EVOLUTION OF IMPACT EJECTION ANGLES: IMPLICATIONS FOR EARLY-STAGE COUPLING

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Introduction: Ejection angles from an impact affect the surface distribution of emplaced mass on planetary bodies. Although ejection angles are commonly assumed to remain constant throughout crater development [1], prior experimental studies indicate that the angle varies with time over the middle [2] and late stages [3] of crater formation. Here we examine the time-resolved evolution of ejection angles at early times in order to understand the progression of the cratering flow-field as it transitions from the compression to excavation stage of crater growth.

Experimental Methodology: A suite of impact experiments into quartz sand was performed at the NASA Ames Vertical Gun Range (AVGR) over an array of impact variables. Through the use of a new high-speed (1000 frames/second) Three-Dimensional Particle Imaging Velocimetry (3D-PIV) system, the velocity and ejection angle of the expanding ejecta curtain could be measured throughout the cratering process with high temporal resolution. Calculation of other ejecta characteristics, such as ejecta curtain radius, from the raw 3D-PIV images allows further insight into the physics of the excavation process.

Results and Analysis: The high degree of temporal resolution afforded in this study permits exploration of the early-stage coupling regime. The ejection angle for vertical impacts increases by ~10° in the first few milliseconds after impact before transitioning to the ballistic excavation flow stage of growth, which is characterized by ejection angles of ~50° from horizontal. This evolution occurs for both low (1 km/s) and high-speed (5 km/s) impacts, and most likely reflects the early-time migration of the flow-field center during the penetration stage. These findings are consistent with prior studies of flow-field center migration [4], but now can be applied to a much earlier stage of growth. The timing of the ejection angle augmentation and subsequent progression to the nominal ejecta-flow pattern is directly related to the shock-coupling in the impact event, and is therefore affected by impactor size, density, and velocity. Measurements of the curtain radius capture the same transition in the flow field, where an initially large curtain radius (i.e. a low ejection angle) develops into main stage ejection flow. As impact angle decreases, departures from the point-source assumption become more pronounced.

Implications: While the point-source assumption provides a useful tool for analytical approximations of the cratering flow-field, it does not capture the full complexity of crater evolution. In particular, application of such models to larger scale impacts break down at high ejection speeds (i.e. the early penetration stage). The 3D-PIV results now allow better characterization of the ejection angle, velocity, and mass flux throughout crater growth using dimensionless scaling relations keyed to different stages of excavation.

References: [1] Housen, K.R., et al. (1983) *Journal of Geophysical Research,* 88, 2485-2499; [2] Anderson, J.L.B., et al. (2003) *Journal of Geophysical Research,* 108(E8), 5094; [3] Cintala, M.J., et al. (1999) *Meteoritics & Planetary Science*, 34, 605. [4] Anderson, J.L.B. and Schultz, P.H. (2006) *International Journal of Impact Engineering*, 33, 35-44.