EXPERIMENTAL AND THEORETICAL ANALYSES OF HYPERVELOCITY PENETRATION PARAMETERS FOR THIN FILMS FLOWN IN SPACE

William G. Tanner*, Robert A. McDonald*, W. Merle Alexander*, and Carl R. Maag**
*Baylor University Space Science Laboratory / Department of Physics / Waco, Texas 76798 USA
**Science Applications International Corporation / Glendora, California 91740 USA

Introduction: Systems exposed to the extreme environment of Low-Earth Orbit (LEO) can avoid catastrophic failures only if the materials which compose them can provide a "shield" against the effects of continuous hypervelocity impacts. The size distribution of the objects a surface will encounter in LEO has not been adequately characterized, especially for that portion of the distribution which contains the highest number of objects, i.e., the smallest. To obtain in situ data depicting the size distribution of these objects in LEO, an experiment has been designed and successfully flown in the Science Applications International Corporation (SAIC) Interim Operational Contamination Monitor (IOCM) aboard the STS-32, STS-44, and scheduled for flight on STS 46 and STS 52. A result of the experimental activities associated with Carl Maag's IOCM missions, an opportunity to participate in the ESA's European Retrievable Carrier (EuReCa) has been provided for a nine-month exposure at 500 km for similar thin film experiments.

Experiment Design: The basic design strategy of the experiment was to suspend a thin metallic film above an impact plate composed of aluminum. Situated below the thin film, each unit possessed a highly polished impact surface on which was sputtered 2000 A of gold. The thin films created by Arizona Carbon Foils (ACF) are vapor-deposited aluminum mounted on a 30 line per inch nickel grid (90% transmissive). Although the primary objective of the STS experiments was to sample the LEO orbital debris and micrometeoroid complex, an additional design goal for these experiments was to test the survivability of a thin film with a thickness of less than 750 A which possessed a density of less than 3.0 gm/cm^3. When the ratio of the particle diameter, dp, to the film thickness, Tf, viz., dp/Tf is large and the density of the material composing the film is comparable to the impacting grain (rp = rf), one can reduce the degree to which the penetrating particle would fragment and thus fragments will impact the gold-coated aluminum plate below.

Computer Simulations of Thin Film Penetration: Interpretation of the evidence presented by these materials will require extensive knowledge concerning the failure modes of similar materials subjected to hypervelocity impacts. Extensive experimental investigations have measured the penetration parameters of several types of metallic substances in the velocity and size regimes commensurate with that of Interplanetary Dust Particles (IDPs) and Orbital Debris. Through numerous hypervelocity impact investigations, BUSSL researchers have accumulated experience which has been applied to hydrodynamic computer program development and the utilization the multidimensional hydrodynamics code CTH produced by Sandia National Laboratory. Primarily, CTH will be used to investigate the relationship between the particle diameter, dp, and the diameter, dh, of the hole created in an aluminum thin film 500 A thick (Tf) for relevant particle sizes, densities and velocities. The results of these CTH runs will be employed to analyze the penetration parameters of the thin films flown on STS and EuReCa 1.

Empirical Estimations of Penetration Parameters: Extensive experimental work has established several empirical relationships which describe the hypervelocity impact event of thin film penetration. Interpretations of the solutions derived by use of CTH must be substantiated by a clear connection with parameters derived by experiment. In order to analyze by empirical means the penetration parameters of thin films like those flown on STS and EuReCa 1, one may utilize the Fish-Sommers penetration formula. Given that the thickness of the metallic foil is 5.00 X 10^-6 cm, density of 2.7 g/cm^3, and velocity of 7 km/s, then the minimum mass which could penetrate the thin film would be:

\[ \frac{T_f}{K \rho_p^{0.148} M_p^{0.352} V_p^{0.667}} \text{ or } M_p = \left[ \frac{T_f}{K \rho_p^{0.148} V_p^{0.667}} \right]^{2.84} = 2.2 \times 10^{-15} \text{ g} \]
where $K = 3.56 \times 10^{-4}$ for Aluminum. A recent empirical equation reported by McDonnell (6) which gives a measure of the penetration limits for metallic films exposed to the LEO orbital debris and micrometeoroid complex can be used to derive the following penetration mass limit:

$$M_p = K'' T_f^3 \left[ \frac{\rho_p}{\rho_f} \right]^{-0.78} \left[ \frac{\sigma_f}{\sigma_0} \right]^{0.24} \frac{v_p^3}{v_f^3} \beta = 1.00 \times 10^{-15} \text{g}, \text{ with } \beta = 0.69 \left[ \frac{\rho_p}{\rho_f} \right]^{0.09},$$

where $K'' = 2.42 \times 10^{-18}$ is an empirically derived constant. These mass calculations suggest that the thin films can be penetrated by a grain which possesses a mass greater than a picogram.

**Results:** Results of Three-dimensional (3D) computer simulations of the hypervelocity impact events which penetrate the STS and the EuReCa 1 thin films will be reported. A relationship between the particle diameter, $d_p$, and the diameter, $d_h$, of the hole created in a 500 Å aluminum thin film ($T_f$) for relevant particle and film parameters will be derived and will be compared with empirical equations. That relationship will be used to analyze insitu data of the thin film experiments flown in LEO, and to determine the size distribution of particles which penetrate the thin films.

[Graph showing the relationship between $T_f/D_p$ and velocity (km/s)]

**References**