight loads



Tube Attachment

8-32 nut plates

4-40 shear pins at separation

- Tapped into fiberglass

Tubes are significantly stronger than expected shear loads

Fin Can

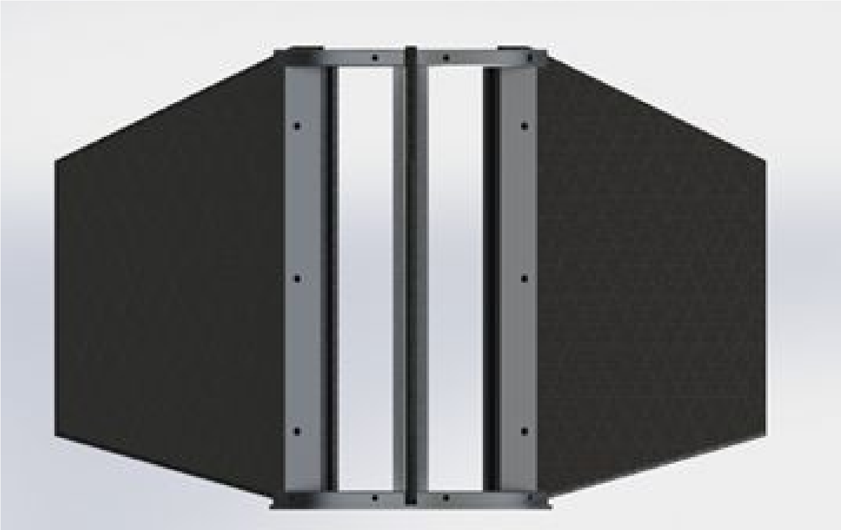
Legacy design

Removable fins

Analysis to cut weight

Rail buttons in lower centering ring, motor retention plate

- 3/8” centering ring plates
- 7/16” thrust plate
- Will support rocket weight



Fins

Stable off the rail

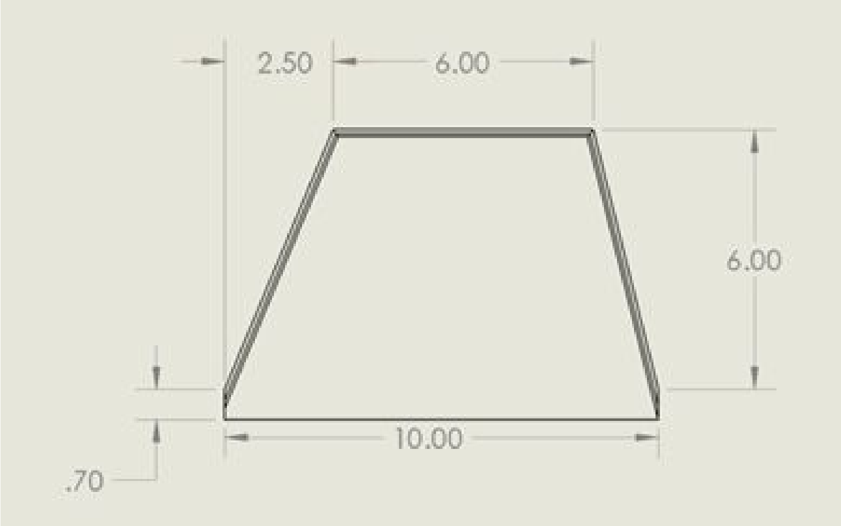
Tapered - will not hit ground first

Shorter than other designs

Two ply carbon fiber over DOW Blue

Foam

- Just foam will withstand max Q
- Need CFD to accurately model shock forces



Risk Matrix

Risk	20%					
	10%					
	5%		1		5	3
	1%			7	8	
	0.1%			2		4, 6
		1	2	3	4	5
Structures		Impact				

Risks

Similar design, similar flight profile

Update simulations

	Risk	Risk Reduction Plan
3.	Separation Failure	Test that all couplers fit without sticking under flight-accurate transverse loads (with safety margin) and that shear pins sized properly for charge size. These tests will reduce the risk to 0.1%.
5.	Delamination or Other Damage to Fiberglass	Test fiberglass under in-flight loads, and handle tubes with caution to avoid damaging the structure before flight
8.	Recovery loads pull out bulkheads	Previously tested bulkhead under similar conditions; run calculations based on recovery loads

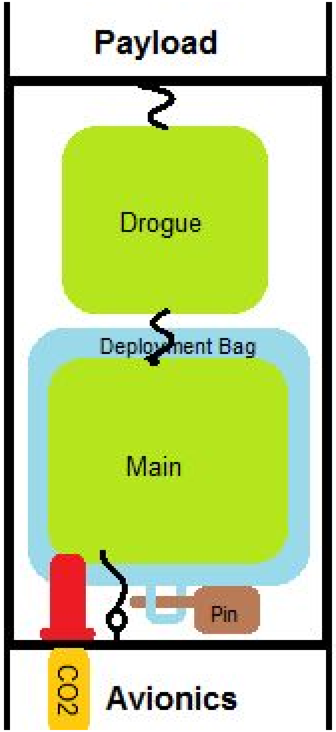
Going Forward Plan

	December	January	February	March	April	May
Composites oven						
Test plans						
Structural testing						
Build Raziel 2						
Test Raziel 2						
Build Raziel 3						
Test Raziel 3						
Build Raziel 4						

Recovery

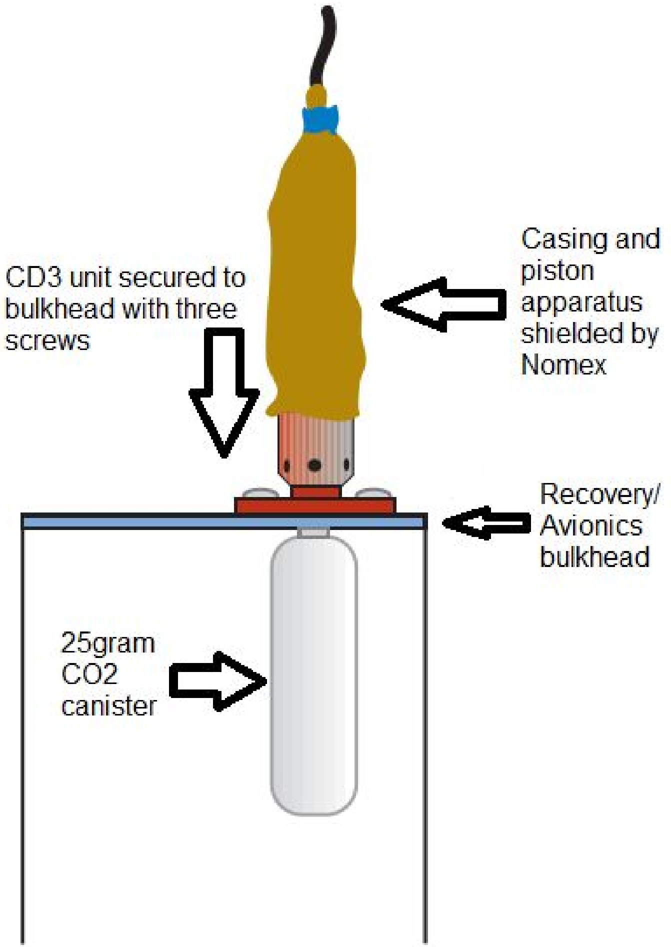
Overview of Requirements

- Dual-event CONOPS
  - Drogue and main parachute
- Successful ground and flight test(s)
- Safe energetics

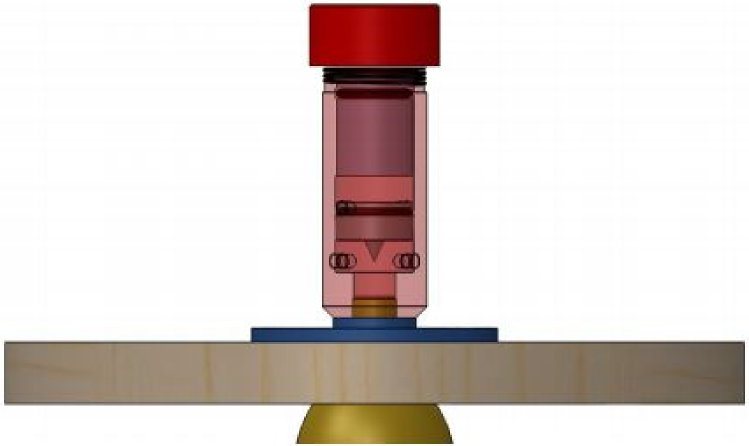


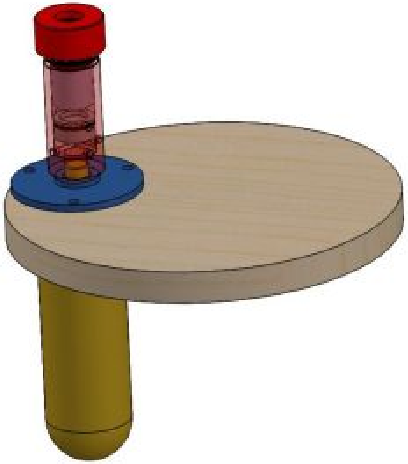
Design Process

- CO_2 system chosen primarily to accompany altitude increase
    - Less human error
    - No damaging residue



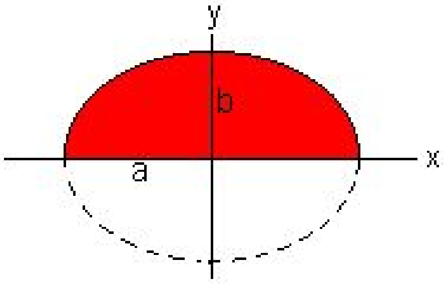
Technical Design and Analysis: CO_2 System



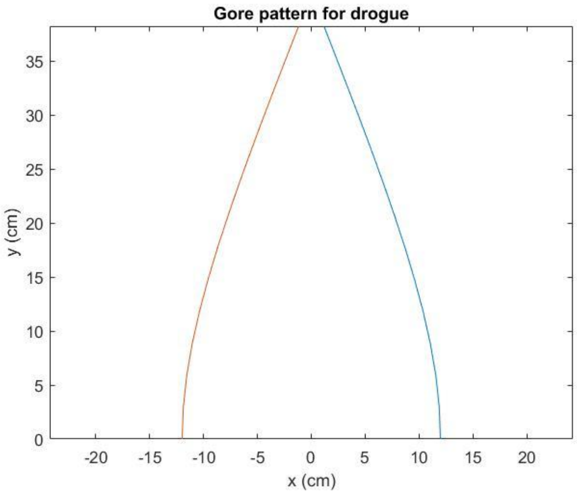


Technical Design and Analysis: Parachutes

- Semi-ellipsoidal design
  - Achieve desirable drag with less fabric
  - 2 ft, 8 panel drogue
  - 9.5 ft, 16 panel main

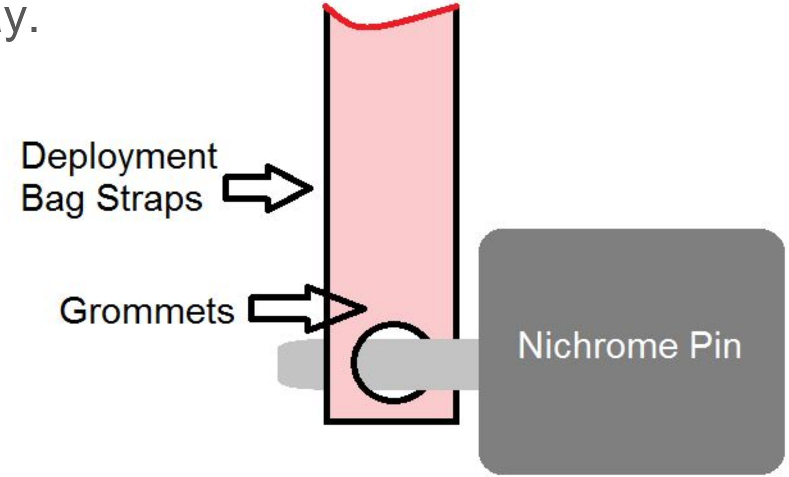


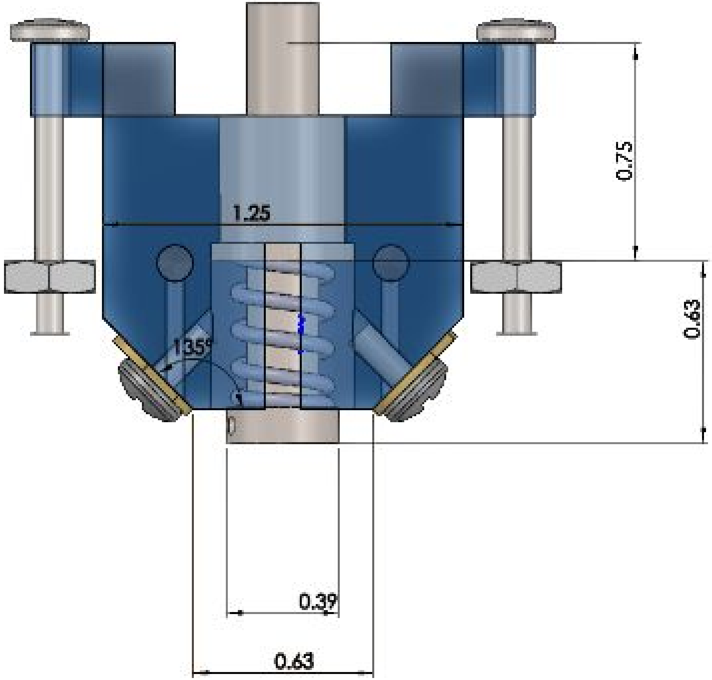
Semi-ellipse with b/a = .707



Technical Design and Analysis: Nichrome Pin Release

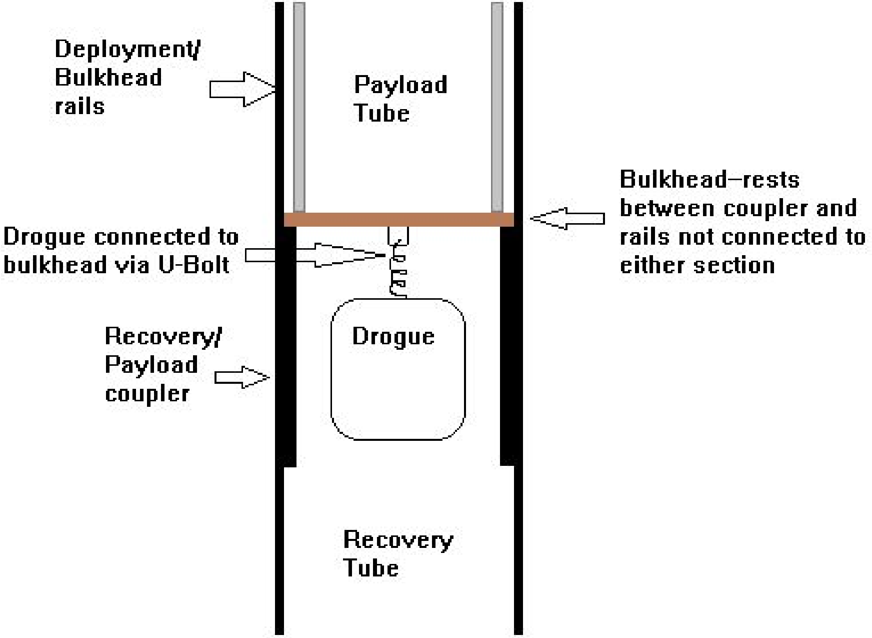
- Spring held under compression by wire.
- Released with current from avionics bay.





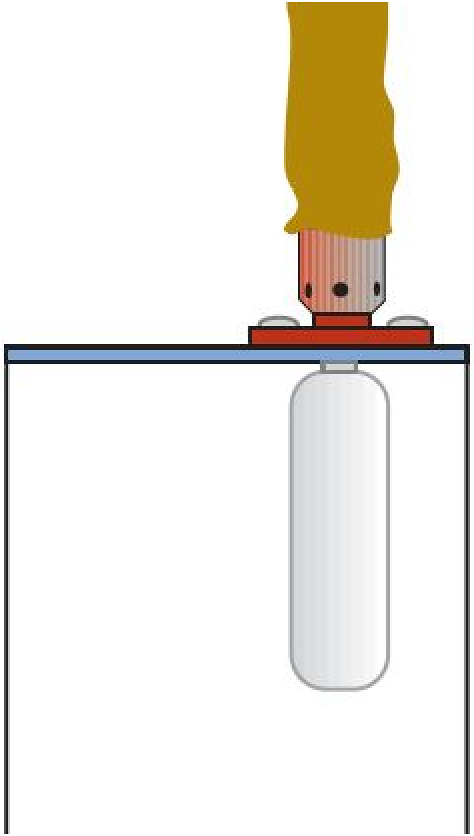
Interfaces: Payload

- “Pressure Bulkhead” between recovery and payload tubes



Interfaces: Avionics

- Easy access to interchange CO_2 canisters through the Avionics bay
- Necessitates an appropriately sized hole in the Recovery-Avionics bulkhead



Key Technical Issues/Risks

Risk	20%					Payload rail failure
	10%				Parachute integrity	Pin jamming, charge malfunction, Drogue deployment
	5%		Av-Bay pressurization			
	1%					
	0.1%					
		1	2	3	4	5
		Impact				

Test Plan

- Testing will allow us to converge on more realistic risk values
- Upcoming/Planned Tests:
  - Nichrome Pin Test
  - Ground Test
  - Flight Test
  - Parachute Construction Test

Moving Forward Plan

	Nov.	Dec.	Jan.	Feb.	Mar.	April	May
Fabrication, Ground and Flight Test 1							
Address flight problems, CD3 improvements							
Parachute fabrication and research							
Ground and Flight Test 2							
Ground and Flight Test 3							
SAC Preparation							

Payload

Official Requirements

Official Requirement and Jurisdiction	Description
2.3.1, Rover	Payload shall weigh at least 8.8 lbs.
2.3.3, Rover	Payload shall be removable from rocket.
2.3.4, Rover	Payload shall stow within a CubeSat Standard geometry (1U, 2U, 3U, etc.), and mechanically approximate a cubesat while stowed (i.e. roughly cuboidal.
2.3.5, Rover	Any radioactive substances within Payload shall be encapsulated and limited to 1μC or less of radioactivity.
2.3.3, Lander	Deployable payloads shall comply with recovery requirements 5.1-5.7.

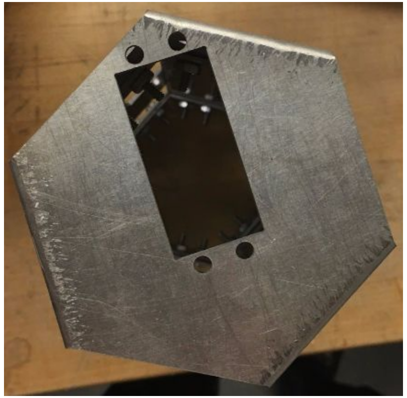
Internal Payload Requirements

Jurisdiction	Description
Rover	Rover shall exit Lander and land safely on ground.
Rover	Rover shall withstand pad and launch environments.
Rover	Rover shall store data and should transmit data.
Rover	Rover should make environmental and ground measurements.
Rover	Rover should drive at least 5ft.
Lander	Lander shall allow rover to exit and land safely on ground.
Lander	Lander shall incorporate and recover nosecone.
Lander	Lander shall be attached to the recovery tube by #4-40 nylon bolts, and shall provide at least 0.25 in^2 of *ledge* within the body tube for the payload-recovery bulkhead to rest on.

Rover

Chassis:

- Hexagonal prism chassis
  - Maximizes available area
  - Landing orientation
  - 1/16” Aluminum sheet metal



Rover Chassis Endcap Prototype

Rover Hexagonal Chassis Prototype

Rover

Wheels:

- Custom 3D Printed wheels
  - Flexible filament will absorb shock on impact
  - Attach directly to motor
  - Custom design will maximize wheel size as permitted by cubesat dimensions
  - Easy to switch to commercial solution

Motors:

- DC motor for actuating drive conditions
- Lower mass than servos, do not need the precise positional control
- In the process of specing motors

Rover: Risk Assessment and Mitigation

Risk	20%					
	10%		1			
	5%					
	1%					
	0.1%			2		
		1	2	3	4	5
Chassis		Impact				

	Risk	Risk Reduction Plan
1	The get stucks on pebbles, loose sand, low vegetation, etc.	Drive around significant obstacles. If stuck, back up.
2	Rover does not survive launch or landing	Test by dropping the rover.

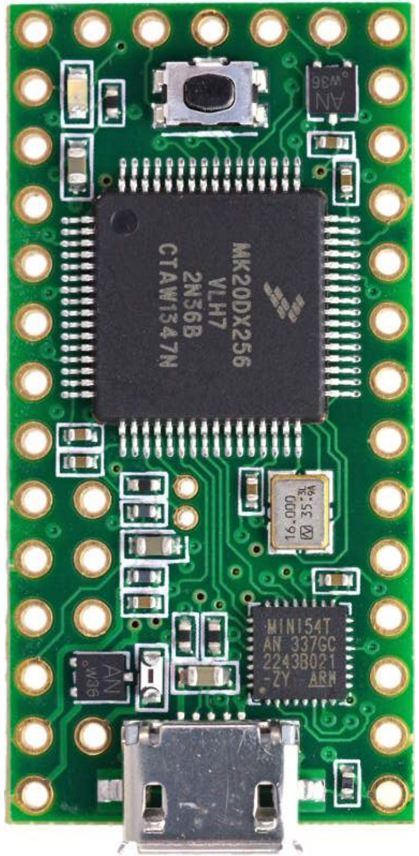
Computer

Microcontrollers;

- Considered Arduino Due and Teensy 3.1
  - Selected Teensy for cost and efficiency
    - Teensy can use ‘C’

Smartphone::

- Used for nuclear experiment data processing



Teensy Microcontroller

Environmental Sensing

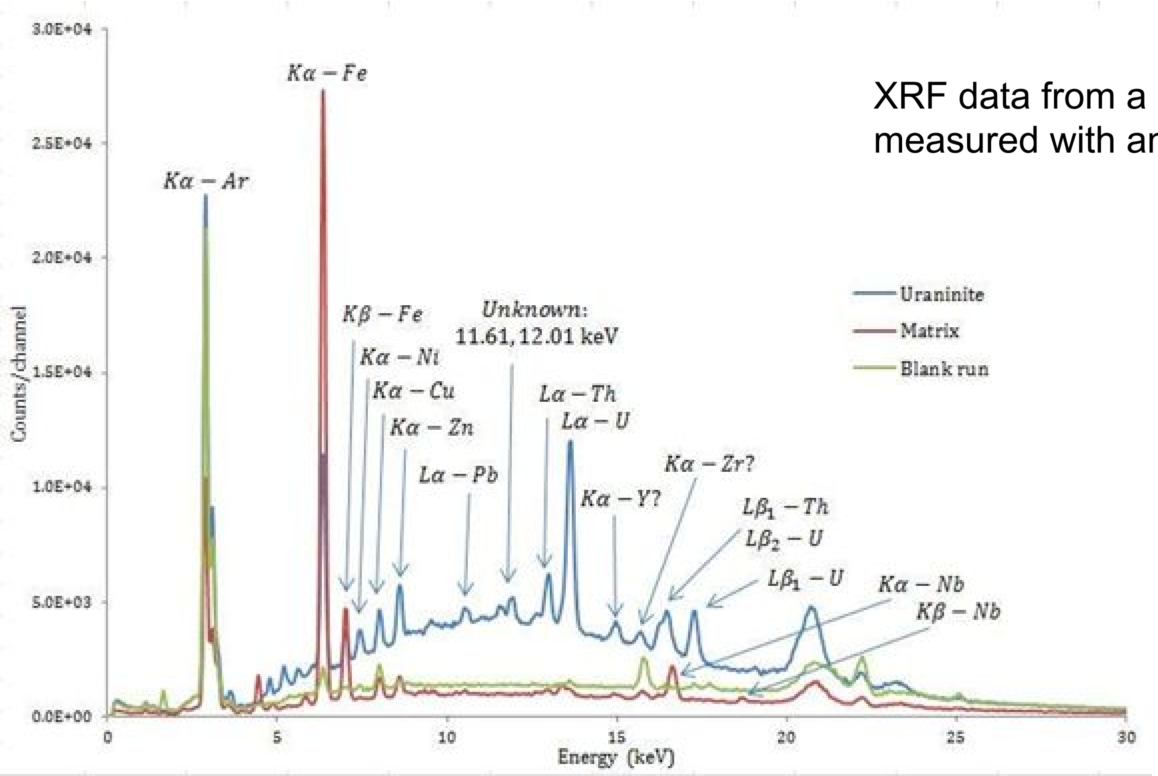
Camera:

- COTS camera attached to rover to take pictures of surroundings upon landing
  - Must withstand launch conditions
  - Must meet rover power requirements

Sensors:

- Atmospheric sensors
  - Temperature
  - Pressure
  - Humidity

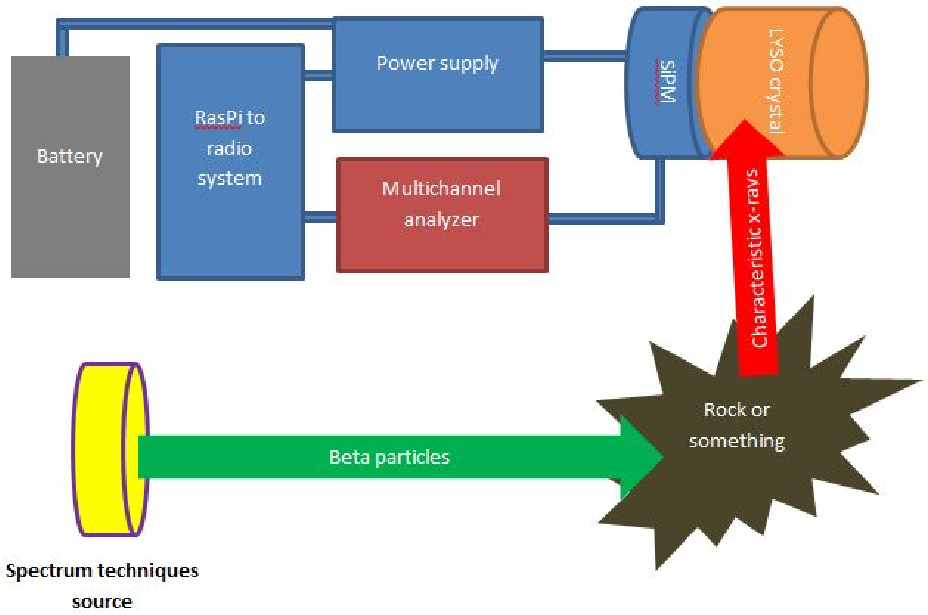
X-Ray Fluorescence Instrument



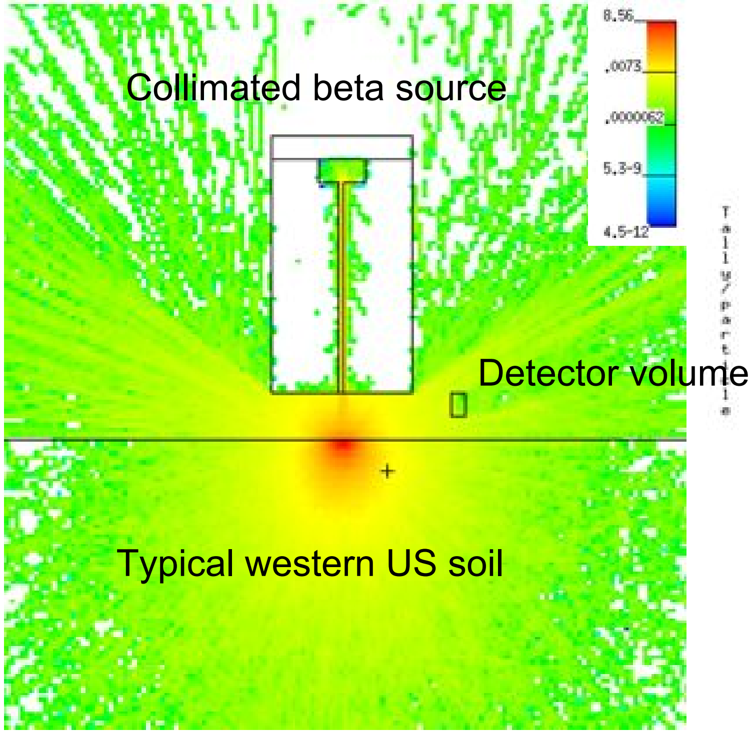
XRF data from a uranium ore sample measured with an Amptek SDD

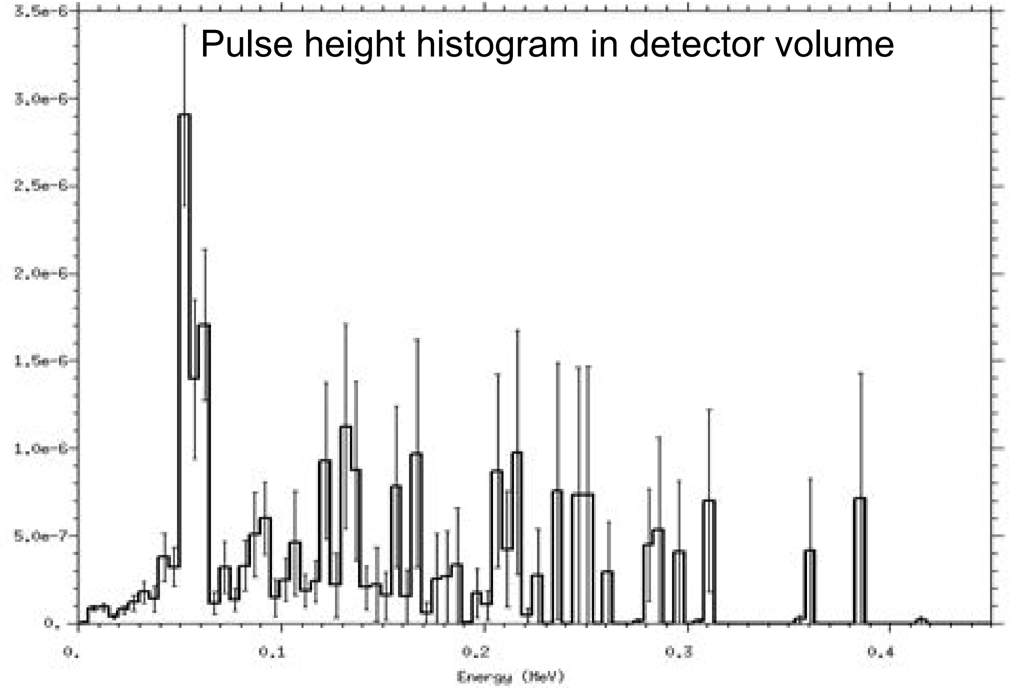
The XRF instrument characterizes soil composition

- Uses a beam of beta particles from a sealed source to excite XRF in soil beneath the rover
- Observes emitted x-rays using a NaI or LYSO scintillator with a collimator
  - Pulses are amplified and histogrammed by an onboard multichannel analyzer, and this data is transmitted back to the bse station

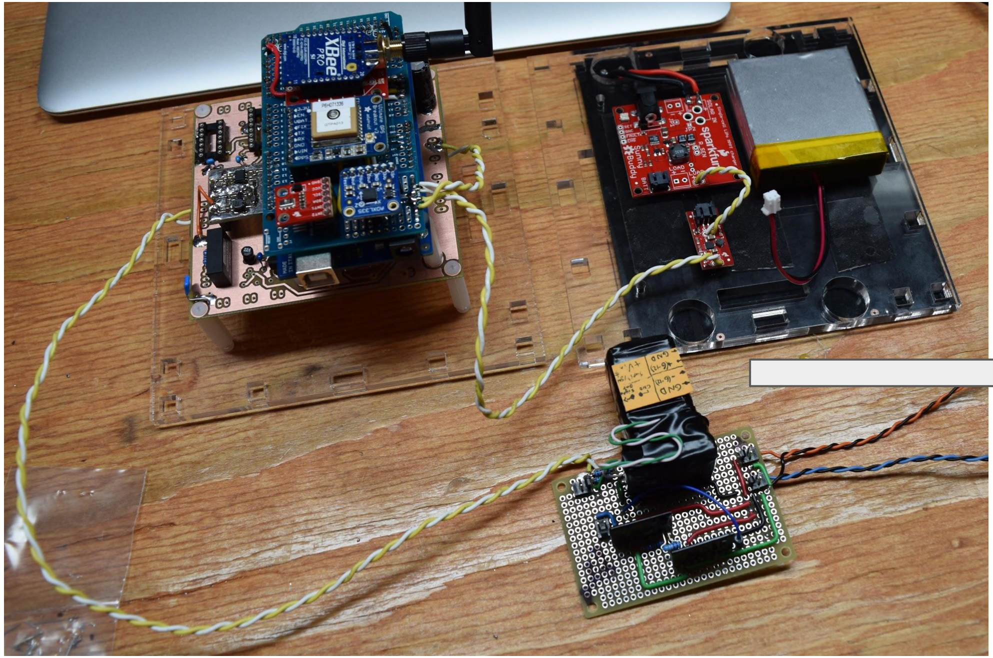


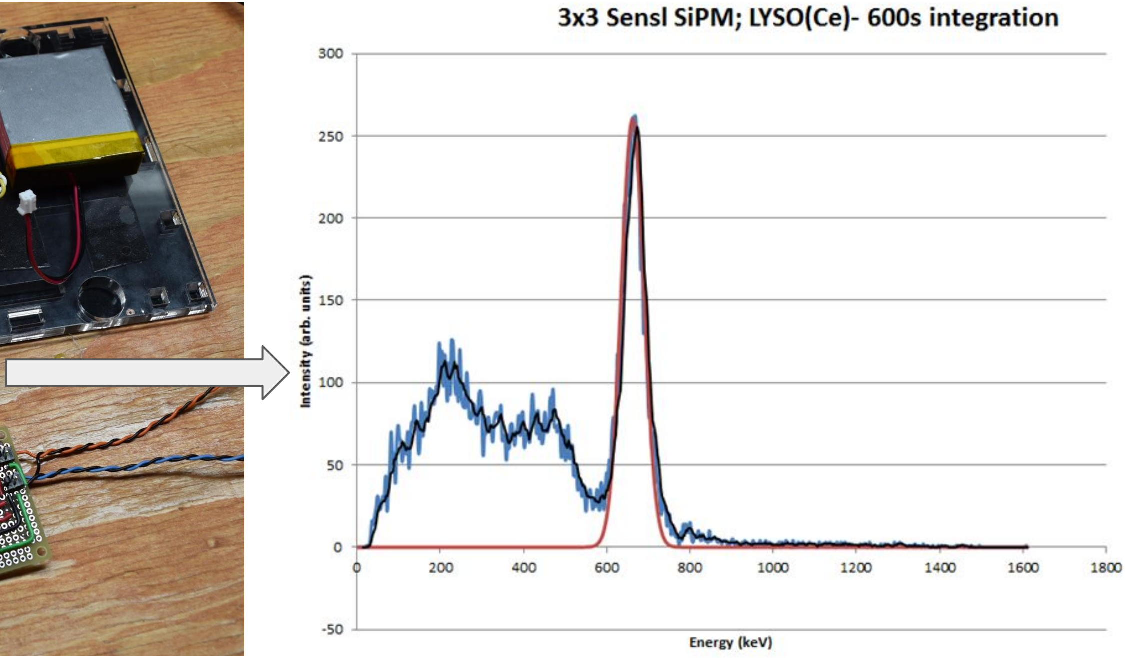
Monte Carlo simulations show instrument feasibility





Testing of a prototype shows favorable behavior





Next steps

- Miniaturize the processing (switch to a soundcard/cell phone?)
- More MCNP simulations to verify behavior
- Begin building collimators and shields
  - Acquire beta source

Lander

Rocket Body Interface:

- Provides interface to Recovery section and nosecone
  - Deploys parachute to recover Payload and nosecone sections

Flight Computer:

- Will use Avionics' Pyxida design

Rover Interface:

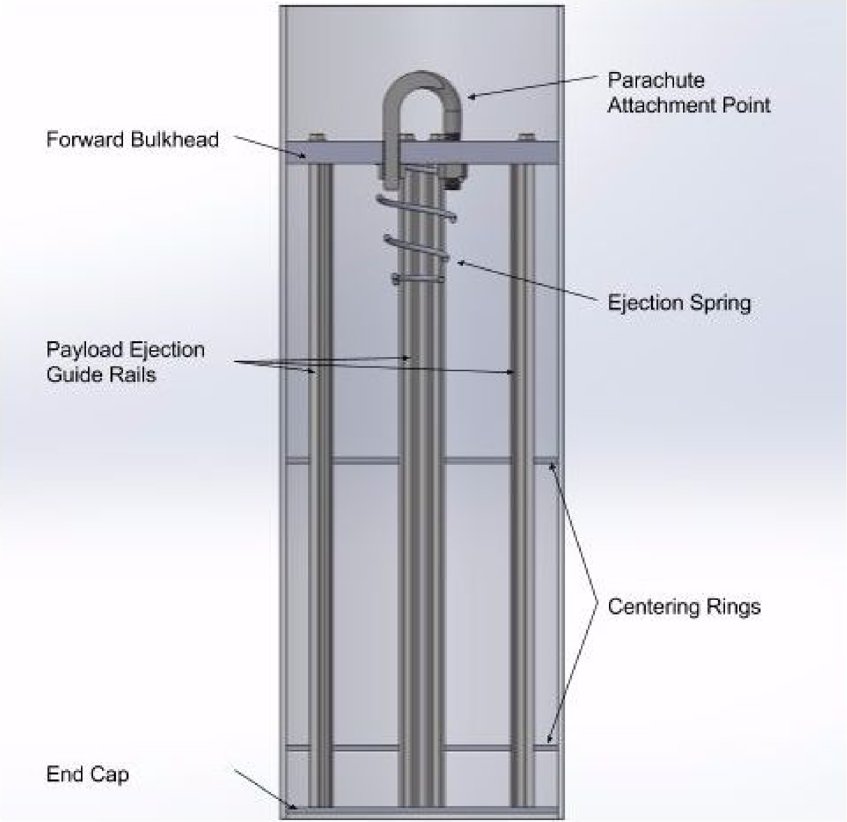
- Provide structural interface to release mechanism

Lander

Rover Interface:

- Bulkhead for parachute attachment
- Release Mechanism support
  - Guide Rails
  - Ejection Spring

Lander Isometric View



Lander Side Cutaway View

Lander: Risk Assessment and Mitigation

Risk	20%					
	10%					
	5%		1			
	1%				2	
	0.1%					
		1	2	3	4	5
Payload Segment		Impact				

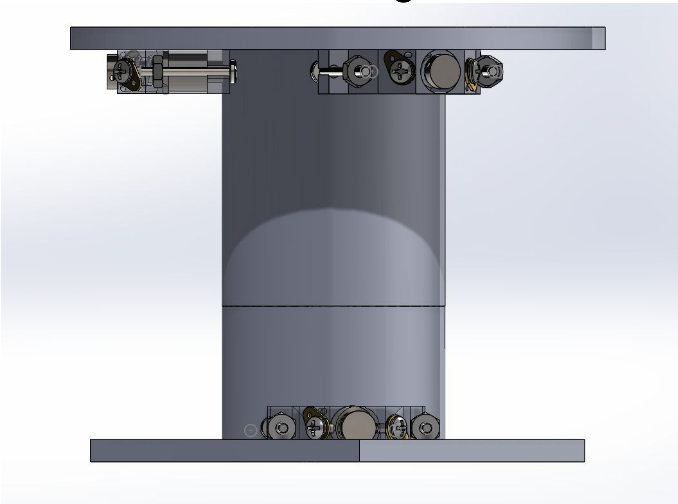
	Risk	Risk Reduction Plan
1	Failure to deploy payload at desired altitude	Ground test system.
2	Failure to deploy parachute	Use redundant flight computers, separated from high pressures and vented to atmosphere. Ground test system. Pack parachute carefully. Pack black powder carefully

Rover Mechanical Release

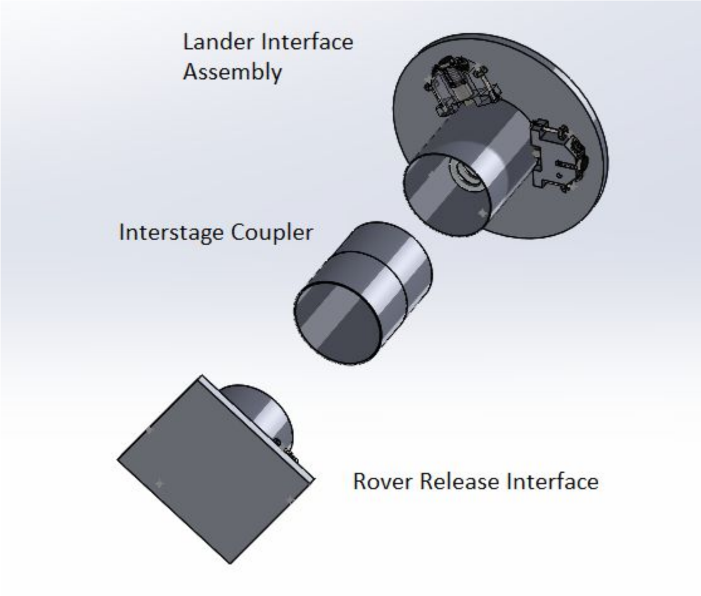
Dual Event Separation

- First event at 200 ft
- Second event at touchdown

Stowed configuration

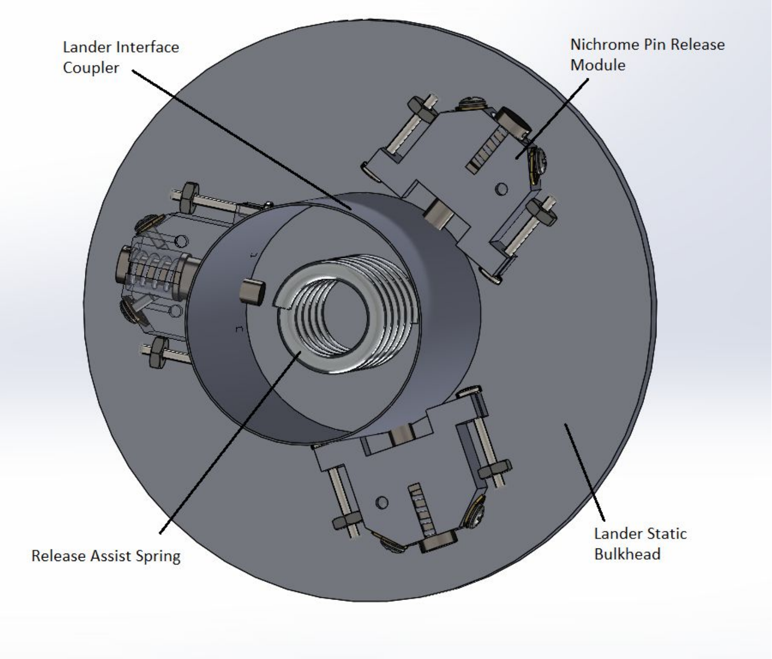


Exploded view

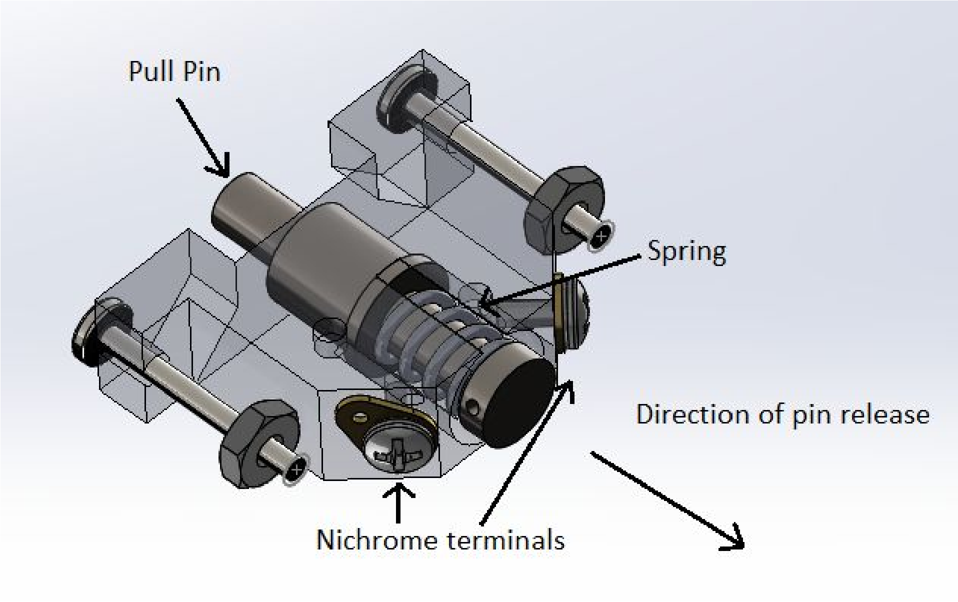


Rover Mechanical Release

Lander interface assembly

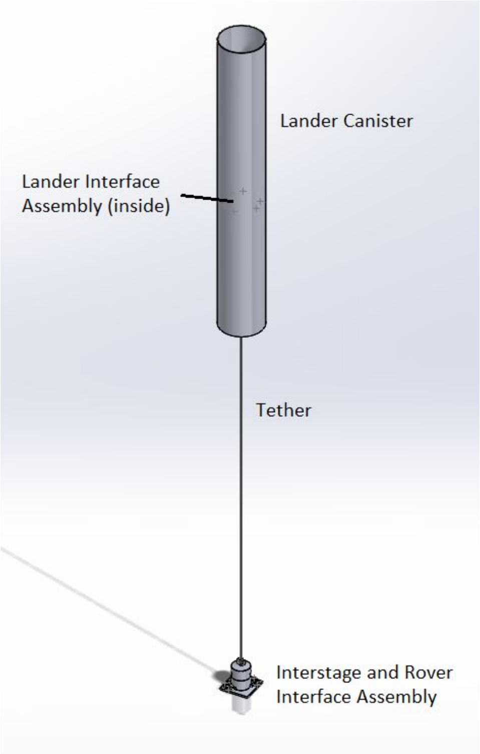


Nichrome pin release module

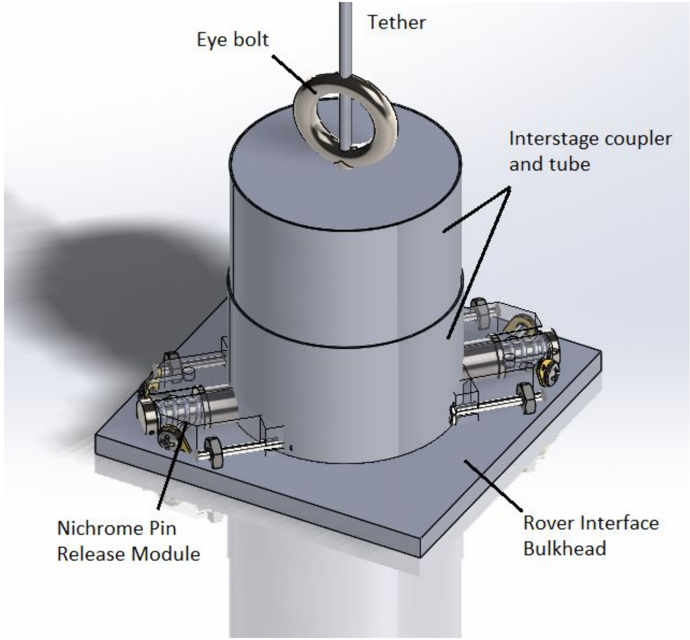


Rover Mechanical Release

First event



Detail of rover interface assembly

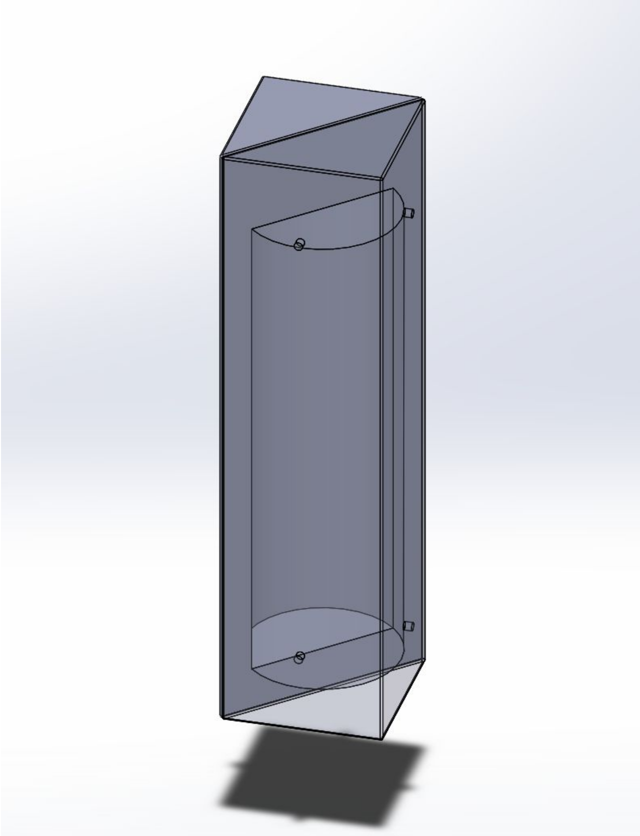


Second event

Rover Mechanical Release

Rover Shell

- Provides support for rover while stowed in lander
- Fits into cubesat rails on lander



Mechanical Release: Risk Assessment and Mitigation

Risk	20%					
	10%					
	5%			1		
	1%			2		
	0.1%					
		1	2	3	4	5
Rover: Mechanical Release		Impact				

	Risk	Risk Reduction Plan
1	Wire does not break	The mechanism and flight computer should be tested extensively.
2	Rocket spinning jam rails	Tabs should be rigid.

Going Forward Plan

- Prototype all components individually by end of semester
  - Fly Lander on first test in December
- Assemble complete rover over IAP
- Test full rover deployment in February
- Continue iterating through April

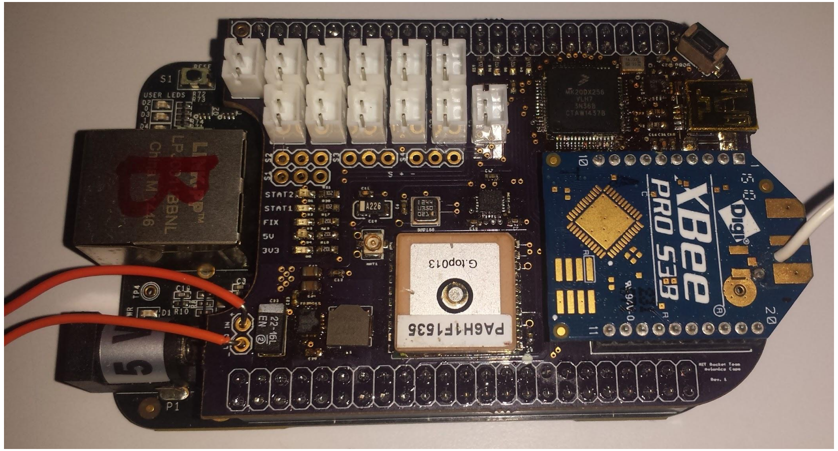
Avionics

Requirements

- Build a flight computer and select a COTS system, both of which must:
  - Gather, log, and transmit data
  - Control flight events
- Aid in the design and assembly of the avionics bay

Last Year's Hardware

- BeagleBone Microcomputer
  - Power for parafoil calculations
- Custom-designed cape (Pyxida 1.0)
  - Beaglebone-centric form factor
  - Sensors
  - Onboard microcontroller



Current Hardware

- Stripped out BeagleBone
  - System too complicated
  - Power not needed
- Cape converted to standalone flight computer (Pyxida 2.0)
  - Easier to develop for
  - Compact
  - All sensors included
  - Onboard memory for logging and saving settings
  - Useable in variety of rockets

Devices

- Microcontroller: Freescale MK20DX256
  - 96 MHz, ARM, Arduino-compatible
- Barometer: Bosch BMP180
- GPS: U-Blox Max-6
- Accelerometer: ADXL375
  - 250 G limit
- IMU: InvenSense MPU-9250
  - 9 DOF, 12 G limit
- Radio: XBee-Pro 900 XSC S3B
- Storage: Micron N25Q256A
  - 256 Mb capacity

Last Year's Software

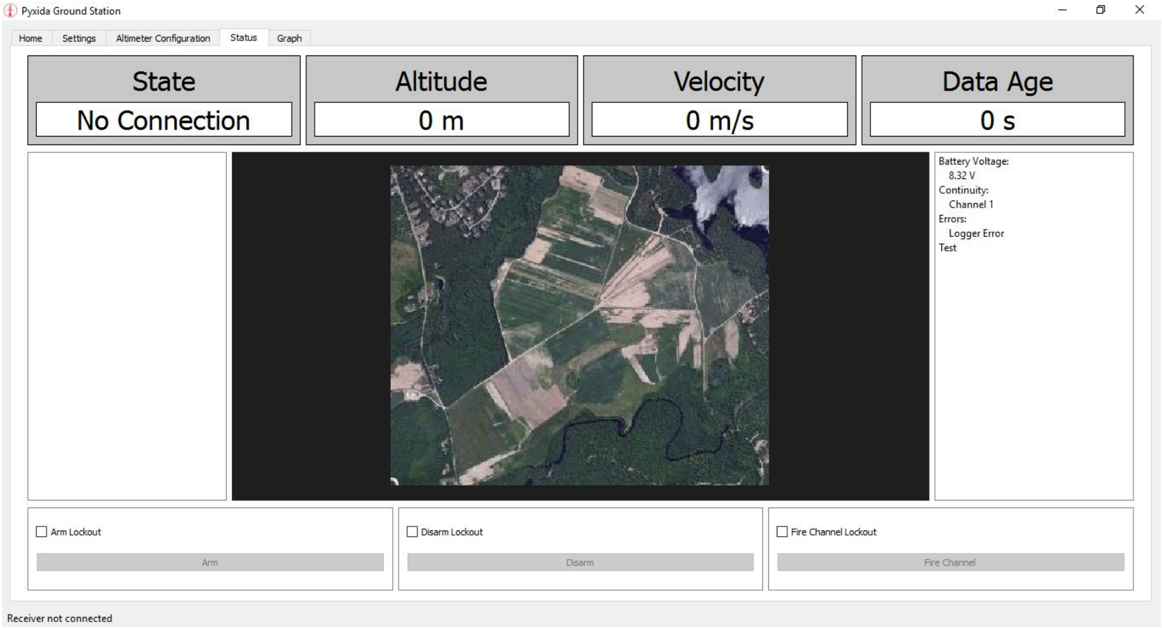
- Implemented base functionality for software and firmware
- Two main code bases
  - Ground station
  - Pyxida firmware
- Ground station displays telemetric data and sends flight commands
- Firmware focused on data collection, telemetry, and flight state transitions

Firmware

- Much of last year’s code base is still relevant
- Improvements:
    - Streamlined data logging
    - XBee telemetry protocol
    - More precise telemetry via Kalman filter
    - Intuitive altimeter configurability

Ground Station

- Used pre-flight to set parameters
- Receives and displays data from rocket during flight
- Supports sending commands to rocket
- Renders graphs of flight data post-flight

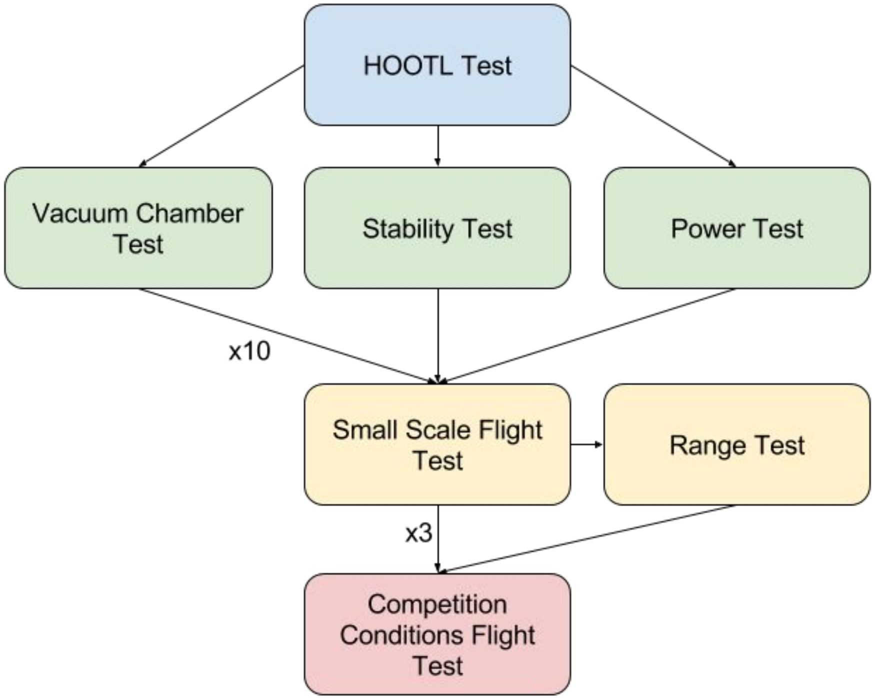


Risks

	Risk
1.	Failure to initiate flight event
2.	Sensor failure
3.	Early initiation of flight event

Unmitigated Risk Table						
Risk	20%					
	10%					
	5%			2		1
	1%					3
	0.1%					
		1	2	3	4	5
Avionics		Impact				

Testing


HOOTL Test
Vacuum Chamber Test
Stability Test
Power Test
x10
Small Scale Flight Test
Range Test
x3
Competition Conditions Flight Test

Mitigation

	Risk
1.	Failure to initiate flight event
2.	Sensor failure
3.	Early initiation of flight event

Mitigated Risk Table						
Risk	20%					
	10%					
	5%					
	1%					
	0.1%			2	1	3
		1	2	3	4	5
Avionics		Impact				

Going Forward

- This semester:
  - Finish firmware support for all devices on the latest revision of the PCB
  - Add all critical features to the Ground Station
    - Map
    - Configuration
    - Data display
  - Build avionics bay
- IAP
  - Assemble final version of hardware
- Next semester
  - Test system in as many flights as possible
  - Freeze firmware development before the end of the semester
  - Polish Ground Station
  - Revise avionics bay

Propulsion

Overview of Requirements

6.0	RRD 2.0	Raziel shall achieve an apogee of 10,000 feet +/- 300 feet.	Propulsion
6.1	Internal	Propulsion shall be single-stage.	Propulsion
6.2	DTEG 2.1	Propulsion shall use non-toxic propellants.	Propulsion
6.3.1	DTEG 2.2.1	Propulsion shall have a two-step arming system which can only be armed when all personnel are at least 50 feet from the Rocket.	Propulsion
6.3.2	DTEG 9.2	Ignition system shall require no more than 15A at 12V to function.	Propulsion
6.4.1	DTEG 2.4	Propulsion testing shall comply with ESRA requirements.	Propulsion, GSE
6.4.2	DTEG 4.2.4.1	The combustion chamber shall be designed for at least twice the maximum chamber pressure. The chamber shall be tested to at least 1.5 times the maximum chamber pressure.	Propulsion
6.5	DTEG 2.4.3	Propulsion shall have a successful static fire test prior to a test launch. Propulsion should have two successful static fires prior to a launch.	Propulsion, GSE

Propellant Formulation

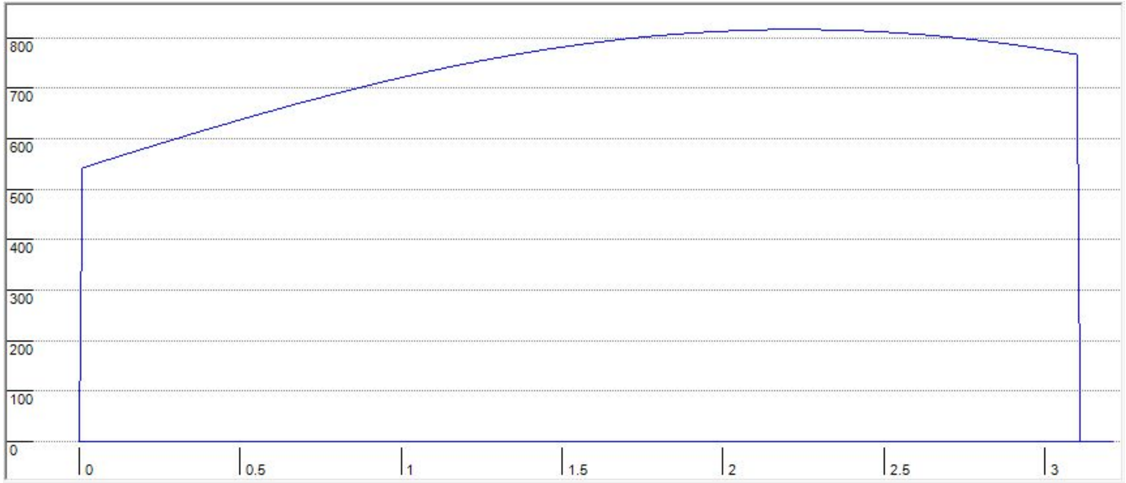
Component	Role
Ammonium Perchlorate	Oxidizer
Hydroxyl Terminated Polybutadiene	Binder
HX-752	Matrix Stabilizer
CAO	Antioxidant
Isodecyl Pelargonate	Plasticizer
Modified MDI	Curative
Aluminum Powder	Fuel
Copper Chromite	Catalyst
Copper Oxychloride	Colorant/catalyst
Castor Oil	Cross-linking promoter
Polydimethylsiloxane	Surfactant
Triton X-100	Surfactant

Grain Geometry

4 BATES geometry Grains

Cylindrical, slightly tapered core

Length	7 inches
Core Diameter	1.25 inches
Outer Diameter	3.27 inches
Core Taper	.5 degrees
Impulse	10200 Ns
Average Thrust	3300 N
Burn Time	3.1s
Propellant Density	1500 kg/m^3
Expected I_{sp}	185 s



Fabrication - Mixing

Uses a 5-quart mixing bowl and KitchenAid mixer

Mixing order:

1. HTPB
2. AP
3. Copper Chromite, Copper Oxychloride, Aluminum, Plasticizer, Castor Oil
4. Surfactants and Curative

Fabrication - Vacuum Processing

Air bubbles are introduced during mixing and casting.

- Small distributed bubbles are introduced in mixing
- Large bubbles are introduced by folds in the propellant during casting

Process the propellant under vacuum twice

- Before casting, process in a wide, flat pan to eliminate mixing bubbles
- After casting, vacuum in the mold to remove casting bubbles.

Fabrication - Casting

Commercial casting tubes

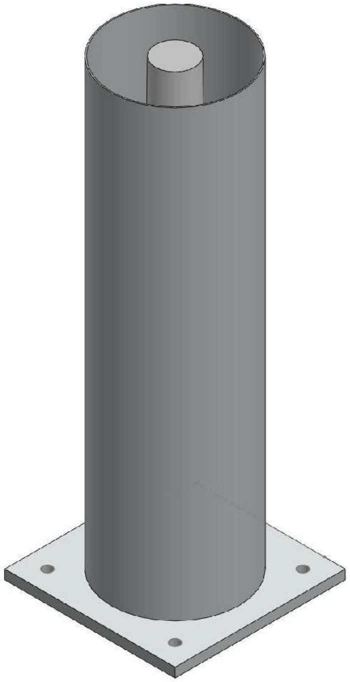
- Also serves as outer wall inhibitor

Polished Aluminum caps

- Center the coring rod and keep the propellant in the mold

Teflon Coring Rod

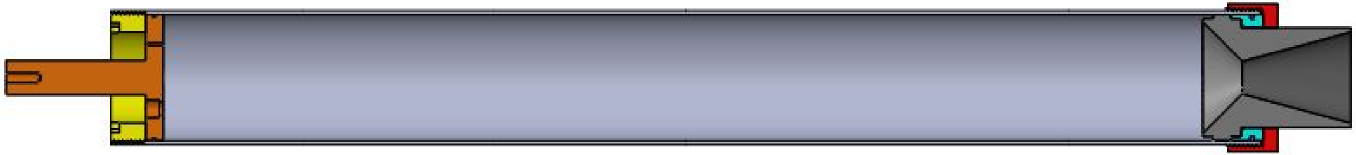
- Tapered for easy release



Motor Casing

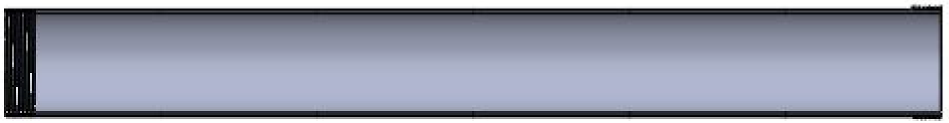
Consists of

- Case Wall
- Forward Retention Ring
- Forward Closure
- Nozzle
- Nozzle Carrier
- Thrust Ring



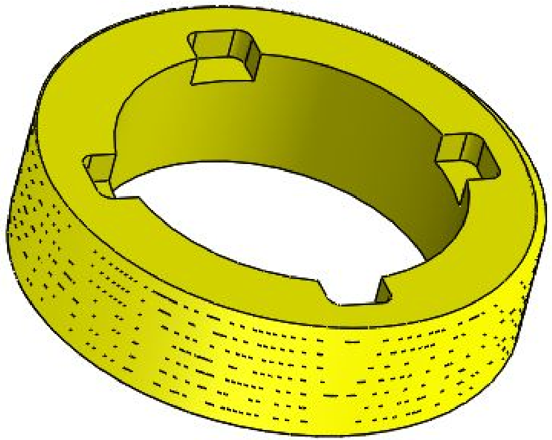
Motor Casing - Case Wall

Case Thickness	.13”
Inner Diameter	3.675”
Outer Diameter	3.88”
Case Length	33”
Upper Thread	3.75”-10 UN
Lower Thread	4”-8 UN
Material	6061-T6 Aluminum



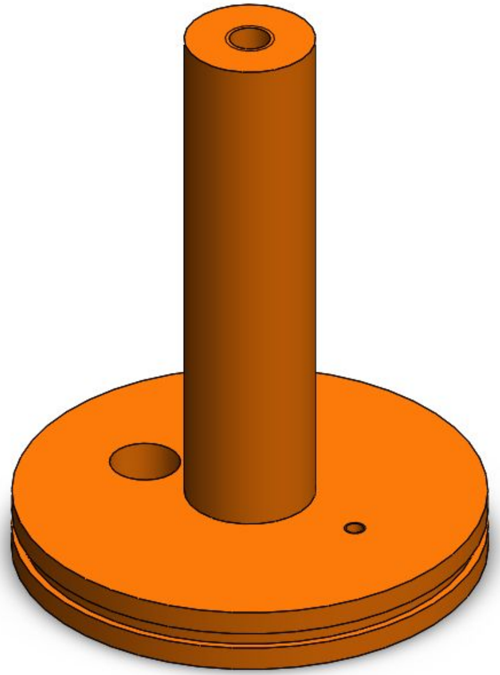
Motor Casing - Forward Retention

Inner Diameter	2.62”
Thickness	1”
Thread	3 ¾” -10
Material	6061-T6 Aluminum



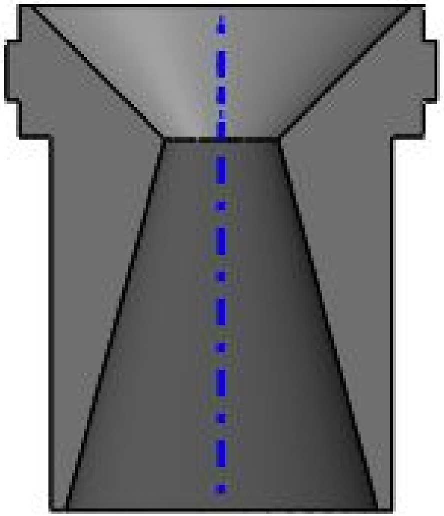
Motor Casing - Forward Closure

Thickness	.5”
Stem Height	4”
Outer Diameter	3.62”
Material	6061-T6 Aluminum



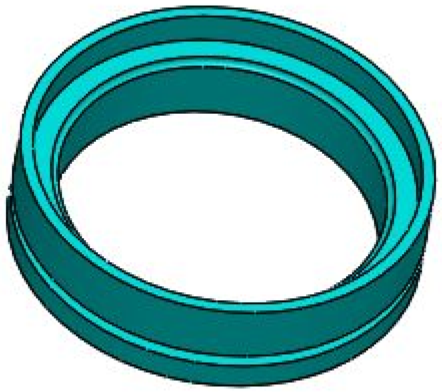
Motor Casing - Nozzle

Nozzle Component	Dimension
Throat Diameter	0.95”
Exit Diameter	2.62”
Length	4.24”
Inlet Diameter	3.2”
Material	Graphite



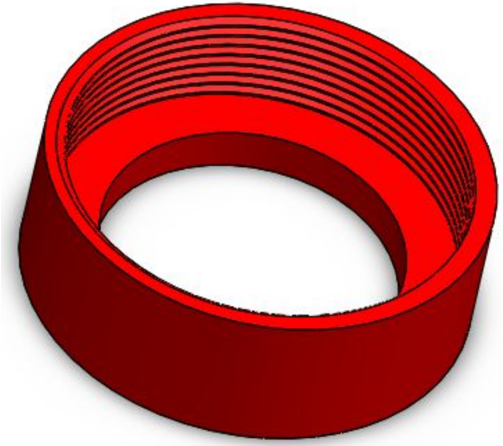
Motor Casing - Nozzle Carrier

Length	0.93”
Inner diameter	2.88”
Outer diameter	3.62”
Inner Step diameter	3.4”
Material	6061-T6 Aluminum
O-Ring Material	Silicone



Motor Casing - Thrust Ring

Outer Diameter	4.25”
Threads	4”-8 UN
Inner Diameter	2.88”
Base Thickness	.42”
Thread Height	1”
Material	6061-T6 Aluminum



Insulation - Liner

Phenolic Composite Liner

- Commercially Bought
- Protects the case wall

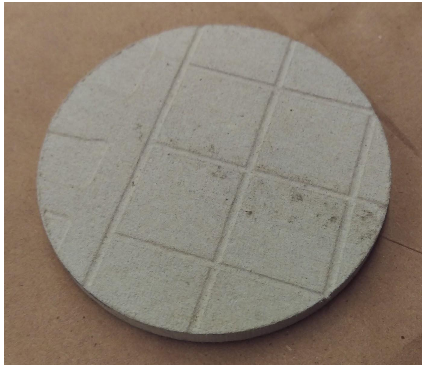
Outer Diameter	3.61”
Inner Diameter	3.375”
Length	29”
Thickness	.118”
Material	Convolute-Wound Cotton/Phenolic Composite

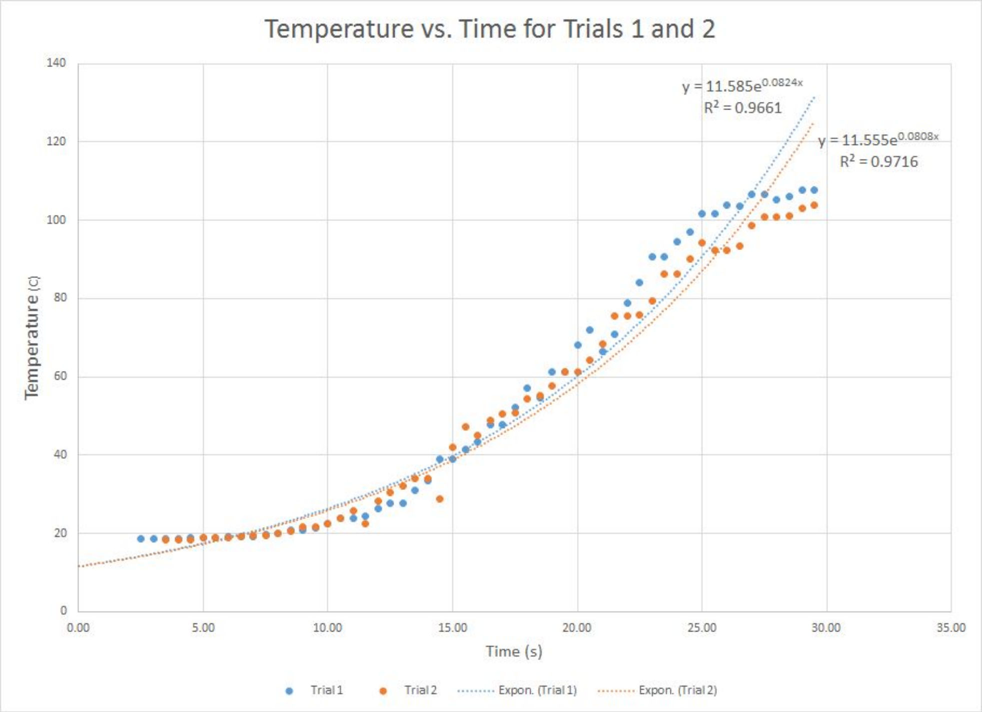
Insulation - Forward Disk

Forward Insulation Disk

- Cement Board
- Protects Forward Closure
- Burn-Through Time of 90s

Thickness	.25"
Outer Diameter	3.37"





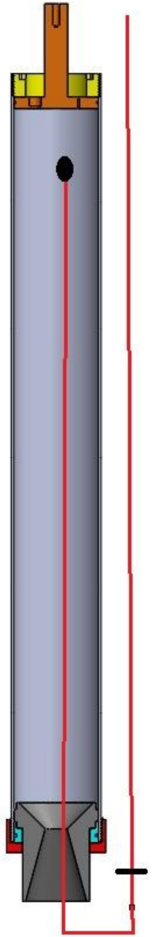
Motor Ignition

Internal Ignition System

- Starter inserted through the nozzle throat
- Ignition wires run outside the motor case through the centering rings
- Mechanical disconnect, allowing starter installation on the pad.
- Onboard avionics fires the starter when the vehicle is ready to be launched.

External Ignition System

- Need to be able to use due to launch field safety requirements.
- Starter connects to a relay controlled at the launch line.

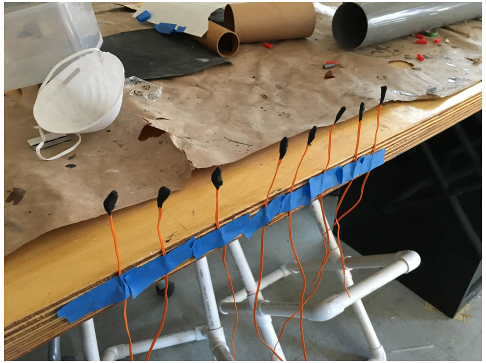


Starters

Hand-Dipped Starters with Commercial Pyrogen and Electric Matches

2 dips used for development motors

More can be used for large motors if needed



Overview of Major Risks

Risk	20%					
	10%		4		2	
	5%	7		6		5
	1%			3	1	
	0.1%					
		1	2	3	4	5

Risk ID	Risk Description
1	Erosive burning causes motor failure
2	Propellant density variation over/underpowers the motor
3	Propellant density variation causes motor failure
4	Equipment exposure to HCl
5	Personnel exposure to HCl
6	Heat transfer from the nozzle causes the threads to fail
7	Igniter does not fire

Risk Mitigation

Simulations

Verification of Motor Manufacturing

Careful Testing with rigorous
safety procedures

Replacement Components

	20%					
	10%	4				
Risk	5%	7				
	1%			6		
	0.1%			1, 3	2	5
		1	2	3	4	5

Test Plan

4 stages of development

1. Strand Burning
    - Propellant Characterization
2. 54mm Development Motor
    - Verify propellant behavior in a motor test.
3. 98mm 1G Development Motor
    - Verify case design, and fine-tune propellant manufacturing procedures
4. Flight-like Motor Static Testing
    - Test that the motor meets the requirements

Test Schedule

Week of	11/13	11/20	11/27	12/4	12/11	FINALS	1/8	1/15	1/22	1/29
Strand Testing										
54mm 1 grain										
98mm 1 grain										
Flight-like motor										

GSE

Overview of Requirements

- The launch-ready pad lifetime of Raziel shall be at least 2 hours.
- Propulsion testing shall comply with ESRA requirements.
- Propulsion shall have a successful static fire test prior to a test launch.
- Propulsion should have two successful static fires prior to a launch.
- All Ground Support Equipment shall be man-portable over a short distance (~500 feet).

Main projects:

- Solid motor test stand
  - DAQ
  - Ignition system
- Antenna tracker
- Rocket cooling system
- Trailer for storage and launch operations (pending parking)

Design Process

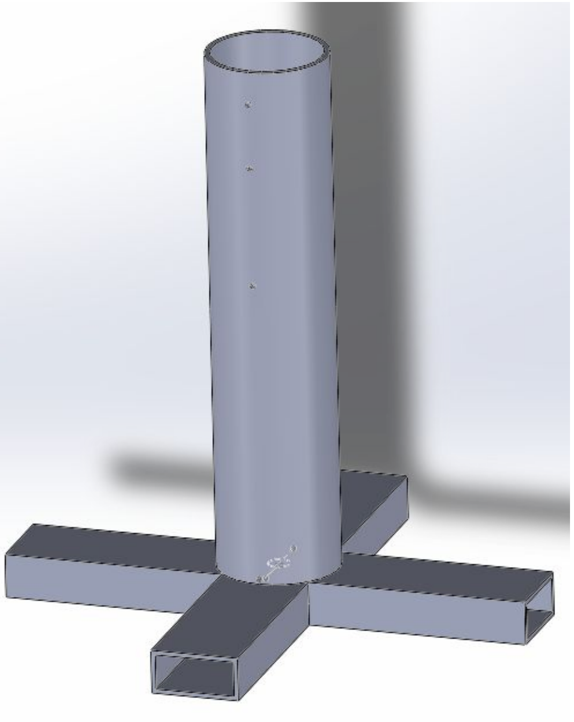
- Literature review for solid motor examples
- Needs for test stand:
  - Vertical firing for flight-like tests and safety reasons
  - Adaptable (one stand for several sizes)
  - Redundant data logging (on SD card and live streaming)
  - Pressure, temperature and force measurements
  - Remote ignition system
- Needs for antenna tracking:
  - Autonomously follow rocket's trajectory
- Needs for ignition system:
  - 2-step starting mechanism
  - Ignition remotely from max. 500 feet

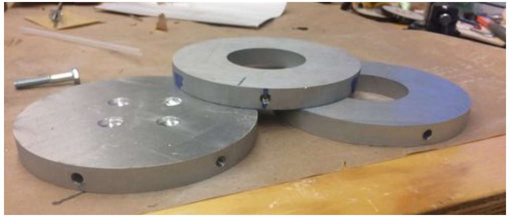
Test stand inspired by above design by Dewayne Doug (http://aeroconsystems.com/cart/test-stand-pictorial)

Technical Design and Analysis

Test Stand:

- Welded steel body
- Aluminum centering rings and load cell plate
  - (x2) 54 mm centering rings
  - (x2) 98 mm centering rings
  - Placed about 1.5” from ends of case
- 2’ tall, 2’ square base, 5.05” ID
- Test in Building 37 blast chamber and experimental outdoor launches (URRG)
  - Pursuing test location at Crow Island, Stow, MA

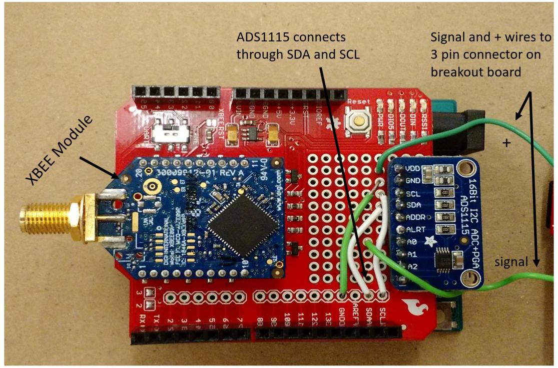


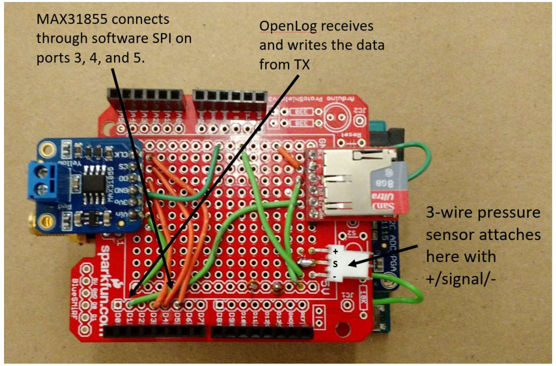


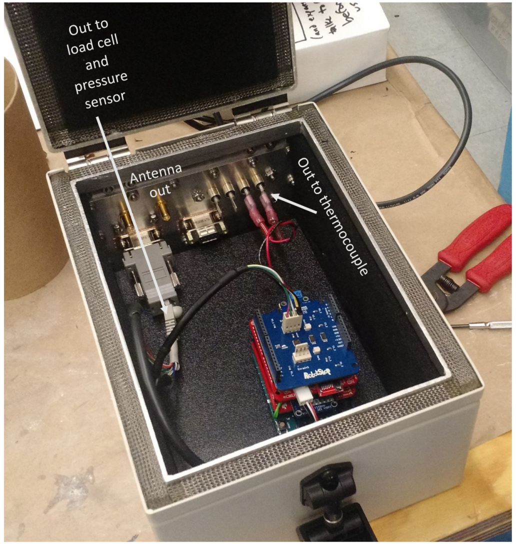
Technical Design and Analysis, Continued

DAQ:

- Arduino Leonardo
  - amplifiers and breakout boards for sensors
  - XBee radio to transmit data
  - SD card to log data
- Currently using Logger Pro for convenience due to faulty parts



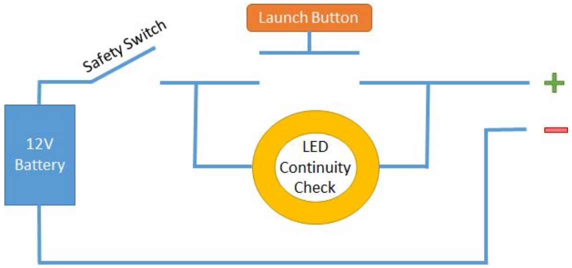




Technical Design and Analysis, Continued

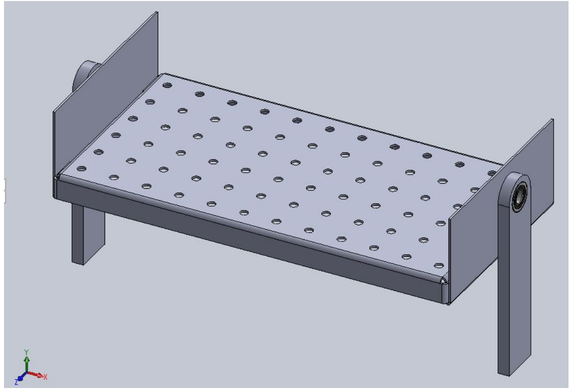
Ignition System:

- 2-step start
  - LED toggle switch and spring loaded button
- Toggle switch is also continuity test
- Powered by 12V battery

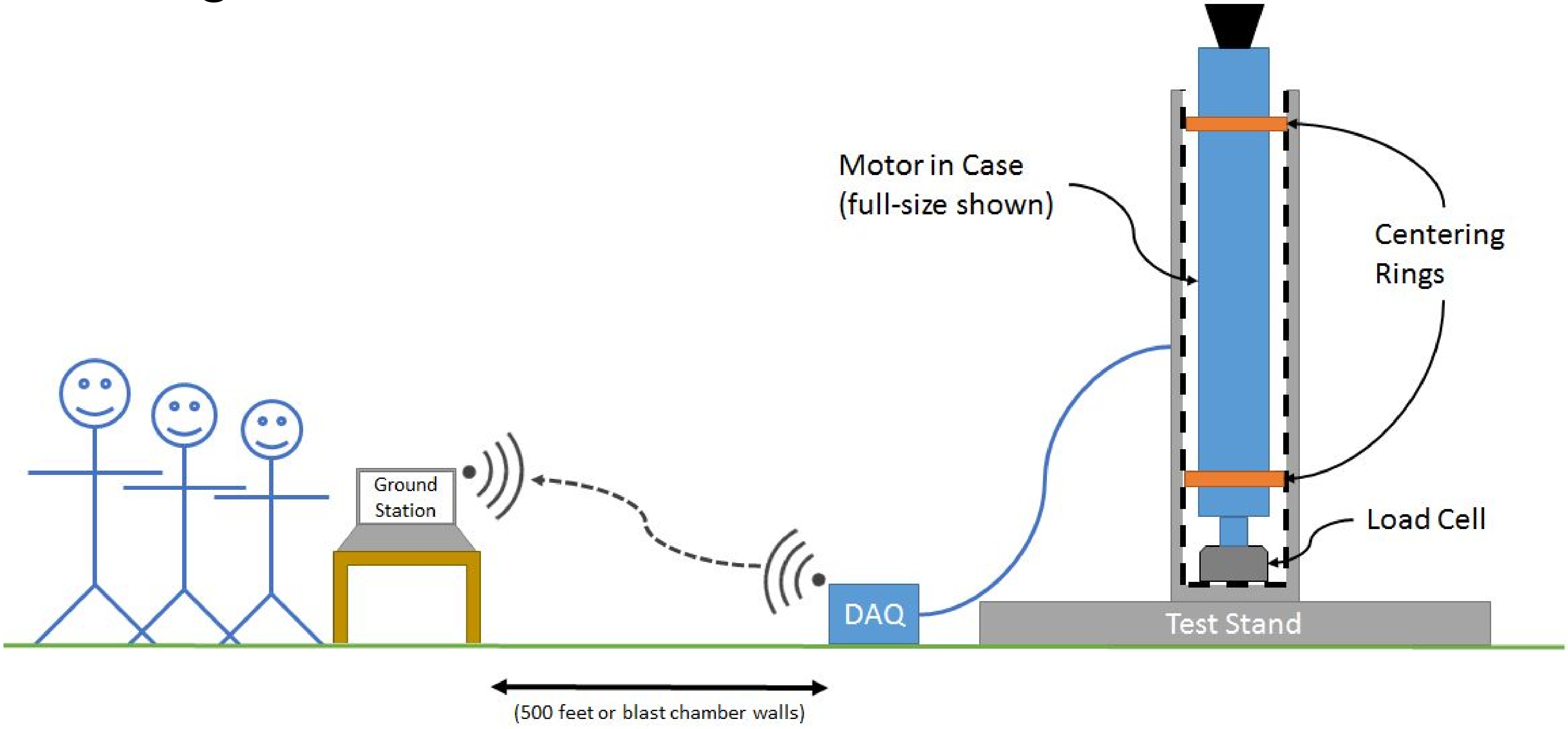


Antenna Ground Station:

- Aluminum and stainless steel construction
- 2 DOF gimbal with 2 Yagi antennas
- Tracking using reported live telemetry from rocket and simulation data passed through unscented Kalman filter



Testing Architecture



Key Technical Issues and Risks

Unmitigated Operational Risk Table: General Operations						
Risk	20%					
	10%	Cooling system: retraction failure	AGS: Degraded vertical slew, Downlink failure			
	5%		AGS: Degraded vertical slew or horizontal slew	Controller failure	Trailer mechanical failure	
	1%		AGS: Degraded horizontal slew failure			
	0.1%			Cooling system: structural failure	Cooling System: simultaneous retraction and interlock failure	Trailer structural failure
		1	2	3	4	5
		Impact				

Cooling System Mitigations: safety interlock to interrupt ignitor continuity or ground station process flow

Antenna Ground Station (AGS) Mitigations:

- Quick-disconnect pins so gimbal can be pointed manually
- Independent flight model to reacquire signal in the event of downlink failure

Trailer Mitigations: Thorough inspection before departure and during stops en route to launch sites

Key Technical Issues and Risks

Unmitigated Test Risk Table: Solid Test Stand During Test Firing						
Risk	20%					
	10%	Igniter malfunction: failure to ignite		DAQ failure		
	5%					Igniter malfunction: unintended ignite
	1%			Sensor failure		
	0.1%				Internal structure failure	Superstructure failure
		1	2	3	4	5
		Impact				

Mitigations:

- DAQ wireless transmission provides redundant data
- New data captures saved to new file
- Safety switch on ignition system visually and verbally confirmed in ‘safe’ position before personnel approach motor

Interfaces

- **Solid Test Stand:**
  - *Propulsion*: test custom solid rocket motors (all sizes)
- **Rocket Cooling System:**
  - *Avionics*: protect sensors and cameras from overheating
  - *Structures*: keep certain rocket body tubes out of direct sunlight
- **Antenna Ground Station:**
  - *Avionics*: tracking system helps reliably receive live telemetry from the rocket
  - *Recovery*: system will help locate rocket during/after landing for recovery operations
- **Trailer:**
  - *All subteams*: provides storage and transportation of critical equipment to and from launches and other events

Going Forward Plan

- **Solid Test Stand: Ready for 54 mm motor testing; two static fire tests complete!**
  - Blast chamber in Building 37
  - Pursuing outdoor test site at Crow Island, Stow, MA
  - DAQ: Currently using borrowed amplifier, our amplifier sent back to manufacturer for repairs

- **Rocket Cooling System: Currently brainstorming**
  - Sun shade
  - Clamshell enclosures
  - Silo with penetrable cover
  - Forced-air cooling (avionics section only)
  - Water-cooled fuselage
  - Refrigerated modules

- **Antenna Ground Station: Currently in design**
  - Anticipating construction and testing in January (MIT's IAP Period)

Systems Level Risk

System risks

	Risk	Reduction Plan
1	Schedule slip	Maintain descope options
2	Testing opportunities	Test early, maintain options
3	Loss of rocket	Test early, produce multiple parts
4	Insufficient funds	If necessary, descope and cut costs
5	Injury to members	Use PPE and safety plan

Overview of Systems Level Risks						
Risk	20%				1	
	10%				2	4
	5%				3	
	1%					
	0.1%					5
		1	2	3	4	5
		Impact				

Schedule (1st semester)

Task	9/3/2015	9/10	9/17	9/24	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3	12/10
Requirements Development															
System Design															
Payload System Design															
Strand Burn Testing															
54 mm, 1 grain program															
98 mm, 1 grain program															
Flight Motor Testing															
Recovery Deployment Dev															
Recovery Test Plan															
Avionics Test Plan															
PDR															
Raziel 1 Build															
Flight Test #1															
Structures Dev. Testing															
CO2 Deployment Dev.															
Payload Prototyping															
Development Reviews															
Raziel 2 Build															
Flight Test #2															
Flight Test #3															
Preparation for SAC															
SAC															

Schedule (2nd semester)

Task	1/2/2017	1/9	1/16	1/23	1/30	2/6	2/13	2/20	2/27	3/6	3/13	3/20	3/27
Requirements Development													
System Design													
Payload System Design													
Strand Burn Testing													
54 mm, 1 grain program													
98 mm, 1 grain program													
Flight Motor Testing													
Recovery Deployment Dev													
Recovery Test Plan													
Avionics Test Plan													
PDR													
Raziel 1 Build													
Flight Test #1													
Structures Dev. Testing													
CO2 Deployment Dev.													
Payload Prototyping													
Development Reviews													
Raziel 2 Build													
Flight Test #2													
Raziel 3 Build													
Flight Test #3													
Build Raziel 4													
Preparation for SAC													
SAC													

Task	4/3/2017	4/10	4/17	4/24	5/1	5/8	5/15	5/22	5/29	6/5-19	6/20-24
Requirements Development											
System Design											
Payload System Design											
Strand Burn Testing											
54 mm, 1 grain program											
98 mm, 1 grain program											
Flight Motor Testing											
Recovery Deployment Dev											
Recovery Test Plan											
Avionics Test Plan											
PDR											
Raziel 1 Build											
Flight Test #1											
Structures Dev. Testing											
CO2 Deployment Dev.											
Payload Prototyping											
Development Reviews											
Raziel 2 Build											
Flight Test #2											
Raziel 3 Build											
Flight Test #3											
Build Raziel 4											
Preparation for SAC											
SAC											

Thank you!