THIN-FILM PENETRATION EXPERIMENTS AT OBLIQUE IMPACT ANGLES; F. Hörz,* M.J. Cintala,* R. Bernhard,** F. Cardenas,** J. Haynes,** W.E. Davidson,** and T.H. See;** *NASA JSC, SN2, Planetary Science Branch, Houston, TX 77058; **LOCKHEED ESC, Houston, TX 77058.

THE PROBLEM: Precise measurement of the trajectories of individual cosmic-dust particles is a major objective of the proposed Cosmic Dust Collection Facility (CDCF) on board the *Freedom* Station. Some trajectory sensors, currently under development, utilize penetrations of ultrathin films to record a particle's velocity vector. Recent observations by Warren *et al.* (1), however, suggest that particle trajectories may be modified during thin-film penetration. They reconstructed the apparent impact angles of hypervelocity particles that penetrated the front sheet of the double-walled *Solar Max* louvers by connecting the centers of the penetration hole(s) in the front sheet with the center of the debris spray on the second layer. The resulting distribution of trajectory angles was highly skewed towards the surface normal compared to an expected distribution from random trajectories. We therefore conducted experiments involving impacts into thin foils at oblique angles to determine the potential magnitude of trajectory modification.

EXPERIMENTS: Aluminum test-films of variable thickness (T_f) were mounted at different angles α from the horizontal path of soda-lime glass projectiles that were accelerated to a nominal 6 km/s (Figure 1). A thick Al witness-plate, mounted vertically at a known separation distance (L_s) from the test film, received the resulting debris cloud. A 1.5-μm mylar film was located some 80 cm uprange from the inclined test-film for precise "registration" of the projectile path. This entire arrangement was mounted on a massive base-plate which was removed from the impact chamber after each shot and placed onto an optical bench; a He/Ne laser beam was then centered through the penetration holes in the register and test films, thereby projecting the initial trajectory and nominal aim-point onto the witness plate to <1mm precision (<<1°). Use of register films demanded massive projectiles that would not fragment prior to their encounters with the inclined test-films. Therfore, all tests were conducted with glass spheres that were 3.175 mm (1/8") in diameter (D_p). Smaller impactors and thinner films will be needed in the future to evaluate the validity of scaling the current experiments to the conditions and dimensions typical of CDCF events and instruments.

RESULTS: The crater distributions and damage patterns on the witness plates display a variety of major features, as conceptualized in Figure 1, that depend sensitively on D_p/T_f and impact angle α. These two parameters are not independent, as the effective mass column (T_f') depends on the angle of incidence. Most witness-plate patterns are very complex and of a gradual, diffuse nature, making exact measurements difficult and rendering some measurements into observer-dependent "estimates". Qualitatively similar features and difficulties in the measurement of their precise dimensions were reported by (2) from oblique impacts of Al-projectiles into Al-bumpers, largely at D_p/T_f<10. All current spray patterns have bilateral symmetry, with the axis of symmetry containing the nominal aim-point. At small values of T_f, the spray patterns are pear-shaped and have a distinct vertical elongation; the blunt end contains a prominent "central cluster" of large, generally overlapping craters, while the pointed end is characterized by widely dispersed, very small craters. Most projectile mass is judged to reside in the central cluster. With increasing T_f or T_f', this pattern becomes squashed; the major axis changes from vertical to horizontal and in the most extreme cases to date, it assumes a crescent shape as sketched in Fig.1. Increasing T_f results in greater numbers of fragments "below" the nominal aim-point, which are clearly pieces from the test-foil itself, as the mass represented by the penetration hole may approach the projectile mass. The craters produced by displaced foil-material are generally readily distinguished from craters produced by projectile fragments on the basis of color, with the glass-Al impacts being darker than the Al-Al craters. While these distinctions cannot be applied quantitatively, there is little doubt that projectile and foil fragments form distinct debris-clouds, with the projectile fragments clustering closer to the nominal aim point and the foil debris recieving a distinct velocity component normal to the test foil, as also reported by (2). Figure 1 defines the linear dimensions measured to obtain the desired angular relationships that describe projectile dispersion and trajectory deviation relative to the nominal path. The dispersion angles β, ϕ_+ and ϕ_- are plotted in Figure 2, with "+" and " -" related to the initial trajectory. Clearly, the geometric center(s) of the dispersion cones are located above the nominal aimpoint. However, the mass-weighted center (angle β) coincides essentially with the center of the central cluster. Figure 3 portrays the angle β in detail, both as a function of α and D_p/T_f. (We extrapolated to the 90° case, where β is expected to be zero).

CONCLUSIONS: We observed that some modification of particle trajectories occurs during oblique penetration of thin films. At sufficiently small, scaled foil-thicknesses and angles of incidence <45°, however, the original trajectory is largely maintained by the center of mass of the projectile-debris cloud. Matters may become intolerably complex at >45° and D_p/T_f<10 for the projectile debris alone, as the center of mass cannot be defined with confidence, and could become even more so if one were unable to differentiate between projectile and foil debris; in these cases, the centers of both figure and mass would be deflected substantially toward the surface normal of the penetration foil. We suggest that the *Solar Max* observations of (1) are due largely to these effects, with corroborating evidence beeing derived from the extreme difficulty, if not inability, to identify impactor residue in many of these *Solar Max* spray patterns (1).

REFERENCES: (1) J.L. Warren *et al.* (1989) *PLPSC 19*, 641-657. (2) W.P. Schonber and R.A. Taylor (1989) *AIAA Journal* 27, 639-646.

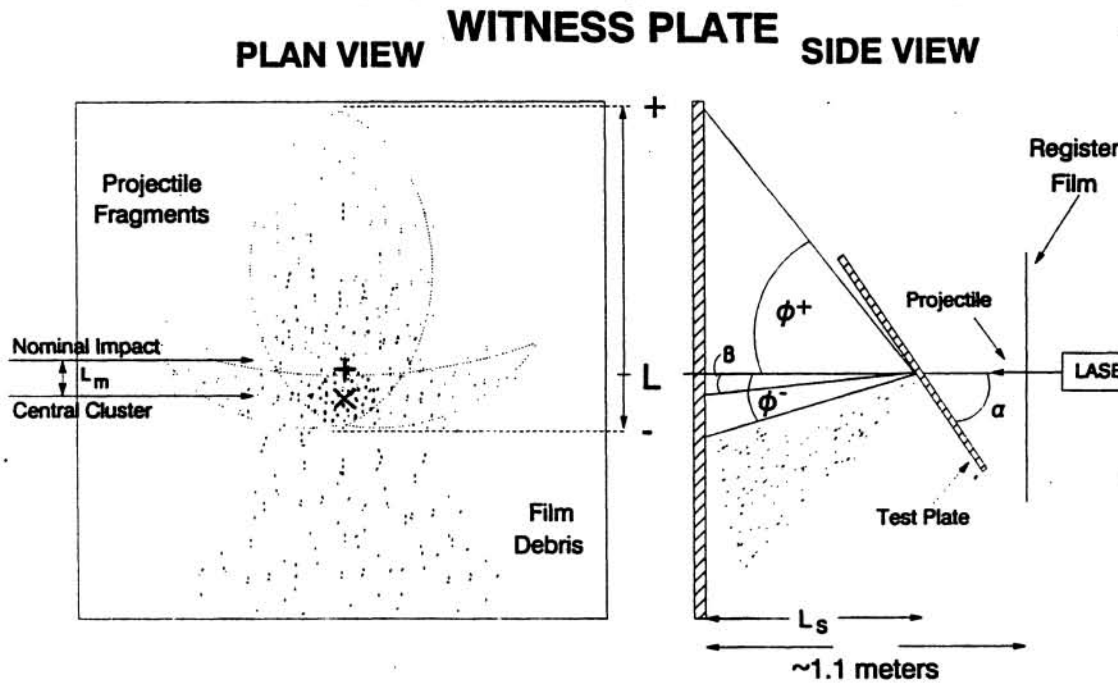

Figure 1.

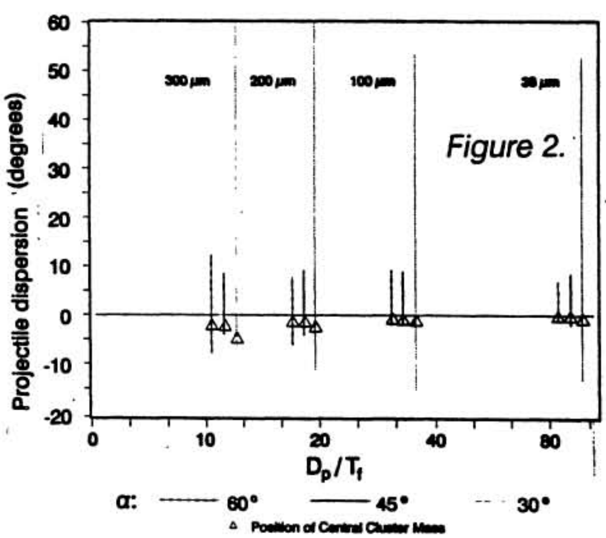

Figure 2.

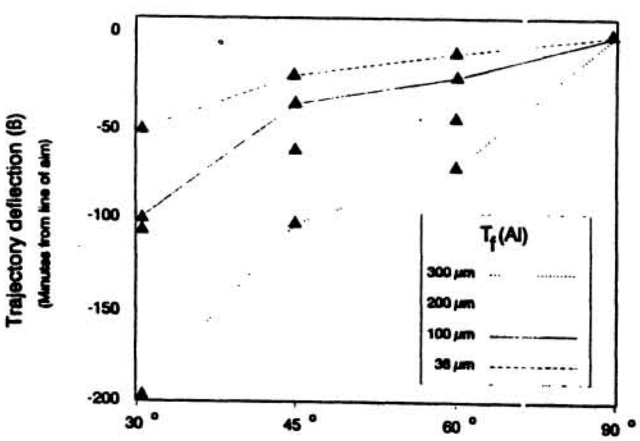

Figure 3.