

# **Conversion of Environment Files from ORDEM 3 & MEM 3 to STENVI**

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## **Abstract**

To perform Micrometeoroid and Orbital Debris (MMOD) analyses, NASA describes the orbital debris particle environment using the ORDEM 3 tool and the micrometeoroid environment using the MEM 3 tool. Both output files that detail the flux of particles as a function of several parameters. European MMOD analyses use different tools to perform similar functions, including the Meteoroid And Space debris Terrestrial Environment Reference (MASTER) environment model, which outputs flux data in the Standard Environment Interface (STENVI) format.

The NASA Johnson Space Center Hypervelocity Impact Technology Group was asked to create a converter to translate flux data from the output file formats used by ORDEM 3.x and MEM 3 into the STENVI file format. Validation was performed to ensure that the converter was reproducing the input data correctly.

The Bumper 3 MMOD risk assessment tool has a capability for reading ORDEM 3.x, MEM 3, and STENVI environment file formats and was used to compare MMOD risk results generated using the converter's output STENVI files to the risk results generated using the input ORDEM 3.x and MEM 3 igloo files. Specific point comparisons validated that the converter translated the environment data correctly, producing the intended output. However, realistic risk assessments showed that the bin methodology employed by Bumper for determining particle flux as a function of particle size when reading files in STENVI format produces much higher MMOD risk than the point-interpolation methodology used in Bumper risk assessments using ORDEM and MEM.

Modifications to how Bumper 3 reads STENVI files during analyses are considered to improve Bumper's ability to perform useful analyses with environment files in this format.

## **1 Introduction**

Micrometeoroid & Orbital Debris (MMOD) analysis relies on complex models of the micrometeoroid and orbital debris environments. In the United States, two NASA offices are responsible for research and development to create and maintain these models: the Meteoroid Engineering Model (MEM), currently on version 3, developed by the Meteoroid Environment Office at Marshall Space Flight Center; and the Orbital Debris Engineering Model (ORDEM) currently on version 3.2, developed by the Orbital Debris Program Office at Johnson Space Center. In Europe, the European Space Agency (ESA) combines these functions in the model: Meteoroid and Space Debris Terrestrial Environment Reference (MASTER). All of these models describe the particle flux dependent on the direction relative to the spacecraft, impact velocity, particle density, and particle size. However, this information is formatted differently, and in some cases the differences extend to what information is included.

The ORDEM and MEM files work with NASA's MMOD analysis tool, Bumper 3. Bumper 3 also has a limited capability to read files in the Standard Environment Interface (STENVI) format used by MASTER.

At a meeting of the Inter-Agency Space Debris Coordination Committee (IADC), NASA took an action to devise a way to convert ORDEM and MEM environment model information into the STENVI format. Thus, ESA would be able to use ORDEM and MEM model output in their MMOD analyses in the file format used by their primary environment model. This paper details the Converter, which is an Excel spreadsheet-hosted Visual Basic macro.

## **2 Conversion to STENVI Format**

The converter has two large buttons, one for converting from ORDEM 3 to STENVI and one for converting from MEM 3 to STENVI. When using the converter with either type, the user first selects the input igloo file, then names the output file to be produced.

When converting ORDEM files, the user is given the option of creating a single STENVI file containing all five populations or creating a separate STENVI file for each of the five ORDEM populations with an underscore and population number in the name. Both options result in the same content, whether in a single file or spread across five.

When converting MEM files, the user is asked whether the input file is a low- or high-density igloo file, as they must be done separately and will each get a separate STENVI file. The user is also given the option of 8 density bins for each file (8x8), the fidelity run in Bumper, or 158 density bins for each file (158x158), the maximum fidelity possible. The highest fidelity option often fails to run to completion due to the large amount of data involved, thus it is recommended to only use the 8x8 option.

The STENVI file format is keyword-driven and divided into sections. These sections will be detailed along with the sources of information for filling them out.

### **2.1 Header**

This first section is composed of the STENVI version, set at 1.0 per existing Bumper read requirements, the name of the environment model, either ORDEM 3 or MEM 3 depending on the source, and comments.

### **2.2 Mission Parameters**

An ORDEM igloo always exists for a single year, specified in the header, with flux given as particle per square meter per year—implying a one-year duration. Thus, the mission begin and end dates are filled in with the relevant year and encompass that year in its entirety. Because the micrometeoroid environment changes only over geologic time, MEM is agnostic to date, and a place-filler is printed in the STENVI file.

The orbit parameters of semimajor axis, eccentricity, and inclination are present in the ORDEM igloo header and filled out. Right ascension of the ascending node and argument of perigee are not in the ORDEM file and set to zero. Because MEM works from state vectors and not Keplerian orbits, none of the parameters are available, thus all are set to zero.

### **2.3 Definition of the output spectrum**

This section lists the number of bins and minimum and maximum values for the azimuth, elevation, velocity, diameter, latitude, and density. These numbers and values are all captured while the lists below are recorded and then filled out in this section.

## 2.4 Azimuth

The converter macro reads each row of the input file and compiles a list of every unique azimuth bin—starting- to ending-angle—in the file. That list is printed in this section, with each unique bin being assigned an ID number. The MEM azimuth values are negated at this step due to MEM measuring azimuth in the opposite direction from STENVI.

MEM uses an igloo that varies the azimuth bins at every elevation to achieve bins of a consistent solid angle all across the sky-sphere. This creates a large number of azimuth bins with overlapping limits, such as 0° to 5°, 0° to 5.14°, 0° to 6.39°, and 0° to 40° among many, each associated with different elevations.

Each azimuth is paired with an elevation to create a threat direction. It may be that every azimuth is paired with every elevation in the form of a grid. However, this is not the case when using MEM. Each azimuth is used exactly twice, once with a positive elevation and once with the complimentary negative elevation. The vast majority of azimuth-elevation pairings that are possible are never used. Which pairings are and are not used will become clear in the flux section.

## 2.5 Elevation

Like azimuth, the converter macro reads each row of the input file and compiles a list of every unique elevation bin—starting- to ending-angle—in the file. That list is printed in this section, with each unique bin being assigned an ID number.

## 2.6 Velocity

The macro reads the velocity bin on each row the ORDEM file and compiles a list of every unique velocity bin—starting- to ending-velocity—in the file. For MEM, the macro reads the column headers that list the bin-center velocities, then creates a list of bins. The bins start at zero, and each bin boundary is the mean of the read-in bin-centers for that bin and the adjacent bins. The upper limit of the final bin is set by making the bin the same width as the previous bin.

## 2.7 Diameter

For ORDEM, the input file gives flux for a set of particle diameters. STENVI requires bins, so each diameter in the ORDEM file is the beginning of a bin, and the next diameter is the end of the bin (and beginning of the next). The largest bin's ending diameter is ten times the starting diameter.

For MEM, the only relevant input is that the file is for flux of a one microgram particle. To create bins of different sizes, decades of mass are taken as bins. The first bin is from one microgram to ten micrograms, the second from ten to one hundred micrograms, through eight bins, ending at one hundred grams. These masses are then converted into diameters, assuming a sphere, for each particle density. Using eight densities in a population, this results in 64 diameter bins in the STENVI file, with only eight diameter bins relevant to each density. The diameter-density pairings are explicit in the flux section.

Note that the STENVI file operates in meters while Bumper used centimeters for particle diameter.

## 2.8 Argument of True Latitude

A standard ORDEM igloo file is for a complete orbit, thus a single argument of true latitude from 0° to 360° is always listed. Because MEM does not consider Keplerian orbits, argument of true latitude is not applicable, and a single entry from 0° to 360° is again listed to meet the need for at least one bin.

## 2.9 Density

For ORDEM, five densities are considered:

- Radar Ocean Reconnaissance Satellite (RORSAT) Sodium Potassium (NaK) droplets: 0.9 g/cc
- Low Density (LD): 1.4 g/cc
- Medium Density (MD): 2.8 g/cc
- High Density (HD): 7.9 g/cc
- Intact Satellites (Int): 2.8 g/cc

For MEM, two options are given to the user, 8x8 or 158x158. In either case, the densities are listed on the “MEM Density Bins” tab of the converter. Table 1 repeats the table for the recommended 8x8 option. The tables list the minimum and maximum values for each bin, which are printed in this section of the STENVI file. The table below also gives the portion of that population’s flux encompassed by each bin.

Table 1. MEM 3 8x8 Density Bins

| Low Density                  |      |       |         |  | High Density                 |      |       |         |
|------------------------------|------|-------|---------|--|------------------------------|------|-------|---------|
| Density (g/cm <sup>3</sup> ) |      |       | Portion |  | Density (g/cm <sup>3</sup> ) |      |       | Portion |
| Min                          | Max  | Point |         |  | Min                          | Max  | Point |         |
| 0.1                          | 0.4  | 0.25  | 0%      |  | 1.6                          | 2.4  | 2     | 2%      |
| 0.4                          | 0.65 | 0.525 | 17%     |  | 2.4                          | 3.15 | 2.775 | 18%     |
| 0.65                         | 0.9  | 0.775 | 39%     |  | 3.15                         | 3.9  | 3.525 | 36%     |
| 0.9                          | 1.15 | 1.025 | 28%     |  | 3.9                          | 4.65 | 4.275 | 28%     |
| 1.15                         | 1.4  | 1.275 | 11%     |  | 4.65                         | 5.4  | 5.025 | 12%     |
| 1.4                          | 1.65 | 1.525 | 3%      |  | 5.4                          | 6.15 | 5.775 | 4%      |
| 1.65                         | 1.9  | 1.775 | 1%      |  | 6.15                         | 6.9  | 6.525 | 1%      |
| 1.9                          | 2.15 | 2.025 | 0%      |  | 6.9                          | 7.65 | 7.275 | 0%      |

## 2.10 Flux

The converter macro reads each row of the input file and compiles a list of every flux value, along with the azimuth, elevation, and velocity, for which each parameter’s ID number is printed in this section of the STENVI file, along with the fixed latitude ID of one.

For ORDEM, each flux value is associated with a specific diameter and density, whose ID numbers are also printed in this section. The flux in the ORDEM igloo is cumulative—particles of that size or larger—while the flux in STENVI is discrete—only particles within that size bin—so when transcribing flux values into STENVI, the value entered is the value being read minus the value for the next larger size of the same azimuth, elevation, velocity, and density.

For MEM, each flux value is, for a given azimuth, elevation, and velocity, the total for the population at one microgram. For each density in that population, the converter runs through the relevant diameter bins representing decades of mass. The flux in each bin is the input value times the Grün fraction for the starting mass times that density’s portion of the total minus the input value times the Grün fraction for the ending mass times that density’s portion of the total. Like ORDEM, the subtraction converts

cumulative flux into discrete flux. The Grün fraction for a given mass is the Grün flux at that mass divided by the Grün flux at one microgram. The Grün flux is given by Eq. 1:

$$Flux = 31557600 * ((2200 * mass^{0.306} + 15)^{-4.38} + (1.3 * 10^{-9}) * (mass + 10^{11} * mass^2 + 10^{27} * mass^4)^{-0.36} + (1.3 * 10^{-16}) * (mass + 10^6 * mass^2)^{-0.85}) \quad (1)$$

The resulting flux value is printed in the STENVI file with the relevant ID numbers for each density and diameter bin pairing.

### 3 Validation

The preferred test for validating that the converter has successfully reproduced the input data in the output STENVI file is to run Bumper analyses to compare the risk result using the new STENVI file to the risk result using the original ORDEM or MEM input file.

For all analyses herein, a simple cube with edge lengths of one meter was run for one year in the environments cited. The cube was rotated by a small arbitrary amount from the default orientation of each face pointing at a cardinal direction. This was done to break up potential symmetry between threat directions as they approach various faces, thus making the exposure of each face unique and ensuring that tests of the environment's directionality were unambiguous.

To test the conversion of ORDEM, the International Space Station orbit was assessed with Bumper, both running ORDEM directly (Table 2 upper) and running a STENVI file the converter produced from the same ORDEM igloo (Table 2 middle). These tables provide the number of impacts by one-millimeter particles to each face of the cube, along with the total, for each population and the total. Table 2 bottom gives the percent differences between the ORDEM direct and STENVI results, which indicate exact agreement. The main STENVI results (left side) used a separate STENVI file for each ORDEM population, which allowed the populations to be broken out in the same manner as is done for ORDEM. A single file containing all five populations was also tested and produced an identical total risk to the five-file approach and ORDEM, though the breakout by population was not available since they were all comingled in a single file.

Table 2. ORDEM 3 /STENVI Bumper Result Comparison, One Millimeter Impacts

| Running ORDEM Directly |          |          |          |          |          |          |             |          |            |  |
|------------------------|----------|----------|----------|----------|----------|----------|-------------|----------|------------|--|
| Cube Face              | Total    | NaK      | LD       | MD       | HD       | Intact   |             |          |            |  |
| +X                     | 1.21E-02 | 0.00E+00 | 1.84E-05 | 1.62E-03 | 1.04E-02 | 1.93E-07 |             |          |            |  |
| -X                     | 7.50E-04 | 0.00E+00 | 3.06E-07 | 1.02E-04 | 6.48E-04 | 2.14E-09 |             |          |            |  |
| +Y                     | 7.54E-03 | 0.00E+00 | 7.20E-06 | 9.87E-04 | 6.54E-03 | 7.38E-08 |             |          |            |  |
| -Y                     | 9.77E-03 | 0.00E+00 | 1.08E-05 | 1.29E-03 | 8.47E-03 | 1.11E-07 |             |          |            |  |
| +Z                     | 2.56E-03 | 0.00E+00 | 3.46E-06 | 3.34E-04 | 2.22E-03 | 3.58E-08 |             |          |            |  |
| -Z                     | 5.17E-04 | 0.00E+00 | 2.04E-07 | 6.14E-05 | 4.56E-04 | 1.52E-09 |             |          |            |  |
| Total                  | 3.32E-02 | 0.00E+00 | 4.03E-05 | 4.39E-03 | 2.88E-02 | 4.17E-07 |             |          |            |  |
| Running STENVI         |          |          |          |          |          |          | Single File |          |            |  |
| Cube Face              | Total    | NaK      | LD       | MD       | HD       | Intact   | Cube Face   | Total    | Difference |  |
| +X                     | 1.21E-02 | 0.00E+00 | 1.84E-05 | 1.62E-03 | 1.04E-02 | 1.93E-07 | +X          | 1.21E-02 | 0.00%      |  |
| -X                     | 7.50E-04 | 0.00E+00 | 3.06E-07 | 1.02E-04 | 6.48E-04 | 2.14E-09 | -X          | 7.50E-04 | 0.00%      |  |
| +Y                     | 7.54E-03 | 0.00E+00 | 7.20E-06 | 9.87E-04 | 6.54E-03 | 7.38E-08 | +Y          | 7.54E-03 | 0.00%      |  |
| -Y                     | 9.77E-03 | 0.00E+00 | 1.08E-05 | 1.29E-03 | 8.47E-03 | 1.11E-07 | -Y          | 9.77E-03 | 0.00%      |  |
| +Z                     | 2.56E-03 | 0.00E+00 | 3.46E-06 | 3.34E-04 | 2.22E-03 | 3.58E-08 | +Z          | 2.56E-03 | 0.00%      |  |
| -Z                     | 5.17E-04 | 0.00E+00 | 2.04E-07 | 6.14E-05 | 4.56E-04 | 1.52E-09 | -Z          | 5.17E-04 | 0.00%      |  |
| Total                  | 3.32E-02 | 0.00E+00 | 4.03E-05 | 4.39E-03 | 2.88E-02 | 4.17E-07 | Total       | 3.32E-02 | 0.00%      |  |
| Difference             |          |          |          |          |          |          |             |          |            |  |
| Cube Face              | Total    | NaK      | LD       | MD       | HD       | Intact   |             |          |            |  |
| +X                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| -X                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| +Y                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| -Y                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| +Z                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| -Z                     | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |
| Total                  | 0.00%    | -        | 0.00%    | 0.00%    | 0.00%    | 0.00%    |             |          |            |  |

Table 3 gives the same set of results for penetrations of a Whipple shield made of a 0.1 cm Al6061-T6 bumper stood off by 10 cm from a 0.3 cm Al6061-T6 rear wall. In this case, the STENVI-based Bumper run results in far more risk, except for the intact population, which produces exactly the same result as the direct ORDEM run.

Table 3. ORDEM 3 /STENVI Bumper Result Comparison, Whipple Shield Penetrations

| Running ORDEM Directly |           |          |          |          |           |          |
|------------------------|-----------|----------|----------|----------|-----------|----------|
| Cube Face              | Total     | NaK      | LD       | MD       | HD        | Intact   |
| +X                     | 1.89E-05  | 0.00E+00 | 6.76E-07 | 1.25E-05 | 5.49E-06  | 1.93E-07 |
| -X                     | 1.30E-06  | 0.00E+00 | 8.51E-09 | 2.41E-07 | 1.05E-06  | 2.14E-09 |
| +Y                     | 6.84E-05  | 0.00E+00 | 2.03E-07 | 5.65E-06 | 6.25E-05  | 7.38E-08 |
| -Y                     | 6.68E-05  | 0.00E+00 | 2.96E-07 | 7.53E-06 | 5.89E-05  | 1.11E-07 |
| +Z                     | 2.22E-06  | 0.00E+00 | 5.93E-08 | 1.69E-06 | 4.34E-07  | 3.58E-08 |
| -Z                     | 1.38E-07  | 0.00E+00 | 4.53E-09 | 9.10E-08 | 4.09E-08  | 1.52E-09 |
| Total                  | 1.58E-04  | 0.00E+00 | 1.25E-06 | 2.77E-05 | 1.28E-04  | 4.17E-07 |
|                        |           |          |          |          |           |          |
| Running STENVI         |           |          |          |          |           |          |
| Cube Face              | Total     | NaK      | LD       | MD       | HD        | Intact   |
| +X                     | 1.02E-02  | 0.00E+00 | 1.83E-06 | 2.12E-05 | 1.02E-02  | 1.93E-07 |
| -X                     | 4.18E-04  | 0.00E+00 | 2.95E-08 | 1.89E-05 | 3.99E-04  | 2.14E-09 |
| +Y                     | 6.56E-03  | 0.00E+00 | 7.30E-07 | 8.48E-05 | 6.47E-03  | 7.38E-08 |
| -Y                     | 8.48E-03  | 0.00E+00 | 1.09E-06 | 7.61E-05 | 8.41E-03  | 1.11E-07 |
| +Z                     | 2.03E-03  | 0.00E+00 | 3.45E-07 | 3.42E-06 | 2.03E-03  | 3.58E-08 |
| -Z                     | 2.20E-04  | 0.00E+00 | 2.00E-08 | 2.57E-07 | 2.20E-04  | 1.52E-09 |
| Total                  | 2.79E-02  | 0.00E+00 | 4.04E-06 | 2.05E-04 | 2.77E-02  | 4.17E-07 |
|                        |           |          |          |          |           |          |
| Difference             |           |          |          |          |           |          |
| Cube Face              | Total     | NaK      | LD       | MD       | HD        | Intact   |
| +X                     | 541.81 x  | -        | 2.71 x   | 69.46%   | 1858.62 x | 0.00%    |
| -X                     | 320.84 x  | -        | 3.46 x   | 78.58 x  | 379.58 x  | 0.00%    |
| +Y                     | 95.86 x   | -        | 3.59 x   | 15.01 x  | 103.58 x  | 0.00%    |
| -Y                     | 126.97 x  | -        | 3.67 x   | 10.11 x  | 142.77 x  | 0.00%    |
| +Z                     | 916.43 x  | -        | 5.83 x   | 2.03 x   | 4667.17 x | 0.00%    |
| -Z                     | 1594.55 x | -        | 4.41 x   | 2.82 x   | 5373.29 x | 0.00%    |
| Total                  | 177.11 x  | -        | 3.24 x   | 7.38 x   | 216.00 x  | 0.00%    |

The reason for the difference is in how flux relates to diameter. In ORDEM, the flux is provided for a set of fiducial points (specific diameters) and non-linear interpolation is used to determine the flux for the critical diameter calculated by Bumper's Response module. This is represented by the blue line in Figure 1, which graphs particle flux in log space as a function of diameter. In the present application of a STENVI file to Bumper, any diameter within a diameter bin is assessed as having the same flux, which is set by the smallest diameter in the bin. This is indicated by the red stair-step line in the figure. Therefore, using STENVI in this way, the flux of 2 mm particles is the same as the flux of 1 mm particles (next lower fiducial point), but for ORDEM, Bumper interpolates a much lower flux for 2 mm particles based on the surrounding fiducial points. The one-millimeter impact result matched exactly because that fixed critical diameter is a fiducial point that sets the flux for the rest of the STENVI bin—in terms of the graph, the diameter used was one of the points where the red and blue lines meet. The intact population continues to give exact results because the critical diameter for this Whipple shield is always

less than 2 cm and the intact population is entirely larger than 3 cm; thus, all of the flux is captured in higher bins that would be included equally regardless of the treatment of the bin containing the critical diameter.

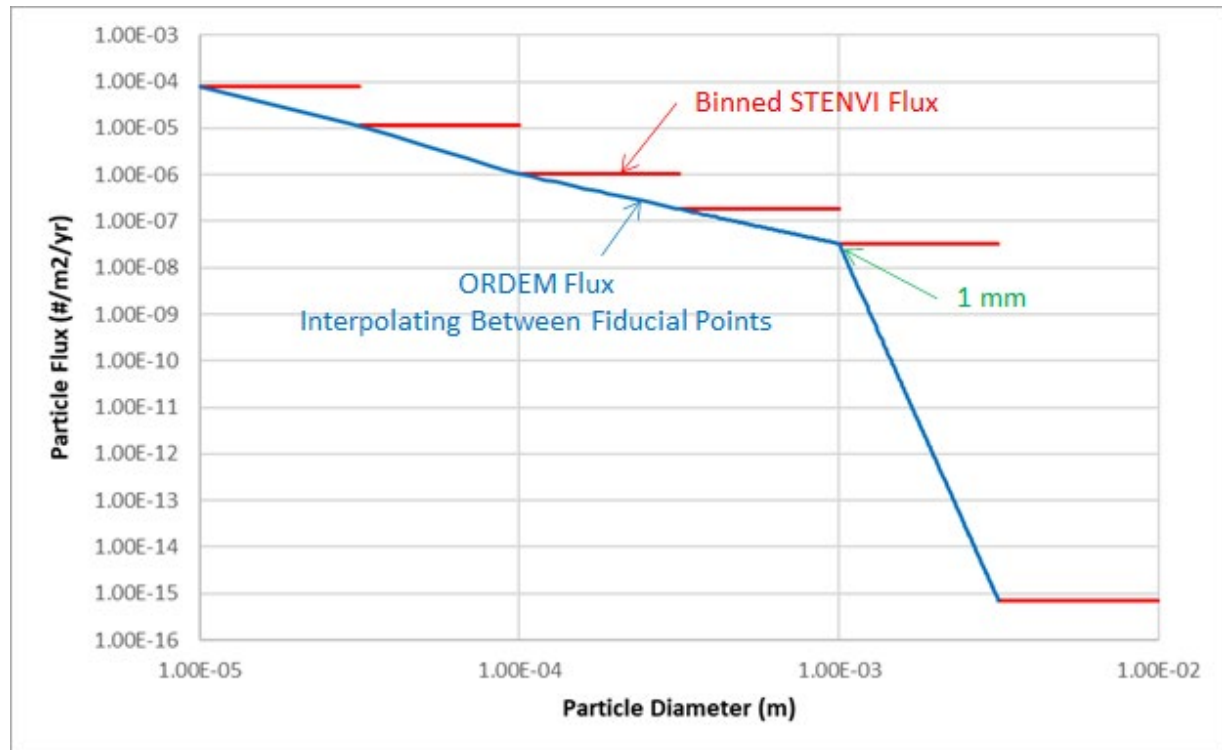


Figure 1. ORDEM 3 & STENVI Methods of Considering Flux vs. Particle Diameter

The same phenomena can be seen in a comparison between using MEM directly and a STENVI conversion of MEM. Table 4 reports the results for the cube placed in a Near-Rectilinear Halo Orbit around the Moon. On the left is the risk of impact by a fixed one milligram particle—because MEM's flux is based on mass, a fixed mass rather than fixed diameter was used. The one milligram is on a fiducial point, thus the results match very closely. On the right is the number of penetrations of the same Whipple shield as above. Again, STENVI produces a much higher risk because it draws flux from a bin based on the lowest fiducial point in the bin, while for MEM, Bumper uses the Grün formulation to determine the flux for the specific critical particle size being addressed.

Table 4. MEM 3 /STENVI Bumper Result Comparison, 1 mg Impacts & Whipple Shield Penetrations

| One Milligram Impacts |          |          |          | Whipple Shield Penetrations |          |          |          |
|-----------------------|----------|----------|----------|-----------------------------|----------|----------|----------|
| Running MEM Directly  |          |          |          | Running MEM Directly        |          |          |          |
| Cube Face             | Total    | LD       | HD       | Cube Face                   | Total    | LD       | HD       |
| +X                    | 8.48E-04 | 4.17E-04 | 4.31E-04 | +X                          | 4.12E-05 | 3.78E-05 | 3.37E-06 |
| -X                    | 1.37E-04 | 2.15E-05 | 1.15E-04 | -X                          | 2.74E-07 | 3.22E-08 | 2.42E-07 |
| +Y                    | 7.84E-04 | 9.83E-05 | 6.86E-04 | +Y                          | 1.51E-05 | 7.92E-07 | 1.43E-05 |
| -Y                    | 9.25E-04 | 1.76E-04 | 7.49E-04 | -Y                          | 2.45E-05 | 2.74E-06 | 2.17E-05 |
| +Z                    | 4.90E-04 | 2.83E-04 | 2.07E-04 | +Z                          | 1.05E-05 | 9.70E-06 | 7.57E-07 |
| -Z                    | 3.63E-04 | 2.12E-04 | 1.51E-04 | -Z                          | 3.98E-06 | 3.52E-06 | 4.66E-07 |
| Total                 | 3.55E-03 | 1.21E-03 | 2.34E-03 | Total                       | 9.55E-05 | 5.46E-05 | 4.09E-05 |
| Running STENVI        |          |          |          | Running STENVI              |          |          |          |
| Cube Face             | Total    | LD       | HD       | Cube Face                   | Total    | LD       | HD       |
| +X                    | 8.49E-04 | 4.17E-04 | 4.32E-04 | +X                          | 2.56E-04 | 2.38E-04 | 1.84E-05 |
| -X                    | 1.35E-04 | 2.12E-05 | 1.14E-04 | -X                          | 1.63E-06 | 1.61E-07 | 1.47E-06 |
| +Y                    | 7.84E-04 | 9.81E-05 | 6.86E-04 | +Y                          | 4.86E-05 | 3.71E-06 | 4.49E-05 |
| -Y                    | 9.25E-04 | 1.76E-04 | 7.49E-04 | -Y                          | 1.88E-04 | 1.43E-05 | 1.74E-04 |
| +Z                    | 4.91E-04 | 2.83E-04 | 2.08E-04 | +Z                          | 9.07E-05 | 8.44E-05 | 6.34E-06 |
| -Z                    | 3.63E-04 | 2.12E-04 | 1.51E-04 | -Z                          | 1.83E-05 | 1.44E-05 | 3.95E-06 |
| Total                 | 3.55E-03 | 1.21E-03 | 2.34E-03 | Total                       | 6.04E-04 | 3.55E-04 | 2.49E-04 |
| Difference            |          |          |          | Difference                  |          |          |          |
| Cube Face             | Total    | LD       | HD       | Cube Face                   | Total    | LD       | HD       |
| +X                    | 0.07%    | -0.03%   | 0.17%    | +X                          | 6.22 x   | 6.29 x   | 5.46 x   |
| -X                    | -0.81%   | -1.47%   | -0.68%   | -X                          | 5.94 x   | 4.99 x   | 6.06 x   |
| +Y                    | -0.05%   | -0.20%   | -0.03%   | +Y                          | 3.21 x   | 4.68 x   | 3.13 x   |
| -Y                    | -0.01%   | -0.09%   | 0.01%    | -Y                          | 7.70 x   | 5.23 x   | 8.02 x   |
| +Z                    | 0.11%    | 0.09%    | 0.14%    | +Z                          | 8.68 x   | 8.70 x   | 8.37 x   |
| -Z                    | 0.06%    | 0.10%    | 0.01%    | -Z                          | 4.60 x   | 4.09 x   | 8.47 x   |
| Total                 | -0.01%   | -0.03%   | 0.00%    | Total                       | 6.32 x   | 6.50 x   | 6.09 x   |

In the comparison above, the one-milligram impact results were close but not an exact match, unlike the ORDEM one-millimeter comparison, which was exact. Table 5 shows the result of a comparison between a MEM file and its converted STENVI file that used a smaller, simpler igloo. The results do match exactly. This validates that the MEM density, diameter, and flux conversion is happening exactly as intended. The difference must lie in the MEM igloo itself.

Table 5. MEM 3 (Special Igloo) /STENVI Bumper Result Comparison, One Milligram Impacts

| Running MEM Directly |          |          |          | Running STENVI |          |          |          | Difference |       |       |       |
|----------------------|----------|----------|----------|----------------|----------|----------|----------|------------|-------|-------|-------|
| Cube Face            | Total    | LD       | HD       | Cube Face      | Total    | LD       | HD       | Cube Face  | Total | LD    | HD    |
| +X                   | 1.15E-04 | 5.74E-05 | 5.74E-05 | +X             | 1.15E-04 | 5.74E-05 | 5.74E-05 | +X         | 0.00% | 0.00% | 0.00% |
| -X                   | 1.15E-04 | 5.74E-05 | 5.74E-05 | -X             | 1.15E-04 | 5.74E-05 | 5.74E-05 | -X         | 0.00% | 0.00% | 0.00% |
| +Y                   | 7.70E-05 | 3.85E-05 | 3.85E-05 | +Y             | 7.70E-05 | 3.85E-05 | 3.85E-05 | +Y         | 0.00% | 0.00% | 0.00% |
| -Y                   | 7.70E-05 | 3.85E-05 | 3.85E-05 | -Y             | 7.70E-05 | 3.85E-05 | 3.85E-05 | -Y         | 0.00% | 0.00% | 0.00% |
| +Z                   | 9.66E-05 | 4.83E-05 | 4.83E-05 | +Z             | 9.66E-05 | 4.83E-05 | 4.83E-05 | +Z         | 0.00% | 0.00% | 0.00% |
| -Z                   | 9.62E-05 | 4.81E-05 | 4.81E-05 | -Z             | 9.62E-05 | 4.81E-05 | 4.81E-05 | -Z         | 0.00% | 0.00% | 0.00% |
| Total                | 5.76E-04 | 2.88E-04 | 2.88E-04 | Total          | 5.76E-04 | 2.88E-04 | 2.88E-04 | Total      | 0.00% | 0.00% | 0.00% |

#### 4 Conclusion

A converter was created that converts ORDEM 3 and MEM 3 igloo files into the STENVI format. Converter operation has been validated via carefully selected Bumper runs matching the risk resulting from these new STENVI files to the risk resulting from the input igloo files. In realistic testing, however, the STENVI files result in substantially higher MMOD risk according to Bumper because flux values are assigned to all particle sizes in diameter bins, while Bumper considers ORDEM and MEM flux with much more precision regarding the intended particle diameter.

This issue is an aspect of Bumper operation with the STENVI file format. This issue is specific to running the STENVI file format and does not apply to Bumper assessments using ORDEM and MEM. ESABASE2 may avoid this issue by using interpolation schemes similar to Bumper's.

Within Bumper, applying the same techniques used with ORDEM and MEM is possible. It would require the STENVI option to branch into different procedures based on whether the STENVI file has its origins in ORDEM or MEM—the interpolation methods for those environments is very different—which is possible since the converter prints the origin in the STENVI file.

Another potential approach is to use much smaller diameter bins. This is easily possible with MEM, however, it will cost file size and run time. With ORDEM, this is more complicated because the diameter bins and flux relationship are specified in the ORDEM igloo—the converter reports all the data it has access to. Using Bumper's interpolation scheme to add new data points between the data points provided is plausible, again costing file size and run time.

Converted files from both ORDEM and especially MEM have possible combinations of azimuth and elevation bins that are not used. These combinations never come up in the flux dataset. Bumper handles this with defaulting to zero flux for any unused azimuth-elevation combination. Other analysis programs will need to address this situation similarly.

The converter is available for use as needed. While Bumper is currently capable of reading the converter output files, modifications to the Bumper code need to be made before such environment files could be used effectively.

#### 5 References

1. NASA/TP-2019-220448. NASA Orbital Debris Engineering Model ORDEM 3.1 – Software User Guide. Orbital Debris Program Office. December 2019.
2. NASA Meteoroid Engineering Model (MEM) version 3. A.V. Moorhead. July 2019.
3. Software User Manual – MASTER, Revision 1.2. European Space Agency. April 2020.
4. ARESCR-BMPCORE-15-003. STENVI version 1 file specification. Michael Bjorkman. March 2015.