EARLY-STAGE EJECTA VELOCITY DISTRIBUTION B. Hermalyn[1], P.H. Schultz[1], and J.T. Heineck[2], [1]Brown University, Providence, RI 02912-1846 (Brendan_Hermalyn@brown.edu), [2]NASA Ames Research Center, Moffet Field, CA 94035

Introduction: The ejection velocity distribution of an impact event determines the emplacement of material on planetary bodies. Dimensional analysis[1] predicts a single power law relationship between ejection velocity and time (or ejection position) for *main-stage* excavation. At very early times, however, when energy and momentum are still being coupled to the target, "[t]he power-law expressions for ejecta velocities may not hold." [1]. This study investigates high speed early-time departures from the accepted power-law relationship over a range of projectile diameters.

Experimental Methodology: A suite of impact experiments into #20-30 sand (nominal grain diameter of ∼ 400μm) was conducted at the NASA Ames Vertical Gun Range (AVGR) for different diameters of Aluminum projectiles: 6.35mm at ∼5km/s and 3.175mm at ∼5km/s. Here we report the results for vertical impacts. Two independent nonintrusive imaging techniques were used to determine the ejection velocity of the experiments: 1) high-speed 3-Component Particle Imaging Velocimetry (3D-PIV) and 2) particle tracking velocimetry (PTV) of the sand grains in the ejecta profile. The 3D-PIV system utilizes a pulsed laser light sheet projected parallel to the impact surface to illuminate horizontal slices of the ejecta curtain (see Fig. 1). These slices are recorded from above in stereo by high speed cameras (in this case, 10,000 frames per second, or fps). Cross-correlation between successive frames and cameras allows determination of displacement, and thus the three-component velocity, of the ejecta curtain[2, 3, 4]. This new high-speed system records the velocities of ejecta throughout the cratering process, whereas past studies [3, 4] were restricted to a single discrete pair of stereo images per impact experiment (one velocity vs. time "data point" per experiment). The PTV technique, where individual particles are tracked in successive frames (3D-PIV relies on denser seeding of the flow field), was used on high-speed (∼11,000 fps) data sets of the profile of the ejecta curtain (i.e. looking parallel to the impact surface). This second technique allows measurement over a greater dynamic range of velocities due to the increased distance individual particles can travel between frames, and permits focus on the area very close to the impact point. The time-resolved nature of these data sets allows investigation of the dynamics of the ejecta flow field in a regime earlier than has been examined in previous PIV studies or [1].

Analysis and Results: When scaled using normal relationships, the ejecta velocity distributions of the projectile diameters studied display a noticeable increase in speed over the power-law predicted slope of -0.709 at very early times (using $\alpha = 0.51$ for impact into Ottawa sand [1]; see Fig.2). To examine the change of slope and transition point to main-stage growth, a two-slope regression is performed and compared to a single power law fit (see Fig. 3). The two slope model is found to be a statistically better fit than the one-slope model at the 99% confidence level for both diameters. In addition, the slope of the single best-fit line is found to be greater than dimensionally predicted in all cases. The different diameters "spread" from the nominal scaling regime at different points, thereby indicating that the physics controlling this early-stage component differs from main-stage growth. This transition point is determined by finding the non-dimensional time of launch, t/Tc, that minimizes the sum of squares of misfits between the two lines; the 95% confidence interval for this transition point is displayed in Fig. 2.

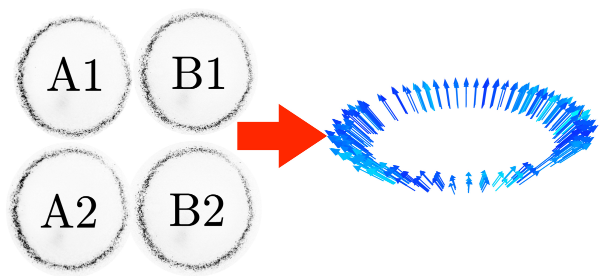

Figure 1: 3-D PIV Data Set. Two stereo image pairs of the ejecta curtain "slices." These images are cross correlated to determine the horizontal and vertical displacements of the particles and, when coupled with the time between successive image pairs, yield the velocity of the ejecta at that moment in time. Images (inverted) are of an impact of a 6.35mm Al projectile traveling at 4.7 km/s at 90° into #20-30 sand.

Conclusions: Experimental results indicate a departure from the power-law scaling of ejecta velocity that characterizes nominal excavation. This deviation is consistent with the transition from early-stage coupling to main-stage excavation of the crater. The total amount of mass ejected during this stage in experimental studies is small relative to main-stage excavation (at least for vertical impacts), and mostly in the form of fine material. This approach, combined with determination of ejecta mass, as in [5], will provide a more complete description of the full evolution of the ejecta distribution.

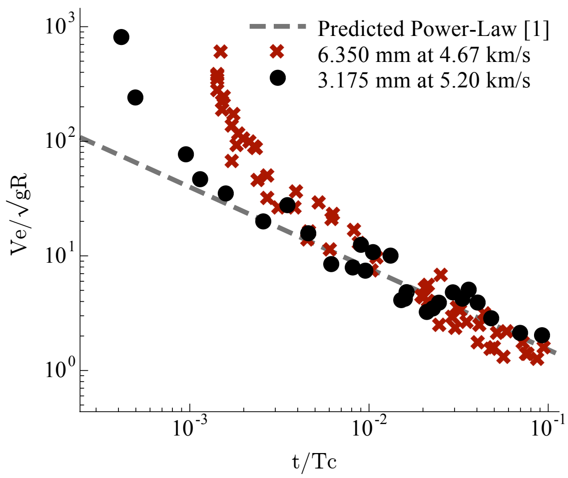

Figure 2: Scaled velocity vs. time. The power-law slope predicted by [1] of -0.709 (using $\alpha = 0.51$) is superimposed as a dashed gray line. Although the velocities seem to scale as expected around $t/T_c = 0.1$, they display a noticeable augmentation at early times. A running mean filter was applied to the data for enhanced visibility.

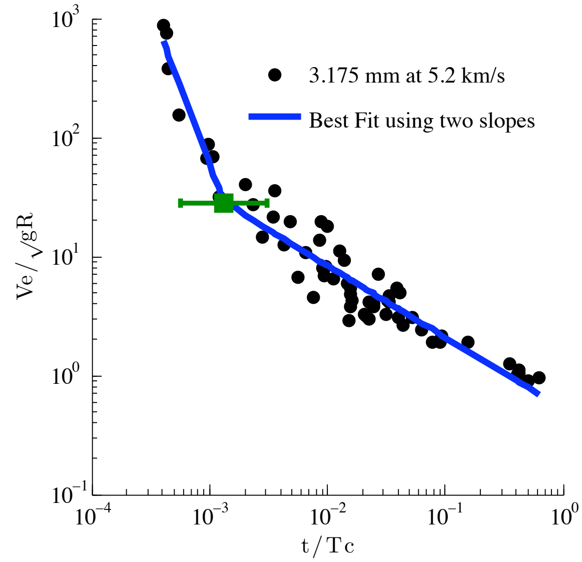

Figure 3: Regression analysis for the 3.175mm projectile velocity data. Raw data is presented as black dots with the best fit lines of the two-slope regression overlaid in blue. The transition point, which minimizes the sum of squares of errors is indicated by the green square; the green error bars indicate the 90% confidence interval for the transition point.

References:

[1] Housen, K.R., Schmidt, R.M., *et al.* (1983) *JGR 88*, 2485–2499. [2] Heineck, J.T., Schultz, P.H., *et al.* (2002) *Journal of Visualization 5*(3), 233–241. [3] Anderson, J.L.B., Schultz, P.H., *et al.* (2003) *JGR(Planets) 108*, 5094. [4] Anderson, J.L.B., Schultz, P.H., *et al.* (2004) *Meteoritics & Planetary Science 39*(2), 303–320. [5] Hermalyn, B., Schultz, P.H., *et al.* (2008) in *LPSC* vol. 39 2292.