The MOONRISE-Payload for Mobile Selective Laser Melting of Lunar Regolith

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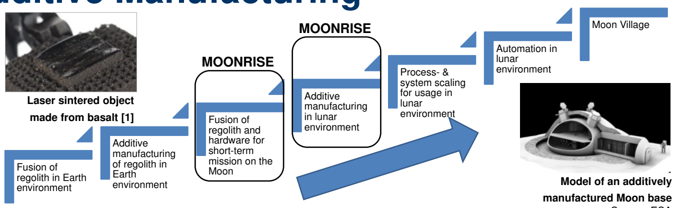
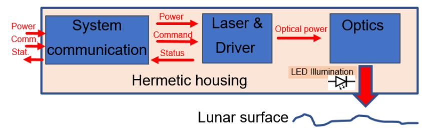
ISRU Construction on the Moon: Additive Manufacturing

- Motivation
  - Additive manufacturing of lunar infrastructure with regolith to reduce space transport efforts
  - Technology trade-off identifies laser melting as most favorable technical approach
- MOONRISE instrument science goal:
  - Proof-of-principle of laser-based fusion of regolith on the Moon
  - Laser melting of regolith pearls (0D), lines (1D), areas (2D)

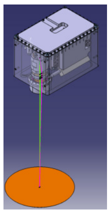


Roadmap for additive ISRU construction on the Moon.

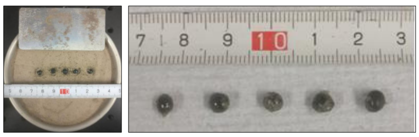
MOONRISE Engineering Model (EM)



Block diagram of the MOONRISE payload.



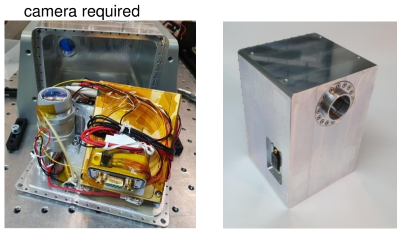
- Payload design
  - Laboratory experiments: all tested types of regolith [2] can be processed in vacuum with good reproducibility for process parameters


Laser melted regolith simulant spheres

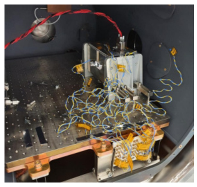
  - Payload specifications deduced from laboratory experiments using a variety of regolith simulants
    - → Optical configuration (type of laser source, beam guiding, working distance, spot size, optical power)
    - → Fusion starts at 35 W optical power at ~1µm wavelength for <10s
  - Use as much COTS as possible (pre-screening)

Parameter	MOONRISE
Optical output power capabilities	6 – 140 W **typ. 70 W**
Power consumption (laser on)	25 W – 340 W **typ. 175 W** for **6 s**
Mass	~2.5 kg (further reduction of 750 g)
Dimensions	1.5 U
Distance to ground	250±30 mm
Operating temperature	-35 °C to +70 °C (tbc)
Storage temperature	-50 °C to +95 °C (tbc)

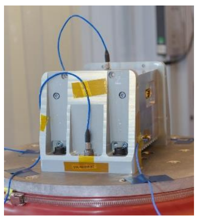
- **Mobility:** Mounting on a rover/robotic arm
- **Verification:** Visualization of fused regolith by external camera required


Engineering Model of the MOONRISE payload.

- Environmental testing
  - TVac: gradual reversible decrease of optical power > 35 °C, but sufficient to fulfill mission goals

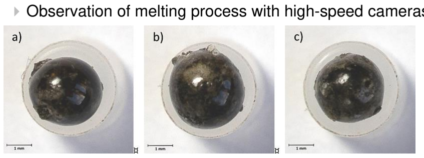


  - Vibration: 16.3 g_{rms}

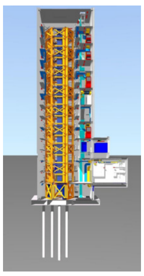


Process Verification with MOONRISE Engineering Model

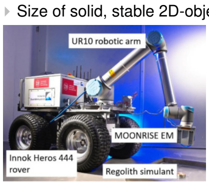
- Lunar gravity
  - Active "drop tower" for experiments in µ*g* to 5 *g* regime [3]
  - Laser melting process in vacuum (10^{-2} mbar)
  - Observation of melting process with high-speed cameras

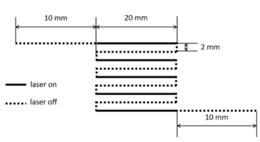


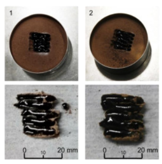
Samples of molten regolith, a) produced at 1 g, b) at 0.16 g and c) at 0 g [4].



- Accommodation on robotic arm
  - Melting of 2D-objects: 120 W optical power, 1 mm/s motion of robotic arm
  - Laser switched off between lines to limit deposited heat & avoid cracking
  - Size of solid, stable 2D-objects: 20 mm x 20 mm x 4 mm







Summary

- Proof of concept of laser-based fusion as part of the roadmap for 3D-printing of regolith structures on the Moon
- Laboratory study for payload design → Engineering Model
- Environmentally tested Engineering Model built
- Melting process verification on ground with Engineering Model (vacuum, under lunar gravity, 2D objects with robotic arm)

Further Resources

- [1] N. Gerdes, L. G. Fokken, S. Linke, S. Kaierle, O. Suttmann, J. Hermsdorf, E. Stoll, C. Trentlage, "Selective Laser Melting for processing of regolith in support of a lunar base," J. Laser Appl. 30, 032018 (2018).
- [2] S. Linke, L. Windisch, N. Kueter et al., "TUBS-M and TUBS-T based modular Regolith Simulant System for the support of lunar ISRU Activities," Planet Space Sci 180, 104747 (2020).
- [3] C. Lotz, T. Froböse, A. Wanner, L. Overmeyer, W. Ertmer, "Einstein-Elevator: A New Facility for Research from µ*g* to 5 *g*," Grav. Space Res., 5(2), 11-27 (2017).
- [4] S. Stapperfend, N. Gerdes, S. Linke, M. Ernst, P. Taschner, J. Koch, P. Wessels, J. Neumann, E. Stoll, L. Overmeyer, "Laser Melting of Lunar Regolith Simulant under Different Gravity Conditions Using the Moonrise-Payload," 8th European Lunar Symposium, Virtual Workshop May 12-14, 2020, https://els2020.arc.nasa.gov/playback, https://www.youtube.com/watch?v=dyYQlTUpXu0
- [5] MOONRISE Video, www.lzh.de/en/videos/moonrise-en

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