Experimental Considerations for Ground-based Testing of Lunar Construction Technologies. J. Long-Fox[1], K. Dudzinski[2,3], R. Mueller[2], L. Sibille[2,4], E. Smith[2], E. Bell[2], J. Gleeson[2], B. Kemmerer[2], J. Fothergill[2], M. Effinger[5], R. L. McCormick[6], D. Newell-Smith[6], S. Moreland[6], L. Hipskind[6], E. Marteau[6] P. Abel[7] [1]University of Central Florida, 4111 Libra Drive Rm 430, Orlando, FL 32816, [2]Swamp Works, NASA Kennedy Space Center, Merritt Island, FL 32899, [3]University of Houston, 4800 Calhoun Rd, Houston, TX 77004, [4]Southeastern Universities Research Association (SURA), Washington D.C., [5]NASA Marshall Space Flight Center, Huntsville, AL 35812, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [7]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135. (Contact: jared.long-fox@ucf.edu)

Introduction: The Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project, under NASA's Game Changing Development (GCD) Program aims to research, develop, and demonstrate lunar surface construction capabilities [1]. Lunar infrastructure development requires quantifying the geotechnical properties of lunar regolith, such as shear strength, compression properties, and angle of repose. Knowledge of geotechnical properties enables prediction of forces and displacements associated with lunar infrastructure development processes including excavation and constructing landing pads, habitats, shelters, and roadways. Ground-based testing of relevant hardware (e.g., robotic arms) in appropriate lunar regolith simulants enables validation of technology choices and tool paths to develop autonomous lunar systems. Such testing also generates data to give insight into the regolith properties on the lunar surface.

Design of Experiments (DoE): Data from in-lab testing of lunar hardware ground interactions can serve as a reference to inform on the geotechnical properties of lunar regolith. Geotechnical studies are concerned with normal and shear loads, so experiments that involve compressive and shear forces should be emphasized. These include pressure-sinkage, shearing, excavation, and induced slope failure.

A resource-efficient DoE created using Taguchi methods [2] minimizes the number of experiments needed to explore the parameter space of the input factors and the goal is to design robust experiments that are informative in uncontrolled conditions [2]. A factorial DoE tests every combination of input factors [3], but available resources do not always allow for the extensive experimentation it requires. Combinations of Taguchi and factorial DoE are being investigated for MMPACT and other lunar missions to maximize the knowledge gained from laboratory testing of lunar construction hardware and to better constrain geotechnical properties.

Geotechnical Data Analysis: Pressure-sinkage experiments provide information on the bearing strength and stiffness of regolith [4] and are directly relevant to lunar construction efforts. Key parameters are the Mohr-Coulomb shear strength parameters of cohesion and angle of internal friction, which can be estimated by slope failure [5] and shearing experiments [6] which also allow estimation of sliding strength (adhesion and angle of external friction) [7]. Excavation forces depend on depth, gravity, and physical properties of the regolith being manipulated [8]. Geotechnical data analysis and force prediction techniques range from analytical models that generally assume simple planar geometries [8] to geometrically-flexible numerical methods such as finite element models (FEMs) [9] and discrete element models (DEMs) [10].

Conclusions: Quantifying the geotechnical properties of lunar regolith is key to lunar infrastructure development efforts, as improper ground-based testing and site characterization puts personnel, hardware, and emplaced infrastructure at risk. Proper testing of regolith-tool interactions in a controlled laboratory setting generates data for comparison to lunar surface data enabling prediction and modeling of forces observed during lunar surface operations.

References:

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