NON-BALLISTIC VAPOR-DRIVEN EJECTA. K.E. Wrobel[1], P.H. Schultz[1], and J.T. Heineck[2], [1]Dept. Of Geological Sciences, Brown University, Providence, RI 02912 (Kelly_Wrobel@brown.edu), [2]NASA Ames Research Center, Moffett Field, CA 94035.

Introduction: Impact-induced vaporization is a key component of early-time cratering mechanics. Previous experimental [1,2] and computational [e.g., 3] studies focused on the generation and expansion of vapor clouds in an attempt to better understand vaporization in hypervelocity impacts.

Presented here is a new experimental approach to the study of impact-induced vaporization. The three-dimensional particle image velocimetry (3D PIV) system captures interactions between expanding vapor phases and fine particulates. Particles ejected early in the cratering process may be entrained in expanding gas phases generated at impact, altering their otherwise ballistic path of flight. 3D PIV allows identifying the presence of such non-ballistic ejecta from very early times in the cratering process.

Method: The 3D PIV system measures three-dimensional ejecta particle positions and velocities within the ejecta curtain as the crater grows. A horizontal laser sheet is projected above and parallel to the target surface (79mm above for the experiments presented here). Ejecta particles within the laser sheet are illuminated and imaged twice in rapid succession by two CCD cameras mounted above the target. Software [4] cross-correlates image pairs from each camera in order to track small groups of particles. This technique directly measures velocities of the ejecta as they pass through the horizontal plane. A narrow bandpass filter (centered on 532nm) is used to eliminate light contamination by the impact flash and subsequent thermal, atomic, and molecular emissions. (For additional description of the 3D PIV system see [5,6].)

Experiments were conducted at the NASA Ames Vertical Gun Range (AVGR). The AVGR can accommodate a wide variety of projectile materials, target materials, impact angles, and impact velocities (≤6.5 km/s). Here the experiments were under vacuum conditions (<0.5 Torr) at impact velocities of ~5.0 km/s with a launch angle of 30 deg. from the horizontal.

Early-Time Cross-Sections: Earlier experiments using 3D PIV [6] focused on the evolution of ejecta 5-50 milliseconds after impact at low impact velocities (<1.5 km/s). In order to capture impact-generated vaporization, much higher impact velocities and earlier times are required (100-150μs). An image taken ~110μs after impact (Figure 1) reveals a cross-section of the early-time ejecta curtain from a 0.635cm-diameter pyrex sphere projectile impact into dolomite. At such early times, the ejecta distribution is highly asymmetric, as previously observed [6].

Instead of a simple asymmetric ring of ejecta particles, the early-time image slice shows two rings: one slightly displaced downrange from the point of impact; the other, offset significantly downrange. This second ring is attributed to vapor expansion created by impacting projectile ricochet downrange. Streamers extending outward from the ejecta ring are evident (arrows in Fig. 1) and are not observed in similar impacts into silicates. These streamers do not follow the same directions as ejecta particles in the rings.

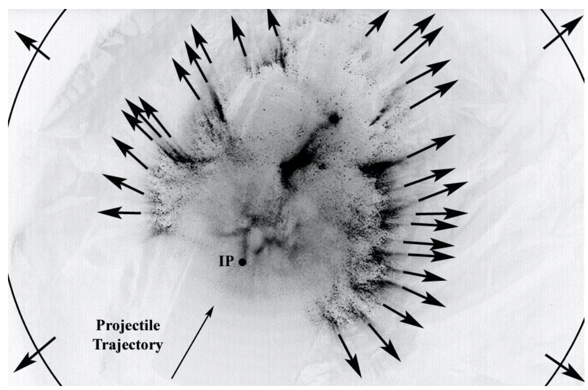

Figure 1. Horizontal cross-section of ejecta from an impact of a pyrex sphere into dolomite (negative image of laser-illuminated ejecta). The impact velocity of the projectile was 4.79 km/s at an angle of 30 deg. from the horizontal. This image was captured ~110μs after impact. The drawn-in circle indicates the current position of the outer edge of the expanding vapor cloud. Arrows denote the direction of streamers, fine particles that have been affected by interactions with expanding gas.

The streamers in Figure 1 are interpreted as fine particle fractions being dragged by an expanding vapor phase. Previous studies [2] indicate a vapor expansion rate of ~2.5 km/s under the same impact conditions. Consequently, the leading edge of the vapor cloud has already expanded to the edge of the frame in Figure 1. However, the streamers represent the effects of interactions of ejecta particles with the expanding gas from a time when they were both near the surface.

Non-Ballistic Trajectories: Ejecta velocities derived using 3D PIV allow calculating the trajectories of particles including ejection positions, velocities, and travel times [5]. Such calculations require the assumption of a purely ballistic flight path. The ejection positions (in the plane of the target surface) of the ejecta in the curtain were calculated, assuming ballistic paths of flight, and are represented as black triangles in Figure 2.

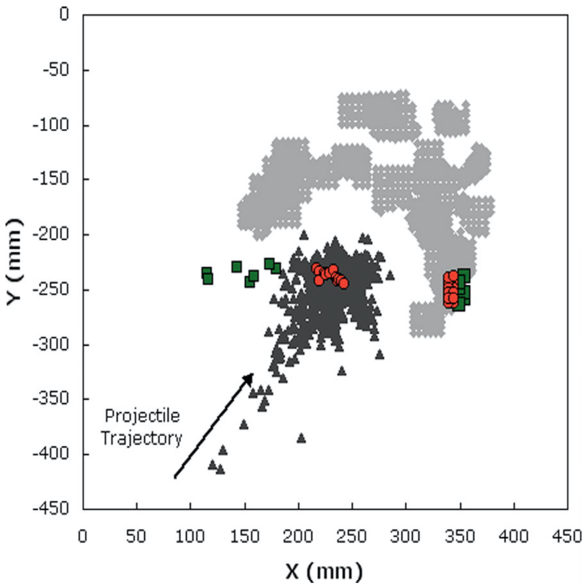

Figure 2. Ejection positions of particles, at the target surface z=0, are shown as black triangles. Gray diamonds indicate the locations of particles captured by the 3D PIV system in the plane of the laser sheet. The red circles denote the positions of ejecta (from the ejecta curtain) that appear to have traveled ballistically. The green squares indicate ejecta (from the streamers) that have launch positions on the surface that require a non-ballistic vapor boost.

Most calculated ejection positions for the primary ring ejecta (not the streamers) fall in a cluster around the original impact point, (x = 228.4, y = -232.0). Particles associated with these ejection positions most likely followed a simple ballistic path to their location in the laser plane. The red circles in Figure 2 denote a subset of these ejecta extrapolated from their location in the laser plane (z = 79mm) to their initial ejection position (z = 0mm).

The green squares in Figure 2, however, highlight a subset of the ejecta streamers that do not ballistically return to the original impact point. These components most likely represent either fine ejecta fractions entrained in the vapor cloud within a few microseconds after impact or fine particles that are currently being winnowed out of the ejecta curtain by continued expansion with the vapor cloud, i.e. winds. Such winds are not the same as those proposed by Rehfuss [7] which involved early vapor expansion interacting with very late excavation and ejecta.

Ejecta Particle Velocities: The 3D ejecta motion information provided by 3D PIV allows for calculations of particle velocities within the laser plane. The velocity calculations for the experimental data shown in Figure 1 are shown in Figure 3. (Figure 3 illustrates velocity vectors primarily for the data within the ballistic curtain slice, not the streamers.) The fastest moving ejecta (reflecting the initial momentum of the impactor) are located downrange and traveling at velocities of ~1-1.5 km/s. Ejecta with the lowest velocities, ~300 m/s, appear to be moving chaotically in the center of the field of ejecta. These slow ejecta correlate with the dark central region in Figure 1 and represent shearing target debris trailing the ricocheted impactor.

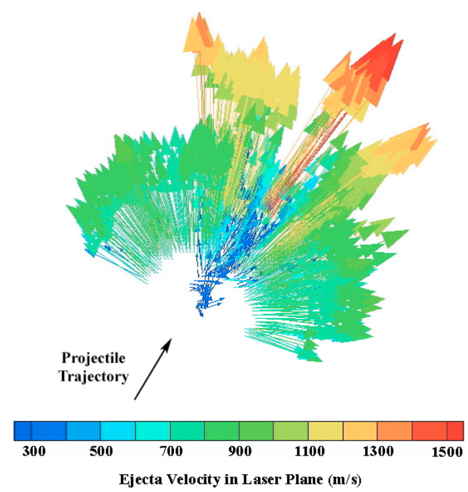

Figure 3. Ejecta velocity vectors for the impact shown in Figure 1. Colors represent the velocities of the particles in the laser sheet in m/s. Image is oriented in the same manner as Figure 1.

Conclusions: Narrow bandpass interference filters allow investigating the cratering process at early stages with the 3D PIV technique. This strategy reveals the interplay between the rapidly expanding vapor that is generated on impact and the developing ejecta curtain. Such data will allow unprecedented comparisons with computational experiments.

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