THE SPACE DEBRIS ENVIRONMENT FOR THE ISS ORBIT

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ABSTRACT

Recent work at the Johnson Space Center has focused on updating the existing space debris models. The Orbital Debris Engineering Model (ORDEM) has been restructured to take advantage of state-of-the-art desktop computing capability and revised with recent measurements from Haystack, HAX, and Goldstone radars, additional analysis of LDEF and Space Shuttle impacts, and the most recent Space Surveillance Network catalog. The new model also contains the capability to extrapolate the current environment in time to the year 2030. A revised meteoroid model that includes the meteor showers for Earth orbit has also been developed. This paper quantifies the space debris environment for the ISS orbit from anthropogenic and natural sources. Particle flux and velocity distributions as functions of size and angle are given for particles 10 microns and larger. The environment is projected forward in time until 2030.

1. INTRODUCTION

With thirty-five planned missions over the next five years, the International Space Station (ISS) will be the focus for manned space activity. At least 6 different vehicles will transport crew and supplies to and from the nominally 400 km altitude, 51.6° inclination orbit. When completed, the ISS will be the largest space structure ever assembled and hence the largest target for space debris.

The ISS was designed with an orbital debris environment in the specifications [1] last updated in 1994. Since then, the environment has evolved and measurements of the environment have continued. Fifty-six satellite fragmentation events were recorded for the period 1990-2000 [2] and an unrecorded number of debris have re-entered. The Haystack radar has continued operations to gather additional statistical data on particles in the 1 cm to 10 cm size range [3]. Further analyses of LDEF surfaces and incorporation of Space Shuttle window impact data have provided additional information on sizes smaller than 0.1 mm. These details and others [4] have been included in a recent revision of the NASA Orbital Debris Engineering Model, ORDEM2000.

The purpose of this paper is to describe the space debris environment for the ISS for the next thirty years using the latest NASA models. Variations of the orbital debris flux with time and altitude will be presented. The directionality of the orbital debris flux in the spacecraft reference frame as a function of particle size will be given, as will the distribution of velocities for various particle sizes. The meteoroid flux for the nominal ISS orbit will be included.

2. METEOROIDS

Spacecraft in the ISS orbit will be impacted by natural space debris in the form of meteoroids. Engineering models of this environment have existed for many years, from initial models in [5] and [6] through [7] and [8] and up to [9].

Divine [10] attempted to synthesize the available interplanetary meteoroid data by modeling a series of five meteoroid families. Matney [11] integrated Divine's meteoroid families into an engineering model that includes the effects of planet gravity and for the Earth-Moon system includes a general meteor shower model. These are refinements over the existing meteoroid model in the ISS documentation. Cross-sectional flux as a function of particle diameter from this new model for the ISS orbit is shown in Fig. 1. The flux is omni directional from approximately the upper hemisphere; the Earth shields the spacecraft from the bottom. Average speed of meteoroid impact on spacecraft predicted by the model for 10^{-4} g particles is 17 km/s. Actual impact speed will vary considerably depending on particle mass and source.

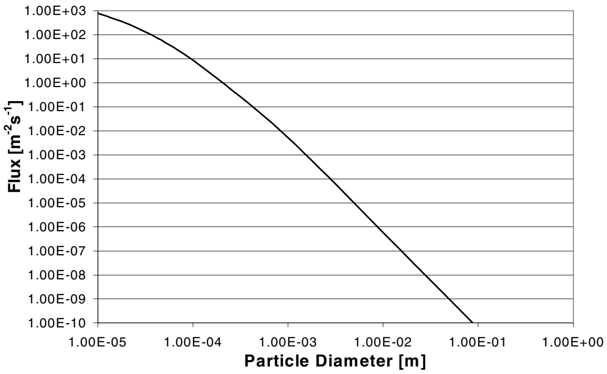

Fig. 1. Meteoroid flux.

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3. ORBITAL DEBRIS

The specified ISS design lifetime is ten years, and it is reasonable to expect the actual lifetime to extend for several years after that. The ISS will fly a constant atmospheric density flight profile, and the altitude of the ISS will vary from the nominal 400 km. Because the orbital debris environment is dynamic, a spacecraft in the ISS orbit will experience an orbital debris flux that varies with both time and altitude.

3. 1 Flux variation with time and altitude

Fig. 2 shows ORDEM2000 flux predictions for thirty years and six particle sizes. The time variation is a function of particle size. Particles smaller than 100 microns tend to have high area-to-mass ratios and de-orbit quickly. The effect of atmospheric drag and hence solar activity has a more pronounced influence on these sizes. During periods of high solar activity, the removal rate can exceed the creation rate leading to a decrease in the small particle population.

The influence of solar activity on objects larger than 10 cm is less pronounced. The population trend for these large size particles is one of slow growth increasing only slightly over thirty years.

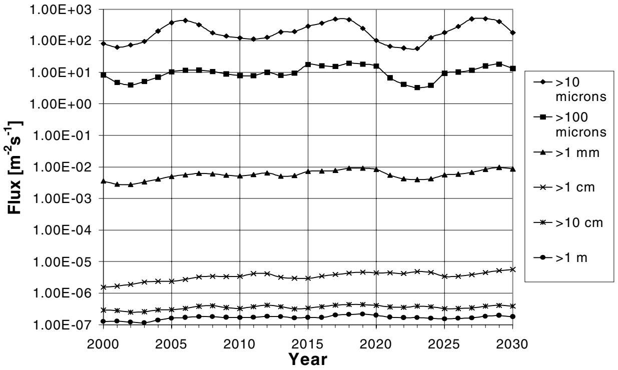

Fig. 2. Orbital debris flux variation with time.

As solar activity levels expand or relax the atmosphere, the station will fly higher or lower than its nominal 400 km altitude in order to maintain its constant density flight profile. Actual maximum and minimum altitudes will depend on specific solar activity levels. It is well known that the spatial density of orbital debris increases with increasing altitude up to about 900 km. This paper will consider variations in the orbital debris flux over the range from 350 to 450 km, a range consistent with ISS design simulations. Fig. 3 shows the year 2000 as an example of the variation in flux with altitude. The increase in flux with increasing altitude is similar at all displayed sizes, changing by a factor of 2 or 3 from lowest to highest.

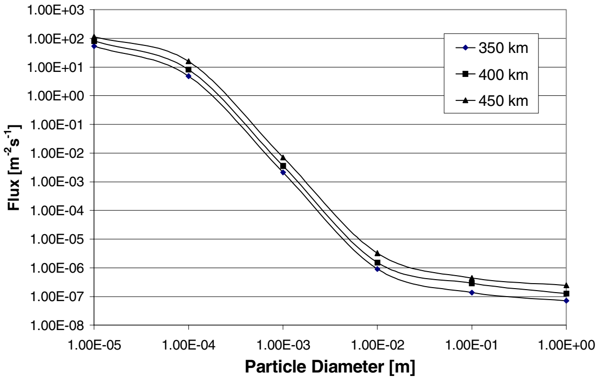

Fig. 3. Example of orbital debris flux variation with altitude.

The altitude and time variations can be combined to give an envelope of the minimum and maximum flux environments for a spacecraft in the ISS orbit. This is shown in Fig. 4. The difference between minimum and maximum values at 10 cm and 1 m is about a factor of 3, while the difference for smaller sizes is about a factor of 10.

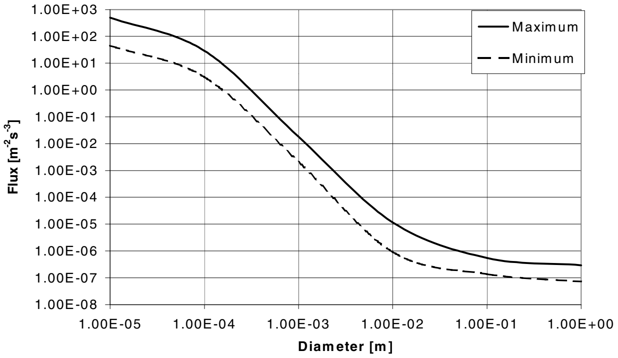

Fig.4. Variation of orbital debris flux with both time and altitude. 350 to 450 km, 2000 to 2030.

3.2 Flux variation with direction

A spacecraft in the nominal ISS orbit of 400 km altitude and 51.6° inclination is struck by debris in orbits different from its own, and this debris will impact the spacecraft from various directions. Fig. 5 shows the relationship between flux and direction for a spacecraft in the ISS orbit for the year 2000. 0° in the figure corresponds to the direction of spacecraft travel and the flux has been calculated in 10° bins with positive angles corresponding to starboard and negative to port. The graphs on the figure are ordered from smallest size particles at the top to largest at the bottom. Because the ISS orbit is circular, very little debris approaches the spacecraft out of its local horizontal plane.

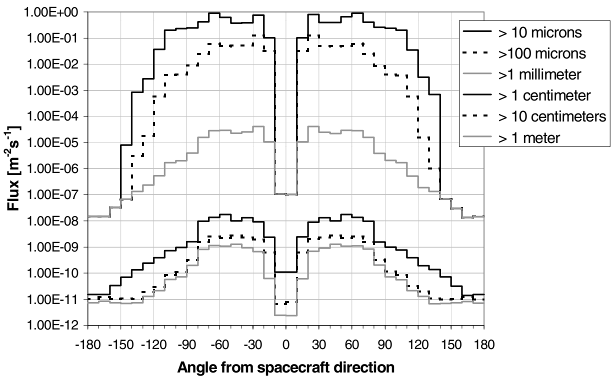

Fig. 5. Flux direction for the ISS orbit in year 2000.

The angles between which the highest flux for a particular particle size can be expected to change with size. For the >10 micron line, the spacecraft can expect fluxes within a factor of 10 from the peak from 20 to 110 degrees and from –20 to –110 degrees. The >10 centimeter line shows a flux within a factor 10 of the peak from 20 to 80 degrees and from –20 to –80 degrees. The spacecraft can be struck from behind, i.e. from angles greater than ± 90° by particles in elliptical orbits, and this is more likely with the smaller particles.

The flux varies by more than 7 orders of magnitude front to back for the >10 micron population and three orders of magnitude front to back for the >1 cm line. This implies that for a spacecraft in the ISS orbit, attitude plays a more important role in exposure to impacts for a specific surface than does either altitude or time variation of the environment.

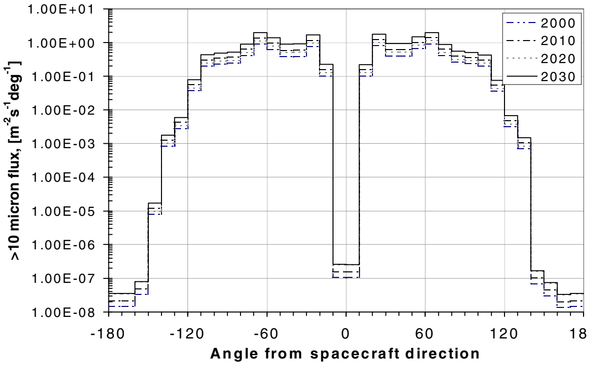

Fig. 6. Impact direction for >1 micron particles, 2000 - 2030.

Fig. 6 shows flux per degree as a function of the angle from the spacecraft velocity vector for the nominal ISS orbit. Debris flux within a factor 10 of the maximum approaches the spacecraft from 10° to 110° on each side. From least to greatest the curves are: 2000, 2020, 2010, and 2030. The yearly variations are not monotonic, but are connected to the solar cycle as noted previously in Fig.2. While the flux values change with time, the shape of the flux versus direction curve does

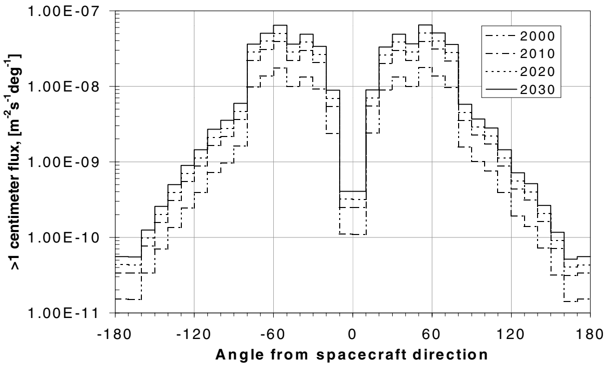

Fig. 7. Impact direction for >1centimeter particles, 2000 - 2030.

Fig. 7 shows the same type of plot for the >1cm particles. In this case, the flux does increase monotonically as these particles are more tied to the environment growth terms than the atmospheric drag. For this size range, flux levels within a factor 10 of the maximum occur from 10° to 80° on each side.

A word of caution in the interpretation of the relative minimum flux levels is appropriate. Consider a small unit area surface on the spacecraft facing directly into the velocity vector. The very low flux from 0 to 10 degrees does not mean that this surface won't receive any impacts. It means that it will receive virtually no impacts from 0 degrees incident angle and many impacts from oblique incident angles.

3.3 Impact Speed

Figs. 8 and 9 show impact speed distributions at the nominal ISS orbit for particles >1 micron and >1cm respectively for years 2000, 2010, 2020, and 2030.

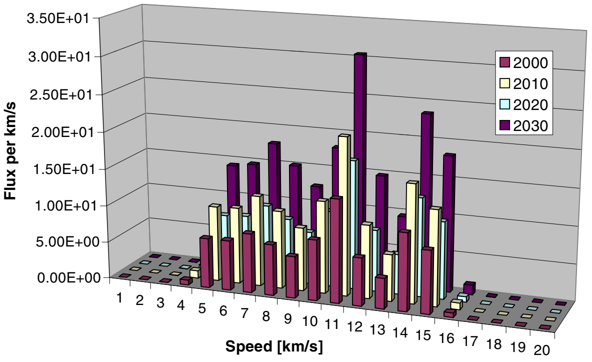

Fig. 8. Impact speed distribution for >1 micron particles

In Fig. 8, the oscillatory behavior of small debris with time is again visible, varying in each speed bin across the years. The primary peak in the distribution is at between 10 and 11 km/s with the second, lesser peak from 13 to 14 km/s. The average velocity, computed as a normalized weighted average, is 10.2 km/s. It stays

The flux of particles >1 cm shown in Fig. 9 increases monotonically with time in each velocity bin. The primary peak in the distribution is between 12 and 13 km/s with a secondary peak from 9 to 10 km/s. The average velocity for this size range, also constant, is 9.8 km/s.

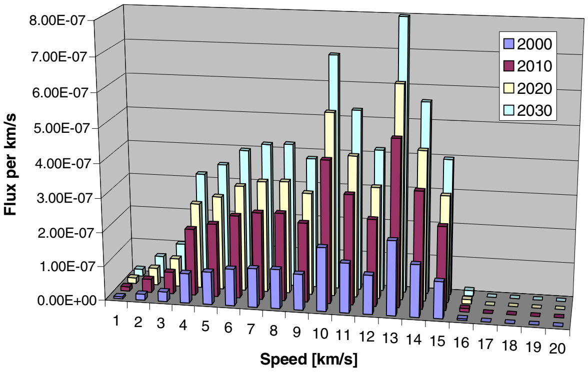

Fig.9. Impact speed distribution for >1cm particles.

4.0 SUMMARY

Table 1 summarizes the survey of results from the application of JSC Meteoroid Model and ORDEM 2000 to the ISS orbit for six different particle size ranges. Meteoroid flux values are yearly averages and can be assumed constant in time. Orbital debris minima and maxima consider variations from altitude and time. The direction range was chosen to include all angle bins with flux within a factor 10 of the maximum for that size. Velocities are weighted averages.

The values in Table 1 are sufficient for back-of-the-envelope style calculations. The intent is to provide engineers and analysts with a simple tool for quick assessments of spacecraft performance in the ISS orbit. Assessments of mission or safety critical items should be done using more sophisticated tools.

Table 1. Summary of space debris for ISS orbit.

	Meteoroid Flux [$m^{-2}s^{-1}$]	Minimum OD flux [$m^{-2}s^{-1}$]	Maximum OD flux [$m^{-2}s^{-1}$]	OD average V [km/s]	OD direction [degrees]
> 10 microns	7.91E+02	4.51 E+01	4.99 E+02	10.2	±110 to ±10
> 100 microns	8.78 E+00	3.05 E+00	2.91 E+01	11.4	±80 to ±10
> 1 mm	5.22 E-03	2.11 E-03	1.82 E-02	10.8	±80 to ±10
> 1 cm	5.92 E-07	9.12 E-07	1.15 E-05	9.8	±80 to ±10
> 10 cm	5.97 E-11	1.38 E-07	5.51 E-07	10.0	±90 to ±10
> 1 m	6.15 E-15	7.16 E-08	2.94 E-07	9.5	±90 to ±20

5.0 REFERENCES

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