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Brownian Motor Using Competitive Clustering of Bi-Disperse Granular Gas

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Granular Gas: Maxwell's Demon and Brownian Motors

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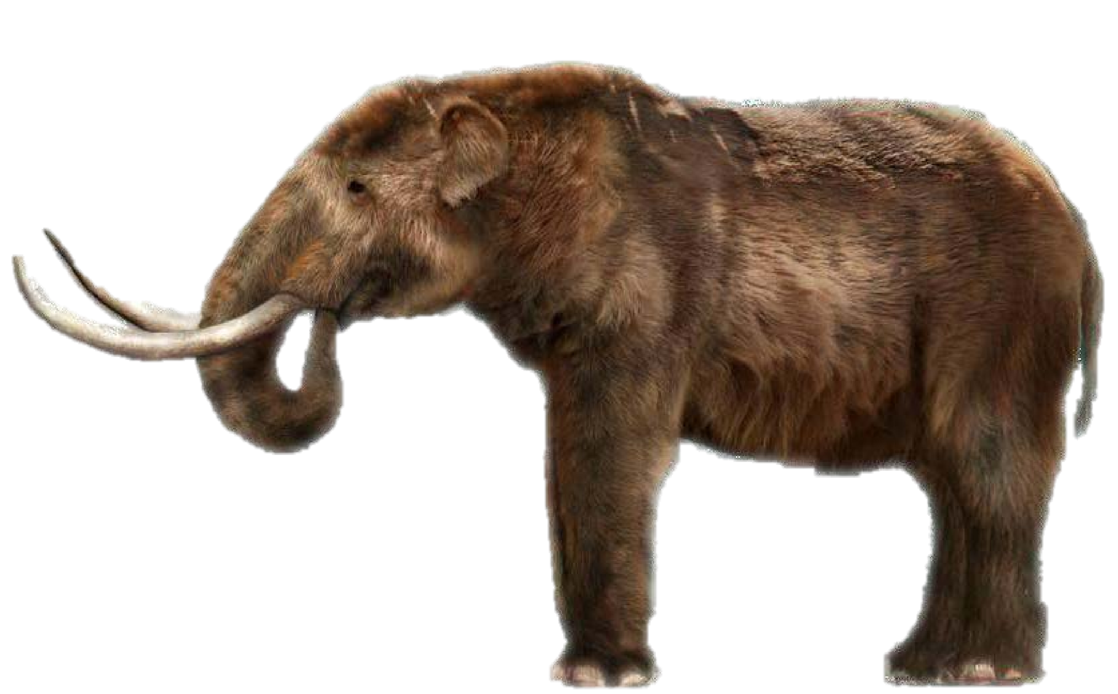


Introduction

Brownian motion, or seemingly random motion under the direction of a complex system, is used on the nano-scale to perform mechanical or electrical work through the use of what is called a Brownian motor. We will investigate the possibility of using competitive clustering in granular gases to achieve this nano-scale effect within a macro-scale system. We are intrigued by this because of the system's inherent complexity, which allows us to learn how non-linear and chaotic systems are modeled with granular hydrodynamics and flux models. There may be practical applications in industrial processing of corn, breakfast cereal, and pharmaceuticals, which could be sorted by weight or size through vibration. Scientific interests arise from granular gas' behavior in Maxwell's Demon experiment, namely the increase in entropy has so small an effect that it may be ignored and the system can be said to become more ordered in time.

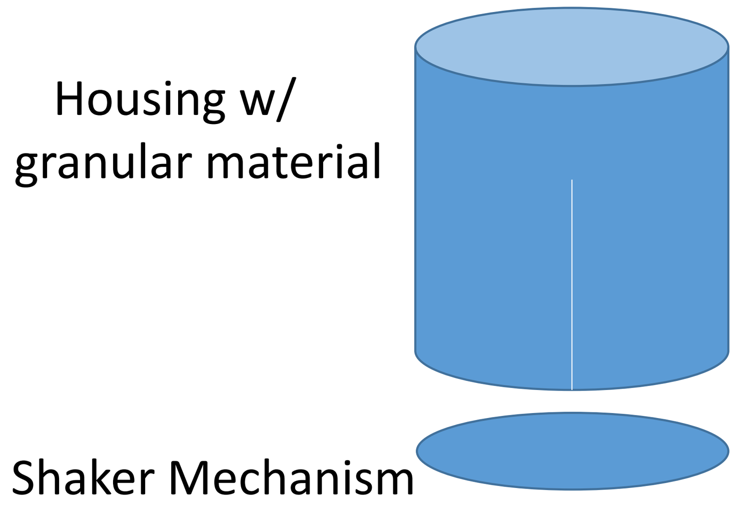
Project Overview

- Gain an understanding of the Flux and Hydrodynamic Models.
- Examine the Non-Linear Behavior and possibly its chaotic behavior.
- Create a computer program to give Flux Model's predictions.
- Build the system.
- Do the results match? Where is the non-linearity? Where is the chaos?

The Experimental Apparatus

Similar to the right picture in the next section.

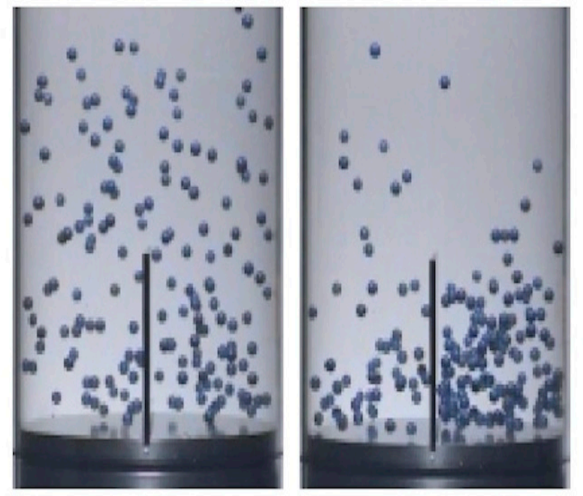
The housing will be made inexpensively with everyday materials. The shaker will either be a proprietary shaker, a speaker run by a function generator, or a circuit using piezo-electric crystals. Glass beads will be used for the particles. We plan to make the housing modular in the sense that it will be made into both a two or three compartment housing.



Visualizing a Granular Gas

Granules of solid matter in a gaseous form. a granular gas.

The cloud following the snowboard is made of snow particles which have mean free path which are roughly the same length as the particle.



Glass beads are the particles within container which is being shaken form a granular gas.

Left: http://www.nasa.gov/centers/ames/images/content/110054main_ACD05-0022-006m.jpg
Middle: http://pichost.me/1746677/
Right: http://stilton.tnw.utwente.nl/people/devaraj/images/twobox.jpg

The Flux Model

The flux function handles a non-equilibrium state in which particles will cluster into one compartment or in the case of the Brownian Motor will result in a flow through the many compartments.

$$(1)\ \Omega(\mathrm{n_k}) = \mathrm{A}\mathrm{n_k^2}\exp\left(-\tilde{B}n_k^2\right), with\ A = c_1\frac{\epsilon g N_{tot}^2 S d^2}{af\Omega^2}\ and\ \tilde{B}=c_2\frac{gh}{(af)^2}\left(\frac{N_{tot}d^2}{\Omega}\right)^2$$

Where n_k is the ratio of the number of particles in the compartment to the total number of particles in the system, N_{tot} is the total number of particles in the system, a is the amplitude of oscillation, f is the frequency of oscillation, S is the surface area of the aperture, Ω is the contact area of the shaker, c_1 and c_2 are free constants to fix the time scale, and $\tilde{B}$ is used as a dimensionless control parameter.

Courtesy of: Granular Gas Dynamics: How Maxwell's Demon rules in a non-equilibrium system. Ko Van Der Weele. Contemporary Physics. Vol. 49. No. 3. May-June 2008 pg. 157-178

The Hydrodynamic Model

By analogy a single granular particle is like that of an gaseous atom or molecule, therefore modeling the granular gas like a molecular gas is easily accomplished. Only two modifications are necessary. One being granular density which is a number density, and granular temperature is truly the average kinetic energy of the particles i.e. $T_g = \frac{1}{2}m\langle v^2\rangle$, with units of Joules and not Kelvins. For simplicity the following is a two dimensional model in equilibrium.

(1) $\Phi_{right\to left} = \Phi_{left\to right}$ *Flux Balance

(2) $\mathrm{p} = \rho T_g$ (Ideal Gas law w/ $K_b = 1$) *Equation of State

(3) $\frac{dp}{dt} = -mg\rho$ *Momentum Balance

(4) $\frac{d}{dz}\left[T_g^{\frac{1}{2}}\left(\frac{dT_g}{dz}\right)\right] = (\pi d^2)\epsilon\rho^2 T_g^{\frac{3}{2}}$ *Energy Balance

$p = pressure\ ; T_g = granular\ temperature\ ; \rho = number\ density\ ; m = mass\ of\ particle\ ; g = local\ gravitation\ constant\ ; \epsilon = inelastic\ constant$

Equation (1) shows that in equilibrium the number of particles moving from the left compartment to the right is equal to the particles moving from the right to left. Equation (2) establishes the state variables of pressure, temperature and number density. Equation (3) gives the pressure at a given height similar to atmospheric pressure. Equation (4) is the energy diffusion between the shaker device and the bottom layer of particles on the left side of the equation. On the right, the energy dissipated in particle collisions is modeled.

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The Next Step

Next we look to develop a computer simulation, build a two compartment system, and a rotary three compartment system in order to test the models, investigate Maxwell's demon, the Brownian motor, and develop the bifurcation diagrams for both systems. When this is complete we intend to seek industrial or commercial applications.