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# IMPACT PENETRATION EXPERIMENTS IN TEFLON TARGETS OF VARIABLE THICKNESS;

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**INTRODUCTION** - Approximately 20.4 $m^2$ of Teflon thermal blankets on the non-spinning Long Duration Exposure Facility (LDEF) were exposed to the orbital debris and micrometeoroid environment in low-Earth orbit (LEO) for ~5.7 years. Each blanket consisted of an outer layer (~125 µm thick) of FEP Teflon that was backed by a vapor-deposited metal mirror (Inconel; <1 µm thick). The inner surface consisted of organic binders and Chemglaze thermal protective paint (~50 µm thick) resulting in a somewhat variable, total blanket thickness of ~180 to 200 µm. There was at least one of these blankets, each exposing ~1.2 $m^2$ of surface area, on nine of LDEF's 12 principal pointing directions, the exceptions being Rows 3, 9 and 12. As a consequence, these blankets represent a significant opportunity for micrometeoroid and debris studies, in general, and specifically they provide an opportunity to address those issues that require information about pointing direction [1] (*i.e.*, spatial density of impact events as a function of instrument orientation). During deintegration of the LDEF spacecraft at the Kennedy Space Center, all penetration holes ≥300 µm in diameter were documented [2] and were recently synthesized in terms of spatial density as a function of LDEF viewing direction by [3]. The present report describes ongoing cratering and penetration experiments in pure Teflon targets, which are intended to establish the relationships between crater or penetration-hole diameters and the associated projectile dimensions at laboratory velocities (*i.e.*, 6 km/s). The ultimate objective of these efforts is to extract reliable mass-frequencies and associated fluxes of hypervelocity particles in LEO.

**IMPACT EXPERIMENTS** - A single piece of round stock (~80 mm in diameter) of $\text{Teflon}^{\text{FEP}}$ was machined into targets of variable thickness, with T ranging from "infinite halfspace" (≥ 25 mm) to 0.5 mm; targets <0.5 mm in thickness were cut from commercially available Teflon sheets. All targets were impacted with 3175 µm diameter ($D_p$) soda-lime glass spheres at 6.2 to 6.4 km/s; a few experiments were conducted with glass projectiles 150 and 1000 µm in diameter at modestly lower velocities of 5.9 to 6.1 km/s. We refer to all experiments as being representative for nominal encounter velocities of ~6 km/s.

**RESULTS** - Figure 1 illustrates some

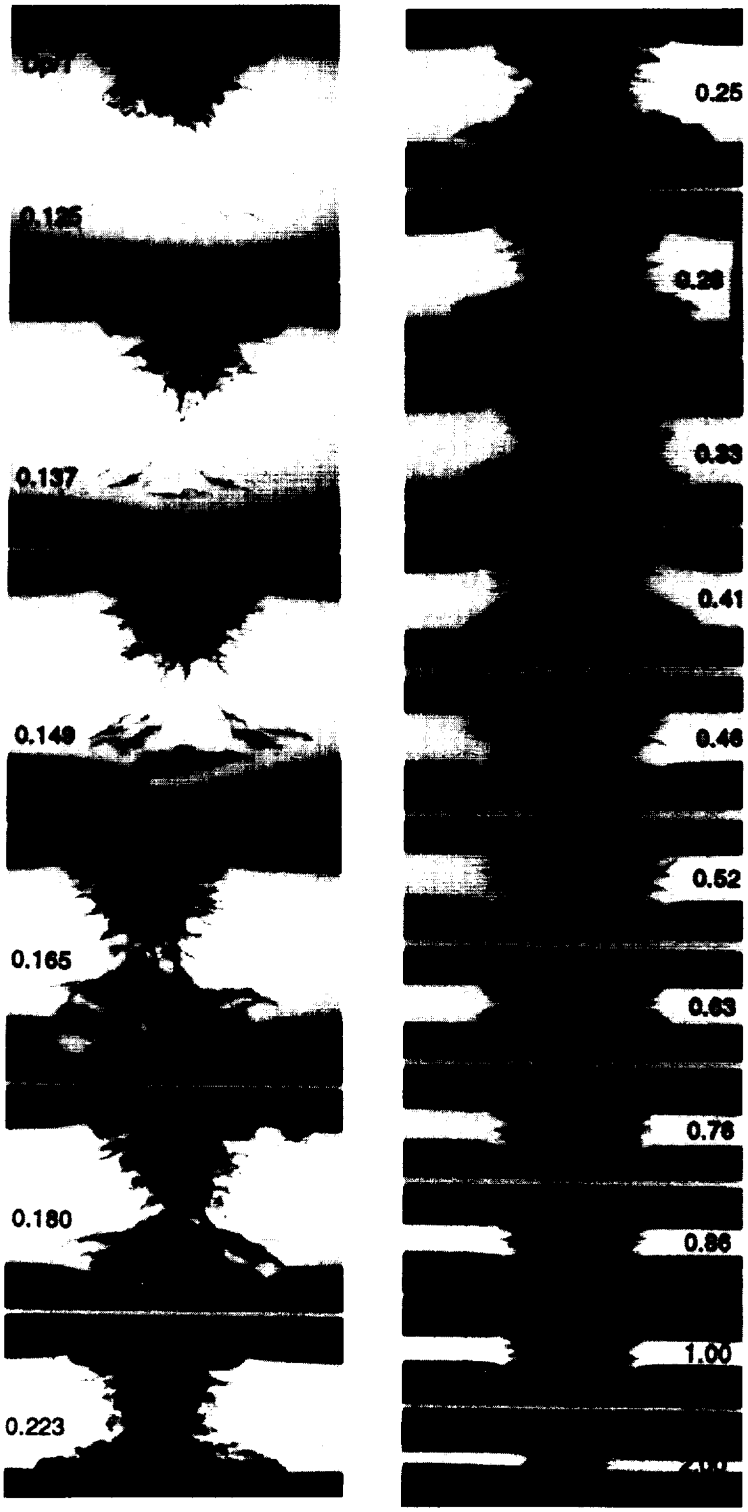

**Figure 1.** Typical cross-sections of craters and penetrations for Teflon target where $D_p$=3175 µm and V=6 km/s. Note $D_p/T$=1.0 for uniform scale.

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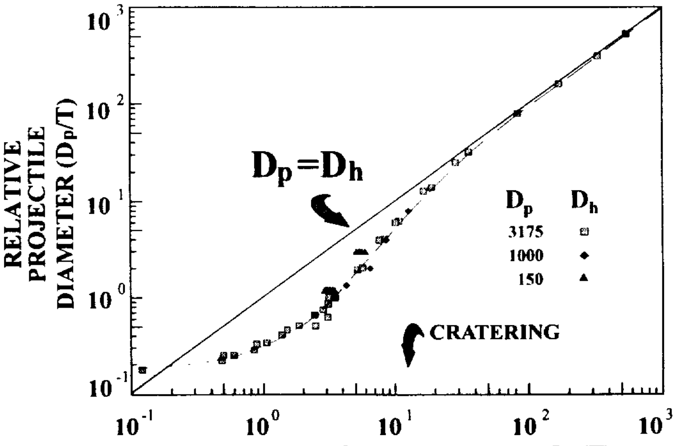

**Figure 2.** Diameter of penetration hole ($D_h$) versus projectile ($D_p$) for Teflon targets of thickness (T) at an encounter velocity of 6 km/s for soda-lime glass projectiles 3175, 1000 and 150 µm in diameter. Solid line represents the case of $D_p = D_h$.

representative cross-sections of penetrations of relatively massive Teflon targets, systematically arranged with increasingly larger relative projectile size ($D_p$/T). Note that Teflon fails largely in a brittle fashion, giving rise to sizeable, highly scalloped spall zones surrounding a central crater on the target's front side, and surrounding the exit hole at the target's rear in the case of penetrations. The poorly defined central craters posses average diameters of 3.6 $D_p$, while the morphologically dominant spall diameters ($D_s$) average 6.1 $D_p$ at 6.3 km/s using the 3175 µm projectiles. As previously described from similar experiments employing aluminum targets of variable thickness [4], penetrations of massive Teflon targets (at $D_p/T<0.75$) must be viewed as truncated craters, because their surface expressions on the front side remain relatively uniform, unlike the spall features at the target's rear. Note that the cross-sections in Figure 1 are totally dominated by spallation phenomena at the rear surface. Foil thicknesses below 1.0 $D_p$ are required for production of penetration-hole diameters that are significantly smaller than the crater diameter ($D_c$) in the "infinite halfspace" Teflon targets. Actual measurements of the penetration-hole diameters for all experiments are summarized in Figure 2. Note that unique solutions for $D_p$ result from any measurement of $D_h$ and T, at least at constant velocity. The delineation between "cratering" and incipient penetration (*i.e.*, the ballistic limit) for Teflon is at $D_p/T=0.17$ under the prevailing conditions, while the ballistic limit for aluminum 1100 occurred at $D_p/T=0.29$ [4]. The condition where $D_h=D_p$ in Teflon is met only at T of ~1/100 $D_p$. The transition from the pure cratering regime in the massive targets to the condition of $D_h=D_p$ is very gradual and encompasses approximately three orders of magnitude in target thickness. This gradual transition illustrates the great care needed when extracting projectile sizes from the LDEF thermal blankets. Figure 3 illustrates the size distribution, normalized to target thickness, of all penetration holes ≥300 µm in diameter that were documented for the LDEF thermal blankets. Note that most penetrations are characterized by $D_p/T<5$. On the basis of Figure 2 it must be concluded that neither pure cratering formulas, much less the assumption of $D_h=D_p$, are suitable to solve for the diameters of the respective projectiles for most LDEF penetrations.

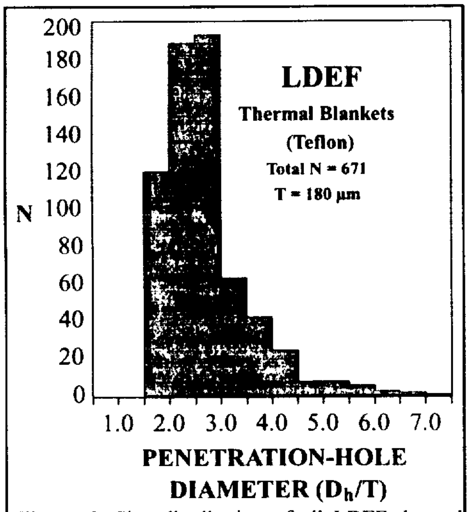

**Figure 3.** Size distribution of all LDEF thermal blanket penetrations ≥300 µm in diameter.

A variety of curve-fitting techniques were applied to the data points in Figure 2, with the best fit resulting from the polynomial equation of the form

$$\log_{10} y = a_0 + a_1 \ (\log_{10} x)^2 + a_2 (\log_{10} x)^3 + a_n (\log_{10} x)^n$$

where $y = D_p/T$ and $x = D_h/T$; for Teflon, the following coefficients apply: $a_0 = -0.485$, $a_1 = 0.667$; $a_2 = 0.562$ ; $a_3 = -0.230$; $a_4 = 0.518$, $a_5 = 0.021$, $a_6= -0.661$, $a_7 = 0.415$, and $a_8 = -0.075$.

**CONCLUSIONS** - Calibration curves for the relationship between the projectile diameter, target thickness, and penetration-hole size were established for pure Teflon targets and spherical glass projectiles traveling at ~6 km/s. These experiments and those of [4] indicate a gradual yet systematic transition from the cratering regime in infinite halfspace targets to penetration(s) of increasingly thinner targets. This continuum is best described by a polynomial fit. This approach eliminates the previous difficulties encountered when converting measured populations of crater and penetration-hole diameters, all derived from a single, space-exposed target, into projectile-size and mass-frequency distributions. Such conversions typically resulted in substantial mass discontinuities, depending on the specific cratering or penetration formula used [*e.g.*, 5 and 6]. Clearly, additional and substantial experimental efforts at higher and lower impact speeds are needed to establish the velocity dependence of the current results. Once this is accomplished, one may apply the mean encounter velocities of [1] for any given viewing direction on LDEF to extract, in principle, a unique projectile size from every penetration hole, making the additional assumption of uniform projectile materials. This seems to be an improvement over traditional ballistic-limit considerations that produced a single, cumulative datum only for all impactors larger than a specified threshold size (for otherwise identical, general assumptions).

**REFERENCES** - [1] Zook. H.A. (1991), in *LDEF-69 Months in Space, First Post Retrieval Symposium, NASA CP-3134*, p. 569-579. [2] See, T.H., *et al.*, (1990), *NASA Johnson Space Center Publication # 24608*, pp. 583. [3] See, T.H. *et al.*, (1992), in *LDEF-69 Months in Space, Second Post Retrieval Symposium*, in press. [4] Hörz, F. *et al.*, (1993), *Int. J. Impact Eng.*, submitted. [5] Warren, J. *et al.*, (1989), Proc. Lunar Planet. Sci. Conf. 19th, p. 641-657. [6] Humes, D.H. (1991), in *LDEF-69 Months in Space, First Post Retrieval Symposium, NASA CP-3134*, p. 399-418.