Project HESTIA

C3: COSMIC Capstone Challenge Track 2

Team VT LUNA
4/16/2026

VT LUNA

Students: Eider Belda Cano, Jonah Bradley, Ty Brennan, Timothy Currey, Katherine Evans, Duncan Foster, Nicholas Harvey, Robert Higinbotham, Abinav Khadka, Braeden Peterson, Hugh Young III

Advisor: Dr. Kevin Shinpaugh
Mentor: Dr. Jessica Pines

COSMIC
THE POWER OF COLLABORATION

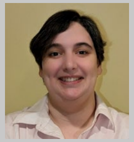
COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF
AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH.

Team Organization

Advisor


Dr. Kevin Shinpaugh

Mentor

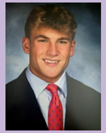

Dr. Jessica Piness

Project Lead


Abinav Khadka

Chief Engineer


Nicholas Harvey

Microwave/Mold	Rover	Filtration Model	PTE
 Ty Brennan	 Juliana Evans	 Duncan Foster	 Hugh Young
 Nicholas Harvey	 Jonah Bradley	 Braeden Peterson	 Robert Higinbotham
 Timmy Currey	 Eider Belda Cano		 Abinav Khadka

Executive Summary

Problem

Plume ejecta erosion from lunar regolith poses a great risk to establishing any permanent lunar infrastructure

Proposal

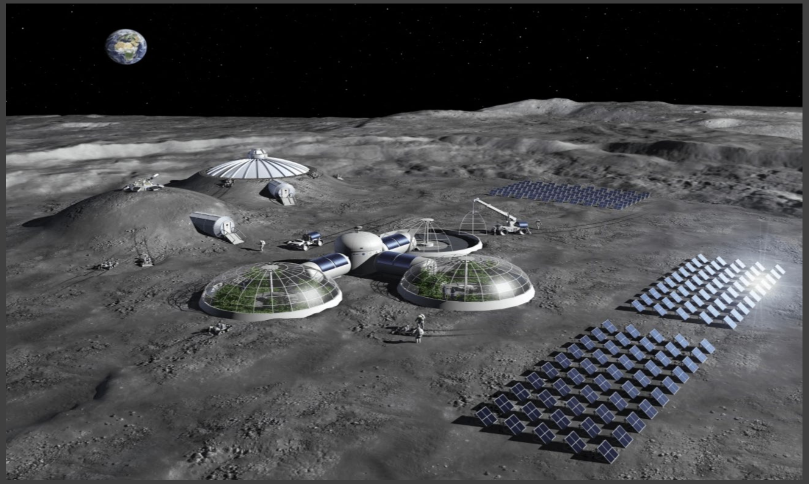
VT Luna proposes designing a payload capable of constructing landing pads on the lunar surface

Solution

Construction of lunar landing pads eliminates the threat of plume ejecta and allows for a safe and repeatable landing site, making completion of a lunar colony more feasible

Status

A payload and mission concept has been developed to address the problem statement, with initial system prototyping underway



[1]

[2]

Preliminary Information

Scope

- Produce structurally and thermally sound launch pad tiles can be fabricated repeatedly
- Test the thermal properties of the produced tiles on site
- Recover produced tiles for Earth based testing
- Assemble tiles in a test configuration
- Scalable to produce launchpads via increases production, automation, and terraforming

Timeframe

- September 2029: Mission launch to the Moon.
- September 2029: System initialization.
- March 2030: Mission completion.

Assumptions

- There will be a local on-surface astronaut.
- Almost constant illumination over 6 months.
- Ability to utilize all Griffin Lander features.

Key Requirements

- System shall have a total mass under 200 kg.
- System shall occupy a volume less than (1.5 m x 1.5 m x 2.5 m).
- System shall autonomously manufacture structurally sound tiles

Advance High Value Mission

A successful demo mission of Project Hestia directly advances the goals of NASA's Moon-to-Mars architecture, and is directly linked to 4/10 High Priority Objectives outlined in NASA's Architecture Overview

Physics and Physical Science

Demonstrate a deeper understanding of the physical properties of lunar regolith and its role as a potential construction material

Lunar Infrastructure

Create essential infrastructure that can be interoperable by a global science community

Transportation and Habitation

Enables a safe, reusable landing point for consistent and reliable transportation objectives

Operations

Enabling safe completion of human operations on the lunar surface, as well as helping ensure a safe return to Earth

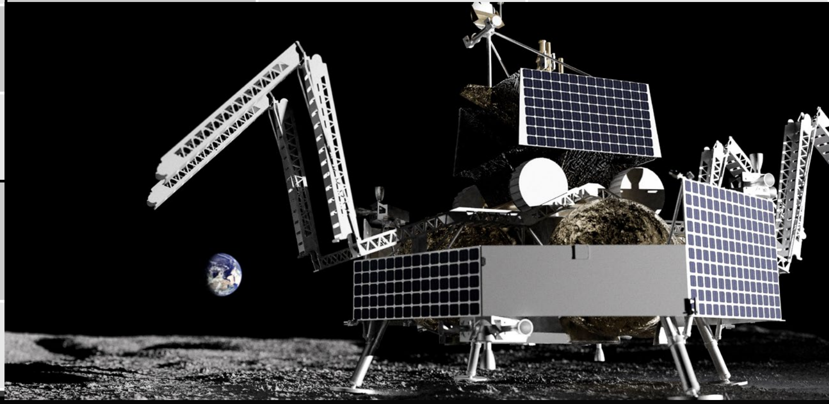
Griffin Lander (Bus)

Griffin Lunar Lander

Category	Item	Details
General Specs	Class	Medium-class commercial lunar lander
	Payload Capacity	~625 kg to lunar surface
	Dimensions	~4.5 m wide, ~2 m tall
Structure & Design	Frame	Aluminum isogrid structure
	Landing Legs	4 legs for stability and shock absorption
	Payload Deck	Large top-mounted deck with standardized interface
	Payload Mounting	Above-deck and below-deck options
	Deployment	Rover ramps available
Propulsion	Main Engines	7 engines (multi-phase mission use)
	Functions	TLI, trajectory correction, LOI, descent
	Attitude Control	4 clusters of control thrusters

Category	Item	Details
Avionics	Computing	Radiation-tolerant onboard computers
	Operations	Autonomous mission capability
GNC (Guidance, Navigation & Control)	Navigation	Autonomous precision landing
	Terrain Navigation	Terrain Relative Navigation (TRN)
Payload Capabilities	Supported Payloads	Rovers, science instruments, small satellites
	Payload Services	Power, comms relay, data handling
Landing Sensors	Doppler LiDAR	Velocity and altitude measurement
	TRN Sensors	Terrain mapping & comparison
	Scanning LiDAR	Detects rocks, slopes, craters
Payload Capabilities	Supported Payloads	Rovers, science instruments, small satellites
	Payload Services	Power, comms relay, data handling

Category	Item	Details
Power System	Solar Arrays	Triple-junction solar cells
	Batteries	Space-grade lithium-ion
	Power Distribution	Dedicated payload power bus
Communications	Transponder	High-powered, flight-proven
	Antennas	Low-, medium-, and high-gain
	Data Interfaces	RS-422, SpaceWire
	Wireless Option	WLAN modem for rover comms



Regolith Manufacturing Trade Study

- Evaluated five regolith processing technologies against mission constraints
- Microwave Sintering was found to be optimal for the mission due to its scalability and reusability

Microwave Sintering	Chemical Binders	Heating Plates	Solar Sintering	Pressed Brick
Reuseable and scalable	Strong chemical bonds	High mass	Little power requirements	Large amount of force generation needed
Uniform heating	Requires use of liquids in space	Slow heating rate	Large tracking optics	Requires some binder
High power requirements	High mass payload to bring binders	High power requirements	High mass and delicate pieces	Contaminates regolith

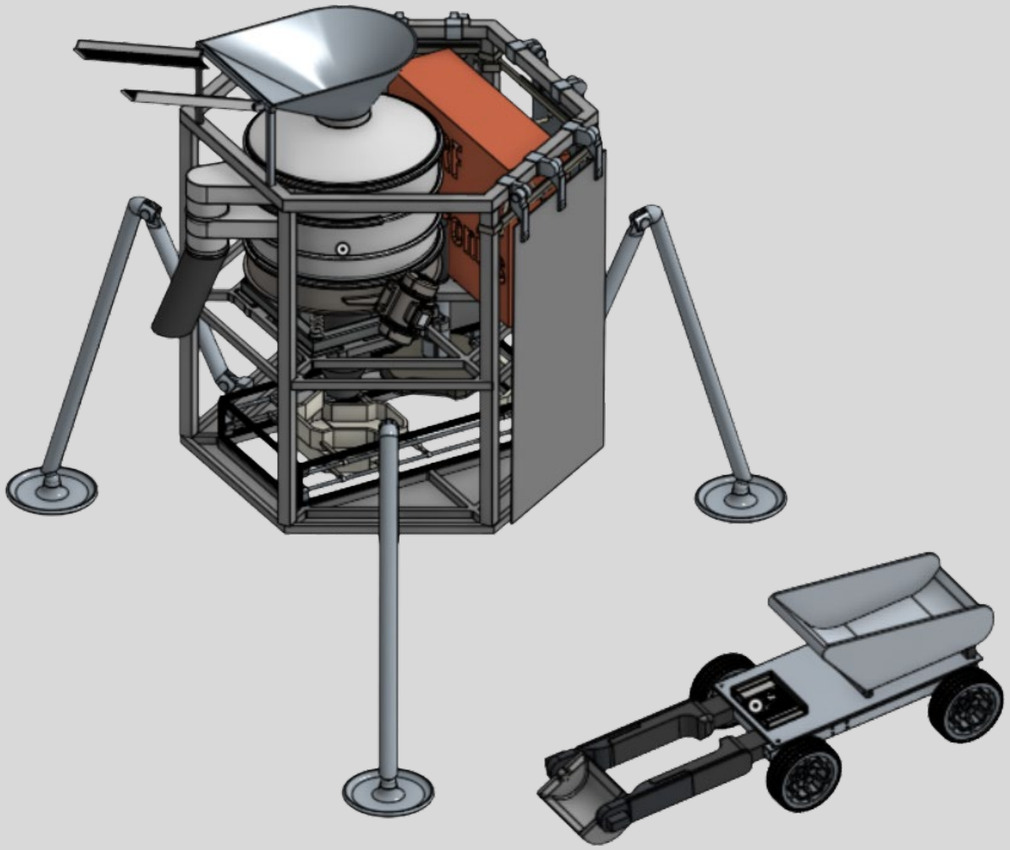
Technology	Mass Score	Power Score	Scale Score	Effect Score	Total Score
Weights	0.30	0.20	0.25	0.25	**1**
Microwave Sintering	0.37	0.05	0.45	0.36	**0.32**
Solar Sinter	0.19	0.42	0.20	0.12	**0.22**
Chemical Binders	0.05	0.42	0.10	0.28	**0.19**
Heating Plates	0.24	0.03	0.15	0.16	**0.16**
Pressed Brick	0.15	0.08	0.10	0.08	**0.11**

Innovative Concepts

Several Concepts Considered For General Architecture

- **Umbilical Cord**
  - Continuous power via spool-mounted harness
  - Full system capabilities in a single system
  - limited range and mobility complexity when scaled
- **Mobile Manufacturer**
  - Wireless charging, sortie style construction
  - Full system capabilities in a single system
  - Massive battery and reduced operation time
- **STiM and Rover**
  - Division of labor through two interconnected systems
  - Continuous power for the manufacturing plant, smaller battery for the collection system

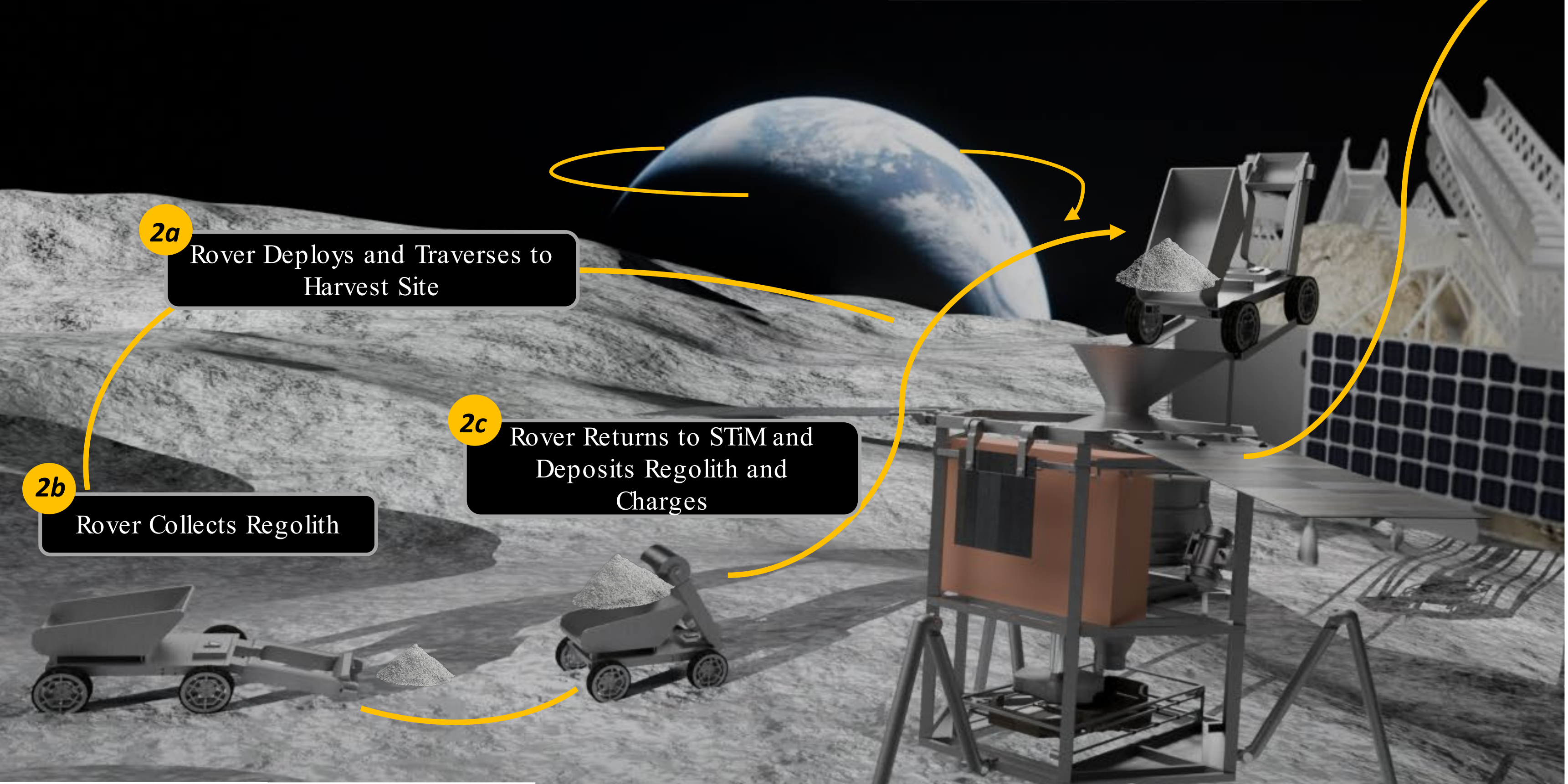
Architecture Selected:
STiM and Rover



CONCEPT OF OPERATIONS

Key Facts:

- Payload Mass: 184kg (29.24kg Rover + 154.96kg STIM)
- Power utilization: 5kW
- Dimensions:
  - Stationary Tile Maker: 1.1m x 1.1m x 1.3m (L x W x H)
  - Rover: 1.2m x 0.5m x 0.4m (L x W x H)



1 System Transported via Griffin Lander and is Deployed to Lunar Surface

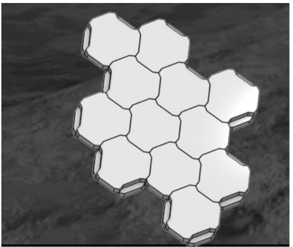
2a Rover Deploys and Traverses to Harvest Site

2b Rover Collects Regolith

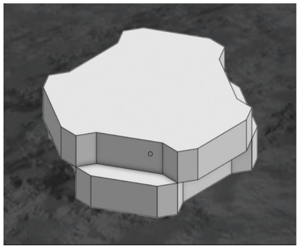
2c Rover Returns to STiM and Deposits Regolith and Charges

5 Ejection Phase, Tile Removed via Rover and Tested

Tile Assembly

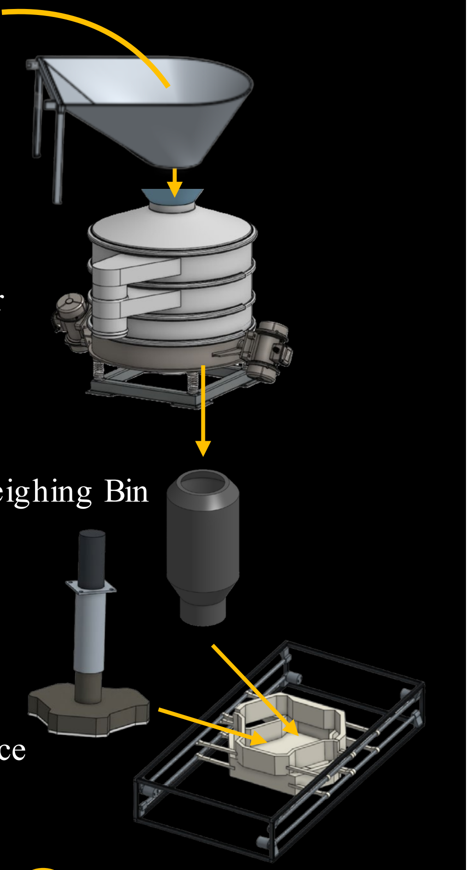


Tile Design



TILE FORMATION

Regolith Conditioning (Flow of Regolith)



3a Reception Hopper Receives Dump

3b Vibratory Screener

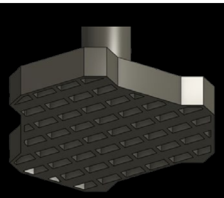
3c Weighing Bin

3d Mold Deposit/ Vibration Sequence

3e Compaction Sequence

4 Microwave Process

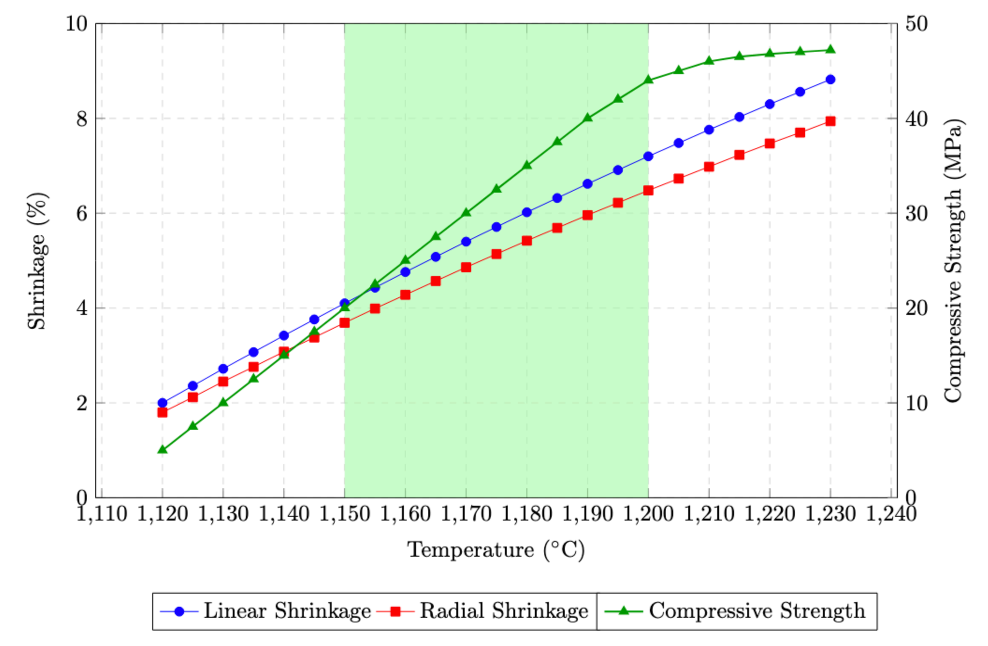
Array Sintering Cycle and Cooling



Sintering Properties and Tile Design

Key Regolith Sintering Properties:

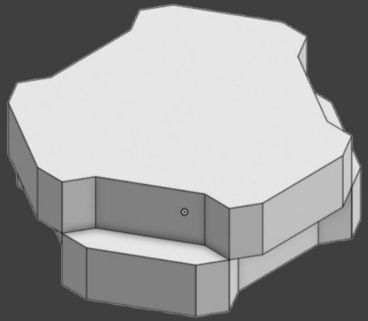
- **Particle Size and Density**
    - Low porosity results in higher compressive strength
    - Average grain size $< 600\ \mu m$ and bulk density $\rho_b = 2.14\ g/cm^3$ yield the best results
- **Composition:**
    - High in TiO2 and FeO for initial heating
    - Particle size averaging <600 μm for sintering
    - Uniform and predictable



ID	Key Tile Requirement
TP 1.0	Must interlock securely with limited manipulation.
TP 2.0	Must withstand 424 kPa of HLS landing.
TP 3.0	Must withstand 25.78 kPa static pressure of HLS.
TP 4.0	Must withstand 17786.3 kW/m^2 heating from plume of HLS landing.

Design Overview:

- Hexagonal tile with $r_{cir} = 0.15\ m$, depth $d = 0.16\ m$, and a fillet $f = 0.025\ m$, was chosen.
- Quadrilaterals and triangles were avoided
- Offset overhangs to allow for interlocking design while only needing one mold

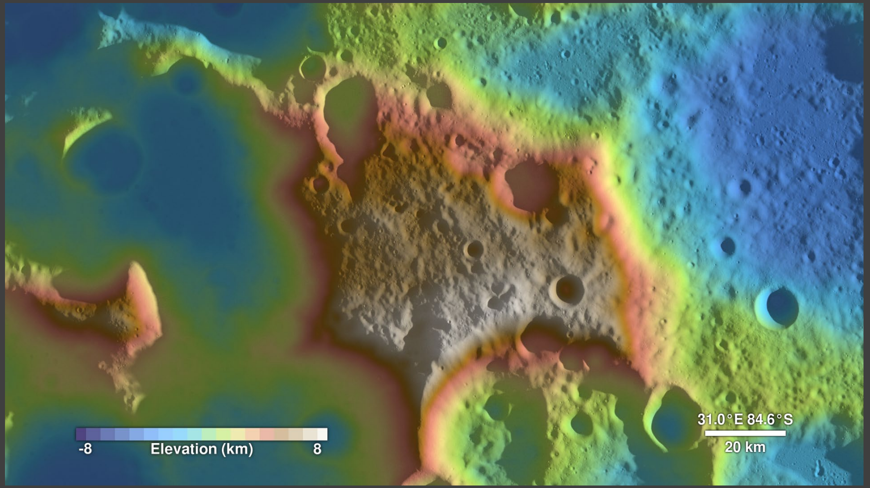


Regolith Properties & Landing Site Selection

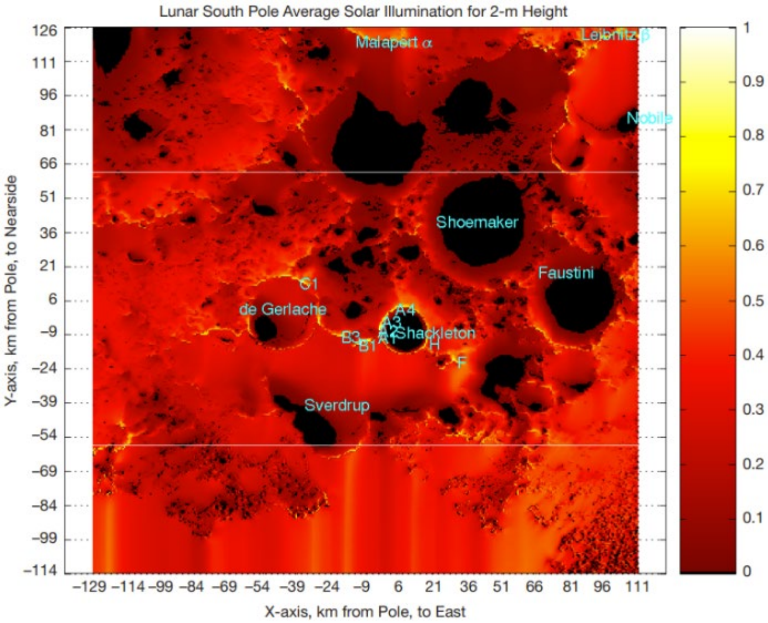
- Evaluated 3 landing site candidates against mission constrains.
- Most important constraint was regolith composition.

	Terrain slope (deg)	Proximity to PSRs score	Illumination (%)	Regolith composition score	Earth visibility (%)	Result
	Minimize		Maximize			
Weights	0.20	0.05	0.25	0.4	0.1	1
Mons Mouton Plateau	7.4 ± 2.3	5	75	5 (High-Ti)	74 ± 19	4.95
Peak Near Shackleton	~7.5	4	85.5	2 (Highland)	~50	3.15
De Gerlache rims 2	~8	3	88	2 (Highland)	~50	3.2

Note: Raw literature values are shown where available; qualitative criteria were converted to scores for the weighted total. Regolith score based on composition uniformity and suitability for sintering.



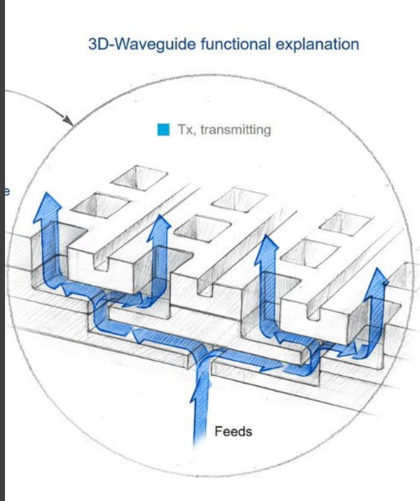
Mons Mouton Plateau. An overhead view of Mons Mouton with color-coded elevation.



Microwave Sintering/Waveguide/Thermal

Microwave Sintering Head

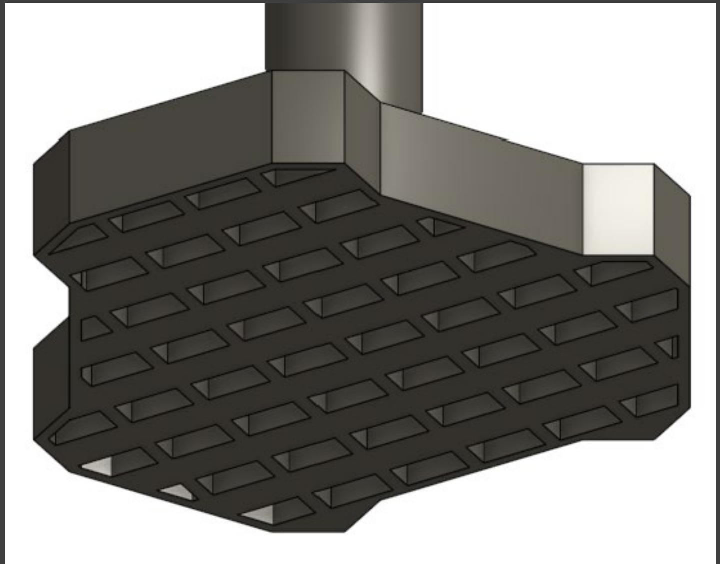
- Tile shaped custom waveguide 915 MHz antenna
- RIM091K5-20 1.5 kW GaN
  - 900 – 930 MHz
  - 63% Efficiency
  - 50 VDC



https://www.fst.com/news-stories/technology-innovation/waveguide-antenna/

Thermal Feasibility and Modeling

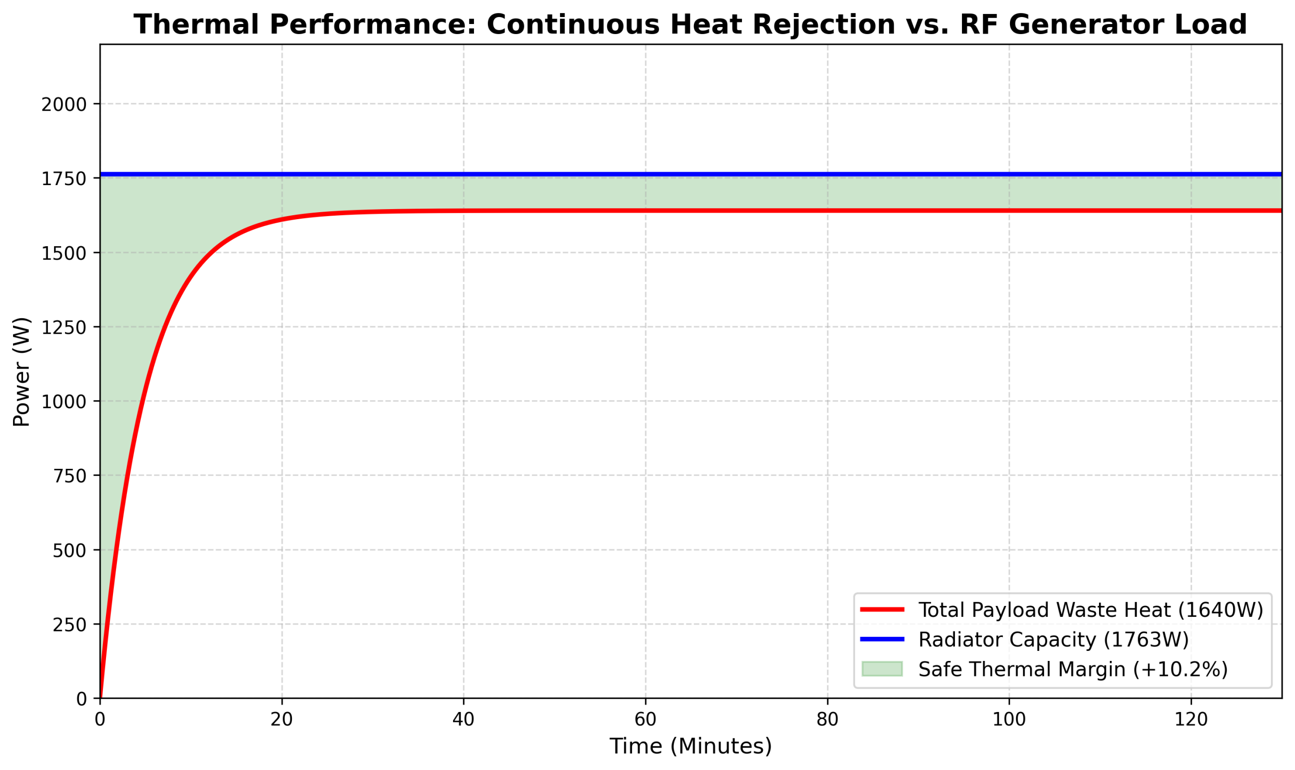
- Custom MATLAB Simulation to test Microwave Sintering Properties in a Lunar Environment
- Outputs
  - 1 mm Layers
  - 234 s per layer
  - 6.9 hrs per tile



Cooling System

2-Loop Hybrid Architecture: Physically separates sensitive Avionics from the massive RF Generator heat loads.

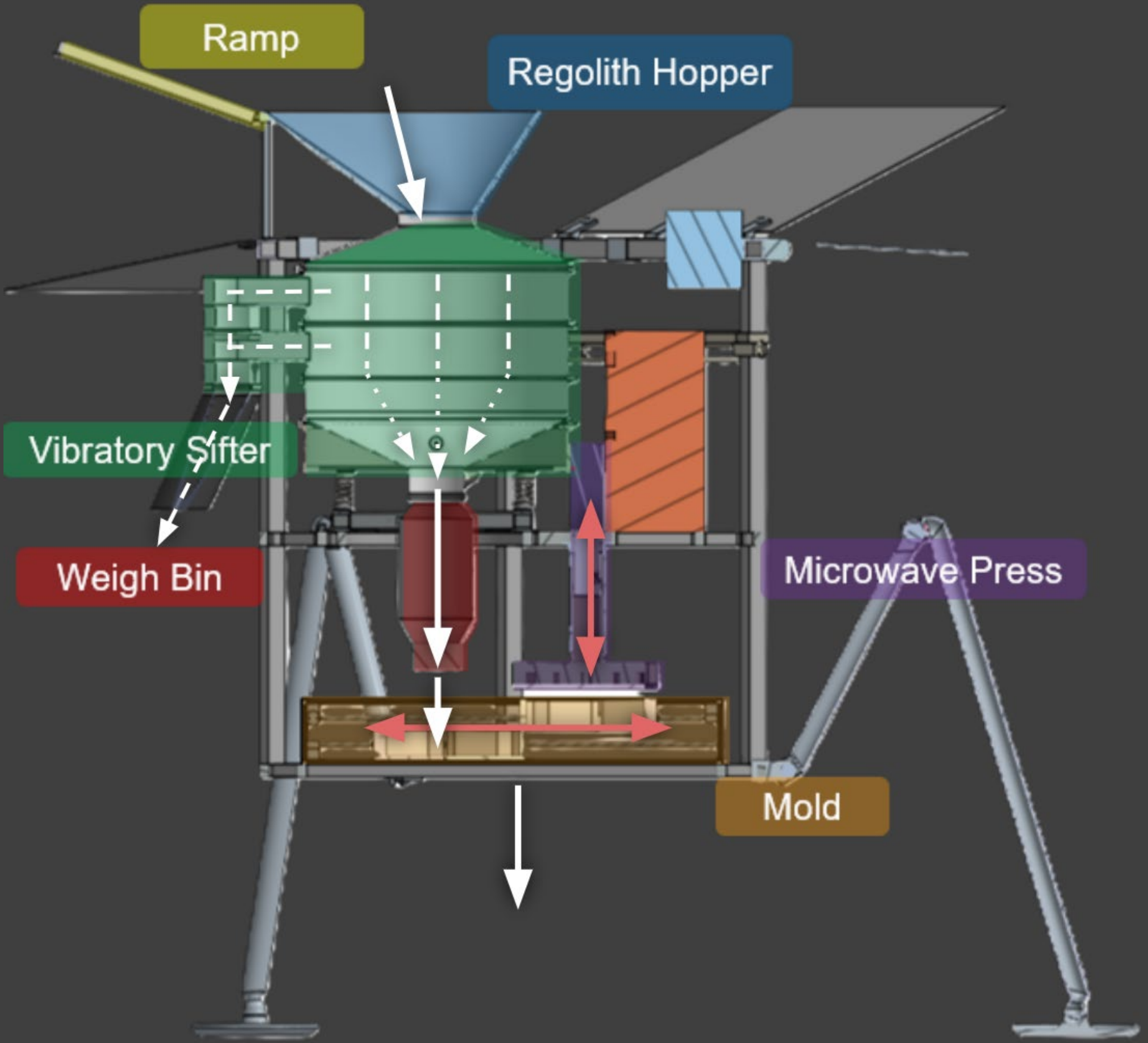
Continuous Sintering: 3 large passive panels provide 1,763 W of constant cooling.



Zero-Power Night Survival: Motorized Avionics panel folds shut at dusk. Using just 2 NASA RHUs, the core effortlessly survives the 1.6 W parasitic leak during the 3–4-day lunar deep freeze at the South Pole.

System Architecture

- Rover Ramp Connected to Griffin
- Regolith deposit into hopper
- Vibratory sifter selection process
- Screened regolith to weigh bin
- Deposit regolith to Mold
- Vibration and compaction cycle
- Microwave sintering cycle
- Tile ejection

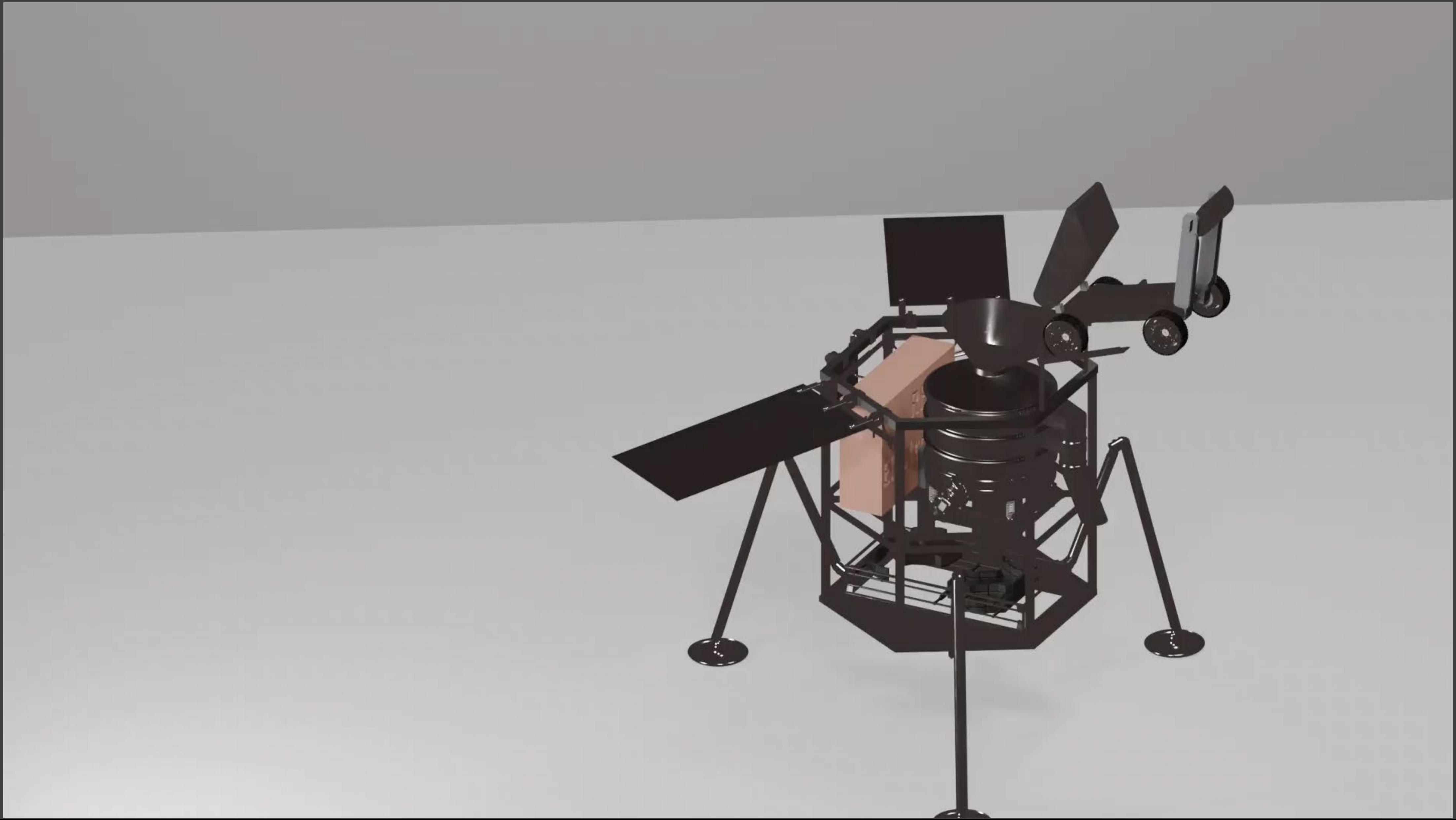


Maximum structural G Loading, n = 2: 24 G

Typical Launch: 3-6 G

Volume within constraints: 1.573 cubic meters

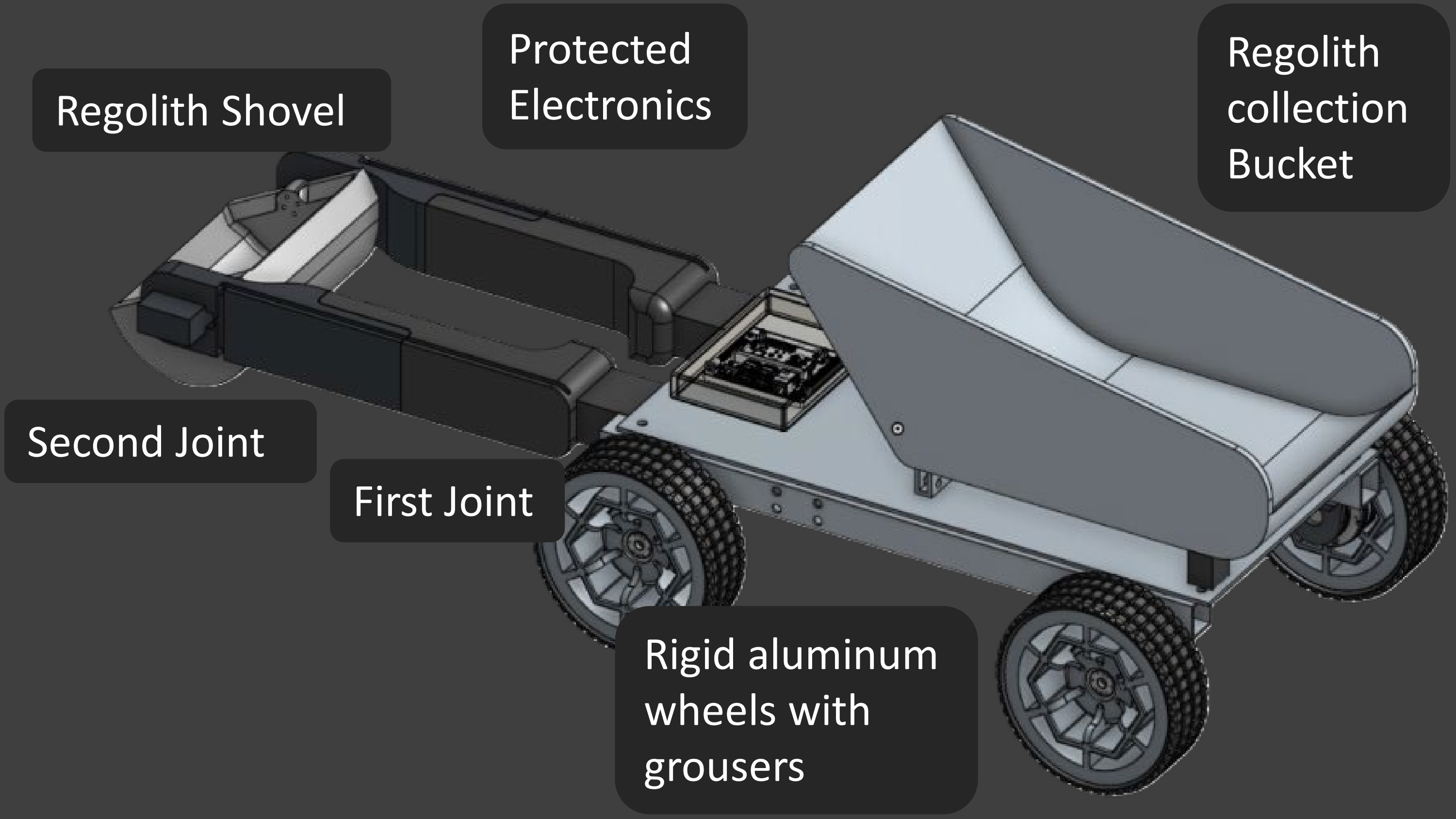
Animation



Rover Architecture

Lunar Rover

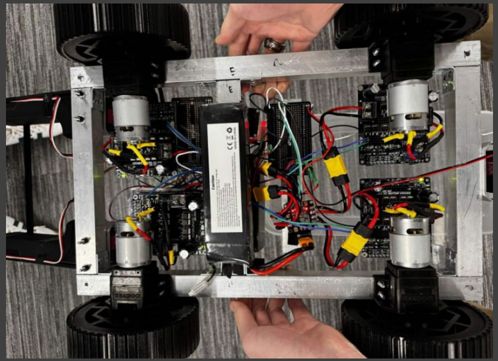
- **Lightweight (30 kg)** rover designed for short-range lunar operations
- **Primary mission:** collect regolith and deliver to processing system
- **2 joint robotic arm** with hopper for material handling
- **Navigation:** wheel odometry + IMU with visual odometry correction
- **Mobility:** 4-wheel drive with aluminum grouser wheels for traction on regolith
- **Power system:** 6S Li-ion Battery Pack (~400 Wh, 22.2V, ~18Ah)
- **Thermal design:** insulated electronics box with low-power Kapton heater for lunar night

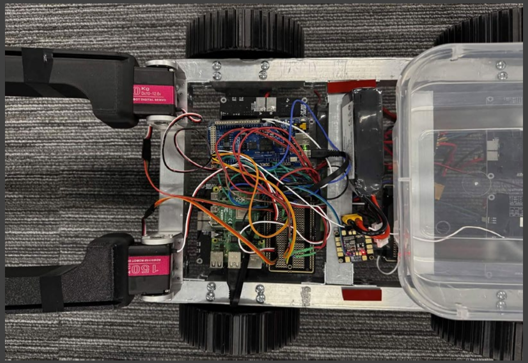


Prototype

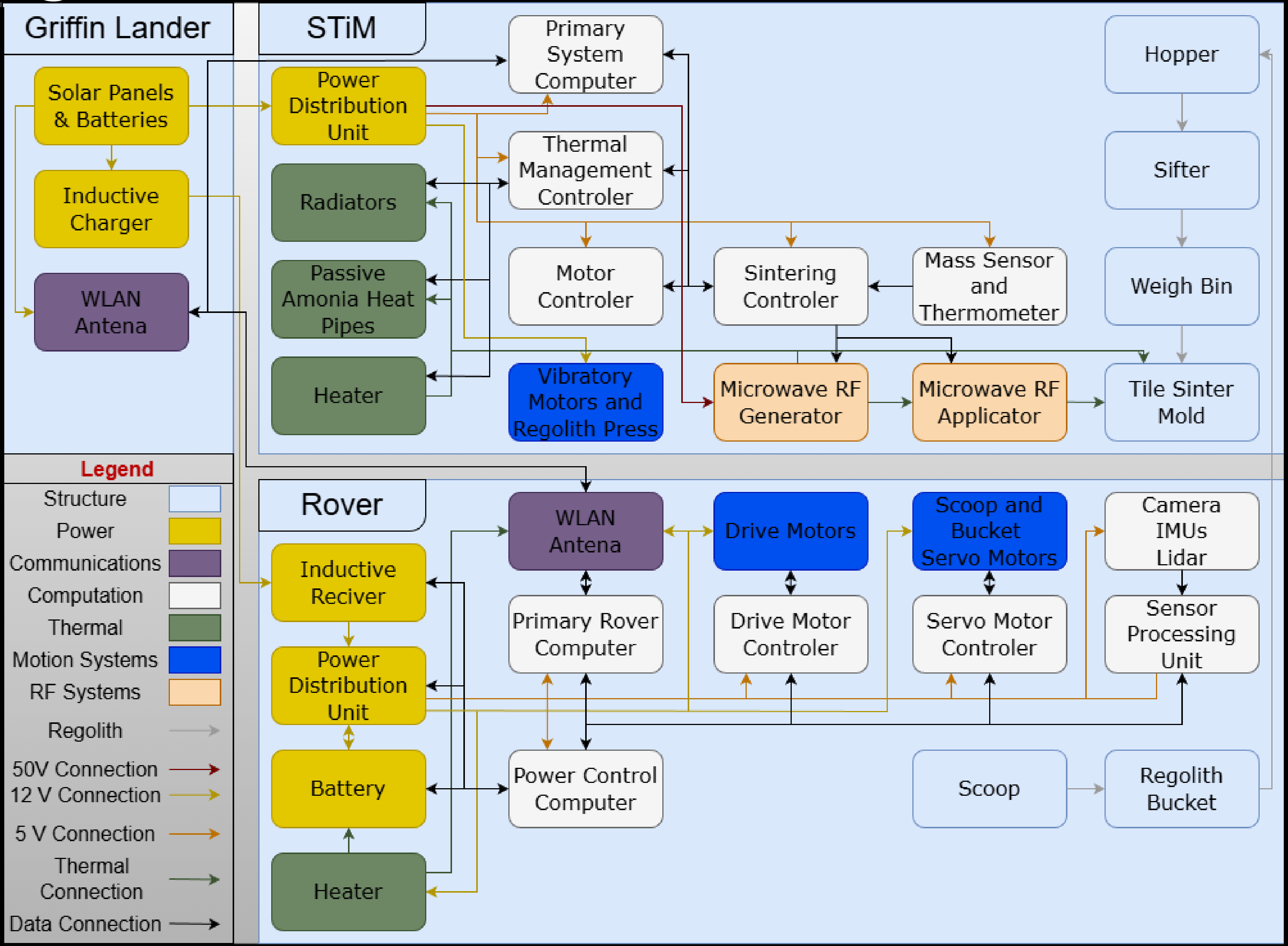
Rover Prototype Details:

- 18 in x 11 in, aluminum and plexiglass chassis.
- 3D printed scoop, arms, and wheels.
- 4x Motors, 4x motor controllers, 2 PDBs, 3x 125 kg servos, 2x 25 kg servos, 6700 mAh lipo battery, 2200 mAh lipo battery.





Energy Diagram



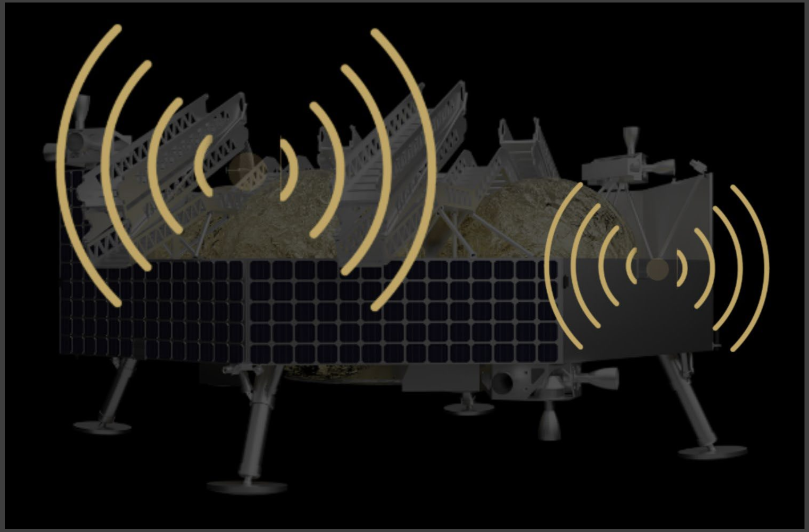
Data Handling and Communications

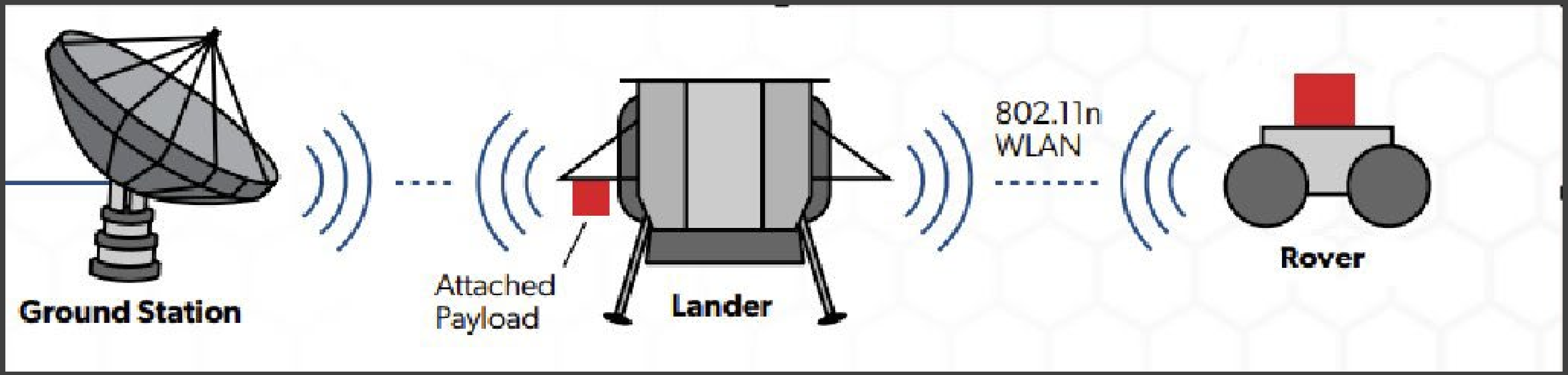
COMMUNICATION SYSTEM:

- The Griffin Lander provides the main relay to Earth through a high-powered transponder and a high-gain antenna.
- Rover uses a 2.4 GHz Wireless Local Area Network modem, compliant with IEEE 802.11n.
- The Rover communicates through the lander using low-gain antenna

SYSTEM REQUIREMENTS:

- Rover sends health, status, and payload telemetry to the lander
- Near-real-time telemetry with low-to-moderate data rate is sufficient
- Full-time observer is not required; only operator commands for supervision and updates.
- Communication must work over the full rover operating range





Budgeting

Rover Mass Budget

Component:	**Mass (kg):**
Battery Pack	2.80
Electronics Components	5.98
Chassis	3.23
4x Wheels	1.09
4x Tires	1.47
Bucket	8.16
2x Scoop Arms	3.87
Scoop	3.14
Harness	0.50
Total Mass:	**30.24**

Rover Cost Budget

Category:	**Cost (USD):**
Power & Thermal	570,000
Navigation Sensors (IMU + Cameras)	1,250,000
Structure & Mechanical Systems	3,650,000
Electronics & Avionics	1,030,000
Actuation (Motor & Gearboxes)	780,000
Software & Integration	500,000
Space-Safe Modifications (600%)	46,680,000
Rover Total Cost:	**54,460,000**

STiM Mass Budget

Component:	**Mass (kg):**
Aluminum Frame	41.0
3x Support Legs	13.5
Battery Pack	30.0
Vibratory Motors	6.35
Regolith Sifting System	9.69
Cooling System	17.31
Hopper & Ramp	5.47
Weigh Bin	5.85
Mold System	11.16
Sintering System	9.23
Total Mass:	**154.9**

STiM Cost Budget

Category:	**Cost (USD):**
Structure & Mechanical Systems	3,625,000
Electronics & Avionics	1,150,000
Actuation (Motor & Gearboxes)	845,000
Regolith Processing (Microwave & Mold)	2,753,500
Power & Thermal	1,392,000
Software & Integration	1,500,000
Space-Safe Modifications (600%)	187,750,000
STiM Total Cost:	**196,537,500**
Total Cost:	**250,997,500**

Rover Power Budget

Mode:	**Power Draw:**	**Description:**
Controls	<200 W	Driving, Dumping, Comms
Digging/Scoop/Dump	<175 W	Collecting Regolith
Total Battery:	480 Wh	Enough power for multiple trips per day

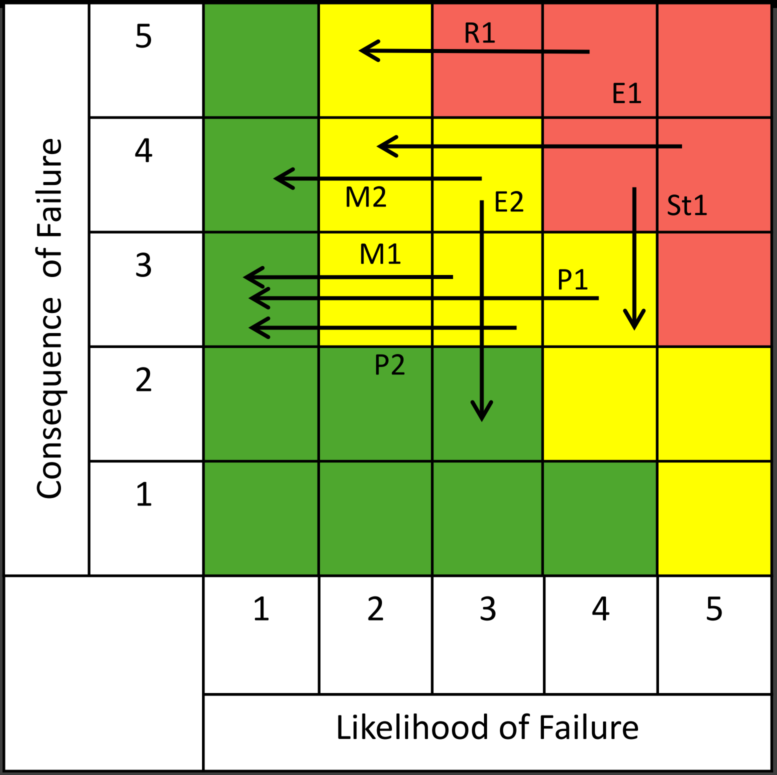
STiM Power Budget

Mode:	**Power Draw:**	**Description:**
Sintering	1.50 kW	1 kW RF, Press, Controls
Ejecting Tiles	0.40 kW	Move finished bricks off the STiM
Conditioning	250 W	Vibratory methods, Release methods
Idle	Day: 50 W Night: <10 W	Day – electronics ready, Night – survival, heat, and comms

Mission Risk Analysis

PROJECT HESTIA

Risk ID	Risk Statement	Consequence	Mitigation Strategy
M1	Tile production rate is too low to meet mission goals	Mission produces too few usable tiles	Optimize rover collection cycles and processing time to maximize tile output.
M2	Solar panels dust accumulation	Reduced available power for rover and tile maker operations	Controlled dumping of regolith and dust shield
P1	Microwave sintering efficiency is lower than expected	More energy is required, reducing tile production performance	Validate sintering efficiency through extensive testing beforehand
P2	Available power is insufficient for sustained sintering operations	Incomplete processing and reduced tile output	Budget power conservatively
R1	Rover is unable to traverse terrain and gets stuck	Regolith delivery to the tile maker is interrupted	Flat site selection and limited collection radius
E1	Landing site regolith is unsuitable for consistent tile production	Reduced sintering quality, leading to weak, cracked, or inconsistent tiles.	Select a location with stable and predictable regolith
E2	Sintering system overheats during operation	Processing must stop or hardware may be damaged	Implementing a cooling system
St1	Produced tiles do not meet the required structural quality for construction use	Manufactured tiles cannot be used for the intended infrastructure application	Include demonstration tile production as a secondary success criterion



Risk Classification
R (Rover)
M (Mission)
E (Environmental)
P (Power and Thermal)
St (Structural)

Consequence of Failure		Likelihood of Failure	
Catastrophic (5)	Total mission failure; failure to satisfy mission requirements	Very High (5)	50% - 100%
Critical (4)	Failure to satisfy multiple mission requirements	High (4)	25% - 50%
Moderate (3)	Failure to satisfy a mission requirement	Medium (3)	12% - 25%
Minor (2)	Mission requirements are met. Disruption to mission timeline	Low (2)	5% - 12%
Negligible (1)	Minimal to no impact on mission outcome	Very Low (1)	0% - 5%

Project Management Milestones

PROJECT START
October 2025

- Landing Pad Construction Selected
- Initialize Trade Studies

October 17, 2025

Microwave Sintering Selected
October 24, 2025

- STiM – Rover Architecture Selected
- Operations concept chosen

November 5, 2025

- Team roles assigned & Project lead select
- System requirements defined

November 8, 2025

Trade studies finalized
November 24, 2025

- Conceptual Design Finalized
- Preliminary Design Review

December 2025

- Conceptual Design refined in detail
- Tile design refined

January – March 2026

PROJECT PRESENTATION
April 2026

Biggest Challenges

Tile design

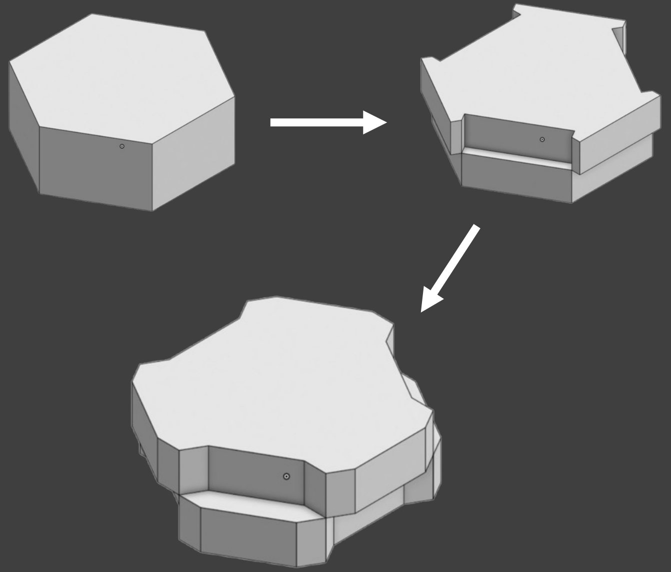
- Volume
- Tileable
- Exhaust proofing
- Low precision construction

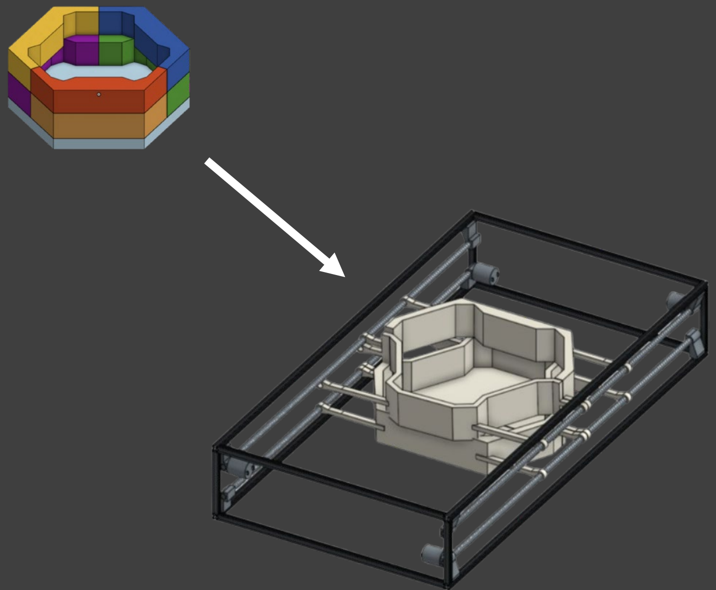
Tile manufacturing

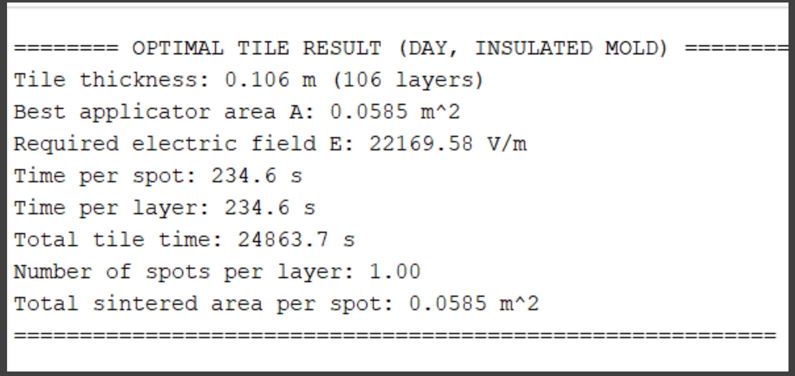
- Layers
- Variable cross-section
- Uniform regolith distribution
- Variable microwave height

Determining microwave feasibility

- Power draw
- Optimal layer volume
- Complex heating equation







```
======== OPTIMAL TILE RESULT (DAY, INSULATED MOLD) ========
Tile thickness: 0.106 m (106 layers)
Best applicator area A: 0.0585 m^2
Required electric field E: 22169.58 V/m
Time per spot: 234.6 s
Time per layer: 234.6 s
Total tile time: 24863.7 s
Number of spots per layer: 1.00
Total sintered area per spot: 0.0585 m^2
============================================================
```

Tech Gap Assessment

Increased Power Access

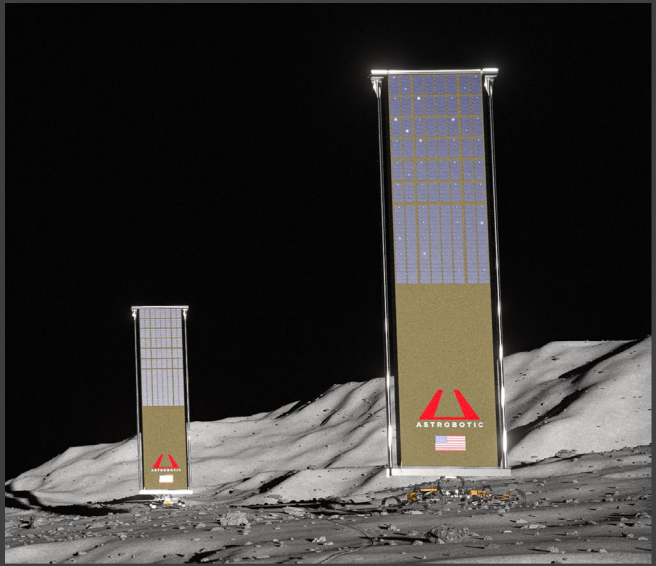
- LunaGrid
- Nuclear Reactor

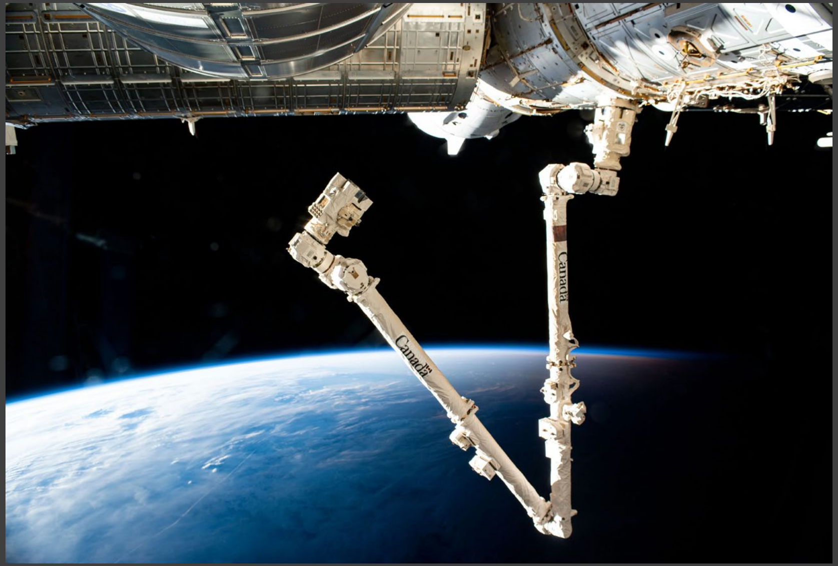
Advanced Testing Technology

- Ultrasonic Penetrating Scanner
    - Scanning for imperfections
- Observe Chemical Makeup

High Fidelity Manipulator

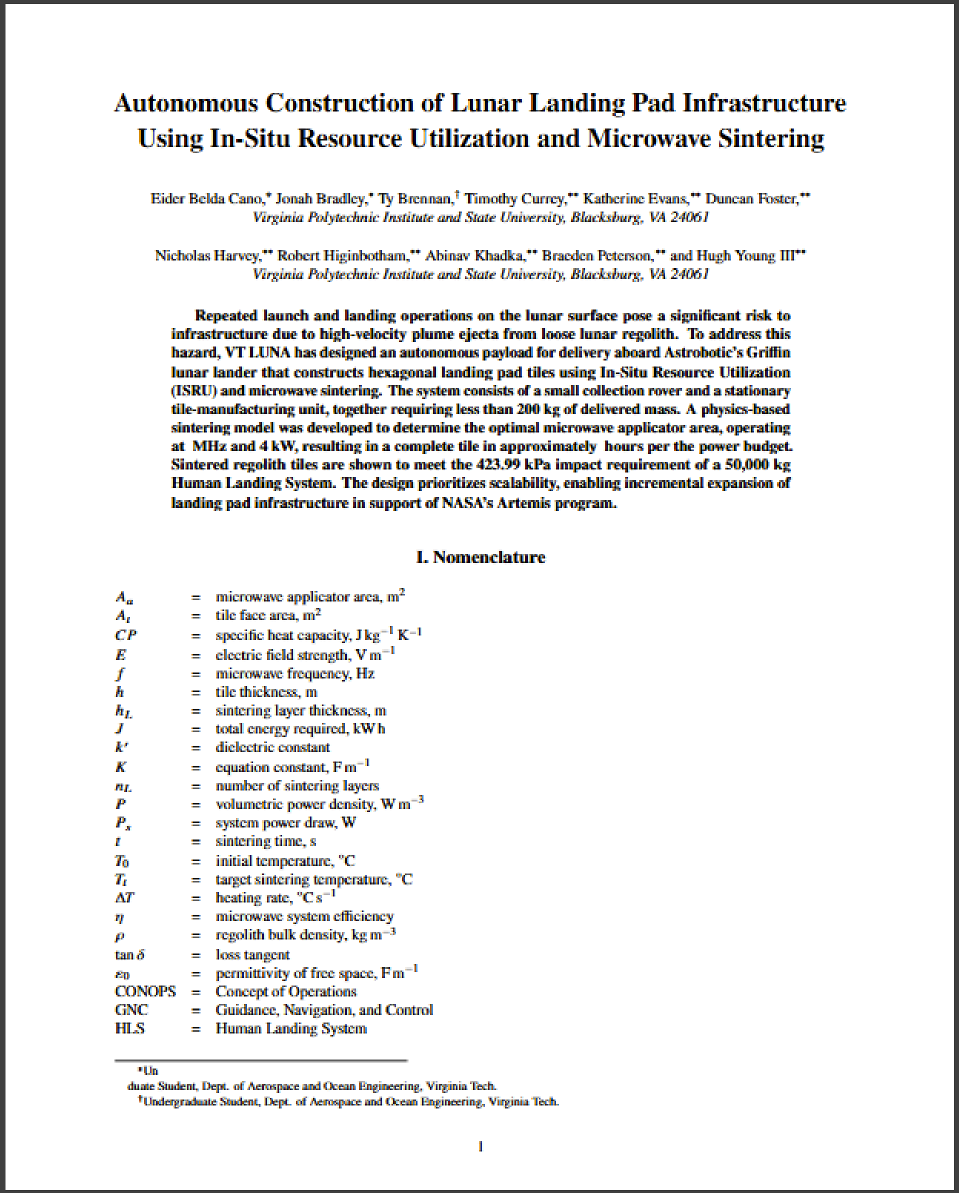
- Tile Placement
- Advanced Regolith Selection
- Terraforming Capabilities





Paper

- **Title***: Autonomous Construction of Lunar Landing Pad Infrastructure Using In-Situ Resource Utilization and Microwave Sintering*
- **Abstract**: 146 words
- **Length:** 22 pages (Figures and references included)
- **Number of references:** 45
- **Potential publication venues:**
  - Aerospace conferences
  - Journals on lunar ISRU, robotics, or space infrastructure



Autonomous Construction of Lunar Landing Pad Infrastructure Using In-Situ Resource Utilization and Microwave Sintering

Eider Belda Cano,* Jonah Bradley,* Ty Brennan,† Timothy Currey,** Katherine Evans,** Duncan Foster,**
Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

Nicholas Harvey,** Robert Higinbotham,** Abinav Khadka,** Braeden Peterson,** and Hugh Young III**
Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

Repeated launch and landing operations on the lunar surface pose a significant risk to infrastructure due to high-velocity plume ejecta from loose lunar regolith. To address this hazard, VT LUNA has designed an autonomous payload for delivery aboard Astrobotic's Griffin lunar lander that constructs hexagonal landing pad tiles using In-Situ Resource Utilization (ISRU) and microwave sintering. The system consists of a small collection rover and a stationary tile-manufacturing unit, together requiring less than 200 kg of delivered mass. A physics-based sintering model was developed to determine the optimal microwave applicator area, operating at MHz and 4 kW, resulting in a complete tile in approximately hours per the power budget. Sintered regolith tiles are shown to meet the 423.99 kPa impact requirement of a 50,000 kg Human Landing System. The design prioritizes scalability, enabling incremental expansion of landing pad infrastructure in support of NASA's Artemis program.

I. Nomenclature

A_a = microwave applicator area, m^2
A_t = tile face area, m^2
CP = specific heat capacity, $\mathrm{J\,kg^{-1}\,K^{-1}}$
E = electric field strength, $\mathrm{V\,m^{-1}}$
f = microwave frequency, Hz
h = tile thickness, m
h_L = sintering layer thickness, m
J = total energy required, kW h
k' = dielectric constant
K = equation constant, $\mathrm{F\,m^{-1}}$
n_L = number of sintering layers
P = volumetric power density, $\mathrm{W\,m^{-3}}$
P_s = system power draw, W
t = sintering time, s
T_0 = initial temperature, °C
T_t = target sintering temperature, °C
ΔT = heating rate, $\mathrm{{}^\circ C\,s^{-1}}$
η = microwave system efficiency
ρ = regolith bulk density, $\mathrm{kg\,m^{-3}}$
$\tan\delta$ = loss tangent
ε_0 = permittivity of free space, $\mathrm{F\,m^{-1}}$
CONOPS = Concept of Operations
GNC = Guidance, Navigation, and Control
HLS = Human Landing System

---

*Un
duate Student, Dept. of Aerospace and Ocean Engineering, Virginia Tech.
†Undergraduate Student, Dept. of Aerospace and Ocean Engineering, Virginia Tech.

1

Path to PDR and Beyond

2025

Structure team

Identify Problem

Identify Stakeholders

Preliminary requirements

Perform trade studies to determine desired concept

2026

Begin detailing concept ideas

Finalize tile design and dimensions

Develop 3D CAD models of both STiM and rover

Estimate and refine mass and power budgets

Estimate total cost of concept

Prototype of rover

Begin prototype of filtration model

Adapt rover for tile receiving and placing capabilities

2027

Finish and test filtration prototype

Prototype microwave sintering and mold

PDR

Manufacture and test prototype tiles using regolith simulant

Update requirements

Update tile properties

Evaluate effectiveness of sintering method

Finalize specific dimensions on rover and STiM

2028

Test microwave sintering of tiles in vacuum

Update mission concept of operations

Test interaction between rover and STiM

Finalize exact path of rover for lunar regolith collection

Finalize payload integration with Griffin lunar lander

Begin manufacturing of all final parts

2029

Construction of final payload

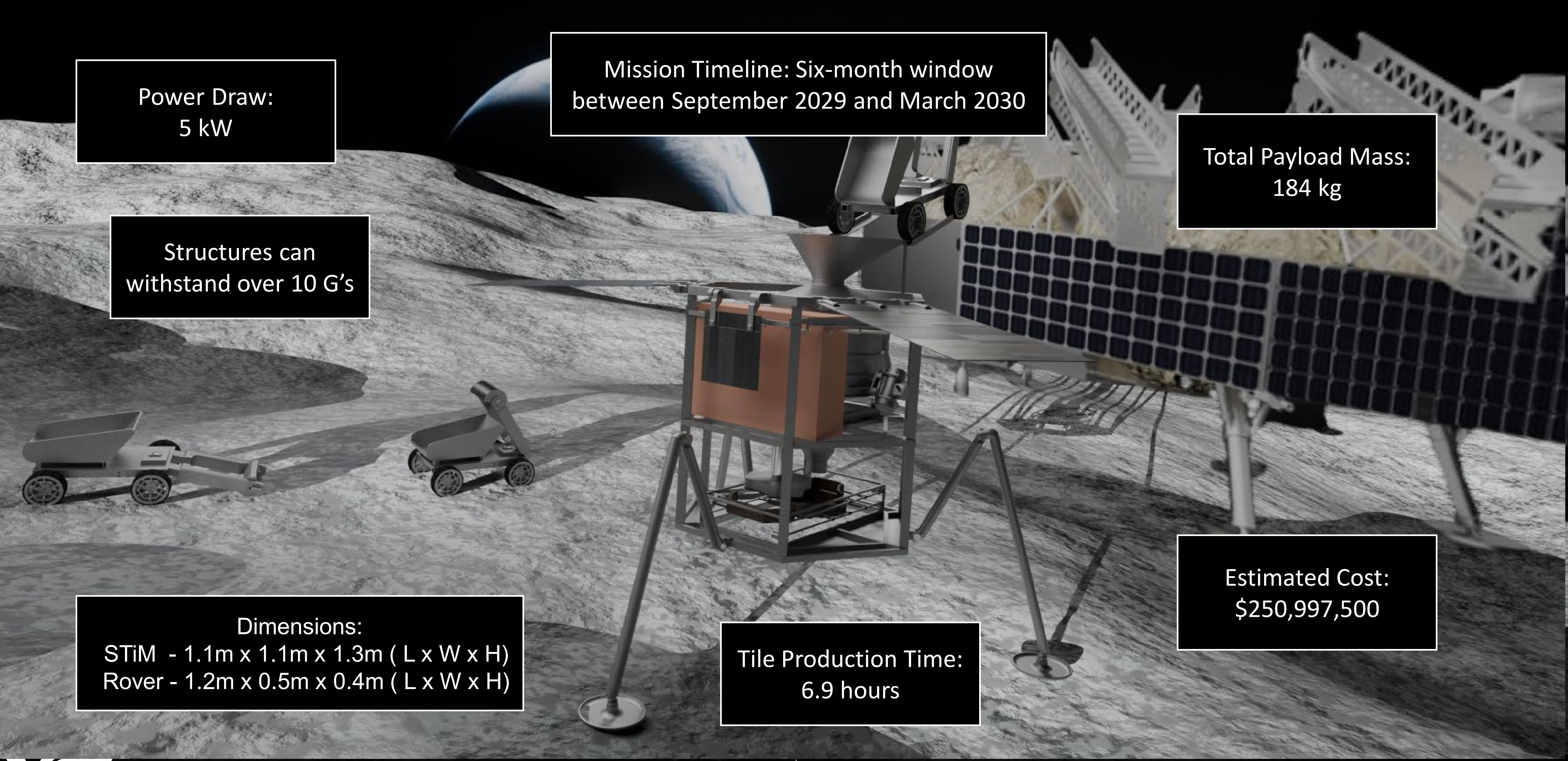
Testing of all components

Launch

🟩 Complete

🟨 Incomplete

Project HESTIA Conclusion



Power Draw:
5 kW

Mission Timeline: Six-month window between September 2029 and March 2030

Total Payload Mass:
184 kg

Structures can withstand over 10 G's

Dimensions:
STiM - 1.1m x 1.1m x 1.3m (L x W x H)
Rover - 1.2m x 0.5m x 0.4m (L x W x H)

Tile Production Time:
6.9 hours

Estimated Cost:
$250,997,500

Questions?

Backup Slides

References

Slide 5: https://www.universetoday.com/articles/whats-the-best-material-for-a-lunar-tower, https://payloadspace.com/lunar-infrastructure-startup-ethos-emerges-from-stealth/

Slide 7: https://payloadspace.com/wp-content/uploads/2024/06/Screen-Shot-2024-06-04-at-2.52.10-AM.png, https://magazine.northwestern.edu/news/building-lunar-landing-pad-icon-nasa-space-moon-dust-construction

https://www.esa.int/ESA_Multimedia/Images/2019/07/Artist_impression_of_activities_in_a_Moon_Base

Slide 8: https://ntrs.nasa.gov/api/citations/20205003590/downloads/20_Wittaletal_LanderPlumeEjecta.pdf, https://magazine.northwestern.edu/news/building-lunar-landing-pad-icon-nasa-space-moon-dust-construction

Slide 10: https://www.nasa.gov/humans-in-space/artemis/, https://www.liebertpub.com/doi/10.1089/space.2022.0015, https://stjerneskinn.com/almanac-2029.htm?utm

Slide 11: https://www.theguardian.com/science/2023/jun/28/nasa-mining-moon-2032, https://www.astrobotic.com/announcing-lunagrid-a-commercial-power-service-for-the-moon/, https://cosmicspace.org/wp-content/uploads/2025/10/C3-2025-26-Information-Packet-Fall-Update.pdf

Slide 11: https://doi.org/10.1016/j.ceramint.2021.10.123

Slide 11: https://doi.org/10.1016/j.addma.2021.102278

Slide 11: https://doi.org/10.1016/j.actaastro.2020.10.030

Slide 14: https://1.bp.blogspot.com/-t_hg0lI33Wo/X3nn51ObmbI/AAAAAAAAFTM/YZL6ba7QXc8Xva61VRbK9JmjSxbF7mScgCLcBGAsYHQ/s2048/SpaceX%2BStarship%2Bat%2BNASA%2BArtemis%2BBase%2BCamp%2Bspaceport%2Bby%2BICON%2B%2526%2BSEArch_closeup_humanmars.net.jpg,
Preliminary concept of the DM-1 MMPACT surface construction system operating from the deck of a CLPS lander on the Moon. R.G. Clinton, et.al. 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022.

Slide 10, 24, 25: https://www.astrobotic.com/lunar-delivery/landers/griffin-lander/, https://www.astrobotic.com/wp-content/uploads/2022/01/PUGLanders_011222.pdf

Slide 12: https://www.nasa.gov/general/nasas-artemis-iv-building-first-lunar-space-station/

Slide 19: https://www.sciencedirect.com/science/article/pii/S0094576521000564

https://www.sciencedirect.com/science/article/pii/S0094576524000961

Slide 27: https://ipnpr.jpl.nasa.gov/progress_report/42-176/176C.pdf

Slide 28: https://www.nasa.gov/news-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon/?utm_

https://www.nasa.gov/news-release/nasa-provides-update-on-artemis-iii-moon-landing-regions/#:~:text=Peak%20near%20Cabeus%20B,with%20Earth%2C%20and%20lighting%20conditions

Slide 36: Lunar Rover Arm Brings Increased Functionality to space missions.

Slide 41: https://www.sshlmachinery.com/how-much-force-can-a-hydraulic-press-produce.html, https://www.maverickmachine.ca/news/hydraulic-actuators-101/, https://www.nasa.gov/ames/arcjet-complex/

Slide 42: https://www.pellenc.com/en-gb/our-products/from-the-vineyard-to-the-winery/winemaking/reception/receiving-hopper

Slide 43: https://www.dahanmachine.com/product-center/Circular-Vibratory-Sifter.html

Slide 44-50: https://articles.adsabs.harvard.edu//full/1973LPSC....4.3133O/0003138.000.html

https://ascelibrary.org/doi/abs/10.1061/%28ASCE%290893-1321%282005%2918%3A3%28188%29?casa_token=SJqBupBG8YYAAAAA%3AzwO9di_ZvCqISFzD1x5suBLF77GmhvY2oG9QubrAvTiEzLNsoMqVZ9EnSooK1Ed4R9HN3jq0L1M

https://automeris.io/

https://www.sciencedirect.com/science/article/pii/S0094576521003349#sec2

https://taylor.utk.edu/wp-content/uploads/2016/03/microwave1.pdf?utm

https://articles.adsabs.harvard.edu//full/1972LPSC....3.3157B/0003157.000.html

https://www.sciencedirect.com/science/article/pii/S0272884221018423

Slide 45: 24v 20ah deep cycle lithium lifepo4 battery | Keheng

Slide 56: https://www.semanticscholar.org/paper/Slotted-waveguide-antennas-for-practical-radar-Sekretarov-Vavriv/f0cf4b7e12d7946aba2782fe245c7e4284caa447/figure/2

Slide 62: https://www.astrobotic.com/wp-content/uploads/2022/01/PUGLanders_011222.pdf

Slide 63: https://www.silabs.com/documents/public/data-sheets/wgm160p-datasheet.pdf, datasheet-eosol-group-24ghz-pagoda-antenna-for-lunar-communications-psakkf_(1).pdf,
https://www.esa.int/Science_Exploration/Space_Science/Rosetta/Communicating_from_space_gaining_a_grip_on_antennas2, https://ntrs.nasa.gov/api/citations/20205007515/downloads/Aerogel%20Space%20Applications_Aerogel%20Summit%20'20.pdf

References

:

- https://www.maxongroup.com/maxon/view/product/motor/ecmotor/ecflat/ecflat32/339259
- https://www.maxongroup.com/maxon/view/product/motor/ecmotor/ecflat/ecflat45/402686
- https://www.maxongroup.com/maxon/view/product/267121
- https://www.maxongroup.com/maxon/view/product/motor/ecmotor/ECX-Flat/ECX-Flat-32
- https://www.newark.com/maxon-motor/251601/dc-motor-brushless-50w-6710rpm/dp/15R2903
- https://www.alibaba.com/product-detail/CUBEMARS-RI50-Pmsm-Frameless-500W-BLDC_1601373249572.html
- https://www.digikey.com/en/products/detail/faulhaber/2224.15000/
- https://www.microchip.com/en-us/product/samrh71
- https://www.maxongroup.net.au/medias/sys_master/root/9227156127774/Space-Catalog-2023-EN.pdf
- https://servo.com.sg/sites/default/files/2018-01/EC%20MOTOR_Program_2017-18_0.pdf
- https://www.northropgrumman.com/what-we-do/mission-solutions/assured-navigation/ln-200s-inertial-measurement-unit
- https://www.aac-clyde.space/what-we-do/space-products-components/payloads/im200
- https://www.enersys.com/en/products/batteries/absl/absl-space/
- https://www.alibaba.com/product-insights/li-ion-18650-6s3p-battery-pack.html
- https://www.minco.com/products/flexible-heaters/polyimide-thermofoil/
- https://www.alibaba.com/

Impact & Scope

Goal

- **Demonstrate that structurally and thermally sound launch pad tiles can be fabricated repeatedly with ISRU capabilities and a rover collection system.**

Future

- **The system can be scaled to construct a full lunar launch pad by increasing production throughput, preparing terrain areas, and advancing automation.**

ID	Key Requirements
SYS 1.0	System shall have a total mass under 200 kg.
SYS 2.0	System shall occupy a volume no greater than 0.75 of the lander payload volume (1.5 m x 1.5 m x 2.5 m).
SYS 3.0	System shall autonomously manufacture structurally sound tiles using In-Situ Resource Utilization (ISRU).

Timeframe

- 9/2029: Mission Launch
- 9/2029: System Initialization
- 3/2030: Mission Completion

Assumptions
There will be a local on-surface astronaut.
Almost constant illumination over 6 months.
Ability to utilize all Griffin lander features.

Cooling Calculations

Q = ε · σ · A_eff · T^4

Given Variables (White Paint)

σ = 5.67 × 10^-8 W/m^2·K^4
ε = 0.91
T = 333 K

Effective Area Calculation

Area of ONE full panel:

0.55 × 0.95 = 0.5225 m^2

Panel 2 Full x 1 cutout (leg clearance):

0.60 × 0.11 = 0.066 m^2
0.5225 - 0.066 = 0.4565 m^2

Total for 3 panels (2 full + 1 cutout):

(2 × 0.5225) + 0.4565 = 1.5015 m^2

Both sides radiating:

A_eff = 1.5015 × 1.85 = 2.778 m^2

Final Heat Rejection Calculation
Q = (0.91)(5.67 × 10^-8)(2.778)(333^4)
Step-by-step:
0.91 × 5.67 × 10^-8 = 5.1597 × 10^-8

333^4 = 12,296,370,321

(5.1597 × 10^-8) × 2.778 = 1.4334 × 10^-7

Q = (1.4334 × 10^-7) × (12,296,370,321)
Final Answer:
Q ≈ 1,763 W

Margin Check
Heat generated (RF Loop 2) = 1,600 W
Heat rejected = 1,763 W

Margin = (1763 - 1600) / 1600 ≈ 0.102 ≈ 10.2%

Cooling System Deployment

1. The Launch (Stowed State)

During the violent rocket launch, your radiator panels are folded tightly against the metal frame of the lander so they fit inside the rocket fairing. The hinges connecting the panels to your frame contain heavy-duty **torsional springs** that are wound up tight.

2. The Hold-Down Release Mechanism (HDRM)

To stop the springs from popping the panels open inside the rocket, the panels are tied down using a standard aerospace tie-down (usually a kevlar cable or a non-explosive frangible bolt).

3. The Deployment (Pop & Lock)

Once the Griffin lander safely touches down on the Moon, the flight computer sends a tiny, one-time electrical pulse to heat up a thermal knife that snaps the tie-down cable.

The Action: The wound-up torsional springs instantly push the panels open 90 degrees.

The Lock: When the panel hits 90 degrees, it hits a hard physical stop, and a simple mechanical ratchet-pin clicks into place.

System Requirements

ID	Requirement Description
SYS1.0	The system shall have a total mass of under 200 kg.
SYS2.0	The system shall occupy a volume no greater than 0.75 of the Griffin Lander payload volume (1.5 m x 1.5 m x 2.5 m)
SYS3.0	The system shall autonomously manufacture structurally sound tiles using In-Situ Resource Utilization (ISRU).
SYS4.0	The system shall accept and process lunar regolith to use as the primary material for tile production.
SYS5.0	The system shall produce hexagonal tiles that meet defined structural and thermal performance standards.
SYS6.0	The system shall operate autonomously for the duration of the mission, including health monitoring and fault recovery.
SYS7.0	The system shall be capable of surviving and operating within the lunar surface environment (thermal and radiation).
SYS8.0	The system shall perform all operations within the allocated peak power and energy-per-tile budget.
SYS9.0	The system should produce 1 structurally sound tiles autonomously in within 2 weeks.
SYS10.0	The system should detect and respond failures with the Griffin Lander.
SYS11.0	The system should store sufficient regolith to produce a 2-3 tile without additional delivery.

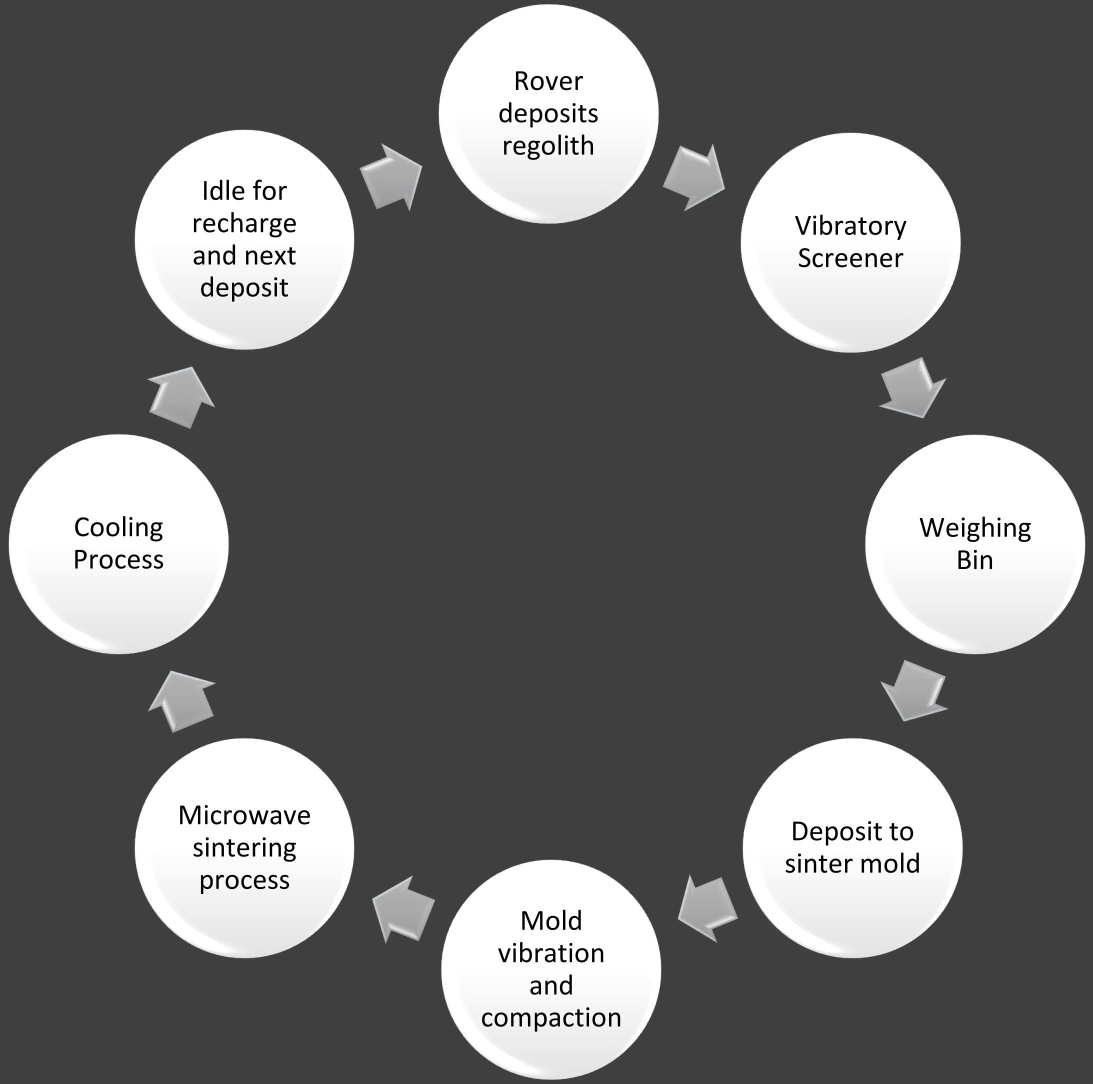
Value System Design

- C3 Lunar
  - Scalability
    - Complexity of scaling up
    - Flexibility
  - Cost
    - Initial setup cost
    - Cost-to-benefit rationance
  - Impact
    - Long-term Effects
    - Short-term Effects
  - Time
    - Estimated duration
    - Time to reach ROI
  - Risk
    - Technical failure likelihood
    - Mitigation and contingency plan
    - Stakeholder risk

Factors	Weight	Rank
Scalability	0.444	1
Impact	0.292	2
Time	0.129	3
Risk	0.081	4
Cost	0.052	5

System Flow Chart

STiM system



Rover deposits regolith

Vibratory Screener

Weighing Bin

Deposit to sinter mold

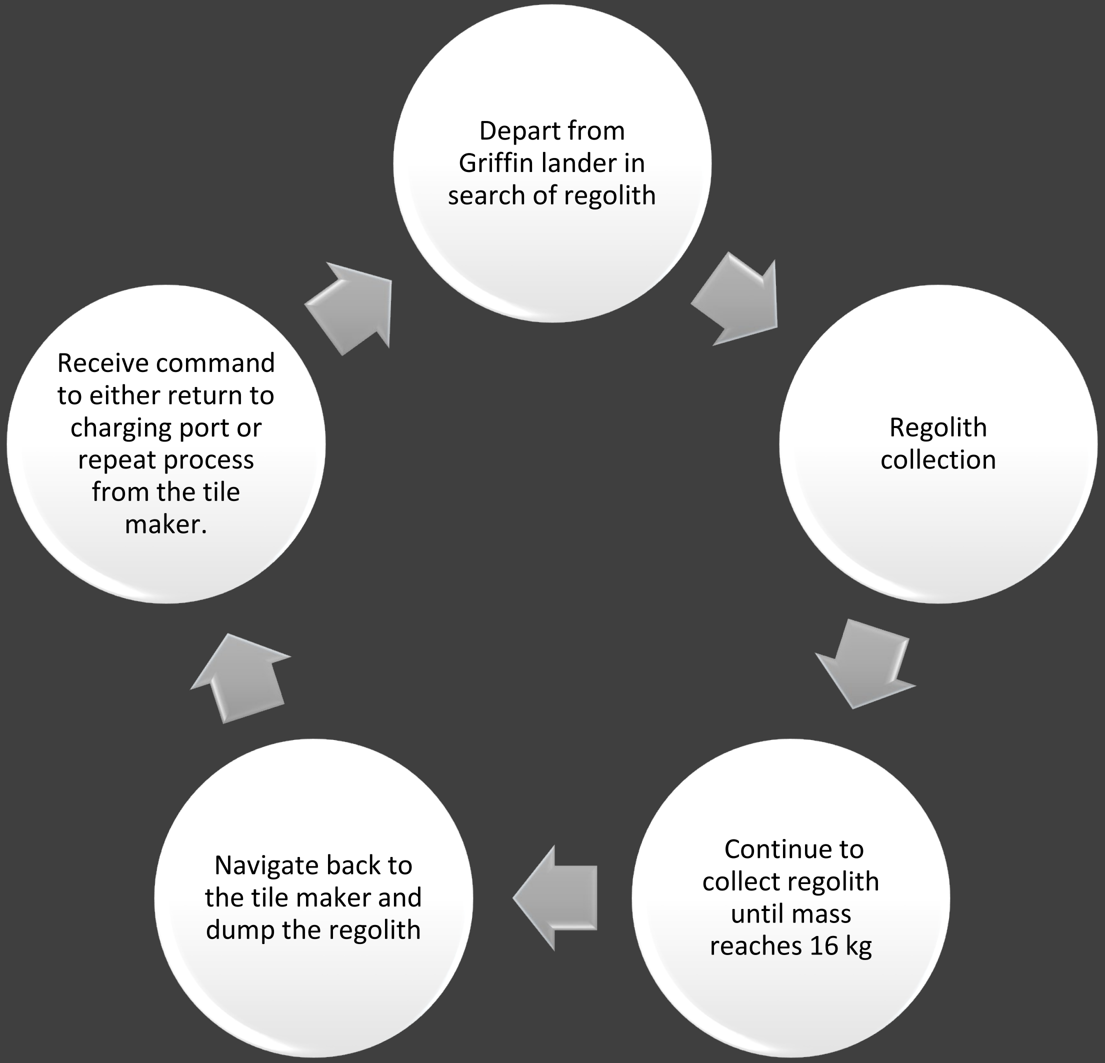
Mold vibration and compaction

Microwave sintering process

Cooling Process

Idle for recharge and next deposit

Rover system



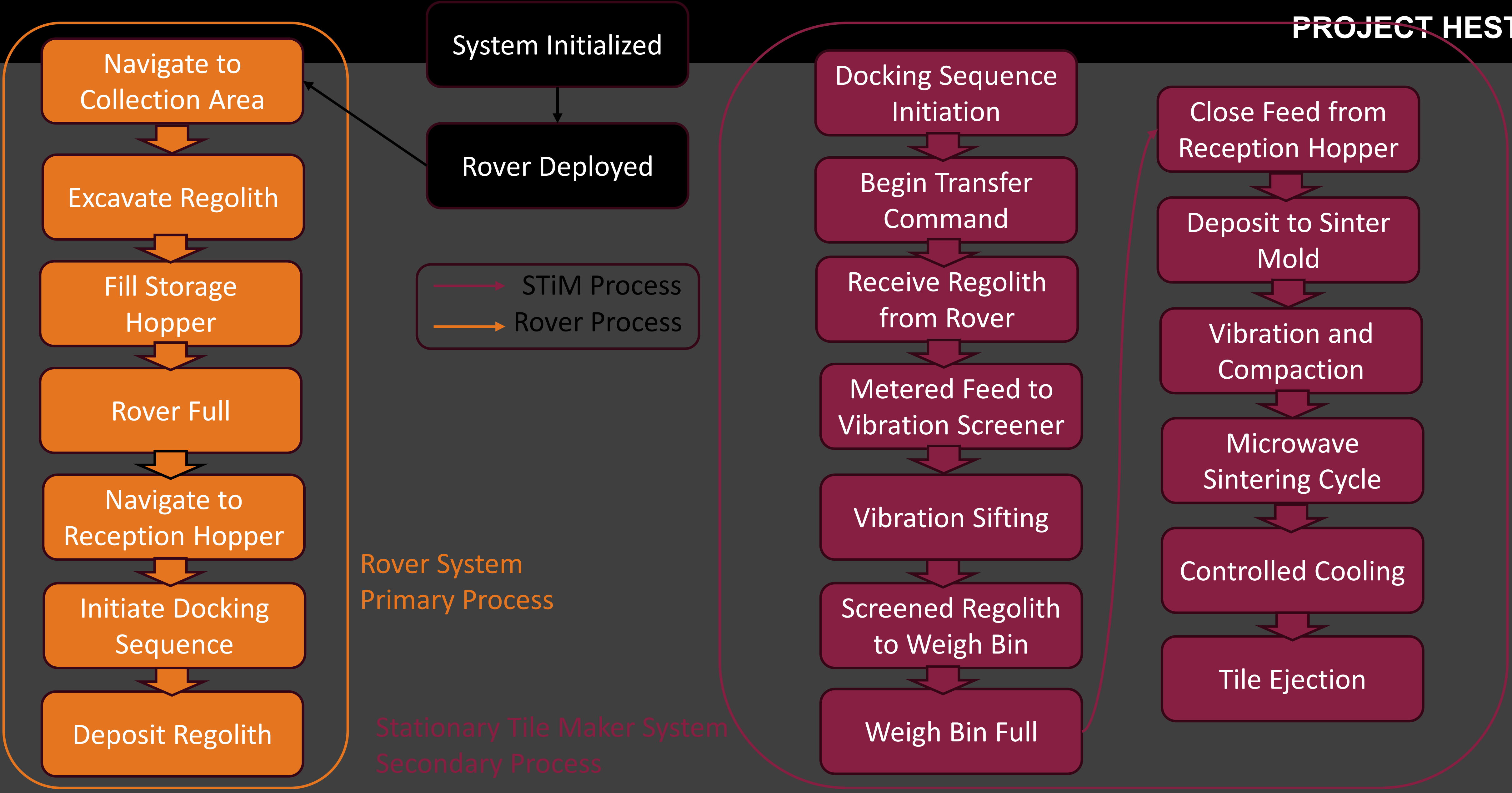
Depart from Griffin lander in search of regolith

Regolith collection

Continue to collect regolith until mass reaches 16 kg

Navigate back to the tile maker and dump the regolith

Receive command to either return to charging port or repeat process from the tile maker.



System Initialized

Rover Deployed

STiM Process

Rover Process

Navigate to Collection Area

Excavate Regolith

Fill Storage Hopper

Rover Full

Navigate to Reception Hopper

Initiate Docking Sequence

Deposit Regolith

Rover System
Primary Process

Docking Sequence Initiation

Begin Transfer Command

Receive Regolith from Rover

Metered Feed to Vibration Screener

Vibration Sifting

Screened Regolith to Weigh Bin

Weigh Bin Full

Close Feed from Reception Hopper

Deposit to Sinter Mold

Vibration and Compaction

Microwave Sintering Cycle

Controlled Cooling

Tile Ejection

Stationary Tile Maker System
Secondary Process

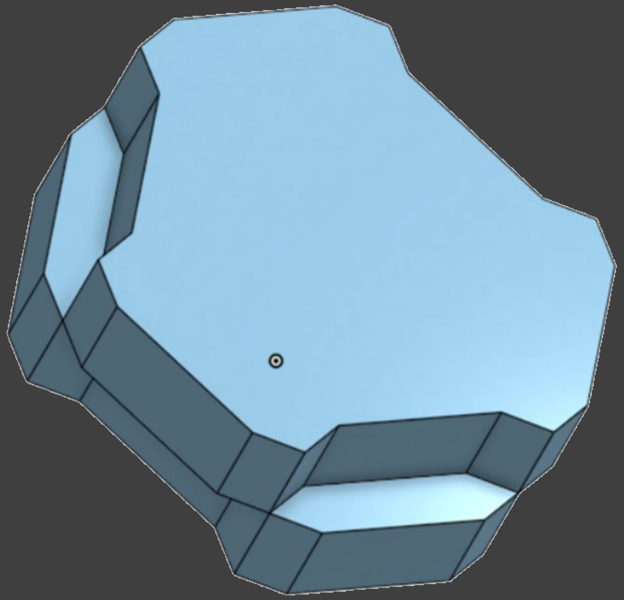
Tile Design

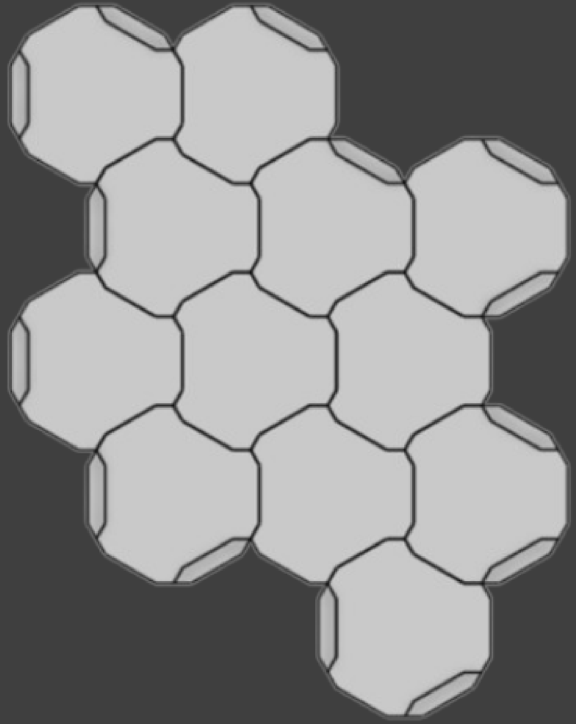
- Must interlock securely with limited manipulation.

- **Must withstand 424 kPa of HLS landing.**
- **Must withstand 25.78 kPa static pressure of HLS.**
- **Must withstand 17786.3 kW/m² heating from plume of HLS landing.**

Design Overview

- A normal hexagonal tile with a circumscribed radius of 0.150 m, a depth of 0.106 m, and a fillet of 25 mm was chosen.
- Quadrilaterals and triangles were avoided as sharp angles are too prone to stress concentration.
- Polygons with more sides were avoided as they do not tessellate

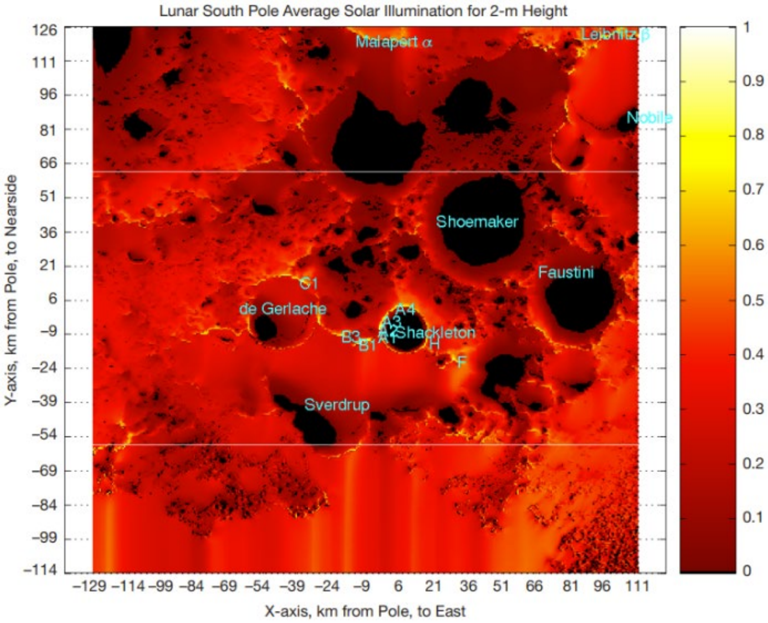




Landing Site Selection Criteria

General Properties

- Maximum Solar Illumination
- Safe and Accessible Terrain
- Communication Access with Earth
- Temperature Stability
- Thick and stable composition of the Regolith

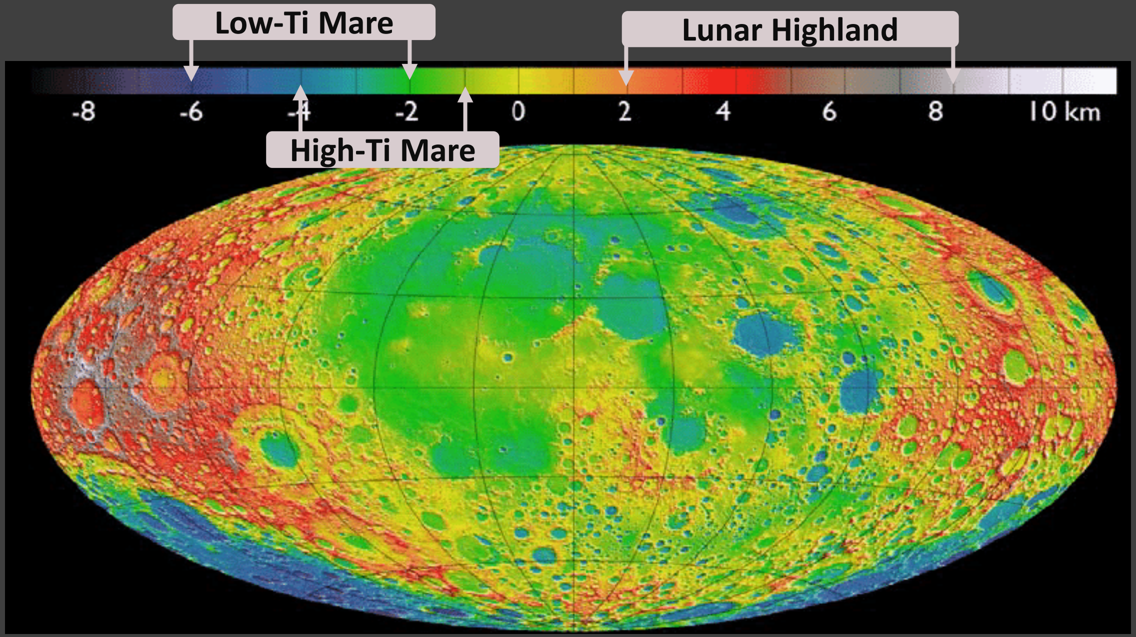


[7]

Specific Regolith properties we are looking for:

- SiO2 concentration
- High TiO2 and FeO concentrations for initial heating
- Low in other contaminants
- Particle size averaging $< 600\ \mu m$

Lunar Regolith Mare Dispersion: 3 main samples analyzed



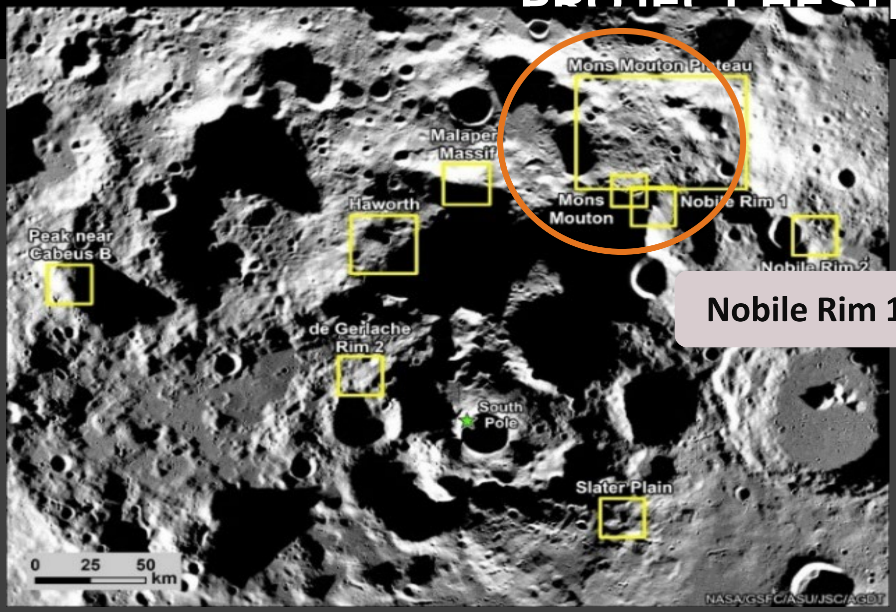
[8]

Landing Site Selection

Final Landing Site Selection: **Mons Mouton Plateau**

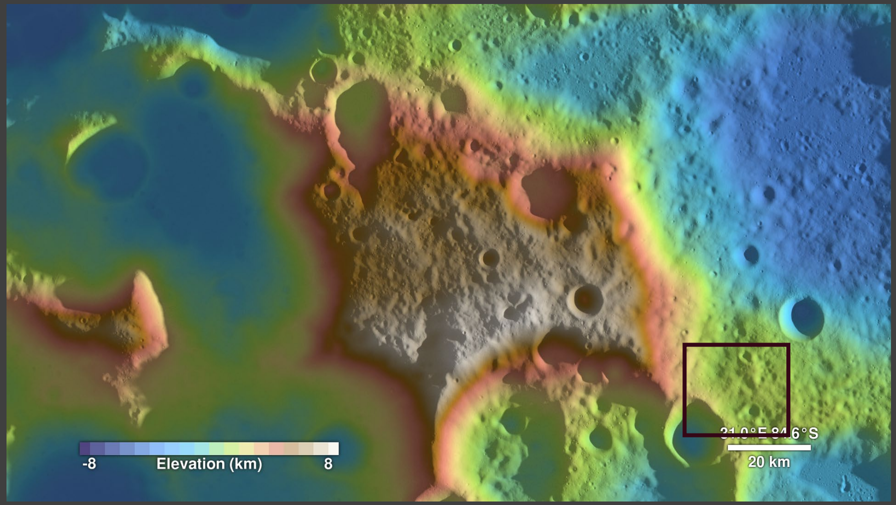
- 70-80% annual illumination
- Flatter and safer terrain than Shackleton or De Gerlache rims
- Reliable line-of-sight communication with Earth
- Close to PSRs (Haworth, Nobile, de Gerlache) for water-ice access
- Thick, stable and predictable regolith composition
- High-Ti Mare: High in Silicon Dioxide as well as Titanium Dioxide and Iron Oxide

	Terrain slope (deg)	Proximity to PSRs (km)	Illumination (%)	Regolith Composition (%)	Earth visibility (%)	Result	Source
	Minimize		Maximize				
Weight	0.20	0.25	0.05	0.4	0.1		
Mons Mouton Plateau	5	5	75	5	5	4.95	
Peak Near Shackleton	2	4	85	3	4	3.15	
De Gerlache rims 2	6	3	88	3	3	3.2	



Nobile Rim 1

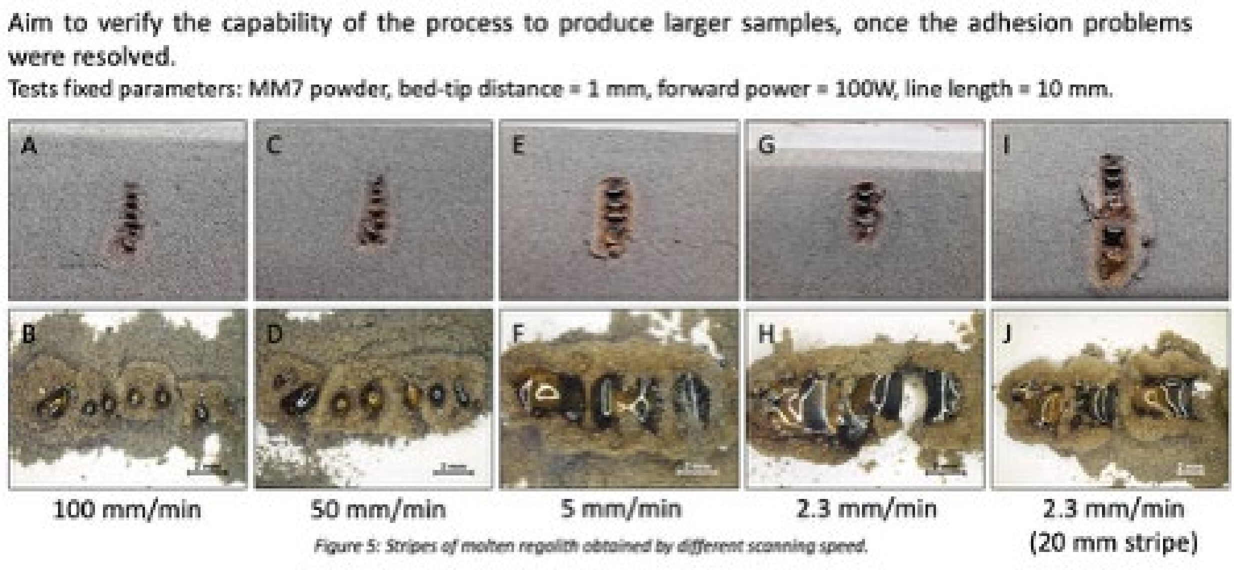
[9]



[10]

Regolith Particle Size and Density

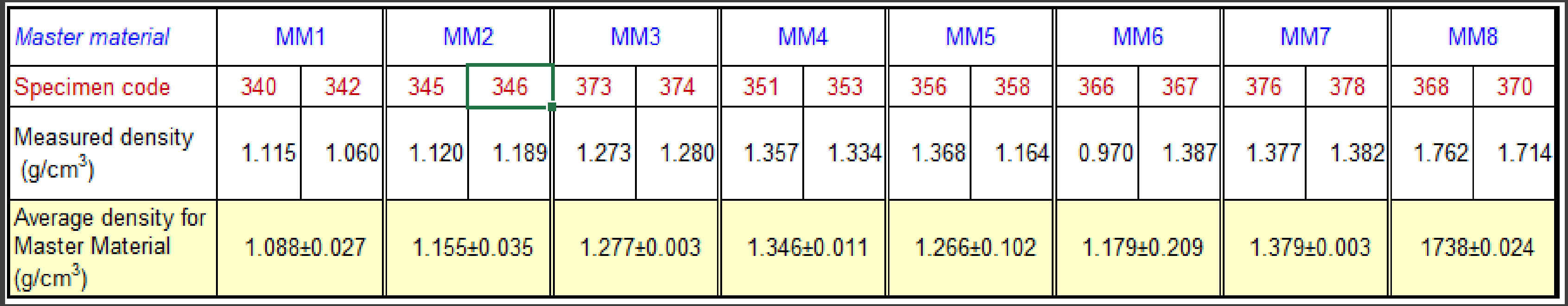
- Using mock regolith particle size and density were analyzed
- Sintering with average grain size $< 600\ \mu m$ yield the best results
- 10.1% mass loss after sintering at 1200 °C



Aim to verify the capability of the process to produce larger samples, once the adhesion problems were resolved.

Tests fixed parameters: MM7 powder, bed-tip distance = 1 mm, forward power = 100W, line length = 10 mm.

Figure 5: Stripes of molten regolith obtained by different scanning speed.

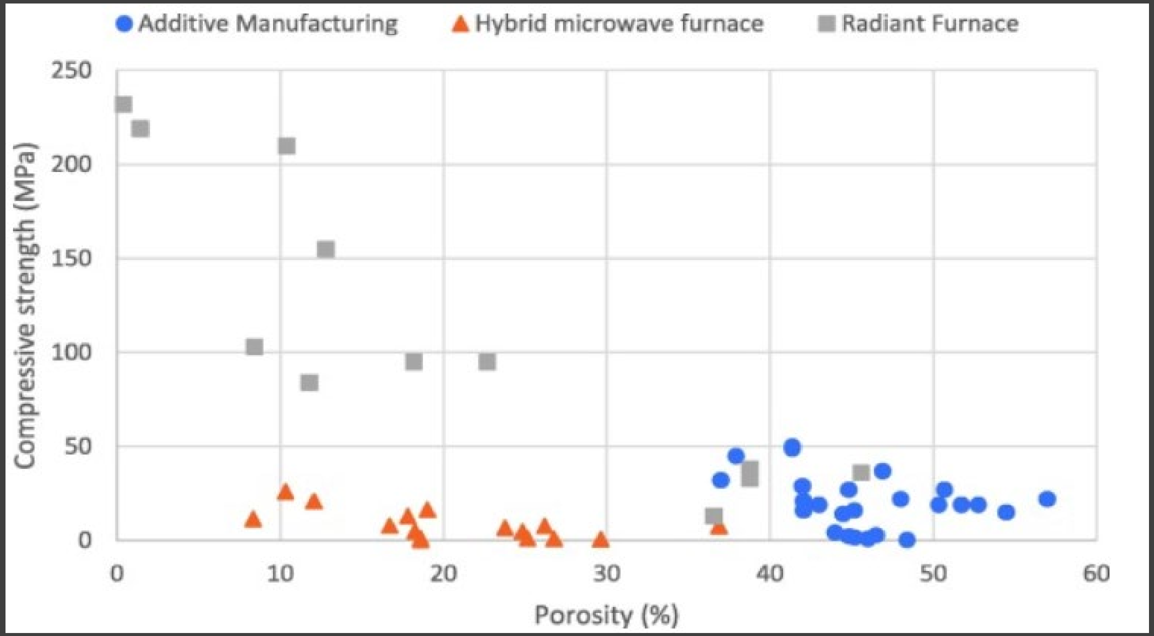


Master material	MM1		MM2		MM3		MM4		MM5		MM6		MM7		MM8	
Specimen code	340	342	345	346	373	374	351	353	356	358	366	367	376	378	368	370
Measured density (g/cm^3)	1.115	1.060	1.120	1.189	1.273	1.280	1.357	1.334	1.368	1.164	0.970	1.387	1.377	1.382	1.762	1.714
Average density for Master Material (g/cm^3)	1.088±0.027		1.155±0.035		1.277±0.003		1.346±0.011		1.266±0.102		1.179±0.209		1.379±0.003		1738±0.024	

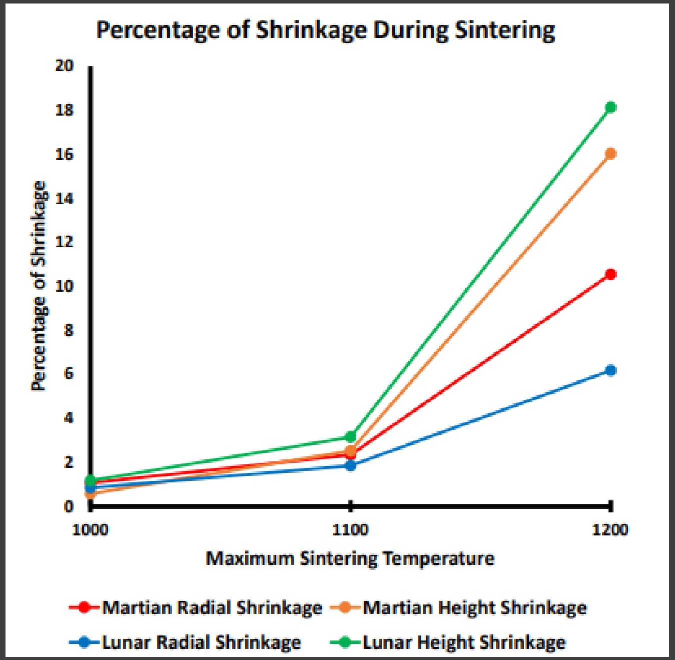
Table 1 – MM Samples Densities

Regolith Tile Properties – Sintering Effects

- **Tiles will be sintered at 1200 °C**
- **The porosity of the tiles will greatly affect the strength**
    - Ensuring that only very fine grains are used to make the tiles will decrease the porosity of the final product



Lunar Rover Arm Brings Increased Functionality to space missions.



Lunar Rover Arm Brings Increased Functionality to space missions.

https://www.researchgate.net/publication/360640968_Effect_of_Sintering_Temperature_on_Microstructure_and_Mechanical_Properties_of_Molded_Martian_and_Lunar_Regolith
*

Regolith Tile Properties – Strength

- **Must sustain an impact pressure of 424 kPa from the HLS landing leg**
  - Differences in the composition of samples and simulants cause the tested properties from different sources to vary
  - The measured compressive strength ranged anywhere from 20 to well over 100 MPa
  - At the lower end of measured compressive strength for lunar samples (20 MPa) a 0.3 m wide (Minimum width of our hexagonal design) tile would have to be 0.106 m thick to have its static compressive strength reach 1.5 times the maximum impact pressure

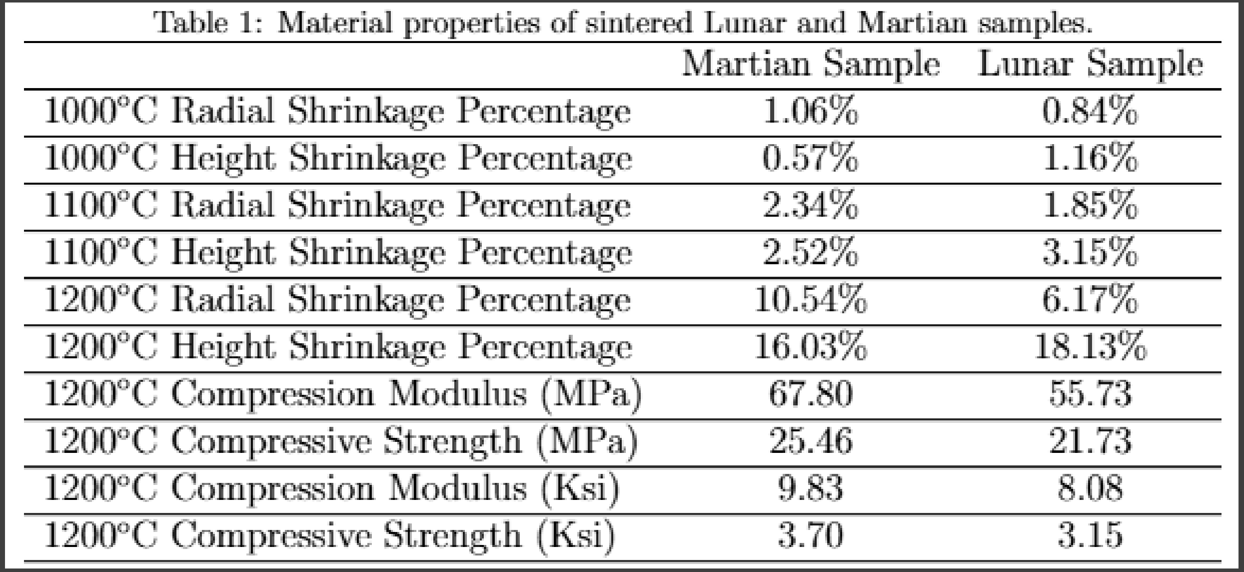
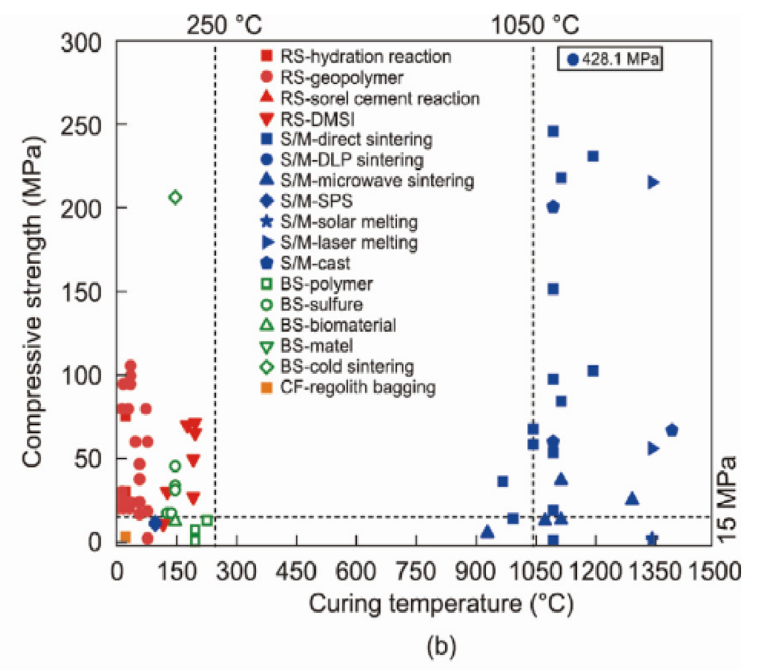


Table 1: Material properties of sintered Lunar and Martian samples.

	Martian Sample	Lunar Sample
1000°C Radial Shrinkage Percentage	1.06%	0.84%
1000°C Height Shrinkage Percentage	0.57%	1.16%
1100°C Radial Shrinkage Percentage	2.34%	1.85%
1100°C Height Shrinkage Percentage	2.52%	3.15%
1200°C Radial Shrinkage Percentage	10.54%	6.17%
1200°C Height Shrinkage Percentage	16.03%	18.13%
1200°C Compression Modulus (MPa)	67.80	55.73
1200°C Compressive Strength (MPa)	25.46	21.73
1200°C Compression Modulus (Ksi)	9.83	8.08
1200°C Compressive Strength (Ksi)	3.70	3.15

https://arxiv.org/pdf/2205.06855



https://www.sciencedirect.com/science/article/pii/S0094576525001419#bib100

Sintering Generator and Applicator

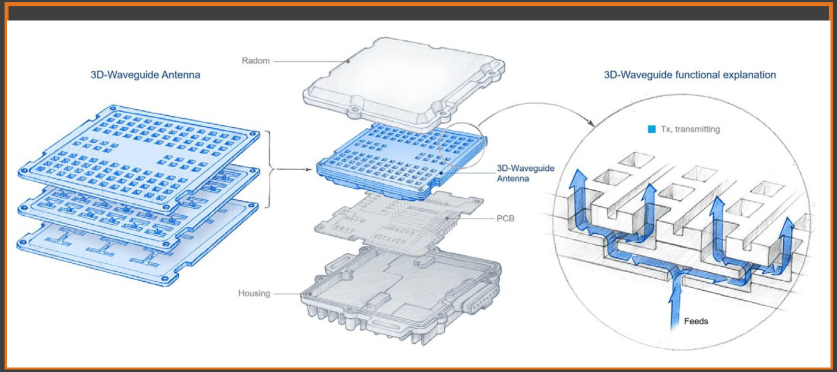
Sintering Power Model - Findings

PROJECT HESTIA

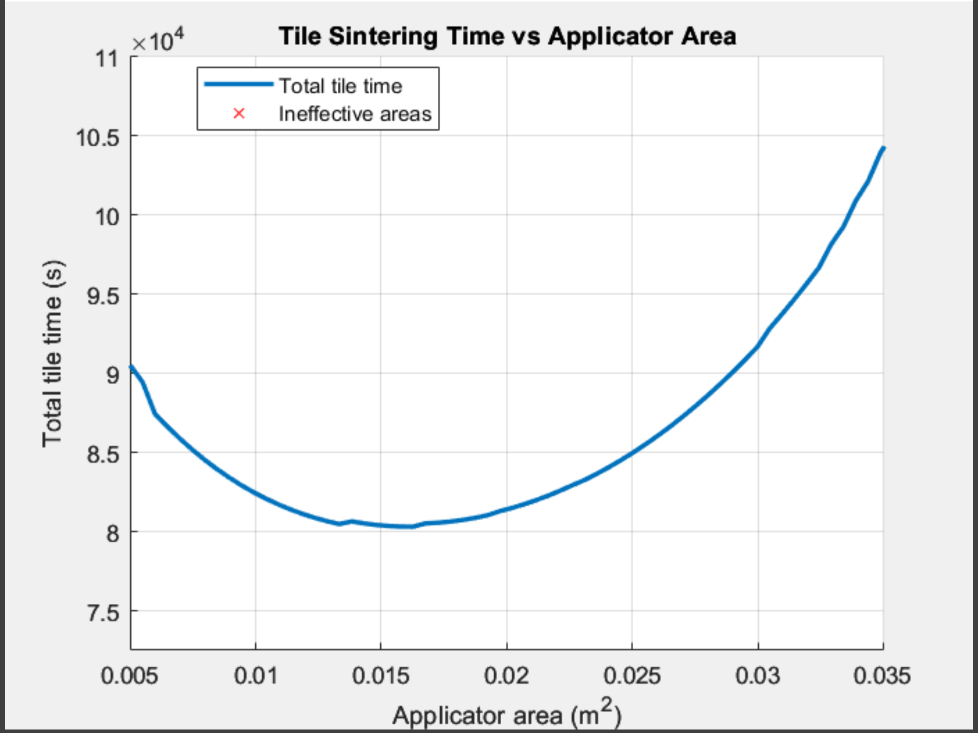
4kW 915 MHz sintering head/plate
- 915 MHz has better penetration compared to 2.45 GHz
- 2.45 GHz shows better power efficiency
- 915 MHz won't interfere with WLAN

3 1.5 kW GaN for RF generations
- RIM091K5-20
- 63 % Efficiency
- Need to replace water loop with PCM cooling

Tile-shaped Waveguide antenna
- Custom designed around the mold for optimal heating



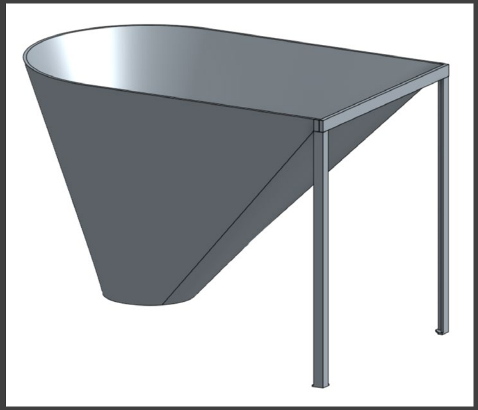
- **Timeline:**
  - Time per spot: 2.6 minutes
  - Time per layer: 12.6 minutes
  - Total tile time 22.3 hours
- **Hardware Requirements**
  - Instant power draw 1kw
  - Frequency 915 MHz
  - E field 21012.2 V/m
  - Applicator area 0.0163 m^2
- **Total energy required 22.3 kWh**
- **Scalable linear relationship (1kw-4kw)**



Regolith Conditioning

Hopper

- **Steep graded walls (45°) prevent regolith accumulation**
- $4\ \mathrm{mm}$ **thick 6061-T6-Aluminum walls**
- **Capable of holding 4-5 tiles worth of regolith**



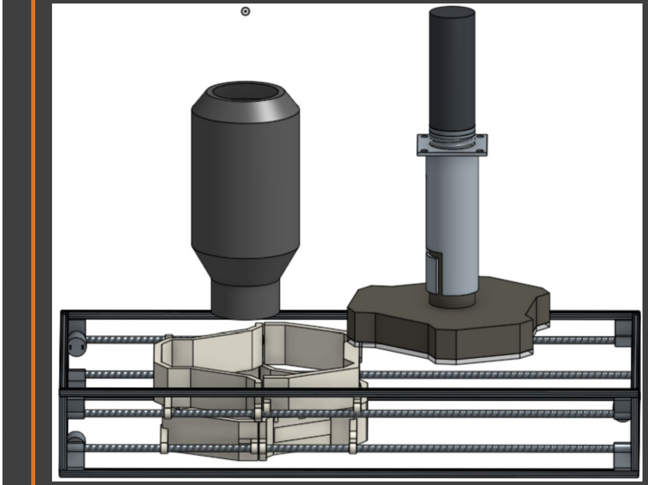
Vibratory Screener

- Ensures optimal granularity
- Oversized chunks sent to chute
- Multiple layers to protect finely woven mesh

Parameter	Unit	Value
Cut Size	$\mathrm{d_{max}}$	$600\ \mu\mathrm{m}$
Layer 1	$\mathrm{d_{m1}}$	$\sim 2.0\ \mathrm{mm}$
Layer 2	$\mathrm{d_{m2}}$	$\sim 0.8\ \mathrm{mm}$
Layer 3	$\mathrm{d_{m3}}$	$500\ \mu\mathrm{m}$
Feed Rate	$\dot{\mathrm{m}}$	$0.15\ \mathrm{kg/h}$
Deck Size	D	$0.545\ \mathrm{m}$

Weigh Bin

- Inlet rotary gate halts flow from screener when $m_{target} = 13.3\ kg$ for one tile is reached
- Outlet rotary gate releases $m_{target} = 12.5\ g$ for each layer



Sinter Mold

- 2 part layered mold
- Mounted to linear actuators
- Vibration and compaction cycle commences
- Compacting plate working in junction with vibrating plate to reach requisite bulk density of $\rho_b = 2.14\ g/cm^3$

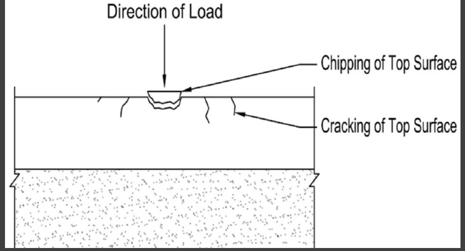
Parameters	Unit	Value
Footprint	A	$0.15\ \mathrm{m}$
Frequency	f	$\sim 50\ \mathrm{hz}$
Amplitude	$\mathrm{A_{pp}}$	$\sim 1\ \mathrm{mm}$
Compaction	σ_c	$\sim 0.4\ \mathrm{Mpa}$

Regolith Tile Properties - Requirements

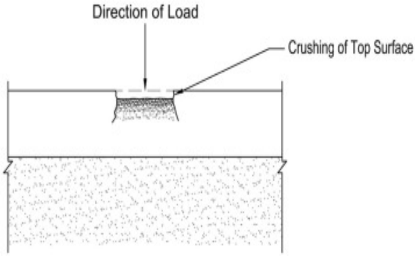
ID	Requirement Description
RTP1.0	The tiles shall be homogenous vertically due to manufacturing process
RTP2.0	The tiles shall be a geometry that tessellates
RTP3.0	The tiles shall be able to withstand a sustained vertical pressure of 35.4 kPa to survive the plume pressure of a Starship Human Landing System (HLS) landing
RTP4.0	The tiles shall withstand 423.99 kPa impact of HLS landing*
RTP5.0	The tiles shall withstand 25.78 kPa static pressure of HLS*
RTP6.0	The tiles shall withstand 17786.3 kW/m^2 heating from plume of HLS landing*
RTP7.0	The system shall be capable of surviving and operating within the lunar surface environment (thermal and radiation).
RTP8.0	The system shall perform all operations within the allocated peak power and energy-per-tile budget.

Modes of Failure

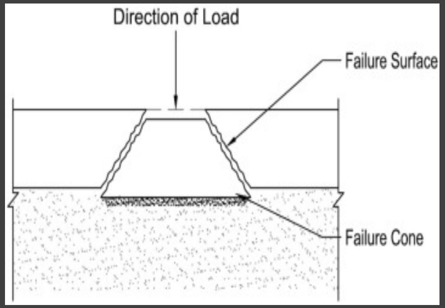
Ablation



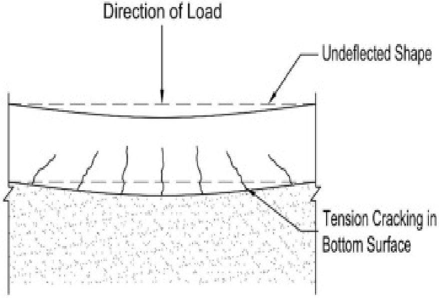
Cracking



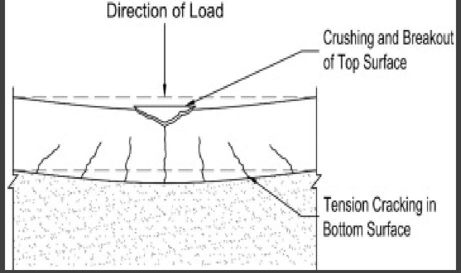
Crushing



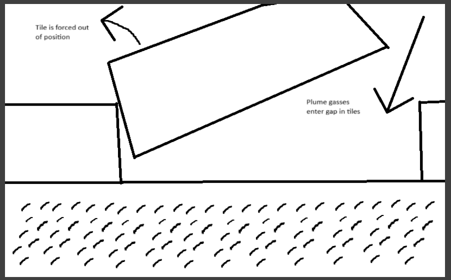
Punching Shear



Bending



Ejection



Rover electronic list

Subsystem / Component	Part Name	Space Grade / Edits Needed	Mass	Size	Power Requirements
Main Autonomy Computer	Rad-Hard 32-bit Arm Cortex-M7 MCU	Space grade	18 g	~28 × 28 × 3–4 mm	3.3 V I/O, 1.8 V core
Wrist Motor	maxon EC 32 flat SPACE + GPX 32 UP (3-stage)	Near-space-grade; minor integration (thermal, harnessing, controller)	~372 g	Ø32 mm; length 66.5 mm	24 V, 0.421 A, ~15 W
Elbow Motor	maxon EC 45 flat SPACE + GPX 42 UP (3-stage)	Near-space-grade; minor integration	~720 g	Ø45 mm motor + Ø42 mm gearhead	12 V, ~50 W
Drive Motor Controller MCU	(Motor Control MCU)	Space grade	~20 g	~30 × 30 × 3–4 mm	5V logic, up to 60V motor supply
Radio / Communications	2.4 GHz WLAN Relay Communication Module + Low-Gain Antenna	Not fully space grade would require major mods	100–250 g estimated	50 × 50 × 20 mm electronics + small low-gain antenna	0.5 W max
Arm & Hopper Controller MCU	SAMRH71 Rad-Hard Cortex-M7 0.053 m²	Space grade	18 g	~28 × 28 × 3–4 mm	3.0–3.6 V I/O, ~1.8 V core
Safety / Power MCU	Microchip LX7720 Motor Driver	Space grade	~20 g	~30 × 30 × 3–4 mm	5V logic, up to 60V motor supply
Hopper Tip Motor	CubeMars RI50 Frameless BLDC	NOT space grade; major mods required	180.8 g	Ø54 × 27 mm	12–48 V, ~500 W
Drive Motors (×4)	CubeMars AK60-6 Actuator (wheel motors)	NOT space grade; major mods required	0.65 kg	Ø42.8 × 12.8 mm	24 V, ~50 W each
IMU (Navigation)	LN-200S IMU	Space grade	~0.5–0.6 kg	~10–15 cm module	~8–15 W
Stereo Cameras (×2)	IM200 Space Camera	Near-space-grade; minor integration	118 g total	~50 × 50 × 50 mm each	~1.4 W total
Navigation Software	EKF + Visual Odometry	Space-appropriate (software validation needed)	N/A	N/A	~5–15 W (shared compute)
Main Battery Pack	6S Li-ion Battery Pack (~400 Wh, 22.2V, ~18Ah)	Space grade	2.80 kg	0.053 m²	(~400 Wh, 22.2V, ~18Ah)
Electronics Box Survival				~75 × 75 mm, ~0.25 mm thick	

Stationary Tile Maker Design

Microwave Sintering Generator

- **4kW 915 MHz sintering head/plate**
  - 915 MHz has better penetration compared to 2.45 GHz
  - 2.45 GHz shows better power efficiency
  - 915 MHz won't interfere with WLAN
- **3 1.5 kW GaN for RF generations**
  - RIM091K5-20
  - 63 % Efficiency
  - Need to replace water loop with PCM cooling
- **Tile Shaped Waveguide antenna**
  - Custom designed around the mold for optimal heating

Vibratory Screener

- Stage 1: Oversized rocks clasts are removed, durable laser cut plate.
- Stage 2: Secondary reject, too coarse for sintering. Laser cut plate protects fine mesh.
- Stage 3: Final cut, fine mesh.

Hopper

- Rover Deposits regolith into the hopper.
- Steep graded walls (~65°) to prevent regolith accumulation.
- 4 mm thick 6061-T6 Aluminum walls.
- Capable of holding 4-5 tiles worth of regolith.
  - 1.24 m^2 opening, narrowing to a 0.07 m^2 inner funnel.

Weigh Bin

- Tube mates to vibratory screener.
- Weigh bin is supported by 4 compression load cells.
- Inlet rotary gate halts flow of regolith when m=13.3 kg is reached.
- Flow spreader is used to evenly distribute regolith to the mold.

Sinter Mold

- Controlled mass dump into the sintering mold.
- Two-part mold for less complexity.
  - Mold is mounted to linear actuators.
- Vibration and compacting cycle commences.
- Compacting plate working in tandem vibrating plate to reach a requisite bulk density of $\rho_b = 2.14\ g/cm^3$.