EXPERIMENTAL STUDIES OF LOW-VELOCITY MICROGRAVITY IMPACTS INTO REGOLITH. J. E. Colwell[1] and S. Sture[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80309-0392, josh.colwell@lasp.colorado.edu, [2]Dept. of Civil, Env., and Arch. Engineering, University of Colorado, Boulder CO 80309.

Introduction: The dusty regoliths of ring particles, proto-planetesimals, planetary satellites, and asteroids are subject to collisions at low velocities (v ~ 0.1-100 m/s) in addition to the hypervelocity (≥ 1 km/s) impacts from the interplanetary micrometeoroid flux. In some regions of Saturn's rings, for example, the typical collision velocity inferred from observations by the Voyager spacecraft and dynamical modeling is a fraction of a centimeter per second [1]. These interparticle collisions control the rate of energy dissipation in planetary rings and the rate of accretion in the early stages of planetesimal formation. Dust on the surface of planetary ring particles and small (1 cm – 10 m) planetesimals helps dissipate energy in the collision, but may also be knocked off, forming dust rings in the case of ring particles and slowing or inhibiting accretion in the case of planetesimals. Secondary impacts on asteroids and small planetary satellites occur at speeds comparable to the escape velocity from the object, or meters/second for objects ~10 km in radius or smaller. We report on impact experiments performed in the reduced-gravity environment of the NASA KC-135 aircraft at speeds between 13 and 220 cm/s into simulated regolith.

Description of Experiments: The Physics of Regolith Impacts in Microgravity Experiment (PRIME) flies on the NASA KC-135 and can perform impacts into granular materials at speeds of ~20-500 cm/s in microgravity. The experiment is conceptually identical to The COLLisions Into Dust Experiment (COLLIDE) which has flown on the space shuttle twice [2, 3]. PRIME allows impacts at angles of 30, 45, 60, and 90 degrees to the target surface. Impacts are performed in vacuo; ground-based experiments at 1g have consistently shown a strong effect of ambient air on the behavior of regolith in low-velocity impacts. Projectiles are spherical particles launched by a spring designed to provide the desired impact velocity. The target materials studied so far are quartz sand, JSC-1 lunar regolith simulant, and JSC-Mars-1 Martian regolith simulant. Projectile materials are Delrin, quartz, Aluminum, brass, and stainless steel, providing a range of masses with the same projectile radius. Impacts are performed in isolated chambers (Figure 1) with up to 8 experiments per flight. The target depth is 2 cm for all experiments performed to date, but that can also be varied. Further experiments using a drop tower are planned that will extend the velocity range down to 5 cm/s.

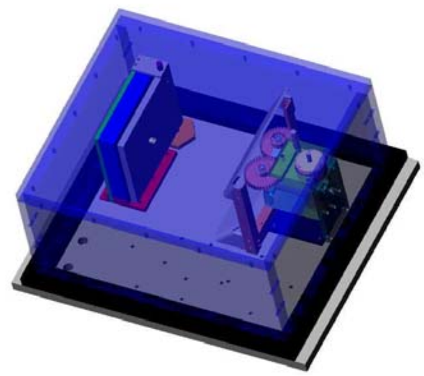

Figure 1. Schematic of a PRIME Impact Chamber. The target material is held in place in the target chamber at left until the airplane is in a stable low-acceleration part of the parabola. The target surface is exposed by manually opening a door through a mechanical feedthrough. The projectile launcher is shown configured for a normal incidence impact at right.

Data are taken with a high speed video camera recording at up to 500 frames per second. The camera views the impact with the line of sight parallel to the target surface and the projectile trajectory in the image plane. Two mirrors inside the impact chamber provide an orthogonal view of the impact (Figure 2). Similar ground-based experiments at 1g have been performed at speeds between 100 and 240 cm/s at normal incidence with JSC-1 and quartz sand targets.

Results: In two flight weeks in 2002 we performed 45 successful impact experiments. Because these 45 impacts included a range of impact velocities, target materials, projectiles, and impact angles, more data are needed to separate the effects of all the parameters on impact outcome. (Flights are also planned for January, February, and May 2003.)

For all normal incidence impacts (34 of the 45 experiments) there is a transition between rebound and no rebound of the projectile at an impact speed of about 50 cm/s. Projectiles rebound from the target at impact speeds as low as 16 cm/s for oblique impacts. Some ejecta were produced in impacts slower than 20 cm/s, but none was produced at the slowest impact at

13.8 cm/s at an angle of 33 degrees to the surface. For comparison, an impact at 12 cm/s at normal incidence in COLLIDE-2 resulted in a small amount of ejecta and no rebound, while at impacts at 28 cm/s and higher there was a large amount of ejecta and the impactor rebounded [3]. The fastest speed which resulted in no ejecta in PRIME was 37.9 cm/s at normal incidence. Rebounding of the projectile does not correlate strongly with impact velocity, however, perhaps because of the residual acceleration in the airplane. In order to compensate for the unavoidable acceleration fluctuations in the airplane, we run the experiment at slightly positive accelerations (~0.02g). This is enough to mask rebound of impactors if the rebound speed is small. Coefficients of restitution measured by COLLIDE are 2-3%, so that rebound speeds are at most a few cm/s. In some cases the rebound of the projectile is obscured by the ejecta cloud, though the orthogonal view in the mirror shows at least whether or not a rebound occurred.

Figure 2. Frame from the PRIME experiment in July 2002. The target surface is viewed edge-on and is at the bottom of the frame. Two mirrors at the top of the frame provide an orthogonal view of the impact. The black cylinder protruding between the mirrors is part of the projectile launcher. In this experiment the target was silica quartz sand and the impactor was a quartz sphere at 160 cm/s. An expanding ejecta cloud is visible at the right and running into the open target tray door at left.

We are continuing data analysis from the first two flight weeks to extract both normal and tangential coefficients of restitution for those cases where the rebound can be observed. Crater formation is visible in the mirror view (Figure 2), although in microgravity we only observe the formation of the transient crater; there is no final stable crater. We will then compare these results to those obtained by COLLIDE on the space shuttle, summarized in Table 1, in a true microgravity environment. PRIME allows more impact experiments to be run so that more parameters can be explored.

We will report on the results obtained from our second set of flight experiments which will bring our total number of microgravity impact experiments to more than 100.

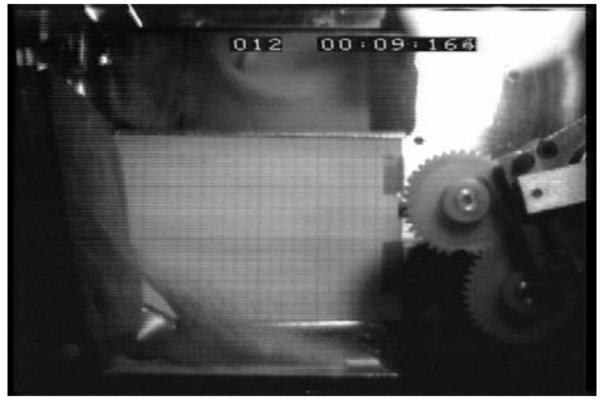

Figure 3. Frame from an impact at 30 degrees incidence angle into silica quartz sand at 140 cm/s at an angle of 30 degrees above the target surface in August 2002. The launcher is visible at right and one mirror at top shows the projectile (Delrin sphere with black marking) in the target material. The highly asymmetric ejecta cloud moves off to the left. Fiduciary marks on the impactor and the secondary view in the mirror allow us to measure the impactor rotation before and after impact, yielding the tangential (sliding) coefficient of restitution.

No.	Impact Speed (cm/s)	Normal Coeff. of Restitution	Crater Diam. (cm)	Max. Ejecta Velocity (cm/s)
1	15	0.028	<1	0
2	17	0.022	<1	0
3	90	0.03	N/M	N/M
4	110	0.01	6±2	10±1
5	3.6	0	0	0
6	1.3	0	0	0
7	81	0.015	N/M	16±1
8	12	0	0	1.5±0.2
9	25	0.02	4±2	3±1

Table 1. Summary of results from the first two flights of COLLIDE [1, 2], showing very low coefficients of restitution, and maximum ejecta speeds of about 10-15% of the impactor speed. N/M means not measured.

References: [1] Esposito, L. W. (1993) *Annu. Rev. Earth Planet. Sci. 21,* 487-523. [2] Colwell, J. E., and Taylor, M. (1999) Icarus *138,* 241-248. [3] Colwell, J. E. (2003) *Icarus* (submitted).