MOONPads:

Microwave-Sintering Operations Of Nanophase-Iron Pads

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Outline

Microwave Sintering

Uses and impacts

Proposed Rover Design

Design showcase & weight/size/cost analyses

Technical Managemen t

CONOPS - from landing to future uses

Impacts and Effects

Scientific, financial, and social impacts

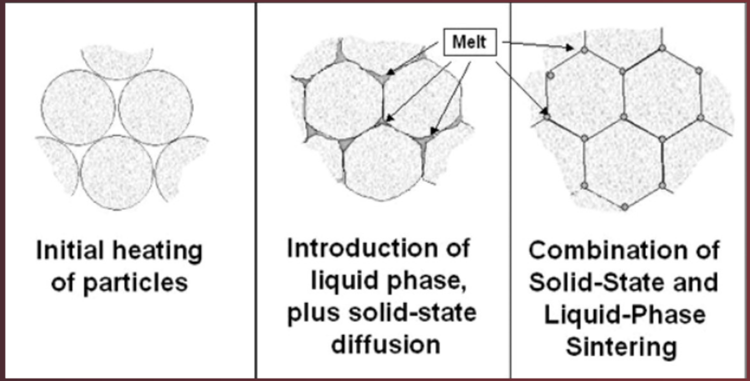
Conclusions

Proposal takeaways

Microwave Sintering

Microwave Sintering

- Microwave Sintering fuses particles with microwaves
  - Volumetric heating process
  - Power efficient with absorptive materials
- Testing on lunar simulant JSC-1 shows:
  - Strong material properties
  - Thermal runaway behavior

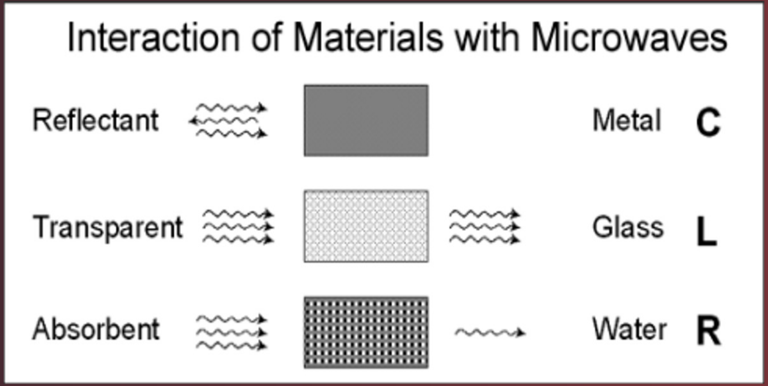


Taylor, L. A., and T. T. Meek (2004)

Microwave sintering is a power efficient process which can result in strong material properties

Microwave Material Classification

- Microwave Material Classifications:
  - Reflectant
  - Transparent
  - Absorbent
- Large metal grain sizes are reflectant
- Small metal grain sizes are absorbent



Taylor, L. A., and T. T. Meek (2004)

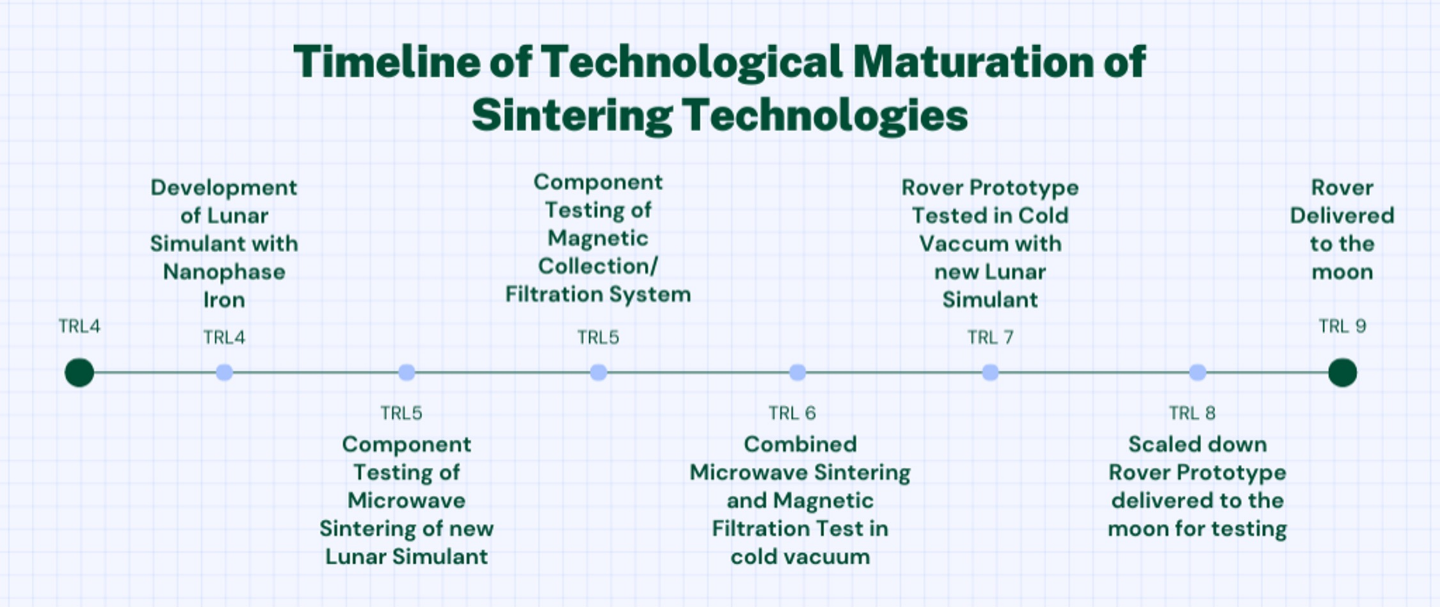
Microwave interaction with iron varies significantly with grain size

Improving Microwave Sintering Data

- Smaller grain sizes in lunar regolith results in:
  - Faster heating rates
  - Inaccurate spatial profile of heating
    - Unknown composition and properties of final products
  - Different onset and location of thermal runaway
    - Unpredictable thermal gradients
    - Different heating risks

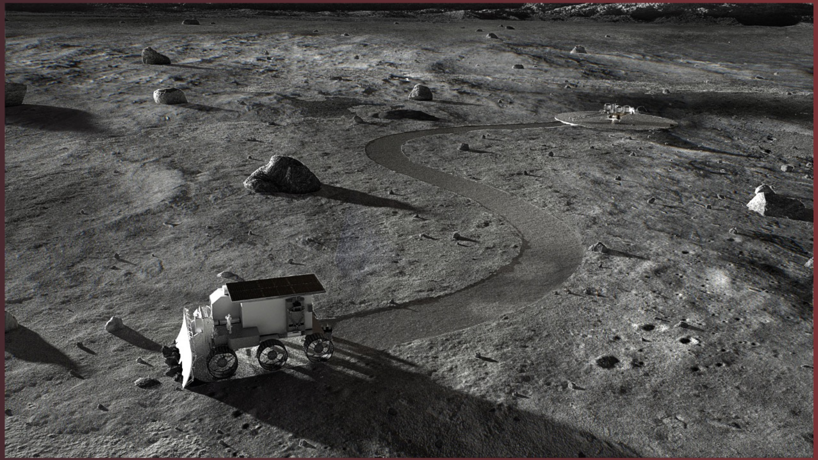
New simulants with accurate iron grain sizes improves validity of testing lunar sintering.

Microwave Sintering Path to Adoption



Proposed Applications of Regolith Sintering

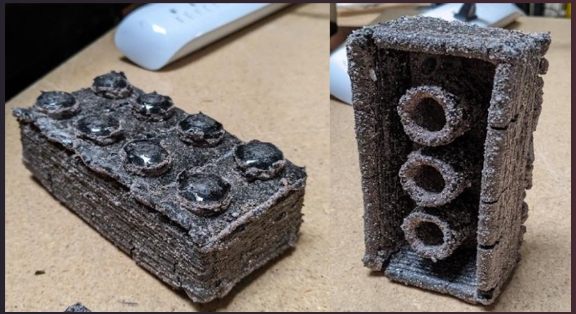
- NASA selected *Redwire* in 2023 to develop sustainable lunar architecture:
    - Landing pads
    - Roads
    - Foundations for habitats (horizontal infrastructure)



Redwire Corporation (2023).

Proposed Applications of Regolith Sintering

- *Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT)* at NASA Marshall is developing lunar regolith densification methods:
  - Processes:
    - Laser-and Microwave-sintered processes
    - Regolith melting/forming
  - Materials:
    - Cementitious
    - Geopolymer/Polymer
    - Thermosetting materials



(MMPACT @ Marshall Space Flight Center)

(MMPACT @ Marshall Space Flight Center)

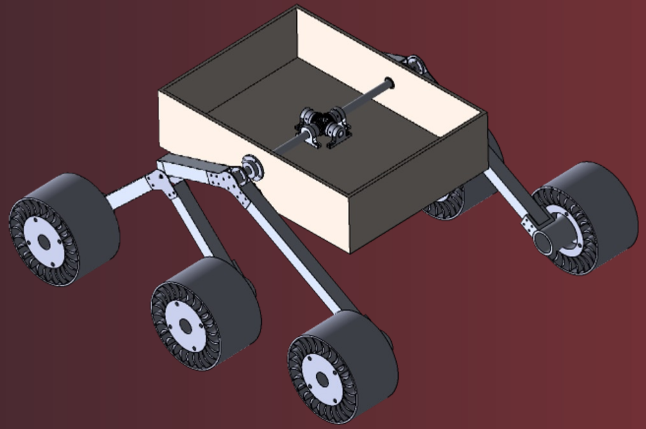
Rover Design

Design and Configuration

Rover Design

Part	Dimensions (cm)
Bottom	150 x 40 x 0.3125
Front	40 x 56 x 0.3125
Back	25 x 40 x 0.3125
Sides (x2)	200 x 25 x 0.3125
Top (x2)	400x 40 x 0.3125

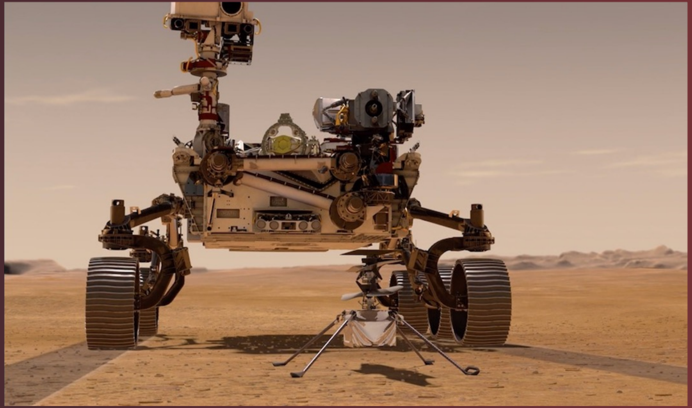
- Aluminum 6061 -T6 for body and leg tubes
- Microwave material Titanium grade 5



GrabCad (2019)

Other technologies and instruments required

- Plutonium 238 Radioisotope Heating Unit
- Multi-layer insulation
- Autonomous and manual movement software
- Cameras
- Communication antennas
- Specialized wheels



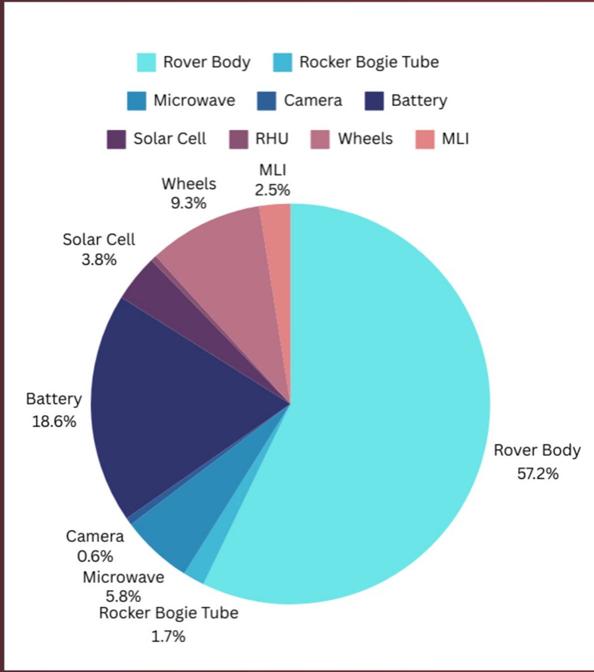
SpaceFlight Now (2020)

National Air and Space Museum (2021)

Aerospace Fabrication (2024)

Weight Breakdown

Part	Weight (kg)*
Rover Body	24
Rocker Bogie Tube (2)	0.7
Microwave	2.4
Camera	0.25
Battery	7.8
Solar Cell	1.6
RHU	0.2
Wheels (4)	3.9
MLI	1.05
Total	**41.9**



*Truncated Values

Cost Breakdown

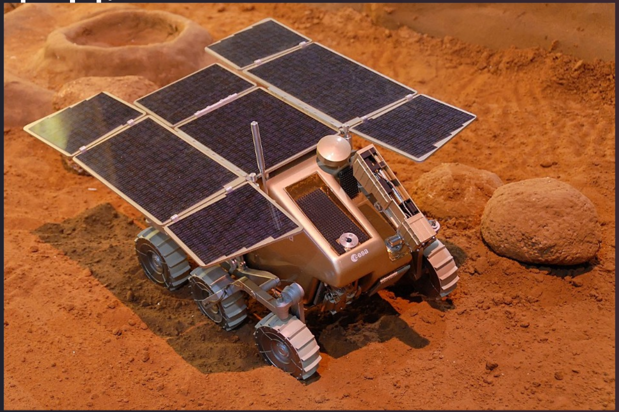
Part	Cost (USD)*
Rover Body	871
Rocker Bogie Tube (2)	652
Microwave	554
Camera	4000
Battery	167
Solar Cell	1000000
RHU	6560000
Wheels (4)	8000
MLI	1313
Total	**7575447**

*Rounded to the nearest dollar

Power Storage and Generation

Solar Panels

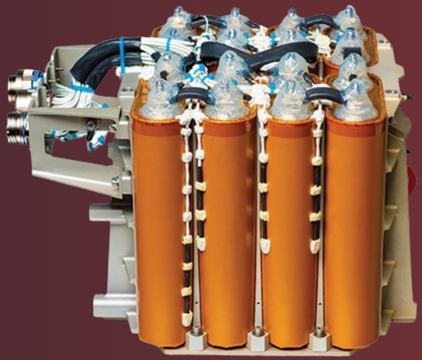
- 1 m x 2 m triple-junction solar panel
- Nitinol wires for shaping and



ESA (2007).

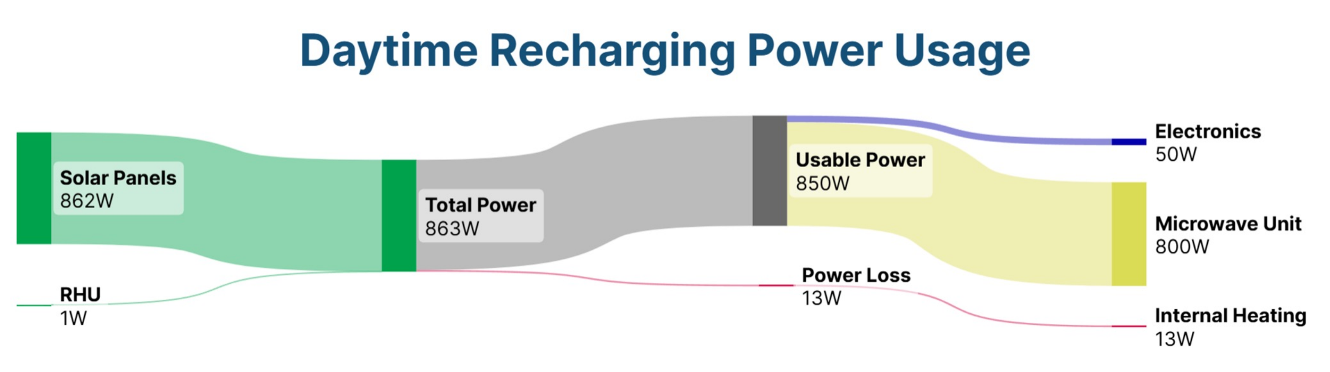
Power Storage

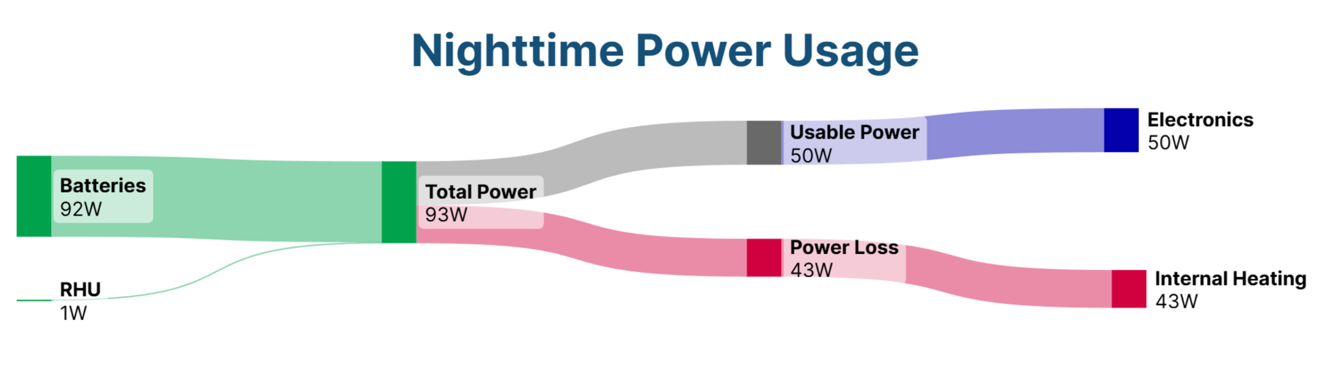
- Required 1200 Wh storage
- Lithium ion cylindrical batteries



Eaglepitcher (2024).

Power Analysis

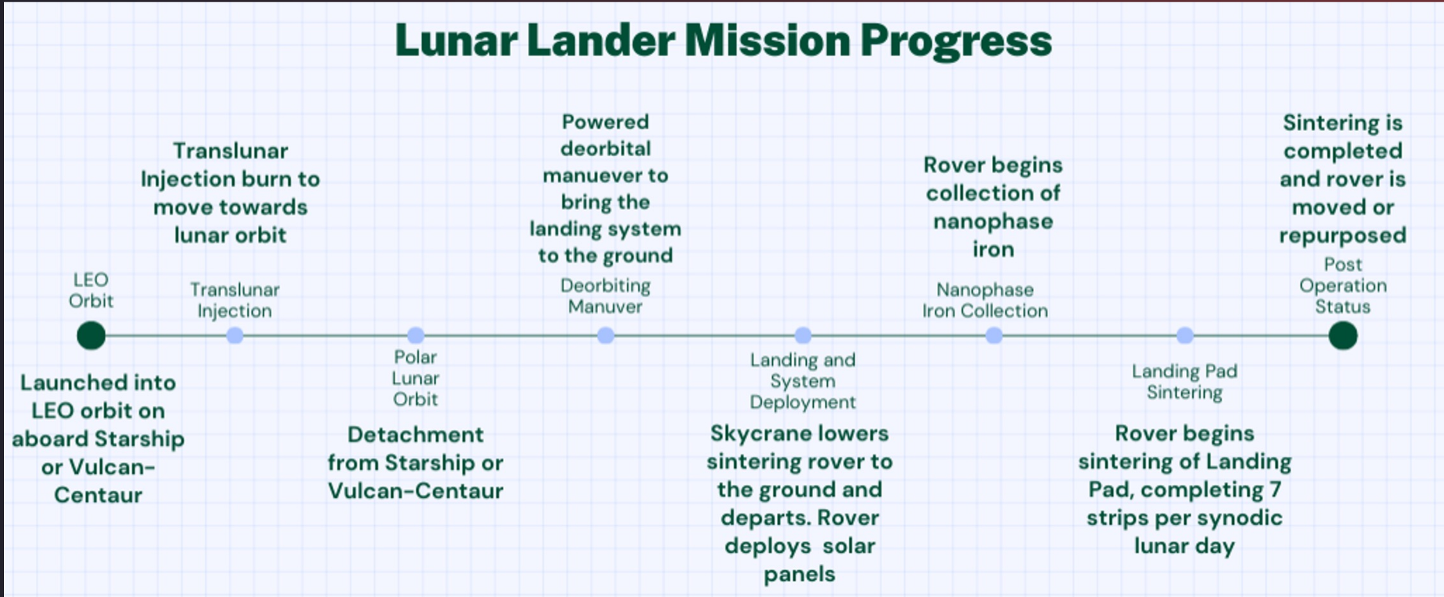




Technical Management

Implementation and Schedule

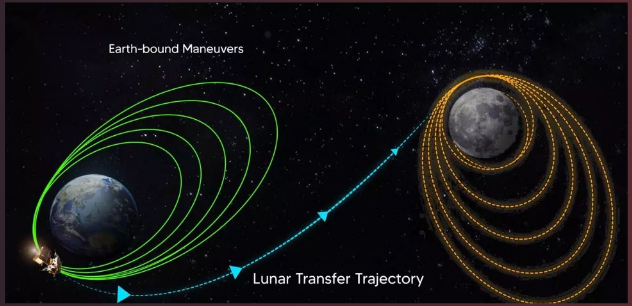
CONOPS:



This proposed CONOPS leverages demonstrated mission profiles whenever possible

CONOPS - Getting to the Moon

- Conduct translunar injection from LEO to Lunar Polar Orbit
  - Similar to planned Artemis missions
- Powered Deorbit Maneuver
  - Skycrane and Rover module utilize active propulsion systems to descend to the lunar surface
  - Rover deploys from the skycrane to minimize initial Plasma Surface Interaction (PSI) impacts
  - Once rover lands on the lunar surface, the skycrane departs to a safe distance



ISRO (2023).

CONOPS - Lunar Operation

- Analyze the nearby area and identify a 30 x 30 m space
    - No large rocks or significantly uneven terrain
- Extract nanophase iron for enrichment
    - This step may be omitted
- Sintering occurs in cycles to match lunar light conditions
    - The solar panels will need to be undeployed during night-time conditions
- Sintering occurs in a line-based pattern, forming strips of landing pad
    - Sinters every other strip at first, to prevent heat damage from hot sintered regolith

CONOPS - Post-Lunar Operation

- Completion of the landing pad will allow the rover to power down
    - Solar panels returns to a closed configuration
- Alternatively, the rover can be moved off site to another landing site
- Rover can be repurposed by the crew for other microwave purposes
    - Cooking food as a house-like appliance
    - Sintering bricks for in situ resource utilization

Key components from the sintering rover can be reused for future lunar bases

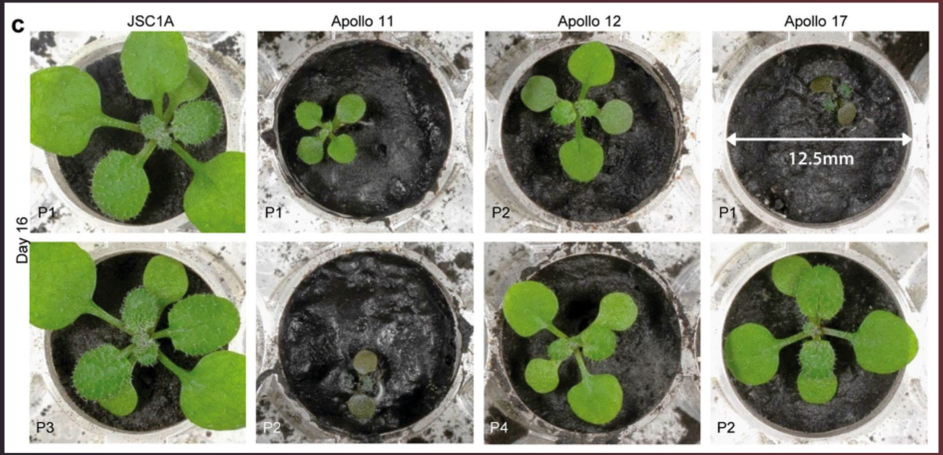
Impacts & Effects

Past Technologies and Improvements

- Microwave sintering, compared to laser sintering:
    - Requires ~23% of the energy required for laser sintering
    - Significantly reduces fabrication time

Past Technologies and Improvements (cont.)

- Scientific:
  - Solid-support substrates for plant growth
  - Sources for extraction of plant-growth nutrients
  - Substrates for microbial populations of degradation of wastes
  - Sources of O2 and H2, which could be used to produce water



Paul et al., 2022.

Past Technologies and Improvements (cont.)

- Financial:
    - Decreased spacecraft maintenance and increased reusability
    - Reliance on required materials from Earth for infrastructure decreases
- Social:
    - Supports a growing amount of landings and launches to/from moon to support NASA's Artemis lunar exploration program

ARTEMIS

Conclusions

MOONPads

- **Methods identified** to fabricate lunar landing pads with autonomous rover
- **Rover designed** with size, cost, and weight constraints and necessary technologies
  - **Risks and challenges identified** with proposal
- **CONOPS proposed** for mission design, from launch to landing
- **Impacts and effects** of mission proposed

Thank You!

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HuLC
HUMAN LANDER CHALLENGE

UNIVERSITY OF CALIFORNIA SAN DIEGO
LET THERE BE LIGHT

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