Pressure-Sinkage Testing for Understanding of Planetary Mobility and Traction. G. E. Blandin¹, J. M. Long-Fox², M. P. Lucas¹, M. P. Conroy², C. R. Neal¹, and D. T. Britt², ¹University of Central Florida Exolith Lab (532 S. Econ Circle Suite 100, Oviedo, FL 32765; gabriel.blandin@ucf.edu), ²University of Central Florida Department of Physics, 4111 Libra Drive Room 430, Orlando, FL 32816, ³University of Notre Dame, Department of Civil & Environmental Engineering & Earth Sciences, 156 Fitzpatrick Hall, Notre Dame, IN 46556

Introduction: In the pursuit of safe and efficient planetary exploration, understanding rover trafficability and traction on diverse planetary surfaces is crucial. Navigating the complex terrains of extraterrestrial bodies, characterized by loose regolith and varying landscapes, demands precise knowledge of pressure-sinkage relationships of regolith which controls traction of wheels. A custom pressure-sinkage test rig (Figure 1) was built to perform pressure-sinkage tests in mineralogically accurate regolith simulants at varying levels of compaction to simulate planetary regolith density profiles. The objective of this study is to test pressure-sinkage relationship of highly compacted lunar highlands simulant to inform testing results from [1], to serve as a proof of concept for the study of pressure-sinkage relationships for other planetary regolith simulants, and for application in future studies in the RIDER (Regolith Interactions for the Development of Extraterrestrial Rovers) rover wheel testbed [2].

![Figure 1. Custom pressure-sinkage electronics control box (A) and test rig (B).](Image)

Methods: Pressure-sinkage experiments were performed in Simplified LHS-1 (LHS-1B) lunar highlands regolith simulant using three 0.64 cm thick 6061-aluminum bearing plates: Bearing Plate 1 (15.24 x 15.24 cm), Bearing Plate 2 (10.16 x 10.16 cm), and Bearing Plate 3 (15.24 x 10.16 cm). In 5 replicate tests of each plate size, these plates are pressed into a freshly compacted surface of the regolith simulant at a rate of 2 mm/s while recording the displacement and force experienced. The simulant test bin was made out of 0.95 cm thick acrylic and is 40 cm tall with horizontal dimensions of 30.48 x 30.48 cm. The regolith was compacted in two 15 cm deep layers to replicate the variations of density with depth during experiments presented in [1]. A high density of 1.82 g/cm³ was selected for the lower layer, and a lower density of 1.76 g/cm³ for the upper layer based on the Apollo 16 penetrometer experiments [5]. Actual densities for each layer for each experiment varied by less than 0.01 g/cm³ from the desired value. The compaction process is a scaled down version of the RIDER compaction method [2], using 1.91 cm thick plywood boards cut to the size of the simulant bin wrapped in landscape fabric with a 90 W vibration motor bolted to the board.

The data gathered from the experiments was used to estimate parameters of the Reece (1965) pressure-sinkage model (Eq. 1) [3] using the analysis pipeline described in [4] to enable prediction of sinkage of the wheels during RIDER experiments and on the Moon.

\[ P = (k_c + bk_d) \left(\frac{z}{b}\right)^n \]  \hspace{1cm} (1)

Here, \( P \) is pressure, \( k_c \) is a constant related to cohesion, \( b \) is plate width, \( k_d \) is a constant related to friction, \( z \) is sinkage depth, and \( n \) is a dimensionless constant. Briefly, the analysis [4] uses a Markov Chain Monte Carlo (MCMC) algorithm to fit a curve to data from each Bearing Plate, then uses these separate curve fits to calculate the values \( k_c \), \( k_d \), and \( n \) as in [5]. To determine values for these parameters, three different combinations of bearing plates were employed, and results compared. Combination 1 consisted of Bearing Plates 1 and 2, Combination 2 used Bearing Plates 1 and 3, and Combination 3 utilized Bearing Plates 2 and 3.

Results: The results of pressure-sinkage testing in Combinations 1, 2, and 3 using the Reece (1965) model of pressure-sinkage [3], are depicted in Figure 2. Table 1-3 displays parameter estimates and 95% confidence intervals of the pressure-sinkage tests.
highly compacted regolith is resistant to disruption by shearing from wheel grousers. The parameters estimated for the Reece (1965) model (Table 1-3) exhibit inconsistencies in value for the various combinations of Bearing Plates. However, models like the Reece (1965) are claimed to enable prediction of pressure-sinkage profiles for any plate/wheel width once $k_e$, $k_\phi$, and $n$ are estimated from data; this is not the case here but further testing in different simulant densities will confirm this. Parameter estimate inconsistencies and high uncertainties may stem from the original design of the Reece (1965) model, which was intended for terrestrial soils, and lunar regolith/simulant geotechnical properties significantly diverge from those of Earth's soils. Moreover, the sinkage variations in the tests here are relatively large compared to the magnitude of the total sinkage; this problem is expected to be less significant in lower density materials where more sinkage occurs and signal to noise ratio is higher. Ongoing efforts are underway to advance more robust characterizations of in situ regolith pressure-sinkage relationships (as well as those for future RIDER experiments), acknowledging the need for models tailored to extraterrestrial regolith.

**Conclusion:** Conducting pressure-sinkage testing is essential for insights into planetary mobility and traction, thereby contributing to the enhancement of rover wheel designs, pathways for exploration, and understanding site specific load bearing capacity of planetary regolith. Recognizing the limitations of existing models, new approaches must be developed to accurately characterize pressure-sinkage relationships for lunar and planetary regolith. It has been observed in this study that the Reece (1965) pressure-sinkage model provides an “average” fit to paired datasets from different Bearing Plates, but seems to fall short in allowing prediction of sinkage of different sized bearing plates (hence wheels) with the same values of $k_e$, $k_\phi$, and $n$. This implies that the model calibration is sensitive to the size of the plates used and that quantitatively predicting sinkage given an applied pressure in a given planetary terrain may require novel models tailored to the unique properties of extraterrestrial regolith.

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