

**PROJECTILE FRAGMENTATION DURING PENETRATION OF THIN TARGETS;** Scott Messenger, University of Washington, Seattle, Washington 98195/Lunar and Planetary Institute, Houston, Texas 77058, and Friedrich Hörz, SN2, NASA/Johnson Space Center, Houston, Texas 77058.

The degree of projectile fragmentation following hypervelocity collisions with targets thin enough to be completely penetrated is of interest to the development of capture media and trajectory sensors for the proposed Cosmic Dust Collection Facility (CDCF) on Space Station (1), to the interpretation of penetration phenomena in thermal blankets exposed by the Solar Max and the Long Duration Exposure Facility (LDEF) satellites (2,3), and to the design of passive shields against collisional damage to spacecraft (4).

**EXPERIMENTS:** A light-gas gun was used to fire soda-lime glass spheres at ~6 km/s into Teflon targets of variable thickness ( $T_f$ ), ranging from infinite halfspace targets to very thin membranes. The choice of Teflon relates in part to ~16 m<sup>2</sup> of thermal blankets (Ag-backed Teflon, ~165  $\mu$ m thick) onboard LDEF that possessed thousands of hypervelocity penetration holes (3), and in part to CDCF, as Teflon is deemed a generic representative for plastic materials and their densities, the latter largely controlling the shock-stresses in the impactor and thereby its degree of fragmentation. The projectile and foil debris was intercepted by massive Al plates (1100 series; >99% Al), intentionally colored blue to better visualize small impacts, and that was located at a known stand-off distance behind the penetration foil. This study employed relatively large soda-lime glass spheres (1.0 and 3.17 mm in diameter  $D_p$ ) of normal incidence as a first step in establishing scaling relationships to guide future experiments with much smaller projectiles. Dimensional analysis and crater counting was performed with a binocular microscope.

**RESULTS:** Typical witness plate spray patterns as a function of  $D_p/T_f$  are illustrated in Figure 1 for some experiments using the 3.17 mm spheres, all at ~6 km/s. At relatively thick targets ( $D_p/T_f < 0.5$ ) most debris consists of massive, low-velocity spall plates from the target, as deduced from crater morphology (i.e., shallow depressions that lack the distinctive rims of hypervelocity craters). Color of the crater-interior is an additional criterion for the trained eye to distinguish between Teflon (i.e., foil) and glass (i.e., projectile) craters, the latter of distinctive, dark grey color and invariably associated with pronounced rims. Most substantial witness plate craters at  $D_p/T_f > 2$  are produced by projectile fragments and at  $D_p/T_f > 10$ , a distinctly clustered depression is caused by a fragmented projectile that dispersed relatively little. However, faint halos of exceedingly small foil debris (craters  $< 0.5$  mm) exist at all  $T_f$  investigated. Penetration experiments employing 1 mm projectiles yield virtually identical spray patterns at similarly scaled  $D_p/T_f$ .

The distinction of witness-plate craters caused by glass or Teflon particles permits determination of associated dispersion angles if the stand-off distance is known. These angles are illustrated in Figure 2, with angle alpha ( $\alpha$ ) representing the projectile and beta ( $\beta$ ) the entire debris cone. No doubt, the distinction between Teflon and glass impacts becomes interpretative in many cases at  $D_p/T_f$  between 0.5 and 4, but it is readily demonstrated that the degree of projectile dispersion depends sensitively on scaled foil thickness at  $D_p/T_f > 4$  for both the 1 and 3.17 mm impactors. In contrast, the dispersion of the total debris cone remains remarkably constant, attesting to the fact that the foil debris is largely produced by relatively invariant spallation processes at the target's rear surface.

Consulting Figure 1, it is obvious that size frequency and spatial density of witness-plate craters are also sensitively related to  $D_p/T_f$ , the reason why crater-counting was performed on select targets employing 3.17 mm spheres. The relative number of witness-plate craters  $> 0.5$  mm is illustrated in Figure 3, normalized to the  $D_p/T_f = 1$  case. Note that (1) the total number of craters  $> 0.5$  mm is strongly controlled by  $D_p/T_f$ , and (2) the relative frequencies of fragment masses/sizes (i.e., slopes) seem to depend on  $D_p/T_f$  as well. The same data are replotted in Figure 4 to better illustrate this change in relative frequency of secondary crater/fragment sizes with changing foil thickness. Lastly, Figure 5 depicts the radial distribution of specific sizes of witness-plate craters to quantify a trend that is readily apparent upon inspection of the witness plates: "large" fragments disperse less than "small" fragments.

**CONCLUSIONS:** The penetration of thin foils by hypervelocity particles results in spray patterns on an underlying substrate that are sensitively related to the absolute dimensions of both the impactor and the foil. These characteristics may ultimately be developed into measurable, quantitative parameters to aid in estimating  $D_p$  for unknown impactors on surfaces retrieved from space. However, extreme care is necessary because physical properties, such as compressive and tensile strengths of the projectile, will play a dominant role and we have investigated only a single case. Indeed, the remarkable scarcity of good spray patterns on surfaces behind mm-size penetration holes on LDEF thermal blankets (see [3] and our own observations) seems to indicate that the majority of "large" projectiles in low-Earth orbit have little cohesion and disperse with substantially greater ease than our laboratory projectiles.

**REFERENCES:** (1) CDCF Steering Committee (1990), NASA TM 102160, 29 p.; (2) Warren *et al.*, (1989), *Proceed. 19<sup>th</sup> LPSC*, p. 641-657; (3) See *et al.*, (1990), *LDEF M&D SIG Report*, JSC Publication No. 24608, 583 p., (4) Cour-Palais, B.G. and Crews, J.L. (1990), *Int. Journ. Impact Eng.*, V 10, p.135-146.

