MODELLING HYPERVELOCITY IMPACTS INTO ALUMINUM STRUCTURES BASED ON LDEF DATA; C.R. Coombs, D.R. Atkinson, A.J. Watts, J.R. Wagner, M.K. Allbrooks, C.J. Hennessy, POD Associates, Inc., 2309 Renard Place, SE, Suite 201, Albuquerque, NM 87106.

INTRODUCTION

Realizing and understanding the effects of the near-Earth space environment on a spacecraft during its mission lifetime is becoming more important with the regeneration of America's space program. Included among these potential effects are erosion and surface degradation due to atomic oxygen impingement, ultraviolet exposure embrittlement, and delamination, pitting, cratering and ring formation due to micrometeoroid and debris impacts. These effects may occur synergistically and may alter the spacecraft materials enough to modify the resultant crater, star crack and/or perforation. This study concentrates on modelling the effects of micrometeoroid and debris hypervelocity impacts into aluminum materials (6061-T6). Space debris exists in all sizes, and has the possibility of growing into a potentially catastrophic problem, particularly since self-collisions between particles can rapidly escalate the numbers of small impactors.We have examined the morphologies of the Long Duration Exposure Facility (LDEF) impact craters and the relationship between the observed impact damage on LDEF versus the existing models for both the natural (micrometeoroid) and manmade (debris) environments in order to better define these environments.

LDEF was designed as a reusable platform for launching and returning long duration (~1 year) space environment exposure experiments. LDEF was launched on April 7, 1984 from STS 41-C into a circular orbit about the Earth. The LDEF mission exposed 57 separate experiments to Earth's space environment at 12 different angles at an altitude of 450 km and an inclination of 28.4° for 53/4 years. Because the satellite was gravity-gradient stabilized, and flew its mission with one end constantly facing space and the other constantly facing Earth, the experiments were constantly oriented in known directions. To better characterize the effects of the near-Earth space environment, this study compared the results of actual impact crater measurement data and the SPace ENVironment (SPENV) program developed in-house at POD to theoretical models established by Kessler[1] and Cour-Palais[2], and the CTH hydrodynamic computer code developed by Sandia National Labs.

BACKGROUND

Two major components currently exist within the dynamic LEO environment; namely natural micormeteoroids from the solar system and manmade debris dating back to the onset of space exploration in 1957. While micrometeoroids arrive at the Earth from almost all directions, the debris is in both near-circular and elliptical orbits around the Earth. Although both types of particles exist all the way out to geosynchronous (GEO) orbits, the major populations of debris are within the altitude range of 350-2000 km. Micrometeoroids arrive at the Earth with differential speeds of from below 12 km/s to 72 km/s. However, when spacecraft orbital speed is included, the resulting impact speeds range from below 5 km/s to 79 km/s, yielding an overall average collisional speed of 20 km/s. The flux of particles is approximately isotropic in free space, but the effect of Earth shielding causes an asymmetry, resulting in a minimum number of impacts for Earth-facing satellite surfaces. As a result, either the RAM (velocity vector) surface or the SPACE-facing surfaces receive the highest number of impacts, depending upon altitude.

RESULTS AND DISCUSSION

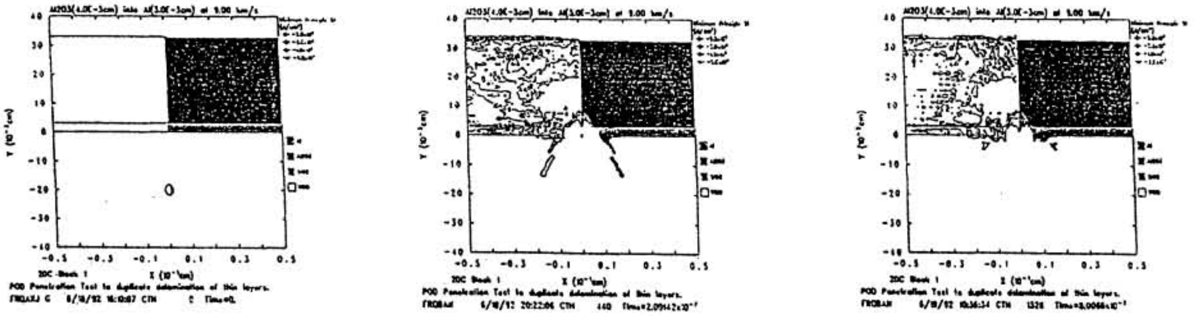
Experimental data for these analyses were collected by the authors and/or provided by several LDEF Principal Investigators, Meteoroid and Debris Special Investigation Group (M&D SIG) members, and by the Kennedy Space Center Analysis Team (KSC A-Team). These data were collected from various aluminum materials from different locations on the LDEF satellite. In addition, POD has written a PC-based computer code (SPENV) to calculate the expected number of impacts per unit area as functions of altitude, orbital inclination, time in orbit, and direction of the spacecraft surface relative to the velocity vector, for both micrometeoroids and debris. Scaling laws relate the models to the actual data (see Watts *et al.*, this volume for more information on the scaling laws). In addition, POD has performed many CTH hydrodynamic compute runs of various impact events, and has identified certain modes of response, including simple metallic cratering, perforations, and delamination effects of coatings, all of which were observed during our LDEF analyses.

Results of the damage analyses on the thermal painted LDEF aluminum panels indicated that more than 5% of surfaces examined were damaged by impact cratering and its coincident effects (i.e., spallation, delamination, and blow-off) causing damage areas to extend as far as 100 crater diameters from the central crater. Since the plates were located at different orientations, their responses to the hypervelocity impacts varied. Crater morphologies range from a series of craters, spall zones, domes, spaces, and rings to simple craters with little or no spall zone. Each of the crater morphologies is associated with varying damage areas, which appear to be related to their respective bay locations, thus exposure angle. In addition, an interesting phenomenon was noted: three "types" of ringed impact features were identified and loosely characterized as "young", "middle" or "old" as an indication of their relative sequence of formation. The "young" group is characterized by the presence of distinct crater "lips" and excavation cavity rims with distinct, visible "flaps" or folds composing the ring zone. The "middle" group appears slightly degraded, with ring edges still distinct and traces of fold-over layers still visible but less pronounced. In the "old" stage, the impact feature is noticeably eroded, with little or no foldover flaps visible and the rings appear as masses of rubble. Following discussions with Dr. Banks[3] we have concluded that these features are due to the interaction of atomic oxygen with the paint surfaces, with the cratering events occuring early to late (young-old) during LDEF's tenure in space.

CTH was used to simulate hypervelocity impacts into coated materials in an effort to begin to understand the formation of the "ring" and "dome" structures commonly observed on painted aluminum surfaces (Figure 1). POD has been successful in replicating "dome" structures but is not yet able to cause a "freezing" of waves to produce a permanent ring structure. The CTH runs have, however, produced transient "ring" motions which may be Rayleigh wave ripples propagating away from the impact site. One interesting note, all high speed (>9 km/s) impacts modelled to date have forged the impactor into a jet structure which is expelled from the hole, leaving very little residue behind.

Results of the data and modelling comparisons and hypervelocity impact simulations show good agreement for spacecraft surfaces. It is interesting to note that hypervelocity impacts into painted aluminum surfaces are morphologically similar to those observed on some planetary surfaces. With the addition of gravity, similar modeling techniques may be used to model impacts into planetary surface materials and structures (*e.g.*, soils, volcanic terrains, crustal materials) to evaluate their strengths and ability to withstand impacts of differing magnitudes (*i.e.*, 4)

REFERENCES: (1) Kessler D.J. et al. (1987) *NASA TM-100471*. (2) Cour-Palais et al. (1969) *NASA SP-8013* (3) Bell R.L. *et al.*, (1991) Sandia Nat'l Lab. . (4) Dr. Bruce Banks, personal communication, 1991. (5) Melosh H.J. and Kipp (1989) *LPSC XX*, pp. 685-686.



(a)
t = 0

(b)
t = 2.00142 x 10^{-7}

(c)
t = 8.0066 x 10^{-7}

Figure 1: Example results from a CTH run where an Al2O3 projectile impacted a 2-layer target at 9.0 km/s.