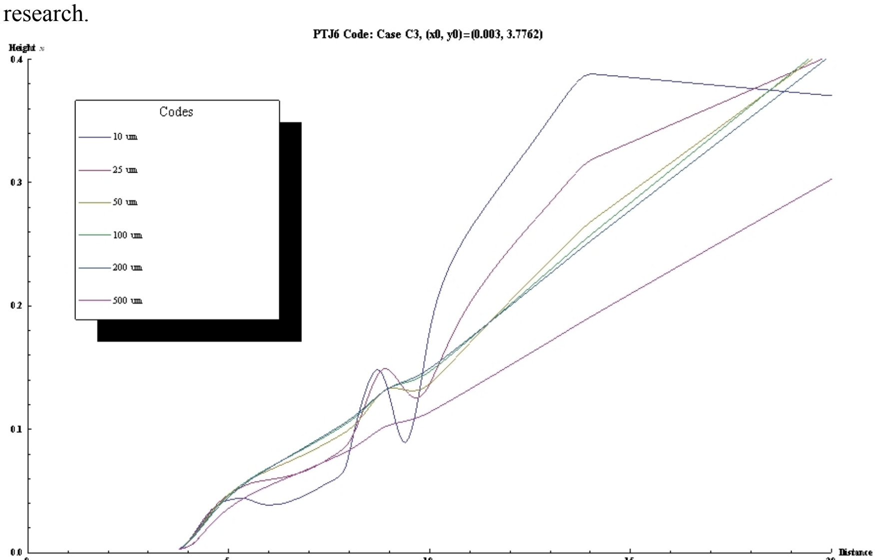
A MODIFICATION AND ANALYSIS OF LAGRANGIAN TRAJECTORY MODELING AND GRANULAR DYNAMICS OF LUNAR DUST PARTICLES. Jason M. Long[1], John E. Lane[2], Philip T. Metzger[3], A.M.ASCE. [1]*NASA/KSC-XA Granular Mechanics and Surface Systems Laboratory, KSC, FL 32899, USA* (Jason.M.Long@nasa.gov) [2]*ASRC Aerospace, Kennedy Space Center, FL 32899, USA* (John.E.Laneg@nasa.gov) [3]*NASA/KSC Granular Mechanics and Surface Systems Laboratory, KSC, FL 32899, USA* (Philip.T.Metzgerg@nasa.gov)

Abstract
A previously developed mathematical model is amended to more accurately incorporate the effects of lift and drag on single dust particles in order to predict their behavior in the wake of high velocity gas flow. The model utilizes output from a CFD or DSMC simulation of exhaust from a rocket nozzle hot gas jet. An extension of the Saffman equation for lift based on the research of McLaughlin (1991) and Mei (1992) is used, while an equation for the Magnus force modeled after the work of Oesterle (1994) and Tsuji et al (1985) is applied. A relationship for drag utilizing a particle shape factor (ϕ = 0.8) is taken from the work of Haider and Levenspiel (1989) for application to non-spherical particle dynamics. The drag equation is further adjusted to account for rarefaction and compressibility effects in rarefied and high Mach number flows according to the work of Davies (1945) and Loth (2007) respectively. Simulations using a more accurate model with the correction factor (€ = 0.8 in a 20% particle concentration gas flow) given by Richardson and Zaki (1954) and Rowe (1961) show that particles have lower ejection angles than those that were previously calculated. This is more prevalent in smaller particles, which are shown through velocity and trajectory comparison to be more influenced by the flow of the surrounding gas. It is shown that particles are more affected by minor changes to drag forces than larger adjustments to lift forces, demanding a closer analysis of the shape and behavior of lunar dust particles and the composition of the surrounding gas flow.

Introduction

The necessity for permanent surface structures on the moon is unavoidable, with future missions to the moon planned and expeditions to Mars in our near future. With this comes the requirement for protection not only from the planetary elements, but also from our own vehicles. Understanding the effects of our interactions with the surrounding environment is imperative if we are to properly prepare for extended missions and protect permanent habitats and structures. In the final stages of decent, the high temperature, supersonic gas flow creates an environment in which lunar dust, gravel, soil, and rocks are driven out radially at high velocities. Evidence of this effect is noted in several videos of the Apollo landings; the thickness of the dust layer and angle of trajectory were estimated from these videos (Immer, 2008), and confirmed using mathematical modeling and software implementation (Lane and Metzger, 2008).

Updates are made to the Lane and Metzger (L&M) model in order to better account for lift forces, rarefaction and compression effects, and interparticle reactions. With these new equations, simulations are run under several different rocket exhaust conditions to stimulate the movement of lunar soil, and to determine the final conditions and trajectories of the lunar particles. The equations used in the L&M model are outlined, as are the changes and modifications made to these equations, and the interpolation code where necessary. Simulations are performed using four new versions of the trajectory code in order to more accurately designate the changes to the proper forces. The main alteration is the replacement of a constant lift coefficient with the extended Saffman lift equation and the addition of the Magnus effect. Variations on the drag force through interparticle reactions are also examined to see what effect, if any, they have on the final trajectory of the particle. Each set of results from the separate versions of the code are compared, and weighed against the L&M model. Finally, suggestions are made for future changes and direction for research.



An Example of Particle Trajectory Simulation Output