EJECTA EMPLACEMENT IN THE LAB. K. D. Runyon[1] and O. S. Barnouin[2], [1]Johns Hopkins University Department of Earth and Planetary Sciences, Baltimore, MD, USA (kirby.runyon@jhuapl.edu), [2]Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA (olivier.barnouin@jhuapl.edu).

Introduction: Ejecta emplacement across the Solar System is a major agent of geomorphic change but much remains poorly understood. We seek to use lab investigations to enhance understanding of: 1.) Controls on ejecta mixing with original regolith with emphasis on lunar highlands/mare mixing [e.g. 1]; 2.) Controls on ejecta runout [e.g. 2,3]; and 3.) Controls on final ejecta morphology with emphasis on ejecta thickness and Martian rampart morphology [2,3]. While the results will be applicable to any solid solar system body, we plan to ultimately focus on the dynamics of ejecta emplaced on the Moon and Mars.

Background: Ballistic sedimentation from ejecta emplacement is responsible for eroding and mobilizing regolith [e.g., 4]. Scaling rules for cratering [5,6,7] describe crater formation, ejecta excavation, and initial ejecta deposition, but do not capture the details of ballistic sedimentation, including subsequent surface flow and estimates of ejecta runout. The presented suite of experiments begins to fill this niche.

Comparisons between planetary ballistic sedimentation with landslides may prove useful. The runout efficiency *L*/*H* of terrestrial landslides is equal to the reciprocal of the resistance-to-flow coefficient, R_f [8] where *L* and *H* are a debris flow's runout length and height displacement. This relationship is derived from balancing potential energy with work. Using an analogous energy-work balance approach we derive [3]

$$\frac{1}{R_f} = \frac{2}{3}\frac{\left(3-\frac{2}{\mu}\right)L}{c^2 e R_t}\left[1-\left(\frac{x_\ell}{R_t}\right)^{3-2/\mu}\right]^{-1}$$

to arrive at ejecta runout efficiency. (Variables given in Table 1). Of note, *e* is unconstrained but is experimentally measureable. Constraining *e* is a major motivation for laboratory ejecta experiments largely due to its implications for ejecta volatile content.

This effort aims to demonstrate that the ejecta emplacement catapult used in this investigation is a useful tool to discover scaling relations for ballistic sedimentation. Preliminary results provide estimates of ejecta runout efficiency and constrain the ejecta energy available for flow. Both these variables are key to place constraints on ejecta flows on planets, moons, and large asteroids.

Experimental Methods: As described elsewhere [9], the ejecta catapult (Figure 1) is a ~1 m^2 curved steel plate shaped to resemble a portion of ejecta curtain. The lower tapered end is mounted to a stiff, spring-loaded pivot. After pull-back, the catapult is loaded with ejecta simulant (coarse pea gravel) that is unaffected by atmospheric drag during flight. Here, we use 6, 8, & 10 kg of ejecta simulant that we launch onto two target surfaces: a hard, smooth surface (plywood) and into catchment bins.

Table1. Variables used in the runout efficiency equation above.

R_f	Resistance to flow
μ	Coupling parameter [5,6,7]; here, 0.5
L	Gravel ejecta runout; found to be 0.27-0.39 m
c	Empirical cratering constant; here, 0.47
e	Ejecta energy available for ejecta sliding = KE_{slide}/KE_{strike}; found to be 0.23-0.28. See text.
R_t	Transient radius of hypothetical crater; found to be 5.5 m (velocity) & 1.9 m (mass)
x_l	Launch distance from impact point inside crater from which an ejecta parcel will reach the edge of the continuous ejecta deposit 1 crater radius from the rim; here, 3.5 m.

Ejecta emplacement onto plywood represents an end-member scenario roughly analogous to an impact on a young surface before a regolith has developed. It is also a simple arrangement and useful for these early catapult experiments for validating the apparatus as a useful research tool.

Ejecta emplacement into catchment bins allows us to measure the mass distribution before it has a chance to slide, including estimating the pre-sliding center of mass (COM). Setups are shown in Figure 1.

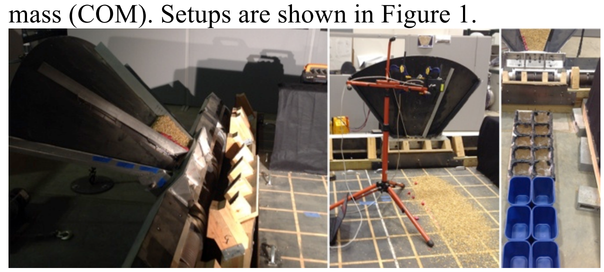

Figure 1. Catapult setup for both runout (plywood, *left 2 frames*) and non-sliding mass catchment (containers) experiments (*right*). 25 cm grid for scale. Middle frame shows laser topographic profiler over an ejecta deposit.

Methodological & Scientific Results: The ejecta catapult methodological results show that the catapult can simulate the mass and velocity profiles of an ejecta curtain, but for hypothetical craters of different sizes. Specifically, the mass profile is representative of an R_t = 1.9 m crater while the velocity profile of the same experimental run is representative of an R_t = 5.5 m crater. Dimensional analysis (e.g. Figures 2 & 3) shows a good match between mass-velocity distributions of the catapult and the initial theoretical behavior of true ejecta.

Non-Dimensional Velocity Profile: The most useful means to model and eventually scale the ejecta's velocity profile is to use the ejecta's ratio of gravitational forces to inertial as given by $\pi_2 = 3.22gr/v^2$, where r is the width of the impacting ejecta curtain, g is Earth's gravity, v is the curtain impact velocity, and 3.22 is an empirical value historically used in the literature [6,7]. Indeed, theory indicates that we're simulating a terrestrial crater of radius R = 5.5 m and depositing the ejecta ~0.7-0.9 crater radii from the hypothetical rim (Figure 2) with a power law extrapolation of the results. These ejecta were excavated ~0.7 crater radii from the hypothetical impact point.

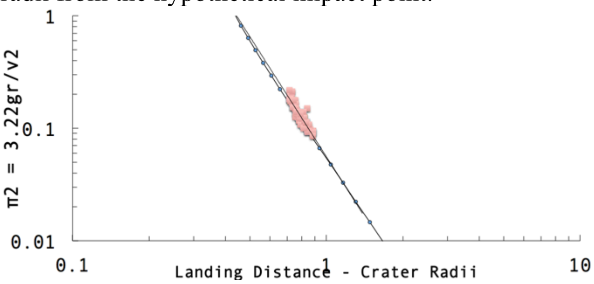

Figure 2. Comparison of the gravitational to inertial ratio of ejecta just before it lands to a theoretical model derived from crater scaling rules. Results show the catapult accurately models ejecta curtains. Comparing this ejecta landing speed to the initial ejecta sliding speed is the starting point for assessing effects of ballistic sedimentation.

Ejecta Runout Efficiency and e*:* Catchment experiments provide the landed-ejecta COM before it slides. Measurement of the deposit using a laser topographic profiler provides the COM post-sliding.

Figure 4 shows that our measured runout efficiencies of ~0.6 are within the predicted range of efficiencies for terrestrial and Martian landslides [3,8] when compared with volume data (Figure 4). A well-known empirical phenomenon is that runout efficiency for landslides (and likely ejecta) is controlled by volume [8,3], though this is unaccounted for theoretically.

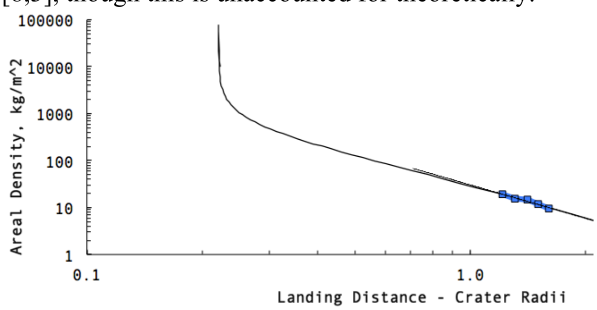

Figure 3. The experimental mass profile for 8 kg of gravel fits the theory well for R_t = 1.9 m and a deposition zone 1-1.1 crater radii from the hypothetical crater rim.

In our experiments we also estimate the ratio of the energy e lost by ejecta at the instant of striking to its remaining energy at the onset of sliding. This value is 0.23-0.28, close to the assumed upper value of 0.3 and much higher than the assumed lower bound of 0.01 [3].

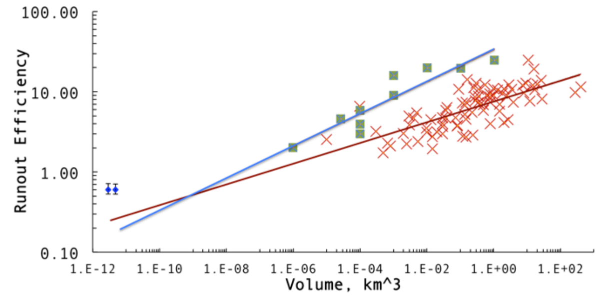

Figure 4. Runout efficiency vs. volume-of-flow for 6 & 10 kg of catapult gravel and dry & wet terrestrial & Martian landslides (green squares & red x's [3]). The lab catapult data (blue diamonds) appear consistent with the power law fit to these field data.

Conclusion: Methodological results show that the ejecta catapult is able to reproduce the expected velocity and mass distributions for natural ejecta curtains and is therefore proving itself a valuable tool in ejecta studies. Early scientific results show that the runout efficiency measured on a smooth surface is comparable to an extrapolation of the expected runout for a range of dry landslides and wet debris flows. These results also show that the measured variable e range from 0.23-0.28, confirming that a significant fraction of the ejecta energy prior to deposition is available for subsequent ejecta sliding and erosion. This is consistent with what we found earlier in qualitative assessments of the ejecta erosion process [10]. Those studies found significant erosion of the surface by the continuous portion of an ejecta deposit. Although a more detailed investigation of ejecta runout on Mercury and Mars (useful because of similar gravities) is truly needed, the results found here might indicate that the runout of ejecta observed on Mars may not need a significant fluid presence to generate the observed layered ejecta patterns. In a future effort we will also measure the erosive efficiency of gravel-on-gravel emplacement to derive scaling rules that we can use to accurately scale laboratory results to real planetary landscapes.

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