# A REEXAMINATION OF LOW-VELOCITY OBLIQUE CRATERING WITH NEW TECHNIQUES.

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**Introduction:** Advances in technology, such as laser-plane imaging and 3D scanning of the final crater, will allow us to gain new insights from a series of low-angle impacts in near-vacuum conditions into mostly strengthless targets, similar in nature to those conducted by Gault & Wedekind [1] over four decades ago. We show results from experiments at a few hundred m/s performed at the APL Planetary Impact Lab, a prelude to hypervelocity experiments planned at the Ames Vertical Gun Range, and relevant to secondary cratering on terrestrial bodies. Angles listed are relative to the target surface, which we refer to as an effective impact angle (EIA).

**Changes in ejecta pattern with impact angle:** A weak butterfly pattern forms at modest impact angles (EIA ~30°) that becomes more defined with increasing obliquity. In planform, the ejecta blanket peaks (i.e., has the greatest quantity of material) downrange, with local peaks offset from the downrange direction that grow and become more crossrange dominant with increasing obliquity (to ~9-15°), and then shift back towards the downrange at extreme obliquities (EIA ~5°). The uprange directed ejecta decreases with increasing obliquity, which results in a downrange-curving envelope delineating a zone of avoidance (Figure 1). As obliquity increases, the zone of avoidance expands and the downrange-curving envelope shifts further downrange until, in the most extreme case, the envelope approximates a line.

**Change in crater shape with impact angle:** The final crater shape is circular for low obliquities (EIA ~30°); develops a modest downrange point and a lowering of the uprange rim at modest obliquities (EIA ~15-20°) (Figure 1); becomes heart-shaped (downrange point and uprange concavity) at high obliquities (EIA ~10°); and becomes tear-dropped shape (fat end downrange) at the most extreme obliquities (EIA ~5°). The center of the crater becomes increasingly shifted downrange of the impact point with decreasing EIA.

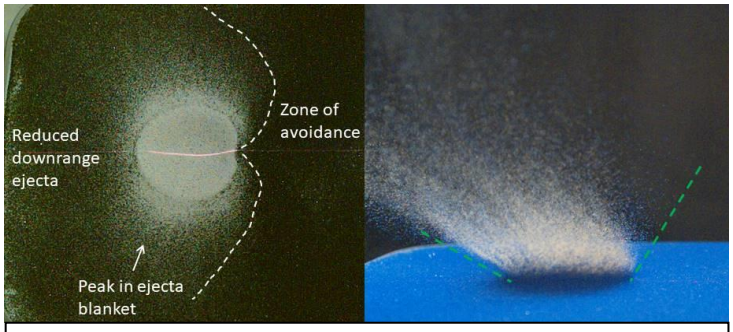


Figure 1. Left – planform view of crater from experiment with EIA 15° with oblique laser plane through crater. Uprange interior slope is steeper than downrange. There is a partial butterfly pattern in the ejecta, with most ejecta between the downrange (to the left) and crossrange directions, and a downrange curving envelope (white dashed lines) in the uprange direction. Right – crossrange view during the excavation process. Dashed green lines mark the approximate edge of the ejecta curtains. Significantly less material is ejected uprange.

The topography of the crater rim evolves as follows: starting at low obliquities (EIA ~30°) the uprange rim becomes severely subdued, followed by the downrange; the crossrange rims remain pronounced until an EIA of ~15°, below which the cross-range rims become similarly subdued; at the most extreme obliquities, the topographic rim is absent.

**Evolution of the ejecta curtain:** The planform growth rates of the ejecta curtain appear dependent on obliquity, forming initially as an ellipse with its greatest length oriented downrange, circularizing, and, in a few modest/high obliquity experiments, forming an ellipse with its long axis oriented across range. The uprange end of the curtain has the lowest rate of growth for all times and all EIA. The downrange direction has the fastest growth; at early times, this is always true; at later times, this is only true for impactors $\geq$30° EIA. Growth in the crossrange direction quickly overtakes the downrange growth for oblique impacts. The growth of the ejecta curtain appears to mirror the evolution of the planform ejecta distribution with the greatest growth seeming to "walk out" from slightly offset of downrange to predominantly crossrange and back towards (but not fully to) downrange as obliquity increases.

In crossrange view, the angle between the target surface and the downrange ejecta cone/curtain decreases (i.e., the downrange end of the ejecta cone/curtain becomes more horizontal) with increasing obliquity. The uprange ejecta cone appears to increase (become more vertical) as obliquity increases, though this appears to be a result of missing material rather than a true increase in the ejection cone angle. The angle encompassed by the downrange and uprange ejecta curtains initially increases with increasing obliquity, then decreases. This appears to be the result of 2 competing effects. First, the projectile clears out material as obliquity increases, allowing for more horizontal travel of grains (i.e., there are more free paths). Second, as the projectile's path becomes more horizontal, less energy is transferred into the target, resulting in less excavation. This is exemplified in the extreme by the tear-drop shaped crater, in which the EIA is ~5° and very little material is ejected. As the excavation process procedes, the center of the curtain, like the center of the crater, shifts downrange.

**References:** [1] Gault D. E. & Wedekind J. A. (1978) *Proc. Lunar Planet. Sci Conf. 9th*: 3843-3875.