Lunar Surface Innovation Consortium (LSIC)

Spring Meeting Program

May 11-12, 2021

Johns Hopkins
Applied Physics Laboratory

LSIC Summary

The purpose of the Lunar Surface Innovation Consortium (LSIC) is to harness the creativity, energy, and resources of the nation to help NASA keep the United States at the forefront of lunar exploration.

LSIC operates in collaboration with the NASA Space Technology Mission Directorate under the Lunar Surface Innovation Initiative. LSIC fosters communications and collaborations among academia, industry, and Government. Members have expertise in LSII key capability areas.

Please visit the APL LSIC website for further information: http://lsic.jhuapl.edu

Agenda
Day 1 – Tuesday, May 11, 2020 (All times EDT)

10:30 AM	**Coffee & Networking**	GatherTown (Poster Viewing, Vendor Booths)
11:00 AM	Welcome and Introduction	Rachel Klima LSIC Director, APL
11:05 AM	Keynote Address: Artemis Update	Bhavya Lal NASA Senior Advisor for Budget and Finance
11:25 AM	NASA Space Tech Update	Jim Reuter NASA Associate Administrator for Space Technology
11:50 AM	Systems Integration / APL LSII	Ben Bussey LSII Lead, APL Karen Stockstill-Cahill APL
12:05 PM	Executive Committee and LSIC Status	Rachel Klima LSIC Director, APL
12:30 PM	Exploration Science Strategy Update	Joel Kearns Deputy Associate Administrator for Exploration, NASA SMD
1:00 PM	**Lunch Break**	GatherTown (Networking, Vendor Booths)
1:45 PM	Focus Group Updates Moderated by Josh Cahill	
		Angela Stickle Extreme Access
		Jorge Nuñez Dust Mitigation
		Karl Hibbitts In Situ Resource Utilization
		Benjamin Greenhagen Extreme Environments
		Athonu Chatterjee Excavation and Construction
		Wesley Fuhrman Surface Power

Agenda
Day 1 – Tuesday, May 11, 2020 (All times EDT)

2:45 PM	Executive Committee Panel: Ensuring LSIC Serves the Community Moderated by Rachel Klima	
		Ariel Ekblaw Director of the Space Exploration Initiative, Massachusetts Institute of Technology
		Lindy Elkins-Tanton Vice President of the Interplanetary Initiative, Arizona State University
		David Murrow Senior Manager of Deep Space Exploration Strategy, Lockheed Martin's Corporation
		Jose Hurtado Technology Chair, Lunar Exploration Analysis Group, The University of Texas at El Paso
		Jake Bleacher Chief Exploration Scientist, NASA Human Exploration and Operations Mission Directorate
3:45 PM	**Break**	
4:00 PM	Panel Discussion: Space Tech Opportunities Moderated by Brenda Clyde	
		Gareth Meirion-Griffith Lead, NASA Lunar Surface Technology Research Opportunity
		LK Kubendran Lead, NASA Commercial Space Technology Partnerships
		Jason Derleth Program Executive, NASA Innovative Advance Concepts
		Amy Kaminski Program Executive, NASA Prizes and Challenges
		Jason Kessler Program Executive, NASA Small Business Innovation Research
5:00 PM	**Adjourn**	

Agenda
Day 2 – Wednesday, May 12, 2021 (All times EDT)

10:30 AM	**Coffee & Networking**	GatherTown (Poster Viewing, Vendor Booths)
11:00 AM	Welcome and Plan for the Day	Rachel Klima LSIC Director, APL
11:05 AM	Panel Discussion: How Technology Enables Lunar Science, Exploration, and Commerce Moderated by Ben Bussey	
		Bill Carter Program Manager, NOM4D Program, Defense Sciences Office, DARPA
		Niki Werkheiser Program Director, Technology Maturation, LSII Lead, NASA STMD
		Raymond Clinton Principal Investigator, Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) Project, NASA
		Sandy Magnus Principal, AstroPlanetview LLC
		Mark Hilburger Principal Technologist for Structures, Materials, and Nanotechnology, NASA STMD
12:00 PM	Community Lightning Talks	
1:00 PM	**Lunch Break**	GatherTown (Poster Session)
2:00 PM	Panel Discussion: NASA Awardees & Partnerships Moderated by Dana Hurley	
		Christy Edwards Lockheed Martin – Vertical Solar Array Tower (VSAT)
		Alian Wang Washington University – Lunar Surface Technology and Research (LuSTR)
		Ahsan Choudhuri Associate Vice President for Aerospace Center, University of Texas at El Paso
		Mihaly Horanyi University of Colorado Boulder – Early Stage Innovations (ESI)
		Luis Maestro Nokia of America – Tipping Point
		Paul van Susante Michigan Technological University – BIG Idea Challenge
		Alex McCarthy Chief Technology Officer, AI Space Factory
3:00 PM	**Break**	

AGENDA DAY 2

Agenda
Day 2 – Wednesday, May 12, 2021 (All times EDT)

3:15 PM	Transition to Breakout Session	Rachel Klima LSIC Director, APL
3:20 PM	Breakout Sessions	
4:30 PM	Presentation of Findings from Breakout Sessions	Rachel Klima LSIC Director, APL
5:00 PM	**Adjourn**	

Breakout Topics

Focus Group Goals and Cross-Group Integration – Although monthly discussions with LSIC center around specific focus groups, there are critical areas of overlap and feedback among them. This breakout offers an opportunity for community members to provide additional input on the focus group goals presented as well as on the focus groups in general. Important questions include identifying any critical technology issues that could be falling in the cracks between focus groups, and how to address them. Another topic for discussion is how to continue to improve on how we share the focus group work in a way that interested participants can stay up-to-date with multiple groups.

Standardization – At the fall meeting, a topic that came up in many discussion groups was the concern of standardization as we build towards a sustained presence on the Moon. The objective of this session is to discuss in more detail what we mean by standards, and what areas are of the highest immediate concern for standardization. While LSIC is not tasked with setting standards, we would like to coordinate with other groups to enable this discussion and to understand where clear standards would facilitate technology development.

Technology Readiness and Demonstrations – The objective of this session would be to dig more into what is needed for development of lunar-rated components. What level (if any) of flight demonstration is needed for critical technologies? Can we provide a recommended hierarchy of what can be tested on Earth, what needs lunar G, and what needs an actual in situ demonstration to economically advance the technology? Should LSIC develop a unified plan for which elements the community highly recommends should be included on CLPS flights?

Consortium Growth/ Community Building/Mentoring Portal – This session will discuss goals related to consortium community building and the development of tools and strategies to enable networking and mentoring within the community. Discussions will consider feedback from the mentoring survey and include brainstorming requirements/desires for the LSIC mentoring portal and a future funding workshop. Other topics include identifying key areas of growth for LSIC, including areas of experience that are missing from regular discussions and how to attract new industry and academic institutions in different demographic and geographic areas.

Centennial Challenges: Watts on the Moon Phase 2 – One goal of LSIC is provide an opportunity for the community to give direct feedback on upcoming solicitations. This discussion section provides an opportunity for those who would like to propose to the second phase of the Watts on the Moon Centennial Challenge to speak directly to the NASA Challenge leaders. This session will provide an opportunity for those in the community to speak directly with NASA about various aspects of the solicitation so that it may be incorporated. Note that proposers to Phase 2 of this challenge do not have to have been selected for Phase 1 funding.

Speakers

Bhavya Lal

Senior Advisor for Budget and Finance, NASA

Bhavya Lal is currently the senior advisor for budget and finance to the Administrator of NASA, and was the seniormost White House appointee and Acting Chief of Staff at NASA for the first 100 days of the Biden Administration, where she oversaw the agency's transition under the administration of President Joe Biden. Before that, she had served as a member of the Biden Presidential Transition Agency Review Teams for both NASA and the Department of Defense.

Lal brings extensive experience in engineering and space technology, serving as a member of the research staff at the Institute for Defense Analyses (IDA) Science and Technology Policy Institute (STPI) from 2005 to 2020. There, she led analysis of space technology, strategy, and policy for the White House Office of Science and Technology Policy (OSTP) and National Space Council, as well as federal space-oriented organizations, including NASA, the Department of Defense, and the intelligence community. She has applied her expertise in engineering systems and innovation theory and practice to topics in space, with recent projects on commercial activities in low-Earth orbit and deep space, in-orbit servicing assembly and manufacturing, small satellites, human exploration, space nuclear power, space exploration, and space science. She has published more than 50 papers in peer-reviewed journals and conference proceedings.

Before joining STPI, Lal served as president of C-STPS LLC, a science and technology policy research and consulting firm in Waltham, Massachusetts. Prior to that, she served as director of the Center for Science and Technology Policy Studies at Abt Associates Inc. in Cambridge, Massachusetts.

Lal is an active member of the space technology and policy community, having chaired, co-chaired, or served on five high-impact National Academy of Science (NAS) committees. She served two consecutive terms on the National Oceanic and Atmospheric Administration (NOAA) Federal Advisory Committee on Commercial Remote Sensing (ACCRES) and was an External Council member of NASA's Innovative Advanced Concepts (NIAC) Program and the Technology, Innovation and Engineering Advisory Committee of the NASA Advisory Council (NAC).

Lal also has served on five National Academy of Sciences, Engineering, and Medicine (NASEM) Committees including, most recently, one on Space Nuclear Propulsion Technologies that was released in 2021.

She co-founded and is co-chair of the policy track of the American Nuclear Society's annual conference on Nuclear and Emerging Technologies in Space (NETS) and co-organizes a seminar series on space history and policy with the Smithsonian National Air and Space Museum. For her many contributions to the space sector, she was nominated and selected to be a Corresponding Member of the International Academy of Astronautics.

Lal earned Bachelor of Science and Master of Science degrees in nuclear engineering, as well as a Master of Science degree in technology and policy, from the Massachusetts Institute of Technology, and holds a doctorate in public policy and public administration from George Washington University. She is a member of both the nuclear engineering and public policy honor societies.

Speakers

James Reuter

Associate Administrator for Space Technology, NASA

James L. Reuter was named NASA's associate administrator for the Space Technology Mission Directorate (STMD) at NASA Headquarters in June 2019, a position in which he served in an acting capacity since February 2017. In this role, he provides executive leadership and management of the technology programs within STMD, with an annual investment value of $1.1 billion.

Reuter was the deputy associate administrator of STMD from February 2017-February 2018. Prior to this role, Reuter served as the senior executive for technical integration in the Center Director's Office at NASA's Marshall Space Flight Center from 2009-2015, providing strategic leadership on critical technology and integration activities. Additionally, Reuter served as the Exploration Systems Division (ESD) Standing Review Board chair, responsible for overseeing development activities of the Space Launch System, Orion Multi-Purpose Crew Vehicle, Ground Systems Development and Operations Programs, and the ESD integration activities.

Previously, Reuter served in many managerial roles at Marshall including Ares vehicle integration manager in the Constellation program, the deputy manager of Space Shuttle Propulsion Office, and the deputy manager of Space Shuttle External Tank Project Office during the shuttle return-to-flight activities. In 2002, he was assigned to a detail at NASA Headquarters as the deputy associate director in the Space Transportation Technology Division in the Office of Aerospace Technology. From 1994 to 2001, he was the Environmental Control and Life Support System manager for the International Space Station at NASA's Johnson Space Center. Reuter began his NASA career in 1983 as an aerospace engineer in the Structures and Propulsion Laboratory in Marshall's Science and Engineering Directorate.

Reuter has a bachelor's degree in mechanical engineering from the University of Minnesota in Minneapolis. He has received numerous NASA awards and honors, including a 2019 Distinguished Service Medal, 2016 Outstanding Leadership Medal, 2013 NASA Exceptional Achievement Medal, a 2008 NASA Outstanding Leadership Medal, a 2002 NASA Exceptional Service Medal, a 1998 Silver Snoopy Award and a 1993 Space Station Award of Merit.

Niki Werkheiser

Program Director, Technology Maturation, LSII Lead, NASA STMD

Niki Werkheiser is the NASA Headquarters Executive for the Game Changing Development (GCD) Program within the Space Technology Mission Directorate (STMD). GCD advances technologies for future space missions. Concurrently, she serves as the Lead for the Agency's Lunar Surface Innovation Initiative (LSII), with the objective of spurring the creation of novel technologies needed for lunar surface exploration. Prior to her current roles, Ms. Werkheiser led the Agency's In-Space Manufacturing (ISM) efforts, including the development and implementation of on-demand manufacturing and repair capabilities. She brings a wealth of expertise and a proven approach to managing complex programs. Ms. Werkheiser is particularly passionate about creating competitive programs and public-private partnerships across government, industry, academia, and non-profit organizations. Ms. Werkheiser earned a M.S. from the University of Alabama in Huntsville with an emphasis in Gravitational and Space Biology, as well as a B.S. in Biology and a B.A. in Russian Studies.

Speakers

Joel Kearns

Deputy Associate Administrator for Exploration,
NASA Science Mission Directorate

Dr. Joel Kearns is the Deputy Associate Administrator for Exploration in the Science Mission Directorate at NASA Headquarters. Dr. Kearns manages the Lunar Discovery and Exploration Program (LDEP) and the Commercial Lunar Payload Services (CLPS) initiatives.

Prior to his appointment as the Deputy Associate Administrator for Exploration, Dr. Kearns served as the director of Facilities, Test and Manufacturing at NASA's Glenn Research Center (GRC) in Cleveland, where he led efforts encompassing facilities infrastructure, aerospace testing, flight research aircraft, and on-site manufacturing and environmental management.

Dr. Kearns also served as the deputy director of GRC's Space Flight Systems Directorate, providing executive direction of projects assigned to Glenn in human exploration and operations, space science and space technology. He has also previously worked at NASA Headquarters in human spaceflight, and at both the Ames Research Center in California and Marshall Space Flight Center in Alabama, where he worked on programs as varied as microgravity research, the space shuttle and SOFIA. He has also held positions in industry.

Joel received his B.S. and M.S. in Mechanical Engineering, and Ph.D. in Materials Science and Engineering, from Worcester Polytechnic Institute. As an associate fellow of the American Institute for Aeronautics and Astronautics, Joel was awarded the U.S. Government's Presidential Rank of Meritorious Senior Executive in 2009. He is also an inventor on four patents for single crystal growth technology.

Speakers

Ben Bussey

Lunar Surface Innovation Initiative Lead,
Johns Hopkins Applied Physics Laboratory

Dr. Bussey is a planetary scientist who is currently the lead of the APL team supporting NASA's Space Tech's Lunar Surface Innovation Initiative. He earned a BA in Physics from Oxford University and a Ph.D. in Planetary Geology at University College London before moving to the United States. He gained both science and mission experience while working at the Lunar and Planetary Institute in Houston, the European Space Agency, Northwestern University and the University of Hawaii, before joining the Johns Hopkins University Applied Physics Laboratory.

Bussey's research concentrates on the remote sensing of the surfaces of planets, particularly the Moon. He has a specific interest in the lunar poles, producing the first quantitative illumination maps of the polar regions. He co-authored the Clementine Atlas of the Moon, the first atlas to map both the lunar near side and far side in a systematic manner.

Dr. Bussey recently completed a 5-year assignment at NASA HQ which included being the Acting Deputy Associate Administrator of Exploration in NASA's Science Mission Directorate. Before that he was the Chief Exploration Scientist in NASA's Human Exploration and Operations Mission Directorate. Prior to his positions at NASA headquarters he was Principal Investigator of the NASA VORTICES SSERVI team and before that of a NASA Lunar Science Institute team that considered the exploration and scientific potential of the lunar poles. He was the Principal Investigator of the Mini-RF radar instrument on NASA's Lunar Reconnaissance Orbiter, and Deputy Principal Investigator of the Mini-RF radar instrument on India's Chandrayaan-1 mission. These instruments acquired the first radar data of the lunar poles and farside.

He enjoys planetary analog field work and has been fortunate to have twice been part of the Antarctic Search for Meteorites expedition to recover meteorites from the Antarctic glaciers.

Rachel Klima

Lunar Surface Innovation Consortium Director,
Johns Hopkins Applied Physics Laboratory

Dr. Rachel Klima is the Director of the Lunar Surface Innovation Consortium and a senior staff scientist in the Planetary Exploration Group at the Johns Hopkins Applied Physics Laboratory. Dr. Klima's research focuses on integrating laboratory analysis of lunar, meteoritic, synthetic, and terrestrial rocks and minerals with near through mid-infrared spectral measurements of solid bodies in the solar system to understand such topics as the thermal/magmatic evolution of the Moon, distribution of minerals, water, and hydroxyl on the lunar surface, and the composition of Mercury's crust. Dr. Klima has been involved with numerous missions to bodies throughout the solar system, including the Dawn Mission, the Moon Mineralogy Mapper, a hyperspectral imaging spectrometer flown on Chandrayaan-1, MESSENGER, and Europa Clipper. She previously served as the Deputy PI of the Volatiles, Regolith and Thermal Investigations Consortium for Exploration and Science (VORTICES) team for the NASA Solar System Exploration Research Virtual Institute (SSERVI). She currently serves as the Deputy PI of the Lunar Trailblazer Mission and is a participating scientist on the Korea Pathfinder Lunar Orbiter.

Speakers

Jake Bleacher

Chief Exploration Scientist, NASA Human Exploration and Operations Mission Directorate

Dr. Bleacher is a planetary geologist who is currently serving as NASA's Chief Exploration Scientist for the Human Exploration and Operations Mission Directorate (HEOMD) at NASA headquarters. In this role he is a science advocate for NASA technology and architecture development that is intended to enable human exploration of the Moon, deep space and beyond. He also serves as a primary contact with NASA's Science Mission Directorate (SMD) and the science community external to NASA. Dr. Bleacher's research focuses on understanding the volcanic history of the Earth, Moon and Mars by remote sensing mapping and field work. Upon joining the NASA workforce he began supporting the Constellation Program Office to conduct studies examining potential landing sites and developing science traverse plans to help define requirements for hardware on the lunar surface. Dr. Bleacher served as a science team member and test subject as a crew member for NASA's Desert Research and Technology Studies (Desert RATS), which focused on field tests of operations associated with prototype human rovers for the Moon. He has served as the lead for the Goddard Instrument Field team, in which he organized GSFC's planetary science field research deployments as well as GSFC's Lead Exploration Scientist, for which he worked to create cross-Center awareness of ongoing human exploration projects. Dr. Bleacher is a co-author on a number of peer reviewed science publications including a cover article for the journal Nature focused on explosive volcanism on Mars as well as the chapter on Mars Volcanism in the Encyclopedia of Volcanoes, 2nd edition. He has served on a series of Special Action Teams (SATs) for the Lunar Exploration Analysis Group (LEAG) and Mars Exploration Program Analysis Group (MEPAG) including the Lunar Sample Acquisition and Curation Review, Candidate Scientific Objectives for the Human Exploration of Mars, and Geological Astronaut Training and has served on NASA's In Situ Resource Utilization (ISRU) Systems Capability Leadership Team. He applies a strong interest in both scientific research and human exploration to his current role at NASA headquarters.

Speakers

Joshua Cahill

Lunar Surface Innovation Consortium Deputy Director,
Johns Hopkins Applied Physics Laboratory

Dr. Joshua Cahill is the Deputy Director of the Lunar Surface Innovation Consortium (LSIC) and a Senior Staff Scientist in the Planetary Exploration Group at the Johns Hopkins Applied Physics Laboratory. He is a multi-disciplinary planetary geologist with experience in the fields of lunar and terrestrial spectroscopy and radar remote sensing, geochemistry, and petrology. He is a Co-Investigator on NASA's Lunar Reconnaissance Orbiter (LRO) mission supporting both the Mini-RF synthetic aperture radar and the Lyman Alpha Mapping Project (LAMP) instrument payloads. For these instruments, he has supported various aspects of lunar surface observation targeting, calibration, mapping, and scientific analysis over the last 10 years. This includes utilizing Mini-RF observations to create some of the first global mapping perspectives of the Moon in S-band radar. His LRO research focuses upon characterization of the lunar surface and subsurface physical and thermophysical properties, composition, volatiles, and how space weathering influences those interpretations. Cahill's studies tend to gravitate towards unusual lunar localities some of which may provide interesting challenges or resources for exploration (e.g., lunar swirls, thermophysical anomalies, photometric anomalies, anhydrous localities, and hydrous signatures in non-polar terrains). Cahill also has an interest in monitoring of the Moon's impact flash and flux, to provide a more accurate accounting of the short and longer term hazards to lunar surface activities, equipment, and personnel during Artemis. He recently co-authored a Planetary Decadal white paper on the topic.

Previously, Dr. Cahill served as a Co-Investigator supporting the NASA Solar System Exploration Research Virtual Institute (SSERVI) node, VORTICES, led by APL and studying volatile detection and processes on the Moon and other airless bodies. And during the precursor to SSERVI, NASA's Lunar Science Institute (NLSI), he supported investigation of lunar polar and non-polar illumination studies of the Moon for detection of areas permanent shadow and near perpetual illumination.

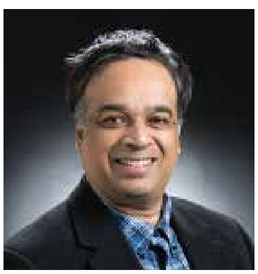
Dr. Cahill has participated in, or led, a number of instrument developments focused upon spectroscopy and radar over the last 15 years. Most recently, responding to NASA's PRISM call to explore the floor of Schrödinger Impact Basin, he acted as Principal Investigator for a highly capable team that developed the Farside GLASS mission concept. Farside GLASS would be NASA's first domestically led lander and rover mission to explore the far side of the Moon.

Speakers

William Carter

Program Manager, NOM4D Program,
Defense Sciences Office, DARPA

Dr. William Carter is a program manager in the Defense Sciences Office. He was formerly the director of the Materials and Microsystems Laboratory at HRL Laboratories. He received his doctorate in applied physics from Harvard University in 1997 and has more than 15 years of experience managing government and industrial materials research programs. His background spans applied physics, materials science, and mechanics. He is author or co-author of over 40 refereed publications and 100 issued patents covering new materials and devices for automotive and aerospace applications. As director of the Materials and Microsystems Laboratory at HRL, he focused on new materials for 3-D printing (including high-strength metals and ceramics), nonlinear mechanical systems for platform stabilization, scalable approaches to high performance anti-fouling and nanomaterial coatings, and MEMS devices for position, navigation and timing. At DARPA Bill manages multiple programs related to materials for extreme environments, particularly hypersonic vehicles, propulsion, decontamination and energy systems. Bill is the program manager for the NOM4D program (pronounced "nomad") which stands for "Novel Orbital and Moon Manufacturing, Materials and Mass-efficient Design.



Athonu Chatterjee

LSIC Excavation & Construction Facilitator

Dr. Athonu Chatterjee is a researcher in the space exploration sector of APL. His background is in mechanical engineering, materials processing, and modeling and simulation. His present activities at APL include laser-material interaction, spacecraft design,and lunar exploration. Prior to joining APL, he worked at the research centers of General Electric (GE) and Corning. There he worked on new product and process development for diverse applications such as high-temperature ceramics matric composites (CMC) for aircraft engines, turbine blade manufacturing processes, solid-oxide fuel cells (SOFC), micro-reactors, etc. He obtained his Ph.D. in mechanical engineering from Stony Brook University, NY.

Speakers

Ahsan Choudhuri

Associate Vice President for Aerospace Center, University of Texas at El Paso

Advanced Thermal Mining Approach for Extraction, Transportation, and Condensation of Lunar Ice

Dr. Ahsan Choudhuri is Associate Vice President for Aerospace Center and Professor of Mechanical Engineering at the University of Texas at El Paso (UTEP). He is the founding Director of UTEP NASA MIRO Center for Space Exploration and Technology Research (cSETR) and holds the endowed Mr. and Mrs. MacIntosh Murchison Chair II in Engineering. Dr. Ahsan Choudhuri's academic career has evolved within the paradigm of UTEP's access and excellence mission. He is a part of UTEP's strategic vision to create abundant educational opportunities to ensure social mobility for the residents of the Paso Del Norte region.

Dr. Ahsan Choudhuri is an internationally renowned expert in aerospace and defense systems. He is the founding director of UTEP NASA supported Center for Space Exploration and Technology Research (cSETR). Dr. Choudhuri led the growth of UTEP's aerospace and defense and energy education and research program from infancy to a nationally recognized program. He has formed strategic collaborations and partnerships with NASA, DOE, DOD, and aerospace and defense industries. Dr. Choudhuri is a key institutional leader for developing and managing the partnership with Lockheed Martin and NASA. Dr. Choudhuri is a member of the Executive Committee of the Lunar Surface Innovation Consortium (LSIC), which supports NASA's Space Technology Mission Directorate.

Dr. Choudhuri is a proud alumnus of Khulna University of Engineering and Technology, where he received his B.S. in Mechanical Engineering. He received his M.S. and Ph.D. from the University of Oklahoma School of Aerospace and Mechanical Engineering.

Raymond Clinton

Principal Investigator, Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) Project, NASA

Dr. Raymond G. "Corky" Clinton Jr. is Associate Director of the Science & Technology Office at NASA's Marshall Space Flight Center (MSFC) in Huntsville, AL. He joined MSFC in 1984 as an aerospace materials engineer in the Materials and Processes Laboratory. He served in a variety of leadership positions in the Engineering and Science Directorates, and Safety & Mission Assurance Directorate. He has long championed the development of in space manufacturing and construction technologies, beginning with MSFC's first 3D printing microgravity experiment test flight in 1999. In 2004, Dr. Clinton led the formation of the In Situ Fabrication and Repair Program, which included foundational elements of the current In Space Manufacturing portfolio and a structural habitat element for additive construction for lunar habitats. This technology was further developed in 2015-2018, through the ACME project. He currently serves as the Principal Investigator for the Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project. Dr. Clinton earned his bachelors, masters and doctoral degrees from the Georgia Institute of Technology. He is the recipient of numerous NASA and industry awards, including AIAA Fellow, Presidential Rank Award for Meritorious Executives, and NASA's Distinguished Service Medal.

Speakers

Brenda Clyde

Program Manager, Lunar Surface Innovation Initiative
Johns Hopkins Applied Physics Laboratory

Ms. Clyde is a systems engineer who is currently the program manager of the APL team supporting NASA's Space Tech's Lunar Surface Innovation Initiative. She earned a BS in Computer Science from University of Mary Washington and a MS. in Computer Science from Johns Hopkins University. She is a member of the Principal Professional Staff at the Johns Hopkins University Applied Physics Lab.

Ms. Clyde has been involved with requirements development, verification and validation, software development and testing for a number of JHU/APL spacecraft including MESSENGER, New Horizons, BOPPS, and Parker Solar Probe.

She recently completed an assignment as Program Manager and Systems Engineer in National Security Space performing Model Based Systems Engineering and architecture definition for the US Space Force.

She enjoys designing, building, and programming hobby robots.

Jason Derleth

Program Executive, NASA Innovative Advance Concepts

Mr. Jason Derleth is an aerospace engineer and technology analyst with experience at NASA Headquarters, the Jet Propulsion Lab, and private industry. He is also an author and craftsman. Jason graduated from St. John's College with a BA in Philosophy in 2000, where he won the Baird Prize for Excellence in the Arts or Sciences for a hand-built cello. He followed this SM in Aero Astro engineering from MIT in 2003. He began working at the Jet Propulsion Laboratory a month after graduation. In 2005, he was awarded the NASA Exceptional Public Service Medal for his work in the Exploration Systems Architecture Study. He transferred to the NASA Civil Service in 2008, joined NIAC as Program Manager in 2011, and became Program Executive in 2015.

Speakers

Christine Edwards

Deputy Exploration Architect, Lockheed Martin

Lockheed Martin's Lunar Demonstration Projects

Dr. Christine Edwards is the Deputy Exploration Architect at Lockheed Martin Space. She specializes in enabling greater autonomy for future space exploration missions through advances in AI and human-machine teaming. Previous positions include serving as Principal Investigator for weather and remote sensing research and development, lead systems engineer and associate manager for Mars Reconnaissance Orbiter (MRO) operations, guidance navigation and control (GN&C) operations for the GRAIL, Mars Odyssey, and Stardust missions, launch support for Juno, and autonomous rendezvous, proximity operations, and docking (ARPOD) development for the Orion. She holds a PhD in systems engineering from Stevens Institute of Technology, Bachelor and Master of Science degrees in aerospace engineering from MIT, is a Research Associate at the Denver Museum of Nature and Science, and was recognized by Aviation Week & Space Technology in their 40 under 40 in Aerospace and Defense.

Ariel Ekblaw

Founder and Director of the Space Exploration Initiative, Massachusetts Institute of Technology

Ariel Ekblaw is the founder and Director of the MIT Space Exploration Initiative, a team of over 50 graduate students, staff, and faculty actively prototyping the artifacts of our sci-fi space future. Founded in 2016, the Initiative now includes a portfolio of 40+ research projects focused on life in space (from astrobiology to space habitats), and supports an accelerator-like R&D program that enables a broad range of payload development. For the Initiative, Ariel drives space-related research across science, engineering, art, and design, and charters an annually recurring cadence of parabolic flights, sub-orbital, and orbital launch opportunities. Ariel forges collaborations on this work with MIT departments and space industry partners, while mentoring Initiative research projects and providing technical advice for all mission deployments.

In addition to the broader Initiative portfolio, her personal research builds on her MIT PhD in space architecture and the TESSERAE platform: Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments. This work explores autonomously self-assembling space architecture for future space tourist habitats and space stations in orbit around the Earth, Moon, and Mars.

Ariel brings a humanist approach to her research at MIT, with undergraduate degrees in Physics, and Mathematics and Philosophy from Yale University, and a master's in distributed systems from the MIT Media Lab. Ariel's prior work experience includes supersymmetry research and big data programming at the CERN Particle Physics Laboratory, microgravity research with NASA, and Mars2020 rover hardware systems engineering at NASA's Jet Propulsion Laboratory. Ariel's work has been featured in WIRED (March 2020 cover story), MIT Technology Review, Harvard Business Review, the Wall Street Journal, the BBC, CNN, NPR, IEEE and AIAA proceedings, and more. Humanity stands on the cusp of interplanetary civilization and space is our next, grand frontier. This opportunity to design our interplanetary lives beckons to us—Ariel strives to bring our space exploration future to life.

Speakers

Lindy Elkins-Tanton

Managing Director of the Interplanetary Initiative,
Arizona State University

Lindy Elkins-Tanton is the Principal Investigator of the NASA Psyche mission, Managing Director of the Interplanetary Initiative at Arizona State University, and co-founder of Beagle Learning, a tech company training and measuring collaborative problem-solving and critical thinking. Her research and efforts are focused on a positive human space exploration future, the effective leadership of teams, and education for the future of society. She has led four field expeditions in Siberia. She served on the Planetary Decadal Survey Mars panel, and the Mars 2020 Rover Science Definition Team, and now serves on the Europa Clipper Standing Review Board. In 2010 she was awarded the Explorers Club Lowell Thomas prize. Asteroid (8252) Elkins-Tanton is named for her. In 2013 she was named the Astor Fellow at Oxford University. She is a fellow of the American Geophysical Union, and of the American Mineralogical Society, and in 2018 she was elected to the American Academy of Arts & Sciences. In January 2020, she was awarded The Arthur L. Day Prize and Lectureship, by the National Academy of Sciences, for her lasting contributions to the study of the physics of Earth, and for illuminating the early evolution of rocky planets and planetesimals. In 2021, she was elected to the National Academy of Sciences. Elkins-Tanton received her B.S., M.S., and Ph.D. from MIT. Together we are working toward a positive space exploration future, and toward creating a generation of problem-solvers.

Wes Fuhrman

LSIC Power Facilitator

Dr. Wesley Fuhrman is a condensed matter physicist passionate about the interface between public and private science, with active research in remote sensing and advanced materials. Wesley earned his PhD from The Johns Hopkins University in spectroscopy of correlated topological materials, involving techniques such as elastic and inelastic neutron scattering, neutron spin echo, prompt-gamma activation analysis, X-ray absorption spectroscopy, X-ray magnetic circular dichroism, etc. Following this, he was an inaugural Schmidt Science Fellow, a program in partnership with the Rhodes Trust which builds interdisciplinary skills that cross boundaries between academia, industry, and government. Materials expertise spans solid-state synthesis (including uranium compounds), characterization, spectroscopy, and theory of strongly correlated and topological materials.

Benjamin Greenhagen

LSIC Extreme Environments Facilitator

Dr. Benjamin Greenhagen is a planetary scientist at Johns Hopkins Applied Physics Laboratory. He is an expert in thermal infrared emission from planetary bodies and leads related instrument development and research investigations, including managing the Simulated Airless Body Emission Laboratory (SABEL) at APL. He also participates in a wide range of active missions and projects. Prior to joining APL, he worked at JPL / Caltech. He obtained his Ph.D. in Geology (Planetology) from University of California, Los Angeles. He engages in the community and encourages professional and personal development at all career stages.

Speakers

Karl Hibbitts

LSIC ISRU Facilitator

As a planetary scientist, Dr. Karl Hibbitts conducts research to understand the compositions of the surfaces of airless bodies in our Solar System, including how otherwise volatile materials like water can exist on the illuminated Moon. He is deputy-PI of the Europa Clipper MISE infrared mapping spectrometer and was deputy-PI and mid-IR camera lead on the NASA BRRISON and BOPPS stratospheric balloon missions that demonstrated the scientific and cost effectiveness of spectral imaging of solar system objects from NASA balloon platforms in the upper stratosphere. Dr. Hibbitts also leads an active planetary laboratory spectroscopy effort in a facility he developed at APL that couples VUV –LWIR spectral capabilities with a UHV system capable of mimicking the vacuum, temperature, and radiation environments of the Moon and other airless bodies in our solar system.

Mark Hilburger

Principal Technologist for Structures, Materials, and Nanotechnology, NASA

Dr. Mark W. Hilburger is a Senior Research Engineer in the Space Technology Exploration Directorate at NASA Langley Research Center in Hampton VA. He was appointed Space Technology Mission Directorate (STMD) Principal Technologist (PT) for Structures, Materials, and Nanotechnology at NASA in 2019. His roles and responsibilities include developing technology investment plans across his assigned areas in coordination with NASA Exploration Programs and Mission Directorates. Identify technology needs that will enable science and exploration missions. Lead focused technology studies and coordinate with Agency Capability Managers in technology development activities to maintain and advance capabilities. Previous to his STMD PT appointment, he was the Principal Investigator and Manager of the NASA Engineering and Safety Center's Shell Buckling Knockdown Factor Project from 2007 to 2018. The goal of the project was to develop and validate new design, analysis, and testing methods for buckling-critical launch vehicle structures. His responsibilities included defining and managing the integration of analysis, design, manufacturing and test teams to develop an efficient, multi-disciplinary approach to optimal structural design, verification, and validation. His staff included experts across three NASA centers, industry, and academia. He also coordinated Space Act Agreements with Boeing, Northrop-Grumman, the German Research Laboratory (DLR) and the European Space Agency (ESA). Dr. Hilburger specializes in High-Fidelity Analysis and Design Technology Development and Experimental Methods for Aerospace Structures. He has been presented with numerous awards and including the 2018 Middle Career Stellar Award presented by The Rotary National Award for Space Achievement; the NASA Exceptional Engineering Achievement Medal, 2010; the NASA Engineering and Safety Center Engineering Excellence Award, 2009; selected as of the nation's top 100 young engineers and scientist by the National Academy of Engineering, 2009; and the NASA Silver Snoopy Award, (Astronauts' Personal Achievement Award), 2006. He received his Ph.D. and M.S.E. in Aerospace Engineering from the University of Michigan in Ann Arbor, MI in 1998 and 1995, respectively, and his B.S. in Mechanical Engineering from Rutgers University in New Brunswick, NJ in 1993.

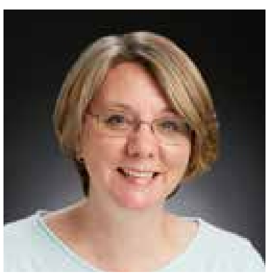
Speakers

Mihaly Horanyi

Professor, LASP and Department of Physics,
University of Colorado Boulder

Modeling Lunar Dust Behavior to Advance the Effectiveness of Dust Mitigation Techniques

Mihaly Horanyi received an M.S. degree in Nuclear Physics, and a Ph.D. in Space Physics at the Lorand Eotvos University, in Budapest, Hungary. He joined the Laboratory for Atmospheric and Space Physics (LASP) in 1992 and the Physics Department in 1999 at the University of Colorado Boulder. His research interests include theoretical and experimental investigations of space and laboratory dusty plasmas. He served as a co-investigator for the dust instruments onboard the Ulysses, Galileo, and Cassini missions. And as a principal investigator for the dust instruments built by LASP: The Student Dust Counter (SDC) onboard New Horizons, the Cosmic Dust Experiment (CDE) onboard the AIM satellite, and the Lunar Dust Experiment LDEX onboard the LADEE mission. He is the principal investigator for the Interstellar Dust Experiment (IDEX) onboard the upcoming IMAP mission. He is a Fellow of both the American Physical Society and the American Geophysical Union.



Dana M. Hurley

Chief Scientist, Lunar Surface Innovation Initiative

Dr. Dana Hurley is a planetary scientist at the Johns Hopkins University Applied Physics Laboratory (APL). Presently, she is Chief Scientist of APL's Lunar Surface Innovation Initiative task in support of NASA Space Technology Mission Directorate. Her research interests center on understanding the evolution of water and other volatile compounds in planetary environments. Her Ph.D. research at Rice University analyzed Mars Global Surveyor magnetometer and electron reflectometer data to examine the martian space environment and the role that the solar wind interaction has in atmospheric escape at Mars. Next, she began modeling the lunar exosphere and the delivery and retention of water ice in lunar polar regions. As a co-investigator on the Lyman Alpha Mapping Project (LAMP) instrument onboard the Lunar Reconnaissance Orbiter (LRO), she examined far ultraviolet spectra to characterize the physical parameters of the lunar exosphere. She built numerical models that reproduced the observed evolution of vapor from impacts on the Moon including the LCROSS and GRAIL spacecraft impacts and impacts from meteoroids. She adapted her exosphere model for application at Mercury and the plumes of Enceladus. Her data analysis experience spanning spectroscopic remote sensing, in situ ion and neutral particle measurements, and magnetic fields allows her to investigate sparse atmospheres and how they interact with planetary surfaces and space plasma environments. In 2016, NASA SSERVI recognized her with the Michael J. Wargo Award for significant contributions through the integration of exploration and planetary science.

In addition to research, Dr. Hurley's management roles at APL include the Assistant Supervisor of the Science and Space Instrumentation Branch and the Strategic Integration Lead for Planetary Sciences. As an active planetary science community leader, Dr. Hurley presently sits on the NASA Planetary Science Advisory Committee and the American Astronomical Society's Division of Planetary Sciences Committee. She was founder and, for its first 6 years, leader of the "Friends of Lunar/NEO Volatiles" Focus Group, which furthers collaboration among the science and engineering professionals interested in lunar volatiles. She is also active in promoting a culture of equity, diversity, inclusion, and accessibility within APL and in the professional community.

Speakers

Jose Hurtado

Technology Chair, Lunar Exploration Analysis Group,
The University of Texas at El Paso

Jose Hurtado is a Professor in the Department of Geological Sciences at The University of Texas at El Paso (UTEP). He joined UTEP in 2002 after completing a postdoctoral fellowship at the NASA Jet Propulsion Laboratory. Dr. Hurtado obtained his Ph.D. in geology at the Massachusetts Institute of Technology and holds an M.S./B.S. in geology from the California Institute of Technology. His research interests include terrestrial geology and remote sensing, focusing on the western US and the Himalaya, as well as planetary science. His planetary science work includes remote sensing studies of the Moon as well as work in analog environments investigating the tools and techniques for planetary surface exploration with humans and robots. During 2014-2015, Dr. Hurtado joined the operations team at Virgin Galactic as an astronaut instructor and also worked on SpaceShipTwo cabin systems and life-support engineering tasks. Dr. Hurtado currently serves on the executive committees for the Lunar Exploration Analysis Group (LEAG) and the Lunar Surface Innovation Consortium (LSIC).

Dr. Hurtado's research expertise is in field geology; remote sensing (including Unmanned Aerial Systems); and terrestrial/planetary tectonics and geomorphology. He applies this expertise in two broad research areas: lunar geology and active tectonics in the Himalaya. Dr. Hurtado's lunar geology work has focused on the use of remotely-sensed datasets to investigate the potential resources on the Moon and their geologic context. This has included using thermal infrared data to discover and characterize caves in the lunar subsurface, hyperspectral data to map the presence of water and Ti, and topographic data to identify water-related volcanic features. He has also conducted work at planetary analog sites to show how geophysical tools (e.g., gravity, magnetics, GPR) can be used to characterize water-related explosive volcanic features on other planets as well as how other field depolyable instrumentation can be used for planetary surface exploration. His terrestrial work has focused on field studies of Quaternary geomorphologic features (river terraces, fault scarps, etc.) that record ongoing tectonic uplift in the Bhutan Himalaya. The objective of this work is to evaluate models for the evolution of the Bhutan Himalaya and assess seismic hazards. In addition to these research areas, Dr. Hurtado also has expertise in human space exploration through ongoing collaborations with NASA in mission simulation activities and astronaut crew training. Dr. Hurtado has also worked on various commercial spaceflight projects, including passenger training program and vehicle development with Virgin Galactic.

Amy Kaminski

Program Executive, NASA Prizes, Challenges, and Crowdsourcing

Dr. Amy Kaminski currently serves as program executive for prizes, challenges, and crowdsourcing at NASA Headquarters in Washington, DC, where she works to develop strategies to expand the space agency's use of a variety of open innovation methods in its research and exploration activities. She served previously as senior policy advisor in the Office of the Chief Scientist, where she led an initiative to support and expand NASA's involvement of citizens as contributors to the agency's research activities. Before joining NASA, Kaminski served as a program examiner at the White House Office of Management and Budget (OMB). She also has held positions in the Federal Aviation Administration and the National Space Society. She is the editor of Space Science and Public Engagement: 21st Century Perspectives and Opportunities (Elsevier, 2021).

Kaminski earned a Ph.D. in science and technology studies from Virginia Tech, an M.A. in science, technology, and public policy from The George Washington University and a B.A. from Cornell University in earth and planetary sciences.

Speakers

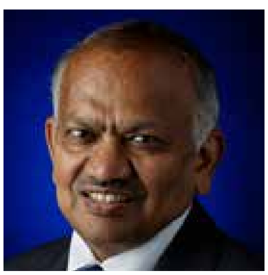
Jason L. Kessler

Program Executive, Small Business Innovation Research & Small Business Technology Transfer Programs

Jason L. Kessler is the Program Executive for NASA's Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STRR) Program. Prior to joining the program in February 2021, Jason served as a Senior Advisor to the Global Knowledge Initiative, where he combined strategy, design, facilitation, and coaching to create systems-focused learning experiences for clients in the developing world. These experiences were targeted at increasing the use of science and technology to enable better outcomes in environmental and climate change programming.

Prior to that, Jason spent nearly 15 years at NASA, serving most recently as a Program Executive in the Office of the Chief Technologist from 2013-2016, and as Deputy Project Director for SERVIR—a unique partnership between NASA and the United States Agency for International Development (USAID)—from 2010-2013. As an entrepreneur and consultant serving outside of government, he has also started several businesses, and still maintains a small contingent of select Executive Coaching clients.

Jason is the recipient of two NASA Exceptional Service Medals and a NASA Group Achievement Award. He holds a B.S. in Chemistry from Vanderbilt University, an MBA from the University of Arizona, and an Executive Coaching Certificate from the Hudson Institute of Coaching. He recently published his first book, Simple Acts, Practices for a Broken World.



Laguduva Kubendran

Lead, NASA Commercial Space Technology Partnerships

As the Lead for Commercial Space Technology Partnerships within the Space Technology Mission Directorate (STMD) at NASA Headquarters, Dr. Kubendran serves as the senior NASA official responsible for STMD's partnership engagement strategy, and is responsible for conducting commercial market research to further commercial content development across all STMD Programs; developing priorities based on availability of commercial technologies and resources, coupled with associated NASA priorities; leading STMD's Flagship Partnership Mechanisms: Tipping Point Solicitation and Announcement of Collaboration Opportunity; identifying how business accelerators and other innovative mechanisms fit into STMD's overall commercial engagement. His previous STMD roles include Portfolio Executive for Commercial Partnerships Portfolio, Program Executive for SBIR/STTR, and Program Executive for Flight Opportunities. Dr. Kubendran received his Bachelor of Technology in Aeronautical Engineering from IIT-Madras, MS and PhD in Aerospace Engineering from Georgia Tech, and an Executive MBA from UCLA. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics.

Speakers

Luis Maestro

Principal Investigator, DMTS, Nokia Bell Labs

LTE Proximity Communications for Future Lunar Missions

Luis Maestro graduated in Mobile Communications (MSc) from Miguel Hernandez University, Spain. He started his career in Nokia in 2007 as an external researcher in Aalborg, Denmark. His research covered advanced multi-antenna techniques, physical layer design as well as different RRM schemes for LTE-A. In 2009, Luis became a member and, later in 2011, Head of Nokia Innovation Centre (NICE) in Madrid working closely with different customer innovation labs on new concepts and solutions for cellular networks. During 2013-2014, Luis' work focused on smartphone and wireless network interactions with Nokia Smart Labs (Dallas, Texas). In late 2014, he joined Nokia Technology & Innovation, later Nokia Bell Labs, and has been leading different innovation programs in the areas of ultra-compact, rapid deployable and mission-critical wireless communications. Luis is currently the Principal Investigator for the NASA tipping point program aiming at deploying the first 4G/LTE network on the lunar surface.

Sandra Magnus

Principal, AstroPlanetview LLC

Dr. Sandra H. "Sandy" Magnus, is the Principal at AstroPlanetview, LLC and the former Deputy Director of Engineering in the Office of the Secretary of Defense Research and Engineering. Prior to joining the DoD she served as the Executive Director of the American Institute of Aeronautics and Astronautics (AIAA), the world's largest technical society dedicated to the global aerospace profession. Selected to the NASA Astronaut Corps in April, 1996, Dr. Magnus flew in space on the STS-112 shuttle mission in 2002, and on the final shuttle flight, STS-135, in 2011. In addition, she flew to the International Space Station on STS-126 in November 2008, served as flight engineer and science officer on Expedition 18, and returned home on STS-119 after four and a half months on board. Following her assignment on Station, she served at NASA Headquarters in the Exploration Systems Mission Directorate. Her last duty at NASA, after STS-135, was as the deputy chief of the Astronaut Office. Before joining NASA, Dr. Magnus worked for McDonnell Douglas Aircraft Company from 1986 to 1991, as a stealth engineer. While at McDonnell Douglas, she worked on internal research and development and on the Navy's A-12 Attack Aircraft program, studying the effectiveness of radar signature reduction techniques.

Speakers

Alex McCarthy

Chief Technology Officer, AI Space Factory

REACT (Relevant Environment Additive Construction Technology)

Even before graduating from MIT in 2014, Alex McCarthy had caught the 3D printing bug. For the last seven years Alex has brought to market numerous engineering grade 3D printing products, with a particular passion for developing next generation materials for next generation applications. As CTO at AI SpaceFactory, this means bringing to light a future in which our homes and workplaces, both terrestrial and extra-terrestrial, are 3D printed from sustainable, high-performance materials.

Alex believes that developing Lunar 3D construction technology will unlock sustained colonization of the Moon, Mars, and beyond. Furthermore, Alex believes the challenge of developing such a construction technology, which must be energy efficient, autonomous, and reliant on in-situ resource utilization, will unlock a new era of green, autonomous, and affordable construction technology back on Earth.

In 2020 AI SpaceFactory was selected as an awardee for the "Announcement of Collaboration Opportunity (ACO), Construction Category". Work on this project, in collaboration with Kennedy Space Center Swamp Works group, began in 2021 with the goal of developing a 3D printable regolith/thermoplastic composite, demonstrating thermoplastic 3D printing under simulated Lunar conditions for the first time, and finally developing a structurally validated building design based on the properties of the regolith/thermoplastic composite.

Gareth Meirion-Griffith

Lead, NASA Lunar Surface Technology Research Opportunity

Dr. Gareth Meirion-Griffith currently serves as lead for the Lunar Surface Technology Research (LuSTR) Opportunities solicitation within NASA STMD's Space Technology Research Grants (STRG) office. Prior to joining STRG in April 2020, Gareth was a Group Supervisor in the Robotics & Mobility Systems section at JPL, PI on several STMD/SMD/JPL extreme robotic access projects, and was mobility lead and rover driver for Curiosity. Gareth particularly enjoys remote-location field trials and has led several in Alaska and Death Valley. He currently lives in Chicago, IL with his wife and two children.

Speakers

David Murrow

Senior Manager of Deep Space Exploration Strategy,
Lockheed Martin Corporation

Dave Murrow is the Senior Manager of Deep Space Exploration Strategy and Business Development for Lockheed Martin's Corporation Space. In his current role he is responsible for positioning the company to support NASA robotic exploration missions in the planetary, lunar, astrophysics and heliophysics arenas. In this role he works with the science, engineering, and programmatic stakeholders to build responsive and compelling mission solutions. He is focused on extending Lockheed Martin's proven heritage in robotic and human spaceflight into the next phase of exploration missions.

Dave previously served as capture manager for NASA proposals, in both the science and human space flight areas. Dave has worked on space science and exploration missions in various roles such as navigator and systems engineer at Lockheed Martin, the Jet Propulsion Laboratory, Ball Aerospace, and as the owner of a small business. He was responsible for the launch campaigns of the Mars Climate Orbiter, Mars Polar Lander, and the Stardust spacecraft, which were all successfully launched in December 1998, January1999, and February 1999.

Dave has a Master's and Bachelor's degrees in Aerospace Engineering from the University of Texas at Austin ('87) and the University of Colorado ('84). In Austin, he also worked at the University's Center for Space Research, supporting high precision Earth gravity field development for the Topex mission.

A Colorado native, Dave lives in Highlands Ranch, Colorado with his wife and has frequent visits from his two grown daughters. He spends his free time reading, skiing, and hiking in the mountains.

Jorge Núñez

LSIC Dust Mitigation Facilitator

Dr. Jorge Núñez is a senior planetary scientist and astrobiologist in the Space Exploration Sector at the Johns Hopkins University Applied Physics Laboratory. He received dual BS degrees in Mechanical Engineering and Physics from the University of Alabama at Birmingham (UAB) and Ph.D. in Geological Sciences from Arizona State University (ASU). His primary research focuses on studying the geology and composition of planetary surfaces from the micro-to the macro-scale using a variety of remote sensing and in situ techniques, as well as development of instruments and technologies for extreme environments such as the Moon, Mars, and beyond. He is a team member on multiple planetary missions and instruments. He has expertise in microscopy, visible/near-infrared spectroscopy, and instrument development. Dr. Núñez also coordinates the Planetary Exploration Research Lab (PERL) at APL. Over the years, he has participated in several analog field tests simulating robotic and human missions to the Moon, including NASA ISRU and Desert RATS field tests, and worked with lunar samples collected during the Apollo missions. He is a Fulbright Scholar and the recipient of a NASA Early Career Fellowship and multiple NASA Group Achievement awards. Asteroid 176610 Núñez was named in his honor.

Speakers

Angela Stickle

LSIC Extreme Access Facilitator

Dr. Angela Stickle is a planetary geologist with a background in Aerospace and Mechanical Engineering, magnetospheric physics, and impact processes on planetary surfaces. She received her bachelors degrees in Aeronautical/Astronautical Engineering as well as Earth and Space Sciences from the University of Washington, and her Masters' degrees in Geology and Engineering and Ph.D in Geological Sciences from Brown University. She is currently a senior research scientist at the JHU Applied Physics Laboratory. Her work focuses on impact processes in the solar system, including the Moon, Mars, asteroids, and the icy moons of Saturn and Jupiter. She is a Co-Investigator on the Mini-RF radar and LRO-LAMP instrument aboard the Lunar Reconnaissance Orbiter, the Dragonfly mission, and leads the impact modeling team for the Double Asteroid Redirection Test. Her research includes lunar surface evolution and maturation, experimental and numerical studies of damage formed by hypervelocity impacts, dynamic failure and fragmentation of materials, planetary defense, as well as cratering processes in icy targets. She uses an interdisciplinary approach to better understand impact phenomena, combining experiments (impact and dynamic failure) with numerical models and remote sensing to evaluate impact structures.

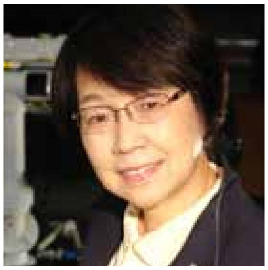
Paul van Susante

Assistant Professor of Mechanical Engineering,
Michigan Technological University

T-REX (Tethered - permanently shaded Region EXplorer)

Dr. van Susante is an assistant professor in the Mechanical Engineering - Engineering Mechanics department at Michigan Technological University in Houghton, Michigan, USA. He graduated from TU-Delft with a MS in Civil Engineering in 2001, a MS and PhD in Engineering Systems from the Colorado School of Mines. He has been involved with Lunar and Mars construction and In-Situ Resource Utilization for 20 years and is the founder of the Planetary Surface Technology Development Lab at MTU which includes a 1.5mx1.5mx2m dusty thermal vacuum chamber and a lunar regolith sandbox for robot testing. He is faculty Advisor of the Mining Innovation Enterprise where we explore space and underwater mining technology. He is PI or Co-I on numerous NASA grants related to In-Situ Resource Utilization (ISRU) including mining water on the lunar poles, extracting oxygen from lunar regolith, mining water from hydrated minerals and buried glaciers on Mars as well as PI for one of the inaugural NASA Lunar Surface Technology Research (LuSTR) awards. He is also PI for the MTU student team that won the 2020 NASA BIG Idea challenge competition and advises a student team for the NASA Lunabotics Mining competition.

Speakers



Alian Wang

Fellow, The Geological Society of America

Research Professor, Washington University in St. Louis

WRANGL3R - Water Regolith ANalysis for Grounded Lunar 3d Reconnaissance

Professor Alian Wang is a Planetary Spectroscopist, who has been working on NASA projects since 1995.

She served as PIs and Co-Is of the projects supported by NASA PIDDP, ASTID, MFRP, ASTEP, MatISSE, SSW, ICEE-2, DALI, SSERVI, and LuSTR programs.

She has participated NASA Mars Exploration Rover missions operation, and the mission proposals to the Moon and Venus in NASA Discovery and New Frontier Programs.

She and her team published over 100 papers in peer-reviewed journals, and made oral and poster presentations in every year's LPSC, AGU, and GSA conferences. She served as panel and external reviewers for NASA programs, and for international journals of spectroscopy, mineralogy, and planetary sciences.

She also organized international conferences and workshops on planetary exploration, science, and data analysis.

Table of Contents for Abstracts

Grain Shape Characterization as an Enabling Capability for Lunar Surface Technologies. K. M. Cannon[1], R. Garvey[2], and S. R. Deitrick[1,3], [1]Colorado School of Mines, Golden CO 80401, [2]Outward Technologies, Broomfield CO 80020, [3]NASA/Jacobs, Houston TX 77058. (Contact: cannon@mines.edu)

Introduction: Lunar regolith has unique physical and geotechnical properties compared with familiar granular materials on Earth, and most lunar simulants as well. Specifically, the cohesion,angle of repose, and compressibility are much higher, and flowability is much lower for lunar regolith than otherwise similar terrestrial-derived materials [1,2]. There is confusion in the literature about the relative importance of vacuum, gravity, and inherent grain characteristics in driving these differences. Here we emphasize the importance of characterizing grain types and shapes for designing and testing lunar surface technologies, including for rover mobility, material handling, soil sampling, and heat transfer analyses. We demonstrate laboratory capabilities and preliminary studies, and outline further work to better characterize and simulate lunar grains to reduce risks for surface activities.

The Importance of Shape: The flowability and geotechnical properties of a granular material are controlled by how grains behave when they try to move past one another: this includes the coefficient of sliding friction and the coefficient of rolling friction. In turn, these properties are influenced by particle size distribution, particle shape, and the cohesive force between two grains. Grain shape is not simple to define, and is usually described in terms of different 2D and 3D shape properties such as aspect ratio, roundness, and concavity.

Characterization Capabilities: We have commissioned and begun tests with a Microtrac SYNC particle analyzer that is located in-house at the Colorado School of Mines. The SYNC is a new type of instrument that combines tri-laser diffraction with Dynamic Image Analysis (DIA) to measure particle size distributions from 10 nm to 2 mm, and 30 different 2D and 3D grain shape characteristics from 5 μm to 2 mm for ~10^5 particles per sample. Fig. 1 shows data from synthetic agglutinate samples created by Outward Technologies, designed specifically to mimic the branching and dendritic morphologies of irregular lunar agglutinates.

We have a pending request through ExMAG to measure 4 Apollo soil samples of differing composition (highlands, mare), and maturity as a proxy for agglutinate content (immature, mature) using these capabilities. These measurements would characterize detailed shape properties for >500,000 lunar grains, study the changes in shape properties after compressive forces are applied to the regolith, and compare with lunar simulants that both do and do not have synthetic agglutinates.

Implications for Lunar Surface Technology: All technology that interacts with the lunar surface will involve regolith. This includes excavation and construction, ISRU, and mobility/access to extreme environments. The poor job that most existing simulants do in replicating geotechnical properties (angle of repose, flowability) is extremely concerning as activity ramps up for design and testing of new surface hardware. Further detailed studies of grain characteristics and efforts to better simulate them will serve as an important technical capability to better predict behaviors on the Moon.

References: [1] Calle C. I. and Buhler C. R. (2020) *Lunar Dust 2020, #5030*. [2] Carrier W. D. et al. (1991) *Lunar Sourcebook, Ch.9*.

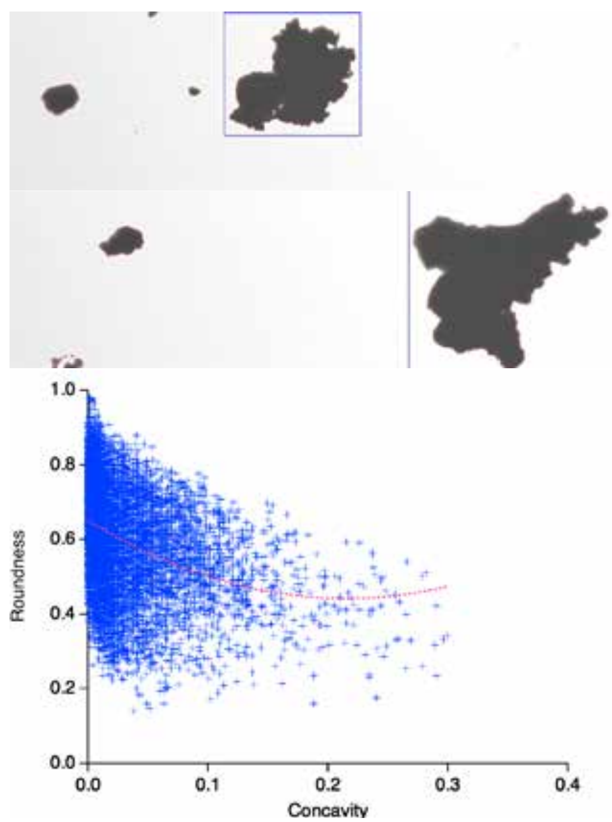


Fig. 1. Top: single grains of Outward Technologies synthetic agglutinates imaged using DIA on the Microtrac SYNC. Bottom: a plot of roundness vs. concavity for the same sample.

REDUCED GRAVITY BIOINSPIRED SUBSURFACE PROBE. Saeedeh Naziri[1], Cyrena Ridgeway [1], Salvador Ibarra[1], Jose A. Castelo[1], Katarina Provenghi[1], Douglas D. Cortes[1], [1]New Mexico State University, 3035 S. Espina street, Las Cruces, NM 88003, p. 575.646.6012 (Contact: dcortes@nmsu.edu)

Introduction: The direct measurement of in-situ regolith properties and the assessment of resources stored within the subsurface are recognized as critical steps in the development of Lunar ISRU technologies. On Earth, subsurface exploration equipment has developed over time to take advantage of the planet's gravitational acceleration and energy availability. Today heavy surface equipment provides the reaction forces needed to overcome the ground penetration resistance. Energy is so readily available that the depth limiting parameter is often the surface anchor weight. Penetration in Lunar regolith poses two primary challenges: a low gravity environment, and limited power supply.

Bioinspiration: Earthworms have had over three hundred million years to develop and fine tune sophisticated light-weight subsurface penetration strategies that work more with the ground than against it. These organisms not only use the granular media for support but are also capable of adjusting their deformable bodies to gain mechanical advantages and maneuver around obstacles, reducing the energy needed for excavation. We created a simple earthworm-inspired soil penetration device by combining a miniature steel cone penetrometer with a soft membrane and deployed it in a bed of Lunar mare regolith simulant (LMS-1).

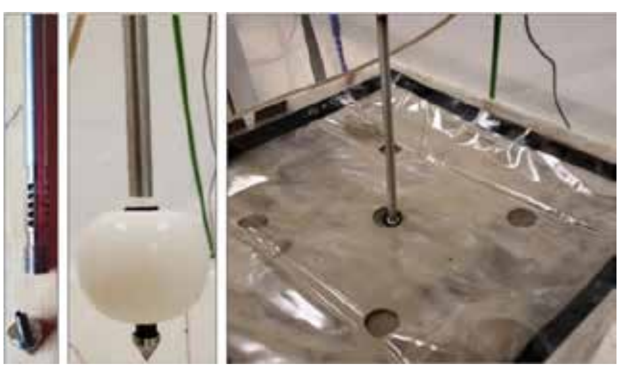


Figure 1. Earthworm-inspired subsurface penetration probe.

Capabilities: Bioinspired penetration tests are conducted under displacement-controlled conditions (velocity 2 = mm/sec) to a pre-set depth of 10 cm while logging the penetration resistance via a load-cell. The driving linear actuator is locked at this position and the membrane is inflated to a selected volume. Pressure sensors in the hydraulic system allow for the determination of the pressure required to inflate the membrane. After that, the membrane is retracted, and the probe is driven deeper into the regolith bed. The subsequent depth intervals and the final membrane volume at each stage are variables used in the study. Some of the test results are presented in figure 2. These consist of three additional penetration intervals (5 cm each) with inflation volumes of 17.5, 35 and 70mL. The control data shown originates from test conducted under similar conditions except the membrane is never inflated.

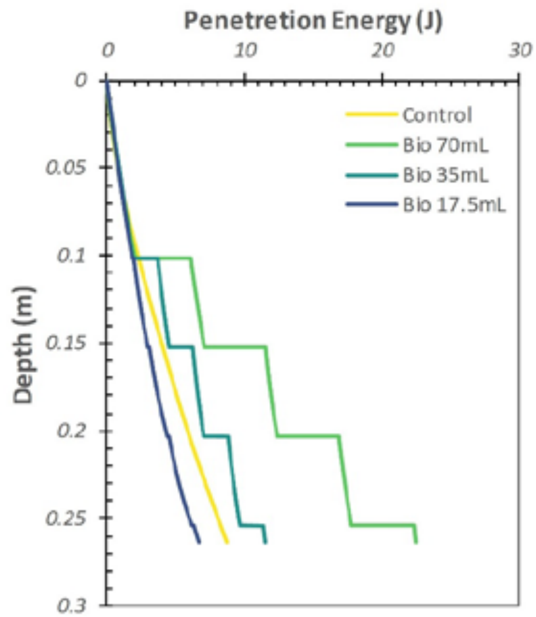


Figure 2. Penetration energy signatures of bioinspired and control penetration tests.

Capabilities: Test results show that an earthworm-inspired penetration strategy can effectively reduce both the penetration force and the penetration energy needed to drive a probe into Lunar regolith simulant. The magnitude of the decline depends on the inflation volume and pressure, which provides additional degrees of freedom to optimize the penetration process. Compared to the control probe driving, the earthworm-inspired penetration can <u>eliminate 67% of the surface mass</u> (@ 35mL inflation volume) and <u>cut the penetration energy by a quarter</u> (@ 17.5mL inflation volume) while limiting peak power consumption to 8 Watts.

Title of Abstract: Dust, Dust, Everywhere – What Are We Going To Do?

Ron Creel[1]- Apollo Veteran; David Cadogan[2] - Moonprint Solutions; Marc Cohen[3] - Space Cooperative

(Contact: roving.ron@gmail.com)

1 - Lunar Dust proved to be a significant and dangerous hazard on previous Apollo Moon exploration missions. Dust was easily stirred up and deposited on crew suits during EVAs and brought into the Lunar Module habitat:



2 - Apollo crews expressed their concerns with Moon dust and <u>inability</u> to clean dirty suits:

Apollo 12 crew noted “Some type of **throwaway overgarment** for use on the lunar surface may be necessary”.

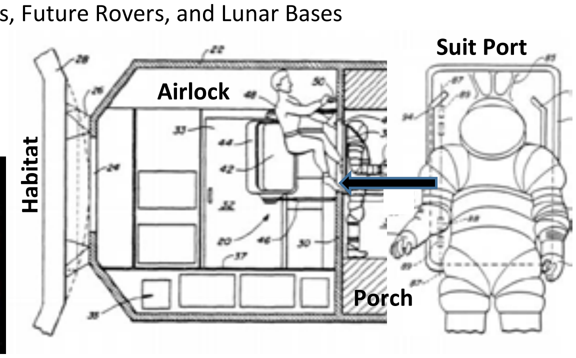
> *“I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust.”*
>
> Gene Cernan, Apollo 17 Technical Debrief

3 - Three “Isolation Technologies” can help solve dust problems for Artemis “Return to the Moon” missions.

Best way to survive adverse lunar dust effects is for <u>Crew Suits</u> to not be directly exposed in the first place.

Recommend: **A** - Lightweight reusable **Suit Covers** for short duration early Artemis Lunar Stays and EVAs, and Addition of **B**- **Airlocks** and **C**- **Suit Ports** for Longer EVAs, Future Rovers, and Lunar Bases

“For long lunar stays with multiple EVA’s, I believe an **Airlock** would be **mandatory**.”
Charlie Duke - LM Pilot and Rover Rider



A - <u>2007</u> – NASA Space Suit Cover Testing

B and **C -** <u>1989</u> Suit Port Extra-Vehicular Access Facility

4 - References - Ron Creel[1] and David Cadogan[2]- (2021) Presentations to LSIC Dust Mitigation Focus Group

Marc Cohen[3]- NASA Ames work and (1989) U.S. Patent No. 4,842,224

Moon Orbiting Reflectors for Surface Power Delivery. H. C. Dragnea, C. Thangavelu, C. D. Appleget, and H. Helvajian; The Aerospace Corporation, 2310 E. El Segundo Blvd., El Segundo, CA 90245-4609. (Contact: horatiu.c.dragnea@aero.org)

Introduction: The availability of power, in the form of both heat and electricity, on the lunar surface is critical for both exploration and long-term settlement. However, landing mass on the Moon is non-trivial and requires large delta-V values. An alternative is to maintain a part of the power infrastructure in orbit, and beam the needed energy down to the surface. Laser and microwave beamed power transmission concepts have been studied in the past [1] and provide certain advantages, such as reduced dispersion. However these methods require on-orbit and ground processing of the incident sunlight and incident laser/microwaves, respectively, resulting in a complex system.

In the interest of maintaining simplicity and keeping costs low, this work focuses on an optical transfer system for delivering solar flux to the surface. The intent is to harness, focus, and project light in the UV/Vis from space down to the lunar surface using an orbiting optical relay system.

Orbiting reflectors have been flight proven with the Znamya-2 [2] for enhanced solar power on Earth and for IKAROS [3] as propellent-less propulsion missions. Moreover, on Earth solar concentrators (heliostats) are actively being used to provide power to the electrical grid [4].

Astrodynamics: This project explores the feasibility of transferring solar flux light (power) deposition over a well-defined lunar surface area given a selective spacecraft constellation. The orbital constellation is selected following the requirement that a relay path must exist from the Sun to the upper and lower layers. Selecting the constellation also involves consideration of revisit time for lunar target regions and upper and lower layer mirror slewing rates that lengthen light exposure to lunar target areas.

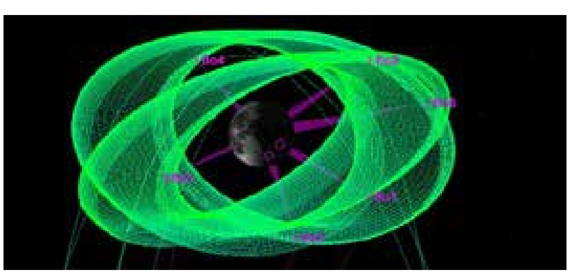


Figure 1: Low altitude layer.

The sun related requirements and to-be-discussed optics benefits have inspired a novel two-layer constellation. This consists of a lower orbit layer (Fig. 1) and a higher orbit layer (Fig. 2).

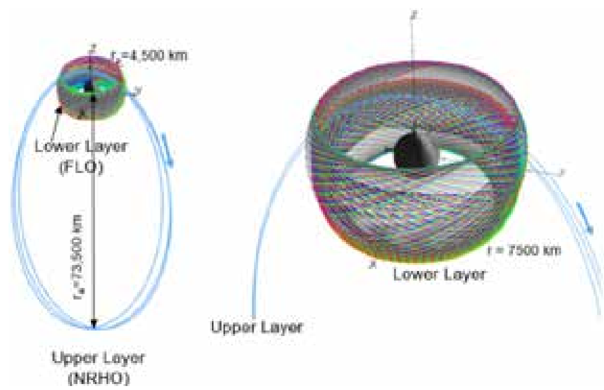


Figure 2: Low and high altitude layers, propagated over 21 days.

Vehicles and Optics:

Two types of vehicles will be used: one that serves an optical focusing function and another for projection to the surface. This combination comprises a two layer system. First, a higher mass (and cost) vehicle will be derived from the HIVE concept [5] which can space-configure to form a multielement, segmented and adjustable mirror construct with high-quality surfaces which is used to harness the solar light and focus. Second, the lower mass (and cost) satellites which will deploy a rotationally stabilized flexible reflector which will be used to project the light.

Results: This work explores vehicle, optical and astrodynamics details of a Moon orbiting surface power delivery system. In addition, based on the values of flux and projection area computed for the lunar surface, several possible applications will be outlined during the presentation.

References:

[1] Jaffe P. B. and McSpadden J. (2013) *Proceedings of the IEEE, Vol. 101, Issue 6,* 1424–1437. [2] Lior N (2013) *Renewable and Sustainable Energy Review, 18,* 401-415. [3] Funase R. et al (2011) *Advances in Space Research,* 48, 1740–1746, [4] Pfahl A. et al (2017) *Solar Energy, 152,* 3–37, [5] Helvajian H. (2020) *AIAA ASCEND 2020,* DOI: 10.2514/6.2020-4172.

Power Architecture for Sustainable Lunar Presence.
C. M. Edwards[1], A. Elhawary[1], R. J. Wiseman[1], and T. Cichan[1], [1]Lockheed Martin Space. 12257 S Wadsworth Blvd, Littleton, CO 80127 (Contact: christine.m.edwards@lmco.com)

Abstract: As part of the Artemis era of space exploration, space agencies will be working together with their industry partners to establish systems and infrastructure that enable sustained lunar missions and develop capabilities for Mars. The planning for this next phase is possible now that Orion and the Space Launch System are about to perform their initial missions together, the initial Gateway elements are in design and production, and the set of regular lunar robotic landing missions from a diversity of countries and companies has begun. Each mission to the lunar surface, both crewed and robotic, offers the opportunity to demonstrate new technologies and operations. These new technologies and operations enhance exploration and scientific discovery, mature those same capabilities for Mars, and build upon previous missions. Unlike in the Apollo era, the focus is on the long-term placement of a diverse set of new infrastructure that supports a sustained lunar presence. Another difference from the Apollo era will be a focus on providing infrastructure capabilities as commercial services to a diversity of customers.

For this presentation, Dr. Christine Edwards, the Deputy Exploration Architect at Lockheed Martin Space, will discuss how the lunar surface power architecture can evolve throughout the Artemis missions to achieve the vision of the Global Exploration Roadmap. The discussion will assess potential growth in power and resource needs as the lunar economy grows and explore the modularity and adaptability of systems like Lockheed Martin's Lunar Vertical Solar Array Technology (LVSAT) that can enable the growth of the lunar power infrastructure. For example, initial power systems can provide supplemental power to Artemis elements, and also grow in a modular fashion to provide power as a service to commercial missions. Because this infrastructure is a key aspect in supporting a budding lunar economy, the power system solutions can both enable the Artemis missions and provide the basis for a lunar economy. Additionally, the power architecture can be designed to adapt from supporting the initial phase of the Artemis program that emphasizes exploration and mobility to a phase of the Artemis program that emphasizes sustained presence and Mars mission support.

Maximum Solar Power from the "Peaks of Eternal Light" with Tall Towers. M. Elvis[1], S. Ruppert[2], A. Ross[2], D. Ineza[2], P. Gläser[3], J. Vlassak[4], [1]Center for Astrophysics | Harvard & Smithsonian, 60 Garden St., Cambridge MA02138, [2] Harvard College, Harvard University, Cambridge, MA, USA, [3] Department of Planetary Geodesy, Technische Universität Berlin, Berlin, Germany, [4] Harvard School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, (Contact: melvis@cfa.harvard.edu)

Introduction: The power requirements for a lunar base are probably in the megawatt (MW) range, while for mining water for the permanently shadowed region (PSRs) they may reach the gigawatt (GW) range (Karnuta et al., 2019.) The high illumination "Peaks of Eternal Light" (really "quasi-eternal") near the lunar South Pole are a promising source of solar power for these activities. It is worth investigating the maximum power achievable with solar panel arrays of various heights, and whether tall towers to support these arrays are feasible. If not, then alternative energy sources, notably nuclear fission, will become higher priorities.

We investigate these questions in a series of papers [2, 3, 4]. The area on which solar power towers can usefully be emplaced is a few sq. km, with consequences for lunar policy [5, 6].

Available Power: We used the average % illumination maps based on LRO LOLA [7] for a range of heights above the local topography from 2 m to 2 km (Figure 1) to determine the total power available as a function of time of lunar day. Overshadowing of highly illuminated areas by towers placed in sunward locations (at a given time of day) limits the total power to much smaller values than the highly illuminated area would suggest.

We find that for near-term realizable towers (up to 20 m), the upper limit to the time-averaged power available is ~6 MW at >90% illumination.

For the more distant future a maximum time-averaged power is ~5.3 GW at 90% illumination for towers up to 2 km in height. Towers 1 km high provide about a factor 2.7 times less power. The variation with lunar time of day ranges from a factor of 1.1 to ~ 3.

Tall Towers: The low gravity, lack of atmosphere, and quiet seismic environment of the Moon suggests that towers could be built much taller than on Earth. We examined the limits to building tall concrete towers on the Moon. We chose concrete as the capital cost of transporting large masses of iron or carbon fiber to the Moon is presently so high as to preclude affordable operation of a power plant. Concrete instead can be manufactured in situ from the lunar regolith.

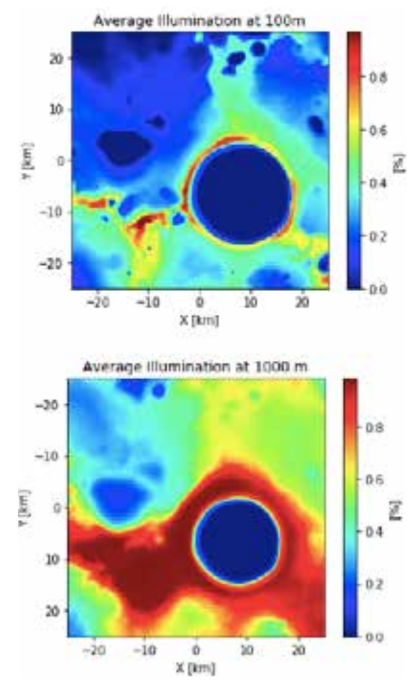


Fig.1: Average illumination at 100 m, 1 km heights in a 50x50km region centered on the S. Pole.

We find that, with minimum wall thicknesses of 20 cm, towers up to several kilometers tall are stable against compression collapse and buckling. The mass of concrete needed, however, grows rapidly with height, from ~760 mt at 1 km to ~4,100 mt at 2 km to ~10^5 mt at 7 km. A foreseeably practical limit is then in the 1-2 km range.

Other failure modes, e.g. shell buckling, and other forms of tower (trusses, tensegrity structures) are being investigated to fill out this initial exploration.

The ability of the regolith near crater rims to support km-scale towers is unclear. Towers must also be stable against regolith lifted by lander exhaust plumes and collisions with ground vehicles.

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MOTE LUNAR PENETRATORS FOR EXPLORATION OF EXTREME TERRAINS AT THE LUNAR POLES T. Marshall Eubanks[1], W. Paul Blase[1], [1]Space Initiatives Inc , Newport, Virginia 24128 USA; tme@space-initiatives.com;

Introduction: Ballistic penetrators allow for rapid precursor missions to difficult to reach terrains such as the polar Permanently Shadowed Regions (PSRs), volcanic vents, crater central peaks and lava tube skylights, and in addition for the rapid placement of instrument arrays distributed over regions of interest such as the lunar swirls [1, 2].

Space Initiatives Inc has developed small "Mote" ballistic penetrators (Figure 1) to provide commercial support for robotic and crewed operations on and near the Moon. The ∼1.5 kg Mote penetrators have on-board processing, communications and sensors, and can be carried by lander and released to fall ballistically, impacting the surface at up to 300 m/s and penetrating 1 meter or more into the typical lunar regolith. In a nominal misson this deployment results in a sensor array distributed over ∼1 km of the lunar surface (Figure 2).

Figure 1: Cutaway drawing of a 388-mm long Mote penetrator designed to penetrate 1 to 2 meters into the lunar regolith.

Deployments into Shackleton Crater: Ballistic penetrators will enable the rapid deployment of instruments into the most difficult lunar terrains, including the permanently shadowed regions. Figure 2 shows the deployment of Motes into Shackleton crater from a supposed CLPS landing delivery on the rim of the crater. In this reference mission the Motes are deployed 24 km downrange and 5 km above the mean lunar surface and take ∼78 seconds to reach the crater floor, ∼2.8 km below the mean lunar surface. At the time of their landing, the CLPS lander will still be well above the surface of the Crater rim and would be able to observe IR emissions from the gas plumes emitted by surface volatiles vaporized by Mote impacts. The chosen landing site is the ∼210 m high "mound unit," the largest feature on the Shackleton Crater floor [3]. The horizontal spread of the Mote's landing sites with deployment separation velocities of ≤ 10 m s^{-1} is sufficient to blanket the mound unit with penetrators.

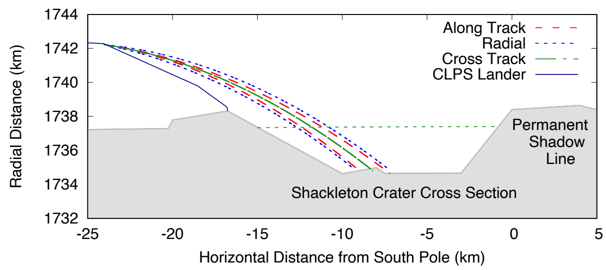


Figure 2: Deployment of Mote Penetrators into the Shackleton Crater PSR. The Motes are released from a CLPS Lander and fall ballistically into the PSR, while the CLPS lander proceeds to soft land a few minutes later on the crater rim.

The PSR Plasma Environment: In the lunar polar regions astronauts will be entering a novel and relatively poorly explored environment, quite different from the direct sunlight and solar wind encountered in Apollo EVAs. In shaded areas the high thermal velocities of solar wind electrons can create large regions with charge separation, potentially leading to dangerous surface charging, as shadowed craters at the lunar poles fill with non-neutral electron clouds [4]. The PSR are thus likely to support very complicated plasma environments with a variety of electrostatic and cyclotron waves at very low frequencies [2]. We are developing surface Mote arrays using low frequency coil radio antennas at extremely low radio frequencies, in order to provide geomagnetic and geoelectic monitoring of the the novel plasma conditions near the lunar Poles. In addition, surface charging changes can be directly monitored, providing direct geotechnic information on the possible electrical risks to astronaut safety in these regions.

References: [1] C. J. Ahrens, et al. (2021) *The Planetary Science Journal* 2(1):38 doi. [2] T. M. Eubanks, et al. (2021) *arXiv e-prints* arXiv:2103.16957. arXiv:2103.16957. [3] M. T. Zuber, et al. (2012) *Nature* 486(7403):378 doi. [4] M. I. Zimmerman, et al. (2012) *Journal of Geophysical Research (Planets)* 117:E00K03 doi.

PLANETVAC: SAMPLE ACQUISITION AND DELIVERY SYSTEM FOR INSTRUMENTS AND SAMPLE RETURN.
Z. Fitzgerald[1], K. Zacny[1], R. Mueller[2], P. Morrison[1], M. McCormick[1], A. Wang[1], L. Thompson[1], H. Jung[1], J. Hernandez[1], K. Leucht[2], M. Dupuis[2]. [1]Honeybee Robotics, 2408 Lincoln Ave. Altadena, CA 91101, KA-Zacny@honeybeerobotics.com. [2]NASA KSC, rob.mueller@nasa.com

Introduction: PlanetVac is a revolutionary technology for acquiring and transferring regolith from almost any planetary body to instruments (for in-situ analysis) or sample returned container (for sample return missions) [1-4].

Numerous surface missions (Viking Mars Phoenix, MSL Curiosity, Venera, Luna, etc.) have shown that sample acquisition and delivery is one of the most difficult aspects of the mission. Several missions, such as Venera and Mars Phoenix did not meet their scientific goals or used only a fraction of their instrument suites as a result of sample delivery complications. PlanetVac solves sample delivery through a robust and dust tolerant pneumatic approach, similar to traditional powder delivery technologies used on Earth.

PlanetVac can be tailored to service a wide variety of instruments and mission specifications. PlanetVac is versatile and can deliver regolith fines or rocklets in quantities ranging from 50 micrograms (for GCMS) to 15g (10cc) or more (for sample return, ISRU) to a variety of containers or instrument-interfacing cups. The PlanetVac pneumatic approach is gravity agnostic (it can work in strong or no gravity field) and it works with non-cohesive or cohesive materials (the latter materials have been the most difficult to deal with on prior missions, especially in low gravitational fields).

PlanetVac: PlanetVac, in the baseline design, is attached to a footpad(s) of a lander or deployed (e.g., using a fifth-leg/boom). It is connected to instruments around the spacecraft via a pneumatic transfer hose. Unlike scoops deployed by robotic arms, the exact location of the instrument is irrelevant since the transfer hose can be routed around other systems. The Sampling Head can be positioned where it is best to sample and the instrument can be positioned where most accommodating.

Figure 1 shows the operational steps of PlanetVac. First, the gas jets inside the sampling head sweep and loft regolith into a transfer tube by injecting the surface with a brief burst of gas. The capture system then separates the sample from the flow and delivers it to the instruments. The process is resource efficient when compared to other sample capture mechanisms (such as robotic arms), with a low overall system mass, minimal total power draw, low gas volumes, and quick operational periods requiring no operator in the loop.

PlanetVac has been selected as part of the NASA Lunar Surface Instrument and Technology Payloads (LSITP) program to fly to the Moon's Mare Crisium in 2023 onboard Firefly's Blue Ghost lander (Figure 2). It will serve as a technology demonstration proving out PlanetVac's capability to collect a significant volume of sample (10cc objective) and separating fines from rockets to service a variety of instruments.

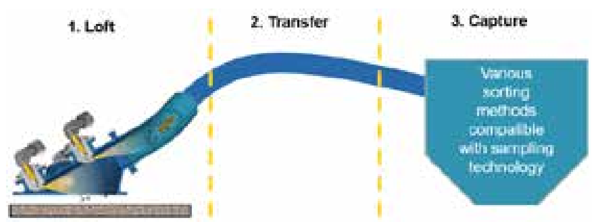


Figure 1. PlanetVac sample acquisition and capture.

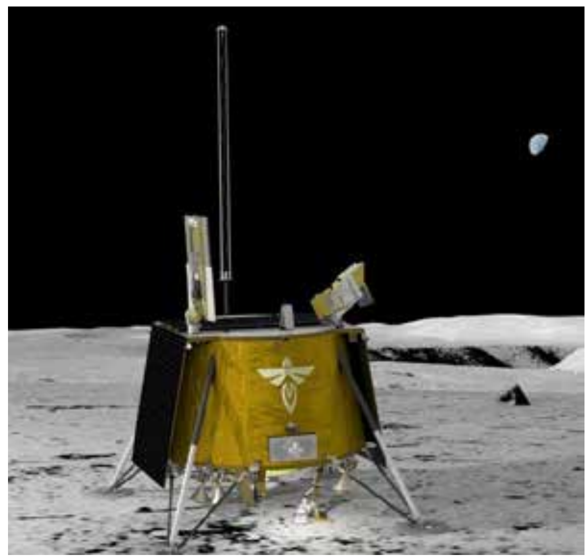


Figure 2. Shown is PlanetVac deployed by a boom (5th leg) on Firefly Blue Ghost lander.

References: [1] Zacny et al., (2020) Pneumatic Sampler (P-Sampler) for the Martian Moons eXploration (MMX) Mission, IEEE Aerospace Conf. [2] Spring et al., (2019), PlanetVac Xodiac: Lander Foot Pad Integrated Planetary Sampling System, IEEE Aerospace Conf., [3] Zacny et al., (2019), Application of Pneumatics in Delivering Samples to Instruments on Planetary Missions, IEEE Aerospace Conf., [4] Zacny et al., (2-14), PlanetVac: Pneumatic Regolith Sampling System, IEEE Aerospace Conf.

Acknowledgments: PlanetVac is being funded under NASA Lunar Surface Instrument and Technology Payloads (LSITP) program.

Dust Mitigation Technology Development for Future Lunar Missions with the Dust Solution Testing Initiative (DuSTI) Project. A. H. Garcia[1], S. R. Deitrick[1], M. C. Sico[2], J. L. Black[3], K. K. John[2], [1]Jacobs Technology, NASA Johnson Space Center, Houston TX 77058, [2]NASA Johnson Space Center, Houston TX 77058, [3]University of Houston – Clear Lake, Houston TX 77058. (angela.h.garcia@nasa.gov)

Introduction: The jagged, hard, and electrostatically-charged dust on the lunar surface is one of the most significant hazards to human exploration of the Moon. The safety of the crew members and sustainability of habitats, science, and supporting hardware depend on effective dust mitigation techniques and technologies. As NASA pursues a new generation of lunar missions with the Artemis program, the Dust Solution Testing Initiative (DuSTI) project is pursuing dust mitigation solutions by performing tests on promising commercial off the shelf (COTS) technologies over FY21.

DuSTI's goal is to increase the technology readiness level (TRL) of COTS technologies by validating components in relevant environments with relevant materials (i.e. lunar regolith simulant). The specific technologies identified for study were selected based on several factors, including a market analysis of current terrestrial dust mitigation applications, availability of the technology, accessibility of various testing facilities, and cost of procurement.

Technology Testing: NASA's official lunar dust mitigation strategy will implement a multi-pronged approach: operational and architecture considerations, passive technologies, and active technologies [1]. DuSTI is focused on passive (non-powered) COTS technology development within three categories: hard good coatings, soft good coating, and pliable cleaners.

Hard Goods Surface Coatings. The substrates of interest for testing are optical surfaces (i.e. polycarbonate and fused silica) and anodized aluminum. We will evaluate the performance of coating adhesion to the substrate, abrasion resistance, and dust adhesion resistance. We will report data on substrate haze and transmission (for optical surfaces), scratch depth via scanning electron microscope (SEM) images, pass/fail coating adhesion via tape press tests, thickness change via micrometer screw gauge, and particle adhesion percentage via optical particle counter.

Soft Goods Surface Coatings. The substrates for this category are candidate spacesuit materials and common intra-vehicular materials. We will evaluate the performance of coating adhesion to the substrate, changes to substrate flexibility after coating, abrasion resistance, dust adhesion resistance, and cleaning easability. We will report data on substrate flexibility pre/post coating via flex tester, particle adhesion percentage via mass change and optical image software analysis of percentage dust coverage change, and abrasion degredation via optical microscopy images and SEM.

Pliable Cleaners. Pliable cleaners are COTS cleaning gel/putty/clays that may gently liberate and store surface contaminates. We will evaluate the effectiveness of various pliable cleaners at removing lunar simulant from hard and soft good substrates for the use case of intravehicular dust mitigation cleaning. We will report data on pliable cleaner simulant saturation, temporal usability, and cleaning effectiveness via mass change and optical image software analysis of percentage dust coverage change; chemical residue via gas chromatography mass spectrometry (GCMS); encapilated particlulate matter via SEM images, and flammability and offgassing via chamber testers.

Future Work: The results of DuSTI testing will be compiled into a technology infusion report in Q4 of FY21 and each year the project is funded. These technologies will be tested using NASA Johnson Space Center, White Sands Test Facility, and Kennedy Space Center test facilities designed to simulate the lunar environments that are expected during the upcoming Artemis missions. DuSTI is aligned to improve upon modern methods of lunar dust mitigation in a variety of lunar surface mission environments, setting the stage for astronauts to address dust mitigation challenges for sustained lunar presence.

Acknowledgements: DuSTI would like to thank the Space Technology Mission Directorate (STMD) Center Innovation Fund (CIF) Independent Research & Development (IRAD) at NASA Johnson Space Center for funding. We would also like to acknowledge late DuSTI team member Alex Hobbs for his everlasting enthusiasm and hard work and would like to dedicate future work in his memory.

References: [1] Johansen M. R. (2020) *Lunar Dust Workshop, No. 2141.*

Lunar Aquaponics. C.G. Greenbaum,[1] Unaffiliated Researcher, 3916 N Potsdam Ave, #2745, Sioux Falls, SD 57104, carlggreenbaum@gmail.

Introduction: Nutrition is a significant challenge for any self-contained, long duration lunar habitation. This poster describes the long-term food production options to support a crew of 12. Aquaponics is the blending of hydroponic plant growth and aquaculture “fish farming”. Fundamentally, the waste matter from the fish tanks is conveyed to the plant beds to nourish their growth. The resulting clean(er) water is cycled back to the tanks. Sizing and species selection are discussed here. Aquaponics knowledge gaps including surviving the trip, prospering in 1/6 G, pollination and balancing the plant and protein production volumes regarding plant food and water quality.

Produce: Growing produce without dirt is a well established industry on earth. Microgravity creates some special challenges based on ISS hydroponics experiments. However, even lunar gravity should mitigate these difficulties.

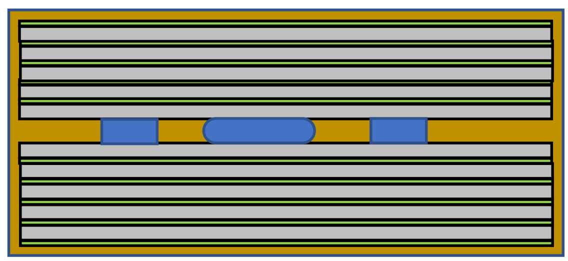
It will grow a variety of perhaps 6 or 8 different fruits and vegetables. It is estimated that 20 m^2 (200 $ft^{2)}$ is needed to feed one person continuously on hydroponics. For 12 people 240 m2 (2582ft^2) are needed fitted into two meter stacked hydroponic beds with mirror directed sunlight supplemented with LED lighting if needed.

Protein: Although some protein will be available from crops, most will come from seafood cultivated within the habitat complex. Initial fish stock selected is Gold Tilapia based on hardiness and fast growth rate[2]. They can grow as big as 40 cm (16 in) with a weight of 1.2 kg (2.6 lbs)! Most importantly this fish is very tough. They can cope with temperatures between18°C and 30°C, poor water quality, pollution, and even low oxygen. They are also largely disease resistant.

Prawns are an interesting possibility but processing their eggs through larval stages in-situ is difficult. If egg resupply from earth is available, Prawns are another fast growth, hearty option for protein diversity. An estimated 2.9 kg/day of Tilapia is needed for 12 people. A 21 m^3 grow-out tank will be needed plus additional fingerling and finishing tanks. These fish have an exceptional Food Conversion Ratio (FCR) of 1.6-1.8:1 (compared to beef cattle FCR at 20:1). Total floorspace is estimated at 40m^2.

Food Production Habitat, Light & Heating: Sci-Fi graphics showing hemispherical clear domes with crops inside abound. Unfortunately, plants and fish are likely not immune to the 200x radiation levels on the lunar surface. The Aquaponics facility will require many hours/day of crew attention, a non-trivial health risk. Furthermore , effective micrometeorite protection is lacking. The solution is an inflatable habitat covered with 1.5-2.0 m of regolith. Lighting is provided by a rotating heliostat (for a polar installations) that directs light into the habitat for mirror distribution throughout. Some of the solar energy is used for water heating.

Knowledge Gaps: Several unknows persist in establishing a functioning lunar aquaponics facility. First is survival of eggs and or fry exposed to the launch noise, shock and vibration environment[3]. The ability of fish to prosper and reproduce at 1/6G is an



50x25m Aquaponics Habitat — Grow-Out, Fingerling and Finishing Tanks — 480 linear meters of 0.5m wide, 2 m high Hydroponic beds with 1.5m access aisles

unknown, not likely to be determined without early lunar surface experiments. Ground based experiments should help to define the optimum ratio of plants and fish to balance fish production of plant food and the water filtering capacity of the plant beds vs the water quality needs of the fish. It would be serendipidous, though unlikely if the optimum ratio matched the plant/protein quantity requirements. Pollenation is another uncertainty but crop selection, mechanical or chemical techniques should eliminate the need for bees.

References:

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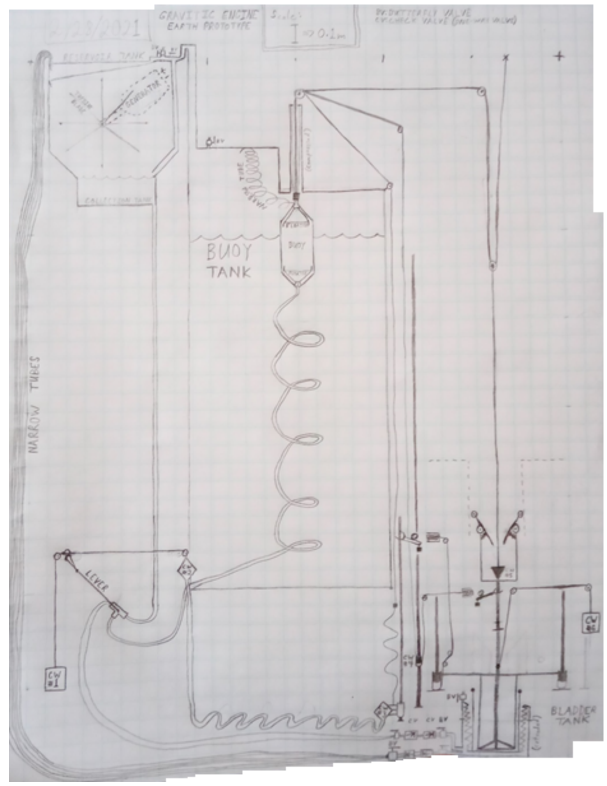
[2] Genello, L., (2015) Why Tilapia? Species Selection at the Aquaponics Project, Johns Hopkins Center for a Livable Future.

[3] Przybyla, C., Dutto, G., Bernard, M. *et al.* European sea bass and meagre fertilized egg resistance to a spacecraft launcher vibration qualifying test. *Aquacult Int* **28,** 2465–2479 (2020).

Use of Gravitic Engine for Surface Power Z. R. Havens[1], [1]Individual, 9601 FOREST LN APT 803 DALLAS, TX 75243. (Contact: graviticengine@gmail.com)

Introduction: A gravitic engine is a device designed to draw energy directly from a gravitational field, by using potential energy against potential energy. If placed on or within the lunar surface, in a pressurized, insulated container, it could continuously generate electricity for long, long periods of time, without conventional fuel requirements or downtime.

Sketch: To the right is a sketch of a potential prototype to build on Earth. The main operation of the device involves a collection tank, buoy tank, a bladder tank, a buoy, and a main weight.



Basic Operation: Liquid flows from the collection tank into the buoy. Buoy sinks, lifting a main weight. Liquid is then transferred to a bladder tank. Main weight falls back on bladder, acting as a pump, sending liquid to a reservoir tank. Liquid falls into the turbine blades, generating electricity, before returning to the collection tank. This is designed as a steady state, where potential energy is the driving force in each stage.

Math: Don't believe me? Force balance equations and input variables can be found under 3/17/2021 math on sheet two of the following url:

https://drive.google.com/file/d/1wXJuLuX7xwTpXZpcZeh-N9p98AqsP2O3/view?usp=sharing

for potential Earth and Moon prototypes of the gravitic engine.

Plan: An animation and an updated description of the general operation of current prototypes should be completed by late April or early May. A moon prototype will be discussed for the sake of surface power at the LSIC conference, but the current idea can be useful on any planet or moon with a solid surface and large enough gravitational pull.

LUNAR POWER LANDER.

D. D. Hawk[1], [1]Watts On The Moon phase 1, Oneida Indian Reservation, N6088 County Rd. E., De Pere, WI 54115. (itspaceagency@gmail.com).

Introduction: Two things are needed to provide a viable lunar surface grid system, 1) decreased single event burnout (SEB) rates of silicon carbide (SiC) power devices and, 2) wireless power transfer (WPT) outside the line of sight (LOS). This abstract is on the latter.

No power poles, no running power cables: It is believed that Paul Jaffe from the U.S. Naval Research Laboratory, states we will not put-up power poles or run long stretches of power cables across the Moon. From this, we can devise what it would take to WPT from a source point to an end point or user, such as a mining operation, just like power poles on Earth. Similarly, to reflect laser by mirror from a point source such as the rim of a PSR crater, like UVA BELLE, to an end point that might be outside the LOS such as a Mobility Platform or mining operation. It would seem, that most Challenges such as the Watts On The Moon Challenge infer an easy and manageable solution such as continuous LOS but, 100% targeting is not real-reality and as such a lunar power lander would be required and is likened to a cut-off man on a baseball field; to capture and redirect power to its intended target outside of LOS.

This suggests, because of remoteness or distance, that lunar power landers, perhaps using repurposed RS-34 hardware can strategically land just about anywhere they are needed to uptake power or laser and store and or retransmit WPT to another power lander or to an end point that is outside of LOS; to complete or redirect laser or WPT from source to an end user just like power poles here on Earth.

THE ROLE OF SPECIAL PURPOSE LUNAR POWER LANDERS SHOULD NOT BE DISMISSED: If we are not going to put up power poles and lay cable across the lunar landscape, it makes sense to discuss what a lunar power lander' role and functions ought to be.

GEOLOGIC CONTEXT FOR LUNAR SOUTH CIRCUMPOLAR REGION (SCR) EXPLORATION: IMPLICATIONS FOR GOALS, SITE SELECTION AND OPERATIONS STRATEGY. J. Head[1], C. Pieters[1], D. Scott[1], M. Ivanov[2], S. Krasilnikov[2], A. Krasilnikov[2], A. Basilevsky[2], H. Hiesinger[3], C. van der Bogert[3], B. Jolliff[4], N. Petro[5], D. Moriarty[5], P. Lucey[6]. [1]Brown Univ., USA; [2]Vernadsky Inst., Russia; [3]Westfälische Wilhelms-Univ., Germany; [4]Washington Univ., USA; [5]NASA GSFC, USA; [6]Univ. Hawaii-Manoa, USA (james_head@brown.edu).

Introduction: National and international exploration of the Moon has become focused on the South Circumpolar Region (SCR) due to: 1) the scientific desire to explore outside the northern nearside Apollo-Luna-Chang'e 3/5 region, 2) the fundamental science questions [1] that can be addressed in the SCR (e.g., crust-mantle structure/composition, absolute chronology, water cycle record/resources, role of South Pole-Aitken basin (SPA-B), etc.) and 3) the need for solar illumination/power to survive lunar night. We focus here on the basic background geologic setting ("bedrock" geology) of the SCR to 1) identify the major sequence of events, 2) assess what this means for addressing the primary (non-volatile) scientific questions, and 3) assess how these influence human/robotic exploration strategy, using a systems approach [2]. SCR polar volatile exploration strategy is treated separately [3]. **Global Context:** The SCR is a fundamentally unexplored region providing access to the farside and two major relatively unexplored lunar crustal terranes (FHT and potentially SPA [4]). **Sequence of Events:** Following magma ocean solidification, the ~2500 km SPA basin formed [5-7], creating the largest and oldest known lunar basin; subsequent impact events dominate the region at all scales (Schrodinger, Orientale, Mendel-Rydberg, subsequent craters, e.g., Shackleton, Cabeus, Haworth, Faustini, Shoemaker, etc.) [8-10]. **South Pole Location:** The center of the SCR is located within the SPA outer ring, equivalent to the Orientale Cordillera but due to the multitude of subsequent impact events and their ancient ages, is more similar to A-16 central highlands (complex impact polymict breccia-dominated geology [11]). Deconvolution of the complex SCR history presents a formidable challenge, requiring an integrated strategy for site selection, traverse planning, sample assessment/documentation/acquisition, and return analyses.

Guidelines for Addressing SCR Scientific Goals: 1. Geologic/Stratigraphic Framework: SCR topography is dominated by the SPA-B outer ring [12], obscured and complicated by multiple subsequent overlapping impacts/ejecta deposits, most like the Apollo 16/Descartes Highlands; detailed local geomorphology provides minimal clues to multiple polymict breccia provenance. At SCR, 20+ km diameter craters/interleaved ejecta deposits at all scales will dominate walking traverse sampling. **2. The SPA Basin Ejecta/Mantle Sampling Paradox**: SCR lies on the SPA basin rim crest interpreted to have formed from an oblique impact (SSW-NNE); most of the ejecta is likely to have been deposited *away* from the SCR. If the SCR SPA-B rim contains any mantle material the most likely sampling locality is the steep-sloped Mons Malapart [12], potentially occurring as small breccia fragments, admixed further by subsequent impacts. **3. Determining Basin/Crater Absolute Chronology:** Dating specific SCR crater/basins will be largely statistical, putting focus on obtaining a regional sample that is both representative of SCR and collects any "exotics". **4. Importance of Secondary Craters in Establishing Absolute Chronology:** Shocked samples at secondaries from distant basins (Mendel-Rydberg, Schrodinger, Orientale, etc.) and craters (e.g., Tycho) where provenance is known [13] will be important to sample in detail to date the source craters. **5. Landing Site Selection:** Pinpoint landing is necessary to ensure access to specific targets of crater/basin ejecta, secondaries, SPA-B mountains. **6. Traverse Design/Mobility**: Two major requirements derive from SCR geology: 1) Due to the complexity of the geology and samples, time at individual sampling stations will be long and learning/discovery-intensive relative to Apollo; 2) Mobility >Apollo 15-17 (>10s of km) is required. DRM-CONOPS might feature long, radially oriented traverses with multiple, widely spaced, long-duration stations, at which large quantities of carefully selected samples are collected. Fresh blocky craters are attractive stations, and rover design should exceed design/performance of Apollo Lunokhod rovers in order to ascend SPA-B massifs (e.g., Mons Malapert [12]). **7. Sampling Procedures:** Triaging polymict breccias on the lunar surface is not a productive option. Required are: 1) Real-time, hand-held, helmet-displayed remote sensing capability to identify key "fingerprints" (e.g., mafic/ultramafic, KREEP-rich), 2) tools ensuring diverse and representative samples (e.g., lunar rake), 3) large sample-return mass to ensure valid petrogenetic and chronologic statistics, and 4) mobility (>10s of km) to determine the regional petrologic variability of 20+ km diameter craters, underlying SPA basin regional ejecta deposits, and basin/crater secondaries. **9. Mission Operations and Science Support:** Very steep on-site learning curve; respect situational awareness, develop ground advisor/consultant psychology [14], practice inter-EVA debriefings; develop Mars exploration techniques.

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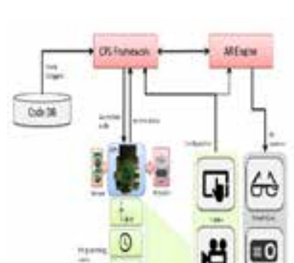
Abstract Title: New Space and Workforce 2.0.

W. C. Houston, Workforce 2.0 – 2300 Fifth Avenue, New York, NY 10037 (Contact: walterh@wf-2-0.com)

A. **Overview: Commercial space, or New Space, startups, and space ventures are some of the most visible and viable trends for the 21st century, a new workforce is required.**[1]

B. **Problem: Dust exposure and inhalation could have a range of toxic effects on human lunar personnel, especially if longer exposure times become the norm during future industrial and production missions, new concepts and modernization is required.**[2]

C. **Our Solution: The ELMS (Enhanced Learning Management System) EXO is a suit designed for deep space industrial tasks, including construction, mining, manufacturing, and other tasks. ELMS is controlled by a modular/compositional CPS framework and is human/machine centric.**[3]



Modular/Compositional Framework, including neuronet and multi-machine interface.

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Cyber-Physical-Systems infused exoskeleton.

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Smart, light, dust resistant, 5G enhanced, ELMS EXO Mach 1 Industrial Extraterrestrial Suit.

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Multi-Product Lunar Regolith Beneficiation System. K.J.H. Kingsbury[1], I. Barton[2], & V. Tenorio[3]. [1]University of Arizona, PO Box #27822, Tucson, AZ 85726. [2 & 3]University of Arizona, 1235 James E. Rogers Way, Tucson, AZ 85719. (Primary contact & lead author: Kerstk@email.arizona.edu)

Abstract:

The utilization of in-situ resources such as water ice and regolith materials found on the surface & near subsurface of the Moon is fundamental to establishing a sustainable and permanent human presence there. Developing new beneficiation techniques that differ from contemporary terrestrial approaches is an imperative to sufficiently utilize those resources.

Step 1: Comminution

The initial step of the new beneficiation technique proposed would utilize a focused high-voltage electromagnetic pulse (E.P.D.) [1] to comminute both water ice and regolith. This would result in drastically less ultra-fine dust being disturbed into the local exosphere than what contemporary mechanical crushers would produce, and would lead to higher disaggregation of water ice enclosed within micropores of the regolith.

Step 2: Separation

The resulting fine-grain material would then be partitioned using a triboelectric-charged belt (T.E.B.S.) [2] to separate water ice particles [3] from regolith material. The remaining fine regolith material would then undergo further belt separation where native metallic particles of iron, titanium, and aluminum [4] may be partitioned out and used for infrastructure or machine part repair. These metallic particles may be made into these forms via sintering in the powder metallurgy technique, which would require no further processing of the particles.

Step 3: Extraction

The remaining regolith minerals may be be developed into various concentrates, which would then be subjected to molten regolith electrolysis [5] to extract additional elemental resources. Thorium [6] may be removed and used as a fuel in a “melt-down-proof” fission reactor. Sulfur may be removed and used as the bonding agent of a waterless lunar concrete, which would use the remaining fine regolith particles as aggregates. [7]. The extremely fine particle sizes E.P.D. can produce and T.E.B.S. can differentiate are large assets in producing quality, uniform aggregate that would lead to the strongest possible concrete. The waste heat generated by the use of molten regolith electrolysis can be used for sintering the waterless sulfur-based Lunar concrete, which would further increase its strength and durability.

Ultimately, this process provides a feasible mineral processing system that would mitigate hazards, reduce infrastructure costs, and may be scaled down to fit the needs of a fledging Lunar outpost.

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ADVANCED, SCALABLE, CONTINUOUS ENERGY & POWER GENERATION and DERIVATIVE APPLICATIONS

M. Kroupa, CE, ME, AE, Physics; Technology Director, New Frontier Technology Group
Email: NFTG_MK@PROTONMAIL.COM

Introduction: A novel, low cost, scalable, versatile, easily manufacturable, power dense system capable of delivering 300-600% more energy output continuously than any system under consideration for power generation and unconstrained mobility or machinery operation.

Overview: It is well known that, due to dependencies, energy is the single most important topic needing to be addressed before any other topic.

Abundant, low cost energy paves the way to more intelligently solving the remaining five LSIC focus areas (in-situ resource utilization, extreme access, extreme environments, dust mitigation and excavation and construction)

To wit, NFTG has conceived a simple, power system based on currently available technologies and several of our simple innovations, which we hope to develop and demonstrate in NASA's current 'Break The Ice" challenge. [We are seeking team members.]

Function, features & benefits: The novel power generating concept and integration of our maximally efficient innovations gives rise to the unprecedented power/energy output. Its ultra high power/energy density, along with scalability of components and the system, allows unconstrained operation of any equipment which is facilitated by the waste heat. Therefore lunar night or geographic location imposes no restriction on the system and adjunct equipment.

The components and system are low cost, simple and robust, providing long life and minimal downtime for any application including our novel high volume, high speed mining, refining, adv. drilling/tunneling, large scale electrostatic dust mitigation and advanced high performance lunar terrain vehicles (LTV) & 'air' mobility systems (LAV). We have also devised novel integrated solutions to mitigate the dust problem in regards to the system and most any complementary machinery. Repair will be possible using 3D printing and other solutions which are low power and compact. Even most of our maximally torque dense electric machine technology can be printed with light weight materials.

The technology can be made modular and to integrate with other power generation technologies, further increasing its versatility and utility.

The combination of constant power output and mining & refining capabilities allows for manufacture and use of simple, large scale [MW], long life [>20yr], non hazardous, non toxic, energy dense batteries based on our associate's technology. Other chemistries are under development.

Hurdles: We are not aware of any significant parameters and constraints on the architecture and ancillary architectures required to support our energy solution and derivative solutions.

IOHO, the design, modularity, scalability, versatility and economics clearly demonstrate superior solution above all others which will enable sustained presence on the lunar surface and beyond for years to come.

TRL: Most of our innovations are at level 2-3 but can rapidly be turned into doctrine with Phase 2 SBIR funding.

Future tech: Our affiliates are developing an overfunded, lower cost and weight energy technology which will integrate with ours or supplant parts of it.

Another strategic partner is developing ultra high efficiency thermoelectric generator technology which will improve output of our architectures.

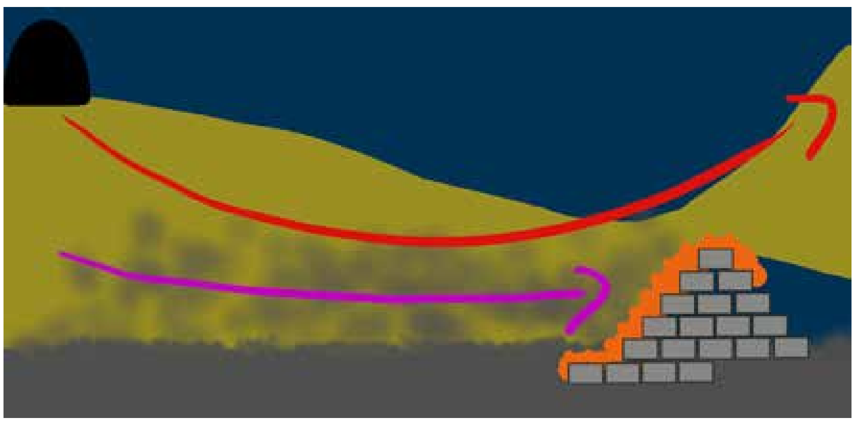
[*I apologize for the brevity of this paper, for the time and IP constraints*]

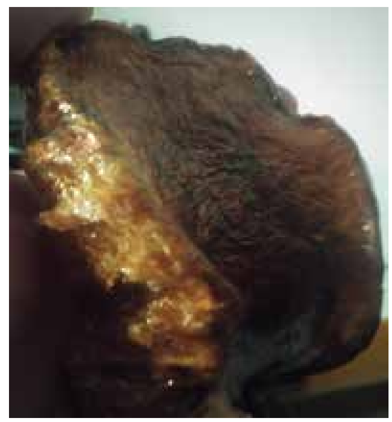
Launchpad Dust Mitigation with Chitosan Biofoam and In Situ Resource

A, Bennet[1] and G, Licina[2], [1,2]Scihouse Inc, 2920 E Jefferson Blvd, South Bend, IN, 46615 (gabriel@scihouse.space)

Introduction: Utilizing Compressed Earth Blocks (CSEB) [1][2] made from lunar regolith and coated with a lyophilized chitosan foam [3] to reduce debris from takeoff and landing from the lunar surface.

Manufacturer of CSEB from In Situ resources: Using the CINVA Ram[2] process to form dry compressed bricks of regolith as a building material. This benefits from a low launch weight and can be manually operated if needed.





Lyophilized Chitosan Foam: Lyophilization of chitosan dissolved in a weak acetic acid solvent forms a solid foam with material properties similar to aerogel as show in orange in above figure

Treating CSEB with chitosan foam: This process involves spraying the foam onto a lattice wall of CSEB's to form a perimeter that will trap regolith from the exhaust gasses. The chitosan foam forms a gyroid pattern with a leading edge that mimics tubercle design [4] which allows lunar regolith to separate from the exhaust gases while also providing a barrier from the exhaust gas and reducing chitosan and brick erosion. The majority of the structural reinforcement is done via a barrier of CSEBs composed of the lunar regolith.

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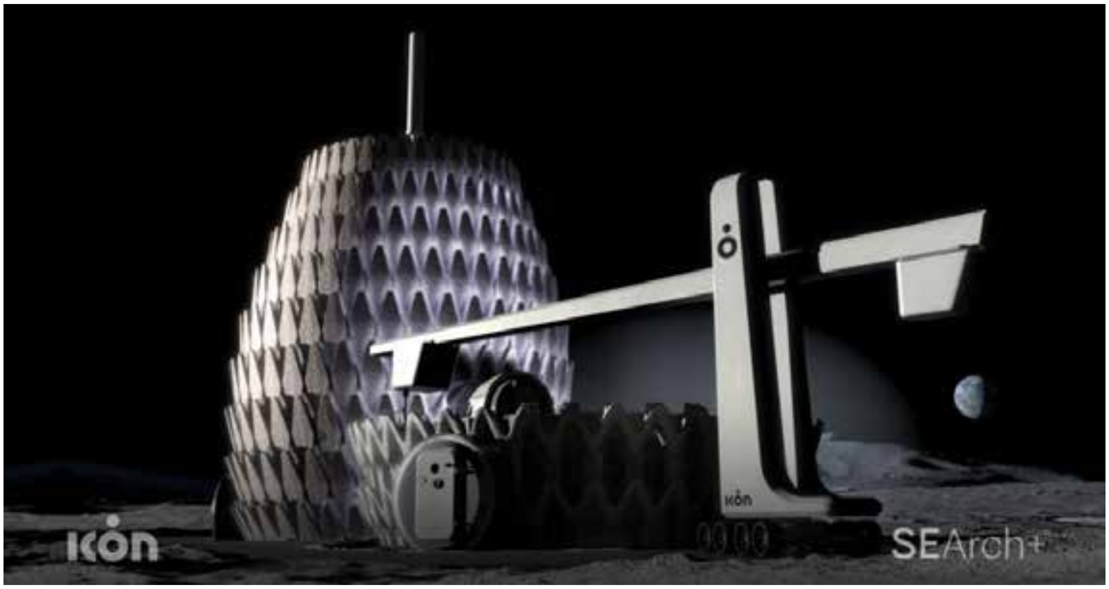
Lunar Surface Innovation Consortium
Spring Meeting May 11 & 12, 2021 (virtual)



The Lunar Lantern for Icon's Project Olympus

Michael Morris[1], Rebeccah Pailes-Friedman[1], Melodie Yashar[2], Christina Ciardullo[3],
SEArch+, 595 Madison Street, Brooklyn, New York 11211

michael@spacexarch.com, rebeccah@spacexarch.com

SEArch+ (Space Exploration Architecture LLC) have developed design schematics for habitat, landing pads, and infrastructure titled "The Lunar Lantern for Icon's Project Olympus" , as part of the Moon to Mars Automated Planetary Construction Technology (MMPACT) Team, a NASA Marshall Space Flight Center (MSFC) funded research initiative to support future long stay human missions on The Moon and Mars. As both catalysts for MMPACT and commissioned designers for Icon's Project Olympus, SEArch+ has expanded upon their NASA award winning portfolio of 3D printed structures from ISRU regolith for Mars with their first comprehensive assignment for The Moon. The Lunar Lantern, developed to spur and manifest Icon's additive manufacturing technology developed for the Moon, and exemplify SEArch+'s rigorous evidence based and collaborative approach in the design habitats, landing pads, and infrastructure. SEArch+'s presentation will include videos, animations, and charts to illuminate their collaborative "human centered" approach to designing extraterrestrial structures that will not only allow mankind to live safely but to thrive within the challenging environments of outer space.

[1] Co-Presenters , Co-Founder & Project Associate, SEArch+
[2] Co-Founder & Project Associate, SEArch+
[3] Co-Founder, SEArch+

Chargeable Atomic Batteries: Watt-Scale Commercial Radioisotope Heating and Electricity Units Enabling Extreme Lunar. C. G. Morrison, USNC-Tech, 2356 W Commodore Way, Seattle, WA 98199, (c.morrison@usnc-tech.com)

Introduction: Atomic batteries possess one-million times the energy density of state-of-the-art chemical batteries and fossil fuels. Atomic batteries are enabling for locations that do not possess access to the sun or other energy sources. Relevant use cases on the Moon include surviving the lunar night, exploring permanently shadowed regions, cave exploration, process heat for ISRU, and other applications. USNC-Tech is maturing a patented (PCTUS2116982, PCTUS2116980) atomic battery technology and is actively engaging the government, commercial companies, regulatory agencies, and maunfacturing partners to achieve a commercial product.

The challenges in production and the complexity of containing nuclear material have limited the application of atomic batteries. Traditional atomic battery solutions focus on the high performance but expensive special nuclear material Plutonium-238. The cost, necessarily controlled nature and limited supply of Pu-238 prevent widespread commercial use.

Atomic batteries are manufactured using natural non-radioactive precursor material embedded within an encapsulation material. The precursor material is then activated or "charged" inside a radiation source and packaged. This concept is known as a Chargeable Atomic Battery or CAB.

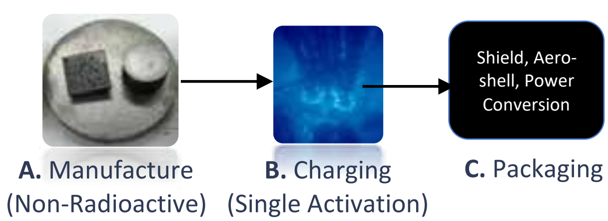


Fig 1. CAB Manufacturing Process

CABs can be manufactured in existing facilities and have a path toward a prototype using available technologies and facilities. For watt-scale batteries, the process can be demonstrated to a TRL of 5 with a ground demonstration in the near-term.

CAB Product: A CAB Unit is a cylindrical heterogeneous ceramic with an outer wall and a filling as shown in Figure 2. The wall is composed of an encapsulation material and the filling is composed of an activation target material known as a precursor material. Multiple CAB units are integrated into a stack. The stack is integrated into a system which could include an x-ray shield, power conversion, thermal managuement and aeroshell.

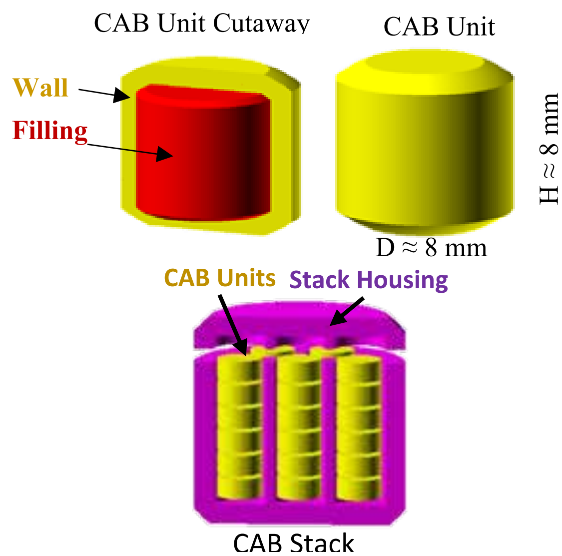


Fig 2. CAB Technology for a Lunar Heater

The encapsulation methods can be used with different types of isotopes and the CAB units can be tailored to meet the half-life, x-ray shielding, and power density needs of different customers.

Precursor	Radioisotope	Half-life [yr]
^{6}Li	^{3}H	12.3
^{169}Tm	^{170}Tm	129 days
^{59}Co	^{60}Co	5.7
^{151}Eu, ^{153}Eu	^{152}Eu, ^{154}Eu	11.0 (avg.)

Table 1. Radioisotopes

CAB systems can be designed to deliver thermal heat (ex. passive heat source to keep the chemical batteries warm), electricity, or passive x-rays for characterization or signaling.

Conclusions: CAB technology a lower performance technology compared to Pu-238. However, CAB technology can provide many of the same benefits to commercial customers who do not have access. USNC-Tech has a development roadmap for CAB technology included licensing, and ground and flight demonstration. Interested parties are encouraged to reach out to the author and attend the meeting session to learn more.

Off Earth Landing and Launch Pad Construction – A Critical Technology for Establishing a Long-Term Presence on Extraterrestrial Surfaces

Nathan J. Gelino[1], Robert P. Mueller[1], Brad C. Buckles[1],Robert W. Moses, PhD[2], Laurent Sibille, PhD [3],

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[2]Langley Research Center, National Aeronautics & Space Administration (NASA), Mail Stop 489, Hampton, VA 23681, USA
[3]Surface Systems Group, Laboratory Support Services and Operations (LASSO), URS Federal Services Inc., Kennedy Space Center, KSC, FL 32899, USA

ABSTRACT
Space Policy Directive 1 has refocused the National Aeronautics and Space Administration (NASA) to lead the return of humans to the Moon for long-term exploration and utilization. A long-term presence on the moon will require numerous lunar landings and launches to build up surface assets, rotate crew, and deliver resources to/from the moon. Interactions between landing/launch plumes and the unprepared surface cause regolith to be eroded and ejected at high velocities from beneath the vehicle. The associated ejecta elevates mission risks by obscuring sensors and human vision during landing; cratering/modifying the surface that the vehicle will land upon; and subjecting the vehicle, surrounding assets, and potentially orbital assets to impacts from high velocity dust particles. A method to mitigate risks stemming from landing/launch plume ejecta is to construct reusable landing/launch pads. A landing/launch pad can provide a known landing/launch surface, minimize ejecta, protect assets from liberated particles, and provide protection in case of a landing/launch anomaly. This presentation will summarize previous work towards construction of off-Earth landing/launch pads and identify key technology gaps. Additionally, this presentation establishes metrics for comparison of pad construction technologies and trades current approaches. The overall objective of this paper is to baseline the state of the art of off-Earth landing/launch pad construction technologies and serve as the starting point for further technical development.

Integrated Lunar Surface Power Grid. M. Provenzano[1], C. Corpa de la Fuente[1], L.Radue[1], T. Arbuckle[1], J. Zimo[1], [1]Astrobotic Technology, Inc., 1016 N. Lincoln Avenue, Pittsburgh, PA 15233, mike.provenzano@astrobotic.com.

Introduction: Astrobotic is developing an integrated lunar surface power grid that can be delivered on a single Astrobotic Griffin (or other CLPS scale) lander and generate power using Astrobotic Vertical Solar Array Technology (VSAT). This end to end offering is called Astrobotic's Mobile Power Distribution (AMPeD) system (Figure 1). AMPeD comprises several products and services that can each be provided as stand alone space qualified solutions including rovers, wireless charging systems, cable reel systems, and connectors.

Each system is funded to achieve high TRL maturation. Astrobotic's Griffin lander is scheduled to fly NASA's VIPER rover to the lunar south pole in 2023. Astrobotic's VSAT was selected as one of five technologies to continue development towards flight qualification. Both the CubeRover and wireless charging system will be flight qualified under two distinct NASA Tipping Point contracts and tested in a lunar night environment. Each technology is configurable to support an array of missions and systems. As such, through combining these technologies, Astrobotic provides a flexible and comprehensive power infrastructure.

The wireless charging system is being developed in partnership with WiBotic and will soon be available in 120 W and 400 W units. These systems are 85% efficient and are actively being improved. Units have been tested at the Kennedy Space Center with the Regolith Advanced Surface Systems Operations Robot (RASSOR). Charging performance was tested with eight different planetary regolith simulants and has proven insensitive to regolith dust coverage.

CubeRover is a first of its kind ultra-light, modular, and scalable commercial rover. It uses the same standard sizing as CubeSats, where each 10 cm × 10 cm × 10 cm volume that supports 1 kg of payload is called a unit or "U." Regardless of size, all CubeRovers utilize the same bus, subsystems, and payload interfaces. This allows the rover to support diverse instruments and technologies, such as a mobile power station shown in Figure 2. Several components have been flown on previous missions or are flight qualified for orbital applications. Qualification tests will be performed on a high-fidelity engineering model in August 2021.

Astrobotic's Griffin lander is capable of carrying 500 kg to the lunar surface. A Preliminary Design Review will be held for this system soon and a structural test model will be built and qualified later this year.

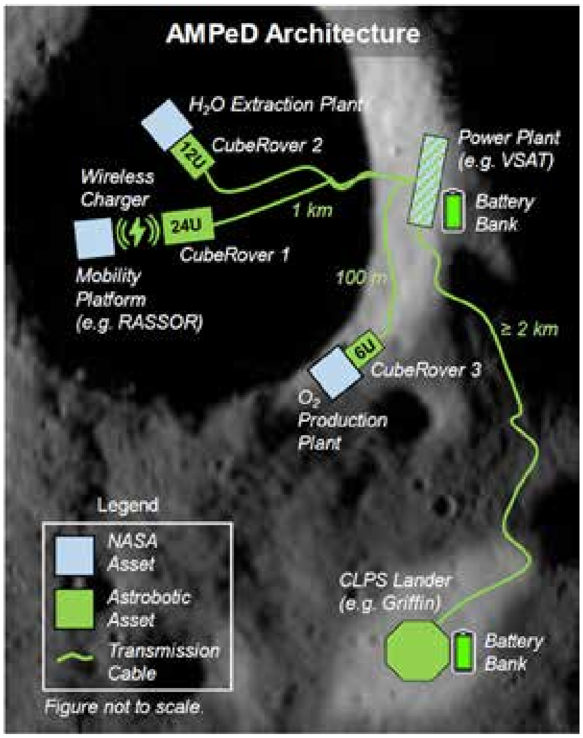


Figure 1. AMPeD Architecture. AMPeD reflects Astrobotic's total mission mindset.Combined with our VSAT and Griffin lander, it forms a complete lunar surface power ecosystem.

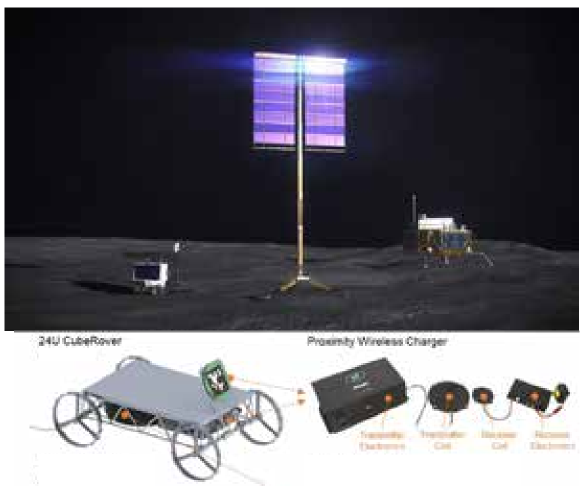


Figure 2. CAD models and images of AMPeD's major hardware components.

LISTER (Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity): A Heat Flow Probe Robotically Deployable to 3-m Depth. V. Sanigepalli[1], S. Nagihara[2], P. Ngo[1], M. Zasadzien[1], A. Wang[1], P. Morrison[1], M. McCormick[1], P. Ng[1], D. Sabahi[1], G. Paulsen[1], K. Zacny[1], [1]Honeybee Robotics, [2]Texas Tech University. (Contact: kazacny@honeybeerobotics.com)

Introduction: LISTER (Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity) is a science instrument designed to measure the heat flow from the interior of the Moon. LISTER can be mounted either to the belly pan or the leg of a lander for deployment (**Figure 1**). The probe can penetrate up to 3 meters into the lunar regolith using a pneumatic drill, and it measures the thermal gradient and the thermal conductivity at 0.5-m depth increments. The heat flow is obtained as the product of these two measurements. The measurements will provide key constraints to the Moon's thermal evolution and the history of the crust-mantle differentiation.

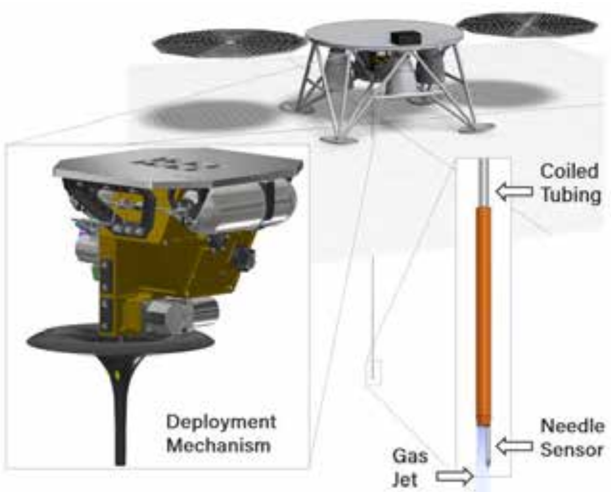


Figure 1: Drawings of LISTER Deployment Mechanism belly mounted to a lander.

LISTER's deployment mechanism uses a 4.5 meter long, seamless, 6.35-mm-dimater tubing made of 304 stainless steel, and the sensors are attached to the end leading into the subsurface soil. The tubing, which is initially stored in a coiled form within the instrument housing, is straightened, as it spools out, by a series of guide and intermesh rollers with a brushless DC motor and a gearhead. The same mechanism can also be used to partially retract the coiled tubing when required to recover from obstacles and/or potential failure modes. Breadboard tests have shown that the coiled tubing can be fully cycled (full deployment and retraction) up to 4-5 times without burnishing the tube.

LISTER excavates a hole by deploying the tubing as the pneumatic subsystem emits a gas jet through the penetrating cone (Figure 1). Due to the expansion of the gas into vacuum, soil transfer efficiencies can reach 1:6000 (1 gram of gas lofts 6000 g of soil) [1]. On the way down, the probe makes 7 stops from the surface to 3-m depth. At each stop, it measures thermal conductivity (k) and temperature (T) using a ~20-mm-long and 2.77-mm-diameter needle sensor at the cone tip. The needle contains a resistance temperature detector and a heater which is used for the thermal conductivity measurement.

Testing and Demonstration: The LISTER architecture has been proven in a vacuum chamber at 900 Pa with 2:1 mix of lunar regolith analog BP-1 [2] Fines and 3-5 mm-diamaterrocks. The system has penetrated up to 1.5+ meter depth at a rate of 13 mm/s. The probe is also able to diplace or separate a cluster of rocks by employing the 'dithering' movement, where the deployment mechanism retracts and re-deploys the tube with 1-cm steps.

The regolith particles blown out of the borehole are diverted radially outward with a Dust Deflector that is mounted above the hole (**Figure 2**). The regolith particles follow a ballistic trajectory due to vacuum and can be directed away from other instruments. The hole diameter can vary, depending on the factors such as regolith composition, depth, gas flow rate, etc.

Figure 2: LISTER pneumatic drilling of lunar regolith analog BP-1 in a vacuum chamber and the regolith is directed out radially using a Dust Deflector (left). The top of the bore hole measures ~80-100 mm in diameter for a rocky regolith mixture (middle and right).

References: [1] Zacny et al. (2010) AIAA Space, 8702 [2] Suescun-Florez et al. (2014) Journal of Aerospace Engineering 28. 04014124.

Acknowledgements: LISTER is funded under NASA Lunar Surface Instrument and Technology Program (LSITP) program.

Lunar Open Architecture. Mehak Sarang[1] and Ariel Ekblaw[2], [1]MIT Space Exploration Initiative, 75 Amherst St, Cambridge MA, 02139 (Contact: msarang@mit.edu)

Introduction: The Lunar Open Architecture (LOA) is the first dynamically-updating and open roadmap for lunar exploration, powered by an evolving database that captures and coalesces current and future missions for lunar exploration. This work, out of the MIT Space Exploration Initiative, builds upon our partnership with the Open Lunar Foundation – a non-profit helping to create a peaceful, cooperative future on the Moon for all life. Together we are working on open-access data, policy and cross-industry partnerships that support a sustainable lunar settlement driven by open values. Over the past few months, we have co-convened a series of research salons, the "Moon Dialogs," which explore questions of governance and coordination for lunar settlement and stakeholder activity on the Moon.

Currently in beta stage, the content in LOA is preliminary and we invite comment, feedback, contribution from the LSIC community. We have pre-populated a demonstration database and interactive, exploratory visualization with certain sample missions. This first prototype relies on the Lunar Exploration Analysis Group's Lunar Exploration Roadmap to establish the first round of objectives, and also includes a schema from the NASA Technology Taxonomy. Content will be added to reflect other strategic roadmaps (from the Global Exploration Roadmap, ESA, and other space agencies as well as industry plans) and critical-path figures of merit associated with roadmap milestones, as we move forward.

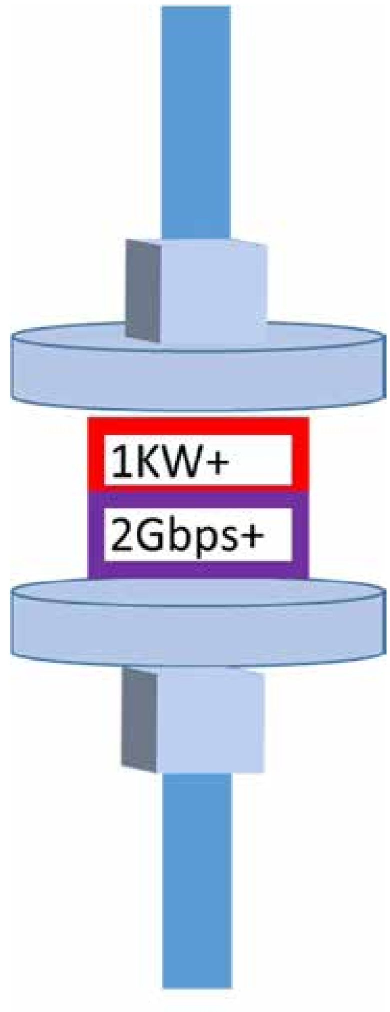
We are building LOA to be a place to share research insights, to identify critical gaps or missing investigations for technology roadmaps, and to identify policy or standards needs as they arise. In addition, the LOA baseline content will reflect the full known ecosystem of lunar missions (viewers can peruse historical, current, and prospective entries in the current visualization). We envision LOA as an industry-informing open repository and as an online place to gather – to discuss visions of lunar exploration, prototype new ideas, and engage in collaboration. In this regard, the next version of the database will expand dramatically, including potential technologies and payloads, capturing information shared during conference proceedings, and even allowing for experts to share insights or opinions on new developments in the industry, adding a level of credibility and data qualification to the database that doesn't exist in other roadmapping efforts.

Our presentation at the LSIC Spring Meeting will focus on the use of LOA particularly for ISRU planning, and will demo an ISRU sub-database and roadmapping effort as a case-study for LOA's use in lunar mission planning and integration with the Artemis program.

Visit https://loa.mit.edu to review the current prototype, and a "Council of Voices" report from leading figures in the space industry on their predictions for what's next in lunar exploration in 2021.

Weatherproof Electrical Interface (WEI). Shengming Shan, SWR Technology Inc., Fremont, CA. (Contact: smshan@swrtec.com)

Introduction: An award-winning Weatherproof Wlectrical Interface (WEI) is introduced to provide highly reliable electrical connections under extreme weather conditions. The electrical interface can deliver power of more than 1KW and data of more than 2Gbps. Furthermore, it also supports various operations features like unlimited mating cycles, lubrication/maintenance free, dust tolerant , galvanic isolation, contactless, and through barriers without drilling [1].



Technology: It's based on SWR Technology's patened technology [2], which enables efficient (95%) wireless power transfer and integrated power/data operation.

Applications: Any industrial, defense and space applications that require highly relaible electrical connections and minimum maintenance will benefit from the Wireless Electrical Interface (WEI). For NASA, WEI might be of specific interest in 2 of Artemis program's focus areas: Extreme Access and Dust Mitigation.

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Design Of A Centralized Supervisory Post For Monitoring Mine Operations And Scientific Studies On The Moon. V.O. Tenorio[1], K.J. Kingsbury[2], K.W. Brown[3], J.B. Nickels[4], G.J. Nail[5], and D. J. Tolmachoff[6], [1]Professor of Practice, Department of Mining & Geological Engineering, Univerisity of Arizona 1237 E James E. Rogers Way, Rm. 237 Tucson, AZ 85721-0021, [2]Student, Department of Mining and Geological Engineering, University of Arizona, 1237 E James E. Rogers Way, Rm. 229 Tucson, AZ 85721-0021, [3]Student, Department of Mining and Geological Engineering, University of Arizona, 1237 E James E. Rogers Way, Rm. 229 Tucson, AZ 85721-0021, [4]Student, Department of Mining and Geological Engineering, University of Arizona, 1237 E James E. Rogers Way, Rm. 229 Tucson, AZ 85721-0021, [5]Student, Department of Aerospace & Mechanical Engineering, University of Arizona, 1130 N. Mountain Ave. P.O. Box 210119 1237 E James E. Rogers Way, Rm. 229 Tucson, AZ 85721-0021, [6]Student, Department of Mining and Geological Engineering, University of Arizona, 1237 E James E. Rogers Way, Rm. 229 Tucson, AZ 85721-0021. (Contact: vtenorio@arizona.edu)

Introduction: Industrial and scientific activities located in Off-The-Earth posts, such as mining, telescope observation, and deep space studies require centralized supervisory facilities located either at line-of sight from the production locations or in strategically designated points sheltered from extreme radiation and other potential hazards, for a convenient centralized supervision. Operations such as icy regolith extraction for water decomposition [1] in or near the craters at the Permanently Shadowed Regions near the South Pole of the Moon will require direct observation at least during the pioneering works [2]. The design of these posts shall consider temperature and atmospheric pressure control, full communications capabilities, emergency procedures for quick evacuation, diverse types of interactive controls for teleoperation and dashboards for decision making during work cycles [3]. Parameters utilized in Earth-bound control rooms may require to be adjusted to acceptable rotation periods, functionality of consoles and displays for safe performance and transmission of commands while continuing with production goals.

Mine Operations Supervory Posts

The dynamics of extraction of natural resources from beneath the ground or on the surface of the Moon will require to consider the proximity to operations in order to obtain a vantage point for observing the production process, and the distance from the camp dormitories. During the pioneering works, it is likely that human presence will be required. In a later stage, many of these activities could be automated or teleoperated, which may allow the post to be relocated to a less hazardous place.

Astronomical and Deep-Space Study

In addition to production activities, the opportunity for astronomical observations and deep-space studies come convenient given the extreme clarity of a firmament without the interference of atmosphere. Platforms for telescopes and other devices could be constructed transforming regolith into a construction material. One more time, the distance of these remote posts from human habitat needs to be considered when designing roads and commuting needs, as well as tolerable rotations.

Earth-to-Moon Communcations

Remote operations and scientific study posts will require a solid communications network. Between the production sites and the Moon cental headquarters, and between the Earth and the Moon, and orbiting Space Stations.

Centralized Supervision of Operations

An array of CubeSat devices could be placed orbiting the Moon, allowing to create a robust 5G communications configuation for standard communcations and advanced telecommand and automation [4]. While some of these systems may run and auto-adjust by themselves, there is always the need of human presence for additional technical support.

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Robot Hibernation: A Concept for Dealing with Long Lunar Nights M.Thangavelu[1] and S.Hunt[2], [1]Conductor, ASTE527 Graduate Space Concept Studio, Department of Astronautical Engineering, Viterbi School of Engineering, University of Southern California, Los Angeles, CA90089-1191, [2]Graduate Student, Department of Astronautical Engineering, Viterbi School of Engineering, University of Southern Califor-nia, Los Angeles, CA90089-1191. (Contact: mthangav@usc.edu)

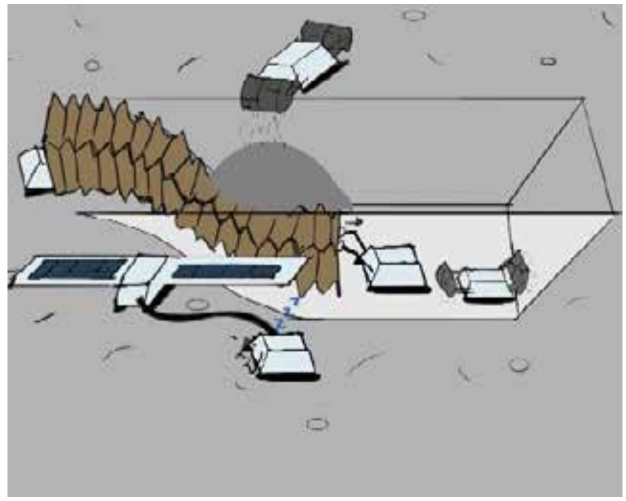
Introduction: NASA's Artemis program has the ambitious goals of putting a woman and man on the Moon by 2024 and establishing a sustainable lunar presence. The Moon's unwelcoming nature, extreme and harsh surface conditions make clear that robotics will be an integral part of any mission; especially those with sustainability in mind. Diurnal temperatures on the lunar surface swing much more widely and dip much lower than on Earth, It can get as low as -173.15 °C and last around fourteen Earth days, which is dangerously cold and prolonged, even for robots. And this phenomenon, especially during the long lunar night has serious consequences for all missions, robotic and human.

Good efforts are being made in lunar robotics through the Commercial Lunar Payload Services (CLPS) initiative, that is intended to provide critical precursory information for ARTEMIS, but none of them seem to directly address the most pressing issue; the extreme diurnal temperature variation.

The proposed robot hibernation concept addresses this critical problem through a unique solution which takes advantage of one key fact. The lunar regolith in a vacuum environment is a good thermal insulator. At approximately 30 cm below the surface, the ambient temperatures remain more stable and survivable. This characteristic can be valuable for the survival of electromechanical robotic systems.

A robot hibernation architectural concept for lunar exploration is proposed, that takes advantage of the ground surface regolith mass already present on the Moon to survive the frigid temperatures of the lunar night. By building a swarm of robots (small but collaborative, and large in number) and enabling them to dig beneath the lunar surface, this concept hopes to prove that subsurface dwelling is a viable method of surviving the lunar night on the Moon. Burrowing under loose boulders and rocks to create thermally stable environment is also suggested as an option.

In addition, this concept believes the swarm nature of the robots will allow them to robustly perform meaningful work using solar power during the lunar day, like preparing the surface for development or collecting regolith in preparation of 3D printing useful elements like tiles and bricks for structures, thus finding a balance between thermal ruggedness and utility. It is proposed that all of this serves the ARTEMIS program and is demonstrated to be part of a CLPS mission with lunar night survival as the primary objective and useful work as secondary. Upon successful demonstration, this robot hibernation concept could very well kick off the process towards a sustainable, naturally protected subsurface human and robotic presence on the Moon.Slides of a version called the PANGAEUS may be found in the Fall 2020 USC ARTEMIS TWINS project archives of the USC ASTE527 Space Concepts Studio and may be accessed at : https://sites.google.com/a/usc.edu/aste527/home



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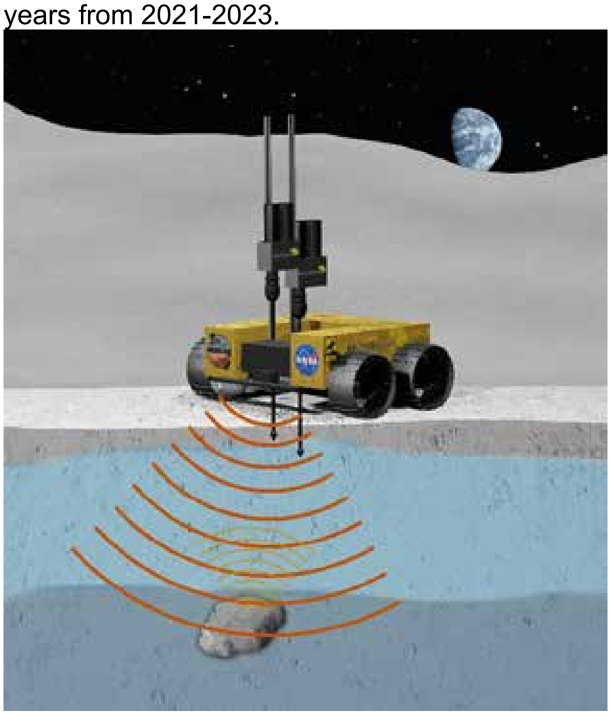
Lunar Geotechnical Property Measurement and Volatile Identification and Quantification using a Percussive Hot Cone Penetrometer (PHCP) and Ground Penetrating Radar (GPR). P.J. van Susante[1] J. Allen[1], T.C. Eisele[1], T. Scarlett[1], and K.A. Zacny[2], [1]Michigan Technological University, 1400 Townsend Dr. Houghton, MI 49931, [2]Honeybee Robotics, 2408 Lincoln Avenue, Altadena, CA 91001. (Contact: pjvansus@mtu.edu)

Introduction: With increased international interest in returning to the lunar surface and harvesting the water ice in the permanently shaded regions it is clear many uncertainties about the geotechnical properties, type and quantity of volatiles remain. Current state of the art in-situ measurements cannot uniquely determine what volatiles are present while determining geotechnical properties. No volatile release profile database exist currently. As part of the inaugural NASA Lunar Surface Technology Research (LuSTR) program [1] our approach to use a percussive hot cone penetrometer (PHCP) in combination with ground penetrating radar (GPR) was selected for funding. The team from Michigan Technological University and Honeybee Robotics will perform this work in two years from 2021-2023.



Planned Approach: Combine a percussive cone penetrometer with heaters and sensors and mount them on the TRIDENT drill z-stage (TRIDENT is scheduled to fly to the Moon as part of PRIME1 and VIPER). In between penetrometer locations, use GPR to determine spatial distribution and layering of ice and rock. This will identify, quatify volatiles in subsurfaceas well as geotechnical properties of the regolith.

Development Objectives: Create prototypes of the heated cone penetrometer and test effectiveness. Using differential scanning calorimetry (DSC) in two percussive cone penetrometers in combination with GPR to determine the type, concentration and vertical and lateral variation in volatiles in the lunar regolith by using thermal profiles and cycling. A dataset of thermal release profiles of cryogenically frozen regolith infused with volatiles will be a major objective.

Testing plan and deliverables: Testing will encompass PHCP testing under lab and field conditions using cryogenically frozen regolith simulant and volatiles in the lab and two field sites, one in a trench filled with different icy layers of regolith simulant to test the PHCP and GPR and another in a natural frozen basalt sand environment where we will create known underground ice and rock layers to identify with GPR. Separate frozen icy regolith simulant test layers will be created in a large freezer for testing the geotechnical property determination using the PHCP as function of ice content and percussive frequency and energy.

Impact and Infusion: The proposed research will provide a dramatic improvement in the direct in-situ measurement of ice concentration with depth at accuracy of 0.1 wt% at 10 cm vertical intervals using DSC. GPR (once calibrated by in-situ measurements) will provide continuous measurement of layers and continuity/obstacles. This will directly inform follow-on missions to the lunar surface and design of the ice mining and extraction equipment Since PHCP will be deployed from a modified TRIDENT-based hammering drill (designed for VIPER), it would fit within VIPER mass/power envelope and as such, it could fly on VIPER 2.0 in 2024 or later. This mission would directly inform the goals of 2028 sustainable lunar presence with mining of polar water ice. Synergy with Astrobotic's SBIR phase II funded GPR development effort will also be possible.

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[1] NASA, https://www.nasa.gov/directorates/spacetech/lustr/US_Universities_to_Develop_Lunar_Tech_for_NASA (2021), last accessed 4/3/2021

T-REX, deploying a super-conducting power and communication cable into PSRs, the NASA BIG Idea Challenge Artemis Award Winner. P.J. van Susante[1] and M.C. Guadagno[2], [1]Michigan Technological University, 1400 Townsend Dr. Houghton, MI 49931, [2]Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931. (Contact: pjvansus@mtu.edu)

Introduction: NASA's 2020 Breakthrough, Innovative and Game Changing (BIG) Idea Challenge sought technology ideas in three areas, 1) to explore lunar permanently shadowed regions (PSRs), 2) technologies to support in-situ resource utilization (ISRU) and 3) capabilities to explore and operate in PSRs. Eight finalist university teams were selected and received funding to build and test their ideas. The Final presentations took place in January of 2021 and Michigan Technological Universitie's (MTU) team won the Artemis Award, winning the overall Challenge with the 'Tethered-permanently shaded Region EXplorer' (T-REX) rover [1].

Concept of Operations: The T-REX rover will be deployed from a CLPS lander that landed within 100m of a PSR. It will then drive into the PSR while deploying a conventional conducting tether (CCT). T-REX will then start descending into the PSR. When the super-conducting tether (SCT) spool have reached super-conducting temperatures (<92K), T-REX will drop the CCT spool which is connected to the super-conducting tether (SCT). Deployment of the super-conducting tether follows while descending into the PSR. Upon reaching a PSR basin after several kilometers of trvel, T-REX will park in its final position. The rover will then function as a local wireless access point and recharging port. T-REX utilizes a HOTDOCK docking port on the front where other vehicles can connect to T-REX and recharge their batteries. Alternatively, T-REX could dock with a stationary plant to hookup power-supply.

Design and Testing Approach: A blended systems engineering and process was used to develop T-REX. A gated requirement verification matrix was used to for high-level development of the mission while a Kanban board was used to track low level tasks. Several prototypes of subsystems were produced and subsequently integrated into the T-REX rover chassis. Rapid testing followed with the goal of requirement verification and raising the technology readiness level (TRL). The MTU team aims to reach TRL-6 by the end of the project.

Test Facility Development: Several facilities were built at MTU to facilite testing. A 14ftx6ftx1ft lunar regolith sandbox with up to 45 degree slope and gravity off-loading capability was built for athmospheric testing. A dusty thermal vacuum chamber was then used for environmental testing. This facility has dimensions of: 1.2mx1.3mx1.7m, can reach 10-6 torr, tempatures of -196C to +150C, while holding up to 700kg of icy regolith.

T-REX Prototype Development Sequence: T-REX was developed with Mk1, Mk2, Mk2.5 and Mk3 iterations. The Mk1 served as proof-of-concept testing on beaches. MK2/2.5 was used for medium-fidelity testing in the regolith sandbox. Mk3 will be a fully integrated system and ready for payload vacuum chamber testing.

Test Result: The fully integrated Mk3 T-REX rover weighs around 30 kg, can carry and deploy 150m of CCT and 2000m of SCT, transfer up to 10 kW of power with 86% efficiency or better, and provide VDSL2 communication speeds exceeding deep space network download capacity.

Conclusions and Future Work: We are continuing to test the T-REX and have submitted our concept and analysis to Watts on the Moon. We are partnering with companies to further develop T-REX and deploy it on the lunar surface one day.

References:

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THE REGOLITH AND ICE DRILL FOR EXPLORING NEW TERRAINS (TRIDENT) ON NASA'S VOLATILES INVESTIGATING POLAR EXPLORATION ROVER (VIPER) AND POLAR RESOURCES ICE MINING EXPERIMENT (PRIME-1). K. Zacny[1], P. Chu[1], V. Vendiola[1], E. P. Seto[1], J. Quinn[2], A. Eichenbaum[2], J. Captain[2], J. Kleinhenz[3], A. Colaprete[4], R. Elphic[4] and TRIDENT/VIPER team, [1]Honeybee Robotics, Altadena, CA, KAZacny@HoneybeeRobotics.com, [2]NASA Kennedy Space Center, FL, [3]NASA Johnson Space Center, TX, [4]NASA Ames Research Center, CA.

Introduction: The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) is an ice mining drill under development for two exploration/ISRU missions to the Moon: Volatiles Investigating Polar Exploration Rover (VIPER) and PRIME1 (Polar Resources Ice Mining Experiment) – see Figure 1 [1]. PRIME1 is scheduled to fly to the Moon in 2022 while VIPER is targeting 2023 launch year. Both missions are targeting South Pole's volatile rich deposits.

The primary goal of TRIDENT is to deliver volatile-rich samples from up 1 m depth to the lunar surface [2]. Once on surface, the material would be analyzed by Mass Spectrometer Observing Lunar Operations (MSolo) and the Near InfraRed Volatiles Spectrometer System (NIRVSS) to determine volatile composition and mineralogy of the material. MSolo will fly on both missions while NIRVSS will fly on VIPER.

Figure 1. VIPER (left) and PRIME1 (right).

TRIDENT is a rotary-percussive drill which enables it to cut into icy material that could be as hard as rock. The drill consists of several major subsystems: rotary-percussive drill head for providing percussion and rotation to the drill string, deployment stage for deploying the drill to the ground, feed stage for advancing the drill string 1 m into subsurface, drill string for drilling and sampling, brushing station for depositing material onto the surface (Figure 2).

Percussive energy is set to 2 J/blow and maximum frequency is 972 blow per minute. The rotation speed is 120 revolutions per minute and the stall torque is 16 Nm. The mass of the drill is 20 kg without harness and the mass of avionics 5.4 kg. The stowed volume of the drill is 20.6 cm x 33.3 cm x 168 cm.

To reduce thermal risks, risk of getting stuck, reduce drilling power, and provide stratigraphic information, the drill will capture samples in so-called 10 cm bites. That is the drill will drill 10 cm at a time and bring up 10 cm worth of material to the surface. For this reason, the auger is split into two sections (Figure 2). The lower section has flutes designed for sample retention: the flutes are deep and have low pitch. The upper section is designed for efficient conveyance of material to the surface: the flutes are shallow and the pitch is steep. This combination allows efficient sampling but inefficient conveyance – the drill should not be used to drill to 1 m depth in a single run as this will lead to increase in drilling power and ultimately heat input into formation.

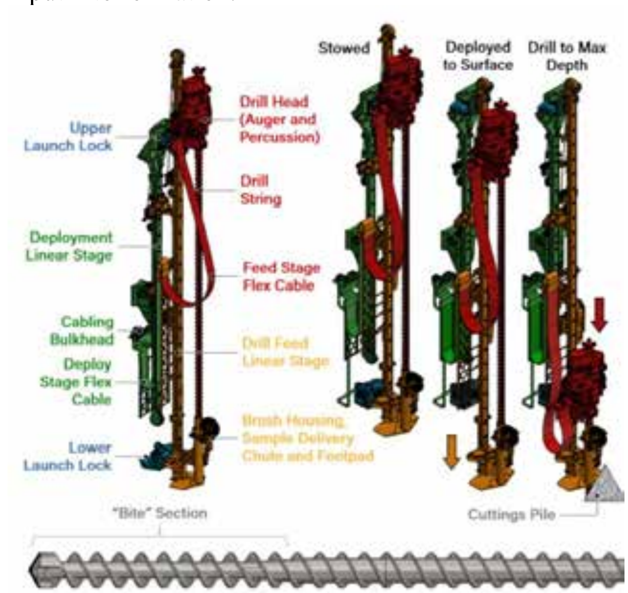

Figure 2. TRIDENT subsystems. The sampling auger is pictured at the bottom.

In addition to being a tool for providing samples, TRIDENT is also an instrument. TRIDENT drilling power and penetration rate is used to determine regolith strength. Measuring the strength in combination with input from MSolo, NIRVSS and Neutron Spectrometer System (NSS), will enable determination of the physical state of ice – whether it's mixed with regolith or cemented with regolith grains. The former will lead to low drilling power and the latter to high drilling power – while the water-ice concentration could be the same.

References: [1] Colaprete et al., (2020), LPSC [2] Zacny et al., (2018), LPSC [3] Paulsen et al., (2018), Aerospace Mechanisms Symposium.

Acknowledgments: This work is being supported by NASA.