BUILDING PLANETS ON SUBORBITAL FLIGHTS. J. E. Colwell[1], J. Blum[2], and D. D.Durda[3]. [1]Department of Physics, University of Central Florida, 4000 Central Florida Blvd, Orlando FL 32816-2385, jcolwell@mail.ucf.edu. [2]Inst. for Geophysics and extraterrestrial Physics, University of Braunschweig, 38106 Braunschweig, Germany. [3]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder CO, 80302.

Introduction: The formation of km-sized planetesimals by collisional accretion of cm- to m-sized dust aggregates in the protoplanetary disk depends on the amount of material that is dislodged in collisions compared to the amount accreted. The standard model of planet formation proceeds from the gravitational collapse of an interstellar cloud of gas and dust through collisional accretion of solids into planetesimals and eventual runaway growth to form the terrestrial and giant planets [1]. For more than 30 years there have been two theories about how one critical stage of that process occurs, namely the growth of solid bodies from mm-sized chondrules and aggregates to km-sized planetesimals where gravity becomes an important force for further growth.

The evolutionary tracks of protoplanetary dust aggregates, from μm-sized dust to cm-sized pebbles lead through a parameter space that has not yet been covered by experiments. Multiple collisions among free-flying particles (e.g. dust aggregates) with velocities <0.01 m/s are impossible to perform in the lab due to the overwhelming effect of gravitational acceleration. Thus, free collisions in the sub-cm/s velocity range require a microgravity environment. We are developing an experiment for flight on a next generation commercial suborbital rocket flight to study the collisional physics of the early stages of planetesimal growth and the behavior of the regolith on planetesimals and other objects with very low surface gravity.

Microgravity Experiment on Dust Environments in Astrophysics: MEDEA is an experiment with three modules designed to study the early stages of planet formation and the behavior of regolith in low-gravity planetary environments.

Protoplanetary Dust Evolution Module. At the start of the Protoplanetary Dust Evolution experiment, dust aggregates will be mechanically excited to induce low-velocity collisions. Due to the mutual, highly inelastic collisions among the dust aggregates the collision velocities will decrease following Haff's law.

For relatively elastic, cm-sized glass beads (ε=0.64), drop-tower experiments showed that the initial velocity of v_0=10 cm/s falls to ~0.3 cm/s within 9 s, according to Haff's law [2]. Based on dust-aggregate collision experiments in the laboratory at velocities ~1 m/s [3,4], we expect coefficients of restitution $\varepsilon \approx 0.2$. For small ε, the coefficient of restitution is no longer important so that the temporal evolution of the particle velocities depends mainly on the number density. We envisage the following parameters: aggregate radius r = 1 mm, thus $\sigma = 4\pi r^2 = 1.3\times10^{-5}$ m^2, number density of dust aggregates $n = 10^7$ m^{-3}, coefficient of restitution $\varepsilon \sim 0.2$, initial velocity $v_0 \sim 0.1$ m/s. Thus, we will reach the desired range of collision velocities within ~1 s after injection.

We expect to extend our knowledge on the collisional evolution of protoplanetary dust aggregates down to collision velocities <1 mm/s, being only limited by the residual acceleration, which will ultimately drive the particles to the walls of the experiment chamber. For mm-sized dust aggregates we expect sticking at velocities below 0.5 mm/s and/or the occurrence of a clumping instability. Both effects should be observable in the experiment. As the expected duration of a single experiment ranges between 10 s and 30 s, we will be able to perform a series of ~10 individual runs, thus gaining statistics and being able to vary the grain properties. The collisional evolution of the dust aggregates (i.e. their individual sizes and velocities) will be followed over time using high-speed video imaging. In addition to that, each individual collision will be recorded in three dimensions so that we can map the collisional outcome for the full parameter space (particle masses, impact velocity, impact angle).

Collisions Into Dust Experiment-3. The COLLIDE-3 module will carry out experiments on low energy impacts into regolith to quantify and understand the production of ejecta and dissipation of energy in collisions between sub-m-scale aggregates and particles in protoplanetary nebulae. This module is a modification of the COLLIDE experiment that flew twice on the space shuttle [5,6]. The collisions in this module investigate the dissipation of energy in low-velocity impacts into regolith. Previous experiments have indicated a possible threshold velocity betweeen accretion and erosion near 10-20 cm/s [6]. The experiments performed in MEDEA will therefore be tuned to explore this part of the parameter space. The results from these experiments will also apply to the collisional evolution of planetary rings, where ring particle collision velocities are < 1 m/s, and the abundance of dust within the rings is directly related to the amount released in collisions between the larger particles [7,8].

This experiment consists of impacts by solid, single-particle impactors that are 1 to 2 cm in diameter into a 2-cm deep bed of simulated planetary regolith. JSC-1 lunar regolith simulant will be used as the target material in most of the impact experiments, with quartz sand used as a control in one experiment. The different shapes of the grains in the two materials lead to different responses to the impacts at low energies. Data will consist of high speed (at least 200 frames/s) video to track the ejecta produced as well as precisely measure any rebound of the impactors.

Rubble Pile Evolution Module. The Rubble Pile module will provide the first microgravity experimental study of the mechanical reorientation of ejecta blocks and test methods of reconstruction of the distribution of the blocks from imaging data. Knowledge of the surface properties of small asteroids and comets is important for relating astronomical observations of these objects to geologic “ground truth”, for understanding their relationships to meteorites, and for designing technologies and techniques for future robotic and human exploration, resource utilization, and impact hazard mitigation. Detailed observations of the surfaces of near-Earth asteroids Eros and Itokawa as observed by the NASA NEAR-Shoemaker and JAXA (Japan Aerospace Exploration Agency) Hayabusa missions, respectively, make the regoliths (the surface “soil”, composed of fragments of rock ground to various sizes by myriad impacts large and small) on these small bodies valuable natural laboratories for evaluating various models of their formation and evolution.

This investigation will examine the settling of regolith blocks in low/micro-gravity conditions applicable to the surface of a small asteroid and the derivation of block shapes from imaging (i.e., comparison of derived axes ratios from 2D projection in images to known true 3D axes ratios). The experiment consists of a simple “box of rocks” (artificial bricks of known size and shape) and a video camera to record images of the settled pile of rubble. The experiment will be executed by imaging the settled positions and orientations of the collection of identically-shaped, unglazed ceramic bricks, a subset of which are artificially colored to distinguish and highlight their shapes in post-flight image analysis using thresholding image processing. Reconstructed dimensions will be compared to the known dimensions of the bricks and compared with similar image analysis efforts conducted by ourselves and others (e.g., [9]) using NEAR-Shoemaker and Hayabusa images to advance our understanding of the morphology of small asteroid regolith structures.

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