ASTEROID REGOLITH MECHANICS AND PRIMARY ACCRETION EXPERIMENTS IN A CUBESAT.
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Summary: Access to stable, long-duration microgravity environments for asteroid regolith experiments, rubble pile asteroid research, small body lander, sampler studies, basic examinations of planetesimal accretion and evolution need not be expensive.

On the one hand, billion-dollar concepts of returning entire ~3-5 m asteroids [1] are being considered that would ‘nab’ an asteroid to cis lunar space [2], where detailed investigations could be conducted at a relaxed pace by astronauts onboard a space station.

A much cheaper and more immediate alternative is to pack a few kg of fine fragments of common meteorite into a cubesat, using it to build a ‘patch of asteroid’ inside two experimental chambers onboard a spun-up 3U cubesat. We show that our design (AOSAT, Fig. 1) can mimic the asteroid surface environment in sufficient detail, providing us with a low cost orbiting laboratory for asteroid and primary accretion research.

Design: Two 1U chambers containing meteorite fragments and dust are on either side of a central chamber containing the spacecraft itself (Figure 1). For zero-gravity research (primary accretion) the spacecraft is stabilized to zero rotation by a magnetorquer (see below). For microgravity research, the spacecraft is spun on its minor axis using a flywheel, until the rocks are accelerated to the walls in simulated microgravity. We show that this approach is suitable, in terms of being a good approximation, and further can be achieved at very low cost, well under $1M.

Scientific Motivations. Zero-G experiments are common, using drop towers and parabolic flights, but in addition to any operational obstacles they are intrinsically limited to durations that are short compared to the predicted aggregation and global interaction timescales of hours to days. A swarm of dust particles may coagulate into ‘primary condensates’ balls, or a landslide might flow at mm/s, but these require >0.1-1 h of observation. Parabolic flights have noise levels far in excess of the ~0.00001-0.0001 G conditions that characterize most asteroids, comets and planetesimals. Human-tended experiments on space stations are costly and cannot introduce risk to astronauts. A centrifuge module for variable gravity research was planned by JAXA and NASA for the ISS but never flown.

Science on AOSAT: Here we describe the planned science investigations for the Asteroid Origins Satellite, related to two themes, or modes of spacecraft activity: (a) direct observations of primary accretion, and (b) studies of microgravity regolith mechanics, deformation, and operations/manipulations therein.

Primary Accretion: The coagulation of micron-sized grains into pebbles and planetesimals remains a fundamental mystery [e.g., 3-5]. How do small granules come together into ever-larger bodies? What are the physical properties of agglomerations, and how do they interact mechanically and electrically? While theoretical inroads are impressive, and computational simulations evocative, it is widely acknowledged that the most meaningful progress will be made by studying realistic materials in realistic environments.

Suitable environments can be fitted onto a cubesat, using commercial satellite and sensor technology and printed modifiable components. In addition to the spacecraft we are designing longer term, autonomously-tended experiments as a low cost laboratory that can be run and operated by investigators and their students. The simplest of these will be to fill a chamber with ~0.5 kg of meteorite dust (produced in hypervelocity impact experiments and preserved in vacuum), subject to electrical charges, for direct observations of coagulation over long time scale.

Regolith Mechanics: Primary accretion produces planetesimals, whose modern relics include many of the asteroids and comets. To understand these bodies we look at them from spacecraft and with telescopes, but observe only their visible surfaces. So there is a dire need to understand the physics of their surfaces – making measurements such as acoustic velocity and thermal diffusivity and cohesion and compressive strength. This is especially true of those objects whose surfaces we hope to sample, asteroids like mysteriously underdense Bennu [6], target of the OSIRIS-REx mission, and the comets whose frozen treasures may hold the key to planet formation.
In asteroid regoliths, compressive stresses are not zero, but ~microbars at centimeters depth, and ~0.1 bar at kilometers depth. This is enough to dramatically change the sound speed in granular solids, for example. Cohesion of fine particles may dominate regolith physics on macroscopic scales [e.g. 7, 8]. So we propose experiments to directly observe and measure the properties of asteroid regolith, as the material in the chamber is spun up from ~0 to ~0.0001 G (a nominal spacecraft spin of ~1 rev/minute).

**Overview and Approach:** We are developing a 4 kg cubesat science laboratory for repeated, monitored experiments. The satellite consists of 3 compartments, with two side compartments on either side to perform experiments. Passive magnetorquers embedded in the photovoltaics stabilize the satellite. An onboard attitude control system consisting of a motor will be used to spin the satellite perpendicular to its main axis at a nominal 1 rev/min. The experiment compartments will have similar mass and mass distribution to ensure an ‘even’ spin, and their responses must be modeled. Precise attitude control is not required, only stable spin during the experiment.

The central 1U houses the main computer to schedule the experiments, collect data and communicate it back to Earth. The system will have at least two levels of redundancy for each critical device. Each experiment chamber will have an embedded controller housed on the science board to perform and manage long-term experiments, and to activate and control experiment specific hardware including embedded actuators to release regolith from the storage container into the experiment chambers. In addition these control boards will operate sensors, including stereo-cameras, accelerometers and gyros.

A power board uses the onboard photovoltaics to generate an average power of 16 W in sun-synchronous orbit. The system consists of two independent power subsystems, each associated to each experiment chamber. A pair of onboard lithium ion batteries, with total a capacity of 30 Whr will be charged using the photovoltaics. The batteries will provide the required peak power of 24 W for experiments and communication.

Communication will be performed with an S-band antenna for a data uplink/downlink rate of 1 Mbps. This will transmit the necessary science data including photos, videos and sensor telemetry. A thermal control system (metabolic heating [9]) will maintain temperatures in the central compartment from -40 to +80 °C, using heat generated from the internal components. The central compartment will be a warm electronics box, insulated to minimize heat loss. Cooling is achieved in a low-power standby state, by operating few system components. While these experiment are long term, use of power-hungry systems will be periodic, lasting just 10s of minutes a day.

**Long Term Goals and Objectives:** In addition to the asteroid/accretion research described, this satellite centrifuge platform will serve as a template for using cubesats as an innovative, low-cost tool to perform hypothesis testing and experiments in planetary physics, life sciences, material science, science instrument testing and space technology development, wherever access to microgravity is required and can be studied in a small research chamber.

**AOSAT-1 is designed to:**
- Demonstrate a relatively simple, low-cost, cubesat based centrifugal science laboratory technology to perform microgravity and low-gravity experiments.
- Make a “real” 10-cm patch of asteroid surface regolith – meteorite dust and rock fragments several cm deep, centrifuged to stable microgravity conditions – for validating and enhancing asteroid models and for developing future approaches to robotic exploration of NEOs, hazardous asteroid mitigation, resource utilization, and sample return.
- Study and determine conditions required for accretion of dust in zero-G as a function of grain size, turbulence, electrical charge, and aggregates disruption.

**References:**