GRANULAR MECHANICS IN ASTEROID REGOLITH: SIMULATING AND SCALING THE BRAZIL NUT EFFECT. P. Sánchez, *U. Colorado, Boulder (Diego.Sanchez-lana@colorado.edu)*, D.J. Scheeres, *U. Colorado, Boulder*.

The simulation and scaling of granular mechanics flows in asteroid regolith is considered, with an initial focus on studying the "Brazil Nut Effect" in gravitational fields of different magnitudes. Initial runs are being made to test ideal scaling relations, for use in interpreting scientific observations of asteroids and in motivating the laboratory simulations of asteroid surfaces.

Introduction It is well known that shaking can drive size sorting and segregation in granular media ([1] and references therein). We consider the hypothesis that seismic shaking on asteroids could promote the size sorting of its constituent particles [2]. Such sorting is evident in the images sent by the Hayabusa mission of the surface of the asteroid Itokawa [3]. The simplest example of this sort of segregation is the well-known Brazil-Nut Effect (BNE), which has been studied in the last few years and validated using both simulations and laboratory experiments. However, all studies carried out to date have assumed a "uniform" terrestrial gravitational field as a constant [1]. On an asteroid this does not hold true. First, the gravitational field itself can vary by a factor of two or more across an asteroid surface. Second, the scale of the total gravitational accelerations are much smaller than those simulated in terrestrial laboratories. In order to properly analyze whether this effect plays a role in the evolution of Itokawa's surface we have initiated a series of granular dynamics simulations that test this effect over a range of different conditions found on asteroids.

Scaling simulations for different gravitational accelerations Computer simulation offers the ability to easily change many system properties not readily adjustable in nature, and to investigate details of the dynamics which are otherwise difficult to study. Still, to simulate granular mechanics flows on the surface of an asteroid can take a significant amount of computational time. This arises mainly due to the long time spans associated with the ballistic flight of particles in a milli to micro G gravitational field.

The gravitational acceleration at the surface of a body can be estimated as: $g \sim \frac{4\pi}{3}\mathcal{G}\rho R$ where $\mathcal{G} \sim 6.672 \times 10^{-8}$ cm^3/g/s^2, ρ is the bulk density in g/cm^3, and R is the body radius. If we assume a bulk density of 2 g/cm^3 we find that $g \sim 5.6 \times 10^{-7} R$ m/s^2, where R is measured in meters. Thus for bodies with mean radii ranging from 100 to 100,000 m the surface gravity will range from 5 micro-G to 5 milli-G (G = 9.81 m/s^2). The rotation of the body will further decrease the effective gravitational acceleration, although for most small bodies this reduction is just a fractional adjustment to the surface gravity.

In a low-gravity environment a crucial limiting factor is the time it takes for a perturbed granular flow to settle. This is controlled by the height to which a granule is excited and the simulated level of gravity. The necessary excitation speed of a particle to reach a given height, H, is $\dot{H} \sim \sqrt{2Hg}$ and the corresponding settling time is $T_s \sim 2\sqrt{2H/g}$. Thus a ballistic arc of height 1 cm in a 1-G environment takes less than 0.1 seconds to settle, but takes about 3 seconds in a milli-G environment and 90 seconds in a micro-G environment. This slows the computation of particle mechanics simulations significantly, and makes it attractive to study how the Brazil Nut Effect scales with total gravitational acceleration.

Implementation of the Simulation In order to gain insight into the effects of a non-uniform low gravity environment on the dynamics of the BNE, we have carried out a number of particle dynamics simulations. We have simulated the motion of 4000 glass spherical grains using a simple 3D soft-sphere linear spring and dashpot model [4]. The particles have a mean diameter of 0.5mm, with a 20% random dispersion. This is done to avoid the crystalization of the system, which will cause the system to fall into a locked state and exhibit non-natural rigidity. The coefficient of normal restitution is $\sim$0.9 and the coefficient of friction is 0.5. Static and dynamic friction, and rotation of the particles have also been implemented in the code ([5] and references therein). Each simulation contains two intruders of 1mm in diameter, the "brazil nuts," with the same physical properties as the rest of the particles. The particles are contained and tapped vertically inside a solid box measuring 12.5mm by 12.5mm in the horizontal plane and 25mm vertically. Particle-wall collisions are treated exactly as particle-particle collisions. The particles are initially positioned in a hexagonal close-packed arrangement, then they are given a random initial velocity and allowed to settle under the simulated gravity.

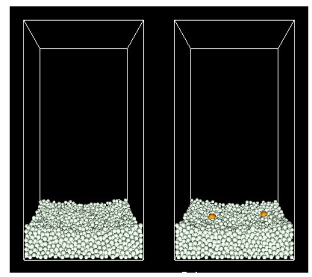
Seismic shaking is simulated by "tapping" the base of the enclosure. This tapping is implemented as a single sinusoidal vertical vibrational cycle with amplitude A

and frequency ω, leading to an induced maximum speed $A\omega$. This simulates how granular flows are energized in terrestrial laboratories and mimics the effect of a seismic wave energizing the particles. To simulate the asteroid environment we allow the system to completely settle between taps. This is consistent with occasional impacts on an asteroid surface causing brief periods of seismic energy that are rapidly dissipated. In our simulation subsequent tapping is started only when the kinetic energy of the particles is less than one thousandth of the initial kinetic energy, taken as the kinetic energy the system has when the bottom of the box reaches the lowest part in its cycle.

The gravitational field mimics a centrifuge operated in a weightless environment, and was chosen as a possible system for which experiments can be carried out in the future. Thus the gravitational acceleration is radial and directed towards a point located over the centre of the base of the box at a height of $50mm$ plus the amplitude of vibration, is repulsive, and varies as R, where R is the distance from this point to each particle. This configuration then creates a non-uniform gravitational field, both radially and laterally. Other configurations for the gravitational field will also be modeled to verify our assumptions and to compare possible differences that exist between centrifuge laboratories and asteroid surfaces.

Results A suite of simulations have been initiated studying the BNE across a range of different scaling parameters. Detailed results of these simulations will be reported at the conference. The simulations carried out so far show that, as in terrestrial BNE experiments, the value $\Gamma = \frac{A\omega^2}{g}$ is important. If $\Gamma < 1$ the particles do not have enough energy to move and rearrange themselves [6]. In our simulations we will control a number of different parameters. Our initial runs keep the height to which the particles are thrown constant, but we will also explore keeping the settling time constant, along with controlling other kinematic and physical parameters. Figure [1] (top) shows a typical example of the initial and final configurations of one of our simulations while Fig. [1] (bottom) shows the evolution of the brazil nuts through the particles as a function of taps.

Applications The results and insights that can be obtained through these simulations will help us design and interpret experiments in mili/micro-gravity environments and will give us a first approach to understanding granular flows in asteroids like Eros or Itokawa [2, 3] and their role in shaping the topography of these and similar asteroids. They will also help calculate the time spans, collision frequency and energy deposition needed in order to drive these granular flows. Additional questions that can be analyzed using simulations include how seismic waves are transmited in such environments. This is a topic that has not been discused in detail in either the granular or planetary scientific communities [7], but one that is needed in order to understand the evolution of asteroids.



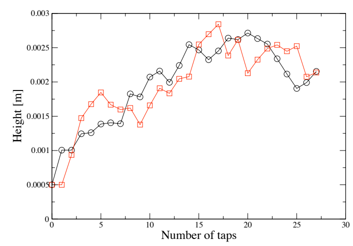


Figure 1: Top: Typical simulation: Initial configuration (left) and final configuration (right). The BNs have been colored orange for visualization. Bottom: Height of the brazil nuts as a function of number of taps. The peak altitudes occur when the brazil nuts reach the top of the particle pile.

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