AstEx Microgravity Experiment: Simulating Asteroid Regoliths

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Abstract

Despite their very low surface gravities, asteroids exhibit a number of different geological processes involving granular matter. Understanding the mechanical response of this granular material subject to external forces in microgravity conditions is vital to the design of a successful asteroid sub-surface sampling mechanism, and in the interpretation of the fascinating geology on an asteroid. The AstEx experiment uses a microgravity modified Taylor-Couette shear cell to investigate granular motion caused by shear and shear reversal forces under the conditions of parabolic flight microgravity.

1. Introduction

Asteroids have a large range in size and thus a consequently larger range in mass. As a result, from planets to asteroids, surface gravities vary by many orders of magnitude. However, despite their very low surface gravities, asteroids exhibit a number of different geological processes involving granular matter.

To date two space missions have characterised an asteroid in detail. The NEAR Shoemaker mission revealed a substantial regolith covering (433) Eros [1], and the Hayabusa sample return mission revealed (25143) Itokawa to be a rubble pile asteroid (essentially made of regolith throughout) [2]. A dichotomy of rough and smooth surfaces was also observed at Itokawa including evidence of varied particle size and grain size sorting.

Bodies with low surface gravity can be very sensitive to processes that appear irrelevant in the case of larger planetary bodies. For instance, seismic vibration induced by small impacts has been proposed to explain the lack of very small craters both on Eros [3] and Itokawa [4].

Recent research has shown that the direction of prior shear influences how granular matter starts to flow [5]. The implication is that regions that normally do not move under steady shear move significantly during reversal of the shear direction. Studying the reversal of shear in a granular material can shed light on different modes of deformation that are evident when granular material is sheared in different directions.

Applying these experimental results to asteroids indicates that the dynamics of granular materials on their surfaces could also depend on the direction of shear that they have undergone. For instance impact phenomena [6][7], tidal forces from planetary encounters [8], and YORP spin up [9] could apply shear forces to the surface. Therefore, their surface materials may not necessarily behave as classically as expected.

2. The AstEx Experiment

The AstEx experiment flew in the ESA 51st Microgravity Research Campaign in November 2009 as part of ESA's 'Fly your Thesis' progamme.

The experimental aim is to characterise the response of granular material to rotational shear forces in a microgravity environment. A particular emphasis has been put on investigating the timescales to reach steady state flow and the memory effects of sheared glass beads in a Taylor-Couette shear cell in microgravity. The Taylor-Couette geometry is shown in Figure 1.

There are two concentric cylinders. The outer cylinder is fixed and its inside surface is rough with a layer of glued on particles; the outer surface of the inner cylinder is also rough but it is free to rotate. The floor between the two cylinders is smooth and fixed in place. The gap between the two cylinders is filled with granular material on which the rotating inner cylinder applies shear stresses. Large velocity gradients are then produced near the inner cylinder as the energy input in to the granular system by the rotating inner cylinder is dissipated by friction in a

narrow band. This localised region of shearing is known as a shear band. An AstEx shear cell is shown in Figure 2.
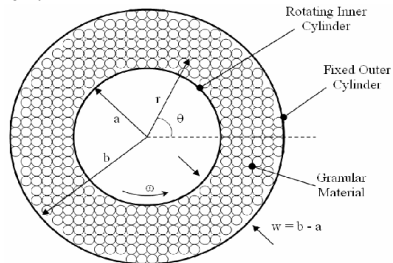

Figure 1: The Taylor-Couette Geometry [10]. (a = Inner Cylinder Radius, b = Outer Cylinder Radius, w = Width of Shear Region, r = Radial Distance, θ = Angular Distance, ω = Inner Cylinder Rotation Rate)
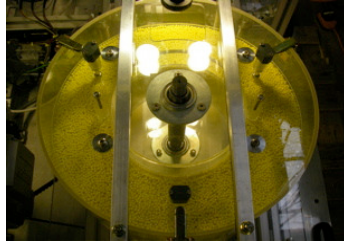

Figure 2: An AstEx microgravity modified Taylor-Couette shear cell filled with 4mm diameter glass beads.

3. AstEx Experimental Method

The nominal gravity regime during a parabola consists of 1.8 g for 20 secs, 0 ± 0.05 g for 22 secs and 1.8 g for 20 secs, where g is the Earth's gravity. During the period of microgravity in a single parabola a granular flow was initiated by applying rotational shear forces to the granular material. High speed cameras imaged the motion of the top and bottom layers of glass beads.

After the flight the individual particles on the surface layers of the granular material were tracked using a particle tracking algorithm [11] (see Figure 3). By calculating the particle velocities, it is possible to determine the timescales involved in initiating a steady state flow in a granular material. These timescales can then be compared to Earth based results. Another investigation considers the effect of reversing the direction of shear on the steady state flow already started in microgravity.
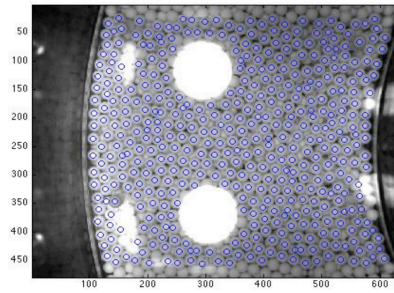

Figure 3: Demonstration of the tracked particles in one image. The bright patches are reflections from the illumination lamps.

4. Results

At the time of preparation of this abstract we are still very much involved in the data analysis phase. However, preliminary results indicate that prior shear direction may play an even greater role in the dynamics of granular materials in a microgravity regime than in a regime where gravity is confining the system. On the other hand, the effect on the granular material of steady state shearing in a direction perpendicular to the gravity field does not seem to be influenced by gravity. More detailed analyses are being performed to check these conclusions.

Acknowledgements

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