SPARTA: A PLANETARY REGOLITH CHARACTERIZATION MULTITOOL FOR SPACE RESOURCE UTILIZATION AND INFRASTRUCTURE DEVELOPMENT. J. M. Long-Fox[1], R. C. Anderson[2], D. L. Buczkowski[3], A. S. Glover[1], I. R. King[4], L. S. Sollitt[5], and D. Y. Wyrick[6], [1]University of Central Florida Department of Physics (4111 Libra Drive Room 430, Orlando, FL 32816; jared.long-fox@ucf.edu) [2]NASA/CalTech Jet Propulsion Laboratory, [3]Johns Hopkins University Applied Physics Laboratory, [4]Honeybee Robotics, [5]NASA Ames Research Center, [6]Southwest Research Institute.

Introduction: Resource prospecting, mobility, and infrastructure development on the Moon and other planetary bodies requires a quantitative understanding of the site-specific properties of the local regolith. The challenges with rigorous quantitative evaluation of regolith properties are numerous, including limited power, time, and payload mass and volume constraints. Hence, compact, multi-purpose instruments are needed to enable safe and efficient exploration and settlement on extraterrestrial bodies. However, there are surprisingly few instruments dedicated to taking measurements of the physical properties of planetary regolith, especially those that can perform multiple simultaneous and complementary measurements at high spatial resolution. To fill this gap, the Soil Properties Assessment, Resistance, and Thermal Analysis (SPARTA; [1]) probe has been developed (Figure 1). The SPARTA toolkit consists of four subsystems that are all based on high-heritage terrestrial soil characterization instruments: a Cone Penetration Tester (CPT), a Vane Shear Tester (VST), a Thermal Conductivity Probe (TCP), and a Dielectric Spectroscopy Probe (DSP). Each of these subsystems has been advanced to Technology Readiness Level (TRL) 6.

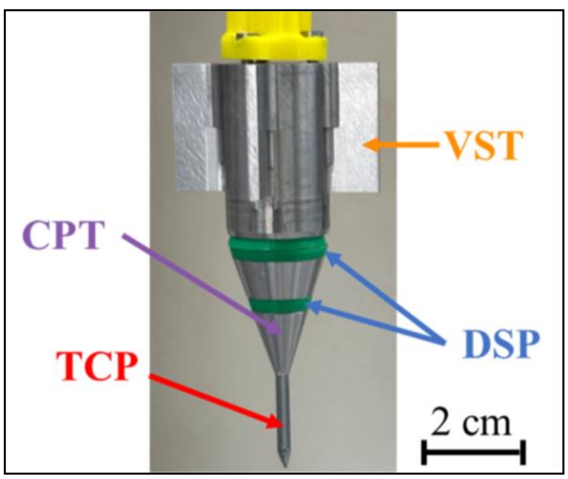

Figure 1. SPARTA probe with instruments labeled.

SPARTA Cone Penetration Tester (CPT): The SPARTA CPT is a cone penetrometer that is pushed into planetary regolith to measure penetration resistance, which is correlated to levels of compaction (density, [2]), particle packing structure, and mechanical stratigraphy. Cone penetrometers were used by astronauts during the Apollo missions and have been shown to have the ability to provide estimates of bulk density [2,3]. This instrument contributes to understanding regolith mechanical properties, particularly its ability to resist penetration and load bearing capacity, which are correlated to shear strength. Results from CPT operations are useful for evaluating rover mobility on fresh terrains and prepared roadways, launch/landing pad development, construction of habitats, berms, and more.

SPARTA Vane Shear Tester (VST): The SPARTA VST determines shear strength by inserting orthogonal blades into the regolith and rotating while measuring torque as the blades rotate. By measuring the torque as a function of rotational displacement, the shear strength (shear stress at failure) can be calculated based on the geometry of the vanes. Performing shear strength measurements at varying depths (and hence different normal stresses) allows for the calculation of the Mohr-Coulomb parameters, namely cohesion and angle of internal friction. Gaining a quantitative grasp on the shear strength of planetary regolith is key, as strength increases with the level of compaction [4] and hence can be used to evaluate sites for feasibility of infrastructure development and validate that site preparation methodologies have brought a development site into acceptable specifications.

SPARTA Thermal Conductivity Probe (TCP): The SPARTA TCP is based on the Transient Line Source method of determining thermal papers of granular geologic media established in ASTM D5334 [5]. The TCP has a heating element that generates a short heat pulse. As the temperature rises and falls from this heat pulse, two resistance temperature detectors (RTDs) track the variation. Based on these temperature variations, the temperature, thermal conductivity, thermal diffusivity, and specific heat (if density of the regolith is known) can be estimated. Since assessing the thermal properties of planetary regolith provides information on composition and volatile content, requirements for resource extraction systems can be gained, and information for thermal management of regolith-based habitats and other infrastructure elements can be generated.

SPARTA Dielectric Spectroscopy Probe (DSP): The SPARTA DSP uses electrical spectroscopy to detect concentrations of electroactive materials (e.g., water ice and other volatiles). By measuring the electrical response of the regolith at different frequencies of AC current, the dielectric constant and concentration of volatiles can be measured, including the ability to distinguish between water ice and hydrated minerals. Dielectric spectroscopy measurements will help validate orbital measurements of volatile content and allow for mapping of the concentration and distribution of volatiles within planetary regolith, which is useful for defining regions that should be mined for valuable resources such as water ice that can be used for on-site human and agricultural use and launch vehicle propellant production.

SPARTA Technology Maturation and Testing: To date, SPARTA has been successfully tested in laboratory, field, and reduced gravity flight conditions. Laboratory testing has included extensive characterization and calibration of each SPARTA instrument (e.g., [2]) in well-characterized materials. Laboratory testing has included both ambient and vacuum conditions. SPARTA has been developed into a portable field unit (Figure 2) and has been deployed in the NASA Jet Propulsion Laboratory (JPL) Mars Yard, planetary analog volcanic sites just outside Lava Beds National Monument, OR and Tule Lake, CA. SPARTA has also been tested on reduced gravity flights— specifically 2 parabolic flight campaigns with Zero-G (Figure 2) and 1 suborbital lunar-*g* flight with Blue Origin. Each of these test campaigns was performed successfully and the TRL of each of SPARTA's instruments has achieved TRL 6 through these tests.

Figure 2. (Left) SPARTA field unit outside Lava Beds National Monument. **(Right)** SPARTA Zero-G parabolic flight testing.

Discussion and Conclusion: SPARTA is a low-mass, low-power regolith characterization toolkit that combines several high-heritage instruments into one probe head that can be used as either an astronaut-, rover-, or lander-deployed instrument. The novel combination of these instruments into one probe allows for direct comparison and cross validation of the complementary information that each instrument provides since each of SPARTA's instrument measurements have well-understood correlations with the others. This allows for reliable measurements of regolith properties when using SPARTA. For example, combining measurements of the CPT and VST provides a first-of-its-kind analysis of regolith strength which is crucial for any interaction with planetary regolith, including mobility, infrastructure site selection, and validation of developed infrastructure element properties. SPARTA Data are analyzed using the SPARTA Data Analysis Software Suite [6] which enables rapid statistics-based parameter estimations from field, flight test, and planetary mission data. Field testing results have also shown that SPARTA can accurately characterize geomechanical and geochemical gradients [7]. SPARTA can easily be configured with different deployment actuators and motors to meet specific mission requirements. During development and testing, different sizes of SPARTA were created and tested successfully, enabling reliable size-scaling of SPARTA for inclusion in a wide variety of mission payloads. SPARTA's ability to simultaneously measure the mechanical, thermal, and electrical properties of planetary regolith at unprecedented spatial resolution enables space, reliable, and efficient space resource utilization and infrastructure development. The SPARTA toolkit represents a critical step in enabling the sustainable exploration and utilization of planetary surfaces, whether it be the Moon, Mars, or other small bodies throughout the solar system.

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