Measurement of Ejecta from Hypervelocity Impacts with a Generalized High-Speed Two-Frame 3D Hybrid Particle Tracking Velocimetry Method

B. Hermaly1,2*, J. T. Heineck1, E. T. Schairer2, P. H. Schultz1

1: Hawaii Space Flight Laboratory, University of Hawaii, Honolulu, HI
2: NASA Ames Research Center, Moffett Field, CA
3: Department of Geological Sciences, Brown University, Providence, RI
*correspondent author: hermaly@hawaii.edu

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Introduction and Background

A hypervelocity impact (e.g., above the speed of sound in the target) sets up a shock-driven flow of material. As the expansion wave passes through the target behind the shock, some of this material (termed “ejecta”) is launched out of the growing crater, and travels ballistically above the target surface (see Fig. 1). It is eventually emplaced some distance away from the impact point (unless the material is traveling at sufficient velocity to encounter the vacuum chamber walls). At laboratory scales, the crater is formed in less than 100msec for impacts into granular particulate targets such as sand. The ejecta velocities are controlled by the initial conditions of the impact; e.g., the size, velocity, and density of the impactor, and the properties of the target. In addition, virtually all impacts occur at some degree of obliquity to the target surface, with a probability distribution that yields a maximum likelihood of 45° (Gilbert, 1893; Shoemaker, 1962). Measurement of the ejecta velocity distribution for these oblique impacts is considerably more difficult due to the spatially and temporally varying ejecta velocities and launch angle that result from asymmetries in the shock (Dahl and Schultz, 2001), yet is vitally important in understanding the appearance of planetary surfaces, interpreting impact mission data (such as NASA’s LCROSS and Deep Impact missions), and in the constraint of shielding requirements for human habitation of the Moon and beyond.

While a significant amount of research has gone into these techniques and their extension to the three dimensions required for many fluidic measurements, past work has set requirements or introduced errors that are not conducive to many high-speed tests (e.g., wind tunnels). Here we describe an implementation of a generalized two-frame hybrid laser particle tracking velocimetry system to measure, with a high degree of accuracy, the three-dimensional location and velocities of particles from simultaneous images taken from multiple arbitrary (e.g., non-collinear) view points applied for granular flow driven from a hypervelocity impact. These data provide a time-resolved view of the ejecta evolution for the first time, and allow development of an analytical description of the velocity distribution as a function of time and azimuth.

Experimental Design

A series of hypervelocity impact experiments into rounded quartz (“Ottowa”) sand grains was performed at the NASA Ames Vertical Gun Range (AVGR) in Moffett Field, CA. The AVGR is a two-stage light gas gun capable of launching projectiles of variety of materials ranging in size from 1.59mm to 12.7mm in diameter at speeds up to ~6km/s to simulate impacts on planetary bodies. This facility is unique in that the launch tube is mounted on a pivoting A-frame to allow a range of incidence angles (from 90°, or vertically orthogonal to the target surface, to a 15° glancing impact in 15° increments). This design permits study of impacts into granular target materials (which are difficult or impossible to study using horizontal facilities, since unconsolidated material will simply fall out of a wall-mounted bucket). A high-speed, dual-head Nd:YLF pulsed laser is spread into a light sheet (7mm in thickness) and projected (through a window in the vacuum chamber) a few centimeters above and parallel to the target surface. The light sheet creates cross-sectional “slices” of the ballistic particulate ejecta. A set of four high-speed CMOS cameras are placed in a non-collinear arrangement (as determined by the locations of the viewing ports) to maximize the parallax angles.

Discussion

The procedure presented here allows extension of 3D photogrammetric Lagrangian laser particle tracking methods to permit full-field, temporally resolved measurement of ejecta from hypervelocity impacts that are traveling multiples of the speed of sound in the material. The high temporal resolution of this study allows a physically based description of the ejecta velocity distribution for oblique impacts for the first time. In the downrange direction, the initial momentum of the projectile is retained in the target, visible in an enhancement of high speed material early in the process. Incomplete coupling at early times uprange results in the “zone of avoidance.” The methodology also mitigates some issues with traditional PIV measurements of granular media. Misalignment between laser plane and calibration is a persistent issue in PIV/PTV studies. Additionally, the dynamic range of measured velocities can be extended arbitrarily, limited solely by the cameras and laser. While developed specifically for granular flow problems, such as the experimental impact ejecta problem carried out above, this technique holds promise for application to wind tunnel and other velocimetry studies. These measurements are vitally important in our understanding of crater and ejecta formation - and associated risks - from hypervelocity impacts on planetary surfaces.

References