EXPLORE SPACE TECH

Advancing In-Situ Resource Utilization Technologies Through Flight Tests

Flight Opportunities Community of Practice Webinar: April 2, 2025

Session will start at 10 a.m. PT – Please mute your microphone and turn off your camera

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

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- Increase the impact of suborbital flight tests
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- Topics are announced in the Flight Opportunities newsletter and website.
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TODAY'S SPEAKERS

Jerry Sanders
Lead for In-Situ Resource Utilization System Capability Leadership Team
NASA Space Technology Mission Directorate

Lexi Humann
Senior Mechanical Engineer
Interlune

Erin Rezich
Aerospace Engineer, Mechanisms and Tribology Branch
NASA's Glenn Research Center

Bob Anderson, Ph.D.
Research Scientist
Geophysics and Planetary Geosciences
NASA's Jet Propulsion Laboratory

Luke Sollitt, Ph.D.
Branch Chief, Planetary Systems
NASA's Ames Research Center

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EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION
In Situ Resource Utilization (ISRU) Overview
Flight Opportunities Community of Practice Webinar
ISRU Panel Discussion
April 2, 2025
Gerald (Jerry) Sanders | ISRU System Capability Lead – STMD | gerald.b.sanders@nasa.gov
Julie Kleinhenz | ISRU System Capability Deputy – STMD | julie.e.kleinhenz@nasa.gov

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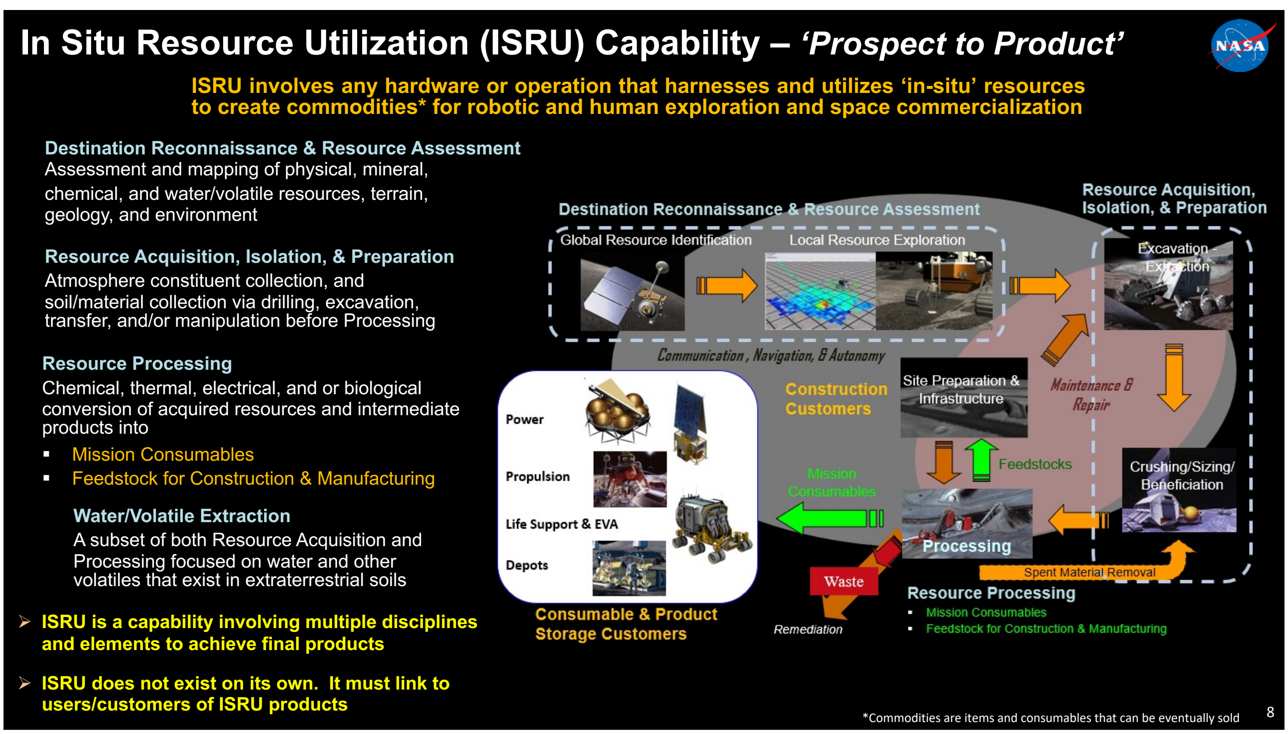
In Situ Resource Utilization (ISRU) Capability – 'Prospect to Product'
ISRU involves any hardware or operation that harnesses and utilizes 'in-situ' resources to create commodities* for robotic and human exploration and space commercialization
Destination Reconnaissance & Resource Assessment
Assessment and mapping of physical, mineral, chemical, and water/volatile resources, terrain, geology, and environment
Resource Acquisition, Isolation, & Preparation
Atmosphere constituent collection, and soil/material collection via drilling, excavation, transfer, and/or manipulation before Processing
Resource Processing
Chemical, thermal, electrical, and or biological conversion of acquired resources and intermediate products into
▪ Mission Consumables
▪ Feedstock for Construction & Manufacturing
Water/Volatile Extraction
A subset of both Resource Acquisition and Processing focused on water and other volatiles that exist in extraterrestrial soils
➢ ISRU is a capability involving multiple disciplines and elements to achieve final products
➢ ISRU does not exist on its own. It must link to users/customers of ISRU products
Destination Reconnaissance & Resource Assessment
Global Resource Identification
Local Resource Exploration
Resource Acquisition, Isolation, & Preparation
Excavation Extraction
Communication, Navigation, & Autonomy
Construction Customers
Site Preparation & Infrastructure
Maintenance & Repair
Feedstocks
Crushing/Sizing/ Beneficiation
Power
Propulsion
Life Support & EVA
Depots
Mission Consumables
Processing
Spent Material Removal
Waste
Remediation
Consumable & Product Storage Customers
Resource Processing
▪ Mission Consumables
▪ Feedstock for Construction & Manufacturing
*Commodities are items and consumables that can be eventually sold
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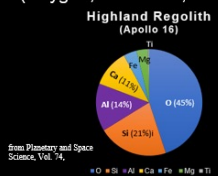
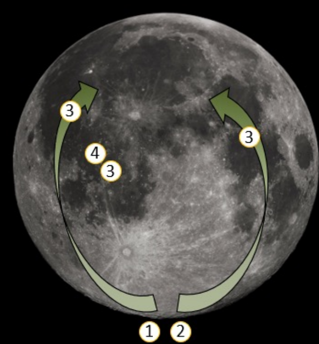
Time and Spatial Evolution of Lunar Resources and Commodities for Commercial and Strategic Interests

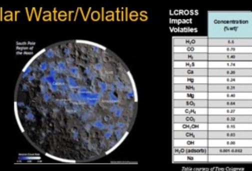
- ISRU starts with the easiest resources to mine, requiring the minimum infrastructure, and providing immediate local usage
- The initial focus is on the lunar South Pole region (highland regolith and water/volatiles in shadowed regions)
  – ISRU will evolve to other locations, more specific minerals, more refined products, and delivery to other destinations

1. Polar Highland Regolith
(Oxygen, Aluminum, Silicon)

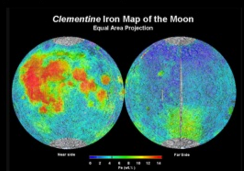


2. Polar Water/Volatiles

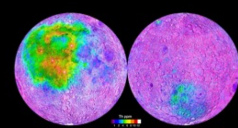




3. Ilmenite and Pyroclastic Glass
(Iron, Titanium, Solar Wind Volatiles)



4. Rare Earth Elements & Thorium



Indication of where KREEP is
(Procellerum KREEP Terrane)

Commodities

- Oxygen
- Water - Hydrogen
- Bulk & Refined Regolith
- Raw & Refined Metals (Al, Fe, Ti)
- Silicon and Ceramics
- Construction Feedstock
- Manufacturing Feedstock
- Fuels, Plastics, Hydrocarbons
- Food/Nutrient Feedstock

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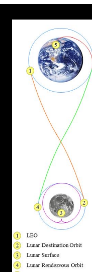
Why Use Space Resources?

- **They can reduce mission and architecture mass and costs**
  - **Launch mass savings**: 1 kg on Moon/Mars = 7.5 to 11 kg launched into Earth orbit
  - **Reduce launch numbers**: lower mass = less launches = reduced mission risk
  - **Supports reuse of mission transportation assets**: reuse = lower cost;
  - **Supports terrestrial industry/Enables space commercialization**: reduces risk for industry involvement thereby reducing development and life cycle costs



A Kilogram of Mass Delivered Here…	…Adds This Much Initial Architecture Mass in LEO	…Adds This Much To the Launch Pad Mass
Ground to LEO	-	20.4 kg
LEO to Lunar Orbit (#1→#2)	4.3 kg	87.7 kg
LEO to Lunar Surface (#1→#3; e.g., Descent Stage)	7.5 kg	153 kg
LEO to Lunar Orbit to Earth Surface (#1→#4→#5; e.g., Orion Crew Module)	9.0 kg	183.6 kg
Lunar Surface to Earth Surface (#3→#5; e.g., Lunar Sample)	12.0 kg	244.8 kg
LEO to Lunar Surface to Lunar Orbit (#1→#3→#4; e.g., Ascent Stage)	14.7 kg	300 kg
LEO to Lunar Surface to Earth Surface (#1→#3→#5; e.g., Crew)	19.4 kg	395.8 kg

- **They can increase safety for crew and mission success**
  - **Ensure crew safety**: dissimilar redundancy for life support consumables, *in situ* repairs, radiation shielding, increased independence for Earth logistics
  - **Provide critical solutions for mission assurance**: safe landing zones preparation, extra propellant for return to Earth (leakage/storage failure), protective shielding
  - **Minimizes impact of shortfalls in other system performance**: launch and lander propulsion performance, life support system closure
  - **Enhance crew psychological health**: provides knowledge and tools for self-reliance and survival; larger habitats
- **They can enhance or enable mission capabilities not possible without them**
  - **Mission life extensions and enhancements**: local supply of critical consumables without waiting for new Earth supply, repairs with local materials, repurposing of end-of-life hardware, trash disposal (propellants and planetary protection),
  - **Increased surface mobility and access**: surface hoppers, ISRU produced reactants for surface mobility fuel cell power, extend duration of exploration activities in extreme environments
  - **Increased science**: more mass for science equipment, greater surface access, ISRU excavation
- **Learning to use Space Resources can help us on Earth**
  - Renewable Energy/CO_2 Reduction, Recycling/Repurposing, Water cleanup, Environmentally-friendly mining and construction

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Camping vs Staying
(Apollo/Sorties vs Lunar Outpost/Artemis Base Camp)

	Camping	Staying	Needed Exploration Capability
Water/Food	Brought: Freeze-dried, packaged, & canned food. Canteen/water bottles Local: stream	Brought: Low mass specialty items (salt, seeds, sugar, spices, yeast) and hunting/fishing equipment Local: Wells and rain water capture, garden/planting, berries/fruit trees, and animals for food	Grow food: use local materials for 'soil', produce fertilizer, local water Make food: produce nutrients and food products Find/make water from local resources
Shelter	Brought: Lightweight tent Local: Wood poles, grass/straw	Brought: Tools for construction (axe, shovel) Local: Cave. Build shelter/cabin	Use local materials 1) for protection, 2) to build radiation/environment shelters (safe havens) and 3) structures that can be sheltered
Energy	Brought: Non-rechargeable batteries, matches, fuel/kerosine Local: Sticks/branches on the ground	Brought: Matches Local: Cut down trees/make charcoal, water wheel, wind	Use local materials to 1) build solar arrays, 2) transmission wires/cables, 3) thermal storage, and 4) electrical storage Use water/local resources to create fuel cell reactants; use local materials to make storage tanks
Local Transportation	Walking, bike	Horse or animal; steam or combustion engine: use local food and fuel	Use water/local resources to create propellants Build roads; clear and level areas
	Take almost everything with you	Take items to help you "Live off the Land"	

You do not need ISRU for camping trips, but you do need it if you are going to stay and be productive

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Artemis Architecture Segments

HUMAN LUNAR RETURN
Initial capabilities, systems, and operations necessary to reestablish human presence and initial utilization (e.g., science) on and around the Moon.

FOUNDATIONAL EXPLORATION
Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (e.g., science) and Mars-forward precursor missions.

SUSTAINED LUNAR EVOLUTION
Enabling capabilities, systems, and operations to support regional and global utilization (e.g., science), economic opportunity, and a steady cadence of human presence on and around the Moon.

HUMANS TO MARS
Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (e.g., science) on Mars and continued exploration.

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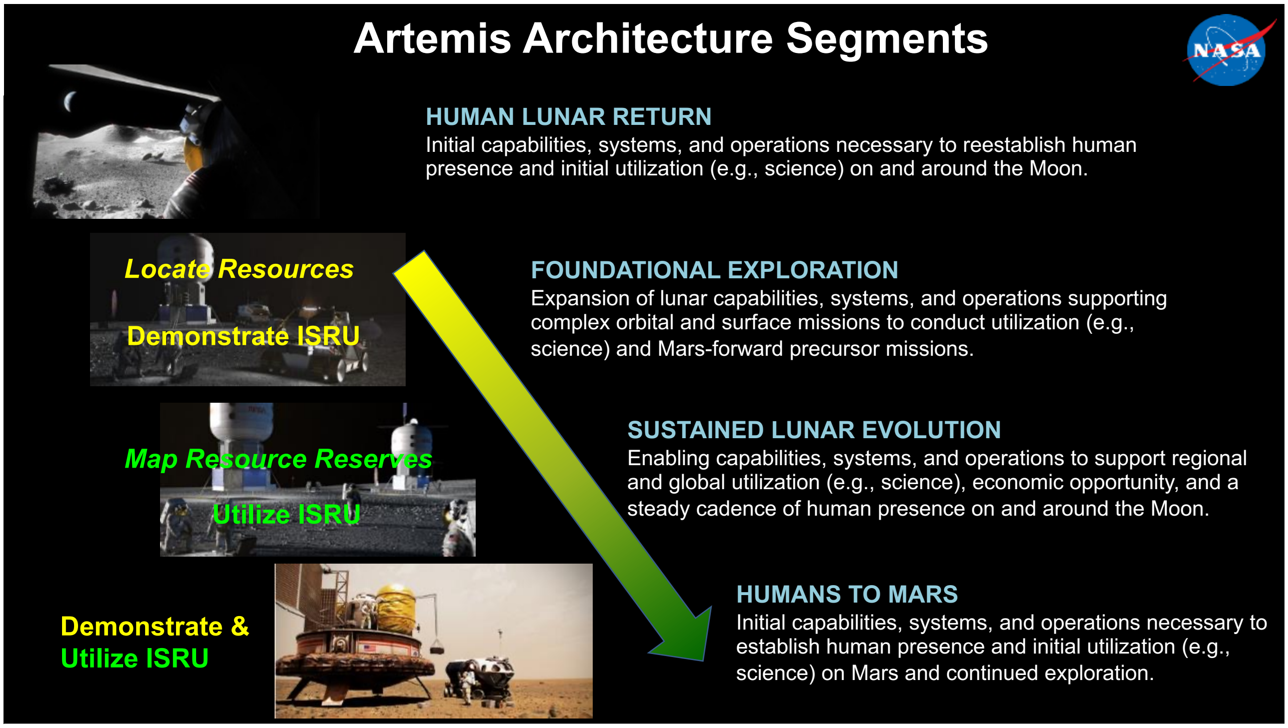
Artemis Architecture Segments
HUMAN LUNAR RETURN
Initial capabilities, systems, and operations necessary to reestablish human presence and initial utilization (e.g., science) on and around the Moon.
Locate Resources
Demonstrate ISRU
FOUNDATIONAL EXPLORATION
Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (e.g., science) and Mars-forward precursor missions.
Map Resource Reserves
Utilize ISRU
SUSTAINED LUNAR EVOLUTION
Enabling capabilities, systems, and operations to support regional and global utilization (e.g., science), economic opportunity, and a steady cadence of human presence on and around the Moon.
Demonstrate & Utilize ISRU
HUMANS TO MARS
Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (e.g., science) on Mars and continued exploration.

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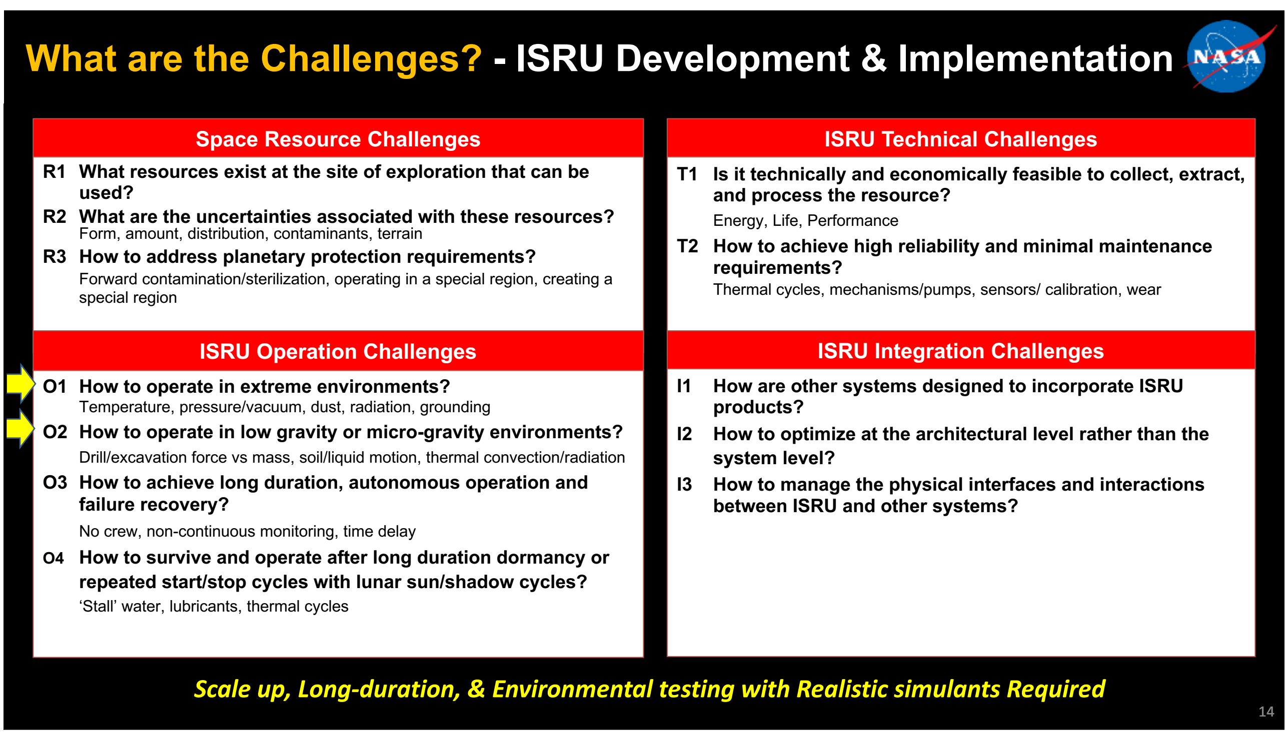
What are the Challenges? - ISRU Development & Implementation
Space Resource Challenges
R1 What resources exist at the site of exploration that can be used?
R2 What are the uncertainties associated with these resources?
Form, amount, distribution, contaminants, terrain
R3 How to address planetary protection requirements?
Forward contamination/sterilization, operating in a special region, creating a special region
ISRU Technical Challenges
T1 Is it technically and economically feasible to collect, extract, and process the resource?
Energy, Life, Performance
T2 How to achieve high reliability and minimal maintenance requirements?
Thermal cycles, mechanisms/pumps, sensors/ calibration, wear
ISRU Operation Challenges
O1 How to operate in extreme environments?
Temperature, pressure/vacuum, dust, radiation, grounding
O2 How to operate in low gravity or micro-gravity environments?
Drill/excavation force vs mass, soil/liquid motion, thermal convection/radiation
O3 How to achieve long duration, autonomous operation and failure recovery?
No crew, non-continuous monitoring, time delay
O4 How to survive and operate after long duration dormancy or repeated start/stop cycles with lunar sun/shadow cycles?
'Stall' water, lubricants, thermal cycles
ISRU Integration Challenges
I1 How are other systems designed to incorporate ISRU products?
I2 How to optimize at the architectural level rather than the system level?
I3 How to manage the physical interfaces and interactions between ISRU and other systems?
Scale up, Long-duration, & Environmental testing with Realistic simulants Required
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ISRU Operation Challenges – Further Details (1 of 2)

- **Operation in low/micro-gravity**
  - Low-gravity on Moon/Mars
    - Solids
      - Low reaction force excavation in reduced and micro-gravity
      - Granular material flows differently in low-g; increase in electrostatic/friction effects
      - Kicking up dust is amplified; dust settling is different
      - Rotational inertia is not reduced, but gravity to resist tipping is reduced!
      - Fluidized gas/solid reactors impacted by gravity and thermal convection differences
    - Liquids
      - Liquid slosh is amplified
      - Influence of surface tension
      - Liquid & molten reactors impacted by gravity and thermal convection differences
      - Unknown impact on biological processing
  - Micro-g environment for Near Earth Asteroids (NEAs) and Phobos/Deimos
    - Solids
      - Anchoring/weight-on-bit for resource extraction
      - Material handling and transport completely different than Moon/Mars techniques
      - Feedstock, product, and reactant separation: Gas/solid reactors and separation
      - Friction, cohesion, and electrostatic forces may dominate in micro-g
    - Liquids
      - Influence of surface tension
      - Unknown impact on biological processing
      - Feedstock, product, and reactant separation: Gas/liquid and liquid/solid reactors and separation

- **ISRU Operations**
  - Granular flow for excavation and transfer
  - Granular size sorting
  - Granular mineral separation: electrostatic, tribocharing, magnetic fluid, etc.
  - Granular material processing (gas/solid)
  - Liquid/granular processing: solid/liquid, and molten regolith
  - Gas/liquid and liquid/liquid processing for reactant regeneration and biological processing

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ISRU Operation Challenges – Further Details (2 of 2)

- **Operation in severe environments**
  - Efficient excavation of resources in dusty/abrasive environments; Wide variation in potential resource hardness, density/porosity, etc.
  - Methods to mitigate dust & dust filtration for Mars atmospheric processing
  - Extreme temperature changes (PSR ingress/egress) and/or extremely low temperatures (PSRs)
    - Material selection, embrittlement, thermal management, etc.
  - Radiation
    - Regolith charge: grounding/electrostatics
    - Impact on biological systems
  - Vacuum operation and exposure: electronics/power systems, reactor pressures/leakage, cold welding, etc.

- **ISRU Operations**
  - Granular flow for excavation and transfer
  - Granular size sorting
  - Granular mineral separation: electrostatic, tribocharing, magnetic fluid, etc.
  - Granular material processing (gas/solid)
  - Liquid/granular processing: solid/liquid, and molten regolith
  - Gas/liquid and liquid/liquid processing for reactant regeneration and biological processing

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Plan to Achieve ISRU Outcome

Scalable ISRU production/utilization capabilities including ***sustainable commodities*** *on the lunar & Mars surface*

Enable Industry to Implement ISRU for Artemis, Sustained Human Presence, and Space Commercialization

Market Transparency
- **Define Initial and Long-term Customer Needs for ISRU-derived Products**
  - Work within NASA and International Partners
  - Work with Industry: Utilize Lunar Surface Innovation Consortium

Technology Innovation
- **Advance ISRU technologies and systems for lunar missions by utilizing NASA solicitations, public private partnerships, internal/external investments**
  - Perform and support extensive development and integration/testing

Scale-up Investment
- **Reduce Risk and Promote Investment in ISRU Systems and Products**
  - Coordinate requirements, development, and implementation of infrastructure required for ISRU operations
  - Provide to industry key and enabling NASA capabilities and resources Support data buys for lunar resource understanding and ISRU technologies/operations
  - Perform and support lunar resource assessment and technology demonstrations (CLPS, HLS, Int'l Partner, Industry)

Readiness for Disruption
- **Promote Industry-led ISRU Development thru End-to-End ISRU Production of Commodities (i.e. Pilot Plant) and usage**
  - Production at sufficient scale to eliminate risk of Full-scale system
  - Promote use of ISRU-derived commodity initially in non-mission critical applications to build market and trust

Circular Economy
- **Promote tracking and usage of all product/waste streams**
  - Minimize waste, promote recycling, refurbishment, and reuse

- **ISRU must be demonstrated on the Moon before mission-critical applications are flown**
  - Utilize lunar flight demonstrations and Pilot Plant operations to break 'chicken and egg' cycle
  - Conduct prospecting missions to locate predicted water/ice reserves proximal to potential base camps.

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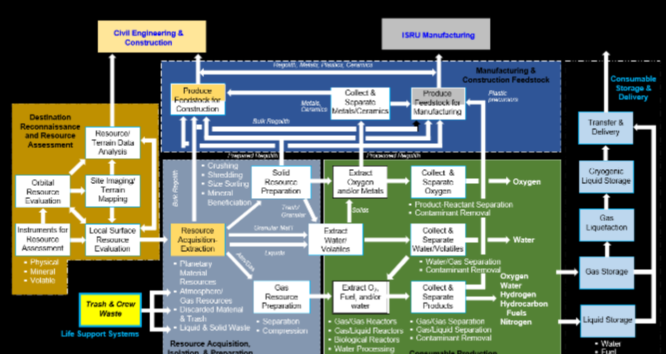
ISRU Functional Breakdown And Flow Diagram

Destination Reconnaissance and Resource Assessment	Resource Acquisition, Isolation, and Preparation	Resource Processing for Production of Mission Consumables	*Resource Processing for Production of Manufacturing and Construction Feedstock*	*Cross Cutting*
• Site Imaging/Terrain Mapping • Instruments for Resource Assessment • Orbital Resource Evaluation • Local Surface Resource Evaluation • Resource/Terrain/Environment Data Fusion and Analyses	• Resource Excavation & Acquisition • Resource Preparation before Processing • Resource Transfer • Resource Delivery from Mine Site and Removal	• Resource Storage and Feed To/From Processing Reactor • Regolith Processing to Extract Oxygen • Regolith Processing to Extract Water • Carbon Dioxide Processing • Water Processing • Instrumentation to Characterize Processing Performance • Product/Reactant Separation • Contaminant Removal from Reagents/Products	• In Situ Excavation and Movement for Construction • Resource Preparation for Construction Feedstock • Material transfer • Resource Processing to Extract Metals/Silicon • Resource-Trash/Waste Gas Processing to Produce Methane/Plastics	• Planetary Simulants for Test & Verification • Planetary Regolith/Environment Test Chambers

- **Functional Breakdown and Flow Diagram used to understand:**
  - Technology State of the Art and gaps
  - Connectivity Internally and with other disciplines
  - Influence of technologies on complete system and other functions
- **ISRU functions have shared interest w/ Autonomous Excavation, Construction, & Outfitting (AECO)**
  - Destination Reconnaissance
  - Resource Excavation & Delivery
  - Construction Feedstock Production



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Lunar ISRU Commodities

- **Water (and Volatiles) from Polar Regolith**
  - Form, concentration, and distribution of Water in shadowed regions/craters is not known
    - Technologies & missions in work to locate and characterize resources to reduce risk for mission incorporation
  - Provides 100% of chemical propulsion propellant mass (O_2/H_2)
  - ➢ Polar water is "Game Changing" and enables long-term sustainability
    - Strongly influences design and reuse of cargo and human landers and transportation elements
    - Strongly influences location for sustained surface operations
- **Oxygen/Metal from Regolith**
  - Lunar regolith is >40% oxygen (O_2) by mass
    - Polar highland regolith: mostly anorthosite rich in aluminum and silicon; poor in iron
    - Equatorial mare regolith: regions of high iron/titanium, KREEP, and pyroclastic glasses
  - Technologies and operations are moderate risk from past work and can be performed anywhere on the Moon
  - Provides 75 to 80% of chemical propulsion propellant mass (fuel from Earth); O_2 for EVA, rovers, Habs.
  - ➢ Experience from regolith excavation, beneficiation, and transfer applicable to mining Mars hydrated soil/minerals for water and *in situ* manufacturing and constructions
- **Propellants/Fuels**
- **Manufacturing & Construction Feedstock**
  - Bulk or refined regolith (size sorted/mineral beneficiation) forms the bulk of the construction feedstock
  - Metals and slag from oxygen extraction can be used or modified as feedstock
  - Chemical and biological processing to produce binders and further refine construction materials
  - ➢ Requires close ties to In Space Manufacturing (ISM) and Autonomous, Excavation, Construction and Outfitting (AECO)
- **Support for Plant/Food/Nutrient Production**
  - Bulk or refined regolith (size sorted, mineral beneficiation, milled, treated) for plant growth media
  - Chemical and biological processing (esp. of carbon/water) of wastes and in situ resources to produce nutrient and food precursors
  - ➢ Requires close ties to Life Support Systems

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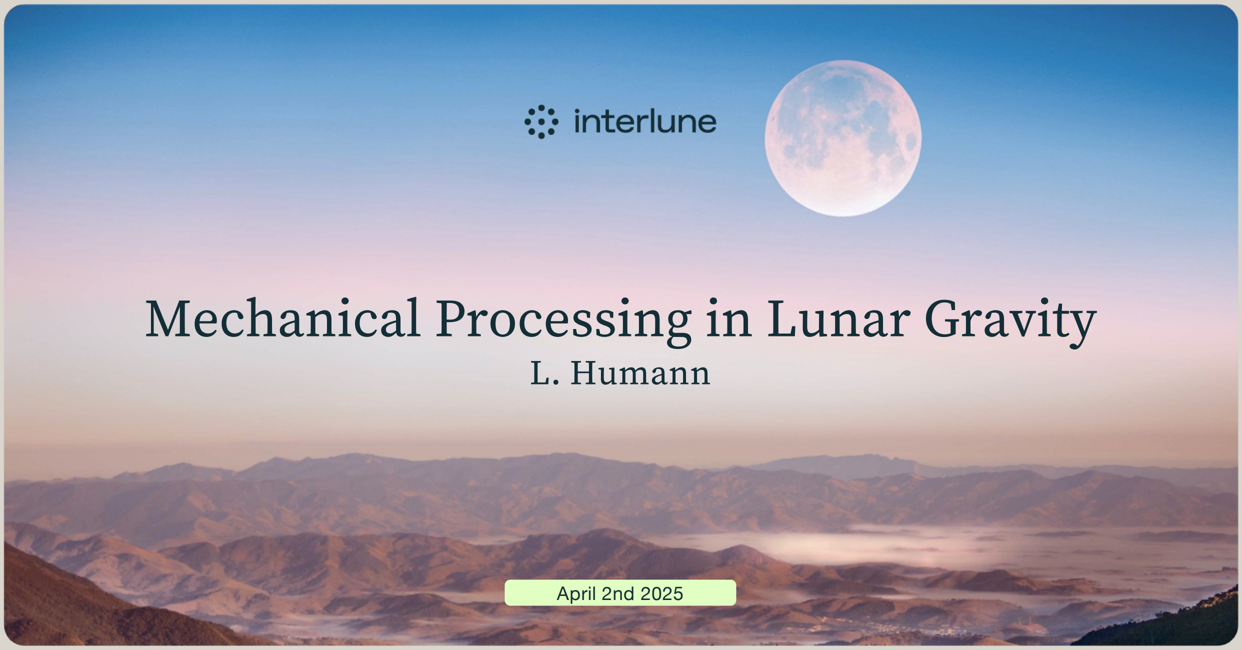

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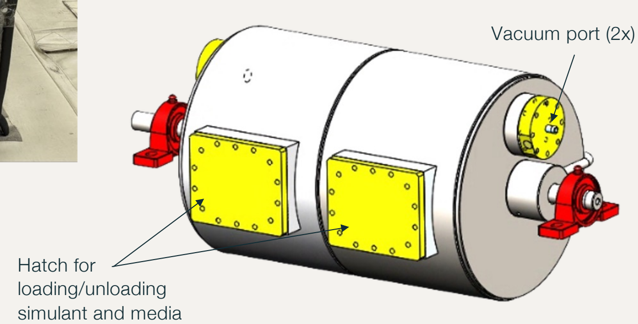
Mechanical Processing Test Flight - Oct 2024



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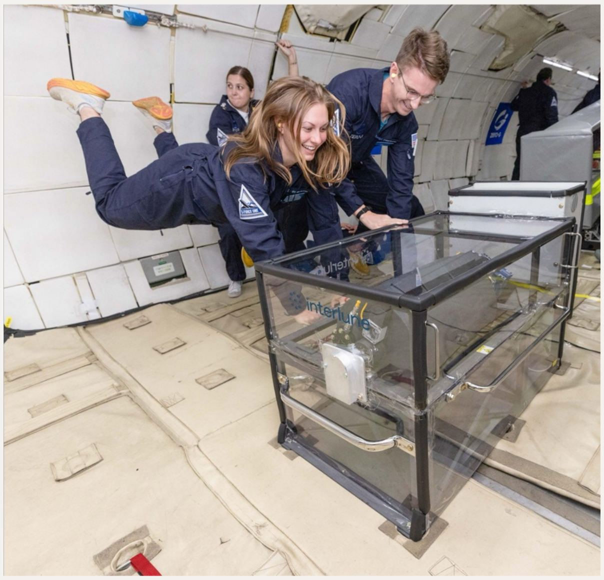
Lessons Learned and Recommendations



- Parabolic dive time varies
  - Consider measuring operational time during the flight test and conducting ground testing after the flight to match duration
- “Ambient” flight environment differs from ground environment; internal pressure will be around 11.9 psi once cruising altitude is reached
  - Consider pressure differential for any sealed experiments
  - Use absolute pressure gages

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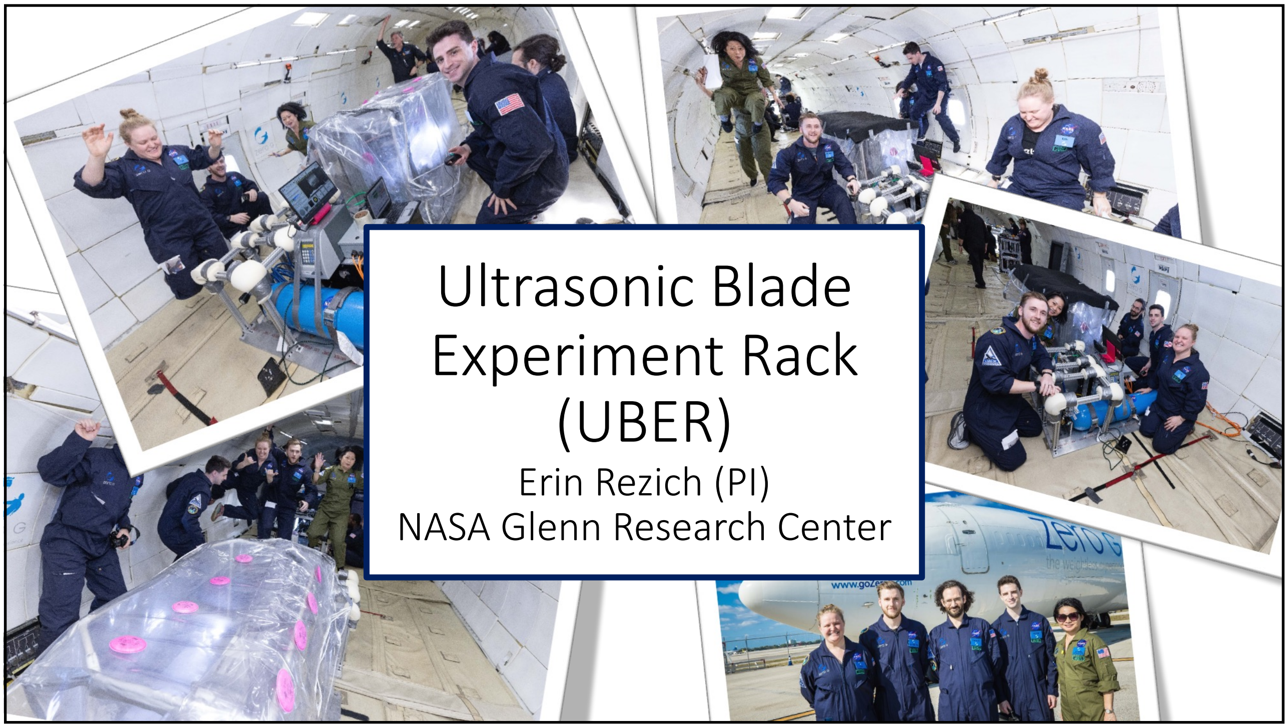

Ultrasonic Blade Experiment Rack (UBER)

Erin Rezich (PI)
NASA Glenn Research Center

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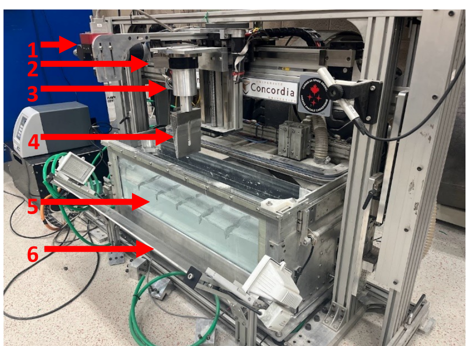
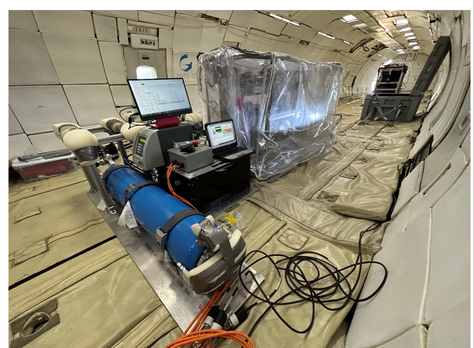
Flight Test Rig and Test Article



Concordia University test rig in the SLOPE Lab.

1. High speed digital camera
2. 6-axis load cell
3. Piezo-electric actuator stack
4. Titanium blade
5. Chenobi lunar highlands soil simulant
6. Camera mirror

Ultrasonic blade test article attached to the piezoelectric actuation stack.



Concordia University test rig installed in G-Force One aircraft.

Journal of Terramechanics
Volume 83, June 2019, Pages 35-44

Rapid automated soil preparation for testing planetary rover-soil interactions aboard reduced-gravity aircraft

Krzysztof Skonieczny, Parna Niksirat, Amir Ali Forough Nassiraei

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In-Flight Experiment and Team Configuration

- Payload had a 10' X 10' bay which allowed for 5 flyers
- Payload placed near windows – affected imagery and video
- Zero-G provided this GoPro footage
- Actual operation tasks were minimized to two button presses

Team in position right before a lunar gravity parabola.

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Automated Soil State Preparation

Loosening Stage

- Pulsed air injection from bottom of soil bin via grid of mushroom head nozzles
- Short pulsed vibration

Compaction Stage

- Long pulsed vibration only

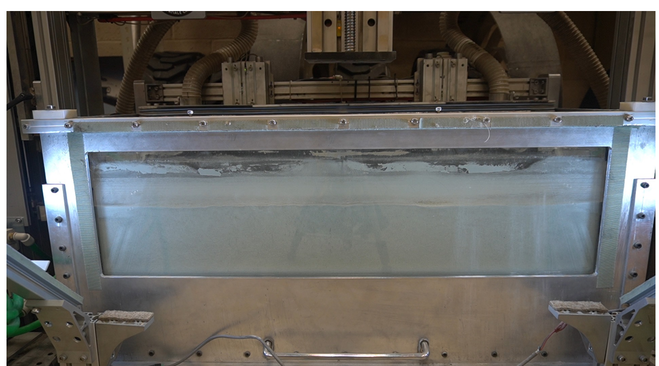
Occurs during "reset period" in flight between sets of parabolas

Method Pros:

- Fully automated
- Repeatable
- Timing works for reset time of < ~2 min

Method Cons:

- Dusty (necessitates dust management)
- Segregates/stratifies simulant some amount
- Somewhat difficult to tune parameters for mildly cohesive simulant



Parabolic flight experiment unit demonstrating an automatic, pneumatic soil condition preparation in the SLOPE Lab at NASA GRC.

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Acknowledgements

- Test Rig provided by Concordia University via International Space Act Agreement
- **Team:** George Butt[1], Pierre-Lucas Aubin-Fournier[1], Dr. Krzysztof Skonieczny[1], Ian Haskin[2], QuynhGiao Nguyen[3]
  [1]Concordia University, Montreal, QC, Canada
  [2]NASA Glenn Research Center
  [3]NASA Langley Research Center

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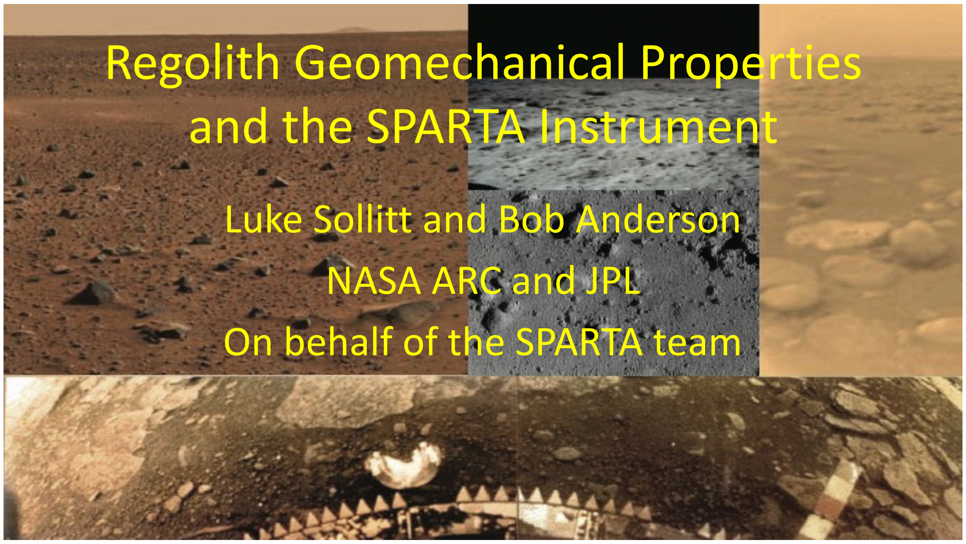

JPL
Jet Propulsion Laboratory
California Institute of Technology

NASA SILICON VALLEY
AMES RESEARCH CENTER

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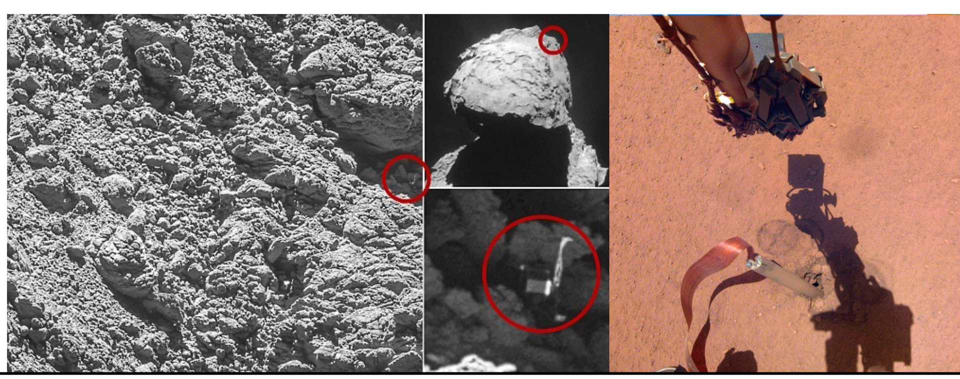
Regolith Geomechanical Properties

- Regolith must be understood *in situ*
- It is dramatically different from Earth soils
  - Different weathering processes give rise to different forms
- Reduced gravity/atmospheric conditions can greatly influence how soils behave



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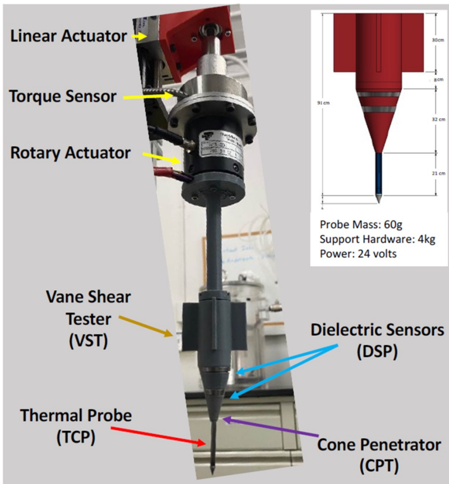
SPARTA
Science Components & Relevance



SPARTA is a unique, all-in-one science toolkit with the ability to **simultaneously measure *in situ* electrical, mechanical (shear and penetration), and thermal properties of lunar regolith**. SPARTA is a versatile system that is able to be deployed on **autonomous rovers and landers or used by personnel** during exploration and resource prospecting efforts

Electrical Properties

- **SPARTA** Dielectric Spectroscopy Probe (DSP)
  - **Measures:** Volatile content
  - **Scientific Relevance:** Spatial extent and mode of water (e.g., adsorbed, bound/film, capillary, or pore water), regolith permeability
  - **Engineering Relevance:** ISRU/human exploration

Mechanical Properties

- **SPARTA** Vane Shear Tester (VST) **and** Cone Penetration Tester (CPT)
  - **Measures:** Shear strength (Mohr-Coulomb cohesion and angle of friction), bearing capacity, compaction, relative density.
  - **Scientific Relevance:** Site characterization, volatile transport, stratigraphy
  - **Engineering Relevance:** Infrastructure development, vehicle/rover design, trafficability, drilling, excavation.

Thermal Properties

- **SPARTA** Thermal Conductivity Probe (TCP)
  - **Measures:** Temperature, thermal conductivity, thermal diffusivity, thermal history.
  - **Scientific Relevance:** Transient thermal gradients, thermal transfer rates, volatile content, compaction, density
  - **Engineering Relevance:** ISRU (volatile extraction, molten regolith electrolysis, additive manufacturing, glass-ceramic production)

Note: SPARTA stands for Soil Properties Assessment Resistance and Thermal Analysis

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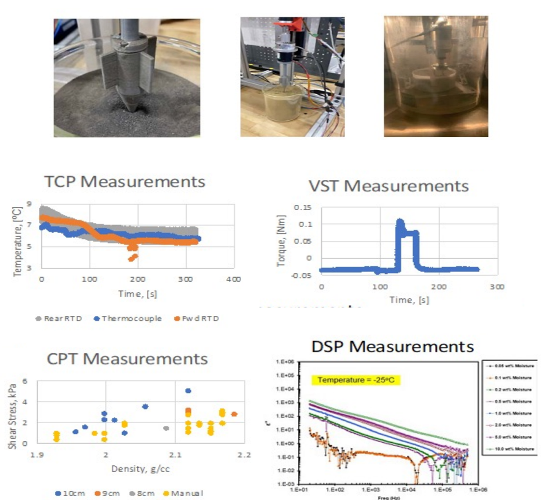
SPARTA in the Lab

- Testing so far in JSC1a, MMS, LHS
- At 1 atm pressure
- At Mars pressures
- At 1 g (obviously)
- DSP testing in low temperature (-40C) permafrost



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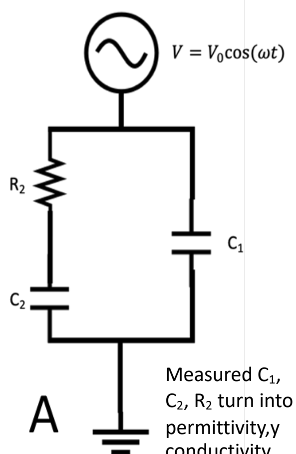
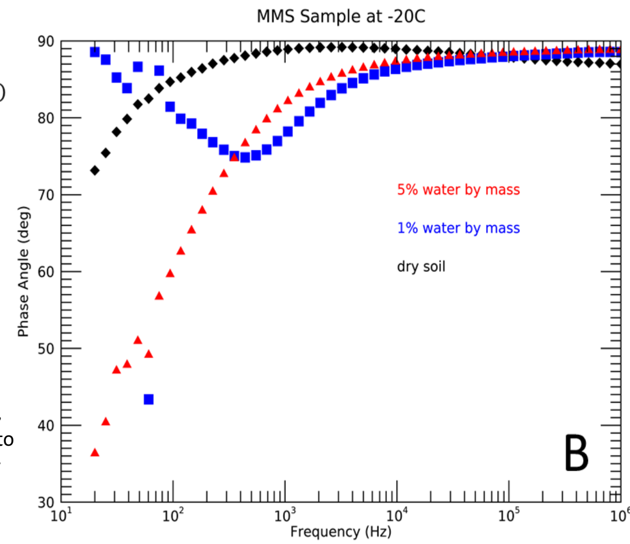
SPARTA in the Lab: Dielectric Spectroscopy

Debye Model for Soils



Measured C_1, C_2, R_2 turn into permittivity,y conductivity (**dielectric constant**)



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SPARTA in the field

Tule Lake field site, May 2024

- Fine lake-bottom silt
- Very soft surface
- Undisturbed, uncompacted
- "Grid 2" – 3X3 meter grid

Linear Stage

Linear Strain Sensor

Rotational Stage

Torque Sensor

Probe Head with Shaft

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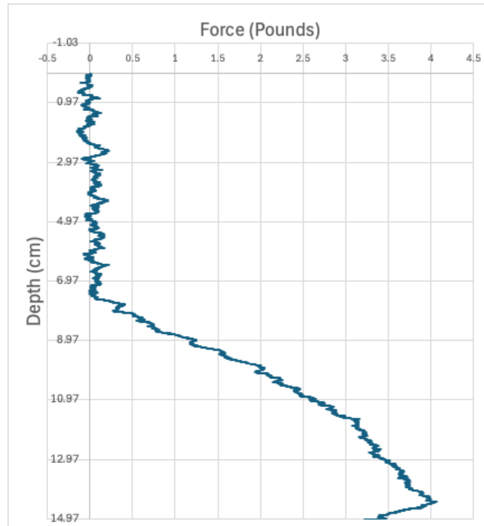
What the Cone Penetrator Does



Grid 2, Row 2, Site 3

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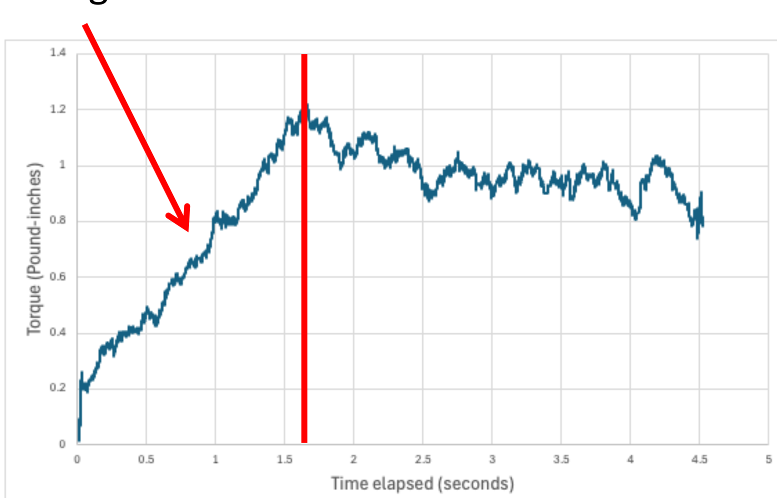
What the Vane Shear Tester Does

Building strain

The soil “breaks” here



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SPARTA in the Air

- Understanding how SPARTA works in relevant conditions
  - Correct ***Gravity***

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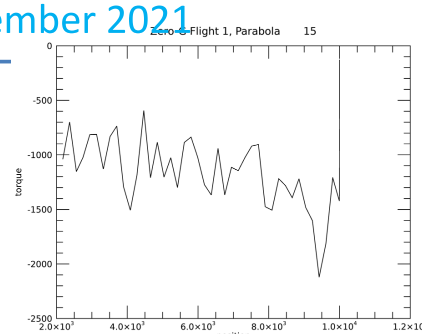
SPARTA Zero-G Testing December 2021



Three gravity regimes:
- Mars
- Lunar
- Zero-g

CPT and DSP tested

Many lessons learned!
- In particular about zero-g testing and testing on aircraft

DSP cylinders

Cone penetrator test cylinder

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SPARTA BLUE

- Flew on NS-29 on February 4, 2025
- Vane Shear Test cylinder
- Two DSP cylinders
  - LMS
  - LHS
- No cone penetrometer

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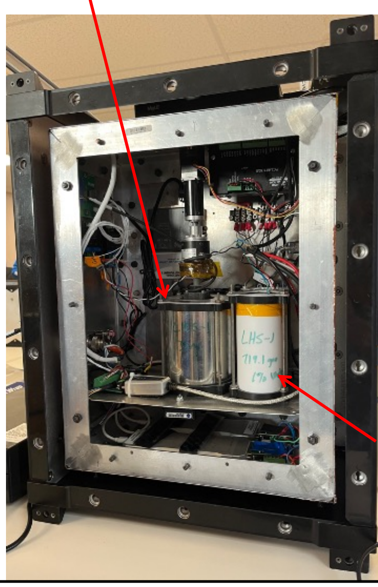
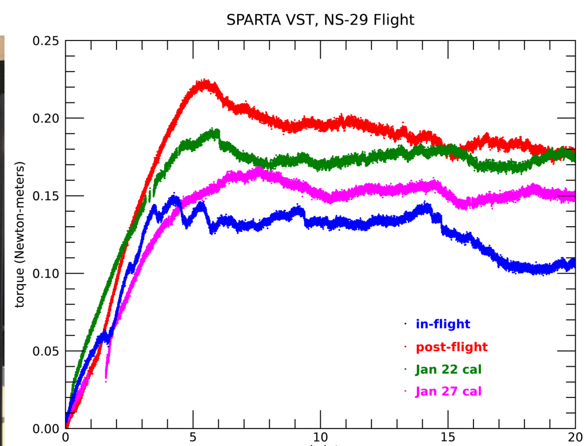
SPARTA BLUE VST RESULTS

VST cylinder





DSP cylinders

- The soil breaks at a lower torque in simulated lunar gravity
- Postflight soil broke at a higher torque (compactified by high g on landing)

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The Next Zero-G Flight: May 2025

- **Add a vacuum chamber** to get higher-fidelity tests – more relevant environment (**gravity** and **atmosphere**)
  - CPT – now with load cells
  - VST – multiple onset tests (different from Blue)
  - DSP
  - TCP – *never flown* with SPARTA
  - We saw bubbling of soils in low gravity – vacuum chamber will solve that
- Incorporate lessons learned from first flight
  - Proper torque and pressure sensors!
  - Better method for resetting soils between parabolas (piezoelectric motor)

SPARTA's third flight! Thank you, NASA Flight Opportunities!

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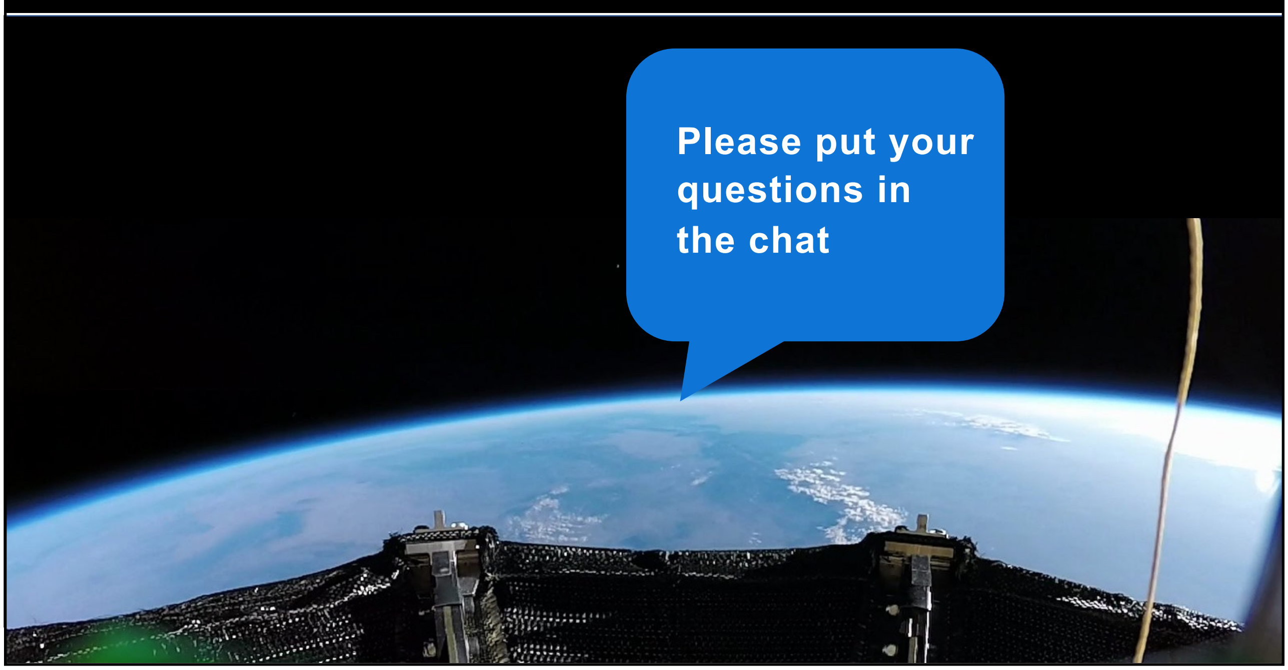
WHAT QUESTIONS DO YOU HAVE?



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