

ORBITAL DEBRIS MEASUREMENTS: D.J. Kessler, NASA, Johnson Space Center, Houston, Texas 77058

An any one time, there are about 200 kgm of meteoroid mass moving through altitudes below 2000 km at an average speed of about 20 km/sec. Most of the mass is found in particles of about 0.1 mm diameter [1]. The meteoroid environment has been a design consideration for spacecraft. The Apollo and Skylab spacecraft were built to withstand catastrophic impacts on critical systems from meteoroids having sizes up to 3 mm. in diameter. Larger sizes were so few in number as to be of no practical significance for the duration of the mission. Some small spacecraft systems required additional shielding against meteoroids as small as 0.3 mm. diameter in order to maintain an acceptable reliability. The trend in the design of future spacecraft (as for example, the Space Station) is towards larger structures, lighter construction, and longer stay times in orbit. These factors increase the range of concern from about 0.1 to 10 mm. in diameter.

However, it is no longer sufficient to consider only the natural meteoroid environment in spacecraft design. Since the time of the Apollo and Skylab programs, launch activity has continued and increased. As a result, the population of orbital debris has also increased substantially. The total mass of debris in orbit is now approximately 2,000,000 kgm at altitudes below 2000 km. Relative to one another, this mass is moving at an average speed of 10 km/sec; or only half the relative speed of meteoroids. The most significant difference between the orbital debris population and the meteoroid population is that most of the debris mass is found in objects several meters in diameter, rather than 0.1 mm diameter as for meteoroids [2]. This large reservoir of mass may be thought of as a potential source for particles in the 0.1 to 10 mm. range. That is, if only one ten-thousandth of this mass were in this size range, the amount of debris would exceed the natural meteoroid environment. The potential sources for particles in this size range are many: (1) Explosions - more than 80 spacecraft are known to have exploded in low Earth orbit. The fragment size distribution is a sensitive function of the intensity of the explosion [3,4]. (2) Hypervelocity collision in space - One or two of the known satellite breakups may have been from hypervelocity collisions. The fragment size distribution of such a collision is known to include a large number of particles in the 0.1 to 10 mm size range. (3) Deterioration of spacecraft surfaces - oxygen erosion, UV radiation and thermal stress are known to cause certain types of surfaces to deteriorate, producing small particles. (4) Solid rocket motor firings - A third of the exhaust products of a solid rocket motor is aluminum oxide particles in the size range 0.0001 to 0.01 mm. (5) Unknown sources - Other sources are likely to exist. Particulates are commonly observed originating from the Shuttle, and other objects in space.

What is currently known about the orbital debris flux is from a combination of ground based and in space measurements. These measurements have revealed an increasing population with decreasing size. Beginning with the largest sizes, a summary of these measurements follows.

NORAD Catalogue. The North American Aerospace Defense Command (NORAD) is responsible for tracking and maintaining a catalogue of "all man-made objects" in space. The catalogue as of September 30, 1985, contained 5712 objects in space [5], most in low Earth orbit, and nearly half resulting from satellite breakups. The ability to catalogue small objects is limited by the power and wave length of individual radar sites, as well as the limitations

on data transmission within the network of radar sites. Consequently, objects smaller than about 20 cm are not usually catalogued.

PARCS Radar. The Perimeter Acquisition and Attack Characterization System (PARCS) at Concrete, N.D. is NORAD's most powerful radar. It can typically detect objects as small as about 8 cm in low Earth orbit. Past [6] and continuing tests with this radar have shown an uncatalogued population which is between 7% and 18% greater than the catalogued population.

Ground Based Optical Telescopes. Lincoln Laboratory was contracted to use their Experimental Test Site (ETS) to search for centimeter sized debris in low Earth orbit. The ETS consists of two, 31 inch telescopes located in White Sands, New Mexico. The telescopes tracked identical overhead star fields for about an hour when the region of space between 500 km to 1000 km was sunlit. The star-like images were detected using low-light level TV cameras and recorded on video tape. Centimeter size objects were seen as 16th magnitude objects moving at about a degree per second through the field of view. Two telescopes were required to obtain the altitude of the object, using parallax. This permitted discrimination between orbiting debris and meteors which are only found below 120 km. Part of the observing program was coordinated with NORAD. The search detected eight times as many orbiting objects as were predicted using the catalogued population [7], indicating that a total population of approximately 45,000 objects larger than about 1 cm are in low Earth orbit. Additional tests of this type are planned to determine probable sources, and to improve statistical uncertainties.

Explorer 46 Meteoroid Bumper Experiment. Explorer 46 was launched into Earth orbit in August, 1972. One of the experiments, the Meteoroid Bumper Experiment, consisted of 3 orthogonal surfaces with areas totaling 19.2 sq. met. These areas were sensitive to penetrations by particles larger than 0.075 mm at 7 km/sec. The distribution of impacts on these orthogonal surfaces illustrated that the surfaces experienced a highly directional flux, one direction measuring a factor of 10 greater flux than another. Assuming the experiment performed as expected, the only explanation is that the satellite became gravity gradient stabilized and mostly measured an Earth orbiting population [8].

Spacecraft Windows. Since the beginning of manned space activities, returned windows have been examined for meteoroid impacts [1]. Beginning with the Apollo/Skylab windows, the windows were examined in the Scanning Electron Microscope (SEM), and some chemistry of the impacting particles was determined. About half of the Apollo/Skylab hypervelocity pits were aluminum lined, and concluded to likely be man-made in origin [9]. However, since Shuttle windows are reused, they cannot be as easily examined.

Three days after the launch of STS-7, the crew reported a pit, about 4 mm in diameter, on the external surface of one of the windows. This damage exceeded safety requirements for launch and the window was replaced. Consequently, this window was examined to the same detail as were previous Apollo windows for meteoroid impacts. Energy Dispersive X-ray Analysis (EDS) was again used to determine the composition of partially fused material found in the bottom of the pit. Titanium oxide and small amounts of aluminum, carbon, and potassium were found added to the pit glass. Crater morphology places the impacting particle diameter at 0.2 mm, and a velocity between 3 km/sec and 6 km/sec. From this data, it is concluded that the particle was man-made and likely an orbiting paint fleck [10]. This is the first conclusive case where orbital debris can be shown to have caused the operational loss to a space vehicle subsystem.

Solar-Max Surfaces. Approximately 1.5 sq. met. of thermal insulation surface, and 1.0 sq. met. of aluminum louvers were returned from the Solar-Max satellite after 50 months of exposure to space at more than 500 km altitude. The thermal insulation consisted of 17 layers of aluminized Kapton, each separated by a dacron net. This type of surface has capture properties similar to the capture cell experiment on LDEF and offers an excellent opportunity to obtain chemistry of impacting particles. About 160 impacts which had penetrated the outer layer were found in 0.5 sq. met. These penetrations deposited ejecta on the following layers. Over a thousand craters were found which did not penetrate the 1st layer -- more than expected from meteoroid impacts alone. EDS analyses shows clear evidence that most of the smaller craters were produced by particles with sufficient velocity to produce melting. EDS analysis also shows that a large number of these pits contain titanium, zinc, potassium, silicon and chlorine. Except for chlorine, this chemistry corresponds to the chemistry of thermal paints currently used by NASA for space applications. Meteoroid impacts have also been identified. While analysis is far from complete, the preliminary results are finding twice as many orbital debris impacts as meteoroids, suggesting that billions of 0.1 mm debris particles are in Earth orbit [10, 11, 12].

Nearly all of the orbital debris measurements to date show an orbital debris flux which exceeds the meteoroid flux. These measurements are summarized and compared with the meteoroid flux in Chapter 7 of this volume.

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