COMPUTATIONAL MODELING OF IPEX DRUM-LUNAR REGOLITH INTERACTION – DISCRETE ELEMENT METHOD AND CONTROL MECHANISMS. Q Chen[1], D Gaines[2], & L Redmond[3], [1]Glenn Department of Civil Engineering, Clemson University, Clemson SC, qiushi@clemson.edu; [2]Glenn Department of Civil Engineering, Clemson University, Clemson SC, dhgaine@clemson.edu; [3]Departments of Civil and Mechanical Engineering, Clemson University, Clemson SC, lmredmo@clemson.edu.

Introduction: NASA's ISRU Pilot Excavator (IPEx) is a 30 kg-class robotic excavator being developed at the Kennedy Space Center, and bucket drum scaling experimental results have been conducted at the KSC [1]. In this work, recent efforts in developing computational models for the IPEx are presented. The discrete element method (DEM) is used to model lunar regolith and its interaction with the rotating IPEx bucket drum during the excavation experiments. DEM model parameters are calibrated using laboratory characterization data of Black-Point 1 (PB-1) lunar regolith simulant. Different control mechanisms are explored in the DEM model for the rotating IPEx bucket drum. The force, torque, and mass accumulation within the bucket drum as a function of time data are obtained from DEM simulations and compared with experimental data.

DEM Model: In this work, commercial software EDEM is used to develop the computational model of the IPEx bucket drum-regolith system. For contact behavior, the Hertz-Mindlin with Johnson-Kendall-Roberts (JKR) contact model is used, where the JKR model provides attractive cohesion forces that are necessary for appropriately accounting for the behavior of the lunar regolith simulant. As for the particles, in this work, a clumped-sphere approach is used to model non-spherical lunar regolith particles, where two equalized 2 mm diameter base spheres are glued together (with overlapping) to form a clumped particle with a maximum dimension of 3 mm. Models of the DEM parameters are calibrated for BP-1 lunar regolith simulant using three types of experiment data: bulk density test, static angle of repose test, and the inclined slope test. Table 1 summarizes the DEM model parameters.

Table 1. *Calibrated DEM parameters for BP-1*

Parameter	Value	Unit
Poisson's ratio	0.25	-
Solids density	3200	kg/m^3
Shear modulus	1.00E+07	Pa
Restitution coefficient (P-P)	0.3	-
Static friction coefficient (P-P)	0.85	-
Rolling friction coefficient (P-P)	0.9	-
Restitution coefficient (P-G)	0.1	-
Static friction coefficient (P-G)	0.675	-
Rolling friction coefficient (P-G)	0.3	-
JKR surface energy	0.9	J/m^2

IPEx Simulation: The IPEx drum geometry file was meshed using the Cubit software and then imported into EDEM. During the excavation, the IPEx drum is first lowered to the regolith bed, and then, it is rotated at a specified speed while moving along the regolith bed at a certain translational speed using a motor with force and torque control. Figure 1 shows the snapshot of the DEM simulation at time t = 20 s, where the motions of the IPEx drum are specified as velocity control.

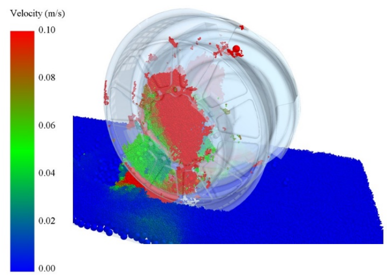

Figure 1. *DEM simulation of the IPEx drum (t = 20 s, translational speed is 30 mm/s).*

In the DEM model, different control mechanisms are explored to simulate the realistic response of the rotating drum during the excavation experiment. Specifically, three different mechanisms are investigated: 1) velocity control, where the rotational and translation motions of the drum are directly specified; 2) force controller, where the translational movement is driven by a force controller, while the rotational speed is directly specified; 3) dual controller, where both the translational and rotational movements are driven by controllers, one for force and one for torque. Preliminary results indicate that the the force and torque responses from DEM simulations are within the range of the experimental data. Moreover, different controller mechanisms have a tangible impact on the drum response and their effects need to further investigated. Ongoing work focuses on control models, validation, and the study of gravity effect.

Reference: [1] Schuler, J., Nick, A., Leucht, K., Langton, A., and Smith, D. (2022) *Earth and Space 2022*, 394 - 407.

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