1

WELCOME TO THE COMMUNITY OF PRACTICE WEBINAR SERIES

Keep your mics muted and cameras off

- Helps ensure a clean recording

The recording will be posted online

- nasa.gov/flightopportunities
- Resources menu
- Community of Practice webinars

Please engage!

- Post your questions in the chat

National Aeronautics and Space Administration

2

2

ABOUT THE COMMUNITY OF PRACTICE WEBINAR SERIES

An opportunity to hear from subject matter experts on best practices for preparing for suborbital flight tests

Researchers, program staff, and flight providers

Connecting and sharing information and lessons learned to:

- Increase the impact of suborbital flight tests
- Transfer best practices
- Optimize the experience of current and prospective program participants

National Aeronautics and Space Administration 3

3

JOIN US FOR COMMUNITY OF PRACTICE WEBINARS

Subscribe to our newsletter for updates on future webinars!

https://www.nasa.gov/directorates/spacetech/flightopportunities/newsletter

Future webinars

- Webinars are usually held 1st Wednesday of each month at 10 a.m. PT.
- Topics are announced in the Flight Opportunities newsletter and website.
- Session recordings are posted on the Flight Opportunities website.
- Let us know session topics you would like to see covered.

National Aeronautics and Space Administration 4

4

TODAY'S SPEAKERS

Mark Hilburger, Ph.D.
Principal Technologist,
NASA Space Technology Mission Directorate

Laki Vlachos
Senior Payload Mission Manager,
Blue Origin

Franklin Robinson
Thermal Engineer and Technologist,
NASA's Goddard Space Flight Center

Aaron Olson, Ph.D.
ISRU & Seals Dust Mitigation Lead, Electrostatics & Surface Physics Laboratory,
NASA's Kennedy Space Center

Vince Vendiola
Program Manager,
Honeybee Robotics, a Blue Origin company

Nicholas Naclerio, Ph.D.
Robotics Engineer,
Honeybee Robotics, a Blue Origin company

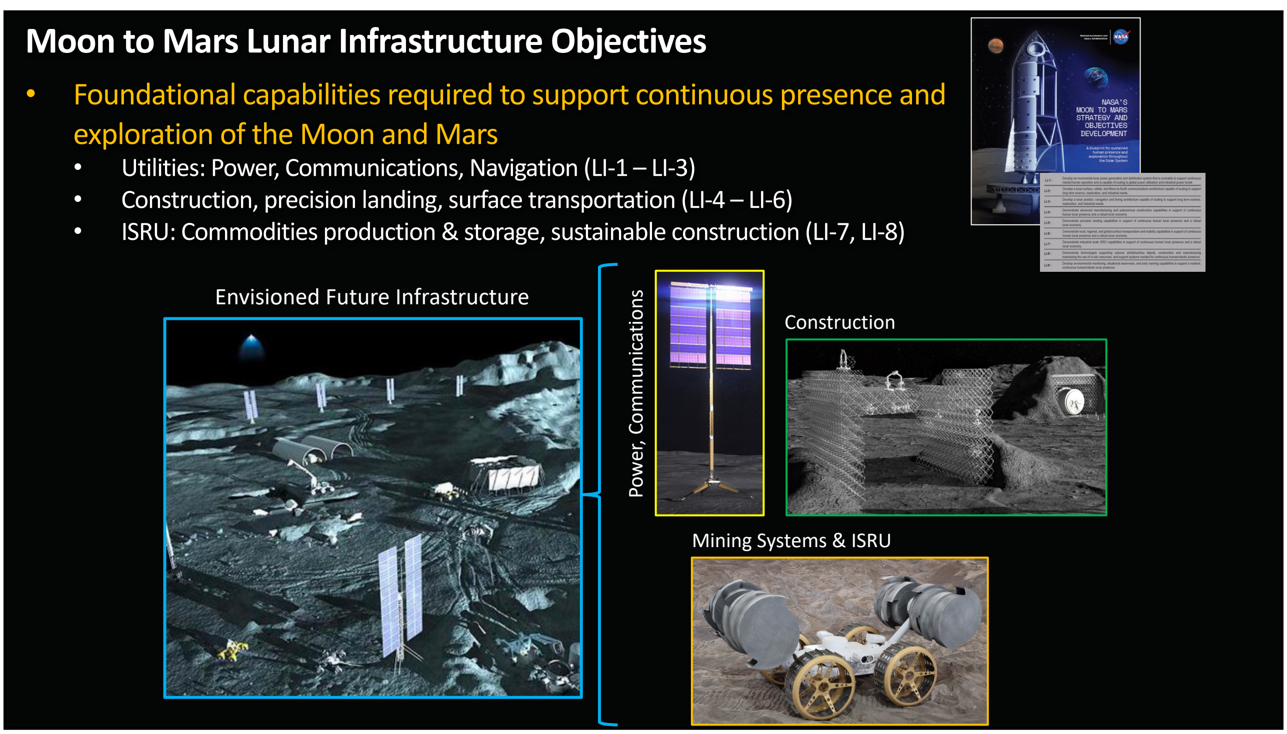
National Aeronautics and Space Administration 5

5

6


EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION
NASA
Advancing Technology Readiness Levels Through Flight Tests
Flight Opportunities Community of Practice Webinar – Lunar Gravity Session
Mark Hilburger - NASA PT for Materials, Structures, & Planetary Excavation and Construction
May 7, 2025

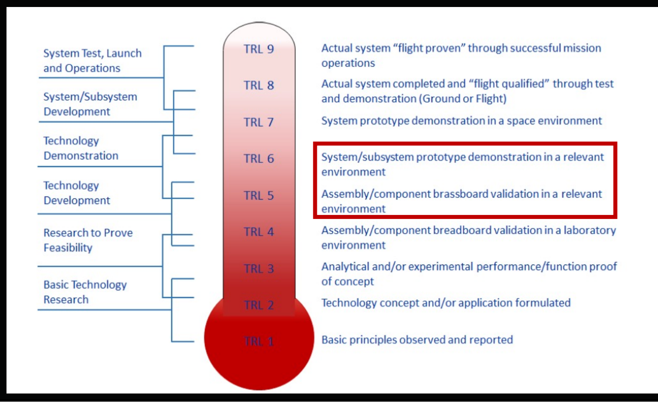
7


Moon to Mars Lunar Infrastructure Objectives
• Foundational capabilities required to support continuous presence and exploration of the Moon and Mars
• Utilities: Power, Communications, Navigation (LI-1 – LI-3)
• Construction, precision landing, surface transportation (LI-4 – LI-6)
• ISRU: Commodities production & storage, sustainable construction (LI-7, LI-8)
NASA'S MOON TO MARS STRATEGY AND OBJECTIVES DEVELOPMENT
Envisioned Future Infrastructure
Power, Communications
Construction
Mining Systems & ISRU

8

Technology Readiness Levels and the Importance of Flight Testing

- "Technology Readiness Level" or TRL is a scale for measuring the maturity of a technology
  - Early basic research and concept validation happening primarily in a laboratory environment (TRL1 – TRL4)
  - Testing in a relevant environment happening in TRL5 - TRL6 phases of development and is critical for technology infusion into future flight missions
- Relevant environments testing includes thermal, dust & regolith, radiation, lighting, gravity
  - 1/6g flights are a low-cost high-payoff test opportunities to simulate gravity conditions we can't achieve on the ground. Example, regolith flow and interaction with hardware



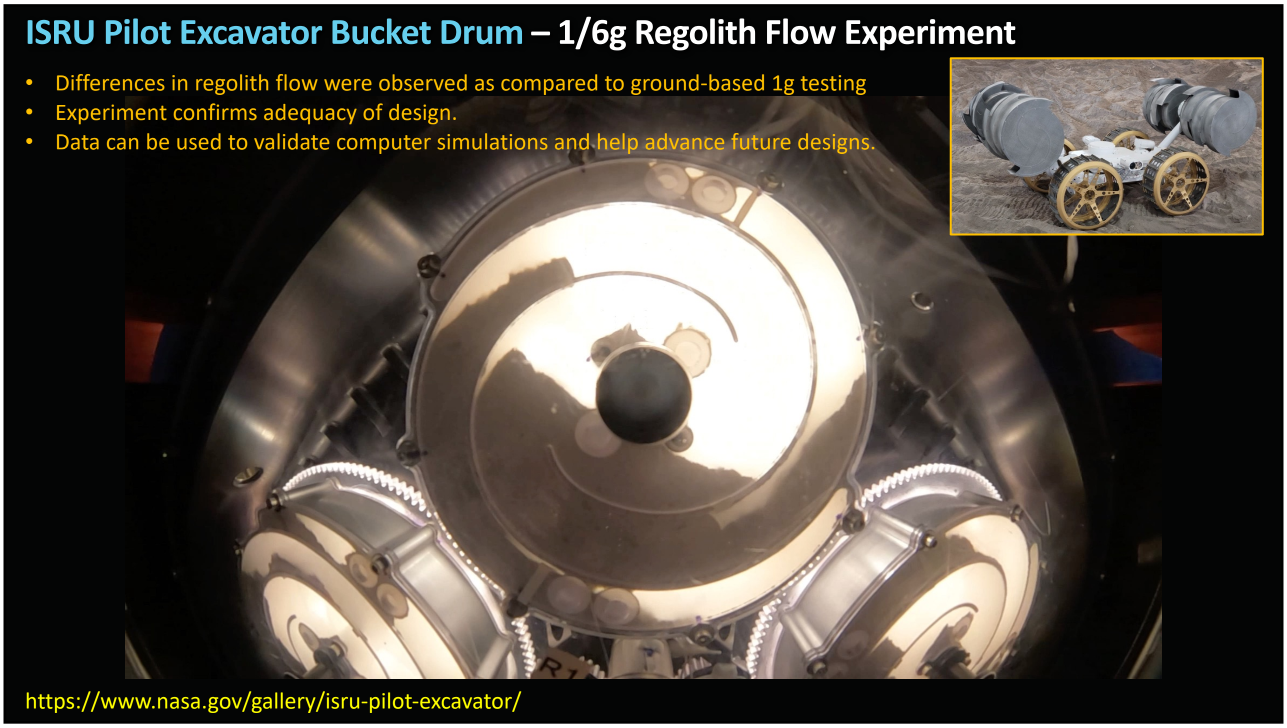
9

ISRU Pilot Excavator - TRL5 Testing Teaser Video

- Test as many of the components and systems as we can in relevant environments prior to flight demos and missions including demo mission ConOps

https://www.nasa.gov/gallery/isru-pilot-excavator/

10


ISRU Pilot Excavator Bucket Drum – 1/6g Regolith Flow Experiment
• Differences in regolith flow were observed as compared to ground-based 1g testing
• Experiment confirms adequacy of design.
• Data can be used to validate computer simulations and help advance future designs.
https://www.nasa.gov/gallery/isru-pilot-excavator/

11


Thank You
Mark Hilburger, Ph.D.
NASA Principal Technologist for Materials, Structures, & Planetary Excavation and Construction
mark.w.hilburger@nasa.gov

12


EXPLORE SPACE TECH
NASA Flight Opportunities Community of Practice
May 2025 I Laki Vlachos

13


BLUE ORIGIN
LAKI VLACHOS
NEW SHEPARD PAYLOAD MISSION MANAGER

14

SUBORBITAL ROCKET

NEW SHEPARD

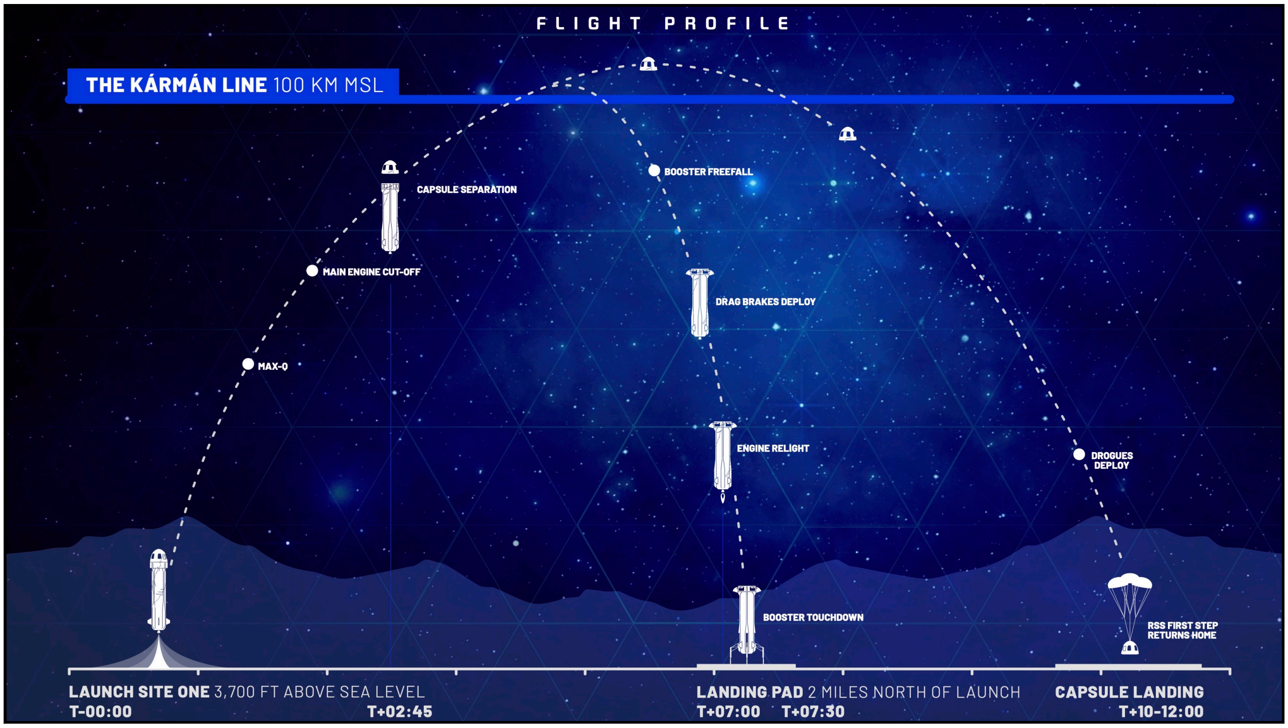
- Fully reusable, autonomous
- Capsule seats six or up to 30 middeck-sized lockers
- Booster includes provisions for payload requiring external access
- 11-minute space journey past the Kármán line
- 3+ minutes of microgravity
- Powered by one BE-3PM engine
- Only flight byproduct is water vapor
- Named after Alan Shepard

15

Launch Site One

- Launched from Launch Site One in West Texas
- Payloads installed days to hours prior to launch
- Boost phase lasts about 150 seconds
- Reaches apogee of approximately 350,000 feet (100km)

16


FLIGHT PROFILE
THE KÁRMÁN LINE 100 KM MSL
CAPSULE SEPARATION
MAIN ENGINE CUT-OFF
MAX-Q
BOOSTER FREEFALL
DRAG BRAKES DEPLOY
ENGINE RELIGHT
DROGUES DEPLOY
BOOSTER TOUCHDOWN
RSS FIRST STEP RETURNS HOME
LAUNCH SITE ONE 3,700 FT ABOVE SEA LEVEL
T-00:00
T+02:45
LANDING PAD 2 MILES NORTH OF LAUNCH
T+07:00
T+07:30
CAPSULE LANDING
T+10-12:00

17


NS-29 MISSION
After separation capsule spins up to 11rpm to create lunar gravity
Uses Capsule's Reaction Control System (RCS)
Payloads experience over 2 minutes of 0.165g accelerations
Capsule spins down after end of lunar gravity phase
BLUE ORIGIN
11 RPM
Centripetal Acceleration
Rotation
Z
Y
1
2
3
4
6

18


BLUE ORIGIN
FOR THE BENEFIT OF EARTH
NEW SHEPARD
BLUE ORIGIN
RESEARCH PAYLOADS

19


NASA
EXPLORE SPACE TECH
NASA Flight Opportunities Community of Practice
May 2025 I Franklin L. Robinson

20

Flow Boiling in Microgap Coolers Lunar Gravity Demonstration

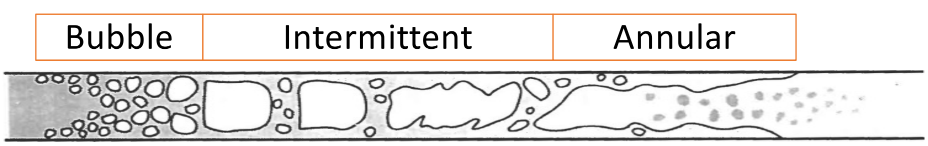
Franklin L. Robinson
NASA Goddard Space Flight Center
May 7, 2025

21

21

Flow Boiling

- Forced flow of coolant undergoing <u>liquid-to-vapor</u> phase change



Carey, 1992

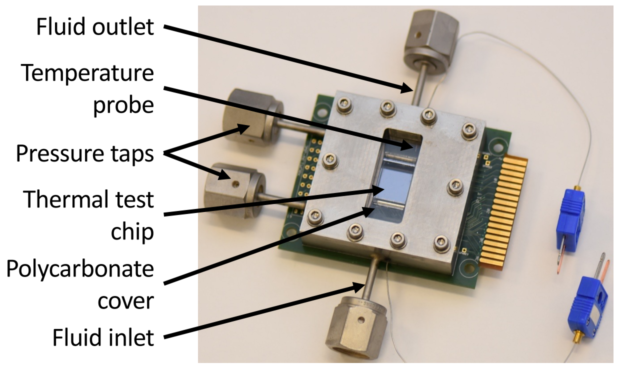
- High heat flux cooling with low pumping power
- Delivers heat to radiator with little temperature drop (T^4)
- <u>Limited use due to complex nature</u>, especially for microgravity and high-g applications

22

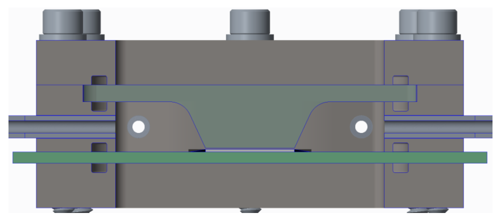
22

Microgap Coolers

- Low aspect ratio channel embedded within or between devices
- Direct contact between devices and coolant flow



Thermal test chip: 12.7 by 12.7 by 0.6 mm^3



Axial Cross Section

23

23

Ground-based Testing

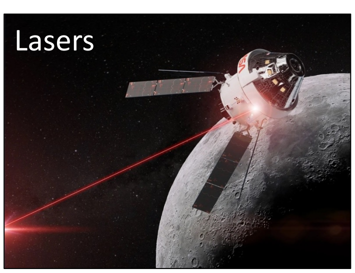
Characterize parameters that govern thermofluid behavior

Suborbital Flights

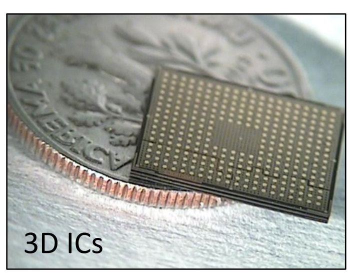
Establish effects of microgravity, high-g, and lunar gravity environments

Integration with Flight Projects

Complete technology maturation process



NASA, 2023

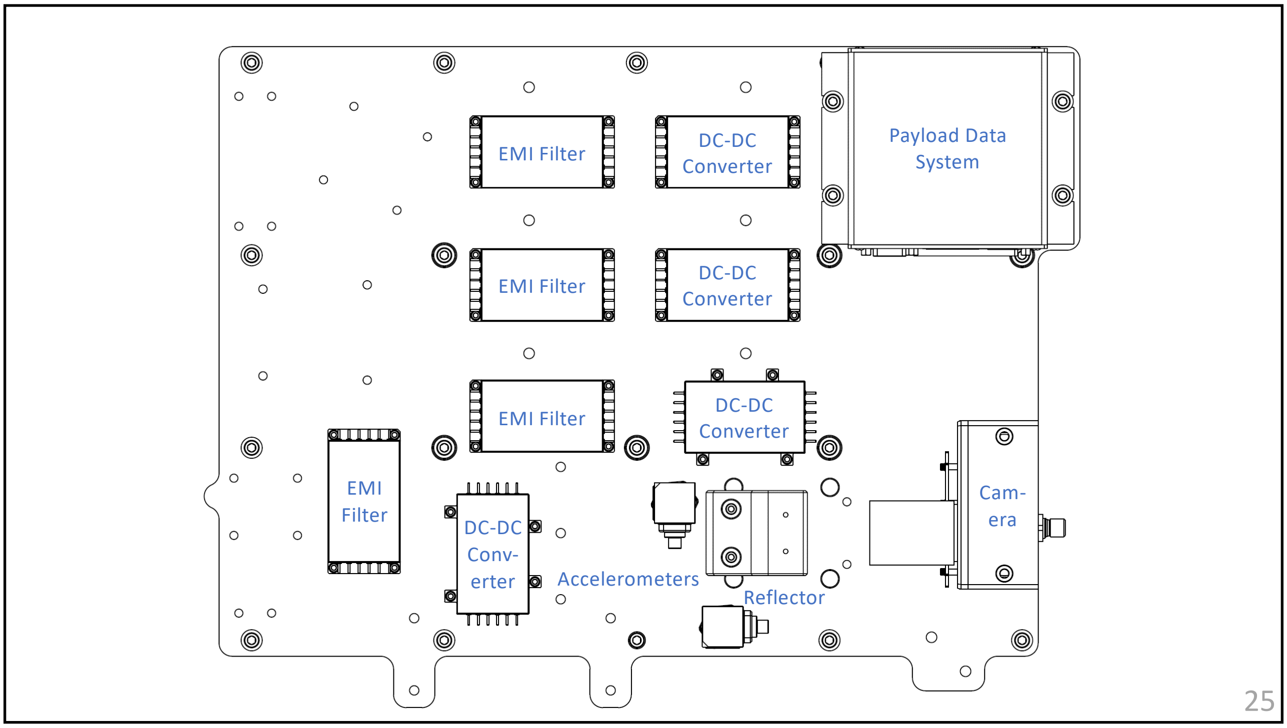


i3 Electronics, 2019

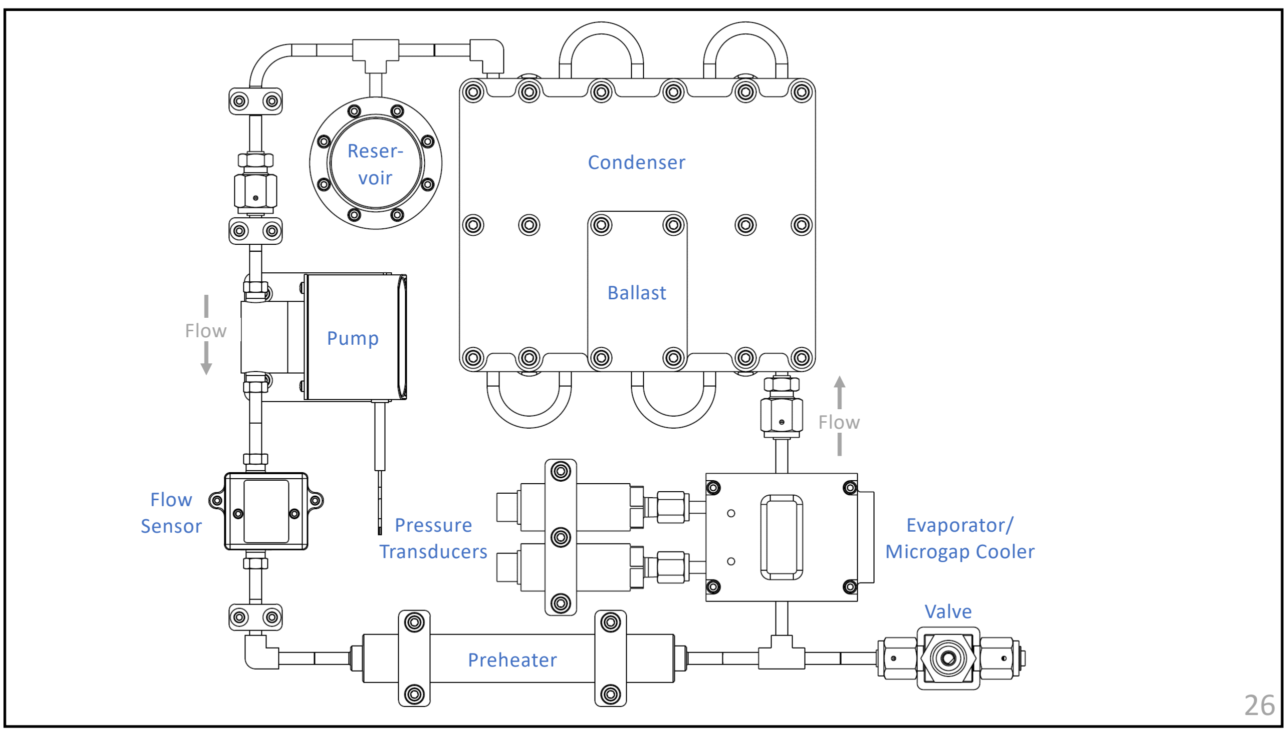
NASA/JPL-Caltech, 2017

24

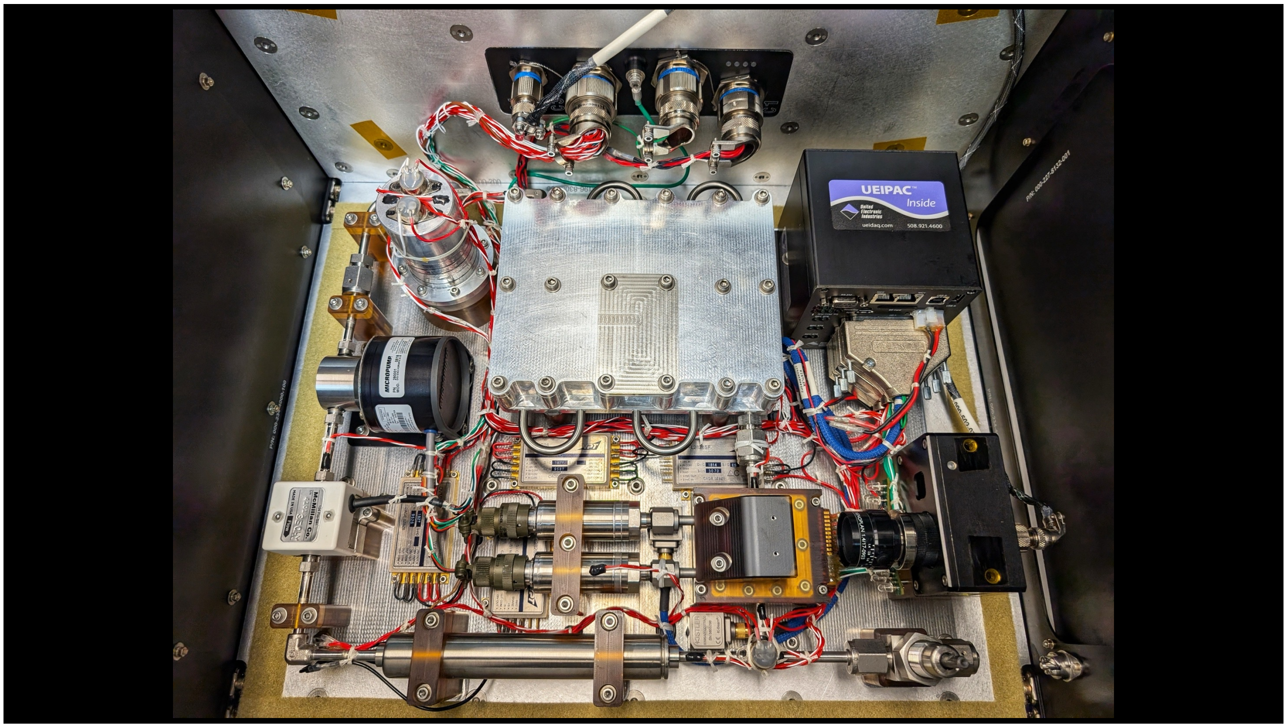
24


EMI Filter
DC-DC Converter
Payload Data System
EMI Filter
DC-DC Converter
EMI Filter
DC-DC Converter
EMI Filter
DC-DC Conv-erter
Accelerometers
Reflector
Cam-era
25

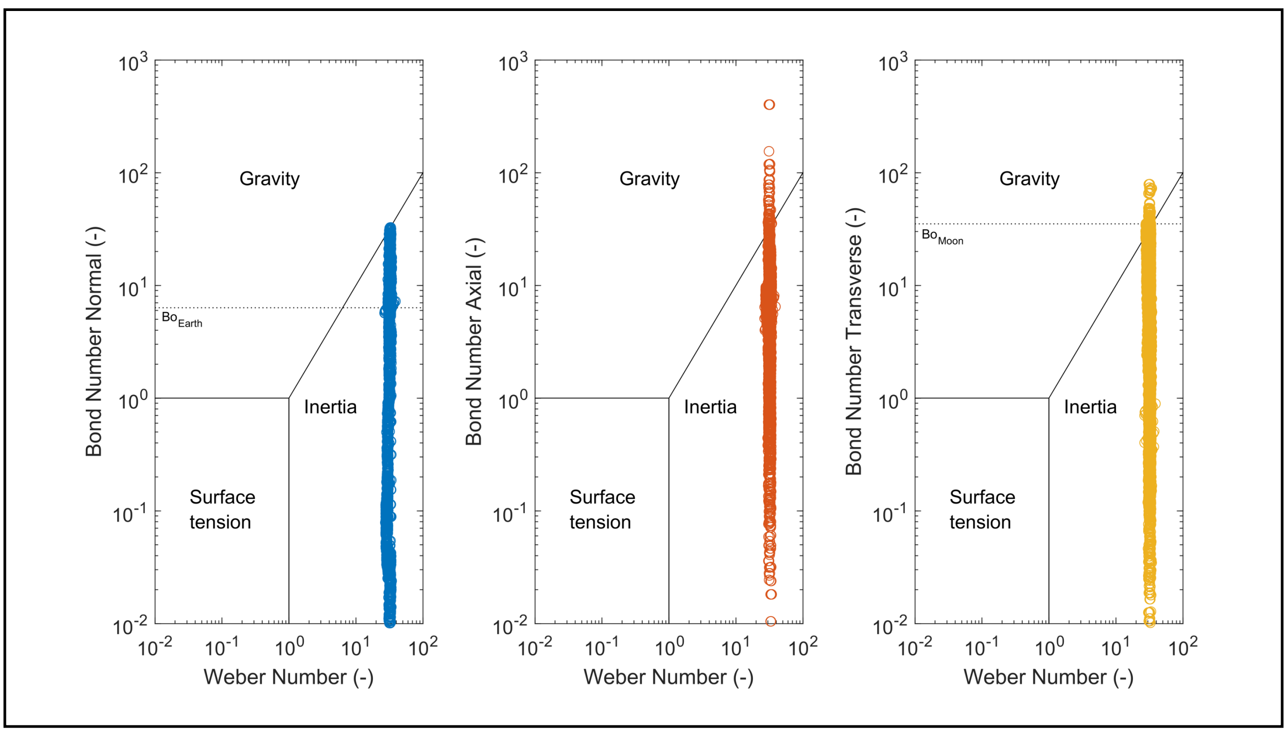
25


Reser-voir
Condenser
Ballast
Flow
Pump
Flow
Flow Sensor
Pressure Transducers
Evaporator/ Microgap Cooler
Valve
Preheater
26

26


UEIPAC
Inside

27


Bond Number Normal (-)
Gravity
Bo Earth
Inertia
Surface tension
Weber Number (-)
Bond Number Axial (-)
Gravity
Inertia
Surface tension
Weber Number (-)
Bond Number Transverse (-)
Gravity
Bo Moon
Inertia
Surface tension
Weber Number (-)

28

Recommendations

1. Make critical measurements internally
2. Make use of everything offered by the flight opportunity
3. Design for multiple flights
4. Allocate resources for post-flight operations

29

29

References and Credits

Slide	Citation or Credit
1	Photo courtesy of Blue Origin
2	Carey, V. P., 1992, *Liquid-Vapor Phase-Change Phenomena: An Introduction to the Thermophysics of Vaporization and Condensation Processes in Heat Transfer Equipment*, Hemisphere Publishing Corporation, Washington.
4	NASA, 2023, "A Visualization of the Orion Spacecraft Orbiting the Moon while Utilizing a New Cutting-Edge Technology, the Orion Artemis II Communications System (O2O)" accessed May 5, 2025, https://www.nasa.gov/directorates/somd/space-communications-navigation-program/nasa-laser-communications-terminal-delivered-for-artemis-ii-moon-mission/.
4	i3 Electronics, "3D Stacking with Heterogeneous MCMs", accessed Aug. 8, 2019, http://i3electronics.com/what-we-do/heterogeneous-mcm/.
4	NASA/JPL-Caltech, 2017, "Artist's Concept of Psyche Spacecraft with Five-Panel Array," accessed Aug. 8, 2019, https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA21499.

30

30


EXPLORE SPACE TECH
NASA Flight Opportunities Community of Practice
May 2025 I Aaron D. Olson, Ph.D.

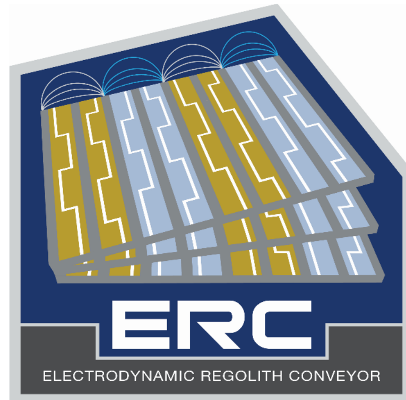
31


Electrodynamic Regolith Conveyor
Sub-Orbital Flight Experiment Overview
Flight Opportunities Program
Community of Practice Webinar
May 7th, 2025
Dr. Aaron Olson
Electrostatics & Surface Physics Lab
Swamp Works
NASA Kennedy Space Center

32

Outline

- Introduction
- Electrodynamic Dust Shield Background
- Payload & Experiment Requirements
- System Design
- Testing & Integration
- Flight Results
- Future Work
- Acknowledgements & References



Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 33

33

Introduction – Electrodynamic Regolith Conveyor

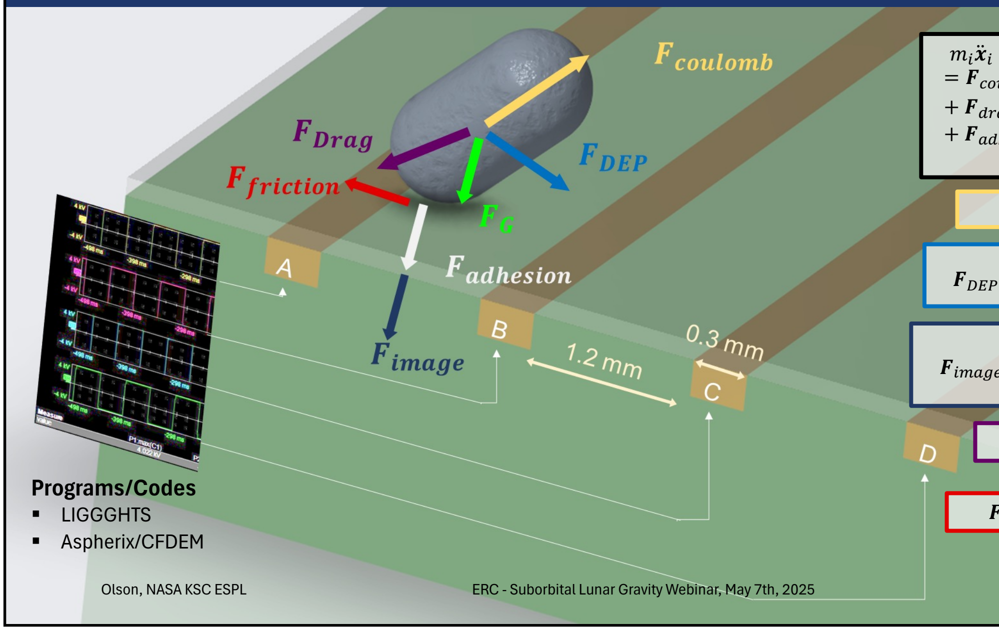
- **NASA KSC is developing the Electrodynamic Regolith Conveyor (ERC) technology as a solution for conveying, directional dust mitigation, soil sampling, and beneficiation**
  - Low power, no mechanical actuation, dust tolerant regolith transport
- **Extension of the flight proven Electrodynamic Dust Shield (EDS)**
  - Developed for lenses, solar panels, radiators, seals, fabric, and foldable mats
- **The objective of the ERC sub-orbital flight experiment is to perform testing to advance the TRL of the ERC technology by:**
  - Measuring regolith transport flow rate, power consumption and range of particle trajectories at four different inclinations in a simulated lunar gravity and vacuum environment.
  - Anchoring discrete element modeling efforts with test data

Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 34

34

EDS Discrete Element Modeling

EDS modeling with various lunar simulant & operating parameters



$$m_i\ddot{\boldsymbol{x}}_i = \boldsymbol{F}_{coulomb_i} + \boldsymbol{F}_{DEP_i} + \boldsymbol{F}_{image_i} + \boldsymbol{F}_{drag_i} + \boldsymbol{F}_{friction_i} + \boldsymbol{F}_{adhesion_i} + m_i\boldsymbol{g}$$

$$\boldsymbol{F}_{coulomb} = \boldsymbol{E}q$$

$$\boldsymbol{F}_{DEP} = \frac{4\pi\varepsilon_0(\varepsilon-1)R^3\boldsymbol{E}_0\nabla\boldsymbol{E}_0}{\varepsilon+2}$$

$$\boldsymbol{F}_{image} = \frac{1}{4\pi\varepsilon_0}\sum_{n=1}^{N}\left(\frac{q_i q_n}{2d}\right)^2\left(\frac{\boldsymbol{d}}{|\boldsymbol{d}|}\right)$$

$$\boldsymbol{F}_{drag} = -6\pi\eta R\dot{\boldsymbol{x}}$$

$$\boldsymbol{F}_{friction} = -\mu\boldsymbol{F}_{\boldsymbol{n}}\boldsymbol{n}$$

Programs/Codes

- LIGGGHTS
- Aspherix/CFDEM

Olson, NASA KSC ESPL — ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 — 35

35

Payload Requirements

- The ERC payload designed for a Blue Origin New Shepard capsule single size payload locker
- Launch loads, EMI/EMC, Interfaces, etc...

Table 1. Blue Origin New Shepard Single Locker

Payload locker type	Single
Internal dimensions	52.3 x 41.4 x 24.1 cm
Payload mass	11.34 +0/-0.045 kg
Payload power	18 V, 8 A max

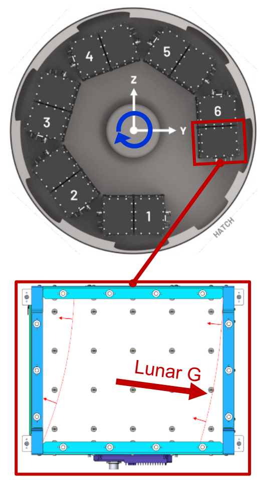
New Shepard sub-orbital vehicle — New Shepard Capsule landing — New Shepard research payloads in microgravity

Olson, NASA KSC ESPL — ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 — 36

36

Experiment Requirements

Capsule simulating 1/6 gravity by spinning during freefall (Blue Origin Payload User's Guide)



Payload locker arrangement inside capsule and the associated centripetal acceleration during the spin phase of flight

Table 2. High level ERC experimental requirements

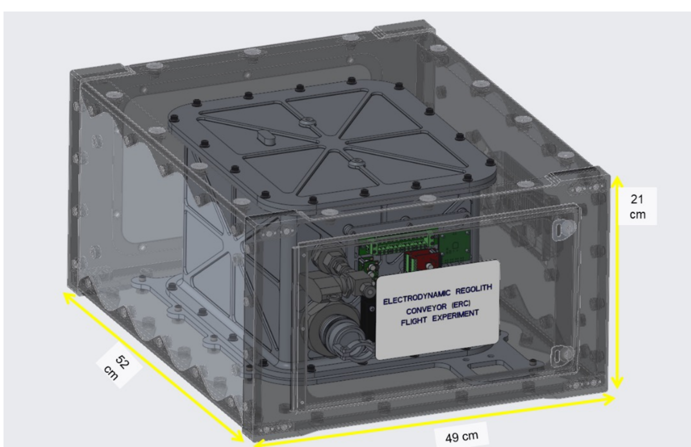
#	High level requirements
	Environmental
1	<500 mTorr experiment pressure during operation
	Regolith Flow
2	Storage of 200 or more g of < 200-micron regolith simulant
3	Feed up to 1.2 g/s of regolith simulant onto and uniformly across the conveyor surface
	Conveyor Operation
4	+/- 4 kV 10 Hz 4-phase square waveform
5	Rotating conveyor plane >10 degrees from horizontal
6	Side and top view of regolith motion
	Instrumentation
7	240 fps video recording, profile and top views
8	Lighting for general observation and particle flow tracking
9	Regolith and experiment temperature measurement
10	Pressure measurement
11	Regolith flow rate measurement
12	Power measurement (voltage and current)

Olson, NASA KSC ESPL   ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025   37

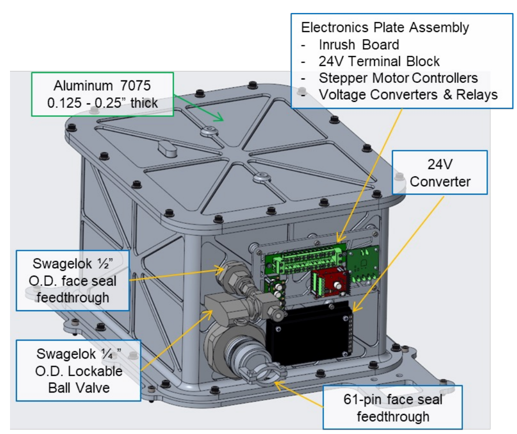
37

System Design

- The ERC payload's primary structure, mounted to its payload locker, is an aluminum vacuum chamber
- ERC consists of three primary internal subsystems: Feeder, Conveyor, Instrumentation



ERC payload design (inside transparent payload locker)



ERC vacuum chamber and its external components

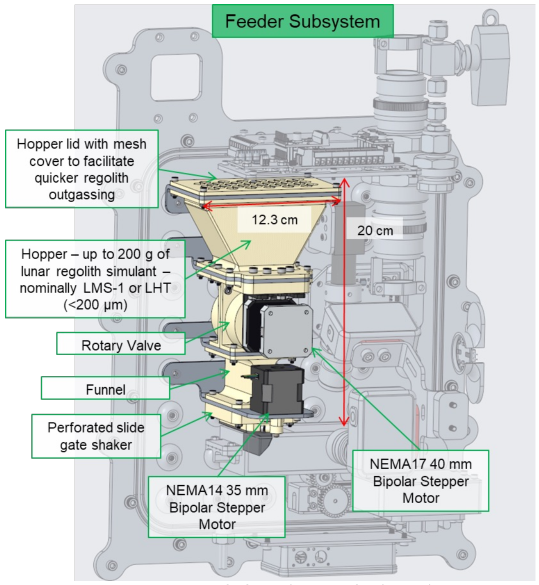
Olson, NASA KSC ESPL   ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025   38

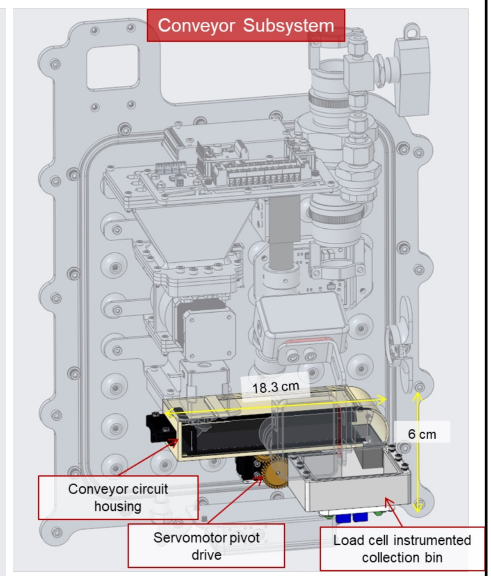
38

Subsystem Design

Feeder
- Stores up to 250 g of regolith
- Feeds regolith at a controllable rate onto the conveyor surface

Conveyor
- 4-phase EDS
- Transparent windows
- Pivots up to 15°
- Load cell instrumented collection bin





Olson, NASA KSC ESPL — ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 — 39

39

Subsystem Design

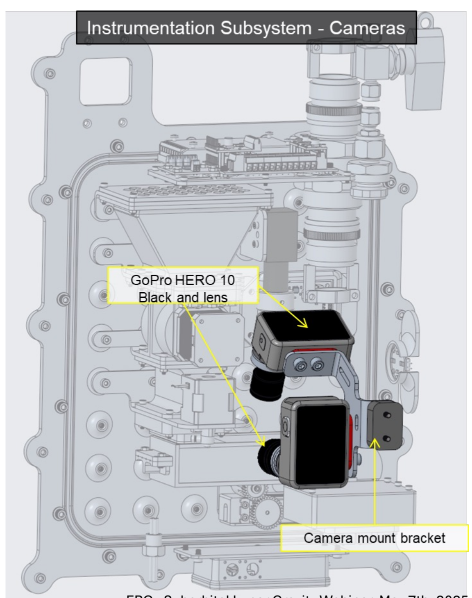
Cameras
- 4K GoPro HERO 10
- Overhead view with LED light
- Profile view – used with laser

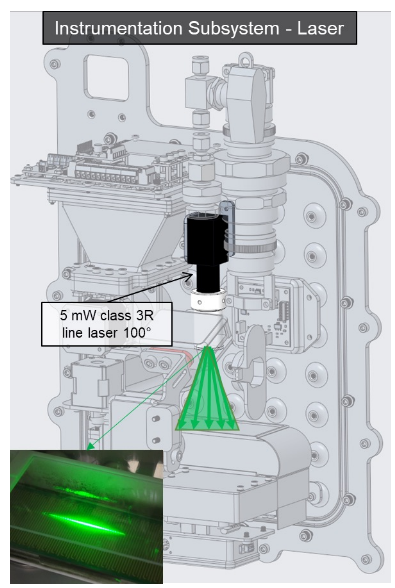
Laser
- 5 mW 532 nm line laser
- Cylindrical lens

Pressure Sensor
- In-vacuum Pirani

Temperature Sensors
- RTDs on chamber, largest motor

Controller Measurements
- Voltage, current
- Load cell data
- Control status
- RTDs
- Pressure





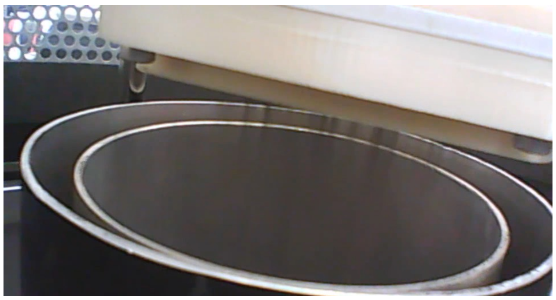
Olson, NASA KSC ESPL — ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 — 40

40

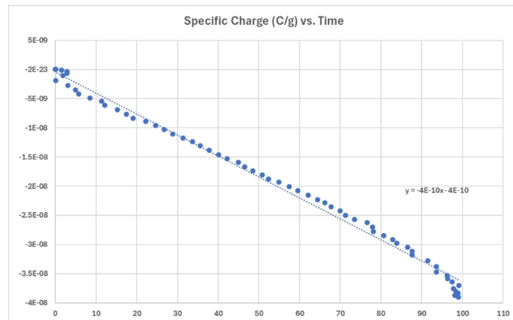
Subsystem Testing

Regolith Storage & Flow

- >200 g hopper regolith storage, and >1.2 g/s flow rate demonstrated
- Charge/mass ratio recorded for post analysis (proportional to coulomb force on particles)



JSC-1A 100-200 micron regolith simulant flowing through the ERC feeder and into an electrometer instrumented faraday cup at ~ 1E-05 Torr



Mass normalized charge vs. time for JSC-1A 100-200 micron regolith simulant from the ERC feeder subsystem

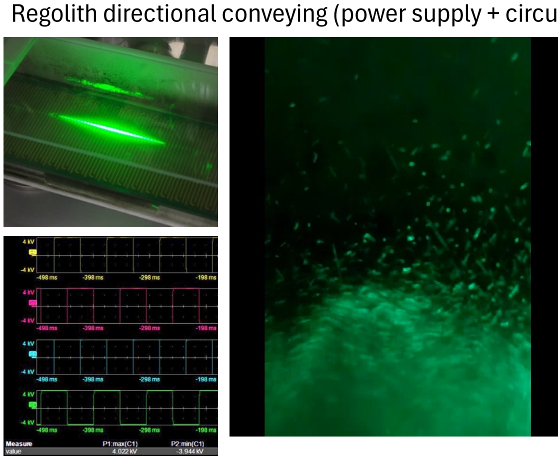
Olson, NASA KSC ESPL ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 41

41

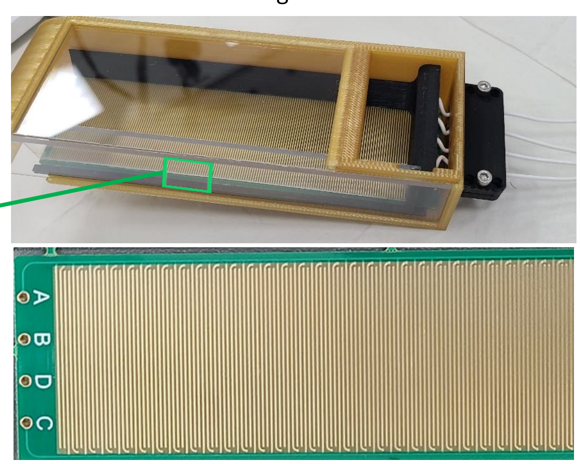
Subsystem Testing

Conveyor Operation & Laser/Camera Testing

- Regolith directional conveying (power supply + circuit) and laser-based flow tracking demonstrated



Line laser impinging on conveyor circuit surface through top window (top left), high voltage power supply +/- 4 kV four phase output (bottom left) and regolith flow (right)

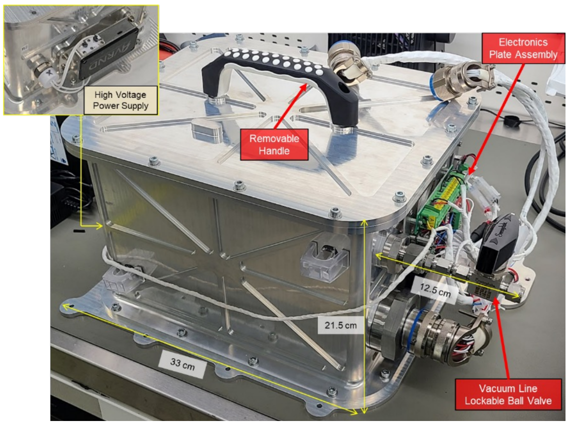


ERC conveyor enclosure (top) and 0.3 mm trace width x 0.3 mm gap width 4-phase circuit (bottom)

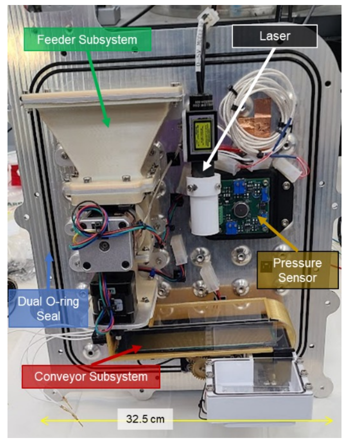
Olson, NASA KSC ESPL ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 42

42

System Integration



Fully integrated ERC payload



ERC components mounted to the vacuum chamber baseplate

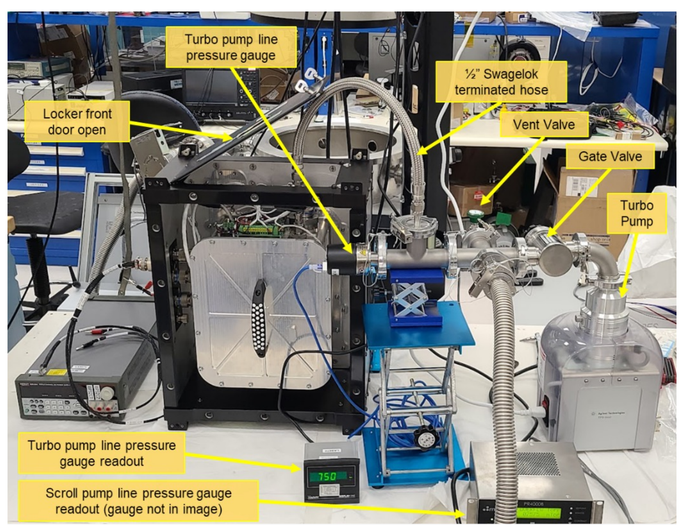

ERC cameras and lenses on the vacuum chamber top plate

System Testing

Payload Interface Requirements Met
- Power, Mass, CG
- Environments

Vacuum Chamber Pressure at Flight Time
- <400 mTorr chamber pressure after 10 hr wait

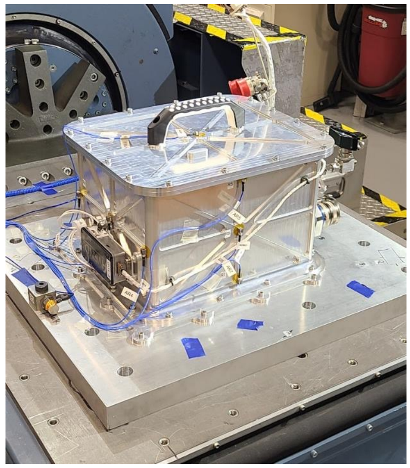
ERC Experiment Requirements Met
- Regolith Storage & Flow
- 4-Phase Conveyor
- Instrumentation



Fully integrated ERC payload after a run for record test at vacuum

Environmental Testing


Random vibration testing


Shock (half-sine pulse) testing

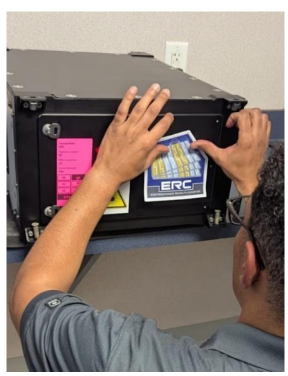

EMI/EMC testing

Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 45

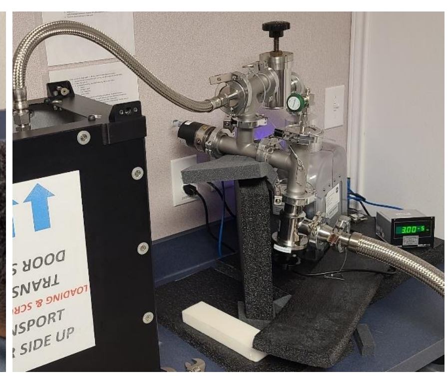
45

Payload Integration

Arrival at Launch Site One



ERC payload checkout


ERC payload pump down prior to flight

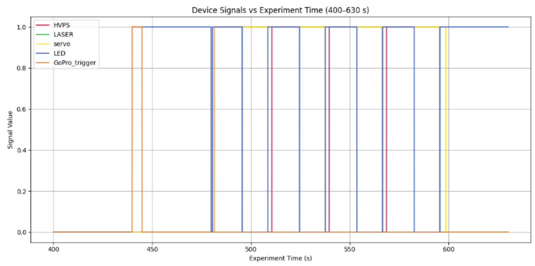
Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 46

46

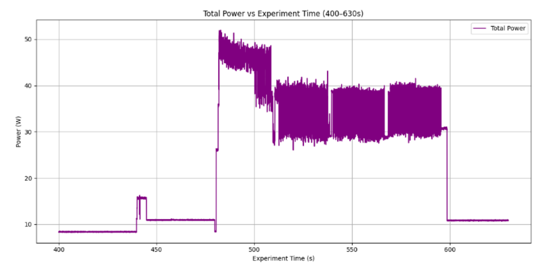
Flight Results

ERC Flight Experiment Accomplishments

#	Objectives	Status	Verification
	Environmental		
1	Operate payload at 1/6 g centripetal acceleration	Achieved	NS-29 capsule accelerometer data
2	Operate payload at <500 mTorr experiment pressure	Achieved	MEMS Pirani gauge measured payload vacuum chamber pressure throughout the flight at <100 mTorr
	Conveyor Operation		
3	Convey regolith simulant with a +/- 4 kV 10 Hz 4-phase square waveform	Achieved	high voltage power supply waveform validated before and after flight
4	Convey regolith simulant at 4 different inclinations - rotating conveyor plane up to 15 degrees from horizontal	Achieved	video recordings show that the conveyor plane's servo motor pivot actuated as expected
	Experimental Data		
5	>120 fps video - profile and top views for particle trajectory tracking	Achieved	the payload's two cameras were successfully triggered and recorded for 5 minutes each starting at MECO (including the lunar gravity phase of flight)
6	Regolith and experiment temperature measurement	Achieved	RTD data was recorded for the payload's measurement points
7	Regolith flow rate measurement through a load cell instrumented collection bin	Issue Encountered	the load cell's measurement did not reflect the amount of regolith conveyed into the collection bin
8	Power measurement (voltage and current)	Achieved	voltage and current data for each of the payload's power channels was recorded



IPC control signals (on/high or off/low) focusing on the period between MECO and coast end



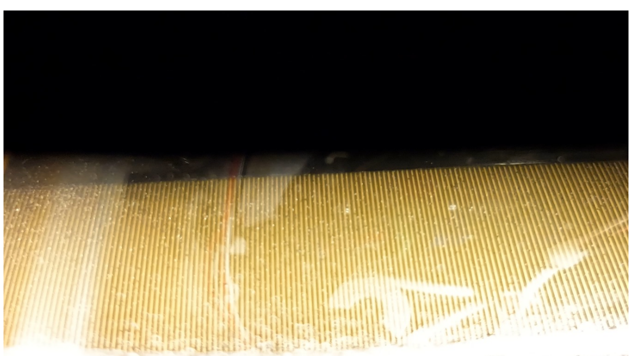
ERC payload power draw vs. time focusing on the period between MECO and coast end.

Olson, NASA KSC ESPL ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 47

47

Flight Results

POST PROCESSING STILL IN WORK



Overhead view of particle transport on a 7-degree inclined 4-phase circuit at 100 mTorr and simulated lunar gravity

Profile view of particle transport on 4-phase circuit at 100 mTorr and simulated lunar gravity

Olson, NASA KSC ESPL ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 48

48

Future Work

- Continued Post Flight Analysis
- Updated Discrete Element Modeling
- Journal Publication
- Technology Maturation & Infusion

Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 49

49

Acknowledgements

Amy Sivak, Dr. Beverly Kemmerer, James Joyner, Jennifer Wilson, Taylor Waddell, Annette Mendoza, Jessica Schwend, Robert Frady, Julian Villamil, David Lund, Dr. Charles Buhler, Dr. Joseph Toth, Jerry Wang, Dr. Krystal Acosta, James Phillips, Monica Hooks, John Lahl, Stephanie Plucinsky, David Miranda, Dr. James Mantovani

Olson, NASA KSC ESPL | ERC - Suborbital Lunar Gravity Webinar, May 7th, 2025 | 50

50

Relevant References

[1] Olson, A. D., "Design and Testing of a Prototype Electrodynamic Regolith Conveyor for Lunar ISRU," 2022.

[2] Tatom, F. B., Adams, J. G., Cline, B. L., Contaxes, N. A., Johnson, R. D., Seaman, H., and Srepel, V., "Lunar Dust Degradation Effects and Removal/Prevention Concepts. Volume 1 - Summary Final Report," *NASA Technical Report*. Volume TR-792-7-207A, 1–3.

[3] Masuda, S., Fujibayashi, K., Ishida, K., and Inaba, H., "Confinement and Transportation of Charged Aerosol Clouds via Electric Curtain," *Electrical Engineering in Japan*, Vol. 92, No. 1, 1972, pp. 43–52. https://doi.org/10.1002/EEJ.4390920106

[4] Masuda, S., Matsumoto, Y., and Akutsu, K., "Characteristics of Standing-wave, Ring-type Electric Curtain. Experimental Study," *Electrical Engineering in Japan*, Vol. 93, No. 1, 1973, pp. 78–83. https://doi.org/10.1002/EEJ.4390930111

[5] Immer, C., Starnes, J., Michalenko, M., Calle, C. I., Mazumder, M. K., Starnes, J., Michalenko, M., Calle, C. I., and Mazumder, M. K., "Electrostatic Screen for Transport of Martian and Lunar Regolith," 2006.

[6] Calle, C. I., Buhler, C. R., McFall, J. L., Snyder, S. J., Buhler, C. R., McFall, J. L., and Snyder, S. J., "Particle Removal by Electrostatic and Dielectrophoretic Forces for Dust Control During Lunar Exploration Missions," 2009.

[7] Calle, C. I., Linell, B., Chen, A., Meyer, J., Clements, S., Mazumder, M. K., Linell, B., Chen, A., Meyer, J., Clements, S., and Mazumder, M. K., "Numerical and Analytical Model of an Electrodynamic Dust Shield for Solar Panels on Mars," 2006.

[8] Calle, C. I., Immer, C. D., Clements, J. S., Chen, A., Buhler, C. R., Lundeen, P., Mantovani, J. G., Starnes, J. W., Michalenko, M., Mazumder, M. K., Immer, C. D., Clements, J. S., Chen, A., Buhler, C. R., Lundeen, P., Mantovani, J. G., Starnes, J. W., Michalenko, M., and Mazumder, M. K., "Electrodynamic Dust Shield for Surface Exploration Activities on the Moon and Mars," 2006.

[9] Manyapu, K. K., de Leon, P., Peltz, L., Tsentalovich, D., Gaier, J. R., Calle, C., Mackey, P., de Leon, P., Peltz, L., Tsentalovich, D., Gaier, J. R., Calle, C., and Mackey, P., "Investigating the Feasibility of Utilizing Carbon Nanotube Fibers for Spacesuit Dust Mitigation," 2016.

[10] Buhler, C. R., "EDS to The Moon!," 2022.

[11] Kawamoto, H., and Shirai, K., "Electrostatic Transport of Lunar Soil for In Situ Resource Utilization," *Proceedings of the 12th International Conference on Engineering, Science, Construction, and Operations in Challenging Environments - Earth and Space 2010*, 2010, pp. 57–65. https://doi.org/10.1061/41096(366)8

[12] Yu, Y., Cilliers, J., Hadler, K., Starr, S., and Wang, Y., "The Motion of Small Particles in Electrostatic Travelling Waves for Transport and Separation," *Powder Technology*, Vol. 425, 2023, p. 118587. https://doi.org/10.1016/J.POWTEC.2023.118587

[13] Yu, Y., Cilliers, J., Hadler, K., Starr, S., and Wang, Y., "A Review of Particle Transport and Separation by Electrostatic Traveling Wave Methods," *Journal of Electrostatics*, Vol. 119, 2022, p. 103735. https://doi.org/10.1016/J.ELSTAT.2022.103735

[14] Kawamoto, H., and Yoshida, N., "Electrostatic Sampling and Transport of Ice for In-Situ Resource Utilization," *Journal of Aerospace Engineering*, Vol. 31, No. 4, 2018. https://doi.org/10.1061/(ASCE)AS.1943-5525.0000866--

.

51

EDS on Blue Ghost Lunar Lander

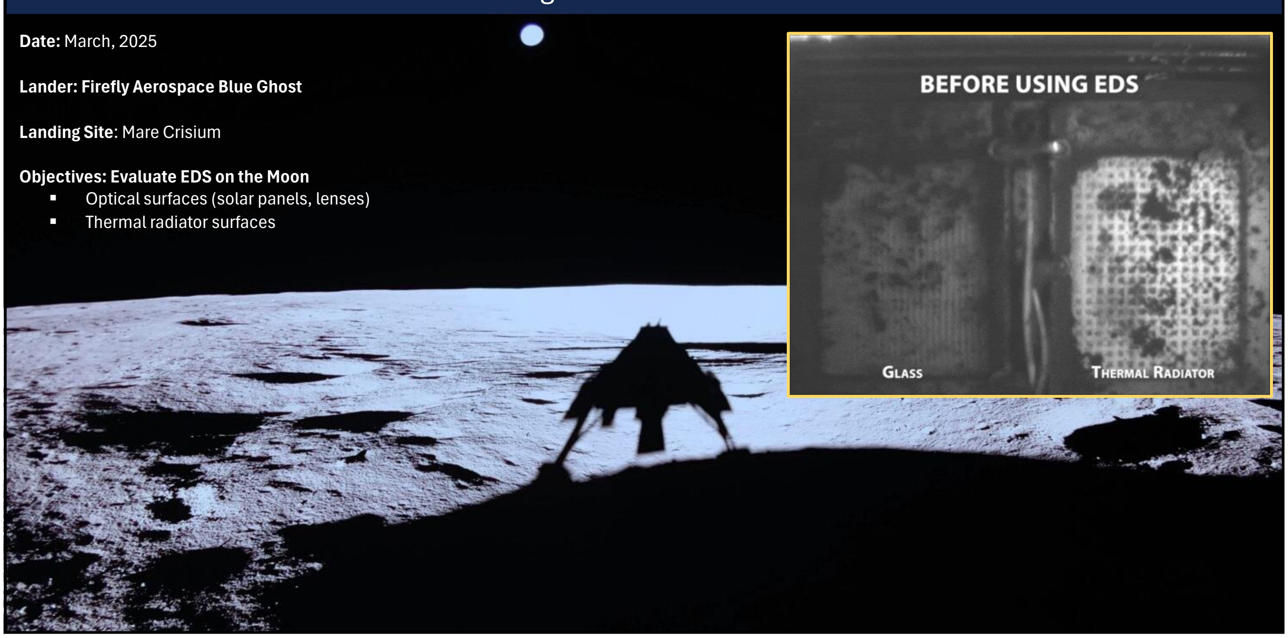
1 & 2-Phase Designs Tested on the Moon at +/-2 kV

Date: March, 2025

Lander: Firefly Aerospace Blue Ghost

Landing Site: Mare Crisium

Objectives: Evaluate EDS on the Moon
- Optical surfaces (solar panels, lenses)
- Thermal radiator surfaces



52

53

Honeybee Robotics NS-29 Payloads

- Honeybee is subsidiary of Blue Origin
- 4 experiments funded by Tech Flight Program
- Focused on lunar g, but applicable elsewhere
- Overcame Eaton Fire to deliver on time

BLUE ORIGIN 8 MAY 2025 54

54

ASSET

ASTEROID SOIL STRENGTH EVALUATION TEST

1. Description

Soil mechanics experiment designed to evaluate bearing capacity of granular materials.

2. Significance

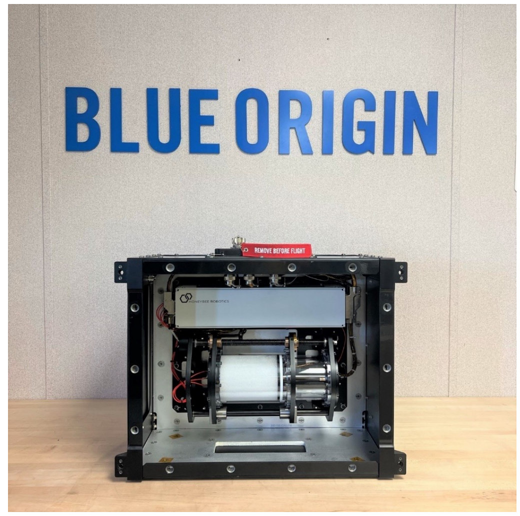
Helps in design of footpads, structures, asteroid landers interacting with regolith.

3. Experiment

Glass beads compressed in a cylinder. Penetrometer driven into the simulant to measure force vs penetration curve.

4. Results

Bearing capacity is ~30% lower at 1/6th g in non-cohesive soil (glass beads).



BLUE ORIGIN

8 MAY 2025 55

55

HBEE

HONEYBEE BUBBLE EXCITATION EXPERIMENT

1. Description

Observes bubble formation and propagation in a viscous fluid.

2. Significance

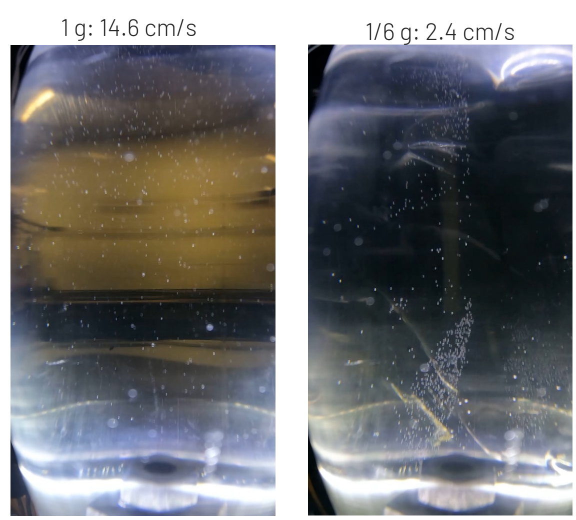
Helps in design of In Situ Resource Utilization processes such as Oxygen generation during Molten Regolith Electrolysis.

3. Experiment

N_2 bubbles introduced into a container with corn syrup

4. Results

Bubbles move 6x slower in lunar g (as predicted). This will affect rate of ISRU, boiling etc.



BLUE ORIGIN

8 MAY 2025 56

56

POCCET

PUFFER-ORIENTED COMPACT CLEANING AND EXCAVATION TOOL

1. Description

Uses puff of air to excavate a hole in cohesive regolith simulant.

2. Significance

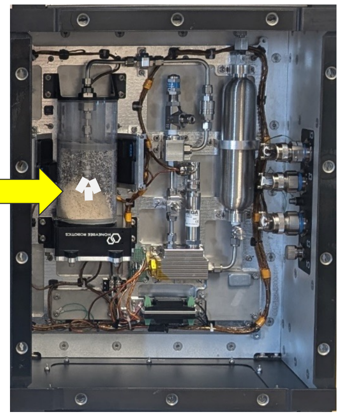
Will help evaluate effectiveness of pneumatic trenching for LISTER pneumatic drill (onboard Firefly Blue Ghost lander), and rocket-plume interaction.

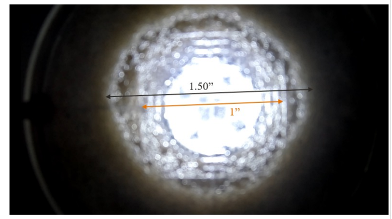
3. Experiment

Puff of N2 into kinetic sand (silicone oil and play sand)

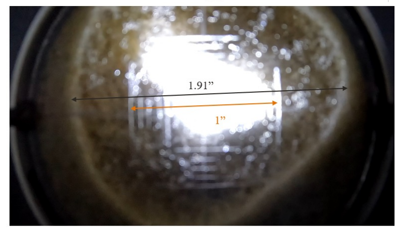
4. Results

Excavates faster and 50% wider at 1/6th g. Rocket plume would make larger holes.





1G



1/6 G

BLUE ORIGIN

8 MAY 2025 57

57

Lunar Anchor

ROOT-INSPIRED LUNAR ANCHORING

1. Description

Demonstrates performance of an inflatable, low-reaction-force anchor that grows into the ground like a plant root.

2. Significance

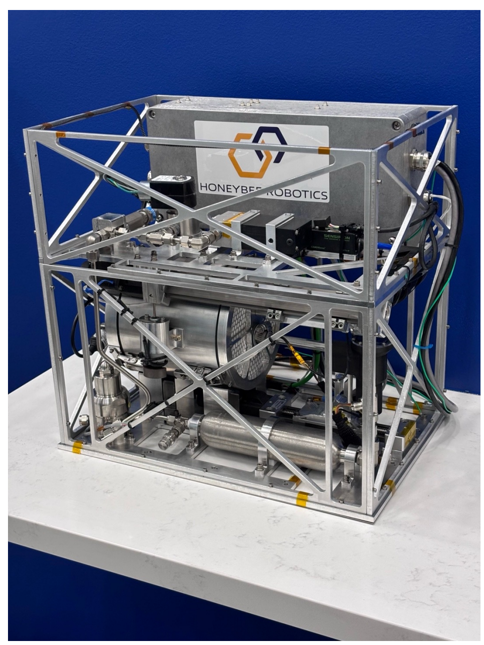
Anchor may be required for stabilizing landers, rovers etc. on small planetary bodies.

3. Experiment

Measure insertion and extraction force.

4. Results

Anchor generates high extraction force while requiring little to no insertion force.

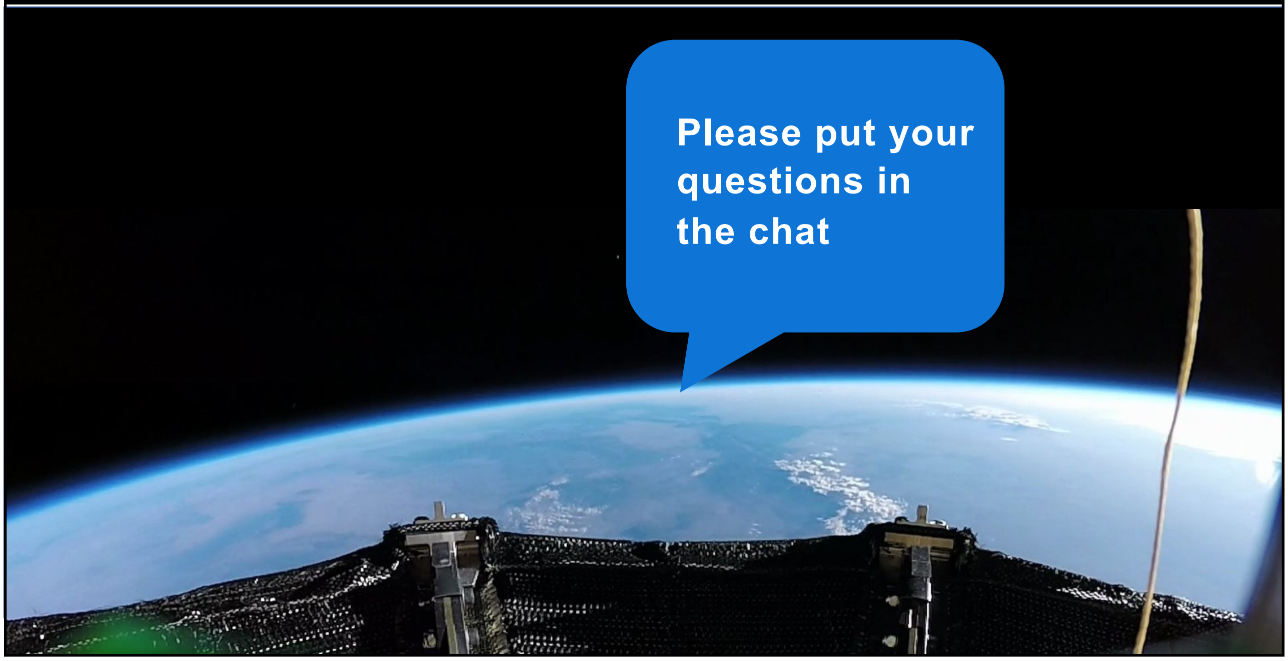


BLUE ORIGIN

8 MAY 2025 58

58

WHAT QUESTIONS DO YOU HAVE?



59

NASA.GOV/FLIGHTOPPORTUNITIES

Our June webinar will be a regolith roundtable.

Visit our websites for more information and resources, including our newsletter and monthly Community of Practice webinars.

Reach out:
NASA-FlightOpportunities@mail.nasa.gov

60