Improved Measurement of Ejection Velocities From Craters Formed in Sand

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A typical impact crater is formed by two major processes: compression of the target (essentially equivalent to a footprint in soil) and ejection of material. The Ejection-Velocity Measurement System (EVMS) in the Experimental Impact Laboratory has been used to study ejection velocities from impact craters formed in sand since the late 1990s. The original system used an early-generation Charge-Coupled Device (CCD) camera; custom-written software; and a complex, multicomponent optical system to direct laser light for illumination. Unfortunately, the electronic equipment was overtaken by age, and the software became obsolete in light of improved computer hardware.

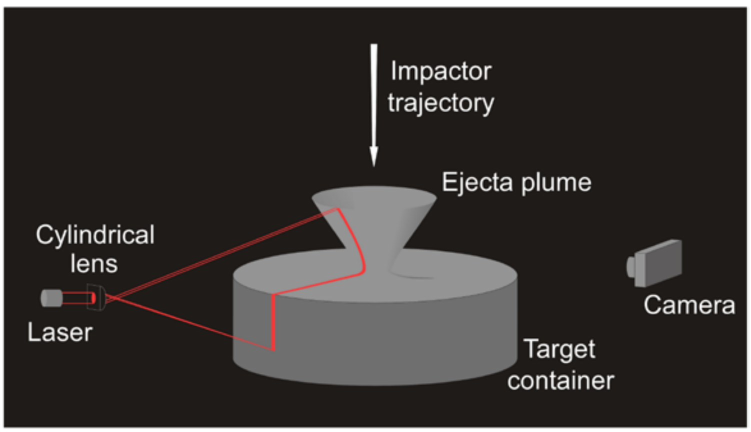

Figure 1.– The EVMS relies on a laser that projects a "sheet" of light through the impact point and perpendicular to the target's surface. A camera, oriented to look at roughly 90° to the laser sheet, takes a time exposure of the event. The laser is programmed to flash at a known rate, providing pictures, such as the one in figure 2.

Experience obtained from years of operating the EVMS has resulted in the design of a new, simplified, and streamlined version. The equipment has been upgraded, LabVIEW has taken the place of the custom computer code, and EVMS v.2 is now up and running. It is a much more robust system, with all of the major components integrated into a single, modular assembly, a straightforward change that greatly improves the process of aligning the optics and camera. A schematic drawing of the system that illustrates the main components is shown in figure 1.

When the button to fire the vertical gun is pressed, a signal is sent to a computer that acts as a controller. The computer sends a signal to the camera (an off-the-shelf digital single-lens reflex camera), which opens its shutter. After a short delay to allow the shutter to open completely, the computer sends a signal to the firing circuit. The gunpowder is ignited, sending the projectile (typically a sphere between 3 and 5 mm in diameter) toward the target. When the projectile interrupts a separate laser that is trained just across and above the target's surface (not shown in figure 1 for simplicity), a detector sends a signal to the illumination laser, turning it on. The illumination laser is programmed to flash at a specific rate; in some cases, a series of different illumination segments is programmed. This permits different lighting sequences to be used at different times during the crater's growth, which is very rapid initially, but much slower toward the end. The camera's shutter remains open while the laser completes its programmed sequence, taking a time exposure. Each photograph thus includes information from every flash of the laser during the experiment.

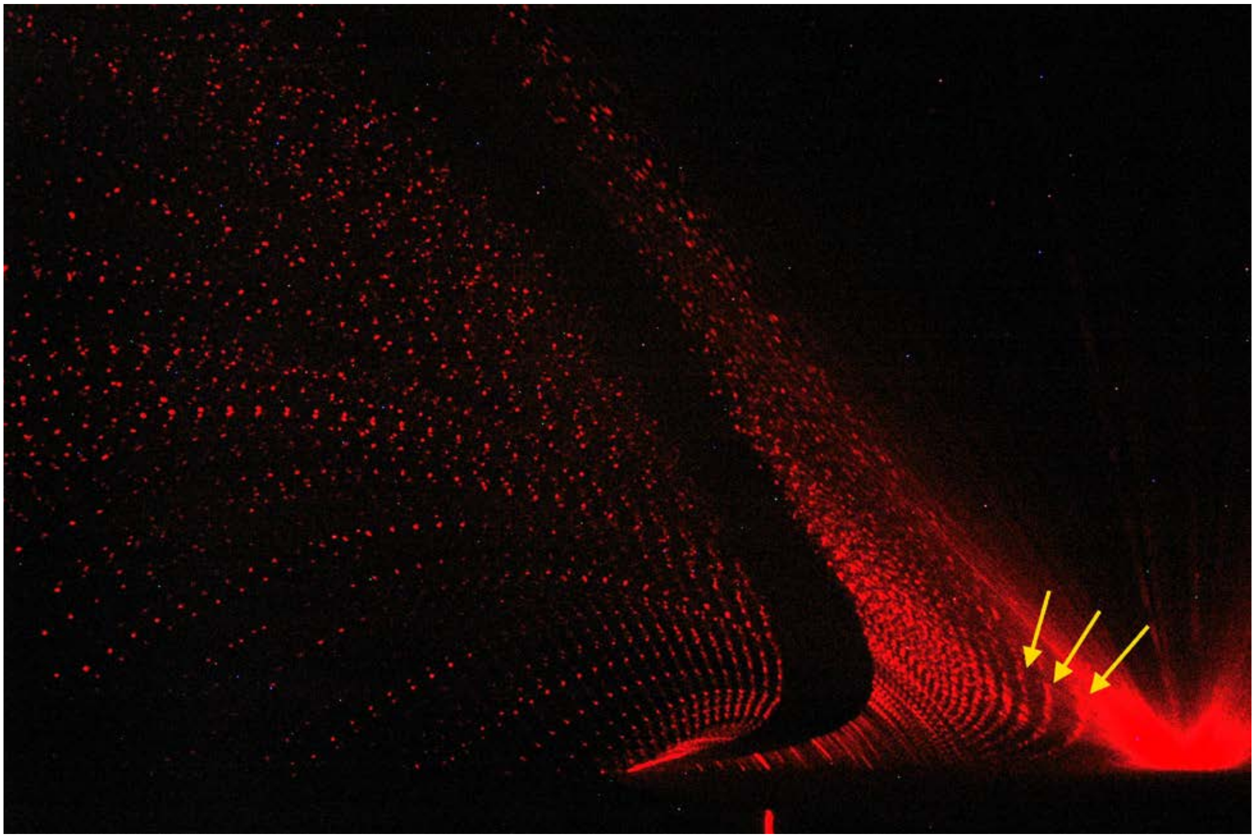

Figure 2.– Photograph of a laboratory impact taken by the newly revamped EVMS. The flash from the impact is in the lower-right corner; the crater grew, and ejecta traveled from right to left. There are two illumination segments in this picture. The one on the left was designed to show individual grains of sand in flight. Each set of dots is composed of multiple images of the same grain of sand, illuminated by the flashing laser as the grain traveled outward from the growing crater. Each set of dots thus defines a unique ballistic trajectory. The laser was flashing much faster in the illumination segment on the right and is much better at showing the shape of the ejecta plume and the rate at which the plume and crater grow. The three yellow arrows point to the profile of the ejecta plume at three different times (compare the plume's profile to that illustrated in figure 1). The black band between the two illumination segments is intentional, marking the period during which the laser was turned off (a duration of 25 ms). It delineates where the first illumination segment ends and the second begins.

An example of the kind of image that can be acquired by this system is shown in figure 2, which was recorded during the impact of a 4.76-mm stainless-steel sphere into 0.5–1-mm sand at a speed of 1.65 km/s. (It would have been very difficult, if not impossible, to image such fine-grained sand with the original EVMS.) The first segment of the illumination sequence turned the laser on once per millisecond; that rate was constant through the first segment. The yellow arrows in figure 2 point to the illuminated profile of the ejecta plume as it grew (compare with figure 1). Because the illumination sequence was constant, the distance between the successive images of the plume's profile is directly proportional to the speed at which the plume expanded. It is readily apparent that the plume (and the crater itself) grew very rapidly just after the impact, when the impact-generated stresses in the target were highest. As time passed, however, the shock wave that initiated the ejection process expanded into the target, losing intensity in the process, much as light will decrease in intensity as the distance to its source increases. As the strength of the shock dropped, so did the motion that it imparted to the sand. Ultimately, the shock decayed to a sound wave; it became too weak to set the sand in motion, and crater growth stopped. This process is reflected in the continually decreasing gaps between the images of the plume (from right to left), until the plume was expanding so slowly that it is difficult to distinguish between the later, successive images.

The second illumination sequence was more leisurely, with 5 ms between flashes. The net effect was to separate individual images of each grain of sand in the laser sheet, allowing their trajectories to be described with very high accuracy and precision. Knowing the time between laser flashes and the scale of the picture, it is then a straightforward task to measure the distances between the successive images of the sand grains. Those data can then be used to derive the trajectories of the grains, and from there, the ejection velocities. Figure 3 illustrates the speeds of ejected grains as a function of each particle's launch position relative to the center of the crater, while figure 4 shows the corresponding ejection angles. The ejection speed drops off very rapidly with distance from the impact point, a feature that is common in all impact-cratering events. The great bulk of material is ejected at drastically lower speeds compared to that of the impactor (1.4 km/s in this case).

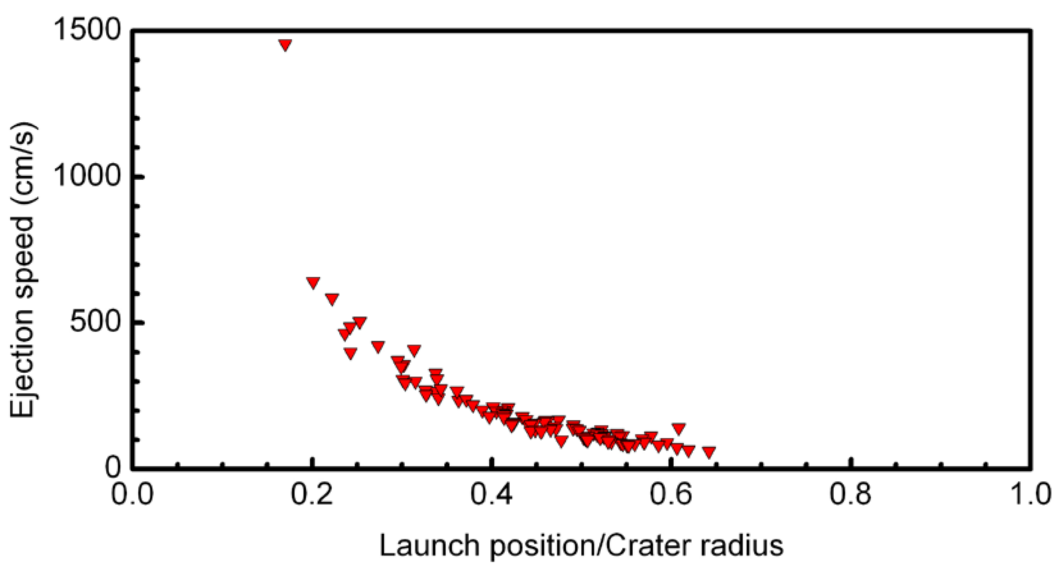

Figure 3.– Ejection speed as a function of the scaled launch position of the particle. In this figure, the center of the crater corresponds to a scaled launch position of 0, while the rim crest of the crater is at a scaled position of 1. Note the tight clustering of the data points, indicating a strong statistical correlation between the variables and the high precision of the EVMS technique.

The ejection-angle data indicate that the earliest material (closest to scaled launch position 0) left the growing crater at steeper angles than most of the material ejected later in the event. Until the advent of the EVMS, it was thought that ejection angles would be more or less constant throughout the formation of the crater. Instead, the data show that the ejection angles not only change but exhibit a more complex behavior than the ejection speeds. Not only do the angles exhibit considerably more scatter, but they also show a gradual decrease as the rim-crest location of the final crater is approached, whereupon they increase rather abruptly. This behavior has since been confirmed by other methods of measuring ejection angles, but its cause remains uncertain.

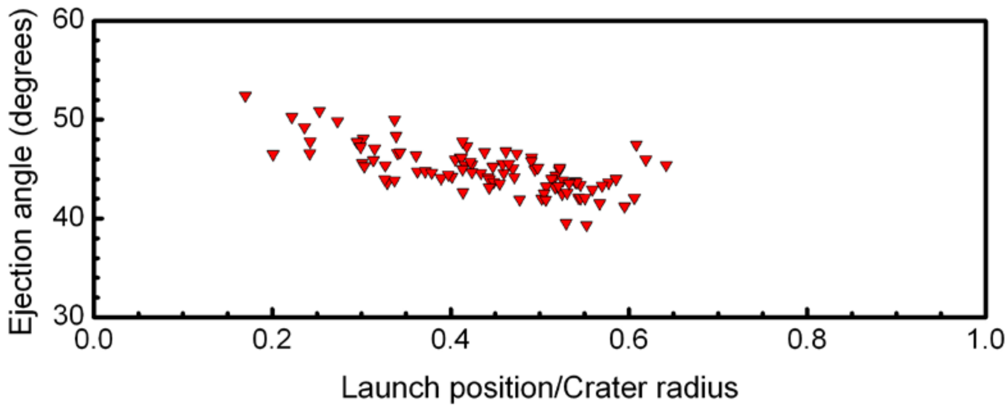

Figure 4.– Ejection angle (measured from the surface of the target) as a function of the scaled launch position. The angles scatter more than the ejection speeds (figure 3), indicating that factors not yet identified affect the geometry of the ejection process.

New Martian Meteorite Is One of the Most Oxidized Found to Date

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As of 2013, about 60 meteorites from the planet Mars have been found and are being studied. Each time a new Martian meteorite is found, a wealth of new information comes forward about the red planet. The most abundant type of Martian meteorite is a shergottite; its lithologies are broadly similar to those of Earth basalts and gabbros; *i.e.*, crustal igneous rocks. The entire suite of shergottites is characterized by a range of trace element, isotopic ratio, and oxygen fugacity values that mainly reflect compositional variations of the Martian mantle from which these magmas came. A newly found shergottite, NWA 5298, was the focus of a study performed by scientists within the Astromaterials Research and Exploration Science (ARES) Directorate at the Johnson Space Center (JSC) in 2012. This sample was found in Morocco in 2008 (figure 1; NWA stands for North West Africa). Major element analyses were performed in the electron microprobe (EMP) laboratory of ARES at JSC, while the trace elements were measured at the University of Houston by laser