THE POWER OF COLLABORATION

COSMIC Capstone Challenge: Final Briefing

H2Space, University of Pittsburgh:
Track 2 G.R.U. 1.0
Ground Regolith Unit

Students: Stephen, Joe, Anthony, Zach, Nathan, Lucas
Advisor: Natan Herzog
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Team Overview

Ground Regolith Unit (G.R.U.) Team

Anthony Matteo
Material Science Engineer

Joseph Long
Mechanical Engineer

Lucas Wiedmann
Mechanical Engineer

Nathan Wei
Mechanical Engineer

Stephen Franke
Computer Engineer

Zachary Spencer
Mechanical Engineer

Executive Summary

Ground Regolith Unit (G.R.U.) Mission

- Future crewed missions to the moon will require infrastructure
  - Facilities to conduct long-term experiments
  - Livable environment
- Not energy or cost effective to transport earth building materials for lunar outposts/colonies
- We propose G.R.U. (Ground Regolith Unit)
  - Regolith excavator that collects lunar regolith for future building materials
  - Decreases energy needed to build
  - Decreases total mass/costs of materials from earth
- G.R.U. is testing essential concept functions:
  - Raising & lowering of chassis
  - Excavation

1.4 Advancing High Value Missions

Advancement Toward Lunar Infrastructure

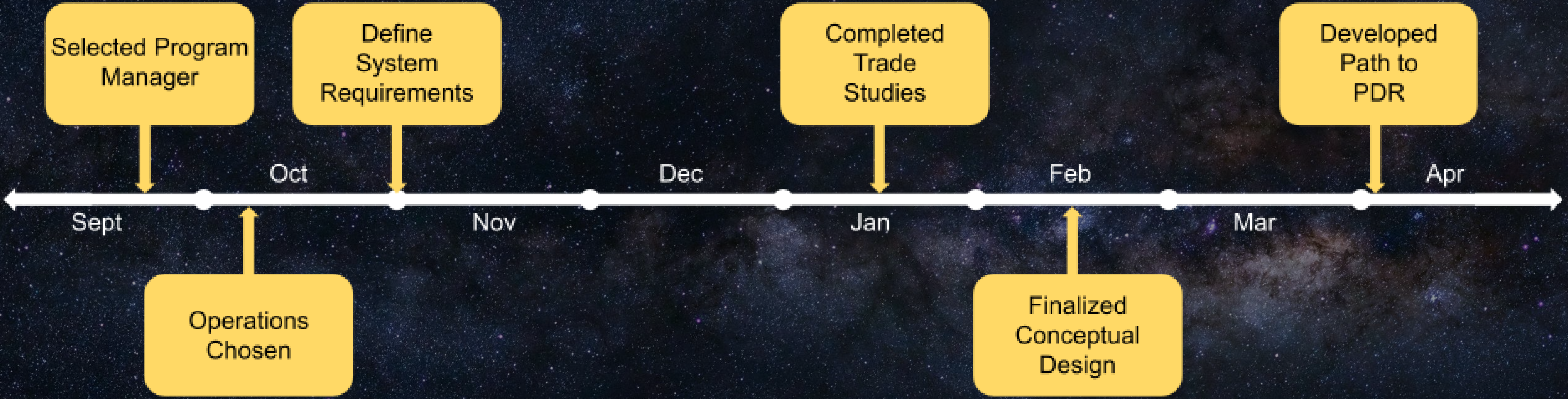
- What will the G.R.U. (Ground Regolith Unit) Mission do to advance lunar infrastructure?
  - Building with lunar material is key to large scale constriction and infrastructure.
  - The first step in building with lunar material is collecting it.
  - G.R.U. will achieve this first step of collecting lunar regolith.

- How does G.R.U fit into the larger mission.
  - Collected regolith can be refined into buildable materials.
  - Building with regolith-based materials will drastically reduce building costs (materials not transported from earth).
  - Lower cost/abundant building materials enables higher scale production of infrastruction

Material Collection, Low Cost

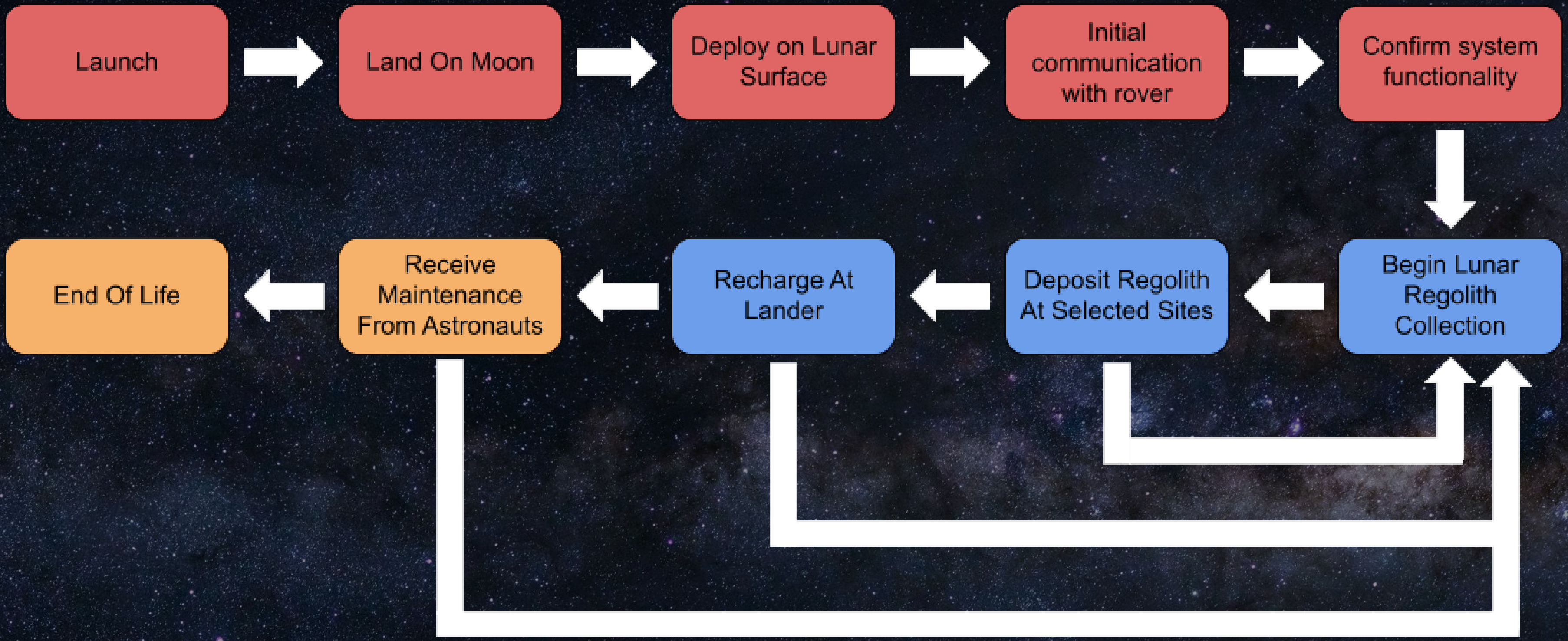
2.4 Program Management Milestones

Timeline Of Team Progression



2.2 Storyboard of Complete Operation

Mission Lifespan



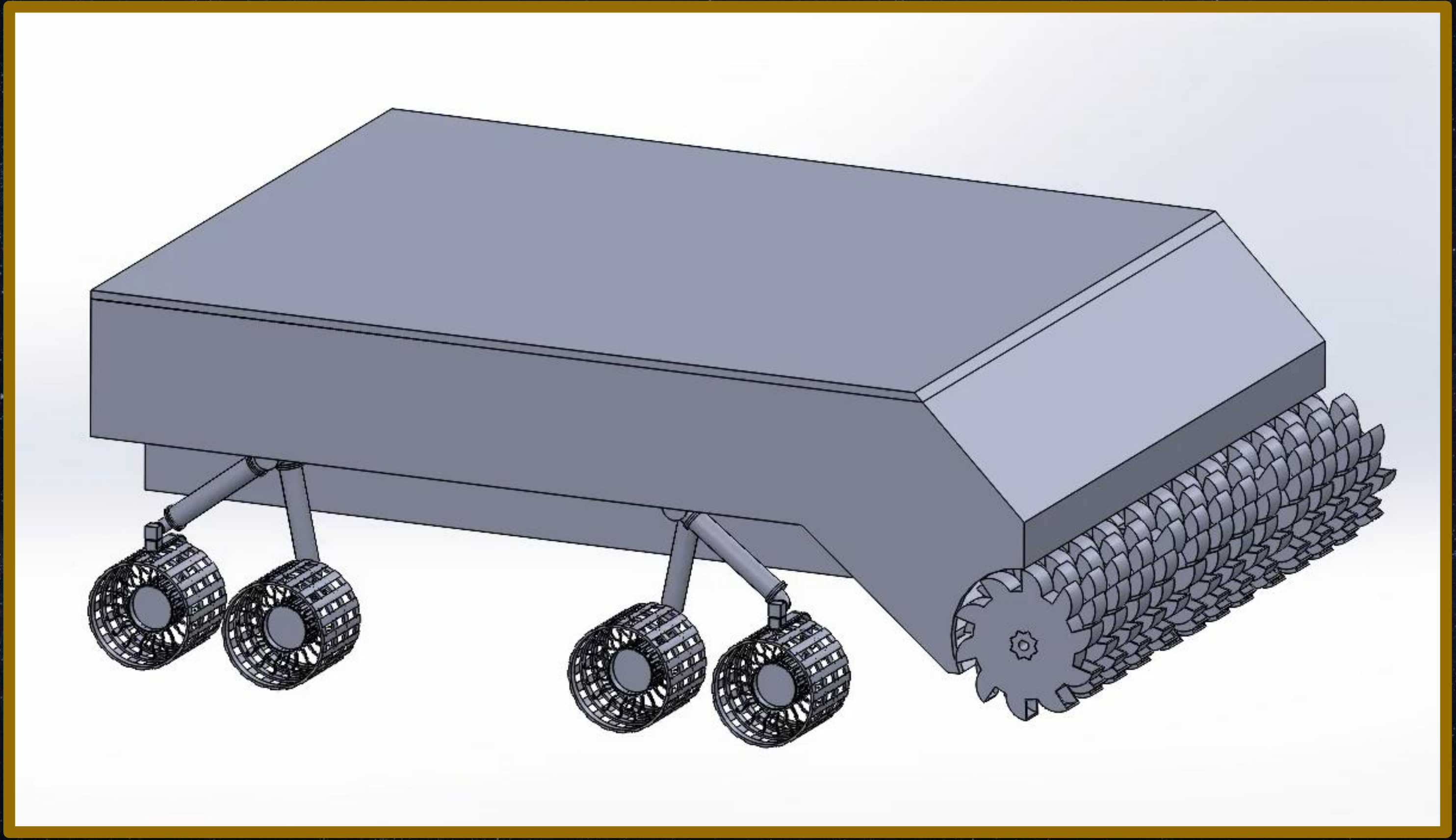
Minimum Operation Life: 2 Years

2.1 Animation of Key Operating Sequence

Mechanical Operation of Actuating Suspension and Drill Head

- Operation stages:
  - Lower chassis via actuating suspension.
  - Begin mining by rotating drill.
  - Raise chassis for traversing.
  - Swivel front and back wheels for turning.
  - Carrying capacity of approximately 0.2 cubic meters

- The actuating suspension solely controls the raising and lowering of drill head.

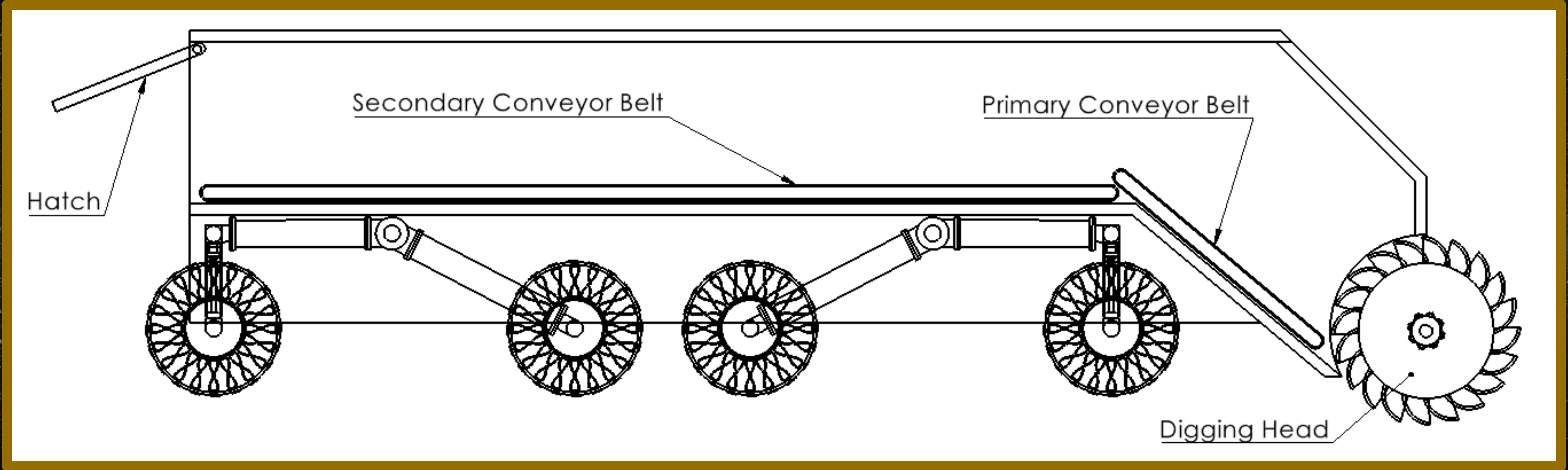


Mechanical Operation, Drill Head Rotation

2.1 Animation of Key Operating Sequence

Operation of Conveyor Belt System

- Conveyor Belt System
  - Regolith will be transported through the rover using two conveyor belts.
  - To unload, regolith will be conveyed out of back hatch.



Conveyor System, Unloading

1.7 Trade Studies

Trade Study Conveyer Belt Material

Hi-Performance Products, Inc. (n.d.). *PTFE Teflon glass*. Retrieved April 2, 2026, from https://hi-performanceproducts.com/fiberglass_teflon

CGS Tape. (n.d.). *Kapton film*. Retrieved April 2, 2026, from https://www.cgstape.com/product/kapton-film

Factor	Weight	Teflon		Kapton		Mylar	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Service Temperature	5	10	50	10	50	3	15
Fracture Toughness	4	8	32	4	16	4	16
Tensile Strength	3	3	9	8	24	9	27
Triboelectric Charging	2	4	8	6	12	2	4
Cost	1	5	5	3	3	10	10
Score		30	104	31	105	28	72

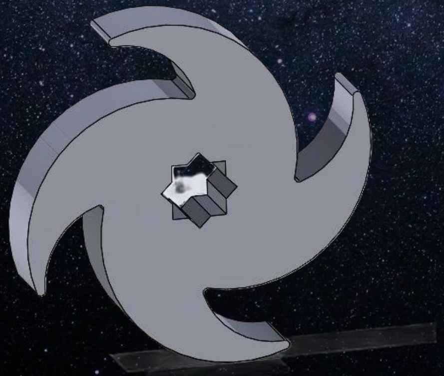
- Teflon and Kapton films are both viable for our conveyer system
- Teflon can be reinforced with glass fabric to increase fracture toughness and reduce triboelectric charging

1.7 Trade Studies

Trade Study Digger Design

Factor	Weight	Four Spoke		Three Spoke		Bucket Wheel	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Volume Excavated	4	3	12	2	8	4	16
Volume Retained	2	3	6	1	2	4	8
Mass of Wheel	1	2	2	4	4	1	1
Score		20		14		25	

- Three versions of a digging wheel were 3D printed and tested
- Most important factors such as volume excavated was weighted the most important


Four Spoke


Three Spoke


Bucket Wheel

1.7 Trade Studies

Trade Study Digger Material

Factor	Weight	Carbon Fiber		Aluminum		Titanium	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Abrasion Resistance	4	4	16	7	28	10	40
Yield Strength	3	9	27	6	18	5	15
Weight	2	8	16	5	10	7	14
Cost	1	3	3	10	10	4	4
Score		24	62	28	66	26	73

- Three material types were considered for our digging head
- Ultimately decided on using a titanium alloy
- In future designs carbon fiber can be incorporated to reduce weight

1.7 Trade Studies

Trade Study Tire Design

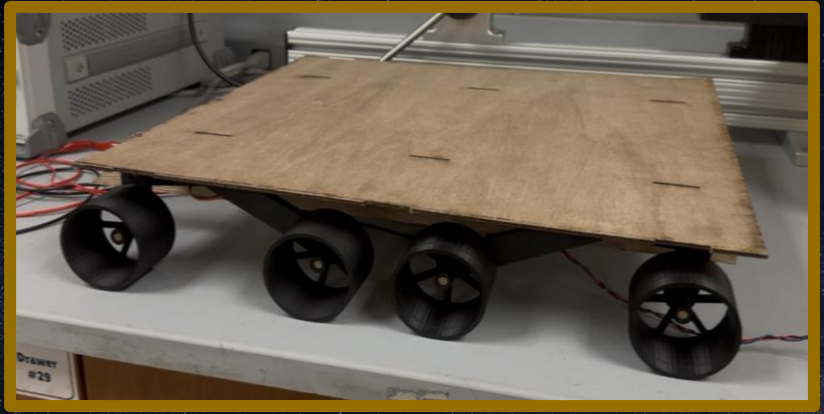
Factor	Weight	Bridgestone		Spring Tire		Traditional	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Durability	5	7	35	5	25	3	15
Weight	3	7	21	10	30	3	9
Complexity	2	5	10	2	4	10	20
Price	1	5	5	2	2	7	7
Score		71		61		51	

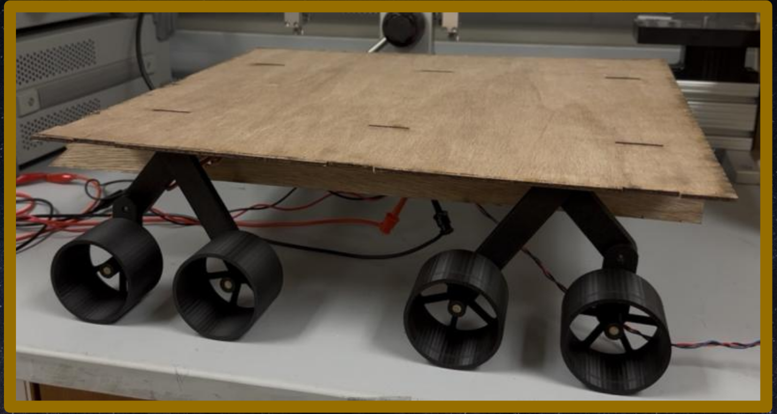
- Three tire designs chosen to study, Bridgestone Second Generation, NASA Spring Tire, and a traditional tire made from full metal alloys
- Each design scored between 1-10, one being bad, ten being best case.
- Weight added between 1 and 5 based on importance of factor, higher weight = greater importance
- Bridgestone tire deemed best from trade study and further research, began designing tire based on similar principles adjusted to the needs of G.R.U.

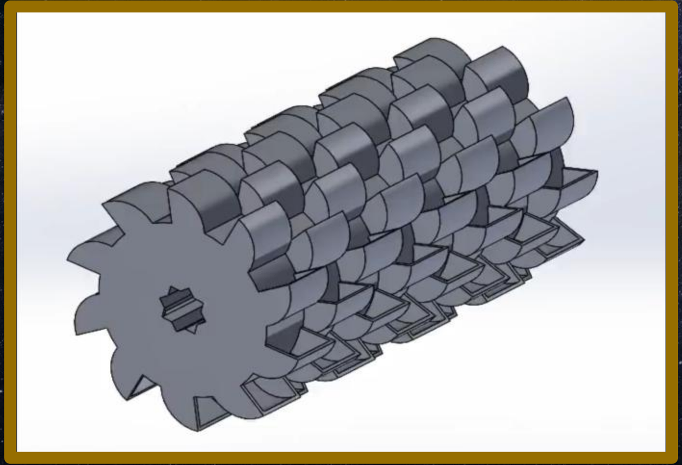
Prototype

Prototypes of Subsystems

- A prototype was created to test two main subsystem functions
  - Suspension mechanism
    - Verify intended mechanical operation.
    - Test ability to lift and lower rover chassis.
  - Digging head
    - Verify ability to dig regolith using sand substitute.
    - Determine optimal digging head design







Suspension Mechanism, Digging Head

2.1 Prototype of Key Operating Sequence

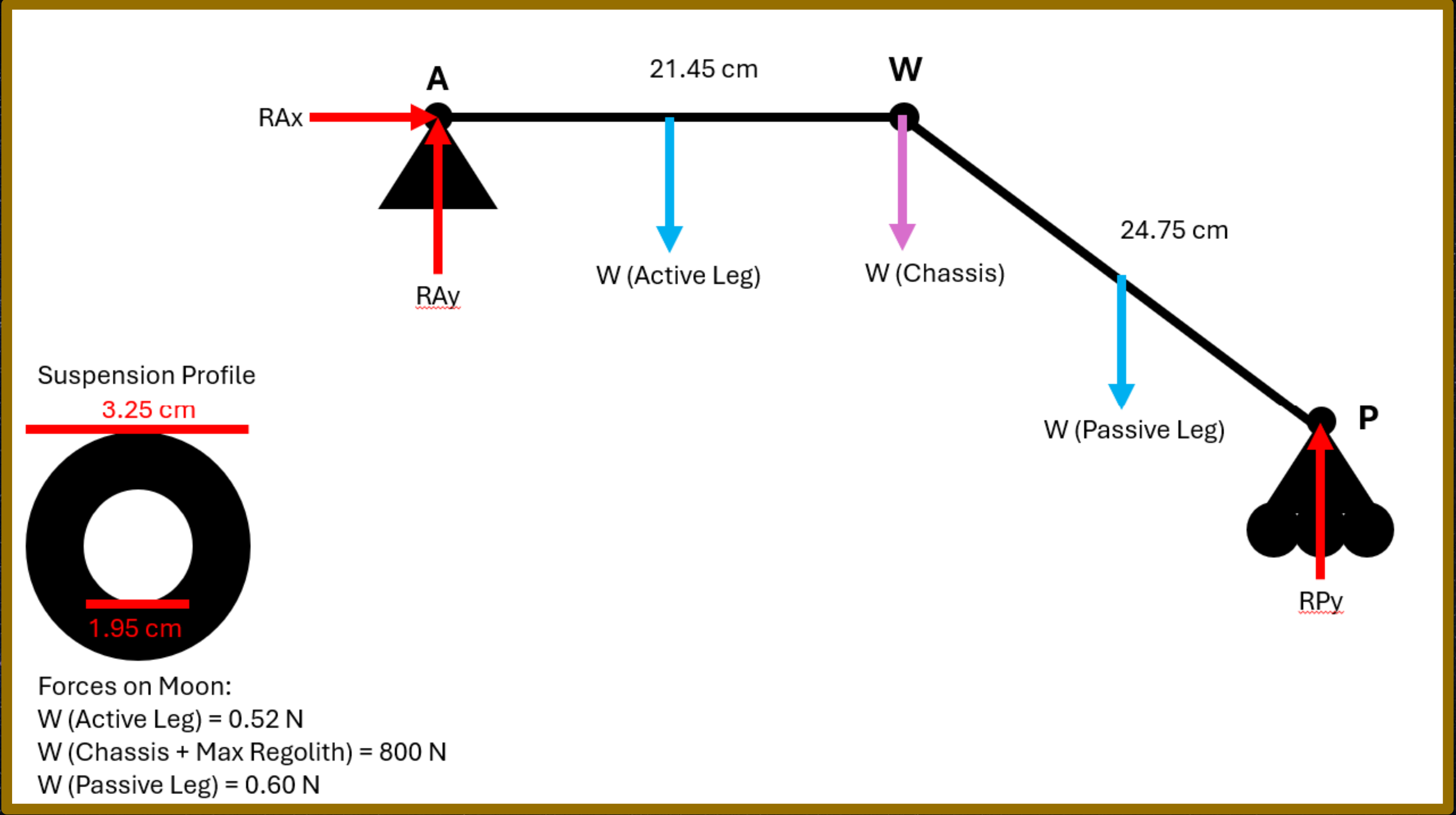
Prototype of Suspension System

- Suspension modeled off the "rocker bogie" system
- Ability to raise and lower, allowing for lower center of gravity during mining
- Pivoting front wheels for steering
- No springs or dampers
- Made of 7075 Aluminum
  - Density: 2.81 g/cm^3
  - Tensile Strength: 503 Mpa
- Carries about 800 N

2.1 Prototype of Key Operating Sequence

Prototype of Suspension System

- Moon Gravity: 1.62 m/s^2
- Largest σ^1 = 29.6 MPa
  - σ^2 = -78.1 KPa
- Minimum moment needed to lift chassis: 86.7 Nm



Forces on Moon:
W (Active Leg) = 0.52 N
W (Chassis + Max Regolith) = 800 N
W (Passive Leg) = 0.60 N

Suspension System

2.1 Prototype of Key Operating Sequence

Prototype of Suspension System

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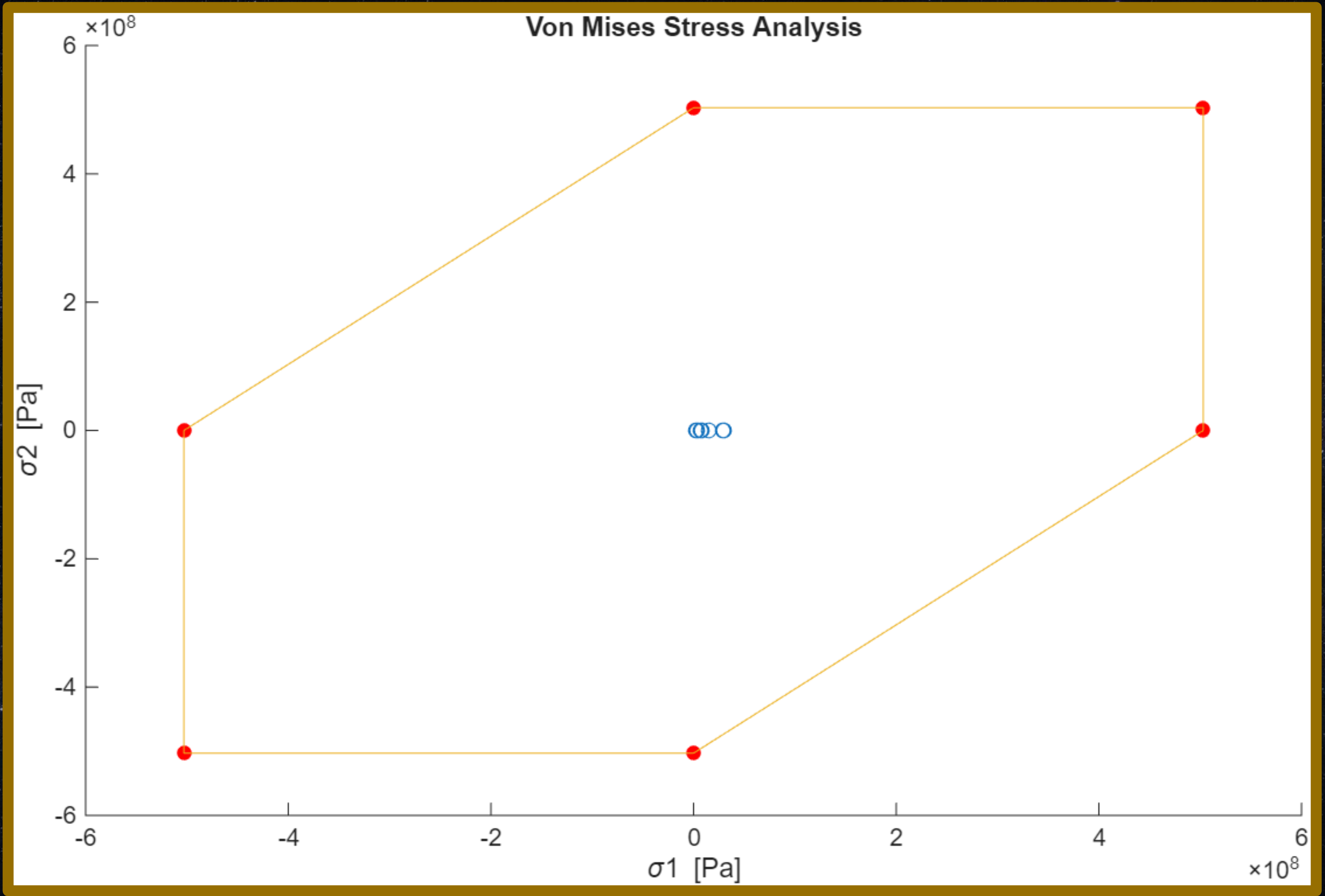


Suspension System

2.1 Prototype of Key Operating Sequence

Prototype of Digging System

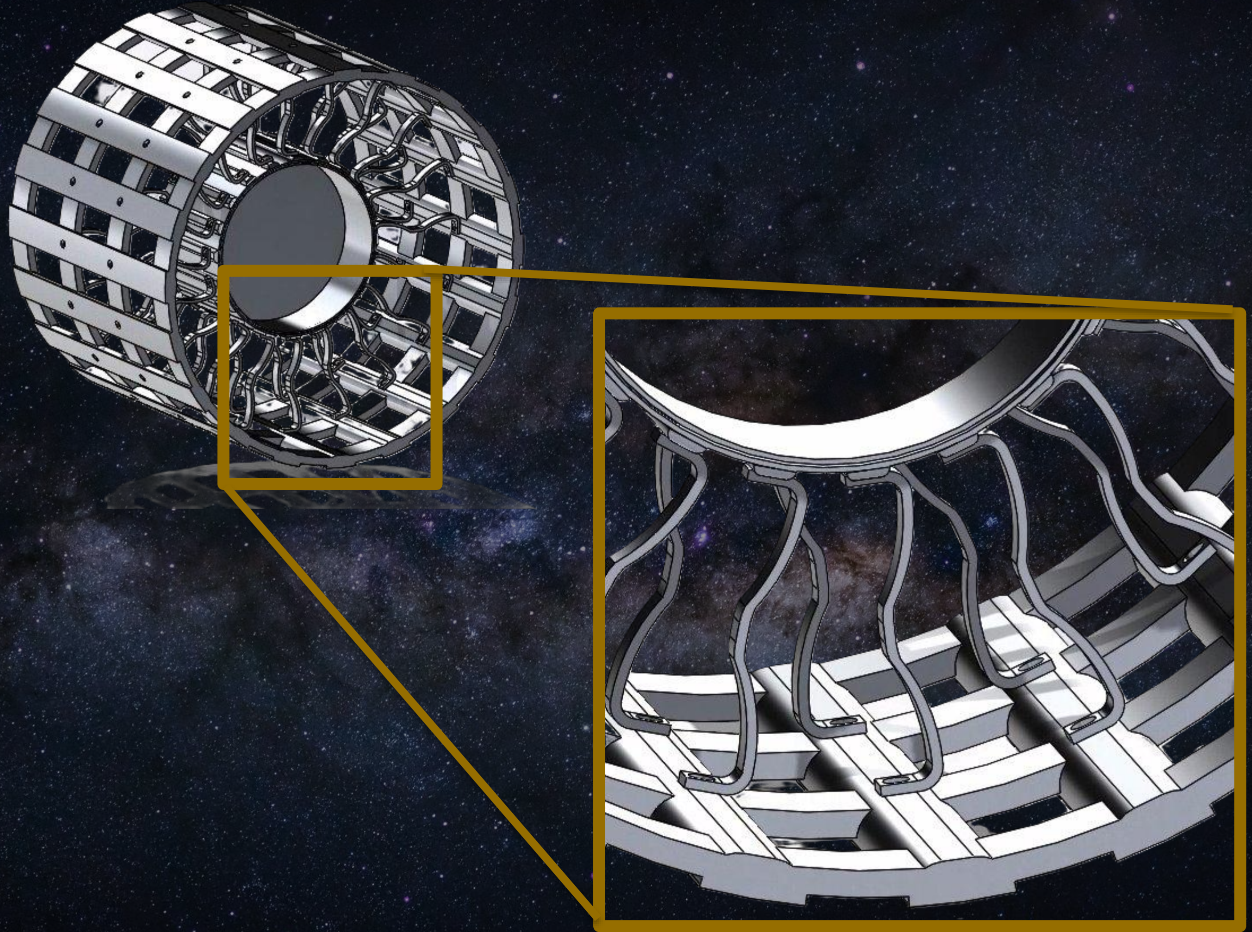
- Prototypes were physically created to test efficiency of digging system and collection success rate
- Three prototypes created which helped to narrow down to two final paths
- More research to be done on new digging designs in upcoming weeks

Drill Head

2.1 Prototype of Key Operating Sequence

Prototype of Tire

- Followed Bridgestone's methodology based on trade study
- Designed two prototypes, adjusting with testing results and project focuses
- Verified prototype could withstand two times expected operational weight and expected torque using an Ansys simulation. Further refining to simulation needed to account for more operating scenarios
- Spokes designed to relieve stresses by allowing for bending during yielding



Tire design and verification

3.3 Data Handling and Comms

Communication with rover and operation requirements

- We will be using real-time downlinks in Telemetry, Tracking, and Command (TTC). This system will collect the status of the rover, battery health, structural damage, etc.
- The operating system will be the C&DH, which will be the computer system on both earth and on the lunar surface.
- We will use a Low-Gain Antenna, which will receive about 1-10 kbps and a High-Gain Antenna which will receive any images from the camera which will receive about 10-50 kbps of signal.
- Another system is MAPS, which will be the navigation system, allowing for autonomous usage, the MAPS system will be mainly using the High-Gain Antenna.

TTC C&DH for health and safety updates with MAPS for navigation

3.2 Risks

Listed possible failure points

Risk	Probability	Impact	Description	Solution
Battery Life Depletion to Zero	5	10	While operating away from the Griffin lander, the rover is unable to return and loses all battery life.	Add solar panels that will capture energy and will charge the rover on the move.
Rover is unable to move	7	10	While the rover is collecting regolith it ends up in a position limiting its movement.	The suspension system will raise and lower the rover, allowing for agility in the rover.
Communication failure	3	10	The communication between earth and the rover is either lost or disrupted	We can use a relay satellite, which would be the backup system to communicate with the rover, while also storing any needed data when the communications reconnect to send to earth or vice versa.

- Probability labeled 1-10, with one unlikely to happen, ten likely to happen.
- Impact labeled 1-10 with one, little to no impact and ten high impact.

3.2 Risks

Additional Risks

Risks	Probability	Impact	Description	Solution
Particle Blockage	3	4	Regolith becomes lodged within the conveyor system causing the conveyor to be stuck or limited operations	Tighten the seals on the conveyor while also allowing for a shaking ability
Motor Failure	6	6	The motors on the rover fail to operate, creating the wheels to not move or grinder to not work. Expected to possibly happen near end of life.	Multiple wheels are given motors to prevent reliance on only some wheels
Code Failure	5	3	Code develops bugs or begins to send bit errors	Run multiple systems at once, with each system running diagnosis on one another, allowing a backup system if one were to fail, while sending an error message back to earth
Electric Degradation	2	7	The temperature, cosmic rays, dust contamination, or any other stress can allow for electronics to suffer	Thermal control, insulation, and radiation hardening can prevent many of these issues

4.3 Biggest Challenges Encountered

Challenges faced by H2Space during development

Challenge	Reason	Solution
Maintaining a rover weight under 200 [kg]	The number of motors needed to complete G.R.U.'s functions took up more than expected weight as well as the batteries needed to power the rover.	Components such as the suspension and frame of the rover were hollowed out where possible to reduce weight while maintaining acceptable strength.
Creating a suspension system that could work with changing weight distribution	Previous rovers studied before design did not have to worry about significant changes in weight distribution.	Designed a suspension system that allowed for changing weight distribution while also following industry standard design.
Providing enough power for all systems to be able to work for a reasonable duration.	Due to the amount of motors needed, the rover requires a large amount of consistent power which 20 [kg] of batteries alone cannot provide.	Placing a solar panel on top of the rover allows for power generation during light hours on the moon. With the solar panel, we can approximate 10 hours of power between charges.

Challenges detected used team brainstorming and cooperation to reach goals

4.1 Most Innovative Concepts Considered

Potential Concepts to Innovate Further

- Tilted suspension system for different angles in digging
  - Actuate front and back suspension at different rates to achieve various digging angles.

- Onboard sintering/refining
  - Refine material on board the unit

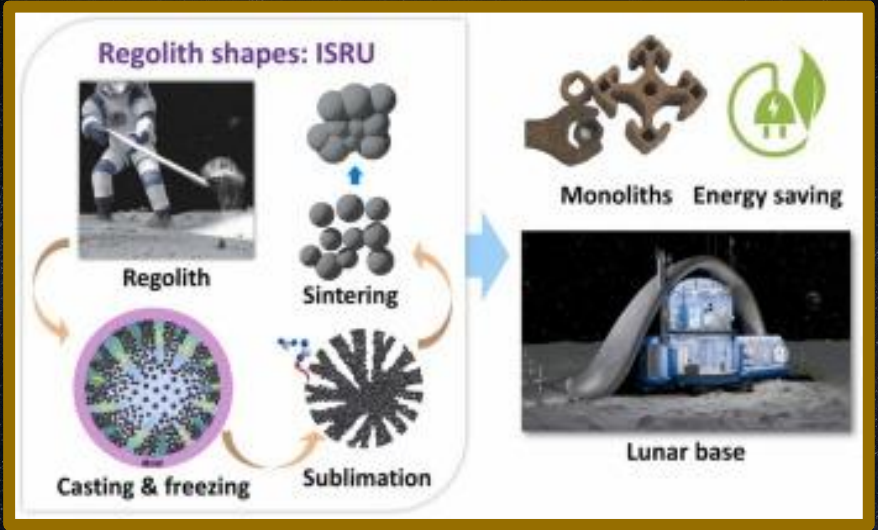
- Filter and magnetic sifter
  - Filter regolith to obtain desired quality of material before unloading
  - Use a magnetic sifter to extract metallic alloys in regolith

Suspension, Refining, Filtering

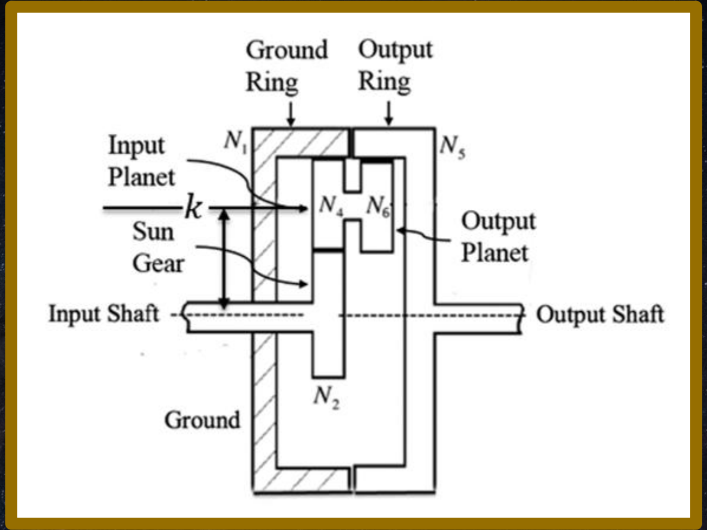
4.2 Most Important Technology Gaps

Technology Gaps

- Protective Material Coatings
  - Wear resistant ceramic coatings
  - Conductive polyimide coatings
- Supporting Systems (ISRU)
  - Filtering
  - Freeze Casting
  - Sintering
- Compact Joint Drive Systems
  - Two stage system as opposed to a typical harmonic drive transmission
  - Drastically reduces the number of parts and reduces risk of failure



Hossain, S. S., & Bullard, J. W. (2025). Fabrication of intricate lunar regolith monoliths via freeze casting. *Journal of the European Ceramic Society*, *45*(10), 117328. https://doi.org/10.1016/j.jeurceramsoc.2025.117328



JDS Transmission J. Mechanisms Robotics. 2017;9(6). doi:10.1115/1.4037567

Important technological gaps are currently in development

Weight Breakdown

Weight Breakdown

Weight Rover	Weight [kg]	Percent Weight
Suspension and Tire System	3.320	6.64%
Frame	97.160	48.58%
Solar Pannel	2.497	1.2485%
Motors	17.672	8.8360%
Cameras and Sensors	9.391	5.6955%
Conveyer	14.000	7.0%
Battery	20.000	10.0%
Digging Head	26.000	13.0%
Total Weight	200	100.00%

G.R.U. 1.0 Meets weight requirements

2.3 Path to PDR

PDR Path From Current Phase

Phase 2.0

-Fabricate further prototype for advance testing

-Finalize methods for heat dissipation and generation

-Further FMEA analysis and solutions

-Begin coding systems for final rover

Phase 3.0

-Finalize wheel and suspension design, select motors and test

-Select two final prototype options for the digging system, test and decide final choice

-Conveyor belt system finalized and parts ordered for construction

-Develop final expected cost for the mission

Phase 4.0

-Finalize any feature of rover not previously considered

-Confirm code functions meet specification and continue development

-Select final electrical components (motors, cameras, sensors)

-Assemble rover

Phase 5.0

-Construct final prototype

-Vibration testing and analysis. Adjust parts of rover if needed

-Finish code and confirm functionality

-Confirm backup systems

-Integrate stereo vision system for environment mapping

5.2 Paper

Designing An Autonomous Lunar Regolith Collection Rover

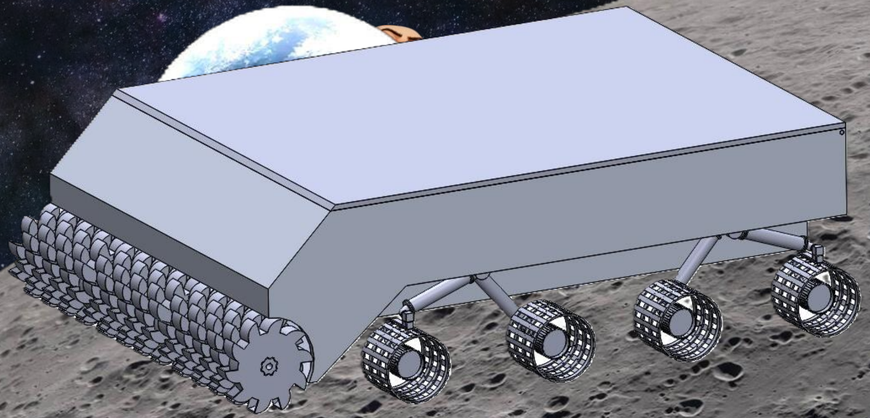
- The paper focuses on the challenges faced and prototype process to reach G.R.U. 1.0
- Information on paper
  - The abstract is 197 words
  - The paper is 14 pages
  - There are a total of 18 sources used
- The team plans to continue refining the paper with guidance from University of Pittsburgh leadership for submission to either AIAA Astronautics Journal and or the SciTech forum.

AIAAJ
AERONAUTICS | ASTRONAUTICS

Summary

G.R.U. 1.0

- Problem Addressed
  - Building structures on the lunar surface is expensive due to cost per kg of material
- Solution
  - Acquire lunar regolith for production of construction materials
- Key Developments
  - Digging Head
  - Suspension tire system
- Biggest Challenges
  - Increasing energy storage
  - Minimizing weight
- Next Steps
  - Continue research and development



COSMIC CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

PITT | SWANSON ENGINEERING

Questions

Please Ask Questions

Questions?

Sources

- [1] U.S. Air Force Space Systems Division, "Lunar Expedition Plan (LUNEX)," Report No. WDLAR-S-458, Headquarters Space Systems Division, Air Force Systems Command, 29 May 1961.
- [2] NASA, "NASA Strengthens Artemis: Adds Mission, Refines Overall Architecture," NASA News Release, 3 Mar. 2026. URL: https://www.nasa.gov/directorates/esdmd/nasa-strengthens-artemis-adds-mission-refines-overall-architecture/ [retrieved 9 April 2026].
- [3] SpaceX, "Mission: Moon," SpaceX [online], URL: https://www.spacex.com/humanspaceflight/moon [retrieved 9April 2026]
- [4] Zhang, R., Wang, T., and Wang, G., "Review of Lunar Regolith Forming Technologies for In-Situ Manufacturing/Construction on the Lunar Surface," *Additive Manufacturing Frontiers*, Vol. 4, No. 3, Sept. 2025, Paper 200238. https://doi.org/10.1016/j.amf.2025.200238
- [5] Agwu, U., Atre, R., Heying, J., and Rome, J., "2025-26 COSMIC Capstone Challenge (C3) Information Packet," Rept. COSMIC-E01-WD005-2025-B, Rev. B, Consortium for Space Mobility and In-Space Servicing, Assembly and Manufacturing (ISAM) Capabilities, 20 Oct. 2025.

Sources

- [6] Spectrolab, Inc., "Triangular Advanced Solar Cell (TASC) Panels," Spectrolab Product Datasheet [online], URL: https://www.spectrolab.com/DataSheets/Panel/panels.pdf [retrieved 9 April 2026].
- [7] Jiregna, I. T., and Sirata, G., “A review of the Vehicle Suspension System,” *Journal of Mechanical and Energy Engineering* Available: https://jmee.tu.koszalin.pl/ojs/index.php/jmee/article/view/171.
- [8] Harrington, B. D. and Voorhees, C., “The Challenges of Designing the Rocker-Bogie Suspension for the Mars Exploration Rover,” *37th Aerospace Mechanisms Symposium*, May 1 2004. https://ntrs.nasa.gov/citations/20040084284.
- [9] “Bridgestone’s Lunar Rover Tire supporting the movement of Lunar Mobility with safety and peace of mind, enabling humankind to pursue the Moon: Bridgestone,” *Bridgestone Corporation* Available: https://www.bridgestone.com/technology_innovation/moon_tires/.
- [10] Stopar, J. D., "Lunar South Pole Atlas," Lunar and Planetary Institute, Universities Space Research Association, Houston, TX, 2019. URL: https://www.lpi.usra.edu/lunar/lunar-south-pole-atlas/ [retrieved 9 April 2026].

Sources

- [11] Keesee, J. E., "Satellite Telemetry, Tracking and Control Subsystems," Massachusetts Institute of Technology, OpenCourseWare Course 16.851, Lecture 20, Oct. 2003. URL: https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/resources/l20_satellitettc/ [retrieved 9 April 2026].
- [12] NASA, "NASA to Demonstrate Autonomous Navigation System on Moon," NASA Marshall Space Flight Center News, 7 Feb. 2024. URL: https://www.nasa.gov/centers-and-facilities/marshall/nasa-to-demonstrate-autonomous-navigation-system-on-moon/ [retrieved 9 April 2026].
- [13] Anzalone, E., "Multi-spacecraft Autonomous Positioning System," NASA Technical Report 20160008032, George C. Marshall Space Flight Center Research and Technology Report 2014, NASA Marshall Space Flight Center, Huntsville, AL, 2015.
- [14] Fan, H., "Understanding Lithium-ion Battery Weight and Energy Density," Large [online article], URL: https://www.large-battery.com/blog/lithium-ion-battery-weight-and-density-explained-guide/ [retrieved 9 April 2026].

Sources

- [15] V. Wiesner, D. R. Lew, N. S. Fransen, L. Das, and C. J. Wohl, "Developing Wear-Resistant Coatings for Lunar Dust Tolerant Applications," NASA Langley Research Center, Hampton, VA, presented at a NASA technical briefing, 2020.

Additional References

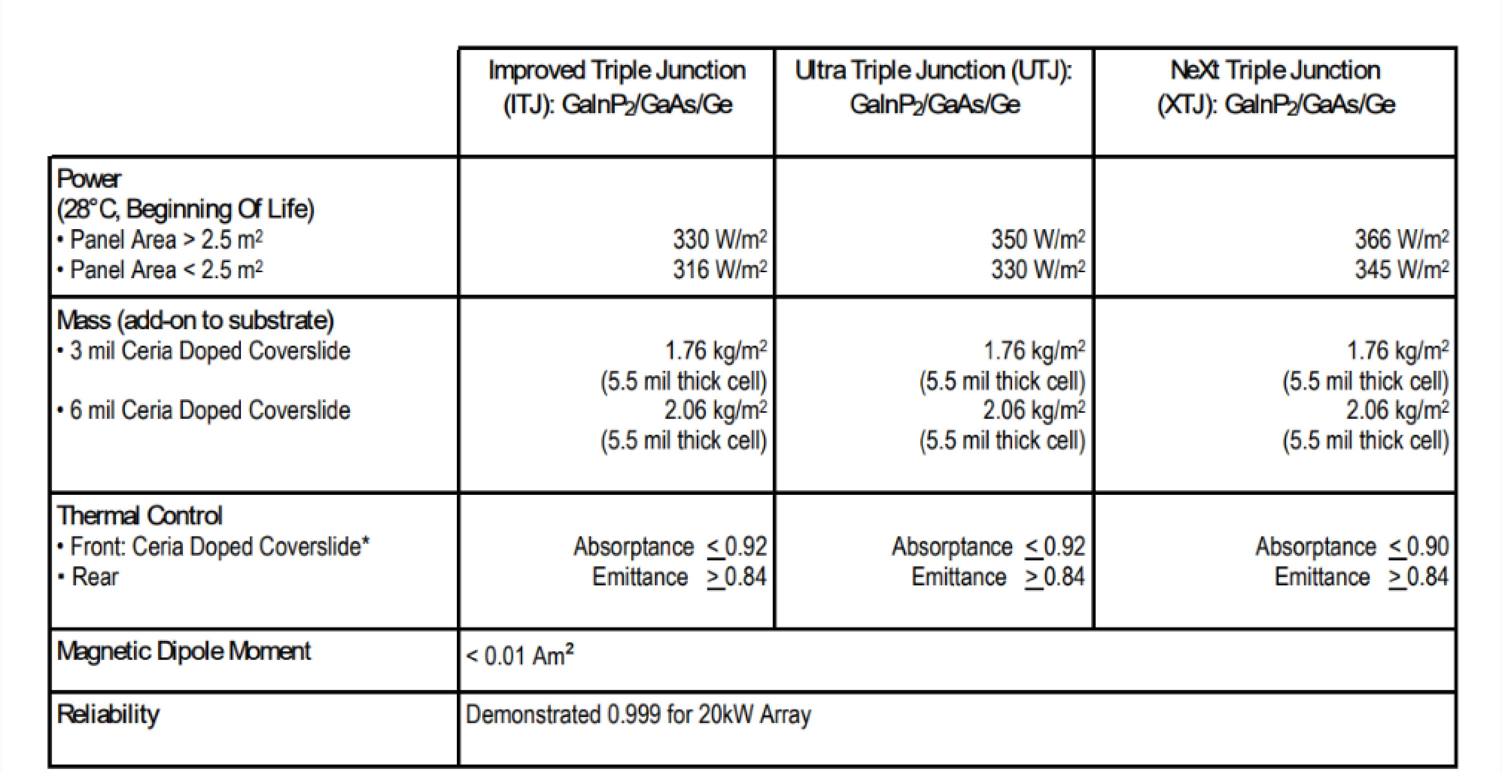
- L. Das, K.L. Gordon, J.H. Kang, V.L. Wiesner, G.C. King, S.J.A. Hocker, et al., Surface Engineering and selection of materials for lunar regolith adherence characterization, Acta Astronautica. 219 (2024) 532–541. doi:10.1016/j.actaastro.2024.03.041.
- Aerospace specification metals offers sheet, plate, Coil, rod, bars, forgings, tubing, extrusions from titanium, high temp super alloys, stainless steel, alloys steel, and aluminum, ASM Aerospace Specification Metals. (2023). https://www.aerospacemetals.com/ (accessed April 3, 2026).
- Online Materials Information Resource - Matweb. (n.d.). https://www.matweb.com/ (accessed April 4, 2026).

Backup Slides

Solar Panel Power Calculation

Calculation of the solar panel power generation

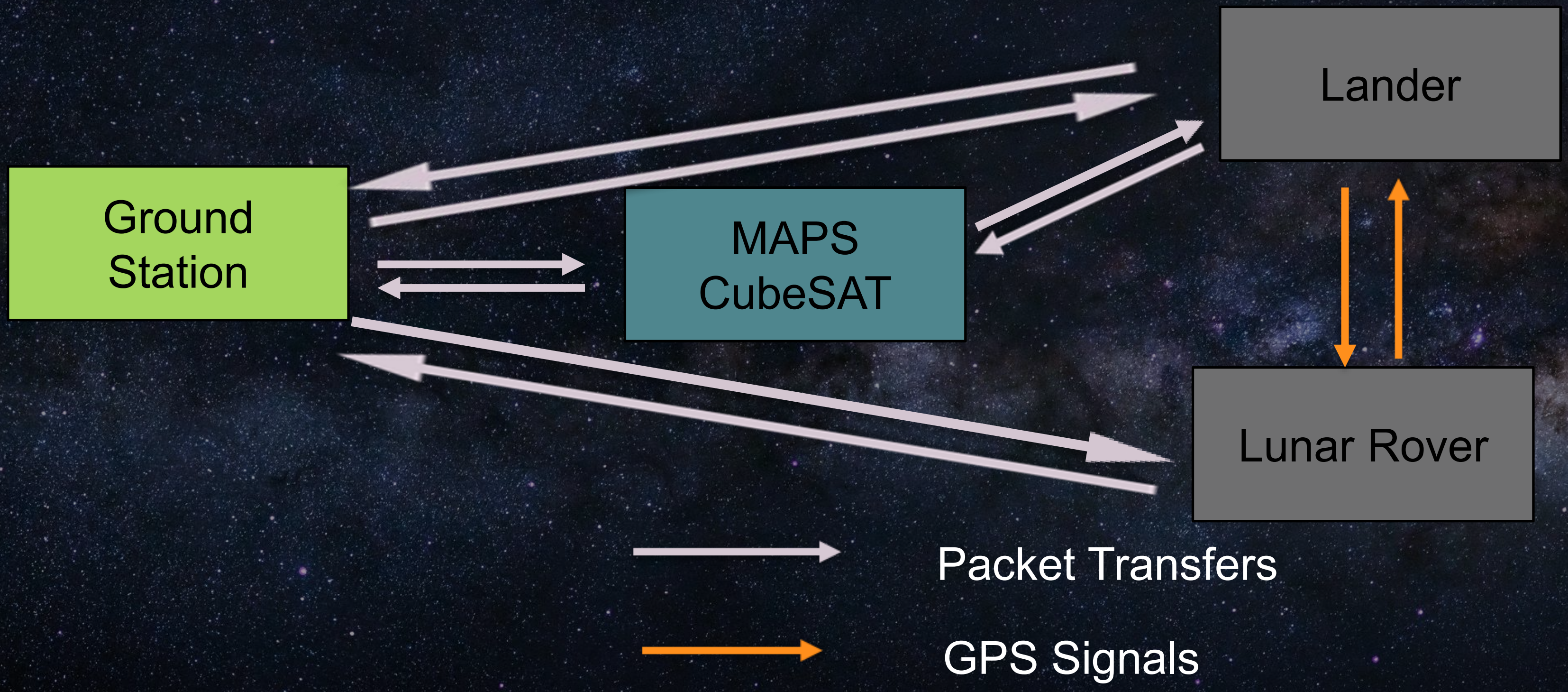
- Area of top of the rover
  - Length: 1.324 [m]
  - Width: 1.072 [m]
  - Calculated Area: 1.419 [m^2]
- Selection of NeXt Triple Junction (XTJ): GaInP2/GaAs/Ge
  - 366 [W/m^2]
  - 3 mil Ceria Doped Coverslide 1.76 [kg/m^2]
- Solar Pannel metrics
  - Weight: 2.497 [kg]
  - Power: 489.555 [Wh]
- We can expect 489.555 watts per hour at the start of the mission



	Improved Triple Junction (ITJ): GaInP$_2$/GaAs/Ge	Ultra Triple Junction (UTJ): GaInP$_2$/GaAs/Ge	NeXt Triple Junction (XTJ): GaInP$_2$/GaAs/Ge
Power **(28°C, Beginning Of Life)** • Panel Area > 2.5 m^2 • Panel Area < 2.5 m^2	330 W/m^2 316 W/m^2	350 W/m^2 330 W/m^2	366 W/m^2 345 W/m^2
Mass (add-on to substrate) • 3 mil Ceria Doped Coverslide • 6 mil Ceria Doped Coverslide	1.76 kg/m^2 (5.5 mil thick cell) 2.06 kg/m^2 (5.5 mil thick cell)	1.76 kg/m^2 (5.5 mil thick cell) 2.06 kg/m^2 (5.5 mil thick cell)	1.76 kg/m^2 (5.5 mil thick cell) 2.06 kg/m^2 (5.5 mil thick cell)
Thermal Control • Front: Ceria Doped Coverslide* • Rear	Absorptance ≤ 0.92 Emittance ≥ 0.84	Absorptance ≤ 0.92 Emittance ≥ 0.84	Absorptance ≤ 0.90 Emittance ≥ 0.84
Magnetic Dipole Moment	< 0.01 Am^2		
Reliability	Demonstrated 0.999 for 20kW Array		

Backup: MAPS System

Integration of the MAPS system

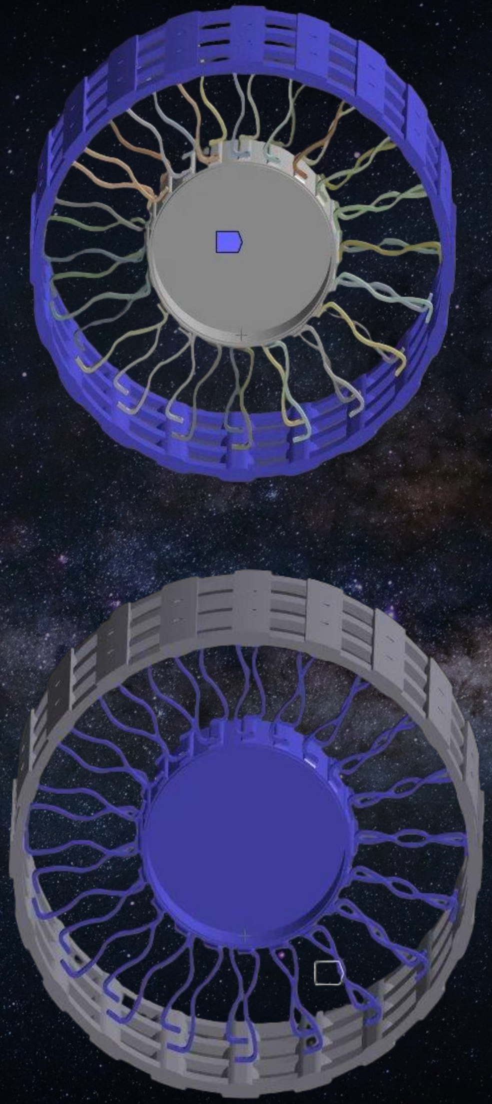


MAPS and Communication signals demonstrated using block diagram

Backup: Finite Element Analysis

Ansys Simulation Meshing

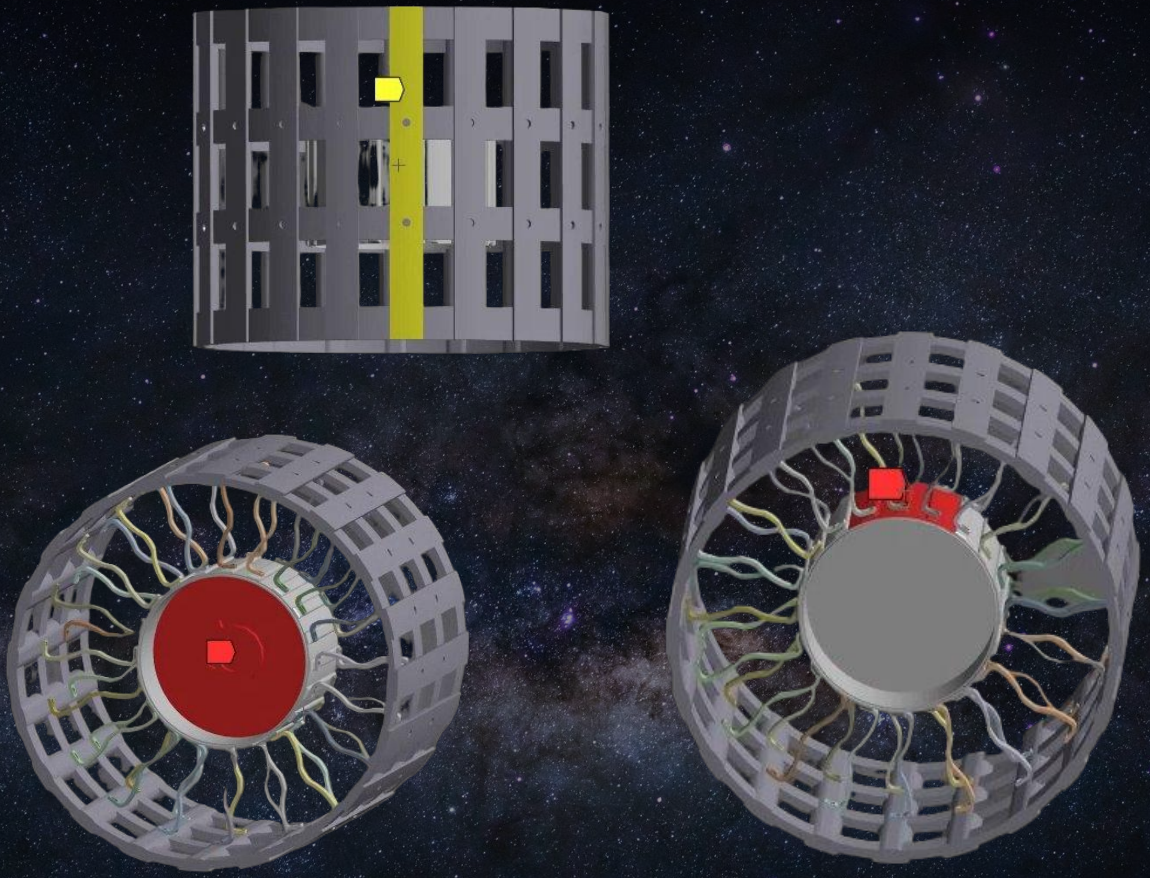
- The outer shell of the wheel was assigned Ti-3Al-2.5V while the spokes and wheel hub were selected to be Al 7075 T6 Wrought.
- Mesh Sizing
  - 1 mm for the outside of the wheel (top image)
  - 0.5 mm for the rest of the wheel (bottom image)



Backup: Finite Element Analysis

Ansys Simulation Forces

- Static structural conditions applied
  - Displacement of zero on the bottom contact point to represent the worse case of a hardened surface that allows for no deformation
  - Torque of 13.5 [N*m] to represent 1.5 times the torque needed to begin wheel movement
  - Force of 410.54 newtons applied to the top of the wheel hub to represent 2.0 times the maximum weight of the wheel if it needs to account for both wheels.



Backup: Finite Element Analysis

Ansys Simulation Results

- The maximum force found on the tire was less than the maximum stress of Al 7075 T6 Wrought.

- Further Ansys simulations are needed to confirm result by refining mesh, however, this result gives the team confidence in the models strength.