Psyche Lander Foot Subsystem

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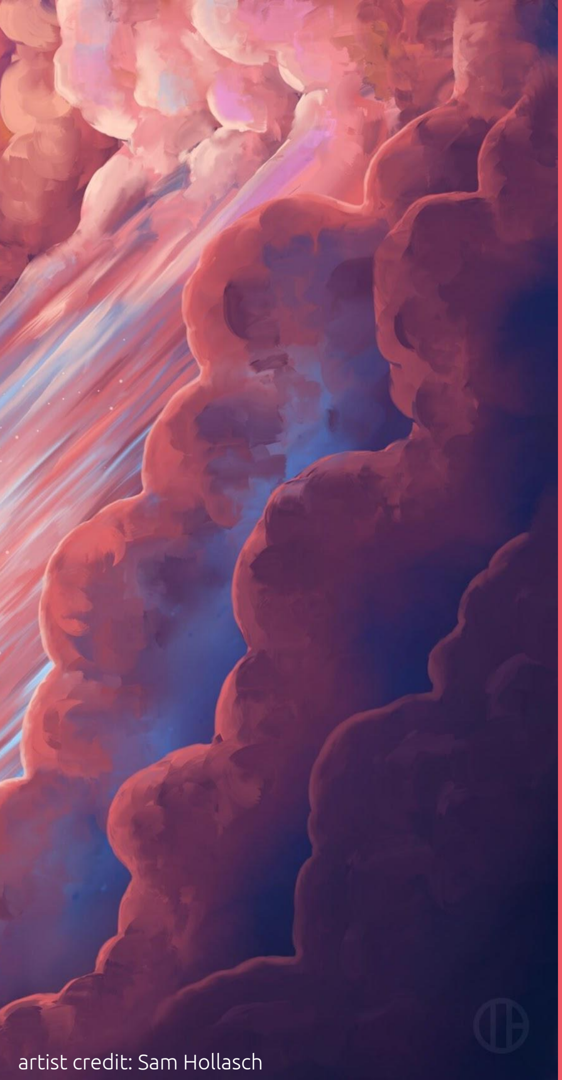
Team 07E | MIME 611.2



artist credit: Sam Hollasch

Phases

1

Concept Generation
What factors contributed to the design?
What ideas came forth?

2

Testing/Iterative
How did the design perform?
What did we learn?

3

Final Design
How do the feet attach to the surface?
How will the feet prevent surface rebound?

Concept Generation

What Were the Driving Design Factors?

Constraints: Project/Asteroid

Project:

- $500 Budget
- 20 Week Deadline
- No Given Lander Design
- Minimal Contextual Information
- Limited Access to Testing Locations
- Earth Properties

Asteroid:

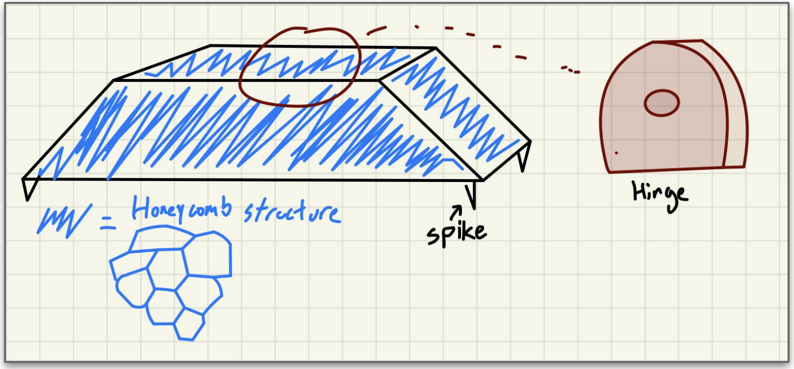
- Unknown Surface Compositions
- Unknown Surface Densities
  - Loose Regolith, Rock, Metal, or a Combination
- Acceleration due to Gravity = $0.144\ m/s^2$
  - Surface Rebound
- Possible Existence of a Magnetic Field
- Extreme Geological Features

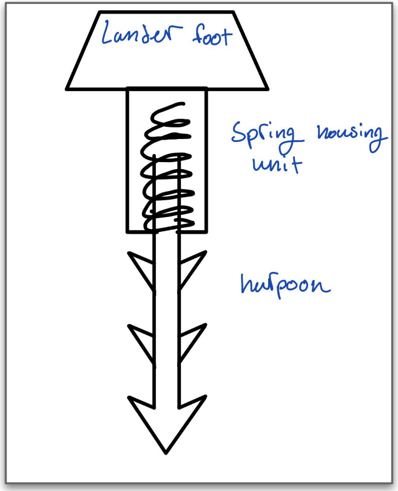
Design Requirements

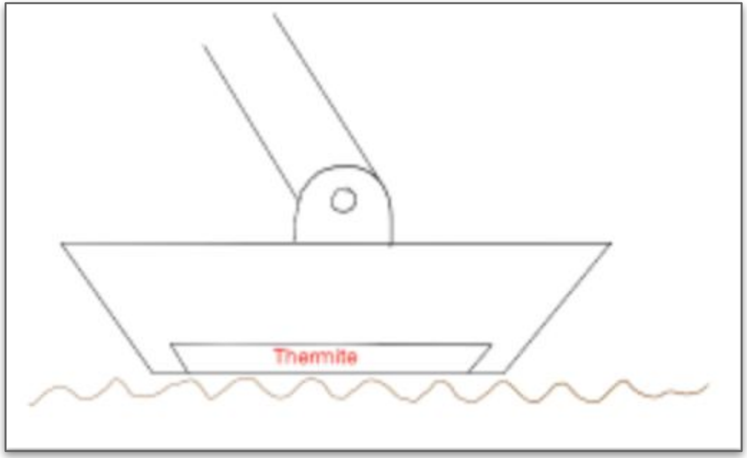
- Promote a Static Mass
  - Minimize/Eliminate Surface Rebound
- Ensure the Safety of the Scientific Instruments Located in the Lander bus
- Total Costs Equate to $500 or Less

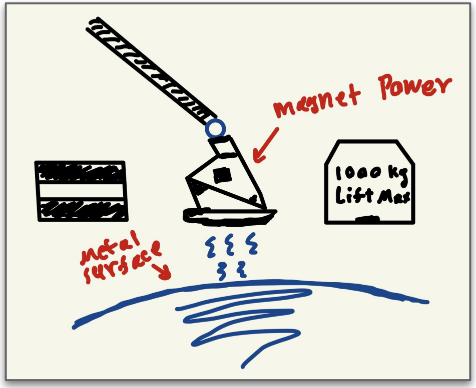
Success!

Initial Concepts

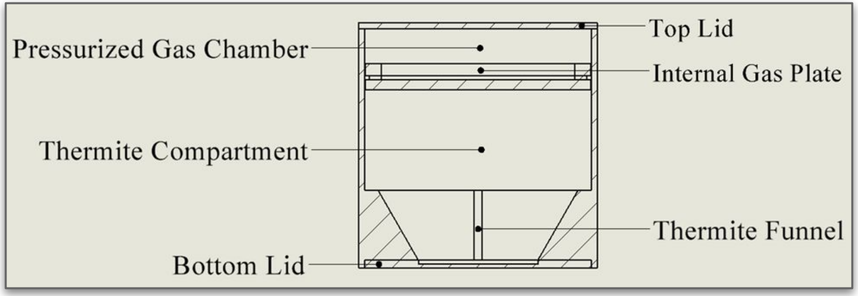


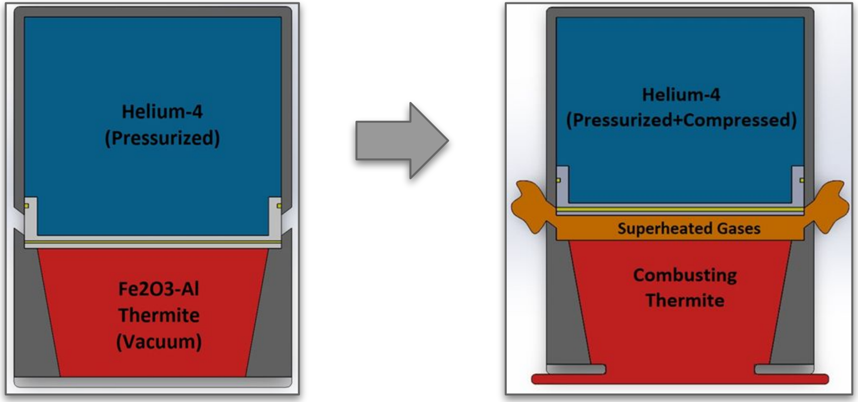




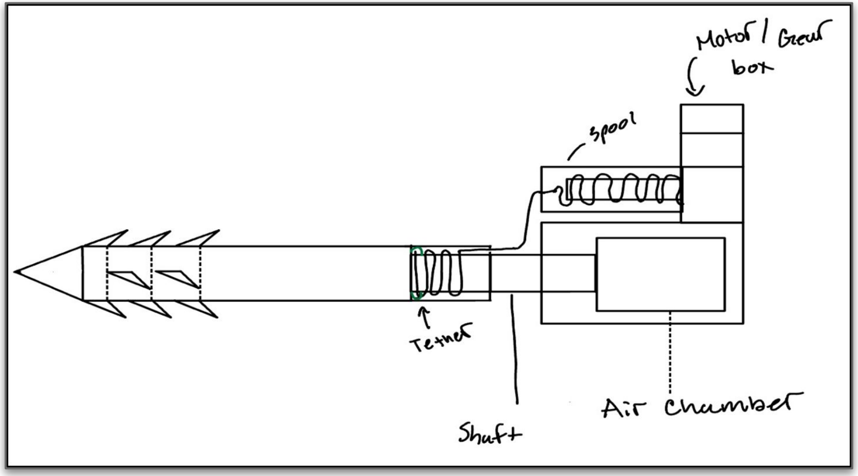


Initial Concepts Cont.



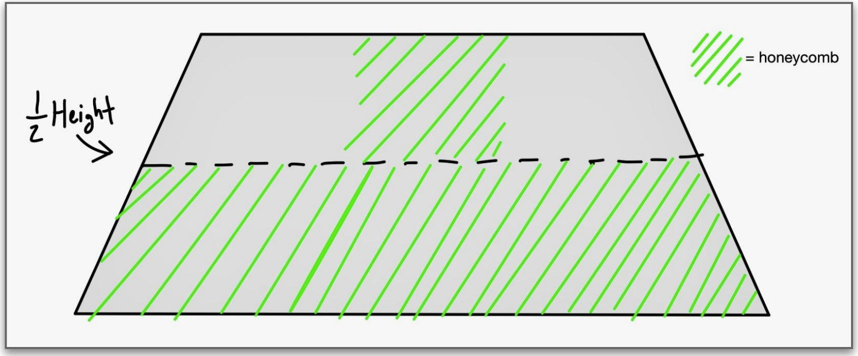


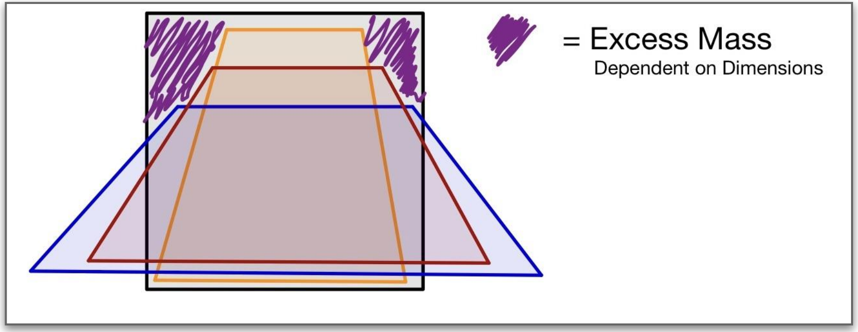
- Relies on gas produced by combusting thermite
- Internal Gas plate and vents to regulate combustion pressure (apply constant pressure)

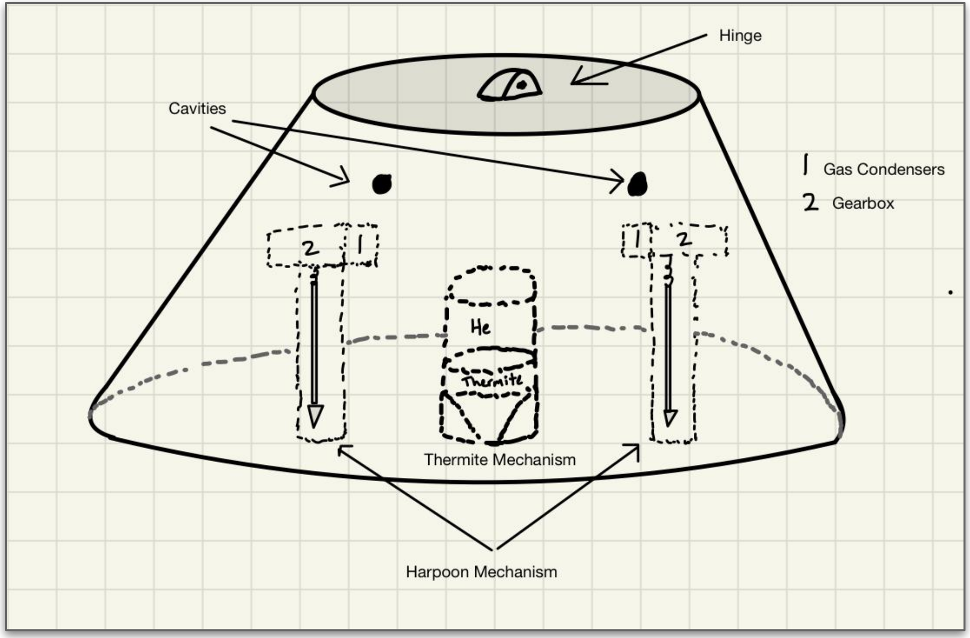


- Relies on air compressor

Initial Concepts Cont.

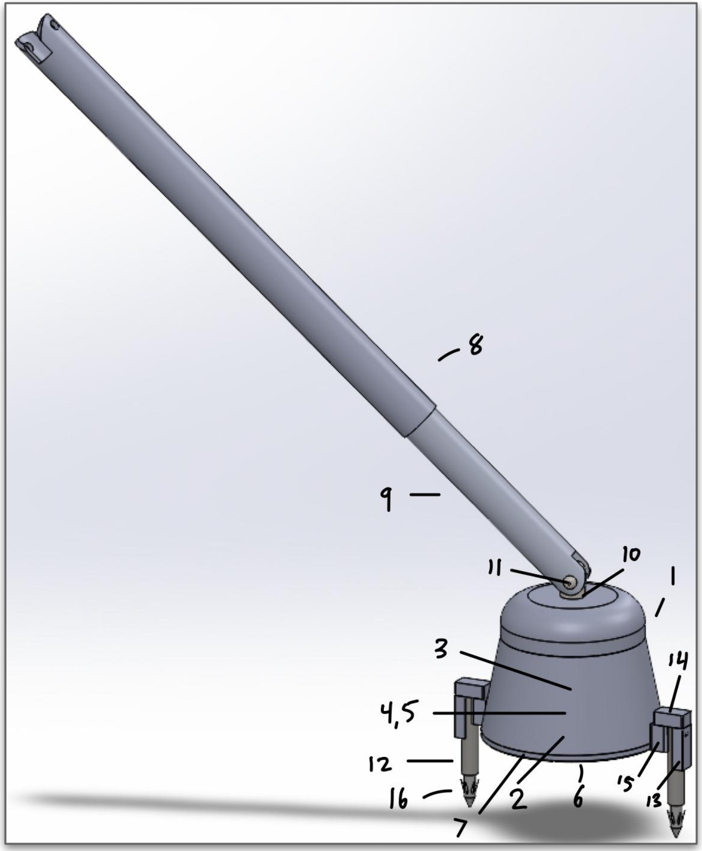


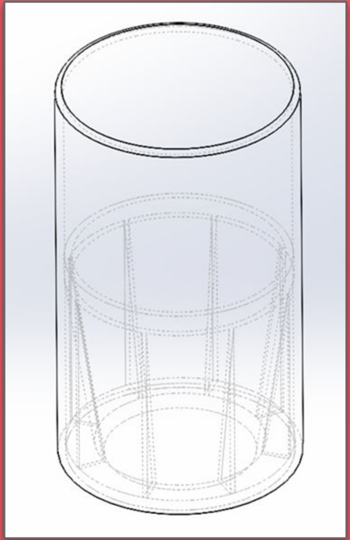


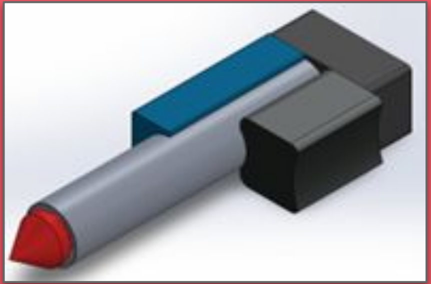


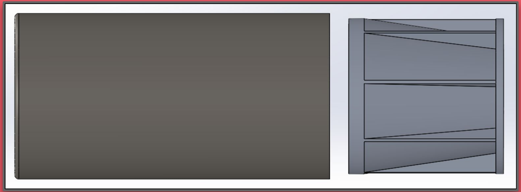
Initial Concepts Cont.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Foot Outer Housing	Outer cover for the foot assembly.	1
2	Extruded Honeycomb	Shock absorbing through plastic deformation.	16
3	Outer Housing	Housing for the thermite and helium chamber.	1
4	Internal Plate	Separating plate between thermite chamber and pressurized helium chamber.	1
5	O-Ring	Rubber o-ring to create a tight seal between pressurized and non-pressurized chambers.	2
6	Low Melting Point Bottom Plate	Polymer plate that melts upon thermite ignition.	1
7	Base of Foot	Contact point between foot and Psyche surface. It also directs the flow of molten thermite.	1
8	Primary Strut-Upper	Upper half of the compressing strut section.	1
9	Primary Strut-Lower	Lower half of the compressing strut section.	1
10	Strut Foot Mount	Mounting point for the foot to a strut.	1
11	Lower Strut Pin	Mounts the strut to the foot.	1
12	Harpoon Housing	Houses the harpoon and acts as a barrel to direct it towards the surface.	2
13	Air compressor housing	Houses the air compressor.	2
14	Spool Housing	Houses the wire spool connected to the harpoon.	2
15	Gear Box Housing	Houses the motor that retracts the harpoon.	2
16	Harpoon	Used for puncturing the surface of Psyche.	2









Chosen Concept

- 2 Anchor Mechanisms:
  - Harpoon system
  - Thermite system
- No External Housing
- No Honeycomb Structure
  - Not Feasible
    - Requires Relatively Flat Surface (+/- 10°)
    - Problems with Extreme Terrain

Testing/Iterative

How Did the Design Perform?

Harpoon: Testing & Proof of Concept

Successful penetration into soft surface.

Unsuccessful penetration into denser surface.

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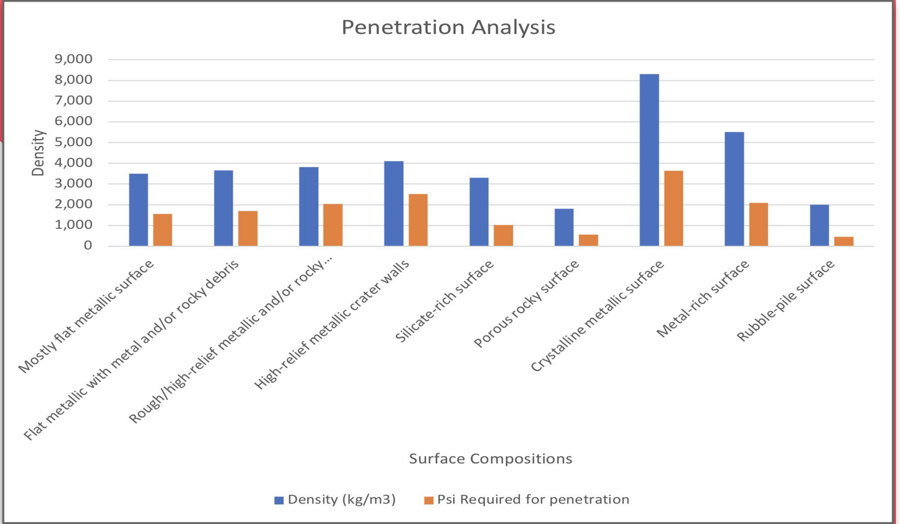
Surface Type	Density (kg/m3)	Psi Required for penetration
Mostly flat metallic surface	3,400-4,100	1,290-1,560
Flat metallic with metal and/or rocky debris	3,400-4,100	1,400-1,700
Rough/high-relief metallic and/or rocky terrain	3,400-4,100	1,680-2,040
High-relief metallic crater walls	3,400-4,100	2,070-2,520
Silicate-rich surface	2,200-3,300	840-1,020
Porous rocky surface	1,200-1,800	460-560
Crystalline metallic surface	7,800-8,300	2,990-3,630
Metal-rich surface	4,500-5,500	1,720-2,090
Rubble-pile surface	1,000-2,000	380-460



Harpoon Analysis

New Design Implementations

- Pneumatic Actuator
- Pressurized air chamber
- Control valve

- Increase pressure to 4000 psi to ensure proper surface penetration at optimal depth
- Lighter cables reduce drag and resistance from spool

Thermite: Proof of Concepts

Robust Surface Composition Tests

Metal

Rock (Medium/Fine)

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Thermite: Iterative Testing

Closed Top

Open Top

Tested both options to analyze penetration depths.

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Thermite: Iterative Testing Cont.

Thermite Analysis

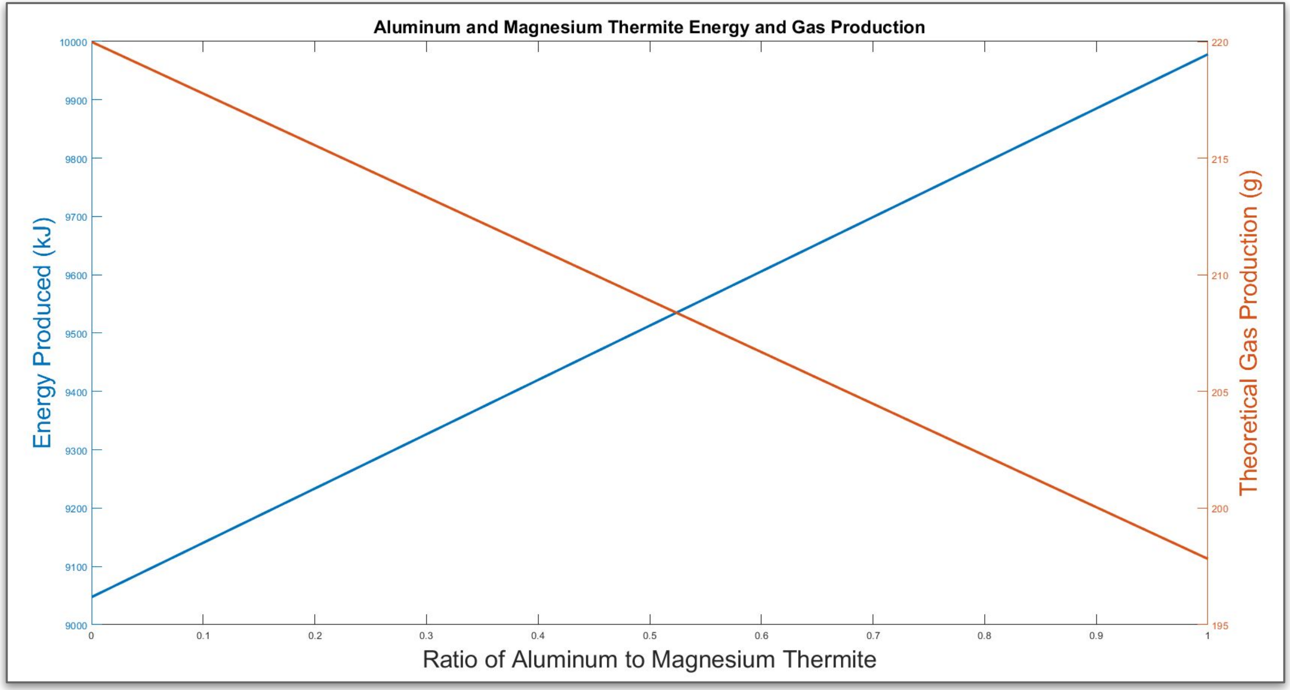
- Baseline Penetration Tests
- “Pressurized” Penetration Tests
- Attempt to Eliminate Gravity as a Variable

- The internal gas plate is unnecessary and adds additional points of failure
- Reactant mass percentages adjusted from 23% Al + 77% Fe_2O_3 to 30% Al + 70% Fe_2O_3
- A rocky terrain would be used for future testing as it is more realistic

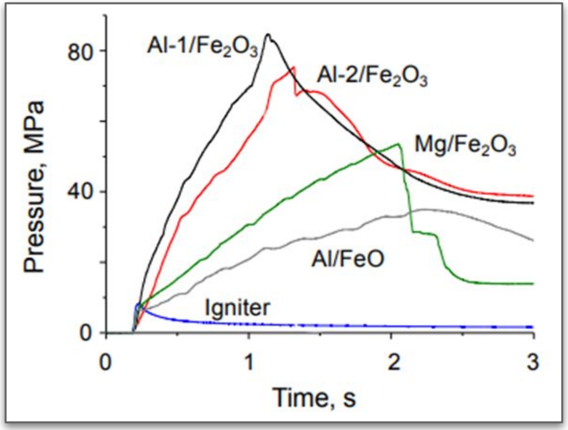
Thermite Analysis Cont.

- The gas production of thermite to expel the molten liquid increases horizontal spread
- The aluminum outer housing fused well with the molten thermite products
- Addition of magnesium to the composition creates additional gas, lowers the ignition temperature, and a violent reaction

Thermite Composition



- Al-Fe2O3 and Mg-Fe2O3 Mixture
  - Lower ignition temperature than pure Al-Fe2O3
- 20% Al + 10% Mg + 70% Fe2O3
  - Mg thermite burns slower to create lower pressure gradient



Final Design

How Will the Feet Prevent Surface Bounce?

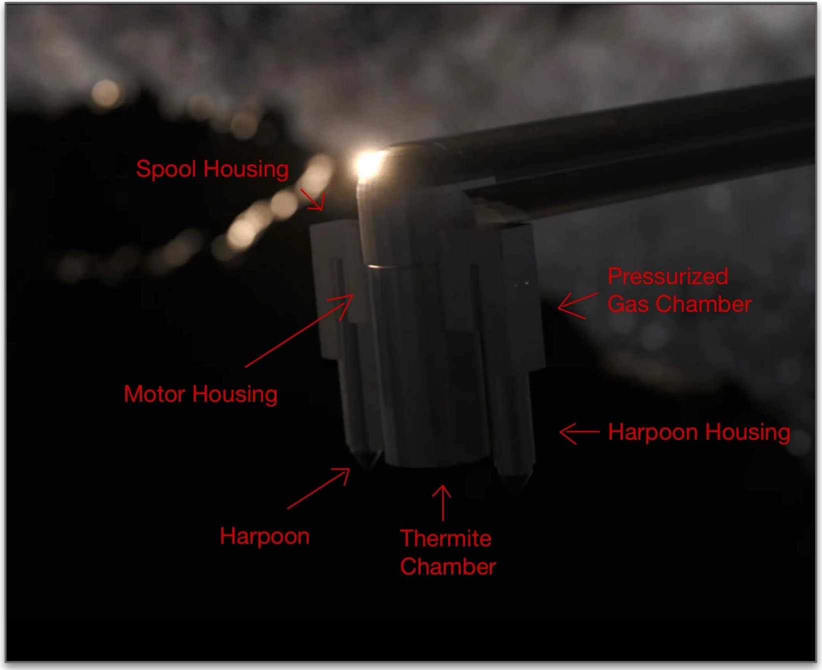
Final Design & Hypothetical Attachment Point

Possible Attachment Strategy:

- Ball Joint Hinges w/ Supporting Struts
- TIG Welded to the Top Surface
- Allows for “Gimballed” Movement

The project scope did not include the legs, solely the foot subsystem.

Come see the physical model in-person at the 2023 Oregon State University Engineering Expo!



Design Assumptions:

- The landing site may be inclined; the landing site is not necessarily flat.
- The lander may touchdown in a position that is not oriented perpendicular to the asteroid's surface (+/- 20°).
- The lander will touchdown using passive soft-impact techniques.
- The lander will not return to Earth.
- The lander fuselage will act as a rigid body through all life phases.
- The ignition power sources, control system, and relay will be placed within the lander bus.
  - Ignition source & control system connections will run through the legs of the lander.

Anchor Mechanisms

Harpoons

Four Main Components:

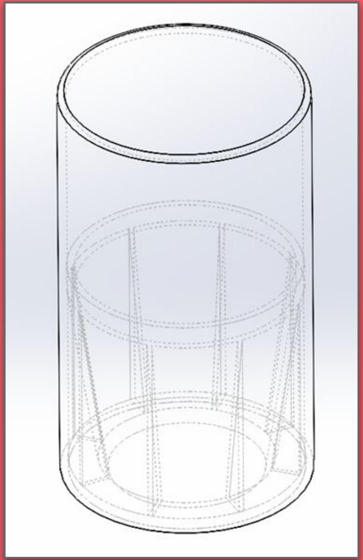
- ½" Radius Titanium Alloy Harpoon
- 80 rpm Turbine Motor
- 4000 psi Minimum Compressed Air Cylinder
- 25' of ¼" Galvanized Aluminum Tethering

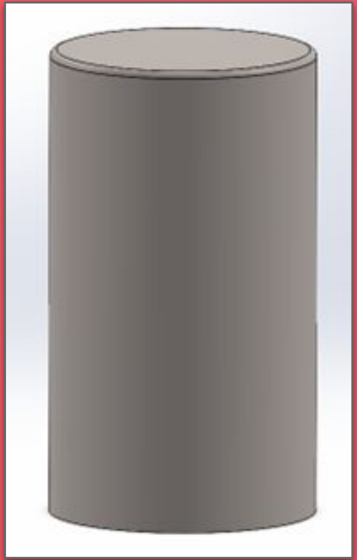
Thermite Cylinder

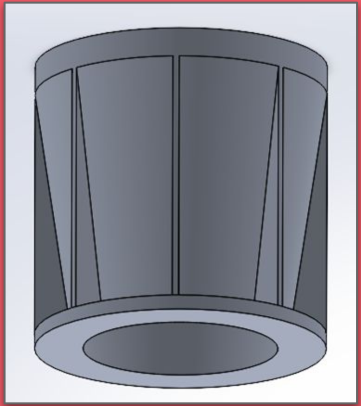
- 20% Al + 10% Mg + 70% Fe_2O_3 Composition
- Titanium Alloy Outer Housing
- 1060 Aluminum Nozzle
- Pressure Differential (Vacuum) Expels Thermite
  - Liquid Roots
  - Surface Weld

Thermite Cylinder

- Addition of Fins to the Nozzle
  - Seats Nozzle into Outer Housing
  - Provides Structural Support to Prevent Deformation
  - Allows for thinner walls
- Elimination of Internal Gas Plate
  - Reduce Points of Failure
  - Redundant Feature

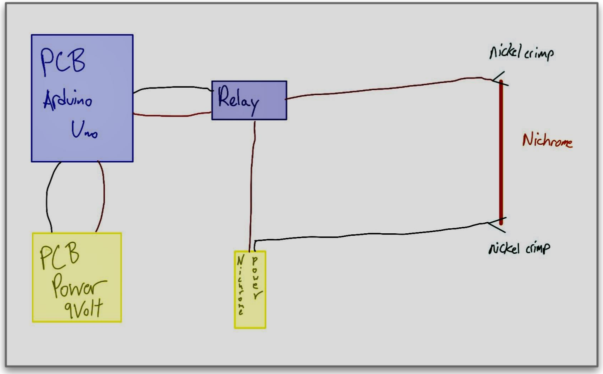


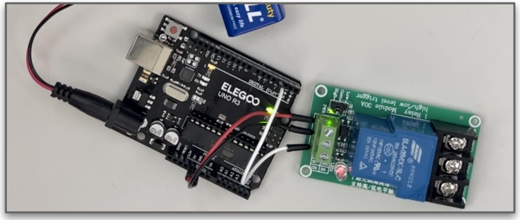




Thermite Ignition

- 2 systems
  - Control (PCB)
  - Nichrome
- 30 Amp Relay
  - Closes/Opens Nichrome Circuit
- Lithium-Polymer Battery
  - Higher Discharge Rates
- Copper (Cu) Wire
- Nickel Springs
  - Crimp Replacement (Cost Reasons)
  - No Tinning
- Nichrome Wire (28 Gauge) | Can Heat Up To 1150℃
- ELEGOO Uno R3 (PCB Board)
  - Actuates Relay





Thermite Ignition

1. PCB Actuates Relay
2. Relay Closes Nichrome Circuit
3. LiPo Battery Outputs current
4. Nichrome Heats to Mg Auto-Ignition temperature
5. Nichrome Ignites Mg
6. Mg Ignites the Remaining Thermite Composition

Consumables:

Nichrome Wire, Ni Springs, and ~ 1 foot of the Cu Wire

Anchoring Comparisons: Hypothetical Surface Compositions

Anchor Points:	Case I **Loose Regolith**	Case II **Rock**	Case III **Metallic**
	Min: 6 | Max: 9	9	Min: 3 | Max: 9
	Harpoon penetrates the deepest; Thermite spreads horizontally to promote stability; Thermite penetrates deeper than Case III	Harpoon penetrates deeper than Case IV; Thermite penetrates the deepest vertically (dependent on the porosity of the surface)	Harpoon and Thermite penetrate the least; Thermite fuses/welds with surface

Case IV (Metallic/Rock): Harpoon penetrates deeper than Case III; Thermite penetrates deeper than Case III (dependent on the porosity of the surface); Thermite fuses/welds with metal compositions

Future Iterations

Thermite:

- Addition of a Preheating Charge
- Silica Based Reflective Coating
  - Limits Undesirable Heat Loss
- Objective Specific Design Modification
- Viscosity Related Composition Optimization

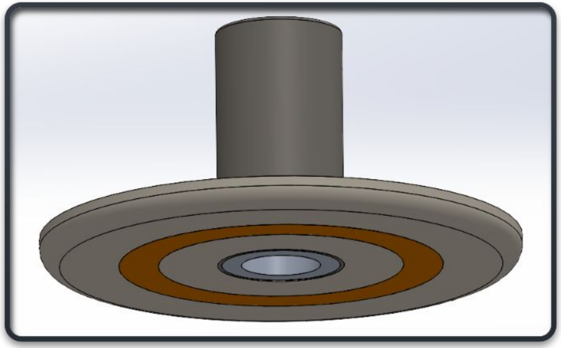
Harpoon:

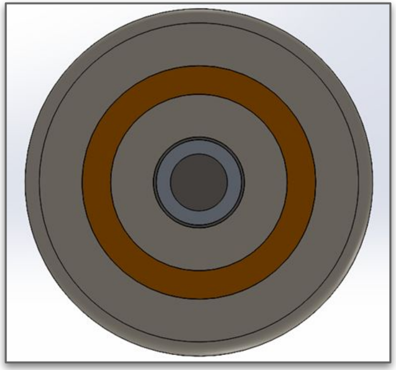
- Rifling of the Harpoon Cylinder & Addition of Pitched Barbs
  - Deeper Penetration due to an Increase in Rotational Energy
  - Greater In-Flight Stability due to Angular Momentum

Overall Structure:

- Filleted Edges of Cylinders
  - Reduces Unnecessary Shearing
- Honeycomb Addition
  - Implement in High Stress Areas to Reduce Unnecessary Cracking/Buckling

Preheating "Charge"





- Prevent or limit instantaneous solidification upon contact with surface
- Ring shaped preheating "charge" concentrated into the ground and towards center
- Thermite should be used rather than electric heating element to conserve power

Project Video: MIME 611.2 (OSU)

Powerpoint: Watch on YouTube for 4K quality
PDF: Click on the image

“FIX YOUR LITTLE PROBLEM AND LIGHT THIS CANDLE.”

Alan Shepard

Sponsors

Acknowledgements: Parker Choc, Tyler McHuron-Guss, Kelton Orth, Sheriff Jerry Williams, and the Refuge.

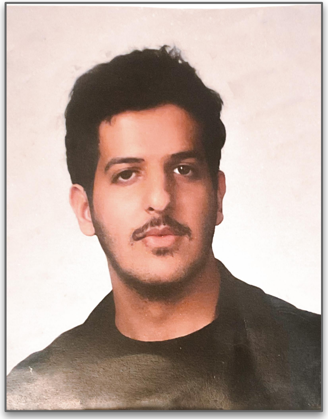
Mission & Project Queries

Psyche Mission: https://psyche.asu.edu/
Project: https://events.engineering.oregonstate.edu/expo2023/project/nasa-psyche-landing-system

Team Lead: John Parks
Harpoon Leads: Joseph Pittman | Ahmed Almansouri
Thermite Leads: Jack Duncan | John Parks
Ignition Lead: John Parks

* Contact information is available on the next slide. *

Meet the Team: 07E | MIME 611.2



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