Environment Modelling in Near-Earth Space: Preliminary LDEF Results

C.R. Coombs, D.R. Atkinson, J.D.Wagner, L.B. Crowell, M.Allbrooks, A.J.Watts, POD Associates, Inc., 2309 Renard Place, SE, Suite 201, Albuquerque, NM, 87106.

INTRODUCTION

The Long Duration Exposure Facility (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 at an altitude of 450 km and orbital inclination of 28.4°. The satellite was gravity-gradient stabilized and flew its mission with one end constantly facing Earth and one side (Row 9) always facing into the RAM direction (Figure 1). Post-retrieval analysis has shown that LDEF was slightly rotated, placing the RAM direction 7 degrees from normal relative to Row 9. LDEF was retrieved January 12, 1990 following a 5¾ year exposure period. The unforeseen delay, was a result of the Challenger accident and mission scheduling delays. At the time of retrieval, the satellite's orbit had degraded to an altitude of 330 km.

The LDEF mission consisted of 57 separate experiments in 86 experiment trays with over 10,000 test specimens. Of interest to the LDEF Principal Investigators were the effects to different materials from the various environments to which the satellite was to be exposed. Among these were: contamination, atomic oxygen, thermal cycling, vacuum, ultraviolet light, electrons, protons, cosmic radiation, and meteoroids and debris.

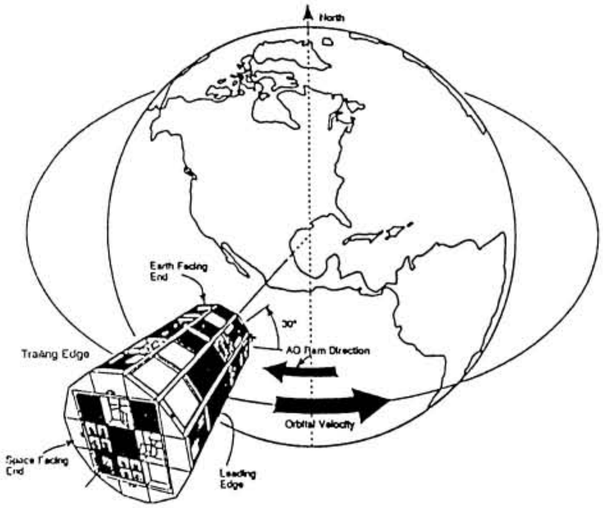


Figure 1: Orientation of the Long Duration Exposure Facility (LDEF) in near-Earth orbit.

In an effort to better characterize the near-Earth space environment, this study compares 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] Results of these efforts directly relate to the survivability of future spacecraft and satellites that are to travel through and/or reside in Low Earth Orbit (LEO) for long and short periods of time.

METHOD

Data utilized in this study originated from three sources: (1) For craters larger than 0.05 cm diameter, measurements were taken by the LDEF Meteoroid and Debris Special Investigation Group's (M&D SIG) Kennedy Space Center Analysis Team on the entire LDEF aluminum structure.[3] (2) For craters larger than 0.003 cm diameter, measurements were taken by the authors from specific aluminum experiment tray covers, and (3) measurements from craters larger than 0.0001 cm diameter were taken by the Interplanetary Dust Experiment (IDE)[4] aboard LDEF during the first year of exposure. Since the latter data were only collected during the first year of flight, they were corrected for the full 5¾ year LDEF exposure time, by assuming no growth in the mean flux values. Separate environment models were utilized to make predictions for meteoroids and debris and compared to the SPENV model results. For meteoroids, the Cour-Palais *et al.*[2] model was used with the Kessler-Erickson velocity distribution as described by Zook.[5] For debris, the Kessler model[1,6] was used. The SPENV program models both the micrometeoroid and debris environment that may be encountered by a spacecraft in an orbit between 200 and 2000 km. Both the Kessler and Cour-Palais models predict particle diameters, whereas the LDEF data provides measurements of crater diameters.

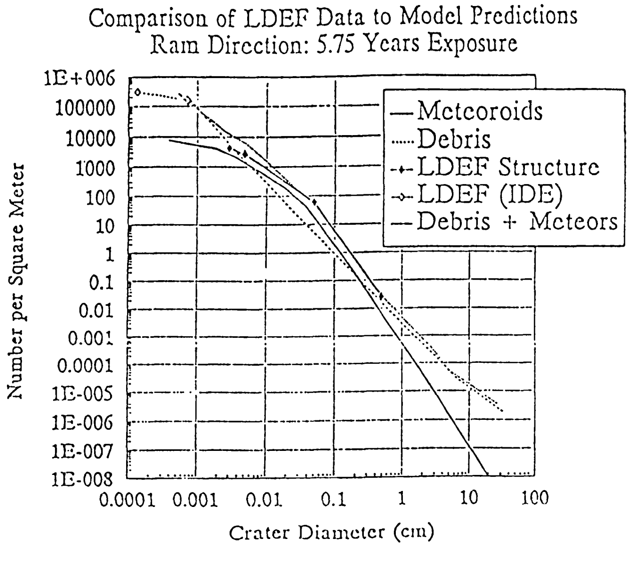
To correct for this, the model's particle diameter (d_p) predictions were converted into crater diameter (d_c) predictions using the following equation: where ρ_p is the particle density, ρ_t is the target density, v is the relative impact velocity, and k is a scaling factor normalized to aluminum impact data from laboratory experiments. This energy equation is valid for impacts with relative velocities greater than approximately 4 kms^{-1}. A 450 km altitude was maintained throughout the running of the SPENV program. However, since LDEF actually descended to 330 km, and since the models are based on the observation that the debris environment lessens with decreasing altitude (<500 km), the models should overpredict the number of impacts of all sizes for LDEF.

$$d_c = kd_p\left(\frac{\rho_p}{\rho_t}\right)^{\frac{1}{3}} v^{\frac{2}{3}}$$

SUMMARY

Figure 2 compares the predictions for the RAM direction from the meteoroid and debris models with the composite mean of the RAM-facing LDEF surfaces. The combined model predictions match relatively well with the LDEF data for impact craters larger than approximately 0.05 cm diameter; however, for smaller impact craters, the combined predictions diverge, or overpredict, from the LDEF data. The divergences cannot currently be explained by the authors or model developers. More specifically, the Kessler debris model overpredicts the mean flux of small craters ~0.05 cm diameter, while the Cour-Palais micrometeoroid model underpredicts the mean flux for these small craters. Since this divergence is noted in all directions, including the Earth- and space-facing ends, the divergence may be indicative of either elliptical orbital particles from natural or man-made sources, of β-meteoroid fluxes, or a combination of the two. The IDE data has positively identified a β-meteoroid component of the natural environment, which is not currently included in the Cour-Palais model. It is unknown whether this β-meteoroid component can account for the entire divergence.

One should be cautious in utilizing these comparisons to validate the micrometeoroid and debris models. The assumptions underlying this analysis are necessarily simplistic. For example, if the IDE mean flux data was assumed to have a growth rate (2%) identical to that used in the models, the IDE data would be 13% higher than shown in the figures. This increase would not solve the model divergence problem and could, in fact, complicate the problem even further. In addition, the IDE data is the only LDEF data which indicates the time dependence of the flux. While the data plotted here is for the IDE mean flux, the actual IDE data varies dynamically by as much as 3 orders of magnitude over time frames that vary from minutes to days. These time-dependent variations may be associated with toroids or clouds of debris impactors. Also, the IDE data indicates that most impactors were not in circular orbits, but were in elliptical orbits; this factor is also not included in the current models.



CONCLUSIONS

The comparisons given here provide a good measure of the relative applicability of the models for first-order engineering design purposes, but illustrate the definite need for higher fidelity in the small impactor - spacecraft degradation - regime.

REFERENCES (1) Kessler, D.J., et al. (1987) NASA TM-100471. (2) Cour-Palais et. al. (1969) NASA SP-8013. (3) See T., et al. (1990) JSC#24608. (4) Unpublished data (1991) IDE Team: Institute for Space Science and Technology (5) Zook H.A. (1990) LPSC XXII, pp. 1385-1386. (6) Kessler, D.J., et al., 1990.