abstract
Vehicles traverse granular media through complex reactions with large numbers of small particles. Many approaches rely on empirical trends derived from wheeled vehicles in well-characterized media. However, the environments of numerous bodies such as Mars or the moon are primarily composed of fines called regolith which require different design considerations. This dissertation discusses research aimed at understanding the role and function of empirical, computational, and theoretical granular physics approaches as they apply to helical geometries, their envelope of applicability, and the development of new laws. First, a static Archimedes screw submerged in granular material (glass beads) is analyzed using two methods: Granular Resistive Force Theory (RFT), an empirically derived set of equations based on fluid dynamic superposition principles, and Discrete element method (DEM) simulations, a particle modeling software. Dynamic experiments further confirm the computational method with multi-body dynamics (MBD)-DEM co-simulations. Granular Scaling Laws (GSL), a set of physics relationships based on non-dimensional analysis, are utilized for the gravity-modified environments. A testing chamber to contain a lunar analogue, BP-1, is developed and built. An investigation of straight and helical grousered wheels in both silica sand and BP-1 is performed to examine general GSL applicability for lunar purposes. Mechanical power draw and velocity prediction by GSL show non-trivial but predictable deviation. BP-1 properties are characterized and applied to an MBD-DEM environment for the first time. MBD-DEM simulation results between Earth gravity and lunar gravity show good agreement with theoretical predictions for both power and velocity. The experimental deviation is further investigated and found to have a mass-dependant component driven by granular sinkage and engagement. Finally, a robust set of helical granular scaling laws (HGSL) are derived. The granular dynamics scaling of three-dimensional screw-driven mobility is reduced to a similar theory as wheeled scaling laws, provided the screw is radially continuous. The new laws are validated in BP-1 with results showing very close agreement to predictions. A gravity-variant version of these laws is validated with MBD-DEM simulations. The results of the dissertation suggest GSL, HGSL, and MBD-DEM give reasonable approximations for use in lunar environments to predict rover mobility given adequate granular engagement.