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WORKING GROUP WRITTEN PRESENTATION

METEOROID/ORBITAL DEBRIS EFFECTS ON MATERIALS

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1. Background

Low earth orbit (LEO) is the most significant region relative to orbital debris, since the flux of orbital debris peaks in the region from 800 to 1000 kilometers, and the relative velocities of objects in LEO are about 10 kilometers per second.

The flux and relative velocities of objects in geosynchronous orbit (GEO) are small, so that debris is not considered to be a problem in GEO.

The meteoroid environment is independent of orbit or altitude, so that its effects are the same in LEO and GEO.

The effects of orbital debris and meteoroid impacts can be divided into two broad regions:

(a) Erosion and pitting. Small particles (less than 100 microns) are very numerous. Impacts from these generally do not lead to penetration of surfaces, but cause pitting and erosion. The Solar Max surfaces were peppered with thousands of tiny impact pits.

(b) Catastrophic impacts. Large debris particles are few in number relative to small debris, so that the probability of an impact is low. However, the effects of an impact of a large particle at 10 kilometers per second are devastating. It is estimated that a 40 square meter spacecraft in LEO would suffer one impact from a 1 centimeter particle every 100 years. While the likelihood of this event is small, an impact of this kind would destroy most spacecraft. There is of course, an intermediate region where either effect can predominate, depending on the system being impacted. The impact of a 1 millimeter particle on a space suit will cause a catastrophic puncture of the life support system, while the impact of a 1 millimeter particle on the Shuttle Orbiter will cause some pitting damage, but nothing of great significance.

2. What materials are vulnerable?

All types of materials can be pitted or penetrated by hypervelocity impacts from meteoroids or orbital debris. Whether or not these impacts are important depends on the function of the material. For example, a mirror could be affected by pitting and erosion caused by the impact of very small particles which would not be a problem for structural materials. A pressure vessel could be damaged catastrophically by the impact of a particle large enough to penetrate its wall, while some other systems could tolerate similar penetrations without difficulty.

3. Correlation between actual effects and laboratory and theoretical simulations.

Material retrieved from the Solar Max satellite, the Palapa and Westar satellites, and the Shuttle Orbiter windows are the only available samples which show the actual effect of the meteoroid/debris environment on materials. These materials show impact pits from both micrometeoroids and very small orbital debris particles, the latter identified as mostly paint flakes and aluminum oxide particles. Microscopic examination of these pits shows shapes and fracture patterns identical to those observed in laboratory hypervelocity impact tests. By analysis of these shapes and patterns, it has been possible in some cases to deduce the size and velocity of the impacting particles. However, there are no laboratory hypervelocity impact tests for comparison with high velocity meteoroid impacts, due to the lack of a capability to make such measurements.

4. Capability for laboratory simulation and theoretical modelling of impact effects.

The effects of orbital debris impacts can be simulated in the laboratory by firing solid projectiles at test targets. Several methods exist for accelerating particles to the necessary high velocities. Van de Graaf electrostatic accelerators can be used to raise small (less than 1 micron) particles to velocities of tens of kilometers per second. One such accelerator exists at the Los Alamos National Laboratory, and another in West Germany. Shock tubes are also capable of accelerating small particles to hypervelocity, but most if not all such facilities are currently mothballed. Light gas guns can accelerate solid particles a centimeter and more in diameter up to velocities of about 7 km/sec. There are a number of such guns in operation in the U.S. In order to accelerate moderate size projectiles to velocities greater than 7 km/sec, the only proven method is the shaped charge gun, which generates velocities up to 11 km/sec. Electromagnetic accelerators, or rail guns, have so far not realized their promise of high velocities. Finally, a pulsed laser can be used to simulate the energy deposition resulting from a hypervelocity impact, and thus simulate the effects of the impact.

The laboratory results obtained at currently available impact velocities can be extrapolated to higher velocities by the use of models whose empirical constants are adjusted to fit the low velocity results. At the present time, this method fails or works poorly with complex materials, such as foams or composites. It is also difficult to deal with complex geometries.

Simulation of meteoroid impacts is more difficult. The impact velocities of micrometeoroids are higher than debris, up to 72 km/sec, and the particles are mostly low-density "snowflake" structures. There is no satisfactory way for laboratory simulation of this combination of properties, although modeling of the impacts is possible.

Synergistic effects can be simulated, where they are known to exist. Examples include the effects of impact pits on the protective coatings for atomic oxygen and stress crack initiation at impact pit sites.

On-orbit collisions which result in total breakup of the colliding objects can be modeled approximately using current theory. However, the size and velocity distribution of the small particles generated in the collision are not well known. This information is essential for predicting the future growth of the debris population, since theory predicts that at some future date, runaway growth of the debris population could occur as a result of cascading collisions.

5. Synergistic Effects.

There are many possibilities for synergistic effects, but their significance for long-term space flight are not known. Examples of such effects include the following:

a. Atomic oxygen erosion initiated by impact on a protective coating. Laboratory studies of protective coatings have shown that atomic oxygen can attack the substrate over a large area through a small break in the coating.

b. Thermal effects could be produced by erosion of thermal control coatings.

c. Spacecraft charging effects can be facilitated by penetrations.

d. Contamination can be induced by vapor from the impact.

e. Impact pits can serve as initiation points for stress cracks produced by thermal cycling.

f. Cascades of effects are conceivable, in which several effects follow one another.

6. Confidence level: Can we build satellites for 10-30 year lifetime?

The answer is probably yes for small conventional satellites (less than about 40 square meters area), where the expected effects of erosion and pitting are taken into account by appropriate protective surfaces. The answer is a qualified no for satellites with large areas (5000 square meters or more) expected to operate for up to 30 years without malfunction. The reason is the debris environment in the size range (up to 1 centimeter) expected to impact a spacecraft of this size is not well enough known, so that the shielding used on the spacecraft may not be adequate. In principle, the spacecraft can be designed with a sufficiently massive shield to cover all possibilities, but in practice, the weight and volume costs for this approach are large, and may become prohibitive as the debris environment becomes more severe in the future.

The answer is also a qualified no for satellites with radically new functions or materials. In these cases, we don't know the synergistic effects, or their importance.

7. Space experiment requirements.

The U.S. Space Command tracks and catalogs all objects in LEO with diameters larger than about 10 centimeters. The orbital debris environment for smaller sizes is poorly defined, with an uncertainty factor of at least 3. The population data for very small debris (less than 100 micron size) in LEO is anchored by only one set of data--that from analysis of the surfaces from the Solar Max satellite. There also exists one limited set of optical data for sizes down to about 2 centimeters. There is no data at all for sizes between 100 microns and 2 centimeters. Rapid changes of the debris environment can occur when new breakups take place, making these few measurements obsolete overnight. Experiments are needed to define the small debris environment below the 10 centimeter level to a degree of confidence significantly better than the current uncertainty factor of three.

Synergism and cumulative effects, particularly from the small debris which cause erosion and pitting, are not wholly predictable, and hence may not all be capable of simulation. A flight experiment which included other materials experiments would exercise all possibilities.

It should be noted that we cannot completely simulate or calculate the effects of hypervelocity collisions of objects in space. In the event that such an event is deliberately planned as part of a space experiment, then every effort should be made to measure the particle sizes and velocities resulting from the collision. Since any instrumentation on the colliding spacecraft will be destroyed by the collision, either ground-based sensors, or sensors aboard a co-orbiting satellite would be required to make these measurements.

The meteoroid environment is better understood than the debris environment, and there is general agreement concerning the definition of an environment suitable for engineering calculations. No further space experiments are needed for assessing the effects of the meteoroid environment on materials.

8. Flight experiments needed.

The first priority is to measure the LEO environment for sizes below 1 centimeter. It is expected that a ground-based radar currently under development will be capable of monitoring the debris environment for sizes above 1 centimeter.

The second priority is to repeat the measurements at intervals to monitor changes which are expected to occur as the rate of space activity increases in the future.

The third priority is to establish the nature and significance of possible synergistic effects.

9. Possibilities for flight experiments: Environment definition

For debris sizes of 1 millimeter and larger, it would be possible to build a dedicated debris sensor satellite. JPL has designed a debris sensor system consisting of two 10-inch telescopes and CCD image detectors which would be capable of monitoring the debris population in orbit down to sizes of 1 millimeter. The cost of building and launching such a satellite has been estimated at $100M. For small debris (100 microns or less), off-the-shelf micrometeoroid sensors are capable of measuring the environment. The Space Electric Rocket Test (SERT) satellite is equipped with a small micrometeoroid experiment, which is probably still functional. Planned EOIM satellite experiments may also provide some new information. Measurements of these kinds provide information on the flux of debris particles, but do not identify their source.

Surfaces which are retrieved from the space environment provide unique information, in that the source of the debris can be identified by chemical analysis of material in the impact pits. Such material retrieved from the Solar Max satellite has provided a wealth of new information on the small debris environment. When LDEF is recovered in 1989, it will have been in LEO for about 5 years. An enormous number of impact pits will be available for analysis, and a new and more exact picture of the small debris environment will emerge from analysis of the LDEF surfaces. The information available from LDEF could be extended in future years by the development of a free-flyer "gas-can" type of experiment, in which an expandable surface would be deployed from the "gas can" to expose a large area to the space environment. After exposure for several months, the surface would be pulled back into the "gas can", retrieved, and returned to Earth for laboratory study. This type of experiment could be repeated at intervals of 2 to 4 years.

The Cosmic Dust Facility planned for Space Station Freedom is intended to measure the flux of micrometeoroids with great accuracy. It will inevitably measure some orbital debris as well, although the experiment is being carefully designed to minimize the count rate of orbital debris.

10. Flight experiment possibilities: Synergism and accumulated effects.

For this problem area, it is necessary to obtain long-term exposure of real spacecraft systems, recover them, and perform detailed interdisciplinary analysis of the kind done on the recovered Solar Max hardware.

One such approach would be to recover old satellites by capture from the Shuttle Orbiter. A survey of candidate satellites for capture by the Orbiter shows surprisingly few possibilities. The best appear to be the Solar Max and SAGE. Both are about 10 years old. SAGE is small enough that it could be recovered in its entirety, but it is likely that Solar Max would have to be dismantled, and only parts retrieved, since it is a large satellite. There are no other candidate satellites with longer exposures available to the Orbiter. There are several TIROS satellites which have been in orbit up to 30 years, but their orbits are such that an ELV mission would be required for recovery. Capture and retrieval of an old satellite is a costly and difficult operation. Strong interdisciplinary justification would be needed to support such a mission.

11. Related topics.

There was considerable discussion in the Workshop concerning measures that could be taken to mitigate the growth of the orbital debris environment. In order of increasing cost and difficulty, these included:

a. Operational procedures to minimize breakups.
b. Improved spacecraft paint
c. Avoidance maneuvers
d. Removal of large satellites
e. Movable shields
f. "Sweeping" of small debris

The most practical and cost-effective measure was considered to be the introduction of operational procedures to minimize future breakups.