EXPERIMENTAL RESULTS INVESTIGATING IMPACT VELOCITY EFFECTS ON CRATER GROWTH AND THE TRANSIENT DEPTH-TO-DIAMETER RATIO.

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Background Non-intrusive measurements of crater growth at low impact velocities (<300m/s) [1] and particle ejection velocity at higher impact velocities (800-2500m/s) [2] indicate that the rates at which a crater shape grows and ejecta particles are launched appear to change with increasing impact velocity. This is at odds with the point-source assumption of the scaling relationships typically used to assess cratering on asteroids and planets [3-5], which states that early coupling between the projectile and target should have no influence on the normalized rates of crater growth and particle ejection as long as identical projectile and target materials are considered. Likewise, the diameter-to-depth relationship of the transient crater when excavation ceases should show no dependence on initial coupling, unlike that observed in [1].

The discrepancy between the scaling rules and the experiments of [1] has been attributed to the low impact velocities (<300m/s) investigated, which are insufficient to cause the projectile to fail. Instead, the projectile interacts with the target through a combination of stress waves and friction. The slow frictional deceleration of the projectile yields a longer interaction time between projectile and target, violating the point-source assumption. The low impact velocities causes a slow decay in crater growth, and permits greater projectile penetration yielding greater transient crater depths relative to their diameters. As impact speeds increase (but still remain low), more rapid frictional deceleration of the projectile leads to point-source like conditions, with more rapid decay of crater growth and shallower depths.

In the case of the experiments discussed by [2], the discrepancy between the scaling rules and the presented results have been attributed to numerous factors. These include the low impact velocities considered (800-2500m/s), where shock effects begin to dominate the cratering processes (the sound speed of this type of target material will be around 150-300m/s [6]), but where some frictional and fragmentation processes remain important [7]. Furthermore, the targets used in these investigations are composed of coarse, angular grains that are only ~2x smaller than the projectiles. Complex shock interactions would be produced as a consequence of such impact conditions that probably influence the observed results [8].

Most planetary collisions occur as hypervelocity impacts, where the projectile velocity significantly exceeds the sound speed of the target and the projectile completely fails on impact. Furthermore, crushing of material near the impact point is anticipated to yield much better coupling between the projectile and target. The point-source assumption should be satisfied for such hypervelocity impacts. Schultz [9], however, provides experimental evidence that, much like in the low velocity experiments of [1], the point-source assumption of the crater scaling rules might not be fully satisfied for these hypervelocity impacts. The time a projectile interacts with the target could influence the cratering process, but for a different physical reason. Here, shock processes rather than friction and stress waves might control how and when the projectile transfers its energy to the target. Under low hypervelocity conditions (<3km/s), the projectile and target will interact for longer periods of time than at higher hypervelocity conditions (>3km/s). The longer interaction yields more cylindrical rather than hemispherical shock waves, which are likely to decay more slowly than their hemispherical counterparts. The longer interaction also allows greater penetration relative to the transient crater diameter when excavation ceases.

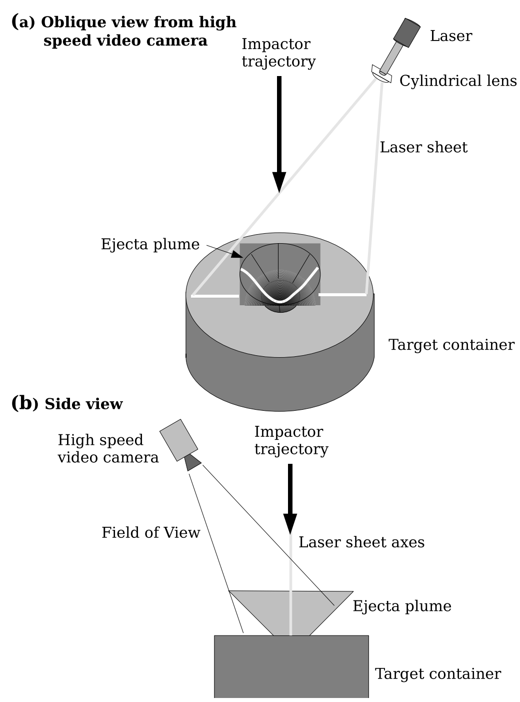

Figure 1. Schematic illustrating the experimental setup used at the NASA Ames and University of Tokyo Vertical Gun Ranges.

Objectives: We performed vertical hypervelocity impacts (0.5-6 km/s) at the NASA Ames Vertical Gun Range to evaluate if increasing impact velocity, which alters the coupling time between the projectile and target, might change the rates of crater growth and transient crater shape. Easily broken, 6.25mm Pyrex projectiles are launched with these velocities into 350μm glass spheres nearly identical to those employed in the low velocity studies of [1]. Measurements made include the rates of crater growth and the aspect ratio of the transient craters. We used the same non-intrusive laser sheet technique employed (Figure 1) during the low velocity study, where laser profiles centered at the impact are monitored through time using two high-speed (2000 f/s) cameras (Figure 2). We also undertook additional low impact velocity studies at the Univ. of Tokyo Vertical Gun Range (<300m/s) to confirm our previous data [1], using the much improved high-speed cameras now available at that facility. The same 350 μm glass beads used at Ames were employed here, rather than the 220μm spherical grains used in [1]. Because of the superior cameras and brighter lasers currently available at NASA Ames and U. Tokyo, it was possible to observe the impacts with the ambient lights on, so that the position of the laser sheet relative to the crater center could be verified throughout the cratering process.

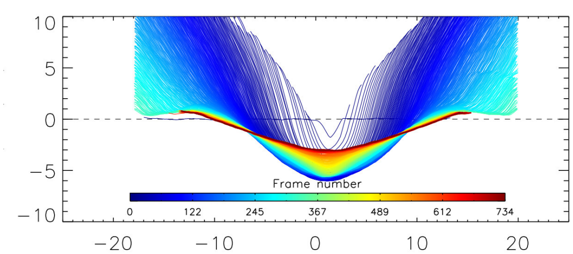

Figure 2. Example showing crater profiles as a function of time (frame number) acquired at 2000 f/s for a 6.25mm projectile launched into 350μs glass beads at 1.32km/s at NASA Ames.

Results and Implications: Figure 3 shows preliminary results of the changes in μ with impact velocities. The parameter μ is equal to the inverse of the rate of crater growth. By the crater scaling rules [3], this parameter should equal the μ measured from relationships for cratering efficiency [5]. The results indicate that while the projectile velocity is less than the sound speed of the target, the value of μ decreases with increasing impact velocity, thereby violating the point-source assumption of the crater scaling rules. However, once the projectile velocities exceed the target sound speed, no systematic changes in μ are observed with increasing velocity, and the scaling rules are satisfied. The value of μ, however, remains smaller than that measured by cratering-efficiency relationships for the targets used in this study. The preliminary results for depth-to-diameter ratio (Figure 4) of the transient crater formed by hypervelocity impact do seem to decrease with increasing impact speed contrary to the self-similarity relations implicit to the point-source approximation. If additional analyses confirm this result, it could have implications for crater modification at planetary scales where large variations in impact velocity might exist, or when the morphology of craters are compared that form at similar gravitational accelerations but dissimilar impact velocities (e.g., on Mars versus Mercury).

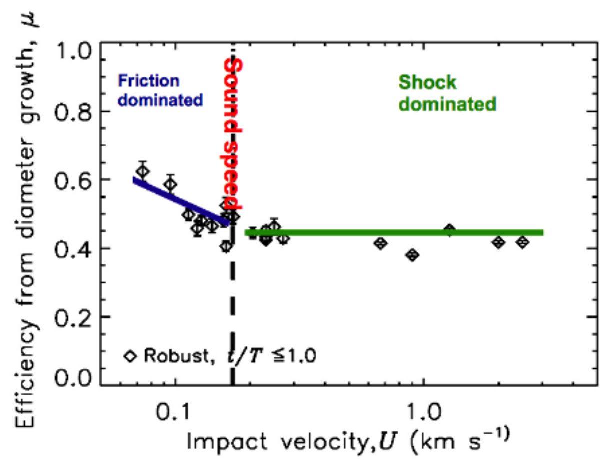

Figure 3: Preliminary results showing changes in the efficiency parameter μ = 1/(rate of crater growth) with impact velocity.

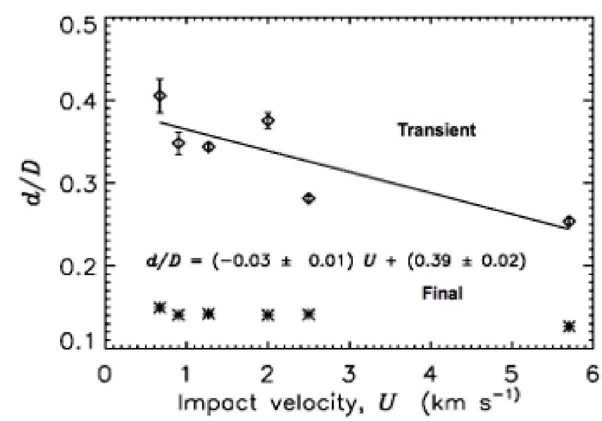

Figure 4: Preliminary results showing changes in the transient and final diameter-to-depth ratio of craters with impact velocity.

References: [1] Barnouin-Jha et al., *Icarus* 188, 506 (2007). [2] Cintala et al., *MAPS* 34, 605 (1999). [3] Housen et al., *J. Geophys. Res.:88*, 2485 (1983). [4] R.M. Schmidt and K.R. Housen, *Int. J. of Impact Engin.* 5, 543 (1987). [5] K.A. Holsapple, *Ann. Rev. of Earth and Planet. Sci.* 21, 333 (1993). [6] Teramoto, K., Yano, H., *LPSC* 36. 1856 (2005). [7] Collins and Wünnemann, *LPSC* 38, 1789, 2007. [8] Barnouin-Jha et al., *LPSC* 36, 1585 (2005). [9] P.H. Schultz, Cratering on Mercury - A relook, in *Mercury*, pp. 274-335, Univ. of Arizona Press (1988).