RIDER AND SPIDR: OPEN-ACCESS COMPLEMENTARY FACILITIES FOR PLANETARY TERRAMECHANICS INVESTIGATIONS. J. Long-Fox[1], H. M. Sargeant[2], M. P. Lucas[3], C. R. Neal[3], J. Conway[1], M. Conroy[1], A. Glover[1], A. Hacker[1], A. Madison[1], G. Blandin[1], P. Easter[1], and D. Britt[1] [1]University of Central Florida (4111 Libra Dr. Rm 430, Orlando, FL, jared.long-fox@ucf.edu), [2]University of Leicester, [3]University of Notre Dame

Introduction: Planetary exploration and infrastructure development rely on safe and efficient locomotion for the transport of personnel, equipment, and resources. To save time, money, and energy and to optimize rover-based operations on the lunar surface, it is key to quantify how the physical properties of lunar regolith and the lunar environment (reduced gravity, lack of atmosphere, and magnetic fields) affect wheel-regolith interactions. The Center for Lunar and Asteroid Surface Science (CLASS) at the University of Central Florida (UCF) provides open-access capabilities and facilities to enable experimental and theoretical investigations into lunar terramechanics and rover designs, specifically, the Regolith Interactions for the Development of Extraterrestrial Rovers (RIDER) wheel trafficability testbed [1] and the Simulator for Planetary Interactions of Dust and Regolith (SPIDR) discrete element model (DEM) workflow [2]. RIDER provides researchers with the ability to test full-scale rover wheels in a gravity-offloading simulant bin, whereas SPIDR provides the ability to computationally simulate wheel-regolith interactions in planetary environments and study dust transport resulting from rover-based operations.

RIDER: RIDER (Figure 1) allows researchers to experimentally study lunar terramechanics as a function of rover specifications and of regolith properties. RIDER subsystems include a 3.8 m long, 0.9 m wide, and 0.5 m deep regolith bin, simulant compaction capabilities, dust mitigation systems, customizable illumination and video recording systems, environmental control systems, a load application/gravity offload system capable of simulating single wheel loads up to 200 kg, and a sealed motor box housing interchangeable motors with different gear ratios (10:1, 50:1, 100:1, and 225:1). Since there is no standard for rover wheel design or mounting systems, RIDER is outfitted with a heavy-duty wheel hub to allow custom adapters to be manufactured to couple with customer rover wheels from 26 cm to 82 cm in diameter. RIDER is housed at the UCF Exolith Lab, and hence has access to world-class simulant production and experimentation facilities which allows for the option of custom simulants to use in experiments and provides regolith testbed preparation expertise. The density of lunar regolith varies both laterally and vertically, and as such, wheel testing should consider a range of regolith compaction states. RIDER has capabilities to simulate lunar regolith density profiles [3] and has access to facilities to analyze simulant physical properties as a function of the amount of wheel traffic and drive specifications. Since dust mitigation is a paramount concern in rover operations in laboratory testing and planetary surfaces, RIDER was developed with a negative pressure system, air filters, sealed doors, and barriers to protect rails and electronics. Since volatile/moisture content is known to affect the physical properties of lunar regolith simulants [4], RIDER is equipped with an industrial dehumidification unit to help minimize moisture in the air and in the simulant. The control system of RIDER allows users to input wheel size, desired speed, and gravity-adjusted rover mass to autonomously test wheel-regolith interactions by driving the wheel back and forth across the simulant bed a specified number of times. Data on wheel rotation speed, linear travel speed, motor drive current, wheel sinkage, and simulated rover mass are logged to comma-delimited ASCII text files for later analysis. A serial communications-based telemetry stream is sent to a display that shows camera feeds from inside the test bin as well as live plots of relevant system parameters. The initial testing campaign of RIDER [3] includes a replica Lunar Roving Vehicle (LRV) wheel, a Resource Prospector wheel, and a prototype Astrobotic Polaris rover wheel. Testing these wheels will provide baseline data to validate the RIDER system based on the associated mission activities for each wheel. The video recording and illumination RIDER subsystems allow for comparison to and validation of computational model-based predictions of wheel-regolith interactions and resulting dust plumes.

Figure 1. RIDER with road tire installed for system validation and testing (March 2023).

SPIDR: SPIDR is a scalable, high-performance Unix-based data analysis and DEM pipeline that allows for the input of CAD-based wheel geometries to simulate in planetary surface conditions (regolith and environment). SPIDR simulations enable the study of methods to minimize the amount of mobilized dust from roving on the lunar surface, thereby protecting equipment and personnel. DEMs are run using the LIGGGHTS [5] open-source particle simulation software and are programmed to fill the lower portion of the model domain with lunar-like particles [6], triboelectric charging [7], density [8], and weight in lunar gravity. Other particle properties are taken from [9]. Before wheel-regolith simulations are run, the material properties of the particles being simulated must be calibrated. SPIDR calibrates the cohesive energy density (CED), rolling friction, and sliding friction coefficients to laboratory-based angle of repose experiments using returned regolith samples. Once the calibrated parameter values are known, a model domain is created to mimic the lunar environment with particles generated with the calibrated material properties, grain sizes, charges, density, and weight. Once the particles are spawned in the model domain, wheel geometry is ingested into the simulation and lowered into the bed of particles at expected sinkage and then rotated and translated across the domain. During SPIDR runs, individual particle locations, velocities, and charges are logged for posteriori analysis. Since regolith-regolith interactions and regolith-wheel interactions are influenced by environmental factors, SPIDR simulates the lunar surface by modeling wheel-regolith interactions in a charged, vacuum environment with realistic electric fields (day-side field of 18V up to a height of 1 m [10,11]). SPIDR focuses attention on the finest fractions of lunar regolith (<2 µm) since this size fraction is the majority of lunar regolith by mass and is expected to interact with electric fields significantly, which will modify their trajectory when lofted. To validate SPIDR, an Apollo 16 LRV wheel and fender are used as model inputs (Figure 2), and results are compared to video data from the Apollo 16 Grand Prix traverse. Initial results indicate that particle velocity and the arc-shape of the dust plumes are in agreement with the Grand Prix footage. The flexibility of SPIDR to incorporate arbitrary wheel designs, calibrate to site-specific regolith properties, modify surface electric fields and particle charges allow SPIDR to be applied to any proposed (or already flown) lunar rover wheel design or mode of operation. Since SPIDR simulations can be modified to simulate rover wheels in any environment, including Earth atmosphere, SPIDR is able to cross-validate with RIDER and results from RIDER can be extrapolated to other environments to define safe and efficient modes of operation for rovers.

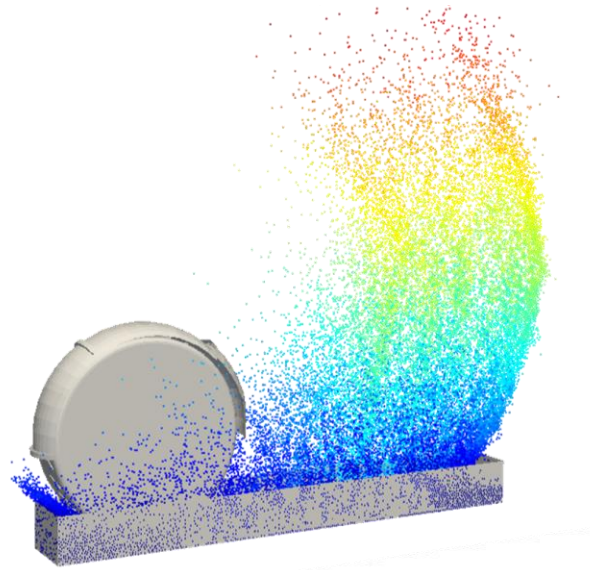

Figure 2. SPIDR simulation of an LRV wheel in a bed of lunar-like particles. Blue indicates lower ejected particle velocity and red indicates higher velocity.

Summary: RIDER and SPIDR are open-access capabilities developed by CLASS at UCF and offer the lunar science and engineering communities the ability to experimentally and computationally test rover wheel designs in terms of efficiency (e.g., slip and sinkage), longevity, and operational modes (speeds, torque, lofted dust). The RIDER and SPIDR teams are able to partner with researchers from government, academic, or commercial institutions to design and run laboratory and/or computational experiments to meet customer needs and lend expertise in terramechanics and geomechanics to analyze and interpret results post-run.

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