Lunar Surface Innovation CONSORTIUM

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

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LSIC Newsletter

The Lunar Surface Innovation Consortium is administered by the Johns Hopkins Applied Physics Laboratory, and operates in collaboration with the NASA Space Technology Mission Directorate under the Lunar Surface Innovation Initiative. Its purpose is to harness the creativity, energy, and resources of the nation to help NASA keep the United States at the forefront of lunar exploration. To find out more, sign up to participate, or access past additions of this newsletter, please visit lsic.jhuapl.edu.

DIRECTOR'S UPDATE

Director's Update

Hello LSIC Community! We have just a couple days left before our Spring Meeting, where we will be hearing about NASA's Envisioned Futures for living on the Moon. This is something we have all been looking forward to, and I hope many of you will be able to join us. I encourage all of you with innovative technologies in development, or in mind as potential concepts, pay close attention to where these could fill gaps or complement the work NASA has invested in so far. What we would like to really understand in earnest is how, and to what degree, NASA's Envisioned Futures interleave with your own goals and strategies.

In advance of this meeting, and especially the breakouts, it would be helpful if members of the community spent some time thinking about your personal envisioned futures for sustained lunar operations. For example, for those of you who are industry members, what is the timeframe for which you would want to see certain pieces of infrastructure in place (comms, power, etc.)?

The Lunar Surface Innovation Initiative supports the efforts for early Artemis missions, but our scope is more than that. The more we can help communicate critical gaps that need investments to NASA Space Tech, the more useful we, as the LSIC community, can be as a partner to NASA in some areas, and in some areas leaders in establishing the sustained infrastructure and operations on the Moon. NASA Space Tech understands that early investment in some of these technologies is absolutely critical, and they are key in trying to stimulate this work in academia and industry.

So please don't be shy. I look forward to many exciting conversations next week!

Rachel Klima
Director, Lunar Surface Innovation Consortium
SES-LSIC-Director@jhuapl.edu

Focus Areas

Monthly Telecon Schedule

Dust Mitigation
Third Thursdays at 12PM Eastern

Excavation & Construction
Fourth Wednesdays at 2PM Eastern

Extreme Access
Second Thursdays at 3PM Eastern

Extreme Environments
Second Tuesdays at 3PM Eastern

In Situ Resource Utilization
Third Wednesdays at 3PM Eastern

Surface Power
Fourth Thursdays at 11AM Eastern

LSIC General Updates

Save the Date: Designing for the Extremes Workshop - Tuesday 07 June

Extreme Access (EA) and Extreme Environments (EE) are inviting you to a half day virtual workshop to talk through the many challenges associated with regolith excavation and transport. Many environmental factors contribute to the engineering and testing of necessary hardware to successfully access and maneuver these sites. Environmental effects and consequences for inadequate requirements need to be explored for technology and data development. This workshop will provide an opportunity to discuss these risks and technologies needed to address them. This interactive workshop will consist of an overview of the Robotics Lunar Surface Operations 2 (RLSO2) study, an Environmental Effects panel with Q&A, a panel with Q&A on technology needed to access these sites, and breakout sessions. The workshop will consist of a plenary speaker and panel discussions in a webinar format (with interactive Q&A during the panels), followed by smaller-group discussions in breakout rooms with interactive brainstorming and note taking using Miro (or similar software). Registration will be opening soon!

The goals of the workshop are to:

- Discuss specific access challenges and how environmental effects affect the design of hardware needed to implement an architecture as defined in the RLSO2 study
- Identify data needed to set design requirements and determine whether that data has already been collected, or what additional data is needed.
- Discuss ways to test to these requirements

Event details can be found here: https://lsic.jhuapl.edu/Events/Agenda/index.php?id=232

Focus Group Updates

Dust Mitigation

The Dust Mitigation (DM) Focus Group held a joint focus group meeting on Wednesday, April 27th with the Excavation and Construction (E&C) focus group. The theme for the joint focus group meeting was “Designing Dust Tolerant Systems for E&C” and focused on the driving questions: How does dust affect design and performance of E&C systems? How to design machines and mechanisms for wear and abrasion? Are there lessons from terrestrial experience? How are repair and maintenance considerations shaped by dust?

The meeting included introductions to the topic by the E&C and DM facilitators, respectively, and featured presentations by Vincent Vendiola from Honeybee Robotics on “Dust-Tolerant Mechanisms” with example of “Trident Dust Tolerance” and Brad Blair from Moonrise Mining Inc. on “Dust, Wear, and Abrasion in Mining.” These presentations were followed by a Q&A with the speakers and engaging discussion on dust mitigation needs/challenges for E&C systems.

Our next focus group meeting will be held on Thursday, May 19th at 1:00 pm EST. The meeting will include featured technology presentations along with a discussion session. We hope you can make it!

Excavation & Construction

In the month of April, the E&C and Dust Mitigation Focus Groups held a joint focus group meeting on Designing Dust-Tolerant Mechanisms for Excavation & Construction. We heard talks from Vincent Vendiola (Program Manager at Honeybee Robotics) regarding Dust-Tolerant Mechanisms and Brad Blair (CTO of Moonrise Mining Inc.) on perspectives from the mining industry – how they navigate dust mitigation, wear, and abrasion. For those attending LSIC Spring Meeting, we look forward to continuing conversations throughout the conference, including a breakout session reflecting on our recent Regolith to Rebar Workshop and identifying next steps.

Extreme Access

The April telecon for Extreme Access had two technology spotlights: Evan Anzalone (NASA) about the Lunar Node 1 navigation beacon system and Dr. Robert Tjoelker (JPL) about the Deep Space Atomic Clock. Please take a look at the Confluence recording if you missed it. The subgroups have also been busy compiling feedback from the past year's discussions. Each subgroup has submitted a short summary of identified gaps and needs to us as a culmination of our annual goal. Thank you to everyone who participated in discussions and to the feedback! We will be submitting the feedback to NASA, and will make it available on the Confluence page soon. This coming month is the LSIC Spring Meeting, which we hope you will attend. We're looking forward to productive discussions. And don't forget to Save the Date for the joint EE/EA workshop on June 7!

Extreme Environments

In April, Extreme Environments had a great follow up to our crosstalk that covered simulants presented by Karen Stockstill-Cahill and the LSIC Facilities Directory presented by Josh Cahill. Soon after the Spring Meeting, our subgroup leads will do an overview of what they have been working on for the past few months during our monthly meeting. EE and EA will host a joint workshop inJune titled "Designing for the Extremes". The workshop will consist of a plenary speaker and panel discussions in a webinar format (with interactive Q&A during the panels), followed by smaller-group discussions in breakout rooms with interactive brainstorming and note taking using Miro (or similar software). Please visit https://lsic.jhuapl.edu/Events/Agenda/index.php?id=232 for more details. As always, if community members have ideas for what they would like to see or discuss, please reach out to any member of EE leadership.

ISRU

The ISRU Focus Group held its April monthly meeting on the 20th, with presentations focused on the upcoming Lunar Surface Science Workshop topic "Lunar Resource Evaluation Campaign" by Clive Neal of Notre Dame, "Mapping and GIS Resources for the Moon" by Trent Hare of the USGS, and on "Value Networking Mapping" by Jodi Berdis and Kirby Runyon. The breakout sessions following the meeting focused on Interoperability & Modularity, O_2 and metal extraction, and Volatile prospecting of water ice in PSRs.

Surface Power

In April, the surface power focus group held a special planning session for a summer workshop on Low-Temperature Power and Energy Storage. The workshop is scheduled for July 27th and 28th, and interests spanned from batteries to grid-scale support during eclipse. The MOSA working group, now LSIC-wide, hosted its first telecon with Chad Thrasher, NASA's Artemis Campaign Development Division Systems Interoperability Lead, who presented on Artemis' Graphical User Interface (GUI) standards. The surface power monthly telecon featured Ansel Barchowsky from JPL, who discussed tethered power distribution. This month in addition to the LSIC Spring Meeting and the monthly telecon, we will refine our next annual goal, and confirm more details of the summer workshop.

Feature Article

2021 Lunar Simulant Assessment Report Overview

By Dr. Karen Stockstill-Cahill, APL Senior Staff and LSIC Lunar Simulants Lead

Introduction: A critical aspect of technology development and maturation for the Artemis missions is testing under relevant lunar surface conditions, including in the presence of and using lunar regolith simulants. Simulants are approximations of lunar regolith that do not reproduce all of the characteristics that the regolith exhibits in situ on the Moon. Simulants need to be verified and validated to ensure that the impact of the differences between the simulants and the lunar regolith is understood, and the impact on the testing of the lunar technologies can be evaluated. In 2020 and 2021, the APL LSII team evaluated commercially-available lunar simulants in terms of composition, particle size and shape, and availability and supply chain reliability.

Methods: The approach used by the JHU-APL LSII simulants team for the evaluation of lunar regolith simulants replicated processes used to study Apollo regolith samples. First, a portion of the samples were sieved into 6 particle size fractions (<45 μm, 45–75 μm, 75–125 μm, 125–250 μm, 250–500 μm, and >500 μm) and fractions were weighed to determine a rough particle size distribution (PSD) by weight. In addition, simulants were characterized for particle size and shape present in samples using the Camsizer X2, a microscope equipped with a high-speed camera that measures particle shape and size of grains entrained in a stream of air. This provided a high resolution (3 μm bins) PSD and particle shape information such as aspect ratio. These particle characteristics were compared to similar data collected for Apollo regolith samples.

Composition of the simulants were determined using several methods. We examined polished epoxy mounts of the 125-250 μm particle size fraction for each simulant using a Hitatchi TM 3000 tabletop Scanning Electron Microscope (SEM). Elemental maps were produced using the associated Bruker Q70+ silicon drift detector energy dispersive spectrometer (EDS) system. In addition, we examined bulk simulant powders using X-ray Fluorescence (XRF) to derive bulk elemental composition and X-ray Diffraction (XRD) to determine the number and rough abundances of crystalline mineral phases present in the sample. Additional details on the methodologies used are available within the assessment.

Results: The most recent assessment looked at eight commercially-available simulants from four companies. These included the LHS-1 (highland) and LMS-1 (mare) simulants produced by Exolith, the OPRH3N (farside highland) and OPRL2N (mare) simulants from Off Planet Research (OPR), LHT-1 (highland) and LMT-1 (mare) simulants from Colorado School of Mines (CSM), and LHA-1 (highland pseudo-agglutinate) and LMA-1 (mare pseudo-agglutinate) simulants from Outward Technologies (OT). The assessment provides a detailed description of each company, their product and feedstocks, and anticipated availability.

Particle shape and size: All highland and mare regolith simulants exhibit a PSD within one standard deviation of an average Apollo regolith, although simulants contain a greater abundance of larger grains, a lower abundance of the smallest grains, and have a steeper slope to their PSD curve (Fig. 1). Apollo regolith grains are relatively elongated (non-spherical), so they have low aspect ratios (AR < 1, aspect ratio of a sphere = 1). The aspect ratios of all lunar regolith simulant grains are more rounded (closer to 1) and display a more limited range of aspect ratios relative to Apollo regolith

samples (Table 1).

Composition: The bulk composition for lunar regolith simulants are plotted with lunar regolith of the same class in Figure 2. Although similar geochemistry does not necessarily imply similar mineralogy, it can be useful to understand inherent differences that could impact some testing. We see a fairly good match in bulk composition to lunar regolith, however there are some important differences to note. First, the Na2O content of all the simulants is much higher relative lunar regolith (Fig.2) due to the sodium-rich nature of terrestrial plagioclase. The simulants also contain more TiO2 and less MgO than measured in lunar regolith (Fig. 2), although mare simulants are designed to have intermediate TiO2. Mineralogy also displays differences, often due to the fact that providers use glassy mafic rocks to mimic the glass content and XRD cannot detect non-crystalline materials.

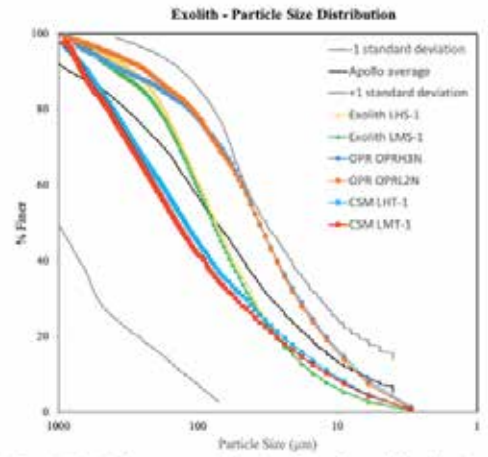

Fig. 1: PSD of lunar regolith simulants from [1] relative to an average Apollo regolith PSD.

Table 1: Aspect ratios for Apollo regolith and lunar regolith simulants.

Sample	Aspect ratio mode*	Aspect ratio median*
14163 Non-mare (1.2 – 30 µm)	0.6 – 0.7	
Exolith LHS-1 (0-900 µm)		0.740 ± 0.004
Off Planet OPRH3N (0-900 µm)		0.698 ± 0.004
CSM-LHT-1 (0-900 µm)		0.719 ± 0.003
12001 Mare (3.2-6.1 µm)	0.3 – 0.4	
15031 Mare (1.2 – 30 µm)	0.4 – 0.5	
15041 Mare (1.2 – 30 µm)	0.6 – 0.7	
15231 Mare (1.2 – 30 µm)	0.5 – 0.6	
Exolith LMS-1 (0-900 µm)		0.735 ± 0.006
Off Planet OPRL2N (0-900 µm)		0.720 ± 0.003
CSM-LMT-1 (0-900 µm)		0.724 ± 0.007

*Apollo data from Carrier et al. (1991). n.b., Liu et al. (2008) reported aspect radio modes of ~0.7 for Apollo soils 10084, 12001, 15041, 70051, and 79221. *Camsizer measurement.

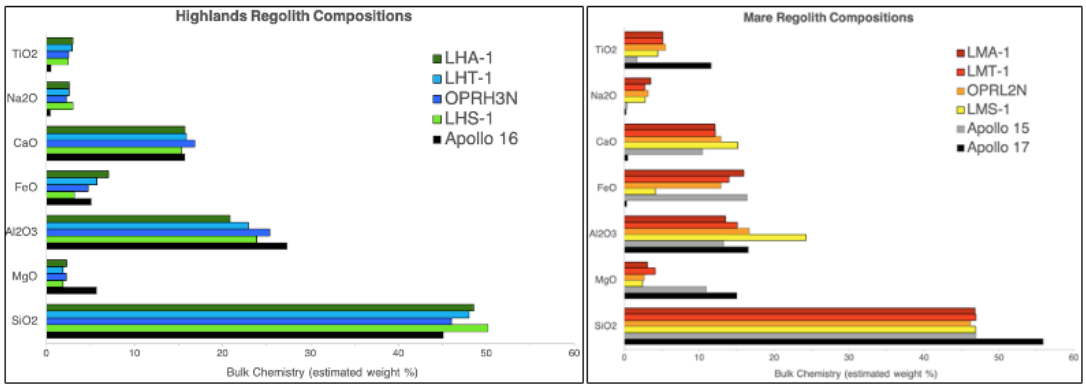

Fig. 2: Bulk compositions (XRF & SEM data) for lunar highland regolith and highland simulants (left) and lunar mare regolith and mare simulants (right).

The complete assessment results were published as an LSII document and made publicly available through the Lunar Surface Innovation Consortium (LSIC) website and confluence pages. The information gathered is also available through a portal located on the LSIC confluence site, which can be accessed by all LSIC members. The JHU-APL LSII simulants team also worked with the NASA LSII simulants team to establish a Lunar Surface Working Group (LSWG) with a presence on the LSIC confluence site to encourage communication within the lunar regolith simulants community. We encourage you to join this group!

Member Spotlight

Parsec, Lockheed Martin

Lindsay Papsidero is on a mission to get as many kids to Space Camp as possible, after her own experience that helped shape her into the aerospace engineer at Lockheed Martin that she is today. Throughout school she excelled in math, science, and art, and was always fascinated by space. By high school, she knew she wanted to be an engineer in the space industry. She went on to study aerospace engineering at Virginia Tech, and immediately after graduating started a rotation program with Lockheed Martin Space in Sunnyvale, CA – and she's been with the company ever since. The program had her move through four different positions in two years, and her favorite was getting to work on the actual build of the Advanced Extremely High Frequency (AEHF) System 4, a protected satcom spacecraft for the military that saw her working in an actual high bay.

Papsidero also spent time working with GEOshare, a wholly owned subsidiary of Lockheed Martin that offers global condosat services. She compared condosats and satellites to condos and houses. Maybe you don't need a whole house, and you'd like to share some of the HOA and maintenance fees – so instead of buying a house you invest in a condo. Condosats have individual payloads where investors get access to space and satellite services while sharing launch, construction, and other fees. Papsidero started at GEOshare as a systems engineer architect and worked her way to chief technology officer. She now brings that same entrepreneurial spirit to her work at Parsec, Lockheed Martin's lunar communications and navigations service, where she serves as program manager.

Lockheed Martin came into being in March of 1995 after the merger of the Lockheed Corporation with Martin Marietta. The aerospace, military support, security, and technology company currently employs about 115,000 people worldwide and is headquartered in Bethesda, Maryland. The four core business units that make up the wider organization are Aeronautics, Missiles and Fire Control (MFC), Rotary and Mission Systems (RMS), and Space. Lockheed Martin Space further divides into Military Space, which serves the Air Force and Space Force; Mission Solutions, which does 'ground work' such as development of smart cities concepts; and Commercial / Civil which covers exploration, science, and commerce. This is where work on the Orion spacecraft is conducted, along with the Human Landing System (HLS) and two upcoming NASA missions to Venus (DAVINCI and VERITAS).

Parsec also sits within Space's Commercial / Civil group, specifically in the Advanced Programs unit, which is all about being visionary, creative, and forward leaning. "I love thinking about what the Moon's going to look like in 2045," shared Papsidero, "and our team's culture is trying to approach things differently with Parsec." She explained that traditionally for space operations, one communications spacecraft would be procured for one mission. But Parsec is looking to offer communications to as many missions that want it. "It's a paradigm shift, a huge pivot in terms of how we all think about doing business in space," said Papsidero. "It's not just one contract with discreet requirements – we're going after the opportunity now and establishing the requirements afterwards." This is a huge pivot for Lockheed Martin, moving from a more traditional (and solidly rooted) position to accepting some ambiguity and risks to drive innovation in an emerging market.

Parsec's plan is to start with a single lunar orbiting spacecraft focused primarily on providing communications from the lunar surface, up to the relay orbiter, and then back down to Earth. Once the signal is back on Earth, it would be sent to the user's mission operations center. Currently the

focus is on far side and south polar landing sites, with plans to extend network coverage over time depending upon where market need is. The idea is to provide end-to-end service and build out infrastructure so that users on the lunar surface who require data relay or higher data rates can use Parsec's system and buy communications as a service rather than having to purchase their own dedicated relay spacecraft. The design of the relay orbiter itself is being developed from Lockheed Martin's existing deep space exploration smallsat work, which is already being used on other science missions for NASA.

Lockheed Martin has seen great value in LSIC from the very beginning, and even has a representative sitting on LSIC's Executive Committee. When asked about why involvement has been so important, Papsidero explained that Lockheed Martin is looking at lunar infrastructure as a whole, and that LSIC's focus areas touch on key things they're already working on themselves. "We don't want to work in a vacuum," she went on, "we want to know what the community wants to do from a mission standpoint." Right now, there are few hard requirements – needs have to be anticipated, and communication with the community looking to build the market on the lunar surface will be key for that. In particular, Papsidero called out the importance of interoperability and establishing standards for infrastructure development. LSIC's new working group dedicated to the Modular Open Systems Approach (MOSA) will be an important part of that conversation – you can find out more about their operations on their Confluence page here: https://lsic-wiki.jhuapl.edu/x/4YAxAg.

Lockheed Martin's Parsec services are an expression of their enthusiasm over this next level of development of the space industry. "I've heard people talk about sending things back to the Moon for decades now, and nothing had come of it," shared Papsidero, "but this time it feels different – it's exciting to see things actually happening." But that's not to say there aren't hurdles to overcome. She acknowledges that space is difficult, and space is expensive. "Space exploration and science have only ever been a government funded activity before. Trying to navigate these waters and understand what kind of blended approach is going to happen will be challenging," she explained. Trying to strike the balance of what must be done now to prepare for activities later will be difficult. "But that's why we do space, because it's hard," Papsidero echoed an American president. "And I don't think any of it is going to stop our momentum."

Find out more about Lockheed Martin's Parsec service here: https://www.lockheedmartin.com/en-us/news/features/2021/lunar-communication-and-navigation-network.html

NASA and Community News

NASA Chooses Small Businesses to Continue Exploration Tech Development

04/28/22 \\ NASA News

https://www.nasa.gov/press-release/nasa-chooses-small-businesses-to-continue-exploration-tech-development

Firefly Completes Integration Readiness Review of its Blue Ghost Lunar Lander

04/27/22 \\ Firefly

https://firefly.com/firefly-has-completed-the-integration-readiness-review-irr-of-blue-ghost-m1/

NASA space technology programs face "constraining" budget

04/23/22 \\ SpaceNews \\ Jeff Foust

https://spacenews.com/nasa-space-technology-programs-face-constraining-budget

NASA, Partners Develop 'Lunar Backpack' Technology to Aid New Moon Explorers

04/20/2022 \\ NASA News

https://www.nasa.gov/centers/marshall/news/releases/2022/nasa-partners-develop-lunar-backpack-technology-to-aid-new-moon-explorers.html

Astrobotic Unveils Peregrine Lunar Lander Flight Model

04/20/2022 \\ Astrobotic

https://mailchi.mp/astrobotic/peregrinelunarlanderunveiled

NASA's next moon rocket gets final repairs ahead of mission launch

04/18/2022 \\ CNN \\ Ashley Strickland

https://www.cnn.com/2022/04/18/world/nasa-artemis-i-rollback-scn/index.html

White House releases in-space servicing strategy

04/13/2022 \\ SpaceNews \\ Jeff Foust

https://spacenews.com/white-house-releases-in-space-servicing-strategy/

Companies build up teams to compete for Artemis lunar rover

04/11/2022 \\ SpaceNews \\ Jeff Foust

https://spacenews.com/companies-build-up-teams-to-compete-for-artemis-lunar-rover/

Funding Opportunities

Student Tech Development

- Over the Dusty Moon Challenge (Colorado School of Mines & Lockheed Martin)
  https://www.overthedustymoon.com/

  June 2022: In-person challenge

Tech Development

- NASA TechLeap Prize: Nighttime Precision Landing Challenge No. 1
  https://www.precisionlanding1.nasatechleap.org/

  Registration due: May 5, 2022 at 5 p.m. PDT; Applications due: May 19, 2022 at 5 p.m. PDT

- Technology Advancement Utilizing Suborbital and Orbital Flight Opportunities "TechFlights"
  https://sam.gov/opp/b428ab6bded1484bb12791197a48d83e/view

  Proposals Due 6/2/2022

- Watts on the Moon Challenge, Phase 2
  https://www.nasa.gov/directorates/spacetech/centennial_challenges/watts-on-the-moon/index.html

  Registration due: June 15, 2022 at 5 p.m. EDT

- Announcement for Partnership Proposals (AFPP) to Advance Tipping Point Technologies
  https://nspires.nasaprs.com/external/solicitations/summary.do?solId=%7b9987D88F-0A12-5203-FC25-423773FAF134%7d&path=&method=init

  Final proposals due: July 28, 2022

- Space Technology Announcement of Collaboration Opportunity (ACO)
  https://nspires.nasaprs.com/external/solicitations/summary.do?solId=%7bA9C79925-6F41-69E8-4BE0-5325903D777C%7d&path=&method=init

  Final proposals due: July 28, 2022

For more funding opportunities, please visit LSIC's website here: http://lsic.jhuapl.edu/Resources/Funding-Opportunities.php