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Bumper 3 Software User Manual

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1.0 Introduction

1.1 Intended Readership

This *Bumper 3* code software user manual is intended for all specialty engineering analysts tasked with determining the risk of a mission-ending impact by a micrometeoroid or orbital debris (MMOD) particle for a spacecraft in Earth orbit.

1.2 Applicability Statement

This software user manual applies to edition BUMPER3-LITE-3.0

1.3 Purpose

The *Bumper 3* code determines the risk of MMOD impact ending the mission of an Earth orbiting spacecraft. The *Bumper 3* code is used to aid developing requirements during the systems requirement phase and to assess spacecraft designs during the development phase.

This document is the user manual for the *Bumper 3* code software and it provides sufficient instructions to operate the *Bumper 3* code.

1.4 Purpose

The new user will want to read Section 2.0, Overview, for an introduction to the *Bumper 3* code tasks. Installation instructions are given in Section 3.0, Software Installation. The new user will then want to run through the probability of penetration task tutorial in Section 4.0 to familiarize themselves with the basic features. The operating instructions for all of the features of the *Bumper 3* code are given in Section 5.0.

Users familiar with prior versions of BUMPER-II will want to read Section 2.2 for a list of the changes and new features. Instructions for using the new features are given in Section 5.0.

1.5 Related Documents

The *Bumper 3* code software project documentation is listed in Figure 1.

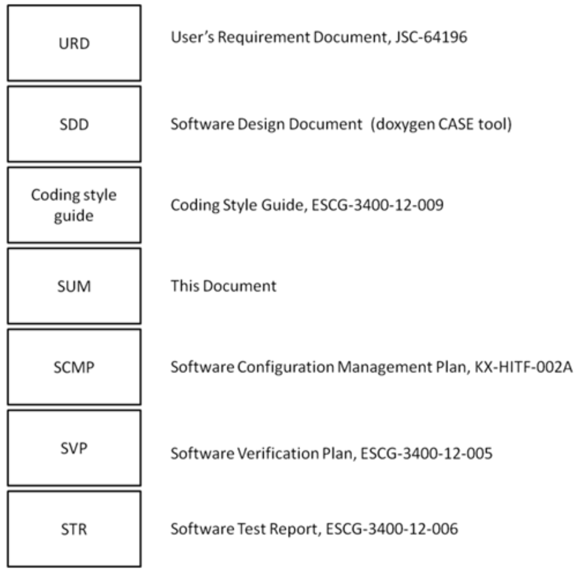


Figure 1. BUMPER software project documentation.

The BUMPER software project documentation was tailored for a small legacy project. The user requirements document, this software user manual, and the software design documentation produced from the *doxygen* computer-aided software engineering tool [1] are the sole design and use information for the *Bumper 3* code software project.

1.6 Conventions

This report uses the following typographical conventions:

1. Italic
   Used in the text paragraphs for email addresses, URLs, filenames, and pathnames. For example:
   Debris Program Office, *http://orbitaldebris.jsc.nasa.gov/model/engrmodel.html*,
2. Constant width
   Used in the text paragraphs for the output from commands, and to designate modules, methods, statements, and commands. For example:
   Change directory to the working directory using `cd $ENV:B3LITEWD`.
3. Constant width with gray paragraph background
   Used for code blocks listing the contents of files. For example:

```
BUMPER3-LITE 3.0.0505.0    *** S H I E L D ***    08-MAY-2014 08:28:25.980
LAST COMMIT DATE: 2014/05/01 15:50:06 STATE OF CURRENT EXE: Modified

SHIELD MODULE SUMMARY FILE

M I C R O - M E T E O R O I D    A N A L Y S I S
```

4. Constant width bold
   Used in code blocks to show commands or text that would be typed by the user. For example:

```
#> ORDEM2K2BII EXAMPLE9\EXAMPLE9.TXT
```

1.7 Problem Reporting Instructions

Fill out a software problem report using the template in Appendix B and email the report to *JSC-BumperSupport@nasa.gov*.

2.0 Overview

2.1 Typical Analysis Flow

Earth orbital spacecraft typically are required to function with a specified reliability in the MMOD environment. Robotic spacecraft may be required to not exceed a minimum probability of loss of critical function, such as the spacecraft failing to enter the desired disposal orbit. Crewed spacecraft typically are required to exceed a specified probability of mission success. These MMOD requirements are commonly verified by an analysis using *the Bumper 3* code.

The verification analysis flow is represented below by Figure 2 with *the Bumper 3* code at the center of the figure composed of three program units, the spacecraft self-shadowing database (GEOMETRY), ballistic limit equations (RESPONSE), and the MMOD environment models and probability of no failure calculation (SHIELD). The inputs to the SHIELD program unit are the spacecraft operating parameters (trajectory and orientation), the spacecraft self-shadowing database of exposed elements and the ballistic limit equations. If the design passes the requirements, then the analysis is done, else the design needs to be iterated. Design iterations typically involve revising the shield design, verifying with impact testing, and developing new ballistic limit equations.

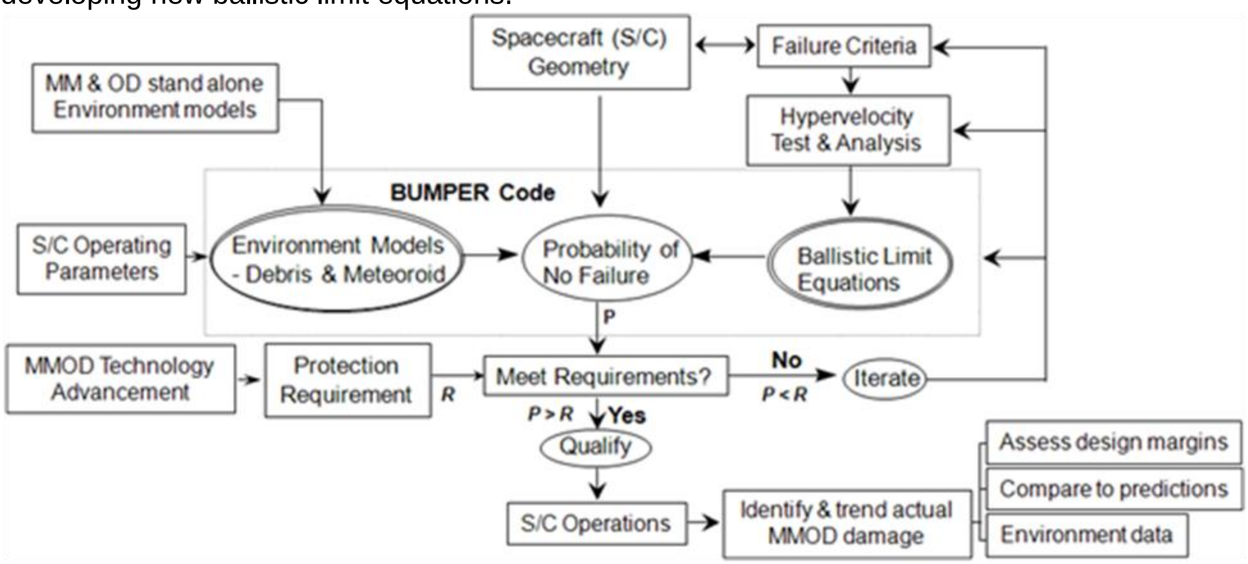


Figure 2. Design verification flow using the *Bumper 3* code.

As mentioned above, the analyst uses the *Bumper 3* code to calculate the probability of no penetration (PNP) of a spacecraft by man-made Earth orbital debris and/or micrometeoroids. The analyst models the exterior of the spacecraft with surface finite elements and then uses the *Bumper 3* code to apply the MMOD environments. The environments are approximated by a large, but finite, number of discrete threat directions and the *Bumper 3* code sums up the probability of each portion of the spacecraft being struck and perforated by MMOD particles approaching from that direction. This approach can be used to analyze any spacecraft shielding configuration that can be modeled as surfaces.

The advantages of this approach include:

- Shadowing of one portion of the spacecraft from the MMOD threat by another portion of the spacecraft (referred to as spacecraft self-shadowing).
- The ability to analyze multiple shield configurations across the spacecraft exterior.
- The ability to determine the effect from changing spacecraft orientation and altitude.

The assessment process begins by building a finite element model (FEM) of the spacecraft, which defines the size and shape of the spacecraft as well as the locations of the various shielding configurations. This model is built using the NX I-deas software package from Siemens product lifecycle management software. The FEM is constructed using triangular and quadrilateral elements that define the outer shell of the spacecraft. The *Bumper 3* code uses the model file to determine the geometry of the spacecraft for the analysis.

The next step of the process is to identify the ballistic limit characteristics for the various shield types. These ballistic limits define the critical size particle that will penetrate a shield at a given impact angle and impact velocity. When the finite element model is built, each individual element is assigned a property identifier (PID) to act as an index for its shielding properties.[1] Using the ballistic limit equations (BLEs) built into the *Bumper 3* code, the shield characteristics are defined for each and every PID in the model.

The final stage of the analysis is to determine the PNP on the spacecraft. This is done using the MMOD environment definitions that are built into the *Bumper 3* code. These engineering models take into account orbit inclination, altitude, attitude, and analysis date to predict an impacting particle flux on the spacecraft. Using the geometry and shielding characteristics previously defined for the spacecraft and combining that information with the environment model calculations, the *Bumper 3* code calculates a PNP for the spacecraft.

2.2 Features New to *Bumper 3*

The following features are new to the *Bumper 3* code:

1. The *Bumper 3* code is now distributed as an MS Windows installer package.
2. The MS Windows installer adds the *Bumper 3* code to the path so that it is possible to execute the *Bumper 3* code from any folder at the command prompt.
3. The Windows installer now places the environment files in the user's *%LOCALAPPDATA%* folder where one copy of the environment files is maintained for all calculations, for increased data security.
4. It's now possible to recompile the code as a 64-bit application.
5. The *Bumper 3* code now reads a runtime control file at startup to initialize some variables.
6. The .GEM file was restructured so that each threat is a record. Only one threat is loaded into memory at a time, thereby decreasing the memory footprint. Much larger models

---

[1] Each range of elements sharing a common shield configuration is assigned the same PID. A typical BUMPER finite element model has many more elements than PIDs.

(>800,000 elements) can now be analyzed with a 32-bit application running in a 32-bit operating system (OS).

7. GEOMETRY can now process universal files with non-consecutively numbered PIDs.
8. The SSP 30425 orbital debris (OD) and ORDEM 2000 environment .GEM files are now independent of the altitude and orbit inclination, just as it is/was for the ORDEM 3, Meteoroid Environment Office Meteoroid Engineering Model (MEMCxP) and MEMR2 .GEM files. The SSP 30425 micrometeoroid (MM) .GEM file is still dependent on the altitude.
9. The International Space Station (ISS) style *mat.prp* header is now used across all versions.
10. The global DEGCUT was removed from the code for increased data security. DEGCUT is now set by each BLE.
11. VBETA calculations are now allowed for both orbital debris and micrometeoroid environments.
12. The ORDEM 2000 environment option in SHIELD can now read an environment file produced by the program *ordem2k2bii*, thereby bypassing the lengthy environment calculation in SHIELD. The program *ordem2k2bii* can calculate environments for elliptical orbits as well as circular orbits, unlike the *Bumper 3* code ORDEM 2000 calculation option that only calculates the environment for circular orbits.
13. The ORDEM 3 orbital debris environment was added to all versions of the *Bumper 3* code.
14. The MEMR2 micrometeoroid environment was added to all version of the *Bumper 3* code.

2.3 *Bumper 3* Code Limitations

The following are the array size limits to *BUMPER3-LITE* version 3.0:

1. No more than 5000 distinct PIDs in the universal file.
2. The largest PID number in the universal file must be less than 25,000.
3. No more than 5,000 element ranges in the SHIELD summary file.
4. No element can belong to more than 20 element ranges.
5. No more than 25 materials in the *MAT.PRP* file.
6. Environments cannot be summed over more than 45 years.
7. No more than 500 BLEs in the RESPONSE user interface.

The following are limitations to the code applicability due to the assumptions from which the MMOD environments were derived (See Table 1 for a summary of the altitude limitations.):

1. The spacecraft must be in a circular orbit about the Earth for the SSP 30425 MMOD environments. The altitude must be below 2000 km for the orbital debris option and below 300,000 km for the micrometeoroid option.
2. The spacecraft must be in a circular closed orbit for the ORDEM 2000 environment option when calculated by the *Bumper 3* code. The orbital altitude must be less than 2,000 km.
3. The spacecraft may be in a circular closed or a closed or partial orbit when ordem2k2bii.exe is used to calculate and ORDEM 2000 environment file to be read by the *Bumper 3* code. The apogee may be any value.

4. The spacecraft must be in a circular or elliptical closed orbit with apogee less than 40,000 km for the ORDEM 3 environment.
5. The spacecraft must be in any closed or open orbit around the Earth for the MEMCxP environment, provided it gets no closer than 66,000 km to the Moon and no further than 925,000 km from the Earth.
6. The spacecraft must be in any closed or open orbit around the Moon for the LunarMEM environment, provided the orbit gets no further than 66,000 km from the Moon.
7. MEMR2 can analyze orbits around the Earth and Moon with the same limitations as MEMCxP and LunarMEM and can also analyze closed or open orbits around the sun with perihelion above 0.2 AU and aphelion below 2 AU.

Table 1. Altitude Limitations on the MMOD Environment Models

Environment	Central body	Minimum altitude (km)	Maximum Altitude (km)
SSP 30425 OD	Earth	100	2000
ORDEM 2000	Earth	200	2000
ORDEM 3	Earth	100	40,000
SSP 30425 MM	Earth	100	300,000
MEMCxP	Earth	0	925,000
LunarMEM	Moon	0	66,000

The following are limitations to the code applicability due to assumptions made during the design of the *Bumper 3* code:

1. The spacecraft geometry must be described by a finite element model using triangular or quadrilateral elements and saved using the I-deas universal file format.
2. The spacecraft must fly with its orientation fixed with respect to its velocity vector; i.e., a fixed attitude in the velocity-normal-conormal (VNC) coordinates system. For a spacecraft in a circular Earth orbit, this is equivalent to a gravity gradient stabilized attitude such as maintained by the ISS.
3. The *Bumper 3* code only considers orbital debris impacts by particles of one shape and yaw.
4. The *Bumper 3* code cannot be used to determine the vulnerability of components shadowed by objects that have a nonzero probability of perforation, such as service module fuel tanks enclosed by the service module radiator. The *Bumper 3* code design assumes that all shadowed objects cannot be impacted.
5. Shield standoff should not be more than 5% of the length of the shielded object or else the rear wall effective cross sectional area will be miscalculated.

2.4 Environment Recommendations

The ORDEM 3 orbital debris environment and the MEMR2 micrometeoroid environment are recommended for all new analyses. The programs used to generate the environment files for the ORDEM 3 and the MEMR2 environments are not provided with the *Bumper 3* code. See the end of Section 3.1 for further details.

The SSP 30425 orbital debris and micrometeoroid environments are included for comparisons with the ISS original design requirements. The ORDEM 2000 orbital debris environment is included for comparisons with the requirements for the more recent ISS modules.

The ORDEM 2000 orbital debris environment and the MEMCxP and LunarMEM micrometeoroid environments are included for comparisons with the Orion Multi-Purpose Crew Vehicle (MPCV) design requirements.

Note that ORDEM 2000 is no longer available from the NASA Orbital Debris Program Office and MEMCxP and LunarMEM are no longer available from the NASA Meteoroid Environment Office.

3.0 Software Installation

The *Bumper 3* code is now distributed as a Windows msi file that installs in the user's account. The procedure for installing the package is described in the Section 3.1. Things to consider when upgrading from BUMPER-II are described in Section 3.2.

3.1 Installing the Windows Executable

The *Bumper 3* code executable for Microsoft Windows is distributed as a Windows installer (msi) package. It does not require administrator privileges to install. However, it will only install to Windows 7 or above. It will not install on Windows XP. Installation of the *Bumper 3* code begins with copying the msi package to your desktop and then double clicking on the msi package desktop icon.

This brings up the welcome dialog shown in Figure 3. Click "Next" to continue or "Cancel" to exit installation.

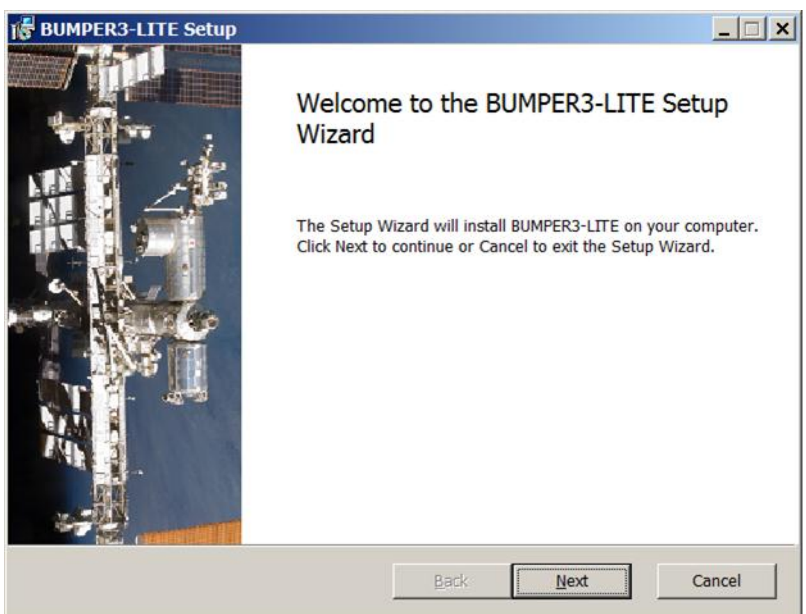


Figure 3. *BUMPER3-LITE* installer welcome dialog.

This brings up the "Custom Setup" dialog. The user may select whether to install the "Examples" feature from this dialog and browse to a custom folder location in which to install the examples. The "Executable and Files" feature is not user selectable; it installs by default. (The user reading this manual will want to install the “Examples” feature. However, for reference, if the advanced user desires to not install the “Examples” feature, select the feature and click the drop down arrow. This brings up the drop down list shown in Figure 4. Click on the red “X”. Then click “Next”.)

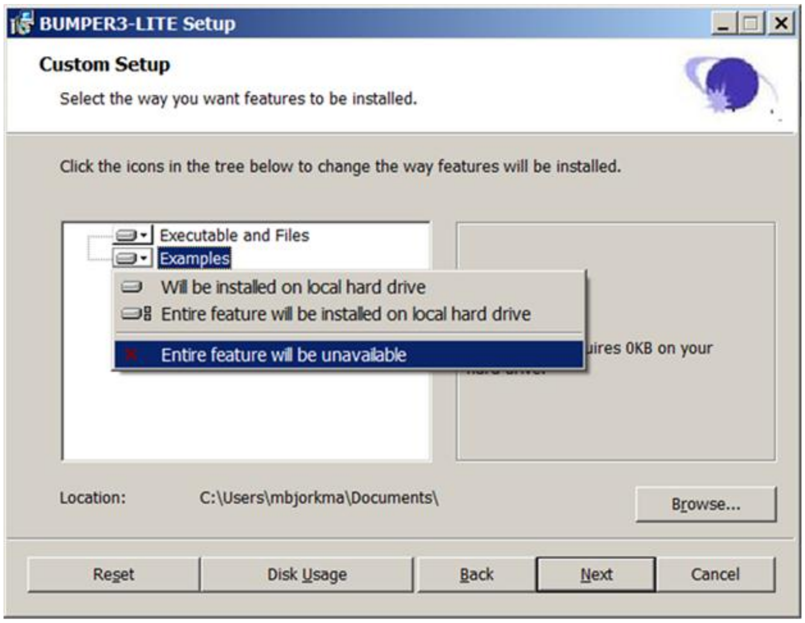


Figure 4. *BUMPER3-LITE* custom dialog feature selection.

To install the “Examples” feature and change the install location select the “Examples” feature and click the “Browse…” button, as shown in Figure 5.

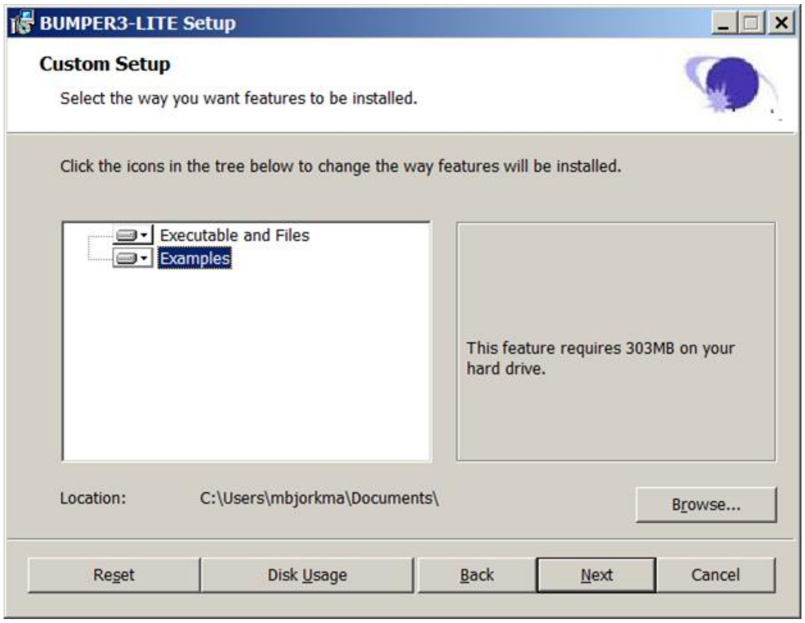


Figure 5. *BUMPER3-LITE* custom dialog feature selection.

This brings up the edit dialog shown in Figure 6 that prompts for the folder path for the example files installation. By default, the installer will create a *NASA HVIT\BUMPER3-LITE* subfolder in your My Documents folder and install the example files in *My Documents\NASA HVIT\BUMPER3-LITE*. If that path is acceptable click the "Next" button.

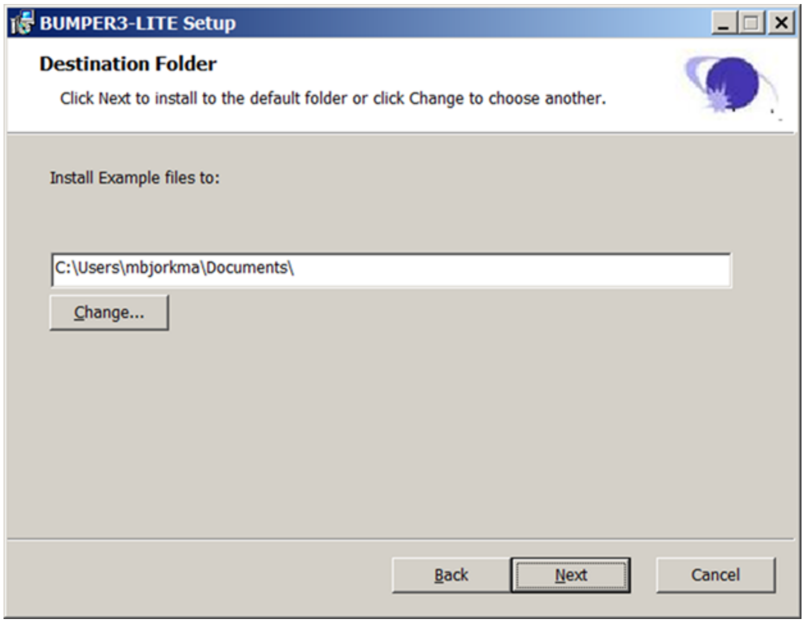


Figure 6. *BUMPER3-LITE* installer install folder dialog.

If you desire to install the examples in a different folder, then click on the "Change…" button. This brings up the folder browser dialog shown in Figure 7. Browse to the desired folder; *D:\My Documents* in the dialog shown. Click the "OK" button to accept the folder selection.

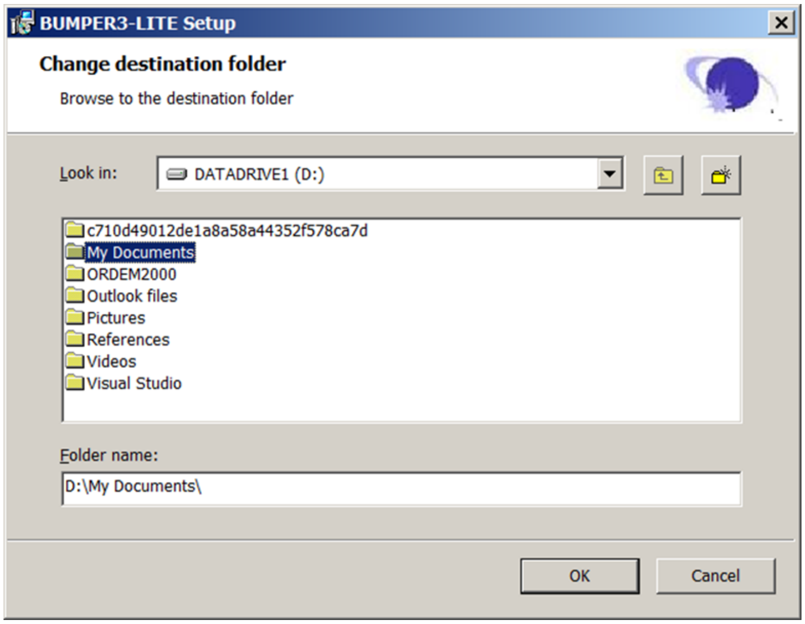


Figure 7. *BUMPER3-LITE* installer change destination folder browser dialog.

After changing the folder path, you're returned to the install folder dialog, as shown in Figure 8. Click "Next" to continue.

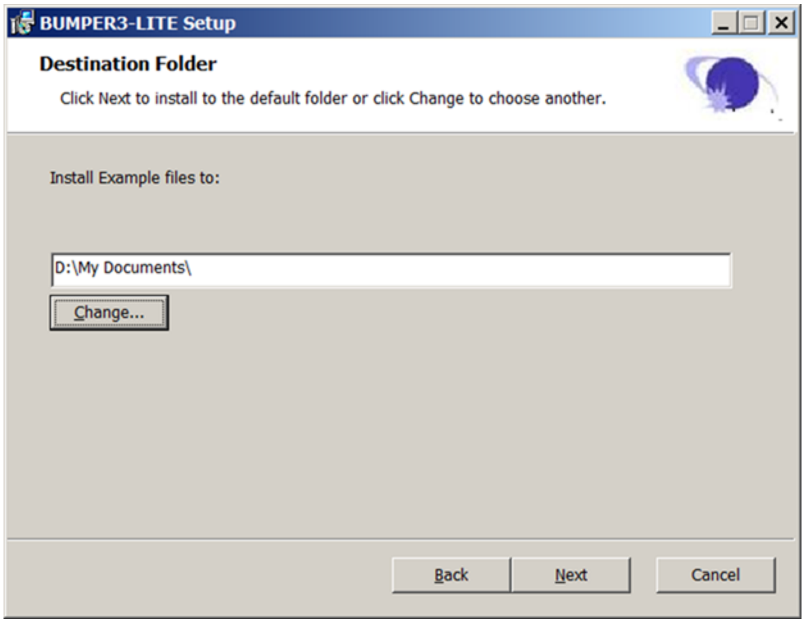


Figure 8. *BUMPER3-LITE* installer destination folder dialog.

This returns you to the “Custom Setup” dialog. With all of the custom features now configured, click on the “Next” button to continue.

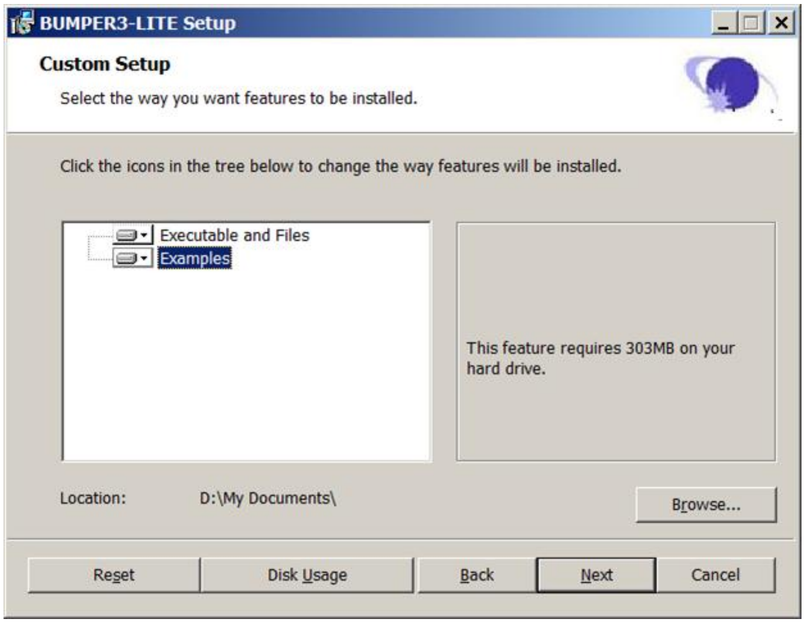


Figure 9. *BUMPER3-LITE* Custom Setup dialog at the completion of customization.

This brings up the “verify ready” dialog shown in Figure 10. Click “Install” to continue with the installation, or “Cancel” to cancel the installation.

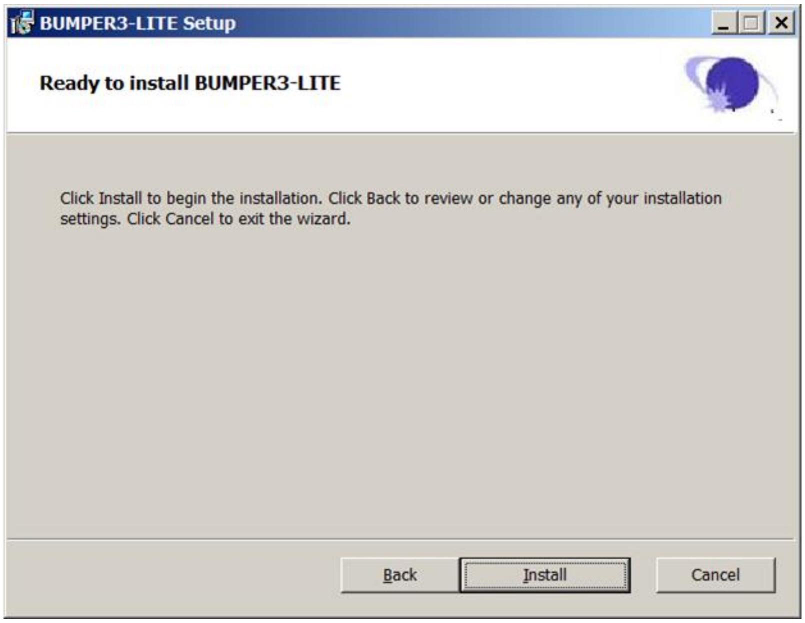


Figure 10. *BUMPER3-LITE* installer verify ready dialog.

After clicking "Install" the status dialog appears, shown in Figure 11. When installation is complete click "Next" to continue.

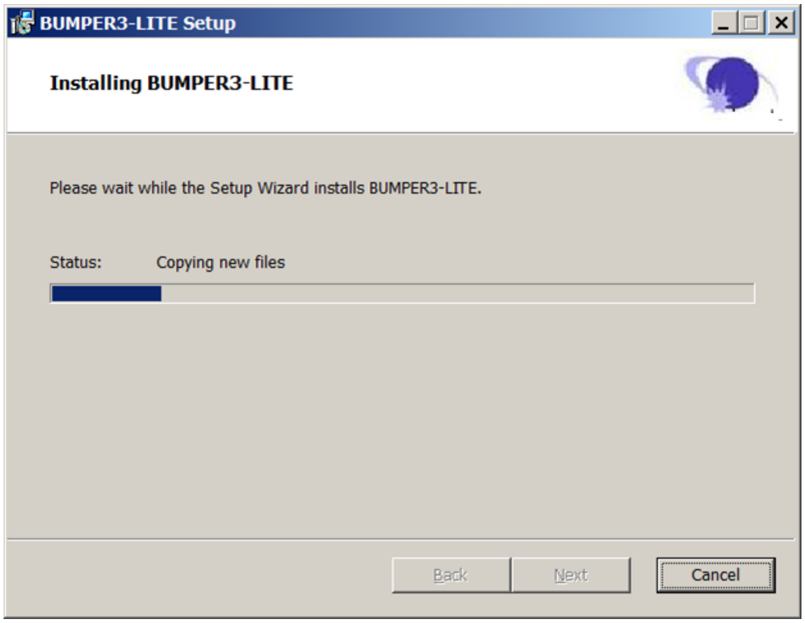


Figure 11. *BUMPER3-LITE* installer status dialog.

After completing installation, the user exit dialog appears. Press "Finish" to complete the installation.

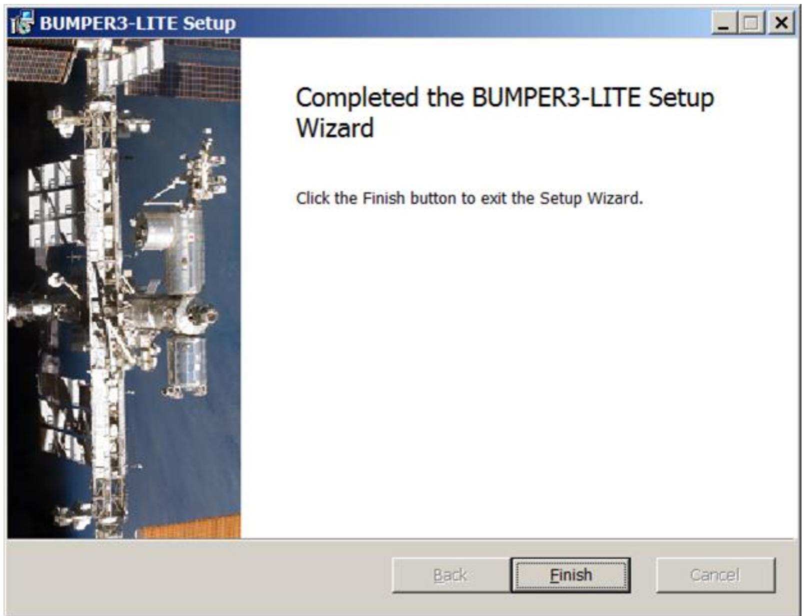


Figure 12. *BUMPER3-LITE* installer user exit dialog.

The executable installer performs the following six steps.

- The *BUMPER3-LITE.exe*, *BUMEPR3-LITE_OMP.exe*, *procloo.exe* and *ordem2k2bii.exe* executables are installed in the directory:
  %LOCALAPPDATA%\Programs\NASA HVIT\bin
  (which is usually *C:\Users\%USERNAME%\AppData\Local\Programs\NASA HVIT\bin*).
- The folder *%LOCALAPPDATA%\Programs\NASA HVIT\bin* is added to the user's path variable *%PATH%* if it is not already part of the path.
- The *mat-lite.prp* file and the *bumper.rc* runtime control file are copied to:
  - *%LOCALAPPDATA%\NASA HVIT\BUMPER3-LITE*
- The environment files are copied to a subfolder of the *%LOCALAPPDATA%* folder.
- ORDEM2000 environment files are copied to:
  - *%LOCALAPPDATA%\NASA HVIT\envFiles\ORDEM2000*
- ORDEM 3.0 environment files are copied to:
  - *%LOCALAPPDATA%\NASA HVIT\envFiles\ORDEM3p0*
- MEMCxPv2 environment files are copied to:
  - *%LOCALAPPDATA%\NASA HVIT\envFiles\MEMCxPv2*
- No MEMR2 environment files are provided with this distribution.
- The example files are copied to a subfolder in the user's My Documents folder (unless changed during install).
  - *C:\Users\%USERNAME%\My Documents\NASA HVIT\BUMPER3-LITE*
- The user environment variable B3LITEWD is created and the path to the example files is copied to the environment variable value.

(See Appendix D for a list of the installed files.)

At the end of the installation one may run *BUMPER3-LITE* from any folder in user space.

Note that if the user wishes to analyze spacecraft in orbits other than the orbits assumed for the installed environment files, then the user must request the ORDEM 3.0 executable from the

NASA Orbital Debris Program Office, *http://orbitaldebris.jsc.nasa.gov/model/engrmodel.html*, and the MEMR2 version 2.0.2.1 executable from the NASA Meteoroid Environment Office, *http://www.nasa.gov/offices/meo/software/index.html*. The procedure for generating environment files for the *Bumper 3* code from these two programs is described in Sections 5.12 and 5.14.

The NASA Orbital Debris Program Office no longer distributes ORDEM2000. The NASA Meteoroid Environment Office no longer distributes MEMCxP.

3.2 Considerations When Upgrading from BUMPER-II

The BUMPER-II user is cautioned that some of the prompts in the GEOMETRY user interface have changed so some changes to any user written driver scripts are necessary. Furthermore, the format of the .GEM and the .RSP files have changed; if the user desires to reuse BUMPER-II .GEM and .RSP files, then the user will need to write programs to reformat the .GEM and .RSP files.

The BUMPER-II user who has written a large number of scripts to automate multiple BUMPER-II runs may not wish to use the runtime control file. This feature can be defeated by deleting or renaming the runtime control file in the local install directory

- *%LOCALAPPDATA%\NASA HVIT\BUMPER3-LITE* on a Windows 7 machine

and ensure that a runtime control file is not present in the *Bumper 3* code executable directory.

However, the recommended procedure is to not alter the runtime control file in the local install directory but to place the following runtime control file with the *Bumper 3* code executable in its directory.

```
#
# BUMPER runtime control file for BUMPER-II behavior
#
#
ORDEM2000DIR ""
#
ORDEM3p0DIR ""
#
MEMCxPv2DIR ""
#
MEMR2DIR ""
#
PRACalc false
#
automaticPIDNumbering true
#
MAT.PRPName "mat.prp"
#
# END
#
```

4.0 Operating Instructions

The following program units are the *Bumper 3* code analysis options.

- GEOMETRY
- RESPONSE
- SHIELD

Each of these units is described in detail in following sections.

4.1 Calculate the Spacecraft Self-Shadowing Database Task

4.1.1 Functional description

The GEOMETRY analysis produces the database of spacecraft geometry visible to the MMOD threat and not shadowed from the MMOD threat by other portions of the spacecraft. This is achieved by approximating the MMOD environment by a number of discrete threat directions, to which a cumulative flux as function of MMOD diameter and closing speed probability density function is assigned. The GEOMETRY analysis is performed for each threat direction on a shell finite element model of the spacecraft. Threat by threat, the analysis sorts the elements into lists of exposed elements and writes the results out to a binary data file. The binary data file is a required input to the SHIELD analysis described in Section 4.3.

4.1.2 Cautions and warnings

- Do use a shell finite element model in I-deas universal file format.
- Do use units in meters to build the I-deas model.
- Do use only one coordinate system to build the I-deas model
- Do use triangular or quadrilateral shell elements.
- Do keep all of the elements approximately the same area.
- Do keep all the elements length to width, or base to height, ratio approximately equal.
- Do remember that the *Bumper 3* code uses rotations about the spatial axes and not the body axes.
- Do remember that rotations do not commute and have to be applied in the correct order.

4.1.3 Procedures

Each of these units is described in detail in following sections.

Setup and Initialization – Build the finite element model and write the finite element mesh out in I-deas universal file format. The finite element model used in this procedure is a cube, composed of one quadrilateral element per cube face.

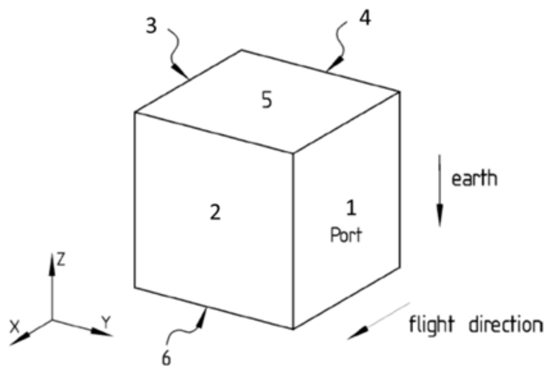


Figure 13. EXAMPLE1.UNV cube model.

The mapping between the element identification (EID) and the face of the cube is shown in Table 2.

Table 2. EXAMPLE1.UNV Element Locations

Element ID	Cube face
1	port
2	RAM
3	starboard
4	aft
5	zenith
6	nadir

Obtain the spacecraft altitude from the mission planner for an analysis using the SSP30425 MM environment. (Not needed for other environments.)

Input Operations **–** Build the finite element model and write the finite element mesh out in I-deas universal file format. The finite element model used in this procedure is a cube, composed of one quadrilateral element per cube face.

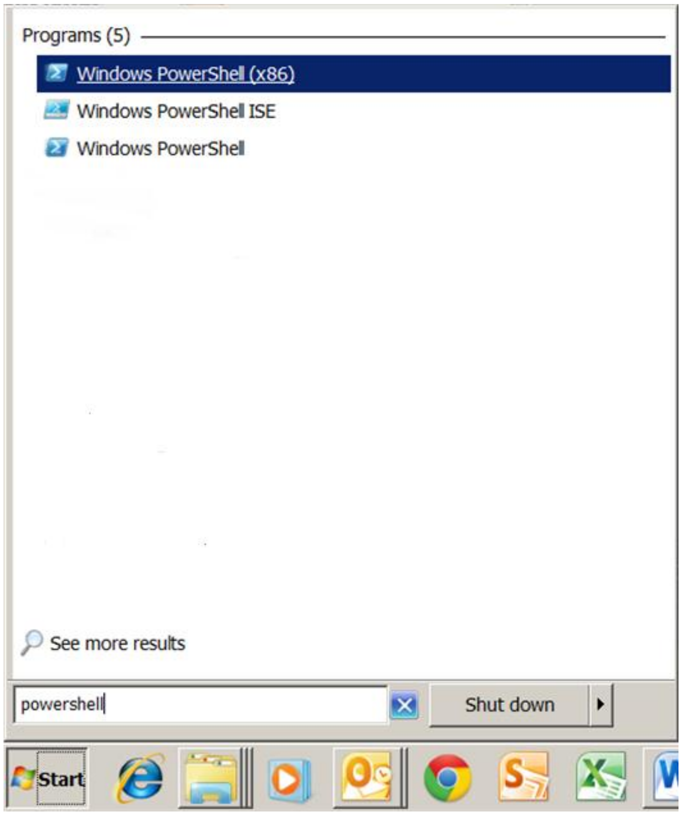


Figure 14. Search results for PowerShell.

Now change to the *Bumper 3* code working directory by typing the command `cd $env:B3LITEWD` at the console prompt, as shown in Figure 15.

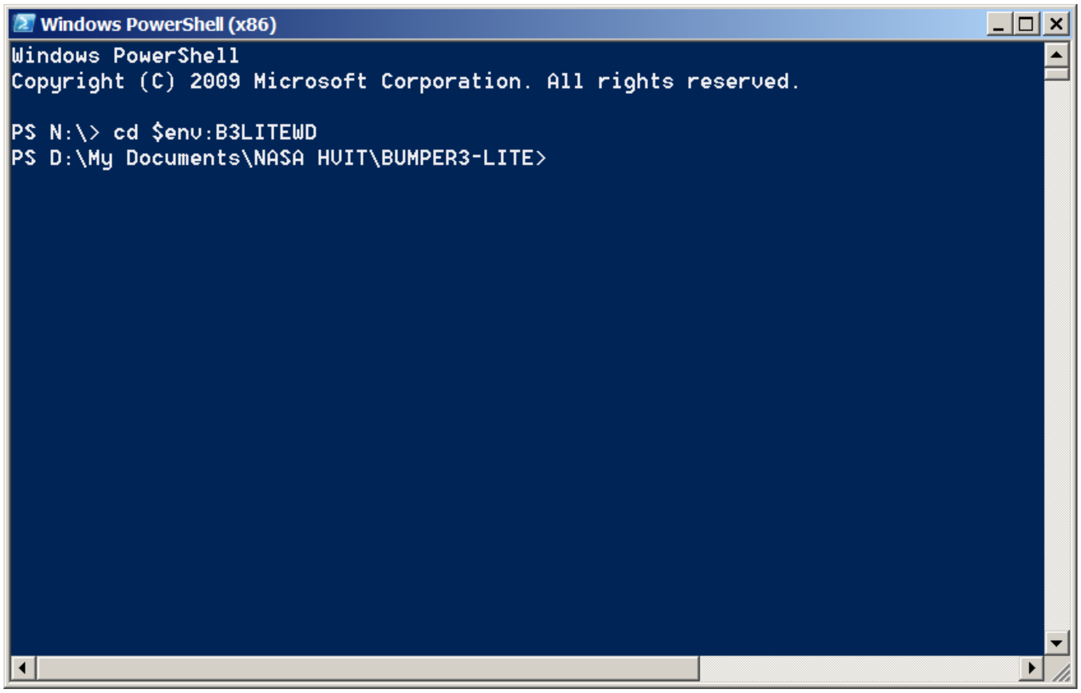


Figure 15. Change to the *Bumper 3* code working directory.

Next, start the *Bumper 3* code by typing `BUMPER3-LITE` at the console prompt, as shown in Figure 16.

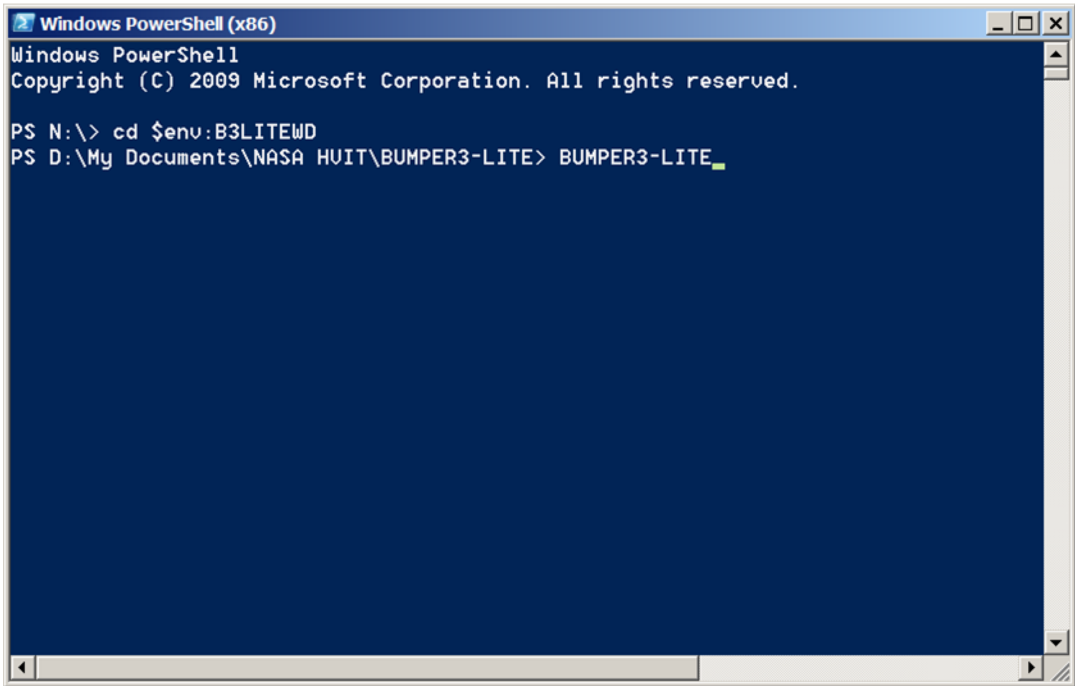


Figure 16. Starting the *Bumper 3* code.

International Traffic in Arms Regulation (ITAR) notice – The first prompt in a *Bumper 3* code analysis is the ITAR notice acknowledgement; see Figure 17. Type a carriage return to continue.

Figure 17. ITAR notice.

Select Analysis – the *Bumper 3* code then prompts for the analysis module to run; see Figure 18. Allowable inputs are listed in Figure 18. Type `1` for this GEOMETRY analysis module example.

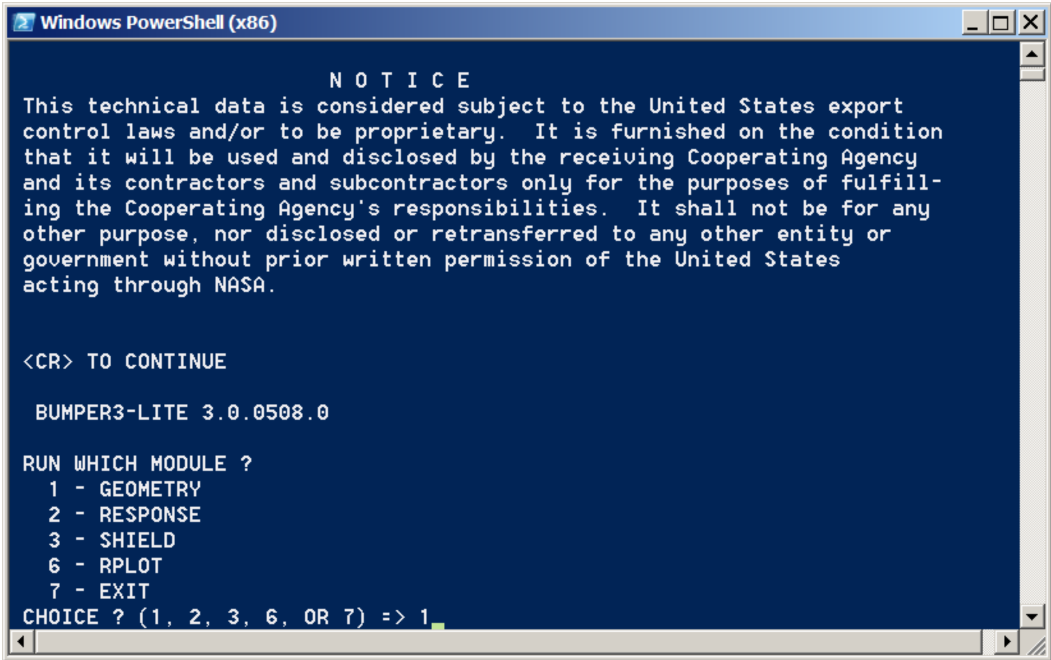


Figure 18. Analysis selection.

GEOMETRY analysis summary filename – Next the *Bumper 3* code prompts for the filename for the GEOMETRY analysis summary log file; see Figure 19. The square brackets surrounding the text string *geometry.gsum* indicate that a carriage return input will result in a default value of *geometry.gsum*. The filename must be less than 256 characters. This is not a limitation because MS Windows limits filenames to less than 260 characters in most cases. Type `EXAMPLE1\EXAMPLE1.GSUM`.

```
This technical data is considered subject to the United States export
control laws and/or to be proprietary.  It is furnished on the condition
that it will be used and disclosed by the receiving Cooperating Agency
and its contractors and subcontractors only for the purposes of fulfill-
ing the Cooperating Agency's responsibilities.  It shall not be for any
other purpose, nor disclosed or retransferred to any other entity or
government without prior written permission of the United States
acting through NASA.


<CR> TO CONTINUE

 BUMPER3-LITE 3.0.0508.0

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 1

GEOMETRY OUTPUT SUMMARY FILENAME ? [ geometry.gsum ] => EXAMPLE1.GSUM
```

Figure 19. GEOMETRY output summary filename selection.

Analysis Type – Next the *Bumper 3* code prompts for the desired MMOD environment type. The allowable inputs are 1 for man-made debris and 2 for meteoroids; see Figure 20. Type `1` for this example.

```
other purpose, nor disclosed or retransferred to any other entity or
government without prior written permission of the United States
acting through NASA.


<CR> TO CONTINUE

 BUMPER3-LITE 3.0.0508.0

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 1

GEOMETRY OUTPUT SUMMARY FILENAME ? [ geometry.gsum ] => EXAMPLE1.GSUM

ANALYSIS TYPE ?
  1 - MAN-MADE DEBRIS
  2 - METEOROIDS
 CHOICE ? (1 OR 2) => 1
```

Figure 20. Analysis and environment type selection.

Environment Selection – Next the *Bumper 3* code prompts, in this example, for the desired orbital debris environment, see Figure 27 below. The allowable inputs are:

1. SSP30425 (The 1991 design environment for ISS.)
2. ORDEM2000 (The obsolete orbital debris environment from 2000.)

3. ORDEM3 (The current orbital debris environment.)

Type `3` (or a carriage return) for this example.

```
Windows PowerShell (x86)

 BUMPER3-LITE 3.0.0508.0

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 1

GEOMETRY OUTPUT SUMMARY FILENAME ? [ geometry.gsum ] => EXAMPLE1.GSUM

ANALYSIS TYPE ?
  1 - MAN-MADE DEBRIS
  2 - METEOROIDS
 CHOICE ? (1 OR 2) => 1

ENVIRONMENT DEFINITION ?
  1 - SSP 30425
  2 - ORDEM2000
  3 - ORDEM 3.0 <CR>
CHOICE ? (1, 2, or 3) [ 3 ] => 3
```

Figure 21. Environment model selection.

Finite Element Model File Type Selection – Next the *Bumper 3* code prompts for the format of the finite element model file: I-deas universal file or PATRAN neutral file. See Figure 22. Type `1` (or a carriage return) for I-deas universal file format. Do not select `2 – PATRAN NEUTRAL` file. This will cause the *Bumper 3* code to terminate. This is a known issue.

```
Windows PowerShell (x86)
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 1

GEOMETRY OUTPUT SUMMARY FILENAME ? [ geometry.gsum ] => EXAMPLE1.GSUM

ANALYSIS TYPE ?
  1 - MAN-MADE DEBRIS
  2 - METEOROIDS
 CHOICE ? (1 OR 2) => 1

ENVIRONMENT DEFINITION ?
  1 - SSP 30425
  2 - ORDEM2000
  3 - ORDEM 3.0 <CR>
CHOICE ? (1, 2, or 3) [ 3 ] => 3

MODEL FILE FORMAT ?
 1 - SUPERTAB UNIVERSAL <CR>
 2 - PATRAN NEUTRAL
CHOICE ? (1 OR 2) [ 1 ] => 1
```

Figure 22. Model file format selection.

Universal input filename selection – Next the *Bumper 3* code prompts for the name of the finite element file. See Figure 23. The file is read from the working directory; however, the file may be read from other directories if a path is affixed to the filename. Again, the path and filename must be less than 256 characters. Type `EXAMPLE1\EXAMPLE1.UNV` for this example.

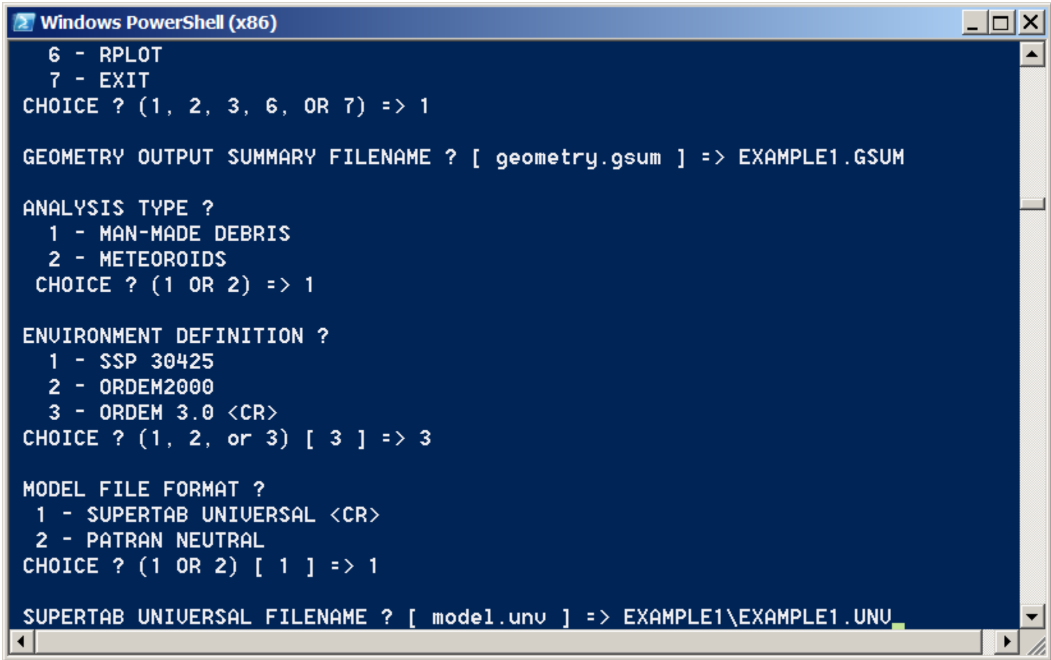


Figure 23. Model filename selection.

Spacecraft self-shadowing database output filename selection - Next the *Bumper 3* code prompts for the name of the spacecraft self-shadowing database file to write out. See Figure 24. The file is written to the working directory. The .GEM file may be written to other directories if a path is affixed to the filename. Again, the path and filename must be less than 256 characters. Type `EXAMPLE1.GEM` for this example.

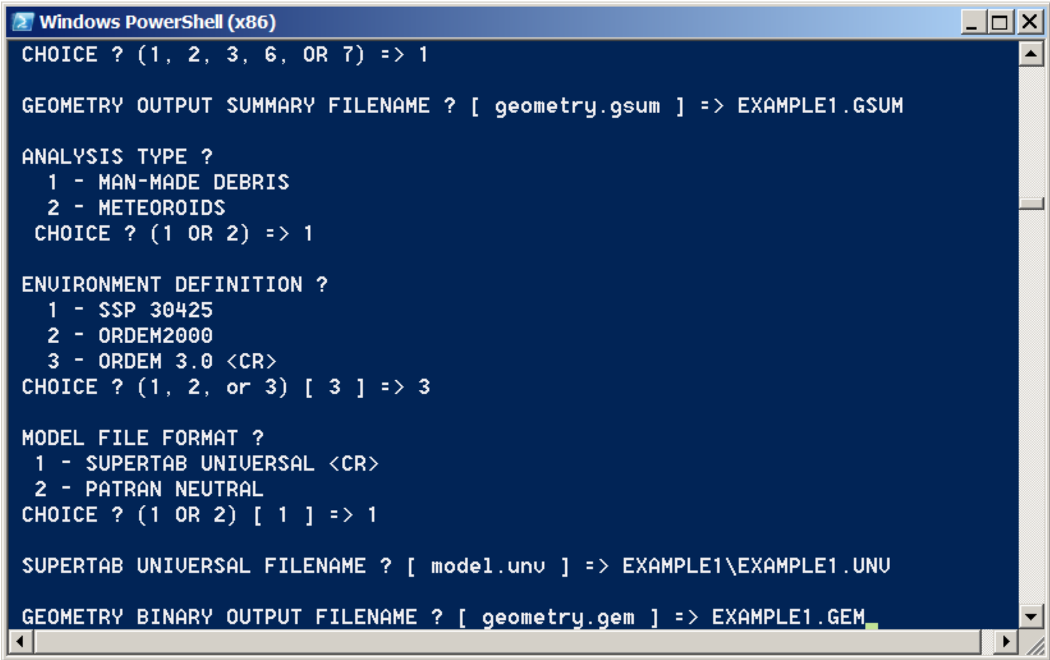


Figure 24. Self-Shadowed element database filename selection.

Model Rotation – Next the *Bumper 3* code prompts for whether to rotate the model. See Figure 25. Enter N (or a carriage return) for no, or Y for yes. Type `Y` for this example. Rotations are around the spatial coordinate axes and not the spacecraft body coordinate axis. Confusing a rotation about the body coordinate axis with a rotation about the spatial coordinate axis will lead to incorrect results.

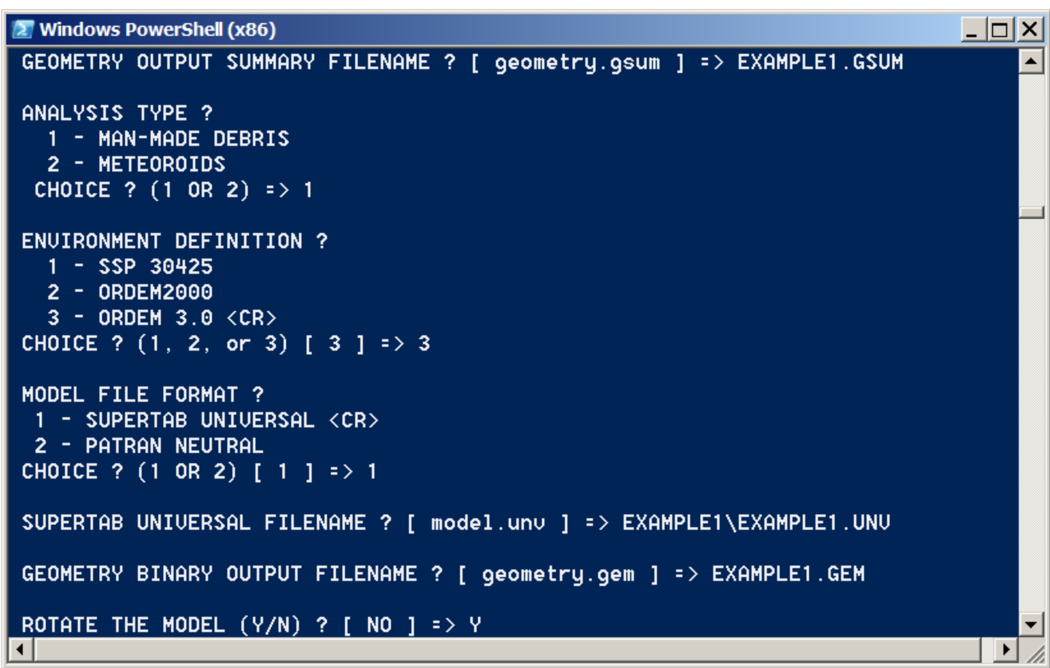


Figure 25. Model rotation inputs.

The next rotation prompt is shown in Figure 26. Up to three rotations about the spatial axes are allowed. The required inputs are in the format: axis label, degrees rotation. The comma is required. Example inputs are: X,45, or Y,32.1, or Z,0.5. For this example type Z,90.

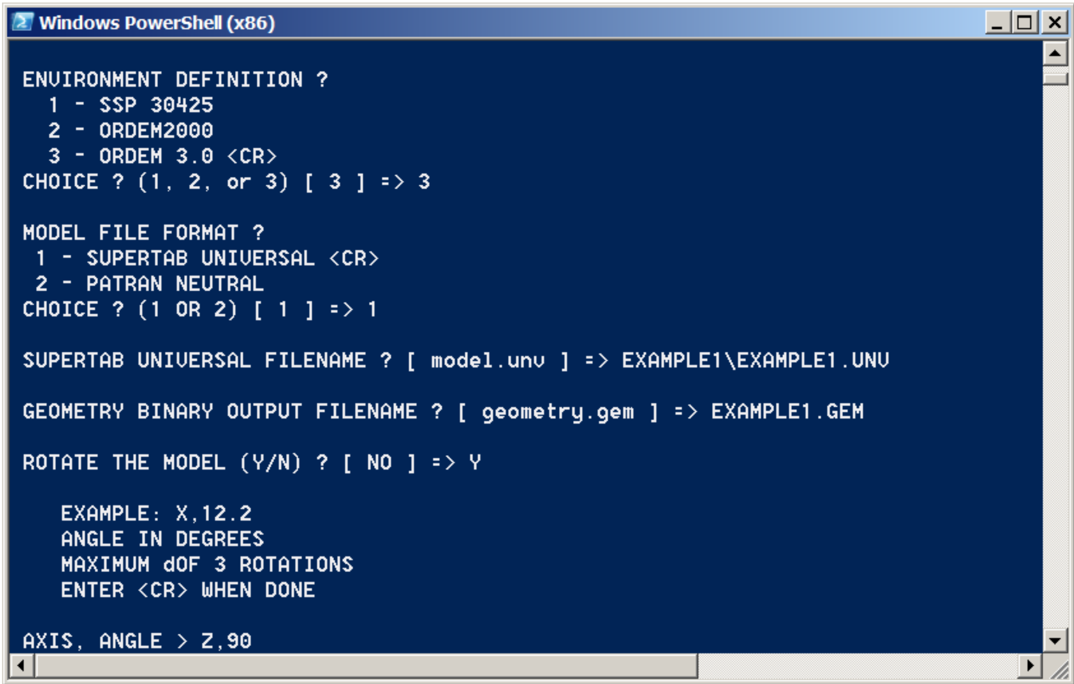


Figure 26. Spatial rotation axis and angle selection.

Remember that the rotation operator does not commute, hence the rotations X,90 followed by Y,90 does not leave the spacecraft in the same orientation as Y,90 followed by X,90.

The *Bumper 3* code will stop requesting rotation axis/rotation angle pairs if three pairs are entered and will start the self-shadowing database calculation. If only one or two rotations are desired, then terminate the input with a carriage return as shown in Figure 27.

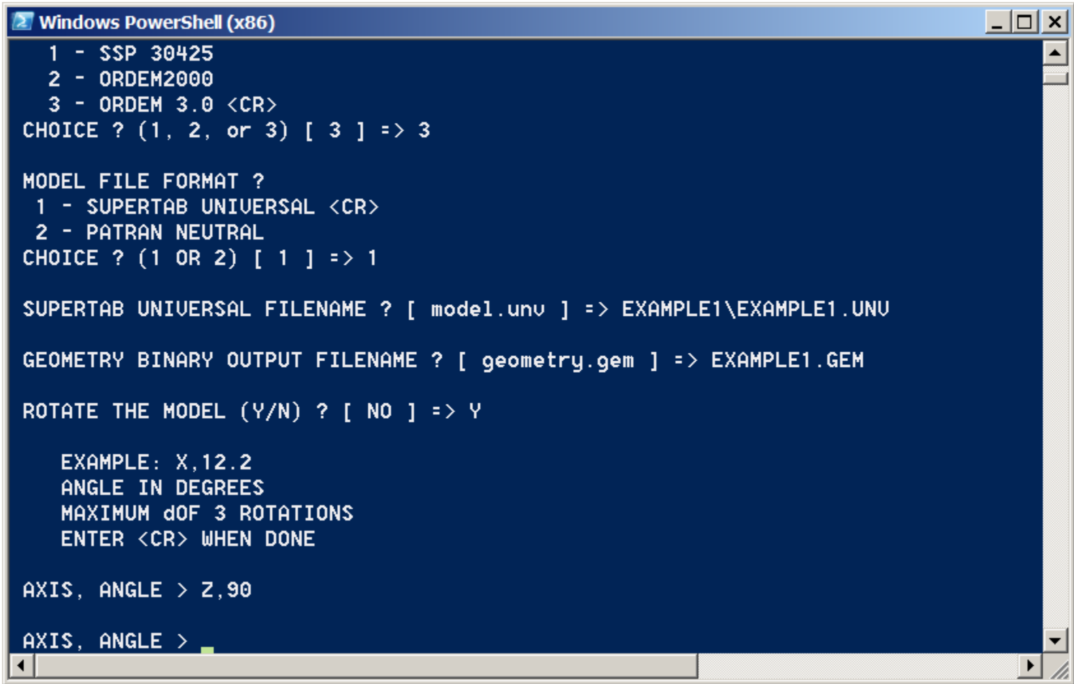


Figure 27. Terminating rotation axis and angle selection.

Results – Figure 28 shows the last few lines of the GEOMETRY analysis screen. The *Bumper 3* code prints to screen the number of the current threat it is working and when completed returns to the Run Which Module prompt.

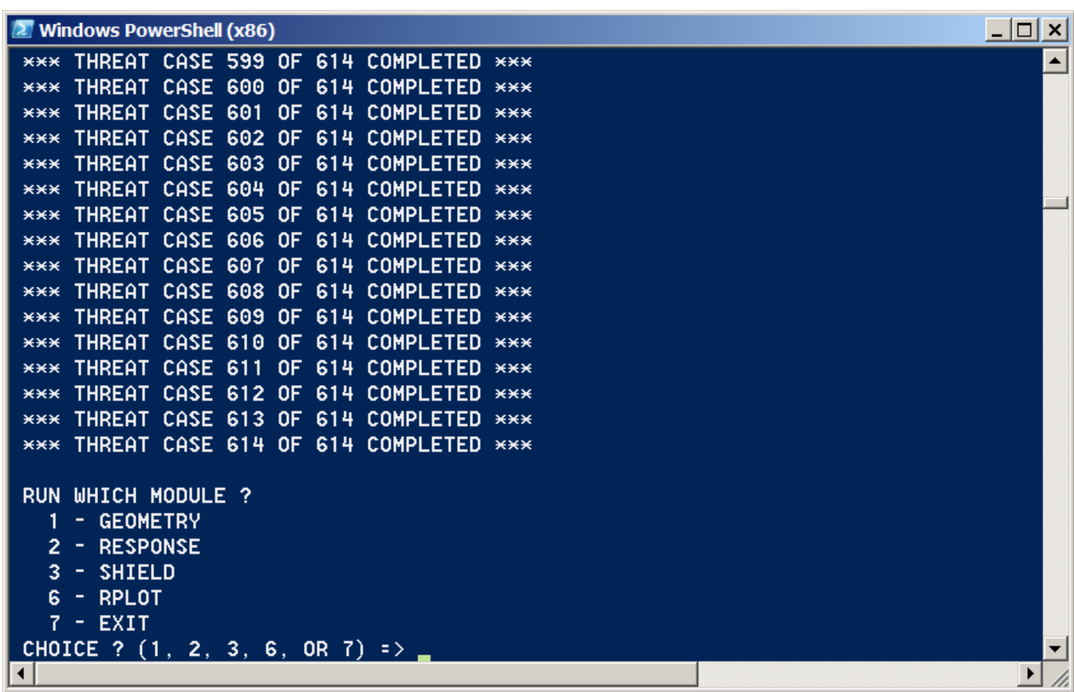


Figure 28. Final screen from a GEOMETRY analysis.

The file output of the GEOMETRY analysis is the text .GSUM log file and the binary .GEM self-shadowing database. The user should archive the .GSUM with the *Bumper 3* code analysis results to document the user inputs. The .GEM self-shadowing database is used as input to the SHIELD analysis.

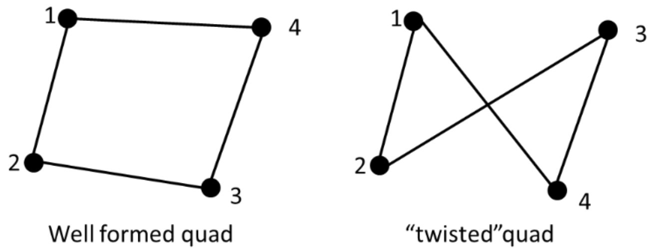
The .GSUM file from the above tutorial is reproduced below. The log file lists the version of the *Bumper 3* code used to make the analysis and the date of the analysis. It then lists the *Bumper 3* code prompts and the user inputs. This is followed by an indication whether the analysis completed. If it did not, the line `614 MAN-MADE DEBRIS THREAT CASES COMPLETED` would be missing from the .GSUM file, see excerpt below.

```
BUMPER3-LITE 3.0.0508.0   ** G E O M E T R Y **        08-MAY-2014 15:57:03.377
LAST COMMIT DATE: 2014/05/08 10:58:44 STATE OF CURRENT EXE: Modified

NAME OF THIS FILE: EXAMPLE1.GSUM

ANALYSIS TYPE ?
   1 - MAN-MADE DEBRIS
   2 - METEOROIDS
CHOICE ? (1 OR 2) =>  1

ENVIRONMENT DEFINITION ?
   1 - SSP30425
   2 - ORDEM2000
   3 - ORDEM 3.0 <CR>
CHOICE ? (1, 2, or 3) [ 3 ] =>  3

MODEL FILE FORMAT ?
   1 - SUPERTAB UNIVERSAL <CR>
   2 - PATRAN NEUTRAL
CHOICE ? (1 OR 2) [ 1 ] =>  1

SUPERTAB UNIVERSAL FILENAME ? [ model.unv ] => EXAMPLE1\EXAMPLE1.UNV

GEOMETRY BINARY OUTPUT FILENAME ? [ geometry.gem ] => EXAMPLE1.GEM

ROTATE THE MODEL (Y/N) ? [ NO ] => Y
   MODEL ROTATED ABOUTZ AXIS, ANGLE =>    90.00

NUMBER OF THREATS =>  614

   ********** MAN-MADE DEBRIS THREAT CASES COMPLETED 614 **********
```

4.1.4 Probable errors and possible causes

- Coordinate Systems (CS)
  - the *Bumper 3* code assumes the following to be true
    - Non-identity transformation of base CS not allowed
    - Non-zero translation of base CS not allowed
    - Multiple coordinate systems definitions are not supported
- Surface elements
- Regular quadrilaterals
  - The presence of malformed elements can impact results if the following are not true
    - Skewed aspect ratio (AR), AR should be approximately 1.0
    - Quadrilateral elements are regular

- Element nodes are defined in a right-hand fashion with the element normal coming out of the “visible” side
  - If reversed, impacts will occur on the interior structures
  - If the connectivity data makes a crisscross pattern across the quadrilateral element, then normal vectors will either be Not a Number (NaN) or erroneous



- Only triangular and regular quadrilateral elements can be defined
- Quadrilateral element nodes must closely approximate a plane
  - Saddle shaped quadrilaterals (see **Figure 55**) will have incorrect normal vectors and results will not be indicative of surface behavior

4.2 Calculate the Spacecraft Shield Ballistic Limit Table Task

4.2.1 Functional description

RESPONSE generates a table of MMOD diameters from the ballistic limit equations. The impact speed runs down the row of the table and the impact angle runs across the column. The tabulated MMOD diameters separate the diameters that perforate from those that don’t at that impact speed/impact angle pair (i.e., the ballistic limit of the shield). A complete table must be generated for each property ID in the finite element model. (Remember that each finite element was assigned PID during the construction of the finite element model.) The RESPONSE tables are saved in a binary format file typically given the file extension .RSP.

The *Bumper 3* code provides a variety of BLEs for use in spacecraft risk analyses. These BLEs should be applied with regard to the design characteristics and assumptions used in their creation.

Table 3 lists the selection number from the RESPONSE prompt/response user interface in column 1, the corresponding BLE name from the user interface (UI) in column 2, the typical use case in column 3 and the reference to the BLE derivation in column 4.

Table 3. BUMPER3-LITE Ballistic Limit Equations

selection	BLE id	Use case	degCut (deg)	reference
1	C-P Single Wall	Single metal sheet with or without an exterior MLI blanket	89.9	[2]
2	Stuffed Whipple	Metal Whipple shield with interior MMOD blanket	89.9	[3]
3	multiShock	Multishock shield made with Nextel layers	89.9	[2]
4	Kinetic Energy	Constant kinetic energy projectile (computed from the normal	60	N/A

		component of the impact velocity)		
5	Const Diameter		NA	N/A
6	Shadow		NA	N/A
7	NNO double wall wMLI	Metal Whipple shield, with or without MLI on the bumper or interior to the bumper. Bumper thickness to projectile diameter ratio must be ≈ 0.25.	60	MLI equations are from [4]
111	Fused Silica		89	[5]

4.2.2 Cautions and warnings

- Do build the I-deas universal file with the element PIDs assigned consecutively. (Groups of elements may share the same PID; however, each group should be assigned a PID from 1 to maximum number of PIDs with no gaps.)
    - Advanced options exist that allow for gaps between PID numbers and the freedom to enter PIDs in a nonconsecutive order. However, this example follows the default behavior of entering PID shield parameter data in consecutive PID order.

Be aware that RESPONSE will set the critical diameters to the same values for impact angles larger than a BLE dependent value called degCut in the source. This is not a user selectable value. See
Table 3 for the values used with the BUMPER3-LITE BLEs.

- Do not use the BLE selection 7, metal Whipple shield, with bumper thickness to projectile diameter (t/d) ratios much different than 0.25 (where the projectile diameter comes from the BLE curve at 7 km/s and 0 degrees impact angle). Adjust the design of the shield until the t/d ratio is approximately 0.25.

4.2.3 Procedures

Setup and Initialization -

- Collect the shield parameters for input to the *Bumper 3* code.
- Add material properties to the *mat.prp* file if the material is not already in the file.

Input Operations – This section details the inputs required for building the table of critical diameters for a PID. The following screenshots are described in the subsections that follow.

Select Analysis – The *Bumper 3* code initially prompts for the analysis module, Figure 29. Allowable inputs are:

1. for a GEOMETRY analysis that will produce the database of exposed elements.
2. for a RESPONSE analysis that will produce the table of critical diameters that will perforate a shield.
3. for a SHIELD analysis, that will calculate the total probability of penetration or impact.
4. for printing out the RESPONSE binary file as an ASCII file.
5. for exiting the *Bumper 3* code analysis.

Type `2` for this task.

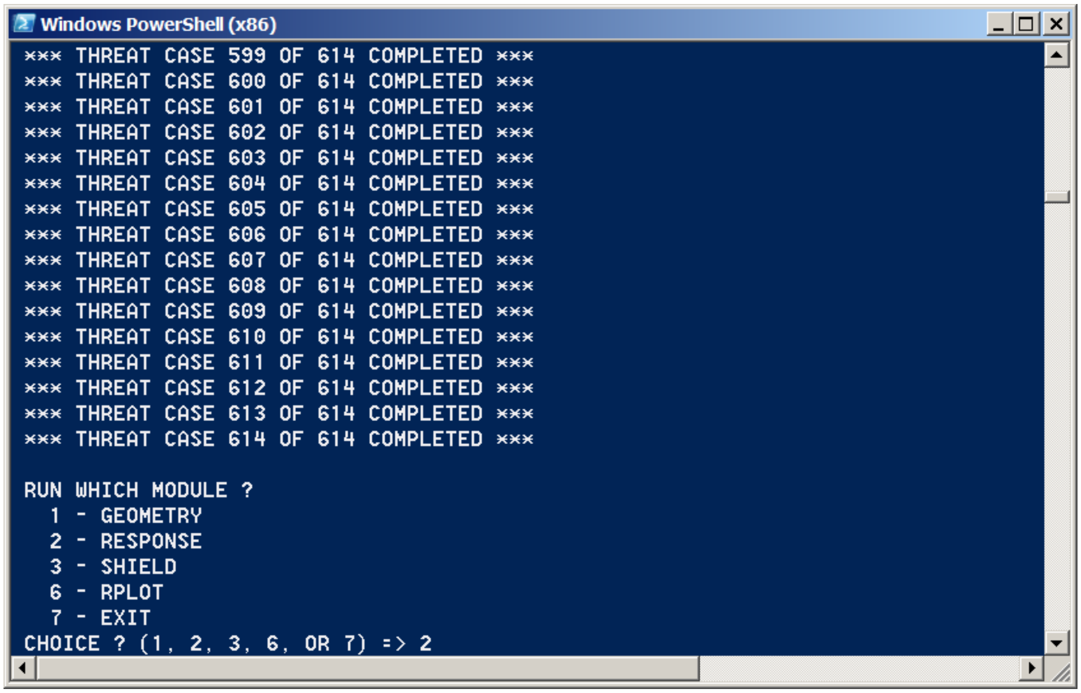


Figure 29. Module selection.

Analysis Type – Next, the *Bumper 3* code prompts for the desired MMOD environment type: man-made debris or meteoroids, see Figure 30. The allowable inputs are 1 for man-made debris and 2 for meteoroids. Type `1` for this example.

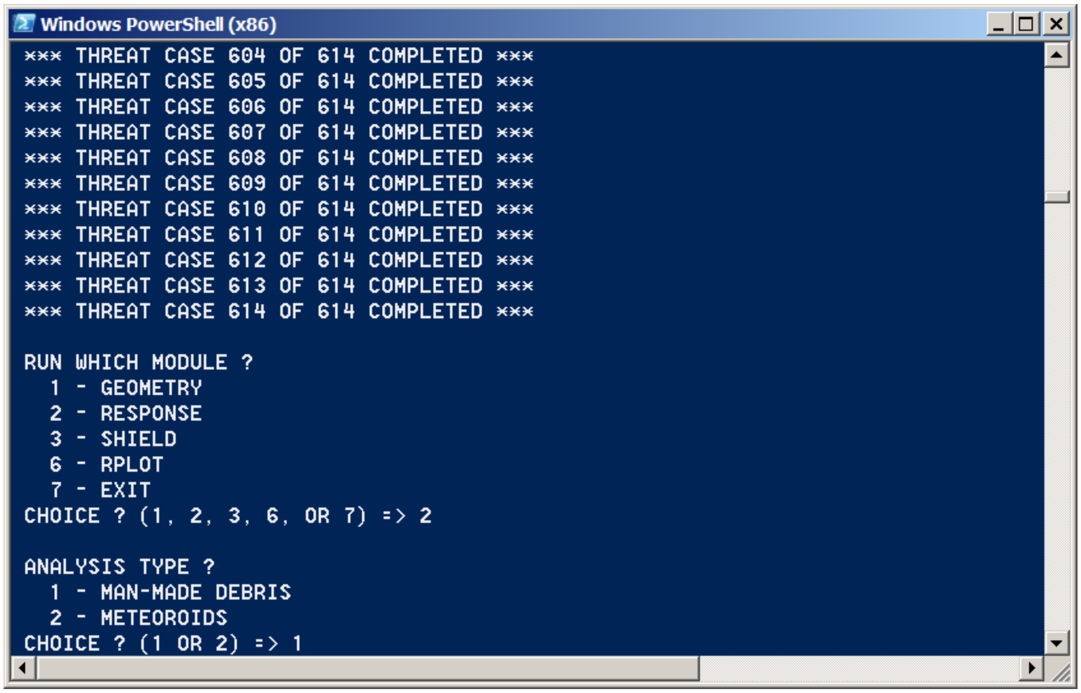


Figure 30. Analysis type selection.

Environment Selection – Next, the *Bumper 3* code prompts, in this example, for the desired orbital debris environment, see Figure 31. The allowable inputs are

1. for SSP30425, the 1991 design environment for ISS.
2. for ORDEM2000, the old orbital debris environment from the year 2000.
3. for ORDEM 3, the current orbital debris environment (recommended).

The recommended choice is option 3 for orbital debris analyses. Type `3` for this example.

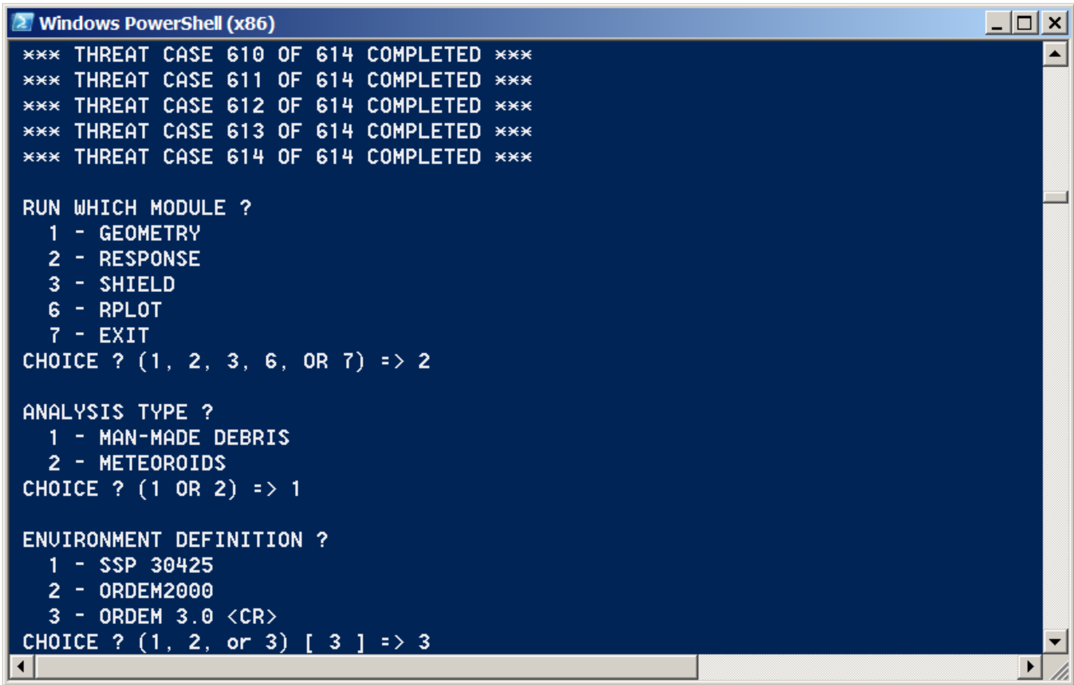


Figure 31. Environment model selection.

RESPONSE summary filename – Next, the *Bumper 3* code prompts for the filename for the RESPONSE analysis log file. The filename must be less than 256 characters. It is written to the working directory where the *Bumper 3* code was executed from. Fully resolved path names (i.e., *C:\TEMP\response.rsum*) or relative path names (*rsum\response.rsum*) may prefix the filename to write to different directories. However, be sure to keep the total path and filename to less than 256 characters. If the *Bumper 3* code detects that the filename is greater than or equal to 256 characters it will stop, see Figure 32. Type `EXAMPLE1.RSUM` for this example.

```
Windows PowerShell (x86)
*** THREAT CASE 612 OF 614 COMPLETED ***
*** THREAT CASE 613 OF 614 COMPLETED ***
*** THREAT CASE 614 OF 614 COMPLETED ***

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 2

ANALYSIS TYPE ?
  1 - MAN-MADE DEBRIS
  2 - METEOROIDS
CHOICE ? (1 OR 2) => 1

ENVIRONMENT DEFINITION ?
  1 - SSP 30425
  2 - ORDEM2000
  3 - ORDEM 3.0 <CR>
CHOICE ? (1, 2, or 3) [ 3 ] => 3

RESPONSE OUTPUT SUMMARY FILENAME ? [ response.rsum ] => EXAMPLE1.RSUM
```

Figure 32. RESPONSE summary filename selection.

RESPONSE binary output filename – Next the *Bumper 3* code prompts for the name of the spacecraft self-shadowing database file to write out. The file is written to the working directory from which the *Bumper 3* code was executed. The .RSP file may be written to other directories if a path is affixed to the filename. Again, the path and filename must be less than 256 characters or else the *Bumper 3* code will stop, see Figure 33. Type `EXAMPLE1.RSP` for this example.

```
Windows PowerShell (x86)
*** THREAT CASE 614 OF 614 COMPLETED ***

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 2

ANALYSIS TYPE ?
  1 - MAN-MADE DEBRIS
  2 - METEOROIDS
CHOICE ? (1 OR 2) => 1

ENVIRONMENT DEFINITION ?
  1 - SSP 30425
  2 - ORDEM2000
  3 - ORDEM 3.0 <CR>
CHOICE ? (1, 2, or 3) [ 3 ] => 3

RESPONSE OUTPUT SUMMARY FILENAME ? [ response.rsum ] => EXAMPLE1.RSUM

RESPONSE BINARY OUTPUT FILENAME ? [ response.rsp ] => EXAMPLE1.RSP
```

Figure 33. RESPONSE binary file output filename selection.

BLE selection – The *Bumper 3* code next displays a list of BLEs contained in the *Bumper 3* code; see Figure 34. Choose a BLE from the list that best represents the structural component to be modeled.

Table 3 provides some guidance on the use cases for the various BLEs. The user may enter either the BLE name or BLE number, do not enter both name and number. The name is not case sensitive. For this example, type `1` for the “C-P single wall” ballistic limit equation for a single metal sheet.

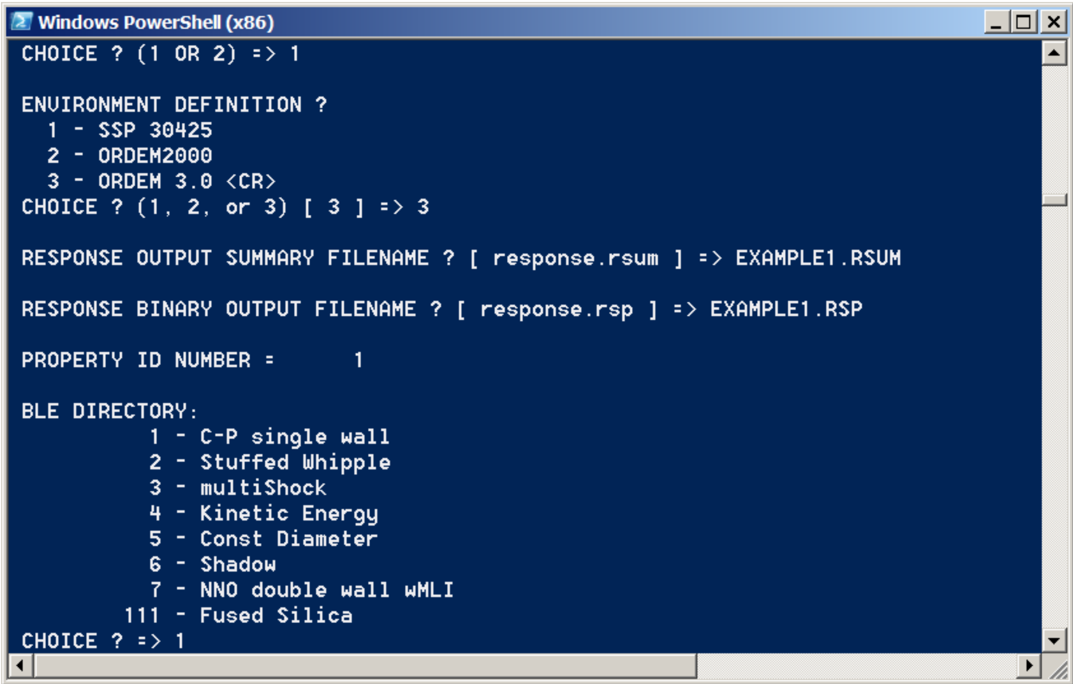


Figure 34. BLE selection for PID 1.

Single wall failure criterion selection – Next the *Bumper 3* code prompts for the single wall failure criterion; see Figure 35. The choices are:

1. for a crater depth calculation.
2. for a perforation calculation.
3. for a rear free surface spall calculation.

Type `2` for this example.

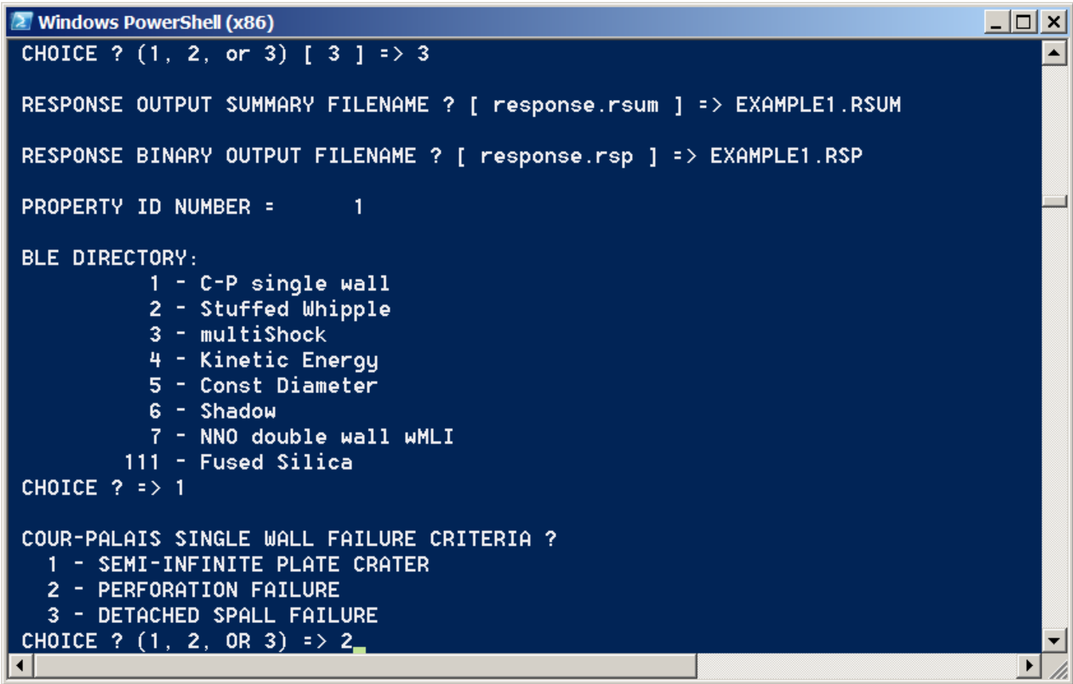


Figure 35. Single wall failure criterion selection.

Single wall material selection – If material properties are required for the PID, then the user will be prompted to choose from the materials listed in the *mat.prp* file. The user will be prompted to choose a material for the rear wall when using the "C-P single wall" relation, the "Stuffed Whipple relation" or the "multishock" shield relation, and for the bumper and rear wall when using the "NNO double wall wMLI" relation; see Figure 36.

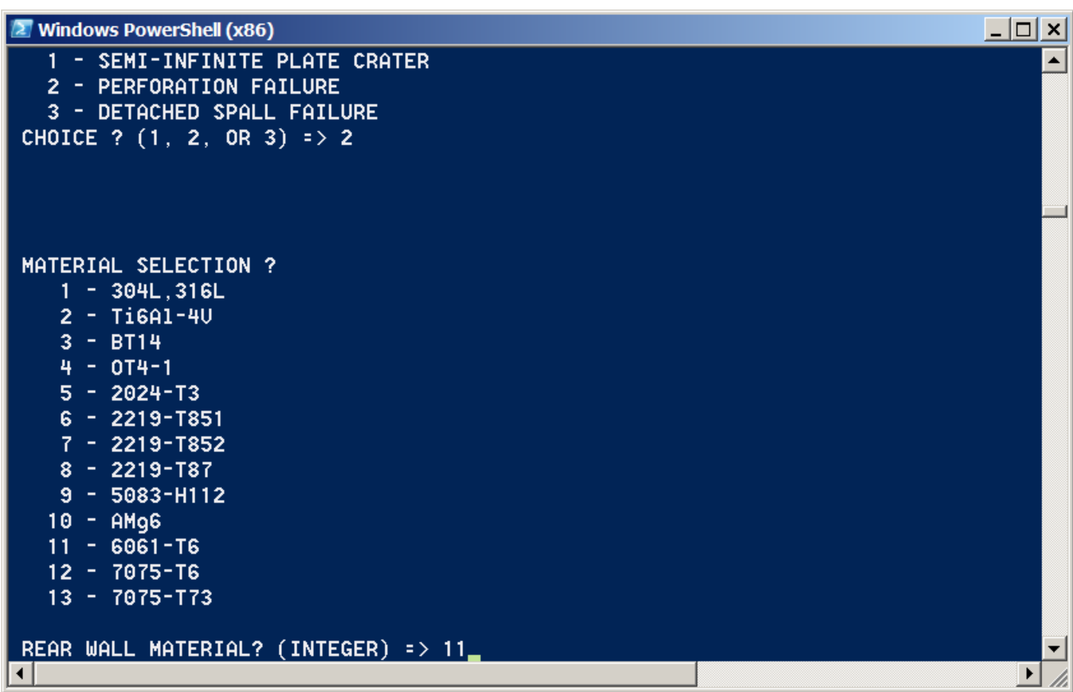


Figure 36. Single wall material selection.

Choosing selection 1 uses common stainless steel properties. Selection 2 choses the most common US titanium alloy. Selection 3 chooses a Russian Ti–4.5Al–3Mo–1V titanium alloy, (also called VT14 in the US. Closest US equivalent is Ti-5Al-2.5Sn.). Selection 4 choses a Russian wrought Ti-2Al-1.5Mn alloy (closest US equivalent is unalloyed Ti 80A). Selections 5 through 13 are aluminum alloys. Selections 6, 7, and 8 are the materials used for the primary structure of the ISS USLAB, Node 1, 2 and 3, Japanese Experiment Module, and Columbus modules. Selection 10 is a Russian aluminum-magnesium alloy, similar to the US alloy 5054-O.

Type `11` to select a 6061-T6 rear wall for this example.

Single wall thickness selection – Next the *Bumper 3* code prompts for the rear thickness in centimeters (cm). Type `0.4` cm for this example.

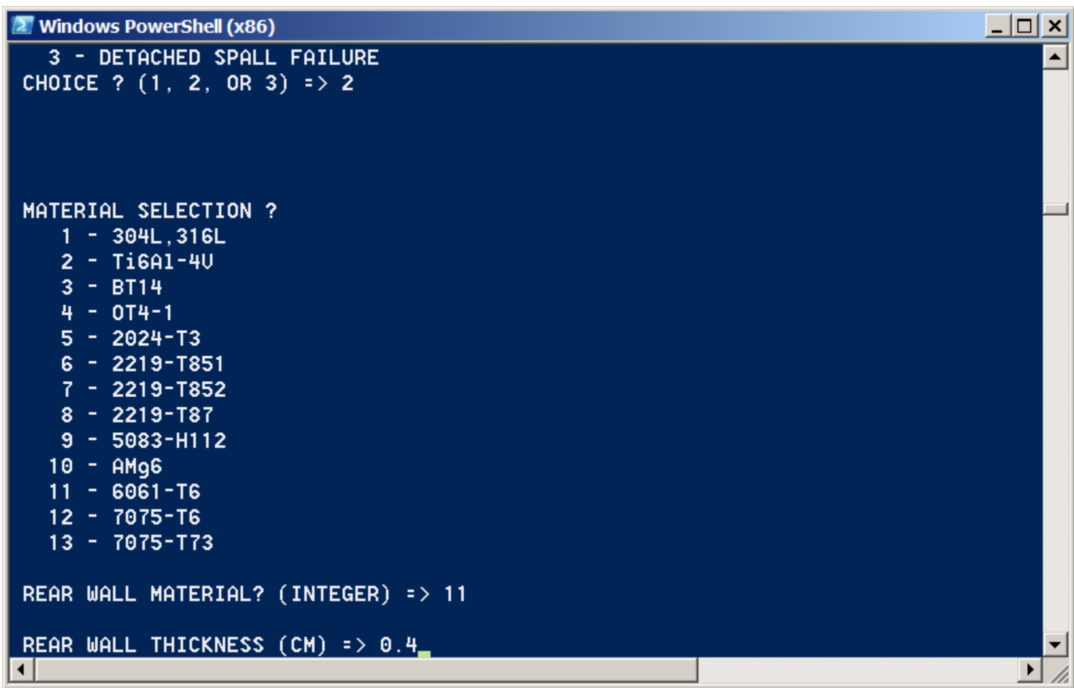


Figure 37. Single wall thickness selection.

MLI presence on the exterior of the single wall selection – Next the *Bumper 3* code prompts for whether the rear wall has a multi-layer thermal insulation (MLI) blanket in contact with the exterior surface. If there is no MLI blanket then type "NO_MLI". If there is an MLI blanket, then type "MLI_AREAL_DENSITY=" concatenated with the areal density in grams per square cm. For this example type `MLI_AREAL_DENSITY=0.06`. The equations for modifying the single sheet ballistic limit equation for the presence of MLI were taken from [6].

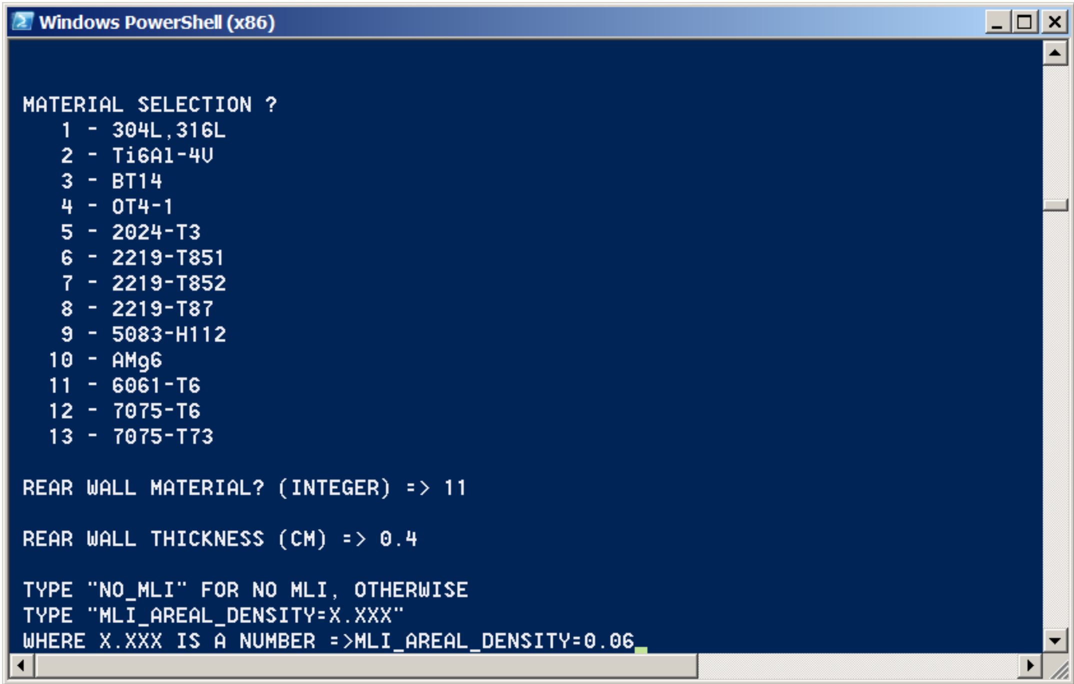


Figure 38. MLI selection.

Continue entering additional PID definitions – Next the *Bumper 3* code prompts the user for more PID shield parameter entries. There is only one PID in the *EXAMPLE1.UNV* file, so type `N` for this this example.

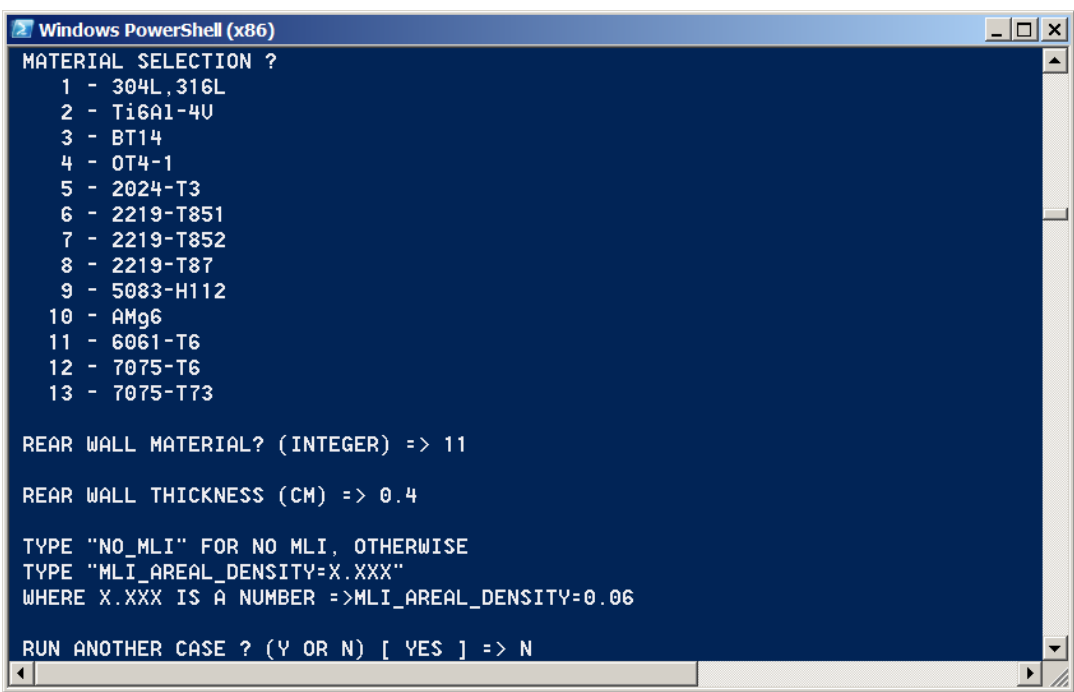


Figure 39. Prompt for next PID.

Results **–** The final screen from the RESPONSE analysis is shown in Figure 40

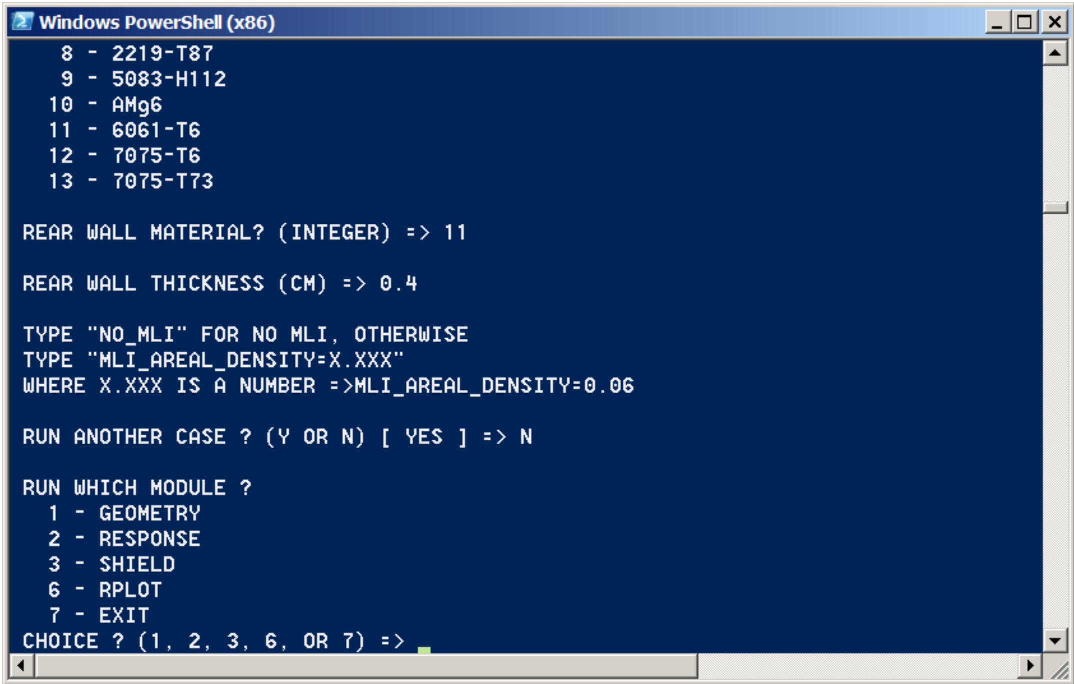


Figure 40. Final screen from a RESPONSE analysis.

The results of the Calculate the Spacecraft Shield Ballistic Limit Curve Table Task described above are:

1. The RESPONSE summary file shown in the code block below:

```
    BUMPER3-LITE 3.0.0505.0    ** R E S P O N S E **    07-MAY-2014 15:45:49.596
    LAST COMMIT DATE: 2014/05/01 15:50:06 STATE OF CURRENT EXE: Modified

    RESPONSE MODULE SUMMARY FILE

    NAME OF THIS FILE:                                 EXAMPLE1.RSUM

    NAME OF THE RESPONSE BINARY OUTPUT FILE:           EXAMPLE1.RSP
    NAME OF THE MATERIAL PROPERTIES FILE:
   C:\Users\mbjorkma\AppData\Local\NASA HVIT\BUMPER3-LITE\mat-lite.prp

    MAN-MADE DEBRIS ANALYSIS
    ORDEM 3.0 DEBRIS ENVIRONMENT



    PROPERTY ID NUMBER =       1
       BLE name => courpal
            PERFORATION FAILURE CRITERIA
            REAR WALL MATERIAL =>                              6061-T6
             REAR WALL THICKNESS (CM) =>                       0.4
            TOTAL MLI AREAL DENSITY (G/CM2) =>                 0.06
```

2. The RESPONSE binary file *EXAMPLE1.RSP* containing the ballistic limit curve table.

4.2.4 Probable errors and possible causes

- Can't find .PRP file

4.3 Calculate the Spacecraft Impact Risk Task

4.3.1 Functional description

The *Bumper 3* code determines the number of penetrations (or PNP) from man-made Earth orbital debris and/or micrometeoroids impacting a spacecraft. The code can perform these calculations for all elements in the spacecraft model together or for specific ranges of element IDs.

The *Bumper 3* code PNP calculation can be broken into five main areas. The first consists of reading in the geometry and response databases. Next, the finite element cases are looped trough, evaluating only the exposed elements for each one. This consists of determining the flux of the critical projectile and storing the sum in a global array. This global array is the multiplied by the element surface array. The array is then summed up by element ID ranges. Finally, the PNP for each range is calculated.

4.3.2 Cautions and warnings

- Don't use the results of a probability of no impact (PNI) or PNP RESULT TYPE calculation to report the risk of failure of a redundant component. The *Bumper 3* code assumes that each component is independent and not redundant; hence the reported probability will be incorrect. See Section 5.14 for the procedure to modify the *Bumper 3* code output for the case of redundant components. (The *Bumper 3* code also doesn't analyze common mode failures, though the output from a *Bumper 3* code analysis could be used in calculation the probability of common mode failures.)

4.3.3 Procedures

Setup and Initialization – Setup and initialization is composed of the following

1. Obtain the spacecraft altitude from the mission planners
2. Obtain the duration of exposure from the mission planners
3. Calculate any environment files required. The following environments (may) require environment files not provided with the BUMPER3-LITE distribution:
4. ORDEM2000 (only required for elliptical orbits)
5. ORDEM3.0
6. MEMCxP v2
7. MEMR2
8. Place a copy of the .GEM file spacecraft self-shadowing database in the working directory
9. Place a copy of the .RSP file ballistic limit equation database in the working directory

Input Operations **–** The input operations are composed of the following steps.

Select Analysis – the *Bumper 3* code initially prompts for the analysis type. See Figure 41. Allowable inputs are

1. For a GEOMETRY analysis that will produce the database of exposed elements
2. For a RESPONSE analysis that will produce the table of critical diameters that will perforate a shield
3. For a SHIELD analysis, that will calculate the total probability of penetration or impact
4. For printing out the RESPONSE binary file as an ASCII file
5. To exit the *Bumper 3* code analysis

Type `3` for this task.

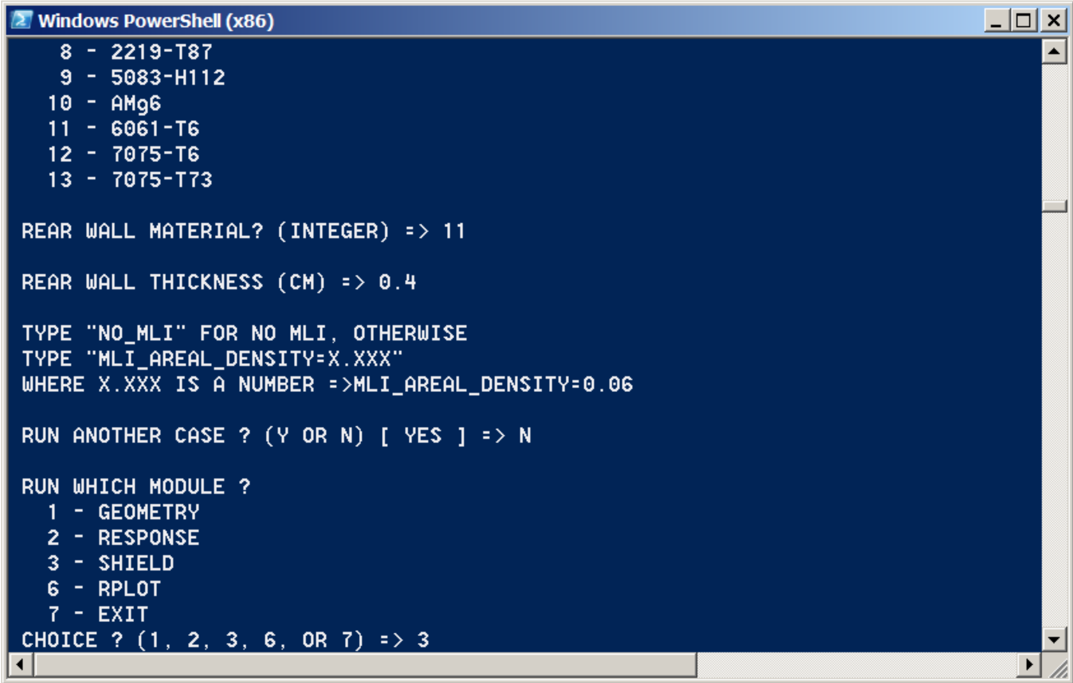


Figure 41. Analysis module selection.

VBETA plots – The *Bumper 3* code then prompts for whether to bin the number of impacts or number of penetrations of each element range by impact speed (V) and impact angle (BETA). Responding with `Y` will start the sorting of the results by element range, impact speed and impact angle. Note that this will have a significant impact on processing speed for large models. This task will respond with N to not perform the sorting. See Section 5.9 for a formal description of the VBETA prompts and response and the format of the .VBETA file.

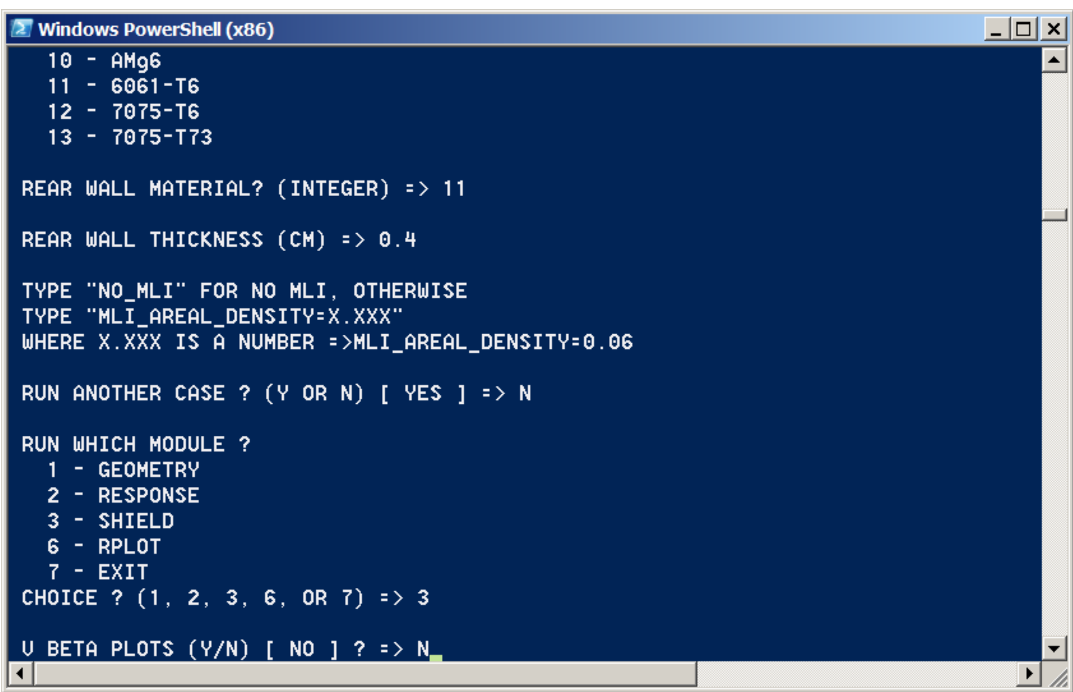


Figure 42. Create V-BETA output files for later plotting selection.

Summary filename – the *Bumper 3* code next prompts for the relative/absolute path and filename of the log file for this analysis task. Enter `EXAMPLE1.SUM` for this task. See Figure 43. The filename and path must be less than 256 characters.

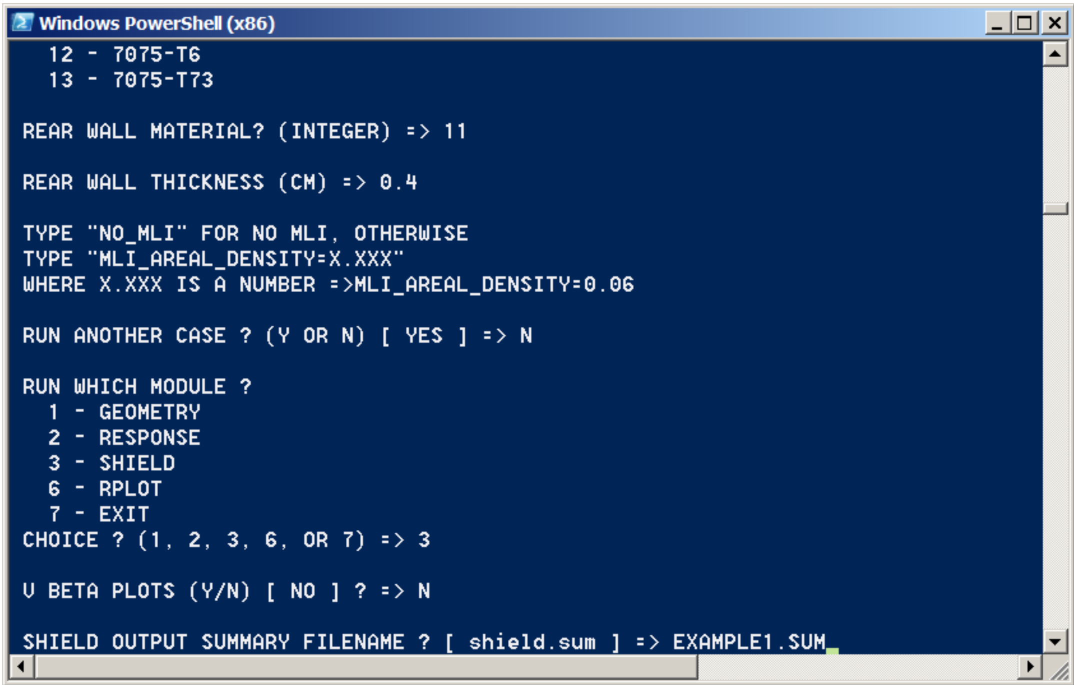


Figure 43. SHIELD summary filename selection.

Result type – The *Bumper 3* code next prompts for whether to calculate the number of impacts or the number of penetrations. Enter `3` for this task. See Figure 44. Do not use options 1 or 2 if there are redundant components and common failure modes. The *Bumper 3* code assumes the failure of each component is independent of another (i.e., no common mode failures) and that no critical capability is provided by redundant components.

```
TYPE "NO_MLI" FOR NO MLI, OTHERWISE
TYPE "MLI_AREAL_DENSITY=X.XXX"
WHERE X.XXX IS A NUMBER =>MLI_AREAL_DENSITY=0.06

RUN ANOTHER CASE ? (Y OR N) [ YES ] => N

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 3

V BETA PLOTS (Y/N) [ NO ] ? => N

SHIELD OUTPUT SUMMARY FILENAME ? [ shield.sum ] => EXAMPLE1.SUM

RESULT TYPE ?
  1 - PNP (PROBABILITY OF NO PENETRATION) <CR>
  2 - PNI (PROBABILITY OF NO IMPACT)
  3 - N (NUMBER OF PENETRATIONS)
  4 - N (NUMBER OF IMPACTS)
 CHOICE ? (1, 2, 3 OR 4) [ 1 ] => 3
```

Figure 44. Result type selection.

Spacecraft self-shadowing database filename – The *Bumper 3* code next prompts for the filename of the self-shadowing database calculated in Section 4.1. See Figure 45. Enter `EXAMPLE1.GEM`.

```
WHERE X.XXX IS A NUMBER =>MLI_AREAL_DENSITY=0.06

RUN ANOTHER CASE ? (Y OR N) [ YES ] => N

RUN WHICH MODULE ?
  1 - GEOMETRY
  2 - RESPONSE
  3 - SHIELD
  6 - RPLOT
  7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 3

V BETA PLOTS (Y/N) [ NO ] ? => N

SHIELD OUTPUT SUMMARY FILENAME ? [ shield.sum ] => EXAMPLE1.SUM

RESULT TYPE ?
  1 - PNP (PROBABILITY OF NO PENETRATION) <CR>
  2 - PNI (PROBABILITY OF NO IMPACT)
  3 - N (NUMBER OF PENETRATIONS)
  4 - N (NUMBER OF IMPACTS)
 CHOICE ? (1, 2, 3 OR 4) [ 1 ] => 3

GEOMETRY BINARY OUTPUT FILENAME ? [ geometry.gem ] => EXAMPLE1.GEM
```

Figure 45. The spacecraft self-shadowing database filename selection.

Environment file definition – The *Bumper 3* code determines from the self-shadowing database file (.GEM) which environment should be evaluated. If the analysis uses the ORDEM 3.0 environment, then the ORDEM 3.0 environment calculations require environment files calculated with *ORDEM-GUI.EXE.* This program is distributed by the NASA Orbital Debris Program Office, Johnson Space Center (JSC), Houston, TX. ORDEM 3.0 environment files are distributed with the BUMPER 3 code. See Appendix D for a listing of the files available. Since we want to calculate the number of perforations of a cube in the ISS orbit during the year 2014 type `OD3_2014_400` for this example.

```
Windows PowerShell (x86)
RUN WHICH MODULE ?
   1 - GEOMETRY
   2 - RESPONSE
   3 - SHIELD
   6 - RPLOT
   7 - EXIT
CHOICE ? (1, 2, 3, 6, OR 7) => 3

V BETA PLOTS (Y/N) [ NO ] ? => N

SHIELD OUTPUT SUMMARY FILENAME ? [ shield.sum ] => EXAMPLE1.SUM

RESULT TYPE ?
   1 - PNP (PROBABILITY OF NO PENETRATION) <CR>
   2 - PNI (PROBABILITY OF NO IMPACT)
   3 - N (NUMBER OF PENETRATIONS)
   4 - N (NUMBER OF IMPACTS)
 CHOICE ? (1, 2, 3 OR 4) [ 1 ] => 3

GEOMETRY BINARY OUTPUT FILENAME ? [ geometry.gem ] => EXAMPLE1.GEM

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ORDEM 3.0 INPUT FILENAME ? > OD3_2014_400
```
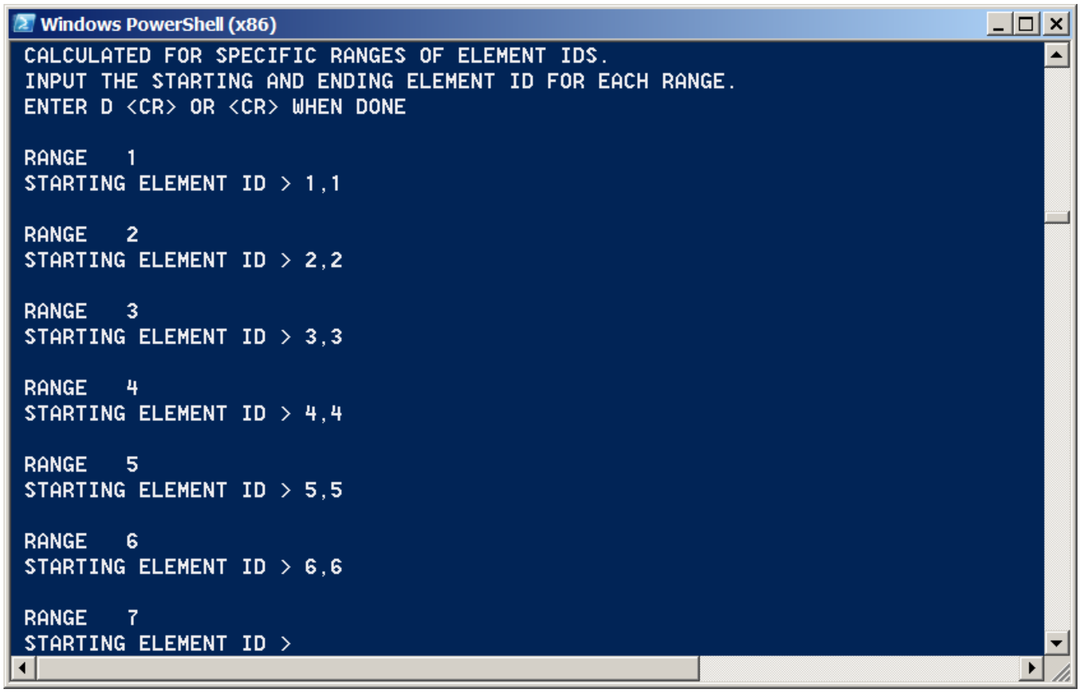

Figure 46. The ORDEM 3 environment filename selection.

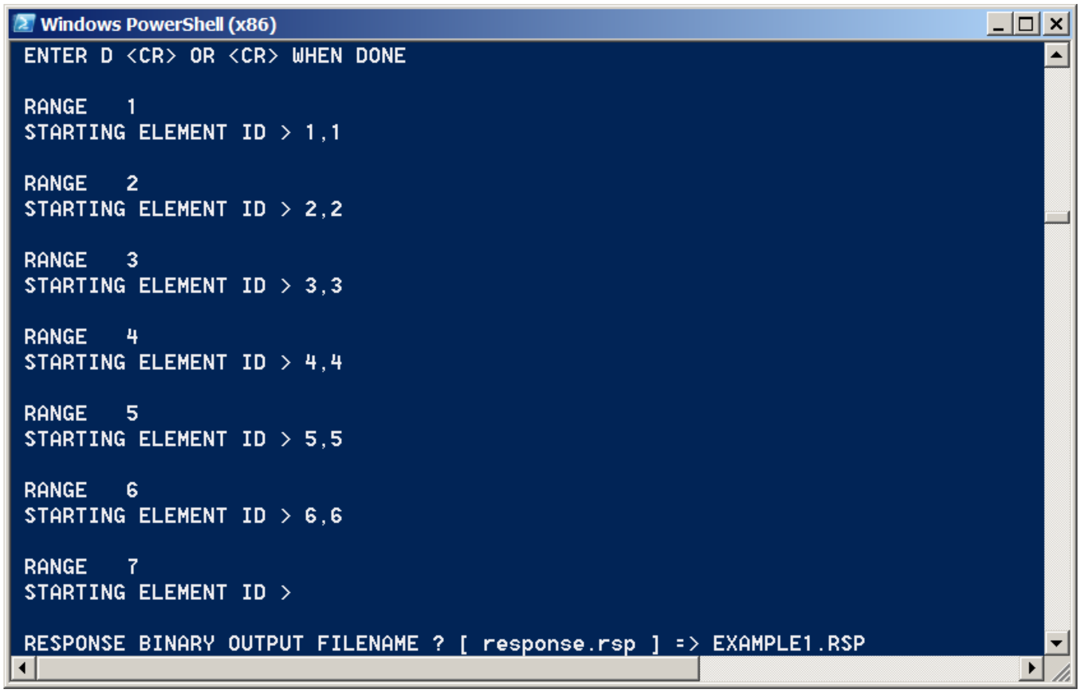
Element ranges – Next, the *Bumper 3* code prompts for the range of elements for which to calculate the total number of penetrations. The *EXAMPLE1.UNV* universal file had one element per cube face. So if we desire the number of penetrations on each side of the cube we need to enter an element range from 1 to1, 2 to 2, etc. This is done by entering the start element ID and stop element ID separated by a comma, all on one line, such as shown in Figure 47. To complete the element range operation, enter a carriage return or a `D`.



```
Windows PowerShell (x86)
CALCULATED FOR SPECIFIC RANGES OF ELEMENT IDS.
INPUT THE STARTING AND ENDING ELEMENT ID FOR EACH RANGE.
ENTER D <CR> OR <CR> WHEN DONE

RANGE    1
STARTING ELEMENT ID > 1,1

RANGE    2
STARTING ELEMENT ID > 2,2

RANGE    3
STARTING ELEMENT ID > 3,3

RANGE    4
STARTING ELEMENT ID > 4,4

RANGE    5
STARTING ELEMENT ID > 5,5

RANGE    6
STARTING ELEMENT ID > 6,6

RANGE    7
STARTING ELEMENT ID >
```

Figure 47. The element ID range selection.

Shield ballistic limit curve table filename – The *Bumper 3* code next prompts for the name of the file from the Spacecraft Shield Ballistic Limit Curve Table task generated in Section 4.2. See Figure 48. Enter the filename `EXAMPLE1.RSP`. The *Bumper 3* code assumes the file resides in the working directory. However, other locations will be searched when a relative path or an absolute path name are added to the filename. Again, the total path and filename must be less than 256 characters.



```
Windows PowerShell (x86)
ENTER D <CR> OR <CR> WHEN DONE

RANGE    1
STARTING ELEMENT ID > 1,1

RANGE    2
STARTING ELEMENT ID > 2,2

RANGE    3
STARTING ELEMENT ID > 3,3

RANGE    4
STARTING ELEMENT ID > 4,4

RANGE    5
STARTING ELEMENT ID > 5,5

RANGE    6
STARTING ELEMENT ID > 6,6

RANGE    7
STARTING ELEMENT ID >

RESPONSE BINARY OUTPUT FILENAME ? [ response.rsp ] => EXAMPLE1.RSP
```

Figure 48. The RESPONSE projectile diameter at the ballistic limit table filename selection.

Contouring data filename – The *Bumper 3* code finally prompts for whether to create the file for contouring data for plotting on the finite element model in I-deas. Type `N` for this tutorial. See Figure 49.

If options 1 or 3 were selected in the *Result Type* section above, then the contouring data are numbers of perforations per square meter times 100. This is approximately equal to the probability of perforation in percent for a total probability of perforation much less than 1. This is why the I-deas contouring file title record is PROBABILITY OF PENETRATION (%) PER M2. This title will print to the screen when contouring the finite element model with the data file. For large numbers of perforations this is just 100 times the number of penetrations.

If options 2 or 4 were selected in the *Result Type* section above, then the contouring data are number of impacts per square meter times 100.

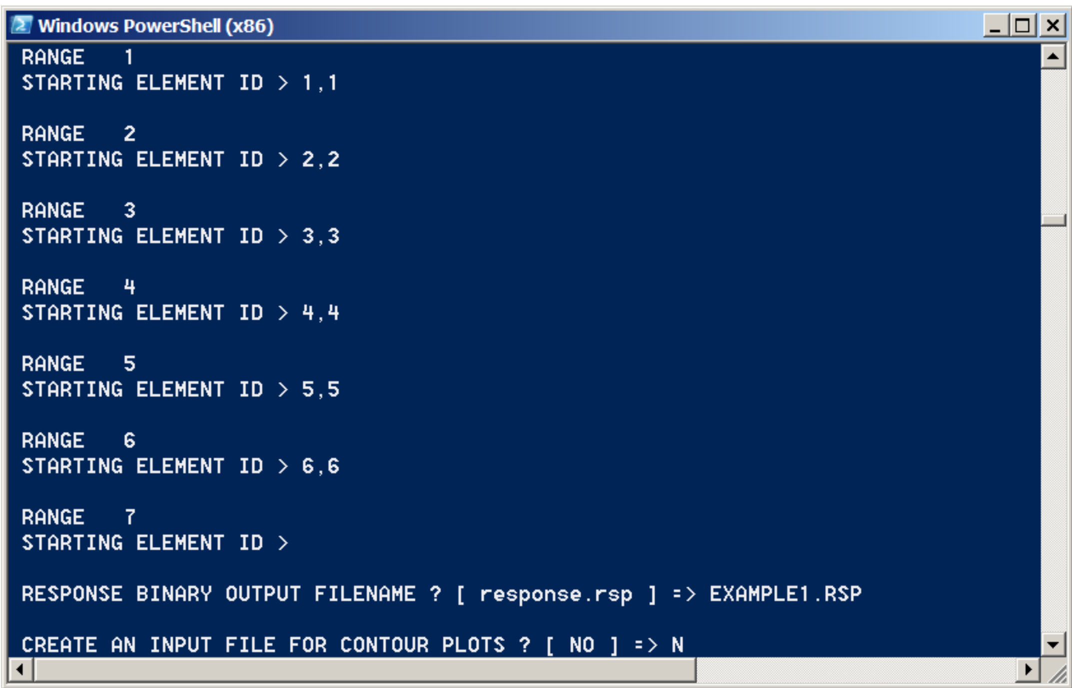


Figure 49. I-deas contouring data filename selection.

SHIELD number of perforations results – Next, the *Bumper 3* code runs through the threats computing the number of perforations of each exposed element. The final results are printed the screen as shown in Figure 50 and to the summary file. The ORDEM 3 results are in 10 columns that wrap to the next line on an 80-column console screen. The first column is the number identifier for the element range. The second column is the starting element ID for the element range. The third column is the ending element ID for the element range. The fourth column is the total number for perforations for that element range. The fifth column is the number of perforations by sodium/potassium orbital debris particles from soviet radar satellites. The sixth column is the number of perforations by low-density orbital debris particles (~1.4 grams per cubic cm). The seventh column is the number of perforations by medium-density orbital debris particles (~2.8 grams per cubic cm). The eighth column is the number of perforations by high-density orbital debris particles (~7.9 grams per cubic cm). The ninth column is the number of perforations by intact objects (~2.8 grams per cubic cm). The tenth column is the total surface area of the element range in square meters.

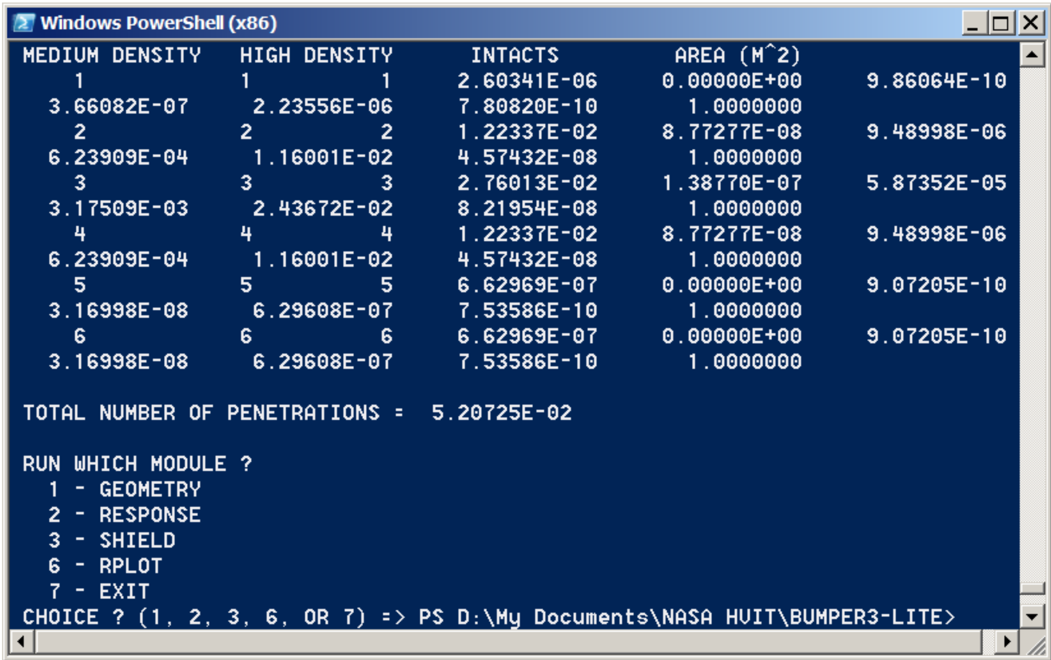


Figure 50. SHIELD number of perforations results.

Results – The results of the Calculate the Spacecraft Impact Risk Task described above are:

1. The spacecraft impact risk task log file (also called the summary file) file lists the numbers of impact or penetration (or PNI or PNP) for each range of elements selected. An example code block is shown below.
    a. The first line of the summary file is the *Bumper 3* code version number and the analysis date.
    b. The second line lists the subversion commit date for the source and whether the executable was compiled from modified source. All distributed *Bumper 3* executables will report they are compiled from modified source because the automated build scripts modify the source with the current build number.
    c. Lines 8 to 11 list the summary filename, universal filename, geometry filename and contour filename for the current analysis
    d. Line 12 to 13 lists whether the model was rotated, and if so by what angles.
    e. Lines 14 to 20 list the environment parameters and the orbit parameters that affect the environment. For ORDEM 3 this includes the environment data filename, the start date of exposure and the exposure duration. The orbit altitude and orbit inclination, important parameters of all environments, were used to compute the environment file and are not inputs to the SHIELD, other than through the fluxes computed for the environment files.
    f. Line 22 lists the name of the shield ballistic limit equation table file.
    g. Lines 24 to 30 list the number of penetrations data. Column one lists the element range ID number, column 2 lists the element range starting element ID number and column 3 lists the element range ending element ID number. The fourth column lists the total number of penetrations for each element range. Columns 5 through 9 list the numbers of penetration broken down by ORDEM 3 population and the last column lists the upside surface area of the element range.
2. The optional VBETA file. See Section 5.9.
3. The optional contour data file. See Section 5.10.

4.3.4 Probable errors and possible causes

- None identified.

5.0 Reference

5.1 Change the Runtime Control File Parameters Operation

Changing the runtime control file parameters operation is optional. The *Bumper 3* code will run with the installed runtime control file.

5.1.1 Functional description

The runtime control file is used to configure the *Bumper 3* code at runtime. Currently, four features are configured:

1. The path to the environment files.
2. Whether the user is prompted for the shield geometry data for PIDs automatically number in sequential order, or whether the user enters the PID number for each shield geometry in an order of their choosing.
3. The name of the *mat.prp* file to read.

First, the *Bumper 3* code writes default values to the variables managed by the runtime control file. Second, the *Bumper 3* code looks for a runtime control file in the program files directory. Finally, the *Bumper 3* code looks in the working directory from which the *Bumper 3* code runs. The *Bumper 3* code uses the last variable read by the runtime control file parser.

The runtime control file is read once during the *Bumper 3* code initialization. Any changes to the runtime control file will not be recognized by the *Bumper 3* code until you close out the running the *Bumper 3* code session and restart the *Bumper 3* code.

5.1.2 Cautions and warnings

- The *bumper.rc* file must be an ASCII text file. Do not use different encodings for the text. This can happen when using Word or Wordpad to edit *bumper.rc*. If you see facing quotes like “ ” and not straight quotes like " ", then the file has been converted to an unusable format. Use Notepad or an editor that gives you control over the character encoding.
- Paths must be entered enclosed by double quotes; i.e., "path variable".
- Paths should be kept to less than 256 characters.

5.1.3 Formal description

The runtime control file is currently composed of comment lines, and data lines composed of a key word and up to seven values. A comment line begins with a hash (#) in the first column, or else the parser will attempt to parse it as a key word/value pair. The data line is composed of a key word, starting in the first column with no spaces. The key word can be a mixture of upper and lower case. However, the parser converts all the characters to upper case so two key words cannot differ by case alone. The values are separated from the key word by spaces. Values may be upper case, lower case, or a mixture of upper and lower case. If a value contains spaces, such is the directory paths shown below, the keyword has to be enclosed in double quotes ("). Note that paths must use the correct case on the Linux operating system. The parser reads the keyword/value record as a string of up to 256 characters long. Therefore the length of the value can be no longer than 256 minus the length of the keyword.[2] So if the ORDEM2000DIR keyword/value record is entered with 244 leading blanks, then the record is truncated, deleting the value string.

The default values and the values set in *bumper.rc* are listed below in Table 4.

Table 4. BUMPER3-LITE *bumper.rc* Default Values

Runtime control variable	Default value	install value	Format
ORDEM2000DIR	“”	“ORDEM2000”	A256 – keyword length
ORDEM3p0DIR	“”	“ORDEM3p0”	A256 – keyword length
MEMCxPv2DIR	“”	“MEMCxPv2”	A256 – keyword length
MEMR2DIR	“”	“MEMR2”	A256 – keyword length
MODELCHECK	true	true	A256 – keyword length
AUTOMATICPIDNUMBERING	true	true	A256 – keyword length
MAT.PRPNAME	mat.prp	mat-lite.prp	A256 – keyword length
ISSHADOWELEMENT	true	true	A256 – keyword length

The default values are obtained when there are no *bumper.rc* files in *%LOCALAPPDATA%\NASA HVIT*\BUMPER-LITE and the working directory. The install values are obtained when there is an unmodified copy of the installed *bumper.rc* in *%LOCALAPPDATA%\NASA HVIT\BUMPER-LITE*. Otherwise, the value is given by the values specified in the working directory copy of *bumper.rc*.

Setting MODELCHECK to false will defeat the model checking step in the *Bumper 3* code calculation. The only situation that this would be desirable is re-running a large model (hundreds of thousands of elements) that has already passed the model check. The model check function may take a long time for large models, hence the option to turn it off. See section 5.3.

Setting AUTOMATICPIDNUMBERING to true will expose the PID renumbering capability in RESPONSE and SHIELD. The PID renumbering operation is described in Section 5.6.

---

[2] This is indicated in Table 4 in column 4 using the FORTRAN edit format statement A256. This is FORTRAN statement for a 256 character long ASCII string. FORTRAN edit format statements are used throughout this software user manual to indicate the data format.

Setting MAT.PRPNAME to a valid filename causes the *Bumper 3* code to read from the specified file and not the defaults. The format of the *mat.prp* file is described in Section 5.5.

Setting ISSHADOWELEMENT to true directs RESPONSE to read the array of logical values that define whether a PID is SHADOW. To have *Bumper 3* use an .RSP file that pre-dates this feature set ISSHADOWELEMENT to false.

5.1.4 Examples

The *BUMPER3-LITE* runtime control file distributed in the Windows installer package is reproduced below in Figure 51.

```
#
#
# BUMPER3-LITE runtime control file
#
#
# ORDEM2000DIR is the relative path to the ORDEM2000 environment files.
#
ORDEM2000DIR "ORDEM2000"
#
# ORDEM3p0DIR is the relative path to the ORDEM 3.0 environment files
#
ORDEM3p0DIR "ORDEM3p0"
#
# MEMCXPV2DIR is the relative path to the MEMCxP ver. 2 environment files
#
MEMCXPV2DIR "MEMCxPv2"
#
# MEMR2DIR is the relative path to the MEMR2 ver. 2.0.1 environment files
#
MEMR2DIR "MEMR2"
#
# automaticPIDNumbering is the flag for switching on a prompt for the PID
number instead of RESPONSE assigning PID numbers
# sequentially.
# automaticPIDNumbering TRUE will run a standard RESPONSE analysis where the
PIDs are entered sequentially and without gaps
# automaticPIDNumbering FALSE will cause RESPONSE to prompt for the PID
number, which can be entered in any order and with
#  gaps in the numbering
#
automaticPIDNumbering true
#
#
# Change the default mat.prp name. Don't add a path to the file name. Your
choices are to locate mat-cev.prp in %BUMPERDIR%
# or in the working directory, and that is it.
#
MAT.PRPName "mat-lite.prp"
#
#
# Check the universal file for large length to width ratio tri and quad
elements and for saddle shaped quads.
#
MODELCHECK true
#
```

```
# END
##
```

Figure 51. BUMPER3-LITE runtime control file, *bumper.rc.*

5.1.5 Possible error messages and causes

- The most common error message is when the path is entered incorrectly and the environment file can't be found.

5.1.6 Cross references to other operations

1. Complementary operations
   a. None
2. Predecessor operations
   a. None
3. Successor operations
   a. Section 5.6 "Calculate the spacecraft shield ballistic limit curve table operation".
   b. Section 5.8 "Calculating the number of spacecraft shield impacts or penetrations operation".

5.2 Create the Spacecraft Geometry Universal File Operation

Create the spacecraft geometry universal file operation is mandatory. The *Bumper 3* code will not run without a spacecraft geometry file.

5.2.1 Functional description

The "Create the spacecraft geometry universal file" operation is performed outside of the *Bumper 3* code, usually with the computer program NX/I-deas. The output of the "Create the spacecraft geometry universal file" operation is an I-deas universal file (.UNV) which is an input to the "Calculate the Spacecraft Self-Shadowing Database" operation, Section 5.4.

5.2.2 Cautions and warnings

- Do use the I-deas Universal File Format (formerly SUPERTAB).
- Do define all nodal coordinates in one global Cartesian coordinate system.
- Do orient the model with respect to the global coordinate system so that the positive X-axis is parallel to the spacecraft velocity vector and the positive Z-axis is pointed toward the zenith (away from the Earth). Failure to follow these conventions will invalidate the model and the analysis. See Figure 52. Note that the analysis orientation of the spacecraft can be changed within the GEOMETRY module of the *Bumper 3* code.

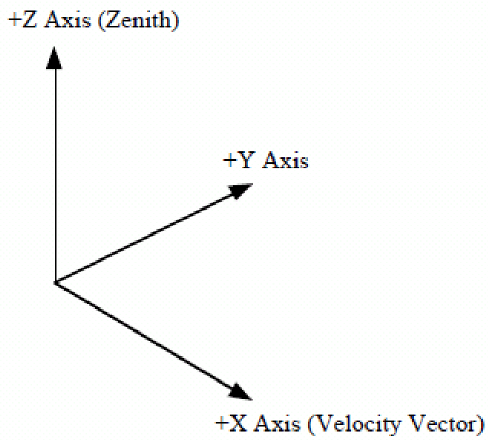


Figure 52. FEM Coordinate System.

- Do use triangular or quadrilateral shell elements.
  - Bricks and beam elements will be rejected by the *Bumper 3* code.
- Do keep the aspect ratio of the elements as close to 1-to-1 as possible.
  - Long thin elements may lead to erroneous results.
- When modeling cylindrical sections, at least 24 divisions should be used around the circumference (24 elements for quadrilaterals, 48 elements for triangles). Axial divisions should then be chosen to optimize the aspect ratio at 1-to-1. The user should ensure an adequate model by verifying that the PNP does not change significantly with changes in mesh size.
- All FEM dimensions must be specified in meters.

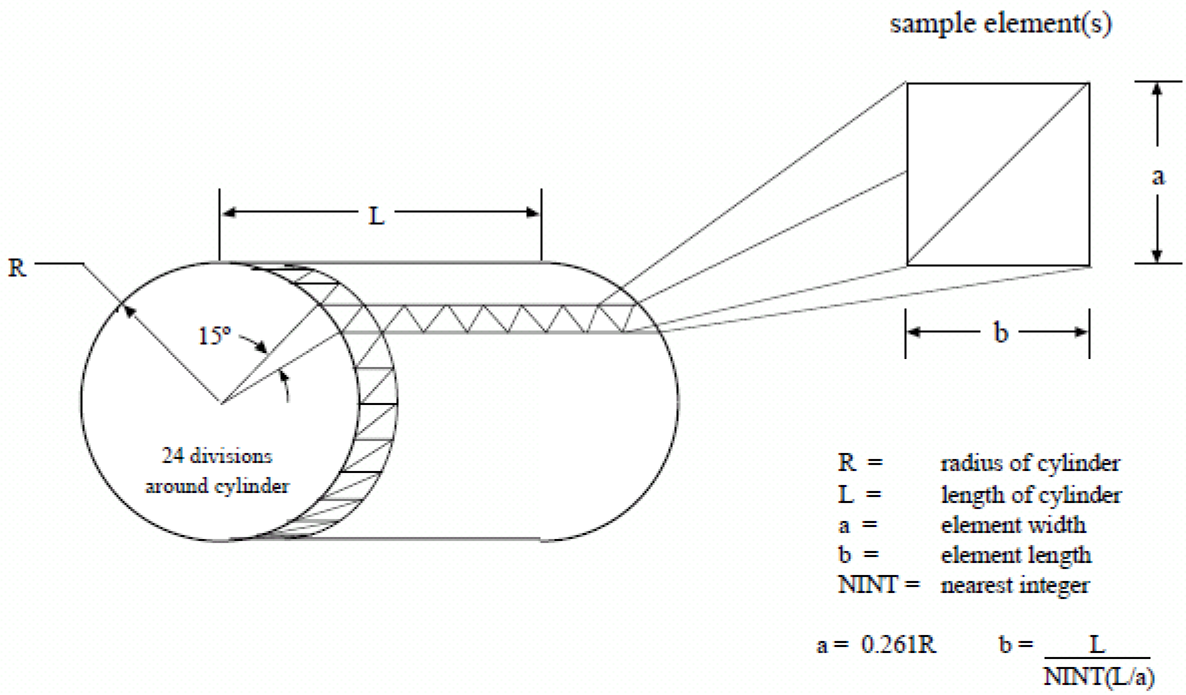


Figure 53. Cylinder modeling techniques.

- Do define the element connectively data so that the element normal points from the inside of the module/structure to the outside, except in special circumstances. Traversing the element connectivity data by the right-hand rule defines the direction of the normal vector.

The element normal vector is used to determine whether the element faces toward the threat. Ordinarily, the outer surface of the FEM consists of elements all having outward-pointing normal vectors. But in special cases where impacts on internal surface are important, additional elements with inward-pointing vectors may be required. This special case is illustrated below with Figure 54 showing the space station solar dynamic receiver model; the first *Bumper 3* code analysis performed in 1987.

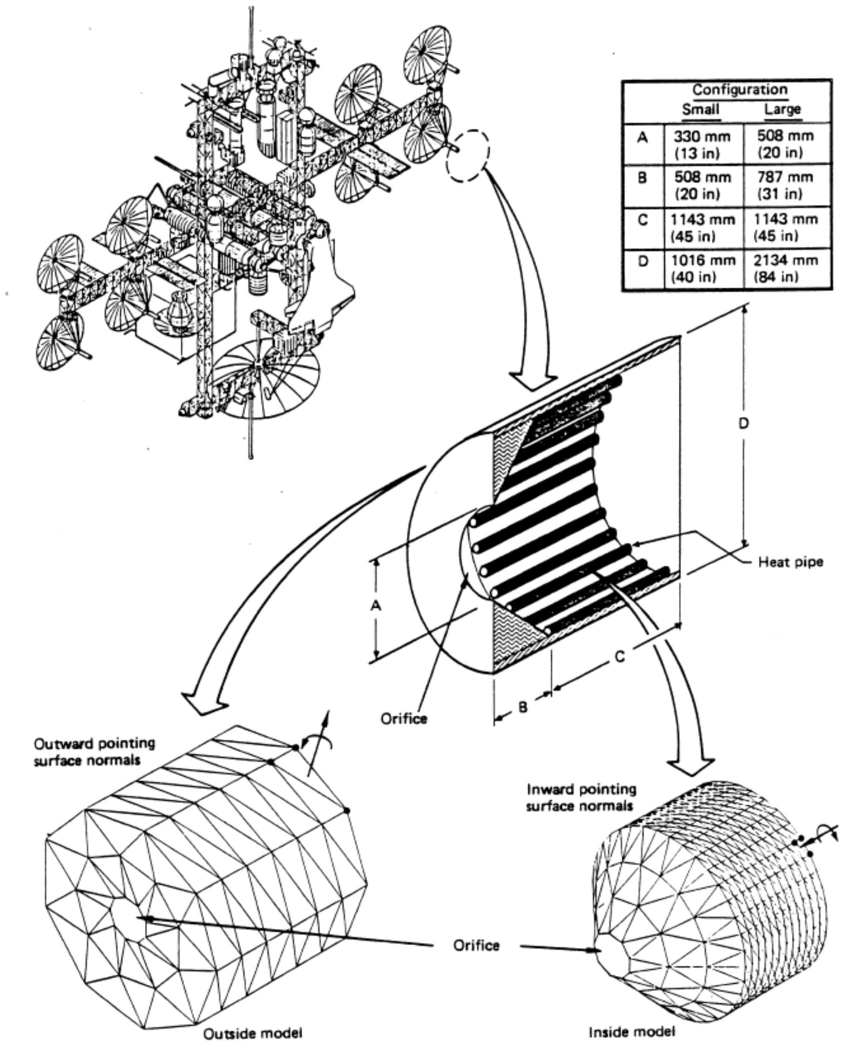


Figure 54. Solar dynamic receiver model.

The issue was the risk of impact on the critical tubes around the interior of the receiver from meteoroids passing through the orifice. The receiver model was constructed from two parts that are shown in exploded form in Figure 54. The normals for the two parts are shown in the upper right-hand corner of each part. The outside part shadows the inside part from impact, except for those threats that pass through the orifice.

Failure to follow the modeling conventions stated above will invalidate the model and the analysis.

- Do number all elements representing a single critical end item using a range of element IDs that does not overlap with any other critical end items. The *Bumper 3* code calculates PNPs or PNIs for a range of elements from the list of ranges of elements provided by the user at runtime. The *Bumper 3* code will list PNPs for every range in the users list; however, it is up to the user to combine the results for groups of ranges of elements. This is can be an error-prone process if the element ranges are significantly fragmented.

- Do keep the number of element ranges less than NRMAX=5,000, which is an array extent set in modPARAMETERS.f90 source file.
- Do keep the number of element ranges any element belongs to less than Nranges=20, which is an array extent set in modPARAMETERS.f90 source file.
- Do keep the largest element PID number less than maxPropertyID=25,000, which is an array extent set in modPARAMETERS.f90 source file. The *Bumper 3* code uses the PID number to assign a ballistic limit curve to each element for the number of penetrations calculation in SHIELD.
- Do keep the number of PIDs in the finite element model less than IPFUNCS=5,000, which is an array extent set in modPARAMETERS.f90 source file.
- Do not assign each element a unique PID number. The PID numbers represent unique shield configurations and are a fixed resource that can be exceeded. Assign piecewise continuous regions of the spacecraft that share a common shield configuration the same PID number.

Many customary FEM limitations do not apply to the *Bumper 3* code. Coincident, extra, and unattached nodes will not cause premature code failure. The model does not require constraints against translations or rotations, as it is used only to define spacecraft geometry. Structures that are in reality attached need only be modeled adjacent to each other. An important criterion is that if a structure normally shadows another structure's view of threat, then it must be modeled with sufficient accuracy and resolution to represent that shadowing. Any elements that are totally enclosed, and therefore completely shielded from all threats by other elements, will not affect the solution.

5.2.3 Formal description

The I-deas universal file is an ASCII text file with input records terminated by a carriage return/line feed pair. The format of the I-deas universal file is illustrated below with an example code block.

Table 5 is a more formal definition of the format using Fortran edit format statements.

The universal file uses input blocks with a start dataset identifier of -1 followed on the next line by the dataset ID and a stop dataset identifier of -1, as illustrated below:

```
    -1
Dataset ID
dataset
    -1
```

The format of the start and stop dataset identifiers are (I6). I-DEAS outputs a large number of datasets. BUMPER uses five of them:

151 header dataset

164 coordinate system dataset

2420 coordinate transformation dataset

2411 nodal coordinate dataset

2412 element connectivity dataset

The I-deas universal file format specification from the Structural Dynamics Research Corporation documentation for the four datasets used by the *Bumper 3* code are included below as Table 5.

Table 5. I-deas Universal File Format

```
Universal File dataset number 151 (header)
Record 1:  FORMAT(80A1)
           Field 1          -- model filename
Record 2:  FORMAT(80A1)
           Field 1          -- model file description
Record 3:  FORMAT(80A1)
           Field 1          -- program which created DB
Record 4:  FORMAT(10A1,10A1,3I10)
           Field 1          -- date database created (DD-MMM-YY)
           Field 2          -- time database created (HH:MM:SS)
           Field 3          -- version from database
           Field 4          -- Subversion from database
           Field 5          -- File type
                              =0 Universal
                              =1 Archive
                              =2 Other
Record 5:  FORMAT(10A1,10A1)
           Field 1          -- date database last saved (DD-MMM-YY)
           Field 2          -- time database last saved (HH:MM:SS)
Record 6:  FORMAT(80A1)
           Field 1          -- program which created universal file
Record 7:  FORMAT(10A1,10A1,4I5)
           Field 1          -- date universal file written (DD-MMM-YY)
           Field 2          -- time universal file written (HH:MM:SS)
           Field 3          -- Release which wrote universal file
           Field 4          -- Version number
           Filed 5          -- Host ID
                               =1 Vax/VMS        =3 HP7xx,HP-UX
                               =4 RS/6000        =5 Alp/VMS
                               =6 Sun            =7 Sony
                               =8 NEC            =9 Alp/OSF
                               =10 PC
           Field 6          -- Test ID
           Field 7          -- Release counter per host
```

```
Universal file dataset number 164 (units)
Record 1:  FORMAT(I10,20A1,I10)
Field 1                -- units code
  = 1 - SI: Meter (newton)
  = 2 - BG: Foot (pound f)
  = 3 - MG: Meter (kilogram f)
  = 4 - BA: Foot (poundal)
  = 5 - MM: mm (milli newton)
  = 6 - CM: cm (centi newton)
  = 7 - IN: Inch (pound f)
  = 8 - GM: mm (kilogram f)
  = 9 - US: USER_DEFINED
Field 2                -- units description (used for documentation only)
Field 3                -- temperature mode
  = 1 - absolute
  = 2 - relative
Record 2:  FORMAT(3D25.17)
Unit factors for converting universal file units to SI.
To convert from universal file units to SI divide by
The appropriate factor listed below.
```

Field 1	-- length	
Field 2	-- force	
Field 3	-- temperature	
Field 4	-- temperature offset	

Universal File dataset number 2420 (coordinate systems)

Record 1:	FORMAT(1I10)	
	Field 1	-- Part UID
Record 2:	FORMAT(40A2)	
	Field 1	-- Part name
Record 3:	FORMAT(3I10)	
	Field 1	-- Coordinate system label
	Field 2	-- Coordinate system type =0 Cartesian =1 Cylindrical =2 Spherical
	Field 3	-- Coordinate system color
Record 4:	FORMAT(40A2)	
	Field 1	-- Coordinate system name
Record 5	FORMAT(1P3D25.16)	
	Field 1	-- Transformation matrix row 1
Record 6	FORMAT(1P3D25.16)	
	Field 1	-- Transformation matrix row 2
Record 7	FORMAT(1P3D25.16)	
	Field 1	-- Transformation matrix row 3
Record 8	FORMAT(1P3D25.16)	
	Field 1	-- Transformation matrix row 4

Records 3 through 8 are repeated for each coordinate system in the part.

Universal File dataset number 2411 (nodes – double precision)

Record 1:	FORMAT(4I10)	
	Field 1	-- node label
	Field 2	--export coordinate system number
	Field 3	-- displacement coordinate system number
	Field 4	-- color
Record 2	FORMAT(1P3D25.16)	
	Fields 1-3	-- node coordinates in the part coordinate system

Records 1 and 2 are repeated for each node in the model.

Universal File dataset number 2412 (connectivity data)

Record 1:	FORMAT(6I10)	
	Field 1	-- element label
	Field 2	-- FE descriptor ID
	Field 3	-- physical property ID
	Field 4	-- material ID
	Field 5	-- color
	Field 6	-- number of nodes per element (n)
Record 2:	FORMAT(8I10)	
	Fields 1-n	-- node labels defining element

Records 1 and 2 are repeated for each element in the model.

5.2.4 Examples

An example of the minimum number of datasets required to successfully input data for a cube into the *Bumper 3* code is shown in the code block below. This code block is a copy of the *EXAMPLE1.UNV* file.

```
    -1
   151
/users/mdb/cube6elem.mf1
/users/mdb/cube6elem.mf1
I-DEAS 9 :    Simulation
30-Apr-02   15:38:54        25         0         0
Never     Never
I-DEAS 9 :    Simulation
30-Apr-02   15:42:49    9    0    2    0    0
    -1
    -1
   164
         1Meter (newton)               2
  1.00000000000000000D+00  1.00000000000000000D+00  1.00000000000000000D+00
  2.73149999999999980D+02
    -1
    -1
  3211
         3         1     65536
tom
tom
tom

    -1
    -1
  2420
         9
Part1
         1         0         8
CS1
   1.0000000000000000D+00   0.0000000000000000D+00   0.0000000000000000D+00
   0.0000000000000000D+00   1.0000000000000000D+00   0.0000000000000000D+00
   0.0000000000000000D+00   0.0000000000000000D+00   1.0000000000000000D+00
   0.0000000000000000D+00   0.0000000000000000D+00   0.0000000000000000D+00
    -1
    -1
  2411
         1         1         1        11
   1.0000000000000000D+00   0.0000000000000000D+00   0.0000000000000000D+00
         2         1         1        11
   1.0000000000000000D+00   1.0000000000000000D+00   0.0000000000000000D+00
         3         1         1        11
   0.0000000000000000D+00   1.0000000000000000D+00   0.0000000000000000D+00
         4         1         1        11
   0.0000000000000000D+00   0.0000000000000000D+00   0.0000000000000000D+00
         5         1         1        11
   1.0000000000000000D+00   0.0000000000000000D+00   1.0000000000000000D+00
         6         1         1        11
   1.0000000000000000D+00   1.0000000000000000D+00   1.0000000000000000D+00
         7         1         1        11
   0.0000000000000000D+00   1.0000000000000000D+00   1.0000000000000000D+00
         8         1         1        11
   0.0000000000000000D+00   0.0000000000000000D+00   1.0000000000000000D+00
```

```
      -1
      -1
    2412
         1         94          1          1          7          4
         3          7          6          2
         2         94          1          1          7          4
         1          2          6          5
         3         94          1          1          7          4
         1          5          8          4
         4         94          1          1          7          4
         8          7          3          4
         5         94          1          1          7          4
         8          5          6          7
         6         94          1          1          7          4
         1          4          3          2
      -1
```

5.2.5 Possible error messages and causes

Not applicable.

5.2.6 Cross references to other operations

1. Complementary operations
    a. None.
2. Predecessor operations
    a. Gather the spacecraft design information.
    b. Build the finite element model with I-deas.
3. Successor operations
    a. Section 5.3 “Check the Model File Operation.”
    b. Section 5.4 “Calculate the Spacecraft Self-Shadowing Database Operation.”

5.3 Check the Model File Operation

The check model file operation is mandatory. The *Bumper 3* code will not continue if the modelCheck operation fails.

5.3.1 Functional description

The model check operation searches for malformed elements in the universal file that will cause the *Bumper 3* code to exit without completing the computation. ModelCheck looks for bad aspect ratio tri and quad elements and for the quad saddle-shaped elements shown in the Figure 55. The dashed line is a line in the plane of the quadrilateral that crosses the element diagonal. If the model is saddle shaped, the line is not in one plane and has a change in slope at the diagonal.

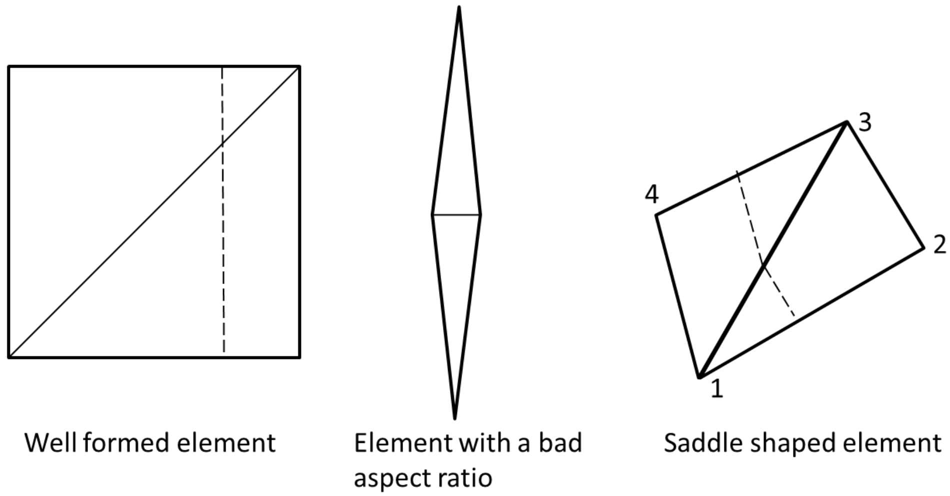


Figure 55. Malformed element shapes detected by the ModelCheck operation.

ModelCheck tests for a bad aspect ratio by computing the ratio of the area of the element divided by the area of circle that circumscribes the element. If the ratio is less than 0.01 for a quadrilateral element or less than 0.005 for a triangular element, then the *Bumper 3* code writes a warning to the .warn file. Bad aspect ratio elements never generate any error. However, the careful analyst will rebuild the model to eliminate bad aspect ratio elements to preclude incorrect self-shadowing analyses.

ModelCheck tests for a saddle-shaped element as follows. Three points define a plane, but a saddle-shaped element has a fourth node that is more than 10% off the plane of the other three nodes. (Figure 55 illustrates the locations of Nodes 1, 2, 3, and 4 with the labels 1, 2, 3, and 4.) This ratio is defined as the distance of node 3 off the node 1/node 2/node 4 plane divided by the length of the chord from node 1 to node 3 or the distance of node 4 off the node 1/node 2/node 3 plane divided by the length of the chord from node 2 to node 4. Whichever ratio is smallest is the ratio that is used. For elements where the ratio exceeds 50%, the element is reported in the .error file. Elements over 10% are recorded in the .warn file.

ModelCheck also tests for whether an element normal can be computed. If the normal has a NaN for a component, then an error is recorded to the .error file.

ModelCheck also checks for whether the model was built using meters for the length measurement, whether there is only one coordinate system, and whether there isn't any coordinate system transformation defined.

If modelCheck writes error messages to the .error file, then the *Bumper 3* code will stop.

5.3.2 Cautions and warnings

- Do use the modelCheck option to preclude *Bumper 3* code errors.
- I-deas computes the model geometry with single precision arithmetic (but formats the output as double). Nodal coordinates differing in the fifth or sixth significant digit will lead to one or two significant figure results.
- Note that modelCheck tests for elements that will result in zero element surface area or elements that have NaNs for surface normal components. This is done to preclude the SHIELD calculation from stopping due to numerical errors. However, none of these tests validate the model's applicability to a self-shadowing calculation. It is up to the analyst to

build the model with elements with aspect ratio of approximately one, with approximately the same surface area, and with sufficient numbers of elements to resolve the shadowing and un-shadowed areas.

5.3.3 Formal description

The ModelCheck option is the default behavior of the *Bumper 3* code self-shadowing database calculation.

The ModelCheck option can be bypassed through the *bumper.rc* option

```
MODELCHECK = false
```

Do not run the *Bumper 3* code analysis without first checking the model.

5.3.4 Examples

EXAMPLE2.UNV was created to show what shape elements would produce ModelCheck warnings and errors. The finite element model is plotted in Figure 56.

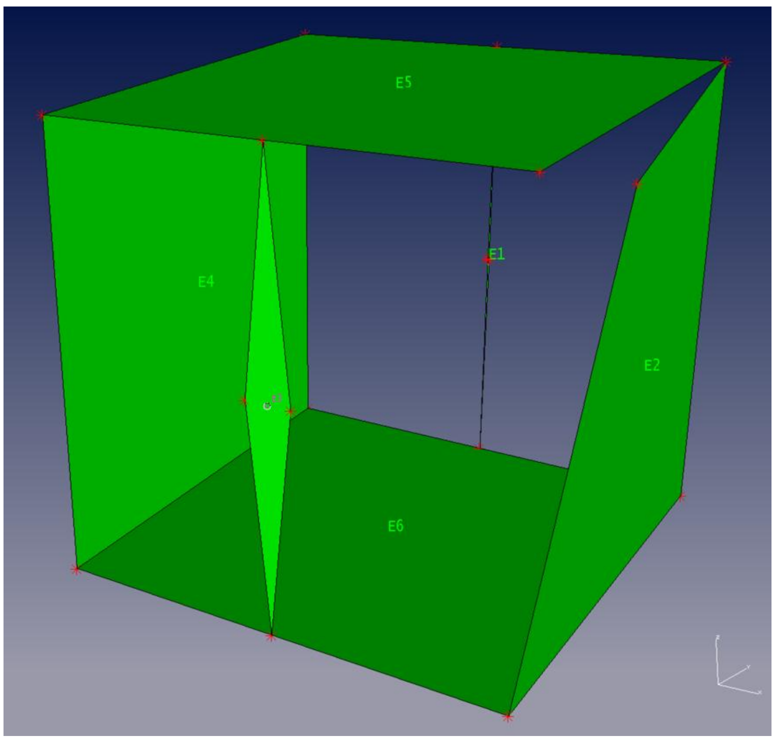


Figure 56. *EXAMPLE2.UNV* finite element model with malformed elements.

Element E3 is a needle-shaped element that generates no warning. However, element E1 is a needle-shaped element whose aspect ratio just barely generates a warning. Element E2 is saddle-shaped element that just barely results in a warning. Elements E4, E5, and E6 are well-formed quad elements that generate no warnings or errors.

Example 2 contains the results of running *EXAMPLE2.UNV* through GEOMETRY. The file *EXAMPLE2.txt* can be used for input redirection to a file. Open an instance of the command console. Change directory to the working directory using `cd $ENV:B3LITEWD`.

First, copy the *EXAMPLE2.UNV* file to your working directory. The *Bumper 3* code will write the .info, .warn and .error files to the same directory as the .unv file. We don't want to overwrite the files in the *EXAMPLE2* folder since we will be comparing out results with the results in the

EXAMPLE2 folder. Type the following at the console prompt to copy the finite element model file to the working directory.

```
#> cp EXAMPLE2\EXAMPLE2.unv .
```

The period is important because it indicates that the file should be copied to the current directory.

Now type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE2.txt*

```
#> cat EXAMPLE2\EXAMPLE2.TXT | BUMPER3-LITE
```

This will re-create the *EXAMPLE2.GSUM*, *EXAMPLE2.info* and *EXAMPLE2.warn* files from the *EXAMPLE2* subdirectory in your working directory.

You can confirm you obtained the same results by differencing the .warn files as follows:

```
#> diff (cat EXAMPLE2.warn) (cat EXAMPLE2\EXAMPLE2.warn)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window.

The *EXAMPLE2.info* file reproduced in the code block below. The file lists the number elements, nodes, and PIDs in the universal file and reports some statistics on the element areas. The goal is to produce a model with elements having the same surface area.

```
************* BEGIN MODEL CHECK REPORT *************

  BASIC MODEL INFORMATION:

    The following information is for model:
         EXAMPLE2\EXAMPLE2.UNV


         Total number of ELEMENTS =>           6

         Total number of NODES =>          24

         Total number of PIDs =>           1

              Total Area (m^2) for PID          1 0.40576E+01

    All area information is reported in square meters

         Total Area =>  0.4057572E+01
         Total Elements=>           6
         Min / Max Area =>  0.1963004E-02  0.1005609E+01



************* END MODEL CHECK REPORT *************
```

The ModelCheck analysis also produced the *EXAMPLE2.warn* file reproduced in the code block below. Warnings were generated for two elements. Element 1 had an area ratio of 0.01, which failed the 0.05 criterion. Note that the algorithm is such a strong function of the aspect ratio that an incremental change in the element 1 width would have caused it to pass the test.

Element 2 generated the second warning with a node out of the plane of the other 3 nodes. Note that element 2 just barely failed the criterion with a 10.61% ratio, which was larger than the 10.0% criterion.

```
 *** WARNING ***




   ASPECT RATIO OF ELEMENTS IS SKEWED


           LINE #        ELEM ID
                1              1
   ASPECT RATIO OF ELEMENTS IS SKEWED, TOTAL ELEMENTS =>           1


 *** WARNING ***




   4th GRID IS OFF SPAN BY MORE THAN 10%


           LINE #        ELEM ID        % OFF SPAN
                1              2          10.61
   4th GRID IS OFF SPAN BY MORE THAN 10%, TOTAL ELEMENTS =>           1
```

5.3.5 Possible error messages and causes

Error messages are routed to the modelCheck error file. Error messages are generated by

- Zero area elements.
- Element normals with NaN components.
- Saddle-shaped quad elements with a node lying above the plane of the other 3 nodes by more than 50% of the quad diagonal length.

The most common modeling error resulting in zero area elements is needle-shaped elements with zero span along one diagonal. *EXAMPLE2.UNV* was modified to reduce the element 1 span between nodes 2 and 4 along the x-direction to zero in single precision arithmetic. The node 2 and node 4 X-coordinates were changed from 0.501963 and 0.498037 to 0.50000001 and 0.49999999 (the same number in single precision arithmetic). The resulting error file is shown in the code block below.

```
*** ERROR ***



  ELEMENTS HAVE NaN NORMAL VECTOR


          LINE #        ELEM ID            NORMAL COMPONENTS
               1              1            NaN     NaN     NaN


*** ERROR ***
  THERE ARE ELEMENTS THAT HAVE NORMAL VECTORS = NaN, SEE ERROR FILE FOR FULL
LIST
```

5.3.6 Cross references to other operations

1. Complementary operations
   a. None
2. Predecessor operations
   a. Section 5.2 “Create the Spacecraft Geometry Universal File Operation”
3. Successor operations
   a. Section 5.4 “Calculate the Spacecraft Self-Shadowing Database Operation”

5.4 Calculate the Spacecraft Self-Shadowing Database Operation

The “calculate the spacecraft self-shadowing database operation” is mandatory. The SHIELD analysis will not run to completion without the results of the “calculate the spacecraft self-shadowing database operation.”

5.4.1 Functional description

GEOMETRY calculates the database of finite elements exposed when viewed from a particular threat direction. GEOMETRY uses the painter’s algorithm to identify the background elements covered by the foreground elements. (GEOMETRY rotates the coordinate frame so that the X-axis is pointed down the threat direction and then sorts the elements by X-values, and then by y-values). GEOMETRY takes as input a finite element model in I-deas universal file format and outputs the list of exposed elements for each threat as the binary .GEM file.

The threat array contains the direction in spherical coordinates from which the orbital debris and the micrometeoroids approach. This array is allocated in GEOMETRY and then written out to the .GEM file. This array is also used in SHIELD, which reads in the contents of the threat array from the .GEM file. The threat array has module scope in GEOMETRY and has module scope in SHIELD but is de-allocated upon exiting GEOMETRY and SHIELD so it is not possible to pass threat data from GEOMETRY to SHIELD or vice versa using the threat array.

Specifically, it produces information about the threat (polar angle, impact velocity, and probability), the finite elements in the model (element ID, property ID, and surface area), and the interaction between the model and the threat (list of exposed elements and their impact angle cosines for each threat). The information is stored in a user-defined binary file.

The environment is modeled as a series of distinct threat cases. The spacecraft geometry is input through the use of a FEM. The model is limited to triangular and quadrilateral elements whose nodes must be in the same coordinate system. GEOMETRY does not check to see whether more than one coordinate system is used. In addition, the X-axis of the reference coordinate system must be parallel to the spacecraft's velocity vector and the Z-axis must be parallel to the Earth radius vector pointing away from the Earth. The model information must be stored in a file using the SUPERTAB Universal File Format.

The GEOMETRY code consists of two main areas. The first consists of the global calculations, which only need to be calculated once. The remainder of the code is specific to determining which elements are exposed to a given threat. This portion of the code can further be broken down into two areas, the first being the elimination of the elements that do not face the threat (back side elements), and the second being the elimination of elements shielded from the threat by other elements.

A PID is assigned to each element. This PID is used to accurately describe the unique wall, shield, spacing, and MLI configuration for that element. Therefore, each model may contain several different wall configurations. Single wall, double wall, multi-wall, and other are the four types of configurations from which to choose. The code assumes all elements are parallel flat plates without curvature for penetration analysis.

The PNP will be calculated for specific ranges of element IDs. Therefore, several items should be kept in mind while building the model and determining the numbering scheme. All elements representing a single critical element should be numbered within a single range of numbers and sequentially, if possible. This allows for determination of a PNP for each critical element.

Many customary FEM limitations do not apply to the *Bumper 3* code. Coincident, extra, and unattached nodes will not cause premature code failure. The model does not require constraints against translations or rotations, as it is used only to define spacecraft geometry. Structures that are in reality attached need be only modeled adjacent to each other. An important criterion is that if a structure normally shadows (hides) another structure's view of threat, then it must be modeled with sufficient accuracy and resolution to represent that shadowing. Any elements that are totally enclosed, and therefore completely shielded from all threats by other elements, will not affect the solution.

5.4.2 Cautions and warnings

- Do be aware that the *Bumper 3* code will not read FEM data in PATRAN neutral file format. There is a feature in the programming that will cause the code to stop if the PATRAN neutral file option is selected.

5.4.3 Formal description

Table 6 is the formal description of the prompt/response user interface inputs for the spacecraft self-shadowing database operation. The menu prompts are listed in column 1. Some of the prompts only occur when specific answers are given at the previous prompt. This is indicated by IF THEN/ELSE pseudo code surrounding the prompts. The rows of pseudo code in the table are grayed out to emphasis they are not part of the prompts. The default inputs are listed in column two. The data types of the inputs are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Table 6. Self-Shadowing Data Base Operation Prompt/Response User Interface

Prompt	default	Type
' RUN WHICH MODULE ? ' ' 1 - GEOMETRY ' ' 2 - RESPONSE ' ' 3 - SHIELD ' ' 6 - RPLOT ' ' 7 - EXIT ' ' CHOICE ? (1, 2, 3, 6, OR 7) > '	none	INTEGER
' GEOMETRY OUTPUT SUMMARY FILENAME ? [geometry.gsum] => '	geometry.gsum	A256
' ANALYSIS TYPE ?' ' 1 - MAN-MADE DEBRIS' ' 2 - METEOROIDS' ' CHOICE ? (1 OR 2) > '	none	INTEGER
IF MAN-MADE DEBRIS THEN		
' ENVIRONMENT DEFINITION ?' ' 1 - SSP 30425 ' ' 2 - ORDEM2000 ' ' 3 - ORDEM 3.0 <CR>' ' CHOICE ? (1, 2 OR 3) [3] => '	3	INTEGER
ELSE IF METEOROIDS THEN		
' ENVIRONMENT DEFINITION ?' ' 1 - SSP 30425 ' ' 2 - MEMCxP ' ' 3 - MEM R2<CR>' ' CHOICE ? (1 2, OR 2) [3] => '	3	INTEGER
ENDIF		
' MODEL FILE FORMAT ?' ' 1 - SUPERTAB UNIVERSAL <CR> ' ' 2 - PATRAN NEUTRAL' ' CHOICE ? (1 OR 2) [1] => '	1	INTEGER
IF SUPERTAB UNIVERSAL FILE		
' SUPERTAB UNIVERSAL FILENAME ? [model.unv] => '	model.unv	A256
ELSE IF PATRAN NEUTRAL THEN		
' PATRAN NEUTRAL FILENAME ? [model.neu] => '	model.neu	A256
ENDIF		
' GEOMETRY BINARY OUTPUT FILENAME ? [geometry.gem] => '	geometry.gem	A256
' ROTATE THE MODEL (Y/N) ? [NO] => '	N	A
IF ROTATING MODEL THEN REPEAT THE PROMPT BELOW UP TO 3 TIMES		
' EXAMPLE: X,12.2' ' ANGLE IN DEGREES' ' MAXIMUM OF 3 ROTATIONS' ' ENTER <CR> WHEN DONE'	none	A1,REAL Angle can be any 9 character or less representation of a REAL number.
ENDIF		

Prompt	default	Type
IF SSP30425 MM THEN		
' SPACECRAFT ALTITUDE (KM) ? [400.0] => '	400.0	REAL (100 to 300,000)
ENDIF		
IF SSP30425 OD THEN		
' NUMBER OF UNIFORM MAN-MADE DEBRIS THREATS (MUST BE ODD NUMBER)? [45] => '	45	INTEGER 45, 47, 49, …181
ELSEIF SSP30425 MM THEN		
' ALTITUDE DEPENDENT NUMBER OF UNIFORM METEOROID THREATS ?' ' 1 - 92 TO 184 <CR>' ' 2 - 163 TO 326' ' 3 - 254 TO 508' ' 4 - 366 TO 732' ' 5 - 498 TO 997' ' 6 - 651 TO 1302' ' 7 - 826 TO 1652' ' CHOICE ? (1, 2, 3, 4, 5, 6, OR 7) [1] => '	1	INTEGER
ENDIF		

5.4.4 Examples

Example 3 calculates the MEMCxP spacecraft self-shadowing database for a 6-element cube universal file. To successfully complete this analysis the EXAMPLE1.UNV file must be in the EXAMPLE1 folder and the example folders must be subfolders of the console current working directory.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE3.txt*

```
#> cat EXAMPLE3\EXAMPLE3.TXT | BUMPER3-LITE
```

This will create the *EXAMPLE3.GSUM* file and the *EXAMPLE3.GEM* files in your working directory. A .GSUM file for comparison is distributed in the *EXAMPLE3* subfolder. You can confirm you obtained the same files as those distributed by differencing the .GSUM files as follows:

```
#> diff (cat EXAMPLE3.GSUM) (cat EXAMPLE3\EXAMPLE3.GSUM)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window. The run date on the first line will be different and possibly the software commit date on the second line will be different. Other than those two differences, the files should be the same.

The format of the GEOMETRY summary is illustrated by the *EXAMPL35.GSUM* file shown in the code block below. Note that some of the text is line-wrapped.

```
BUMPER3-LITE 3.0.0505.0    ** G E O M E T R Y **         08-MAY-2014 08:22:05.384
LAST COMMIT DATE: 2014/05/01 15:50:06 STATE OF CURRENT EXE: Modified

NAME OF THIS FILE: EXAMPLE3.GSUM

ANALYSIS TYPE ?
   1 - MAN-MADE DEBRIS
   2 – METEOROIDS
CHOICE ? (1 OR 2) =>  2

ENVIRONMENT DEFINITION ?
   1 - SSP30425
   2 - MEM <CR>
CHOICE ? (1 OR 2) [ 2 ] =>  2

MODEL FILE FORMAT ?
   1 - SUPERTAB UNIVERSAL <CR>
   2 - PATRAN NEUTRAL
CHOICE ? (1 OR 2) [ 1 ] =>  1

SUPERTAB UNIVERSAL FILENAME ? [ model.unv ] => EXAMPLE1\EXAMPLE1.UNV

GEOMETRY BINARY OUTPUT FILENAME ? [ geometry.gem ] => EXAMPLE3.GEM

ROTATE THE MODEL (Y/N) ? [ NO ] => N

NUMBER OF THREATS => 1652

   ********** METEOROID THREAT CASES COMPLETED1652
```

The first line of the summary file lists the analysis date and time

The second line lists the information related to when the source code was committed to the software version control system.

The fourth line lists the .GSUM filename.

Lines 6 through 25 echo the *Bumper 3* code console output and the user responses.

Line 27 lists the number of threats that should be completed during a successful GEOMETRY run.

Line 29 lists the number of threats actually complete. Most errors will prevent this line from being printed during an incomplete number of threat calculations.

5.4.5 Possible error messages and causes

See Section A.1 for a list of the error messages that may occur during the “calculate the spacecraft self-shadowing database operation”.

5.4.6 Cross references to other operations

1. Complementary operations
   a. None
2. Predecessor operations
   a. Section 5.2 “Create the Spacecraft Geometry Universal File Operation”

3. Successor operations
    a. Section 5.8 “Calculating the Number of Spacecraft Shield Impacts or Penetrations Operation”

5.5 Modify the Material Properties File Operation

Changing the material properties file parameters operation is optional. The *Bumper 3* code will run with the installed material properties file.

5.5.1 Functional description

The material properties file is read at the start of a RESPONSE analysis. If the default file or the file specified by the runtime control file can’t be found, then the user is prompted for the filename.

5.5.2 Cautions and warnings

- Do keep the number of materials in the *mat.prp* file less than IMATRLS =25, which is an array extent set in *modPARAMETERS.f90*.
- All numbers must be entered with a decimal point. (Fortran interprets numbers without a decimal point as INTEGERS and not REALS. So use 32000.0 or 32000. and not 32000 to avoid reading the value incorrectly with no error message! For example 32000 would be read as 32.0.)
- Do not change the encoding of the *mat.prp* file to Unicode. The *Bumper 3* code will not read text files with Unicode encoding correctly.

5.5.3 Formal description

The *mat.prp* file is an ASCII text file that can be edited with a text editor such as NOTEPAD or EMACS.

The *mat.prp* file may start off with a multi-line header file. The header is identified by delimiters. Equal signs (=) in character positions 2 to 10 indicate the start of the header and minus signs (-) in character positions 2 to 10 indicate the end of the header. (The delimiters can extend beyond character positions 2 to 10; however, they must fill positions 2 to 10 or the *Bumper 3* code will not recognize the delimiters.) Any number of informational lines may be entered between the delimiters; however, no more than 120 characters per line will be read. The *Bumper 3* code will also read a *mat.prp* file with no header.

The following describe column definitions:

- First column is the material name. The format is ‘(A15)’.
- The second column is the mass density in pounds per cubic inch with format ‘(E12.5)’.
- The third column is Fty the tensile 0.2% offset yield strength in psi with format ‘(E12.5)’.
- The fourth column is Ftu the ultimate tensile yield strength in psi with format ‘(E12.5)’.
    - NOTE: This parameter was only used by the metals cratering relation in Schmidt-Holsapple cratering relation from 1983, which is no longer part of the *Bumper 3* code.
- The fifth column is the shear strength in psi with format ‘(E12.5)’.
    - This was used in the PEN4 ballistic limit equation, which is no longer part of the *Bumper 3* code.
- The sixth column is the Wilkinson constant for the Wilkinson BLE with format ‘(E12.5)’.
    - This was used in the Wilkinson ballistic limit equation and is no longer part of the *Bumper 3* code.
- The seventh column is the bulk wave sound speed in feet per second with format ‘(E12.5)’.

- The eighth column is the slope of the linear Us-up Hugoniot relation with format '(E12.5)'.
    - This was used in the PEN4 ballistic limit equation, which is no longer part of the *Bumper 3* code.
- The ninth column is the Brinell hardness for the Cour-Palais BLE and has format '(E12.5)'.
- The tenth column is the elongation in percent with format '(E12.5)'. This parameter is only used in the RICHARDSON BLE, which is not provided with BUMPER3-LITE.

The SUBROUTINE INPUT_R_MTRL reads the file *mat.prp* until in runs out of records, at which point it traps the error and proceeds on in the processing.

It is possible to enter the same material name for different material properties. The *Bumper 3* code does not check for repeated material names, or for materials with different names but the same properties. It is up to the user to make sure that the correct names and material properties are in the *mat.prp* file.

5.5.4 Examples

An example *mat.prp* file is shown below in Figure 57.

```
===============================================================================================================
Material Properties file BUMPER3-LITE version 1.
(This is a re-ordered version of mat-iss.prp minus the verification test cases material properties.)
Columns 001-015: Name
Columns 016-027: Density (lb/in^3)
Columns 028-039: Yield Strength (lb/in^2)
Columns 040-051: *** NOT USED! *** Ultimate Tensile Strength (lb/in^2)
Columns 052-063: *** NOT USED! *** Shear Strength (lb/in^2)
Columns 064-075: *** NOT USED! *** Wilkinson Constant (km/s)
Columns 076-087: Speed of Sound (ft/s)
Columns 088-099: *** NOT USED! *** slope of the uniaxial strain shock speed/particle speed (Us-up) relation (unitless)
Columns 100-111: Brinnell Hardness Number (unitless)
Columns 112-123: *** NOT USED! *** Total Elongation (%)
===========================================================================================================================
000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000111111111111111111111111
000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999000000000011111111112222
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123
>-------------<>----------<>----------<>----------<>----------<>----------<>----------<>----------<>----------<>----------<
304L,316L           .286      100000.     99999.      99999.       1.630      18106.       1.345        88.          40.
Ti6Al-4V            .162      120000.        0.          0.        .  0      16358.       0.0         240.
BT14                .163      130000.     130000.     35000.        .292      16630.       1.345       135.
OT4-1               .164      85000.      100000.     40400.       1.630      16372.       1.345        88.          40.
2024-T3             .101      47000.      54000.      29000.        .425      17024.       1.345       120.
2219-T851           .103      47000.      00000.      00000.        .000      17200.       0.000       130.
2219-T852           .103      46000.      62000.      36000.        .322      16500.       1.345       115.
2219-T87            .103      57000.      63000.      37000.        .270      16620.       1.345       125.
5083-H112           .096      27600.      00000.      00000.        .000      17200.       0.000        81.
AMg6                .095      35000.      45000.      35000.        .292      16630.       1.345        73.
6061-T6             .098      35000.      42000.      35000.        .292      16630.       1.345        73.
7075-T6             .101      68000.      78000.      47000.        .345      16540.       1.345       135.
7075-T73            .101      56000.      67000.      38000.        .343      16500.       1.345       125.
```

Figure 57. Mat.Prp file.

5.5.5 Possible error messages and causes

- File not found.
- The read will fail if values are entered so that they cross a format boundary. The format boundaries are the center of the '<>" symbols on line 5 of Figure 57.

5.5.6 Cross references to other operations

1. Complementary operations
    a. None
2. Predecessor operations
    a. Gather the material properties information
3. Successor operations

a. Section 5.6 “Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation”

5.6 Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation

The “calculate the spacecraft shield ballistic limit curve table operation” is mandatory. The SHIELD analysis will not run to completion without the results of the “calculate the spacecraft shield ballistic limit curve table operation.”

5.6.1 Functional description

RESPONSE creates the database of MMOD particle diameters that just perforate the shield as a function of impact speed and impact angle. Two databases are required, one for orbital debris and one for micrometeoroids. RESPONSE creates these databases for up to 5,000 unique shield configurations. These configurations are identified through the use of element PIDs in the FEM. No PID can have a value larger than 23,000. RESPONSE does not have available any information about the model; therefore, the user must keep track of the number of PIDs and their relationship to the actual spacecraft. RESPONSE will prompt the user with various questions to determine the shield configurations for a particular analysis type. The results of the analysis are written out to the binary *response.rsp* file. RESPONSE runs quickly and is easily regenerated. The prompt/response user interface is described in Section 5.6.3.

5.6.2 Cautions and warnings

- Avoid using the “NNO Double Wall wMLI” relation with shield t/d less than 0.25 or greater than 0.25, where d was computed for 7km/s impact speed and 0 degrees impact angle. See [6] for an explanation.
- Avoid using the “NNO Double Wall wMLI” BLE for shield standoff to projectile diameter ratios (S/d) larger than 30, where d was computed for 7km/s impact speed and 0 degrees impact angle. See [6] for an explanation.

5.6.3 Formal description

Table 7 is the formal description of the prompt/response user interface inputs for the “spacecraft shield ballistic limit curve table operation.” The menu prompts are listed in column 1. Some of the prompts only occur when specific answers are given at the previous prompt. This is indicated by IF THEN/ELSE/ENDIF pseudo code surrounding the prompts. The rows of pseudo code in the table are grayed out to emphasis they are not part of the prompts. The default inputs are listed in column two. The input data types are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Table 7. Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation Prompt/Response User Interface

Prompt	default	Type
‘ RUN WHICH MODULE ? ‘ ‘ 1 – GEOMETRY ‘ ‘ 2 – RESPONSE ‘ ‘ 3 – SHIELD ‘ ‘ 6 – RPLOT ‘ ‘ 7 – EXIT ‘ ‘ CHOICE ? (1, 2, 3, 6, OR 7) > ‘	none	INTEGER
‘ ANALYSIS TYPE ?’ ‘ 1 – MAN-MADE DEBRIS’	none	INTEGER

Prompt	default	Type
‘ 2 – METEOROIDS’ ‘ CHOICE ? (1 OR 2) > ‘		
IF MAN-MADE DEBRIS THEN		
‘ ENVIRONMENT DEFINITION ?’ ‘ 1 – SSP 30425 ‘ ‘ 2 – ORDEM2000 ‘ ‘ 3 – ORDEM 3.0 <CR>’ ‘ CHOICE ? (1, 2 OR 3) [3] => ‘	3	INTEGER
ELSE IF METEOROIDS THEN		
‘ ENVIRONMENT DEFINITION ?’ ‘ 1 – SSP 30425 ‘ ‘ 2 – MEMCxP ‘ ‘ 3 – MEMR2 <CR>’ ‘ CHOICE ? (1 OR 2) [2] => ‘	3	INTEGER
ENDIF		
IF SSP30425 ORBITAL DEBRIS		
‘ MAN-MADE DEBRIS DENSITY ? 1 – CONSTANT (2.80 g/cm3) <CR> 2 – SIZE FUNCTION CHOICE ? (1 OR 2) [1] =>	1	INTEGER
ELSEIF SSP30425 MICROMETEOROID		
METEOROID DENSITY ? 1 – CONSTANT (1.00 g/cm^3) <CR> 2 – VARIABLE (SSP 30425) CHOICE ? (1 OR 2) [1] =>	1	INTEGER
ENDIF		
‘ RESPONSE OUTPUT SUMMARY FILENAME ? [response.rsum] => ‘	response.rsum	A256
‘ RESPONSE BINARY OUTPUT FILENAME ? [response.rsp] => ‘	response.rsp	A256
‘ ROTATE THE MODEL (Y/N) ? [NO] => ‘	N	A1
‘ BLE DIRECTORY:’ ‘ 1 – C-P Single Wall’ ‘ 2 – Stuffed Whipple’ ‘ 3 – multishock’ ‘ 4 – Kinetic Energy’ ‘ 5 – Const Diameter’ ‘ 6 – Shadow’ ‘ 7 – NNO Double Wall wMLI’ ‘ 111 – Fused Silica’ ‘ CHOICE ? =>’	none	INTEGER
IF 1 THEN		
COUR-PALAIS SINGLE WALL FAILURE CRITERIA ? 1 – SEMI-INFINITE PLATE CRATER 2 – PERFORATION FAILURE 3 – DETACHED SPALL FAILURE	none	INTEGER

Prompt	default	Type
CHOICE ? (1, 2, OR 3) =>		
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73 REAR WALL MATERIAL? (INTEGER) =>	none	INTEGER
IF FAILURE CRITERION = 1 THEN		
PENETRATION DEPTH? (CM) =>	none	REAL
ELSEIF FAILURE CRITERION =2 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
ELSEIF FAILURE CRITERION =2 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
ENDIF		
TYPE “NO_MLI” FOR NO MLI, OTHERWISE TYPE “MLI_AREAL_DENSITY=X.XXX” WHERE X.XXX IS A NUMBER =>	none	A30 MLI areal density can be any 12 character or less representation of a REAL number.
ELSEIF 2 THEN		
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73	none	INTEGER

Prompt	default	Type
SHIELD MATERIAL? (INTEGER) =>		
SHIELD THICKNESS (CM) =>	none	REAL
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73 REAR WALL MATERIAL? (INTEGER) =>	none	INTEGER
REAR WALL THICKNESS (CM) =>	none	REAL
SHIELD STANDOFF (CM) =>	none	REAL
ELSEIF 3 THEN		
TOTAL SHIELD AREAL DENSITY (G/CM2) =>	none	REAL
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73 REAR WALL MATERIAL? (INTEGER) =>	none	INTEGER
REAR WALL THICKNESS (CM) =>	none	REAL
TOTAL SHIELD SPACING (CM) =>	none	REAL
ELSEIF 4 THEN		
‘ CRITICAL KINETIC ENERGY (J) =>’	none	REAL
ELSEIF 5 THEN		
‘ IMPACTING PARTICLE DIAMETER (CM) =>’	none	REAL
ELSEIF 6 THEN		
N/A	none	N/A

Prompt	default	Type
ELSEIF 7 THEN		
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73 SHIELD MATERIAL? (INTEGER) =>	none	INTEGER
SHIELD THICKNESS (CM) =>	none	REAL
MATERIAL SELECTION ? 1 – 304L,316L 2 – Ti6Al-4V 3 – BT14 4 – OT4-1 5 – 2024-T3 6 – 2219-T851 7 – 2219-T852 8 – 2219-T87 9 – 5083-H112 10 – Amg6 11 – 6061-T6 12 – 7075-T6 13 – 7075-T73 REAR WALL MATERIAL? (INTEGER) =>	none	INTEGER
REAR WALL THICKNESS (CM) =>	none	REAL
SHIELD STANDOFF (CM) =>	none	REAL
TYPE “NO_MLI” FOR NO MLI, OTHERWISE TYPE “MLI_AREAL_DENSITY=X.XXX” WHERE X.XXX IS A NUMBER =>	none	A30 MLI areal density can be any 12 character or less representation of a REAL number.
IF MLI_AREAL_DENSITY=X.XXX THEN		
TYPE “ON_BUMPER” FOR ON BUMPER, OTHERWISE TYPE “REAR_WALL_STANDOFF=X.XXX” WHERE X.XXX IS A NUMBER =>	none	A48

Prompt	default	Type
ENDIF		
ELSEIF 111 THEN		
FUSED SILICA FAILURE CRITERIA? 1 – PERFORATION FAILURE <CR> 2 – DETACHED SPALL FAILURE 3 – BACKSIDE CRACKING FAILURE 4 – CRATER DEPTH 5 – CRATER DIAMETER 6 – SHATTER DAMAGE FAILURE	none	INTEGER
IF FAILURE CRITERION = 1 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
IF FAILURE CRITERION = 2 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
IF FAILURE CRITERION = 3 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
IF FAILURE CRITERION = 3 THEN		
PENETRATION DEPTH? (CM) =>	none	REAL
IF FAILURE CRITERION = 3 THEN		
CRATER DIAMETER (CM) =>	none	REAL
IF FAILURE CRITERION = 3 THEN		
REAR WALL THICKNESS (CM) =>	none	REAL
ENDIF		
ENDIF		
‘ RUN ANOTHER CASE ? (Y OR N) [YES] =>’	Y	A1
‘ RUN WHICH MODULE ?’ ‘ 1 – GEOMETRY’ ‘ 2 – RESPONSE’ ‘ 3 – SHIELD’ ‘ 6 – RPLOT’ ‘ 7 – EXIT’ ‘ CHOICE ? (1, 2, 3, 6, OR 7) =>’	none	INTEGER

5.6.4 Examples

Example 4 runs through all 20 BLE cases using the MEMCxP environment assumptions. The BUMPER3-LITE keyboard input can be redirected to the file *EXAMPLE4.txt* using the following procedure. Open an instance of the PowerShell command console. Change directory to the working directory using cd $ENV:B3LITEWD.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE4.txt*

```
#> cat EXAMPLE4\EXAMPLE4.TXT | BUMPER3-LITE
```

This will create the *EXAMPLE4.RSUM* and *EXAMPLE4.RSP* in your working directory.

You can confirm that the *Bumper 3* code accepted the same inputs as the example file in the *EXAMPLE4* folder by differencing the .RSUM files as follows:

```
#> diff (cat EXAMPLE4.RSUM) (cat EXAMPLE3\EXAMPLE4.RSUM)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window. (The first line of the .RSUM file will always be different because they contain the date and time of the *Bumper 3* code run.)

The *EXAMPLE4.TXT* input for PID 1 uses the single wall BLE to calculate the MM particle diameter that will produce a 1-mm-deep crater in a 6061-T6 sheet. The *EXAMPLE4.RSP* will be reused, along with the *EXAMPLE3.GEM* file, in the EXAMPLE 5 numbers of 1-mm-deep craters calculation. The 20 PID .RSP file can be used even though there is only one PID in the GEM file because the *Bumper 3* code will ignore PIDs 2 through 20 in the .RSP file. However, it is mandatory that there is a PID in the .RSP file for each PID in the GEM file.

5.6.5 Possible error messages and causes

The "Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation" error messages are listed in Section A.2.

5.6.6 Cross references to other operations

1. Complementary operations
   a. none
2. Predecessor operations
   a. Gather the shield geometry and materials information
3. Successor operations
   a. Section 5.6 "Calculating the number of spacecraft shield impacts or penetrations operation"

5.7 Format the Ballistic Limit Curve Table for Plotting Operation

The "format the ballistic limit curve table for plotting operation" is optional.

5.7.1 Functional description

RPLOT processes a subset of the binary .RSP file into an ASCII text file. The .rplot files are typically read into Excel as text files, converted to columns and then plotted. The rows of the .rplot file are constant impact speed, and the columns are constant impact angle. Each row corresponds to an impact speed in the table, but each column corresponds to every third impact angle. (The table impact angles occur in 5-degree increments: 0, 5, 10, 15, … 90 degrees. The .rplot table impact angles correspond to 0, 15, 30, 45, 60 and 75 degrees.)

5.7.2 Cautions and warnings

- Do be aware that the .rplot files list the projectile diameters in cm.
- Do be aware that RPLOT will write over any existing .rplot files with the same filename.

5.7.3 Formal description

Table 8 is the formal description of the prompt/response user interface inputs for the "format the ballistic limit curve table for plotting operation." The menu prompts are listed in column 1. The default inputs are listed in column two. The input data types are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not.

Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Required Parameters - The required inputs are listed in Table 8.

Table 8. Format the Ballistic Limit Curve Table for Plotting Operation Prompt/Response User Interface

Prompt	Default	Type
' RUN WHICH MODULE ? ‘ ' 1 - GEOMETRY ' ' 2 - RESPONSE ' ' 3 - SHIELD ' ' 6 - RPLOT ' ' 7 - EXIT ' ' CHOICE ? (1, 2, 3, 6, OR 7) > '	none	INTEGER
' RESPONSE OUTPUT FILENAME? [response.rsp] => '	response.rsp	A256
' RPLOT OUTPUT FILENAME? [response.rplot] => '	response.rplot	A256

The RPLOT analysis is entered by typing **6** at the RUN WHICH MODULE ? prompt. The prompt will only take the integers 1, 2, 3, 6, or 7. Any other integer or any number with a decimal point will cause the *Bumper 3* code to re-prompt for the input.

The next input is the name of the RESPONSE file to be processed. The filename must be less than 256 characters in length. The filename should include the filename extension .RSP; however this is not mandatory.

The next input is the name of the RPLOT file to be created. The filename must be less than 256 characters in length. The filename should include the filename extension .RPLOT; however, this is not mandatory.

The *Bumper 3* code then checks for the existence of the .RSP file; if the .RSP doesn’t exist, then the *Bumper 3* code stops.

Optional Parameters – None.

Default options – None.

Parameter order and syntax – The order of the input must be

```
6 <CR>
Response file name <CR>
Rplot file name <CR>
```

where the symbol <CR> represents the pressing the enter key on the keyboard.

5.7.4 Examples

Example 5 illustrates the procedure for using RPLOT to read the binary EXAMPLE4.RSP file and write the .RSP file values to a human readable ASCII file. The file *EXAMPLE5.txt* can be used for input redirection to a file. Open an instance of the PowerShell command console. Change directory to the working directory using `cd $ENV:B3LITEWD`.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE4.txt*

```
#> cat EXAMPLE5\EXAMPLE5.TXT | BUMPER3-LITE
```

This will create an *EXAMPLE5.RPLOT* file in the working directory, assuming that the *EXAMPLE4.RSP* is in the working directory.

You can confirm you obtained the same results as the example file in the folder *EXAMPLE5* by differencing the RPLOT files, as follows:

```
#> diff (cat EXAMPLE5.RPLOT) (cat EXAMPLE5\EXAMPLE5.RPLOT)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window.

The *EXAMPLE5.RPLOT* file is composed of a two-line header and the RPLOT tables for the 20 PIDs in the *EXAMPLE4.RSP* file. The code block below lists the first 23 rows of PID 1 from the *EXAMPLE5.RPLOT* file. This code block shows the format of the .RPLOT file for the single population environments. PID 1corresponds the case of an MM particle producing a 1-mm-deep crater in a sheet of 6061-T6 aluminum. The first column lists the PID, the second column lists the impact speed in km/s, the third column lists the critical diameter in cm for a 0-degrees impact angle, the fourth column lists the critical diameter in cm for a 15-degrees impact angle, … and the eighth column is the critical diameter in cm for a 75-degrees impact angle. The .RPLOT file lists critical diameter in cm.

```
     METEOROID CRITICAL DIAMETERS
    PID        Vi        0        15        30        45        60        75
         1      1.0000   0.2904   0.2968   0.3180   0.3614   0.4499   0.6819
         1      2.0000   0.1874   0.1916   0.2053   0.2333   0.2904   0.4401
         1      3.0000   0.1451   0.1483   0.1589   0.1806   0.2248   0.3407
         1      4.0000   0.1210   0.1237   0.1325   0.1506   0.1874   0.2841
         1      5.0000   0.1051   0.1074   0.1151   0.1308   0.1628   0.2467
         1      6.0000   0.0936   0.0957   0.1026   0.1166   0.1451   0.2199
         1      7.0000   0.0850   0.0868   0.0930   0.1058   0.1316   0.1995
         1      8.0000   0.0781   0.0798   0.0855   0.0972   0.1210   0.1834
         1      9.0000   0.0725   0.0741   0.0794   0.0902   0.1123   0.1702
         1     10.0000   0.0678   0.0693   0.0743   0.0844   0.1051   0.1593
         1     11.0000   0.0639   0.0653   0.0699   0.0795   0.0989   0.1500
         1     12.0000   0.0604   0.0618   0.0662   0.0752   0.0936   0.1419
         1     13.0000   0.0575   0.0587   0.0629   0.0715   0.0890   0.1349
         1     14.0000   0.0548   0.0561   0.0601   0.0683   0.0850   0.1288
         1     15.0000   0.0525   0.0537   0.0575   0.0653   0.0813   0.1233
         1     16.0000   0.0504   0.0515   0.0552   0.0627   0.0781   0.1184
         1     17.0000   0.0485   0.0496   0.0531   0.0604   0.0752   0.1139
         1     18.0000   0.0468   0.0478   0.0512   0.0582   0.0725   0.1099
         1     19.0000   0.0452   0.0462   0.0495   0.0563   0.0701   0.1062
         1     20.0000   0.0438   0.0447   0.0479   0.0545   0.0678   0.1028
         1     21.0000   0.0425   0.0434   0.0465   0.0528   0.0658   0.0997
         1     22.0000   0.0412   0.0421   0.0451   0.0513   0.0639   0.0968
         1     23.0000   0.0401   0.0410   0.0439   0.0499   0.0621   0.0941
```

Figure 58. Format of the SSP30425OD, ORDEM2000, SSP30425MM and the MEM .RPLOT files.

The Figure 60 code block shows an example of the .RPLOT file for the five population ORDEM 3 environment. Note that the file has been clipped at the second column of the second population to fit the page. This file is not included in the examples. Again, PID 1 listed in Figure 60 corresponds to the case of a particle that produces a 1-mm-deep crater in a sheet of 6061-T6 aluminum. The format is similar to the single population file shown in Figure 58, only repeated 5 times. Each table corresponds to an orbital debris population identified by a 2- to 3-character code in the 0-degrees impact angle column:

- NaK – Sodium Potassium particles from the Soviet radar satellites (around 0.9 grams per cubic cm).
- LD – Low-density particles typical of circuit boards (around 1.4 grams per cubic cm).
- MD – Medium-density particles typical of aluminum structure (around 2.8 grams per cubic cm).
- HD – High-density particles typical of steel structure (around 7.9 grams per cubic cm).
- INT – Intact spacecraft and spacecraft components. The *Bumper 3* code calculates the risk from impact by compact fragments and not by structures. Hence, it treats a 10-cm-diameter spacecraft component as a 10-cm-diameter sphere of aluminum. If the user finds this assumption too conservative, then an alternative analysis tool will be necessary.

The *Example5.rplot* data are imported into an Excel workbook by selecting all the data in the file, copying the data to the clipboard, and pasting the data into a worksheet. Select the column of data in the worksheet and then convert the text to columns using Data → Convert Text to Columns. When the Convert Text to Columns dialog appears, push the Fixed Width radio button, then click OK. The chart in Figure 59 was created by selecting the PID 1 second through eighth columns and then Insert→Scatter.

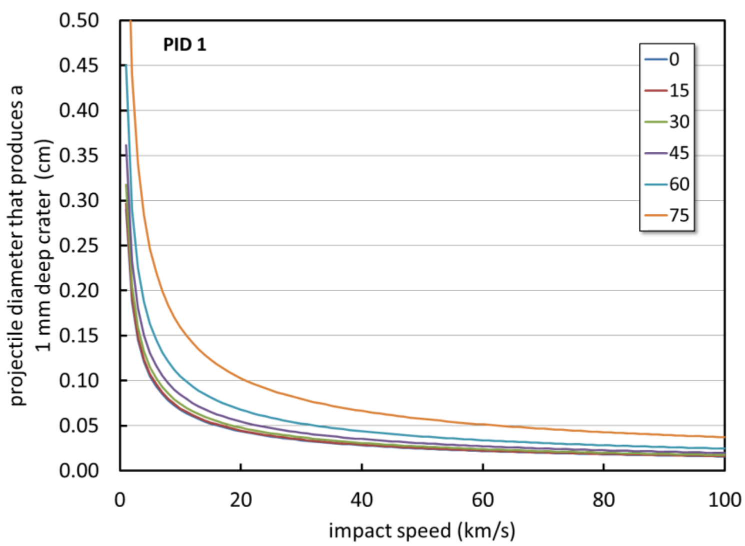


Figure 59. Excel plot of the Example 5 PID 1 RPLOT data.

```
 MAN-MADE ORBITAL DEBRIS CRITICAL DIAMETERS
   PID        Vi    NaK 0        15        30        45        60        75        LD 0        15
     1    0.5000      1.8919    1.9338    2.0718    2.3547    2.9307    4.4415      1.5349    1.5689 …
     1    1.5000      0.9455    0.9664    1.0354    1.1767    1.4646    2.2196      0.7671    0.7840 …
     1    2.5000      0.6848    0.7000    0.7499    0.8523    1.0608    1.6077      0.5556    0.5679 …
     1    3.5000      0.5537    0.5660    0.6064    0.6892    0.8578    1.3000      0.4493    0.4592 …
     1    4.5000      0.4725    0.4829    0.5174    0.5881    0.7319    1.1092      0.3833    0.3918 …
     1    5.5000      0.4163    0.4255    0.4558    0.5181    0.6448    0.9772      0.3377    0.3452 …
```

1	6.5000	0.3746	0.3829	0.4102	0.4662	0.5803	0.8794	0.3039	0.3106	…
1	7.5000	0.3422	0.3498	0.3748	0.4259	0.5301	0.8034	0.2777	0.2838	…
1	8.5000	0.3162	0.3232	0.3463	0.3936	0.4899	0.7424	0.2566	0.2622	…
1	9.5000	0.2948	0.3013	0.3228	0.3669	0.4566	0.6920	0.2392	0.2444	…
1	10.5000	0.2767	0.2829	0.3030	0.3444	0.4287	0.6497	0.2245	0.2295	…
1	11.5000	0.2613	0.2671	0.2861	0.3252	0.4047	0.6134	0.2120	0.2167	…
1	12.5000	0.2479	0.2534	0.2714	0.3085	0.3840	0.5819	0.2011	0.2056	…
1	13.5000	0.2361	0.2413	0.2586	0.2939	0.3658	0.5543	0.1916	0.1958	…
1	14.5000	0.2257	0.2307	0.2472	0.2809	0.3496	0.5299	0.1831	0.1872	…
1	15.5000	0.2164	0.2212	0.2370	0.2693	0.3352	0.5080	0.1756	0.1795	…
1	16.5000	0.2080	0.2126	0.2278	0.2589	0.3222	0.4884	0.1688	0.1725	…
1	17.5000	0.2004	0.2049	0.2195	0.2495	0.3105	0.4706	0.1626	0.1662	…
1	18.5000	0.1935	0.1978	0.2119	0.2409	0.2998	0.4543	0.1570	0.1605	…
1	19.5000	0.1872	0.1913	0.2050	0.2330	0.2900	0.4395	0.1519	0.1552	…
1	20.5000	0.1814	0.1854	0.1986	0.2257	0.2810	0.4258	0.1472	0.1504	…
1	21.5000	0.1760	0.1799	0.1927	0.2191	0.2726	0.4132	0.1428	0.1460	…
1	22.5000	0.1710	0.1748	0.1873	0.2129	0.2649	0.4015	0.1388	0.1418	…

Figure 60. ORDEM 3 .RPLOT file example.

5.7.5 Possible error messages and causes

There are no runtime error messages from an RPLOT analysis.

5.7.6 Cross references to other operations

1. Complementary operations
    a. None.
2. Predecessor operations
    a. Section 5.6 “Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation.”
3. Successor operations
    a. Plot up the RPLOT curves and evaluate for consistency with test data.

5.8 Calculate the Number of Spacecraft Shield Impacts or Penetrations Operation

The “calculate the number of spacecraft shield impacts or penetrations operation” is mandatory.

5.8.1 Functional description

SHIELD calculates the PNP or PNI of the spacecraft. The code can perform these calculations for all the elements in the spacecraft model together or for specific ranges of elements.

The SHIELD code can be broken into five main areas. The first consists of reading in the geometry and response databases. Next, the finite element cases are looped trough, evaluating only the exposed elements for each one. This consists of determining the flux of the critical projectile and storing the sum in a global array. This global array is next multiplied by the element surface array and then the arrays are summed up for all the element ranges. Finally, the PNP or PNI for each range is calculated.

5.8.2 Cautions and warnings

- *BUMPER3-LITE* will stop if the GEM file was created for a different MMOD environment than the .RSP file.
- Incorrect paths to the environment files will cause *BUMPER3-LITE* to re-prompt for the environment file.
- *BUMPER3-LITE* will overwrite prior versions of the SUM file if the same output name is given.

5.8.3 Formal description

Table 9 is the formal description of the prompt/response user interface inputs for the "Calculate the number of spacecraft shield impacts or penetrations operation." The menu prompts are listed in column 1. Some of the prompts only occur when specific answers are given at the previous prompt. This is indicated by IF THEN/ELSE/ENDIF pseudo code surrounding the prompts. The rows of pseudo code in the table are grayed out to emphasis they are not part of the prompts. The default inputs are listed in column two. The input data types are listed in column 3. INTEGER indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. REAL indicates the numerical input can include a decimal point, but a decimal is not mandatory; e.g., 1, 1.1 and 1.0 are all accepted.

Table 9. Calculate the Number of Spacecraft Shield Impacts or Penetrations Prompt/Response User Interface

prompt	default	Type
' RUN WHICH MODULE ? ' ' 1 - GEOMETRY ' ' 2 - RESPONSE ' ' 3 - SHIELD ' ' 6 - RPLOT ' ' 7 - EXIT ' ' CHOICE ? (1, 2, 3, 6, OR 7) > '	none	INTEGER
' V BETA PLOTS (Y/N) (<CR>=N) ?'	N	A1
'SHIELD OUTPUT SUMMARY FILENAME ? (<CR>=shield.sum) > '	shield.sum	A256
' RESULT TYPE ? 1 - PNP (PROBABILITY OF NO PENETRATION) <CR> 2 - PNI (PROBABILITY OF NO IMPACT) 3 - N (NUMBER OF PENETRATIONS) 4 - N (NUMBER OF IMPACTS) CHOICE ? (1, 2, 3 OR 4) >4'	1	INTEGER
IF NUMBER OF PENETRATIONS THEN		
' LIMITING PARTICLE DIAMETER (CM) ? (<CR>=1.0) > '	1.0	REAL Note 1
ENDIF		
' GEOMETRY BINARY OUTPUT FILENAME ? '	geometry.gem	A256
BLOCK DEPENDENT ON THE ENVIRONMENT USED TO GENERATE THE .GEM FILE		
IF GEOMETRY FILE ENVIRONMENT IS SSP 30425 OD THEN		
' SSP 30425 DEBRIS ENVIRONMENT' ' SPACECRAFT ALTITUDE (KM) ? [400.00] => '	400.0	REAL Note 2

prompt	default	Type
' SPACECRAFT ORBIT INCLINATION (DEGREES) ? [51.6] => '	51.6	REAL Note 3
' VALUES FOR SOLAR RADIO FLUX DATA?' ' 1 - NOMINAL' ' 2 - MINIMUM' ' 3 - CONSTANT <CR> ' ' CHOICE ? (1, 2, OR 3) [3] => '	3	INTEGER
IF CHOICE IS ‘CONSTANT’ THEN		
' SOLAR RADIO FLUX LEVEL (10**4 JY) ? [70.0] => '	70.0	REAL
ENDIF		
' SPACECRAFT BEGINNING EXPOSURE DATE (1994-2037) ? [2001] => '	2001.0	REAL Note 4
' SPACECRAFT EXPOSURE TIME (YEARS) ? [1.0] => '	1.0	REAL Note 5
ELSEIF GEOMETRY FILE ENVIRONMENT IS ORDEM 2000 THEN		
" ORDEM2000 DEBRIS ENVIRONMENT" ' CALCULATE ORDEM2000 ENV. OR READ IT FROM A FILE? (READ/<CALC>)> '	CALC	A4
IF ‘READ’ THEN		
' ORDEM2000 ENVIRONMENT FILENAME ? > '	o2kFile.dat	A256
ELSEIF ‘CALC’ THEN		
' ORDEM2000 ENVIRONMENT FILENAME ? > '		A256
' SPACECRAFT ALTITUDE (KM) ? [400.0] => '	400.0	REAL Note 2
' SPACECRAFT ORBIT INCLINATION (DEGREES) ? [51.6] => '	51.6	REAL Note 3
' SPACECRAFT BEGINNING EXPOSURE DATE (1990-2030) ? [2001] => '	2001.0	REAL Note 4
' SPACECRAFT EXPOSURE TIME (YEARS) ? [1.0] => '	1.0	REAL Note 5
ENDIF		
ELSEIF GEOMETRY FILE ENVIRONMENT IS ORDEM 3 THEN		
“ ORDEM 3.0 DEBRIS ENVIRONMENT “ ORDEM 3.0 INPUT FILENAME ? >	none	A256
ELSEIF GEOMETRY FILE ENVIRONMENT IS SSP 30425 MM		
" SSP 30425 METEOROID ENVIRONMENT" METEOROID VELOCITY DISTRIBUTION ? 1 - SINGLE VELOCITY (VM = 16.85) <CR> 2 - SSP 30425 REV. A CHOICE ? (1, OR 2) >	1	INTEGER
' SPACECRAFT EXPOSURE TIME (YEARS) ? [1.0] => '	1.0	REAL

prompt	default	Type
ELSEIF GEOMETRY FILE ENVIRONMENT IS MEMCXPV2 THEN		
“ MEM METEOROID ENVIRONMENT” ' MEM INPUT FILENAME ? > '	MEM.DAT	A256
' SPACECRAFT EXPOSURE TIME (YEARS) ? [1.0] => '	1.0	REAL
ELSEIF GEOMETRY FILE ENVIRONMENT IS MEMR2 THEN		
“ MEM METEOROID ENVIRONMENT” ' MEM INPUT FILENAME ? > '	MEM.DAT	A256
' SPACECRAFT EXPOSURE TIME (YEARS) ? [1.0] => '	1.0	REAL
ENDIF		
‘ THE PROBABILITY OF NO IMPACT WILL BE ‘ CALCULATED FOR SPECIFIC RANGES OF ELEMENT IDS. ‘ INPUT THE STARTING AND ENDING ELEMENT ID FOR EACH RANGE. ‘ ENTER D <CR> OR <CR> WHEN DONE ‘ RANGE 1 ‘ STARTING ELEMENT ID >’	<CR>	INTEGER or INTEGER, INTEGER or A1 (a <CR> or D)
IF TYPE EQUALS INTEGER THEN		
‘ ENDING ELEMENT ID >‘	none	INTEGER or A1 (a <CR> or D)
ENDIF		
INCREMENT RANGE WHILE INPUT NOT “D” OR “”		
IF NUMBER OF PENETRATIONS CALCULATION THEN		
' RESPONSE BINARY OUTPUT FILENAME ? (<CR>=response.rsp) >’	response.rsp	A256
END IF		
‘ CREATE AN INPUT FILE FOR CONTOUR PLOTS ? (<CR>=NO) >’	N	A1
IF CREATE CONTOUR FILE THEN		
‘ CONTOUR FILE FORMAT ? 1 - SUPERTAB UNIVERSAL <CR> 2 - PATRAN NEUTRAL CHOICE ? (1 OR 2) >’	1	INTEGER
IF SUPERTAB FORMAT THEN		
‘SUPERTAB UNIVERSAL FILENAME ? (<CR>=contour.uni) >’	contour.uni	A256
ELSE		
‘PATRAN NEUTRAL FILENAME ? (<CR>=contour.neu) >’	contour.neu	A256
ENDIF		
ENDIF		

prompt	default	Type
Notes: 1. *MMOD particle size range*. SSP30425OD – *Bumper 3* will accept 0.0001 to 500 cm. ORDEM2000 – *Bumper 3* will accept 0.001 to 100 cm. ORDEM 3.0 – *Bumper 3* will accept 0.001 to 100 cm. SSP30425MM – *Bumper 3* will accept 0 to 2.673 cm, but will set all diameters less 1.2407e-5 cm equal to 1.2407e-5 cm. MEM – *Bumper 3* will accept 0.012407 to 2.673 cm. 2. *Altitude ranges of applicability*: SSP30425OD – 100.0 to 2000.0 km. ORDEM2000 – 200.0 to 2000.0 km. ORDEM 3 – Not a *Bumper 3* input. However the ORDEM 3 application will accept altitudes between 100 to 40,000 km. SSP30425MM – 100.0 to 300,000.0 km. EarthMEM – Not a *Bumper 3* input. However the MEM application is "…valid for all Earth orbiting missions and lunar transit missions out to the Moon's sphere of influence (~66,000 km radius from Moon)." LunarMEM – Not a *Bumper 3* input. However the MEM application is "…valid for all Moon orbiting missions within the Moon's sphere of influence ~66,000 km radius." IPMEM – Not a *Bumper 3* input. However the MEM application is applicable over the range 0.2 AU to 2.0 AU. 3. *Inclination ranges of applicability* SSP30425OD – 25.0 to 124.99 degrees. ORDEM2000 – 0.0 to 180.0 degrees. ORDEM 3 – Not a *Bumper 3* input. However the ORDEM 3 application will accept any inclination. MEM – Not a *Bumper 3* input. However the MEM application will accept any inclination. 4. *Spacecraft exposure start dates ranges of applicability*. SSP30425OD – *Bumper 3* will not accept start dates less than 1994 or greater than 2037. ORDEM2000 – *Bumper 3* will not accept start dates less than 1991 or greater than 2030. ORDEM 3.0 – Not a *Bumper 3* input. However the ORDEM 3 application will not accept start dates less than 2010 or greater than 2035. SSP30425MM – Not a *Bumper 3* input. The environment is time independent. MEM – Not a *Bumper 3* input. The start date is an input to the STK output file used by MEM as an input. Hence it is subject to the limitations of STK. 5. *Spacecraft exposure duration ranges of applicability*. SSP30425OD – 0.001 to (2038.0 – start date) years. ORDEM2000 – 0.001 to MIN(15.0, 2030.0 – start date) years. ORDEM 3.0 – Not a *Bumper 3* input. However *procloo* will accept any value between 0.0 to (2035.0-start date). SSP30425MM – 0.001 to 1000.0 years. MEM – 0.001 to 1000.0 years.		

5.8.4 Examples

Example 5 runs the ORDEM 3 number of craters with 1-mm-depth analysis. To successfully complete this analysis, the examples from Sections 5.4 and 5.6 must have run to completion depositing the files *EXAMPLE1.GEM* and *EXAMPLE3.RSP* in the working directory.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE6.txt*

```
#> cat EXAMPLE6\EXAMPLE6.TXT | BUMPER3-LITE
```

This will re-create the *EXAMPLE6.SUM* file from the *EXAMPLE 6* subdirectory in your working directory.

You can confirm you obtained the same results by differencing the .SUM files as follows:

```
#> diff (cat EXAMPLE6.SUM) (cat EXAMPLE6\EXAMPLE6.SUM)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window.

The format of the SHIELD summary is illustrated by the *EXAMPLE6.SUM* file shown in the code block below. Note that some of the text is word-wrapped.

```
 BUMPER3-LITE 3.0.0505.0    *** S H I E L D ***    08-MAY-2014 08:28:25.980
 LAST COMMIT DATE: 2014/05/01 15:50:06 STATE OF CURRENT EXE: Modified

 SHIELD MODULE SUMMARY FILE

 M I C R O - M E T E O R O I D     A N A L Y S I S

 Summary file : EXAMPLE6.SUM
 I-deas file  : EXAMPLE1\EXAMPLE1.UNV
 Geometry file: EXAMPLE3.GEM
 Response file: EXAMPLE4.RSP
 Contour file : none

 ROTATION AXES AND ANGLES (DEGREES)
  No Rotations

 MEMR2 METEOROID ENVIRONMENT
 NUMBER OF THREATS                  =    1652
 SPACECRAFT ALTITUDE (KM) IMPLICIT IN
C:\Users\mbjorkma\AppData\Local\Programs\NASA
HVIT\envFiles\MEMCxPv2\MEMCxPv2_LEO_ISS.out
 MEM DATA FILE                      =
C:\Users\mbjorkma\AppData\Local\Programs\NASA
HVIT\envFiles\MEMCxPv2\MEMCxPv2_LEO_ISS.out
 SPACECRAFT EXPOSURE TIME (YEARS)   =       1.0000

 RANGE  STARTING EID  ENDING EID  PENETRATIONS      AREA (M^2)
     1            1          1     2.68267E-02       1.0000000
     2            2          2     6.52269E-02       1.0000000
     3            3          3     2.62351E-02       1.0000000
     4            4          4     9.93695E-03       1.0000000
     5            5          5     3.49975E-02       1.0000000
     6            6          6     3.00957E-04       1.0000000

 TOTAL NUMBER OF PENETRATIONS =  1.63524E-01
```

The first line of the summary file lists the analysis date and time

The second line lists the information related to when the source code was committed to the software version control system.

The ninth line lists the filename of the universal file used to create the GEM file.

The tenth line lists the filename of the GEM file used to create the SUM file.

The eleventh line lists the filename of the .RSP file used to create the SUM file. (This line will be missing if the summary file is the log file of PNIs or number of impacts calculations.)

The twelfth line lists the filename of the I-deas contouring data file. (See Section 5.2.)

Lines 14 and 15 list the spatial rotations applied to the universal file while calculating the GEM file.

Line 20 lists the filename of the MEMCxP environment file used to calculate the number of penetrations.

Line 21 lists the duration of exposure of the spacecraft in decimal years.

Lines 23 through 29 list the results of the calculation by element range

- The first column lists the element range ID (A sequential number from 1 to the total number of element ranges entered by the user: in this case, 6 element ranges.)
- The second column lists the starting element ID number for the element range.
- The third column lists the ending element ID number for the element range.
- The fourth column lists the total number of craters in the element range.
- The fifth column lists the total surface area of the elements in the element range. The surface area is given in square meters.

Line 31 lists the total number of impact craters. (This is the total of the elements, whether or not all the elements were included in an element range. Further, it is possible to include an element in up to 20 element ranges without generating an error condition that stops the *Bumper 3* code. This means that line 31 can exceed the sum of column four, but can also be less than the sum of column four.)

5.8.5 Possible error messages and causes

The “Calculate the number of spacecraft shield impacts or penetrations operation” error messages are listed in Section A.3.

5.8.6 Cross references to other operations

1. Complementary operations
    a. None
2. Predecessor operations
    a. Section 5.4 “Calculate the Spacecraft Self-Shadowing Database Operation.”
    b. Section 5.6 “Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation.” (If a probability of penetration or number of penetrations calculation is performed. If it is a probability of impact or number of impacts calculation, then the .RSP file is not needed.)
3. Successor operations
    a. None

5.9 Calculate the Number of Impacts or Penetrations as a Function of Impact Speed and Impact Angle Operation

5.9.1 Functional description

As an intermediate step, SHIELD can output a table of increments of number of impacts or penetrations as a function of increments of impact speed and impact angle; i.e., a discrete bivariate probability-density-function. Typically, this information is used by the NASA hypervelocity impact technology team (HVIT) to align the test conditions with the most probable impact conditions. The impact speed variable in the *Bumper 3* code is V and the impact angle variable (angle between the trajectory and the element surface normal) is BETA. Hence, the table is referred to in the prompt/response user interface as VBETA data.

5.9.2 Cautions and warnings

- Don't select the VBETA option for the SSP30425MM environment. The *Bumper 3* code will report an error and stop.
- Don't use more than 9999 element ranges or the VBETA filename will be malformed. (The *Bumper 3* code is currently formatted for no more than NRMAX=2000 element ranges. Therefore this can only occur by editing and recompiling the source.)

5.9.3 Formal description

Table 10 is the formal description of the prompt/response user interface inputs for the "calculate the number of impacts or penetrations as a function of impact speed and impact angle operation." The menu prompts are listed in column 1. The default inputs are listed in column two. The input data types are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Required Parameters – the required inputs are listed in Table 10.

Table 10. Calculate the Number of Impacts or Penetrations as a Function of Impact Speed and Impact Angle Operation Prompt/Response User Interface

Prompt	default	Type
' V BETA PLOTS (Y/N) (<CR>=N) ?'	N	A1

Any string starting with 'N' or 'n' is interpreted as a No response and any string beginning with a 'Y' or 'y' is interpreted as a Yes response.

Optional Parameters – None.

Default options – The default option is 'N''; that is to not write out the VBETA data.

Parameter order and syntax – Not applicable.

5.9.4 Examples

Example 7 runs one calculation of the number of impacts by 1 mm MMOD particles onto an oriented cube for the MEMCxP micrometeoroid environment. The calculation outputs the VBETA files for all six sides of the cube.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE7.txt*

```
#> cat EXAMPLE7\EXAMPLE7.TXT | BUMPER3-LITE
```

The VBETA analysis outputs files named *⟨sum filename⟩_XXXX.OUT*; where *⟨sum filename⟩* is the SHIELD summary file root and XXXX is the element range number assigned by the *Bumper 3* code to the user range input. The range numbers are the first column of numbers in the SHIELD summary file and the column is labeled RANGE.

Example 6 will create the *EXAMPLE7_0001.vbeta* through *EXAMPLE7_0006.vbeta* files. You can confirm you obtained the same results by differencing the .vbeta files as follows:

```
#> diff (cat EXAMPLE7_0001.vbeta) (cat EXAMPLE7\EXAMPLE7_0001.vbeta)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window.

The code block in Figure 61 is a listing of the *EXAMPLE7_0002.vbeta* file. This file was produced from the calculated number of impacts by 1-mm-diameter orbital debris particles on the ram side (element range 2) of the cube using the MEMCxP micrometeoroid environment for 1 year in the ISS orbit. The first column of the VEBTA file lists the closing speed bin number. The first bin corresponds to an impact speed range of 0 to 1 km/s for orbital debris analyses and to 0 to 5 km/s for MEMCxPv2. Bin number 2 corresponds to speeds from 1 to 2 km/s for orbital debris analyses and 5 to 10 km/s for MEMCxPv2, etc. The second column of numbers lists the number of impacts or penetrations for the impact angle bin 0 to 10 degrees. The third column of numbers are the numbers for the impact angle bin 10 to 20 degrees, and so forth, to the last column, which corresponds to the impact angle bin 80 to 90 degrees (nearly parallel to the element).

```
 1  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 2  3.24633E-06  7.46068E-06  8.88416E-06  9.13835E-06  8.40665E-06  6.34099E-06  4.13754E-06  2.19033E-06  6.34464E-07
 3  1.86054E-05  4.28593E-05  5.00808E-05  5.03754E-05  4.53588E-05  3.36183E-05  2.17522E-05  1.14733E-05  3.34154E-06
 4  4.45125E-05  1.03449E-04  1.22190E-04  1.25001E-04  1.14616E-04  8.61390E-05  5.61934E-05  2.98512E-05  8.72256E-06
 5  5.69729E-05  1.33091E-04  1.59012E-04  1.64642E-04  1.53173E-04  1.16798E-04  7.69854E-05  4.10957E-05  1.20595E-05
 6  3.64028E-05  8.64435E-05  1.02941E-04  1.05901E-04  9.78559E-05  7.40172E-05  4.84129E-05  2.58675E-05  7.68181E-06
 7  2.55120E-05  6.13037E-05  7.35377E-05  7.55706E-05  6.95372E-05  5.19778E-05  3.34628E-05  1.76174E-05  5.18443E-06
 8  1.69014E-05  4.10258E-05  4.94617E-05  5.05074E-05  4.60126E-05  3.37976E-05  2.13240E-05  1.10253E-05  3.20541E-06
 9  9.79502E-06  2.39607E-05  2.88033E-05  2.88748E-05  2.56678E-05  1.82774E-05  1.11985E-05  5.66649E-06  1.63007E-06
10  4.67630E-06  1.14754E-05  1.35270E-05  1.31048E-05  1.11861E-05  7.65717E-06  4.58686E-06  2.31797E-06  6.76307E-07
11  1.62617E-06  3.99836E-06  4.55858E-06  4.28722E-06  3.60340E-06  2.52173E-06  1.62024E-06  8.96243E-07  2.81561E-07
12  4.96499E-07  1.28796E-06  1.48364E-06  1.50733E-06  1.44804E-06  1.19636E-06  8.94317E-07  5.45048E-07  1.77382E-07
13  3.88107E-07  1.05369E-06  1.20360E-06  1.23441E-06  1.20815E-06  1.00243E-06  7.37689E-07  4.34010E-07  1.35261E-07
14  3.06023E-07  8.30747E-07  9.24426E-07  9.16533E-07  8.65331E-07  6.88728E-07  4.81641E-07  2.66510E-07  7.76109E-08
15  1.75034E-07  4.71563E-07  5.08241E-07  4.81187E-07  4.30429E-07  3.21143E-07  2.08562E-07  1.05777E-07  2.79595E-08
16  4.84247E-08  1.29099E-07  1.33923E-07  1.20315E-07  1.01109E-07  6.97910E-08  4.13057E-08  1.86570E-08  4.34134E-09
17  2.05487E-09  5.37973E-09  5.27906E-09  4.37592E-09  3.40825E-09  2.13990E-09  1.09416E-09  4.09232E-10  7.76190E-11
18  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
19  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
20  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

Figure 61. Format of the VBETA file *EXAMPLE7_0002.vbeta.*

The data in the VBETA file can be plotted with Excel. The *EXAMPLE7* folder contains the Excel work book named *example 7 VBETA plots.xlsx*. The VBETA data file listed in Figure 61 were imported into Excel and parsed into the worksheet columns. The spread sheet was then used to generate the three-dimensional (3D) bar chart shown in Figure 62.

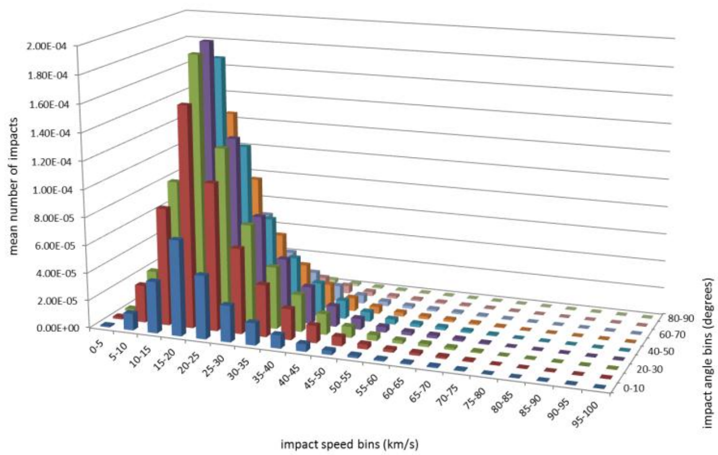


Figure 62. 3D bar plot of the ram side impacts from *EXAMPLE7_0002.vbeta.*

5.9.5 Possible error messages and causes

See Section A.4 for a list of the error messages that may occur during the "Calculate the number of impacts or penetrations as a function of impact speed and impact angle operation."

5.9.6 Cross references to other operations

1. Complementary operations
   a. None
2. Predecessor operations
   a. Section 5.4 "Calculate the Spacecraft Self-Shadowing Database Operation"
   b. Section 5.6 "Calculate the Spacecraft Shield Ballistic Limit Curve Table Pperation"
3. Successor operations
   a. None

5.10 Plot Contours of Number of Impacts or Penetrations on the Finite Element Model Operation

5.10.1 Functional description

The "plot contours of number of impacts or penetrations on the finite element model operation " creates an input file for I-deas, which is used by I-deas to contour the finite element model with numbers of impacts or number of penetrations data. Answering 'Y' to this option writes the probability of penetration per surface area for each element of the model to an output file written in the SUPERTAB file format.

5.10.2 Cautions and warnings

- Do be aware that the contour plot option will write over any existing files with the same filename.
- Do be aware that the *Bumper 3* code will not write out contour file data in PATRAN neutral file format. There is a feature in the programming that will cause the code to stop if the PATRAN neutral file option is selected.

5.10.3 Formal description

Table 11 and Table 12 are the formal description of the prompt/response user interface inputs for the “plot contours of number of impacts or penetrations on the finite element model operation.” The menu prompts are listed in column 1. The default inputs are listed in column two. The input data types are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Required Parameters **–** The required inputs are listed in Table 11.

Table 11. Plot Contours of Number of Impacts or Penetrations on the Finite Element Model Operation Prompt/Response User Interface Required Parameters

Prompt	Default	Type
'CREATE AN INPUT FILE FOR CONTOUR PLOTS ? (<CR>=NO) > '	N	A1

Any string starting with ‘N’ or ‘n’ is interpreted as a No response and any string beginning with a ‘Y’ or ‘y’ is interpreted as a Yes response. Typing a carriage return with no text input will default to a “No” response.

Optional Parameters **–** The optional parameters shown in Table 12 are encountered when the user responds **`Y`**.

Table 12. Plot Contours of Number of Impacts or Penetrations on the Finite Element Model Operation Prompt/Response User Interface Optional Parameters

Prompt	Default	Type
' CONTOUR FILE FORMAT ?' ' 1 - SUPERTAB UNIVERSAL <CR> ‘ ' 2 - PATRAN NEUTRAL' ' CHOICE ? (1 OR 2) > '	1	INTEGER
IF CHOICE IS 1 THEN		
' SUPERTAB UNIVERSAL FILENAME ? (<CR>=contour.uni) > '	contour.uni	A256
ELSE		
' PATRAN NEUTRAL FILENAME ? (<CR>=contour.neu) > '	contour.neu	A256
ENDIF		

Default options **–** The default option is ‘N’’; to suppress writing the contouring data.

Parameter order and syntax **–** The order of the input to write the contour file data must be

```
Y <CR>
1 <CR>
Contour data file name <CR>
```

where the symbol <CR> represents the pressing the enter key on the keyboard.

The order of input to suppress writing the contour file data is

```
N <CR>
```

5.10.4 Examples

Example 8 runs one calculation of the number of impacts by 1 mm micrometeoroid particles onto an oriented cube for the MEMCxP environment. The calculation outputs the results contouring data for the I-deas finite element pre and post processor.

Type the following at the console to redirect the *Bumper 3* code keyboard input to the file *EXAMPLE8.txt*

```
#> cat EXAMPLE8\EXAMPLE8.TXT | BUMPER3-LITE
```

The example contour plot analysis outputs a file named *EXAMPLE8.UNI*.

You can confirm you obtained the same results by differencing the .UNI files as follows:

```
#> diff (cat EXAMPLE8.UNI) (cat EXAMPLE8\EXAMPLE8.UNI)
```

The difference command only reports lines that are different. If all of the lines are the same, then the difference command will return without printing anything to the console window.

The code block in Figure 63 is a listing of the *EXAMPLE8.UNI* file. The first 10 rows are header information. Rows 11, 13, 15, 17, etc. list the EID in the first column. Rows 12, 14, 16, 18, etc. list the mean number of impacts on the element with the EID listed in Rows 11, 13, 15, 17, etc., respectively.

```
    -1
    56
 METEOROID ANALYSIS
 PROBABILITY OF PENETRATION (%) PER M2
NONE
NONE
NONE
         1         0         1         1         2         1
         1         1         1
  0.00000E+00
         1         1
  0.17600E+00
         2         1
  0.34766E+00
         3         1
  0.17374E+00
         4         1
  0.67569E-01
         5         1
  0.25702E+00
         6         1
  0.23568E-01
    -1
```

Figure 63. Format of the contour plot file *EXAMPLE8.UNI.*

Figure 64 is an I-deas contour plot using a FEM with hundreds of thousands of elements [7]. The contours plot numbers of ORDEM 2000 particle impacts per square meter. Typically, the contours are used to identify regions that could use more shielding or attitudes that could protect vulnerable components.

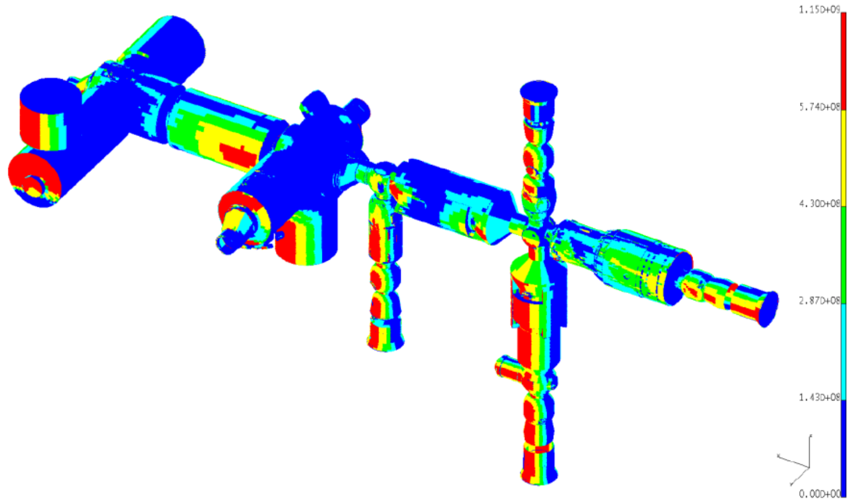


Figure 64. Contour plot of impacts per square meter for a recent ISS analysis.

Possible error messages and causes

None.

5.10.5 Cross references to other operations

1. Complementary operations
   a. None
2. Predecessor operations
   a. Section 5.4 “Calculate the Spacecraft Self-Shadowing Database Operation”
   b. Section 5.6 “Calculate the Spacecraft Shield Ballistic Limit Curve Table Operation”. (If a probability of penetration or number of penetrations calculation is performed. If it is a probability of impact or number of impacts calculation, then the .RSP file is not needed.)
   c. Section 5.8 “Calculate the Number of Spacecraft Shield Impacts or Penetrations Operation”
3. Successor operations
   a. Use I-deas to apply the contouring data file to the finite element model.

5.11 Calculate with ORDEM2000 Environment Files Operation

The “Calculate with ORDEM2000 environment files operation” is optional for SHIELD calculations using circular orbits and ORDEM2000 the orbital debris environment. The *Bumper 3* code can calculate the ORDEM2000 environment for circular orbits. However, this operation is mandatory for SHIELD calculations of spacecraft in elliptical orbits using the ORDEM2000 orbital debris environment.

5.11.1 Functional description

The “Calculate with ORDEM 2000 environment files operation” is performed outside of the *Bumper 3* code using the program *ordem2k2bii.exe* supplied with the *Bumper 3* code 3 distribution. The output of the “Calculate with ORDEM 2000 environment files operation” is an ASCII text file containing the flux increment for each threat direction for six reference sizes. ORDEM2000 interpolates between the reference sizes to determine the flux of particles whose diameters lie on the ballistic limit curve.

5.11.2 Cautions and warnings

- Do be aware that ORDEM2000 uses the velocity vector local horizontal (VVLH) coordinate system, unlike ORDEM 3 and MEM which use the VNC coordinate system. The *Bumper 3* code XY plane is horizontal to the surface of the Earth in the ORDEM2000 environment with the –Z axis pointing through the center of the Earth, and the spacecraft velocity vector in the *Bumper 3* code XZ plane. For a circular orbit the *Bumper 3* code X-axis is along the velocity vector. For a very elliptical orbit the spacecraft velocity vector can translate in the XZ plane from nearly the +Z-axis to nearly the –Z-axis. (The VNC coordinate system has the *Bumper 3* code X-axis pointing along the velocity vector and the *Bumper 3* code Y-axis parallel to the spacecraft orbital momentum vector.)
- Do be aware that *ordem2k2bii.exe* expects the ORDEM2000 population files to be located in the folder *%LOCALAPPDATA%\NASA HVIT\envFiles\ORDEM2000* and that it is not possible to redirect the search to another folder.
- The *o2kFile.dat* environment file is a table of fluences (#/sq. m) and not fluxes (#/sq. m/yr) like the ORDEM 3 and MEM environment files. The user is prompted for the duration of exposure in *ordem2k2bii.exe* and not in SHIELD.
- Do be aware that *ordem2k2bii.exe* sums over 9,999 increments of an orbit, while the *ORDEM2000.exe* GUI distributed by NASA's Orbital Debris Program Office (ODPO) summed more than 100 increments and BUMPER-II summed more than 1,000 increments. Therefore, *ordem2k2bii.exe* produces slightly different, but more accurate, answers than either ORDEM2000 or BUMPER-II.
- Do be aware that for circular orbits the same results will be obtained for any argument of perigee between 0 and 360 degrees, including the random argument of perigee option.
- Do be aware that the ODPO recommends using a random argument of perigee for elliptical orbits.
- Do be aware that the ORDEM2000 environment, as distributed by the ODPO, is not defined above 2,000 km altitude. The HVIT program *ordem2k2bii.exe* was modified to assume no flux above 2,000 km (option 1), a constant spatial density of orbital debris particles above 2,000 km (option 2) and a spatial density of orbital debris particles that varied with the inverse square of altitude for altitudes above 2,000 km (option 3). Option 3 is recommended for apogees above 2,000 km. However, be aware that this is known to overestimate the flux at altitudes above 2,000 km.

5.11.3 Formal description

Table 13 is the formal description of the prompt/response user interface inputs for the "calculate with ORDEM2000 environment files operation." The menu prompts are listed in column 1. The default inputs are listed in column two. The input data types are listed in column 3. Integer indicates that the numerical input cannot include a decimal; e.g., 1 is accepted but 1.0 is not. Real indicates the numerical input can include a decimal point; e.g., 1, 1.1 and 1.0 are all accepted.

Required Parameters – The required inputs are listed in Table 13.

Table 13. *ordem2k2bii.exe* Prompt/Response User Interface

Prompt	Default	Type
' ORDEM2K2BII VERSION 1.3 MON SEPT 24, 2012 CALCULATION TYPE 1. STANDARD BUMPER ORDEM2000 MULTIPLE ORBIT FLUX	none	A4

2. FRACTION OF A SINGLE ORBIT FLUX CHOOSE 1 OR 2:'		
PERIGEE (km):	none	REAL
APOGEE (km):	none	REAL
Type of high altitude flux calculation: 1 - zero OD spatial density above 2,000 km 2 - constant OD spatial density above 2,000 km 3 - 1/r^2 OD spatial density above 2,000 km Choice:	none	INTEGER
INCLINATION (deg):	none	REAL
Argument of perigee (0 to 360 degrees or -1 for random):	none	REAL
IF CALCULATION TYPE EQUALS 1 THEN		
START TIME (decimal yr CE):	none	REAL
DURATION (yrs):	none	REAL
ELSEIF CALCULATION TYPE EQUALS 2 THEN		
YEAR OF FRACTIONAL ORBIT:	none	REAL
angle of starting point:	none	REAL
angle of ending point:	none	REAL
ENDIF		
analysis title:	none	A80

REAL variables can be entered at the prompt in single or double precision. However, the *o2kFile.dat* environment file is written out single precision.

Optional Parameters – The *ordem2k2bii.exe* executable has two options. Calculate the environment for an orbit making many circuits of the Earth (CALCULATION TYPE option 1) and the environment for a segment of a single orbit (CALCULATION TYPE option 2).

The optional parameters for the multiple orbit calculation are listed in Table 14.

Table 14. CALCULATION TYPE Option 1 (multiple orbits) Prompt/Response User Interface

Prompt	Default	Type
IF CALCULATION TYPE EQUALS 1 THEN		
START TIME (decimal yr CE):	none	REAL
DURATION (yrs):	none	REAL

The optional parameters for the segment of a single orbit calculation are listed in Table 15.

Table 15. CALCULATION TYPE Option 2 (orbit segment) Prompt/Response User Interface

Prompt	Default	Type
ELSEIF CALCULATION TYPE EQUALS 2 THEN		
YEAR OF FRACTIONAL ORBIT:	none	REAL
angle of starting point:	none	REAL
angle of ending point:	none	REAL

Default options **–** There are no default options.

Parameter order and syntax – The order of the input to write the *o2kFile.dat* environment file for multiple orbits must be

```
1 <CR>
Perigee in km <CR>
Apogee in km <CR>
1, 2 or 3 <CR>
Inclination in degrees <CR>
Argument of perigee in degrees <CR>
Start date of exposure (fractional year CE) <CR>
Duration of exposure (yrs) <CR>
Analysis title <CR>
```

The order of the input to write the *o2kFile.dat* environment file for a fraction of a single orbit must be

```
2 <CR>
Perigee in km <CR>
Apogee in km <CR>
1, 2 or 3 <CR>
Inclination in degrees <CR>
Argument of perigee in degrees <CR>
Year of fractional orbit (CE) <CR>
Mean longitude of starting point in orbit in degrees <CR>
Mean longitude of ending point in orbit in degrees <CR>
Analysis title <CR>
```

where the symbol <CR> represents the pressing the enter key on the keyboard.

5.11.4 Examples

Example 9 creates an ORDEM2000 environment file, called *ordem2k.dat*, for the ISS orbit and the year 2014.

Type the following at the console to run *EXAMPLE9.txt* as an option at the command line.

```
#> ORDEM2K2BII EXAMPLE9\EXAMPLE9.TXT
```

Alternatively, *ordem2k2bii.exe* can be run using a prompt/response user interface by typing the following at the command line.

```
#> ORDEM2K2BII
```

The prompt/response session for EXAMPLE 9 is shown in Figure 65.

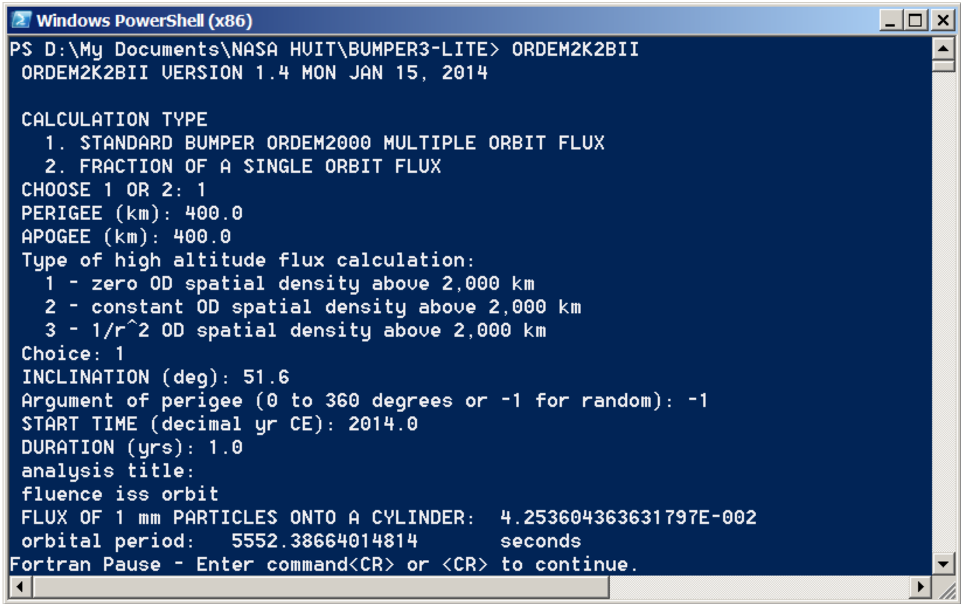


Figure 65. Input prompts for the environment application ordem2k2bii.

First prompt is for the calculation type:

- Enter 1 for a multiple orbit analysis. This option calculates a flux averaged over the whole orbit.
- Enter 2 for a fraction of a single orbit. This option calculates the flux averaged over the desired fraction of the orbit.

Second prompt is for the orbital perigee as height above the surface of the Earth, in km. The perigee must be equal to or larger than 200.0 km.

Third prompt is for the orbital apogee as height above the surface of the Earth, in km. The apogee must be equal to or larger than the perigee.

Fourth prompt is for the assumed orbital debris spatial density above 2,000 km. Choose option 3 for apogee above 2,000 km.

Fifth prompt is the orbit inclination is in degrees and has its usual meaning. The inclination must be greater than or equal to 0.0 degrees and less than or equal to 180.0 degrees.

Sixth prompt is for the argument of perigee in degrees. Per the ODPO's direction, for calculation type 1 enter -1 for random argument of perigee. For calculation type 2 (fraction of an orbit) enter the argument of perigee, in degrees, provided by the mission planners. The ODPO recommends using a random argument of perigee. This results in the flux varying from run to run by about 2% around the mean for the ISS orbit. For comparisons with BUMPER-II use the value 0, which BUMPER-II used because it analyzed circular obits and the ORDEM2000 flux is independent of argument of perigee for circular orbits.

Seventh prompt is for the start time, given as a decimal year, e.g., March 8, 2011 = 2011.183. The start year must be greater than 1991.0 and less than 2030.0.

Eighth prompt is for the duration of exposure given as a decimal year. This value cannot exceed 15.0 years.

At the end of the computation, *ordem2k2bii.exe* prints out the cross sectional area flux of 1-mm-diameter orbital debris particles and the orbital period in seconds. The cross sectional area flux is printed out so that it can be compared with *ORDEM2000.exe* provided by the ODPO.

5.11.5 Possible error messages and causes

- `'ORDEM2000 ANALYSIS CANNOT EXTEND PAST THE YEAR 2030!'`
    - Use years between 1991 and 2030.
- `'ORDEM2000 WAS NOT DESIGNED FOR ANALYSIS > 15 YEARS!'`
    - Spacecraft exposure duration cannot exceed 15.0 years.
- `' APPDATA folder does not exist'`
    - *ordem2k2bii.exe* shares the ORDEM2000 population files with BUMPER 3. Hence it also looks in in *%LOCALAPPDATA%\NASA HVIT\envFiles\ORDEM2000* for the population files. If they are not there, then copy them to that location. *ordem2k2bii.exe* does not run with the ORDEM2000 population files in any other location.
- `' Error code ",I4," when searching for APPDATA folder. '`
    - Error message from the Windows operating system with the %LOCALAPPDATA% variable doesn't exist.

5.11.6 Cross references to other operations

1. Complementary operations
    a. None
2. Predecessor operations
    a. Gather orbit parameters. For a Calculation Type 2, fractional orbit, you'll have to get the mean longitudes from the mission planner performing the trajectory analysis.
3. Successor operations
    a. Section 5.8 Calculate the number of spacecraft shield impacts or penetrations operation.

5.12 Calculate with ORDEM 3 environment files operation

The "Calculate with ORDEM 3 environment files operation" is mandatory for SHIELD calculations using the ORDEM 3 orbital debris environment.

5.12.1 Functional description

The "Calculate with ORDEM 3 environment files operation" is performed in two phases as shown in Figure 66.

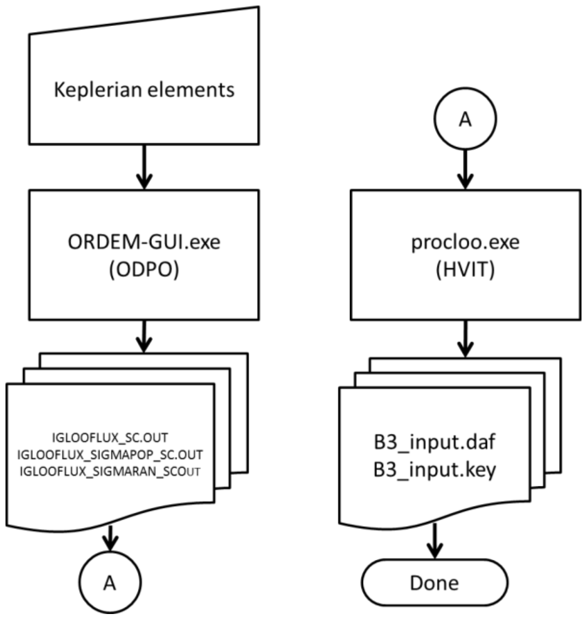


Figure 66. The two phases of the "calculate with ORDEM 3 environment files operation."

The first phase is performed with the ODPO program *ORDEM-GUI.exe* supplied by the NASA JSC Orbital Debris Program Office. The Keplerian elements are input to the program for each year of exposure and the program outputs the flux tables for each year. The HVIT program *procloo.exe* (supplied with the *Bumper 3* distribution) is then used to combine the files into one compressed data file (the B3_input.daf file) and one file used to expand the compressed data file (the B3_input.key file).

5.12.2 Cautions and warnings

- Be aware one should use different project folders for each change of input. *ORDEM-GUI.exe* overwrites the output of previous analyses with the output of the current analysis using the same, unchanging filenames.
- *ORDEM-GUI.exe* produces 3 output files: *IGLOOFLUX_SC.OUT*, *IGLOOFLUX_SIGMAPOP_SC.OUT* and *IGLOOFLUX_SIGMARAN_SC.OUT*. All three files must be present for *procloo.exe* to run to completion.
- Be aware that the environment file calculation can take considerable time, so the analyst must plan accordingly. Figure 67 is a plot of *ORDEM-GUI.exe* runtimes as a function of altitude. The runtime for the ISS orbit is around 15 minutes. However, it reaches a maximum of 73 minutes at 2,000 km altitude and gradually drops off to 35 minutes at geosynchronous altitudes.

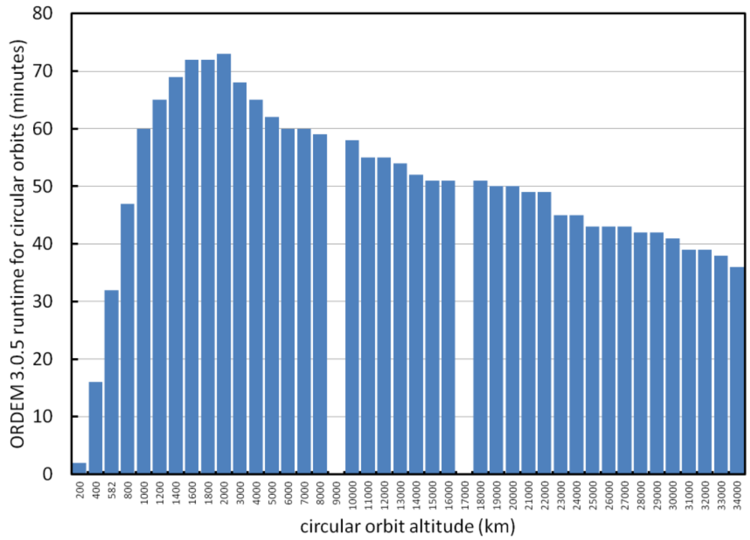


Figure 67. ORDEM 3 GUI runtimes for circular orbits with different altitudes but fixed 28.5 degree inclination and random argument of perigee.

Calculation of the environment files for elliptical orbits will take times similar to those whose altitudes they cross. Thus, an elliptical orbit calculation with an apogee of 2,000 km will take about an hour and a half.

- Be aware that calculating the flux on a spacecraft in the ISS orbit with 0° argument of perigee takes about 1 min 20 seconds while calculating with a random argument of perigee takes about 12 minutes. However, the results are (nearly) equal. Choosing non-random argument of perigee or right ascension of ascending node (RAAN) can affect the calculated flux for spacecraft in Molniya-type orbits or the geosynchronous Earth orbit (GEO) regime, respectively. The low-Earth orbit (LEO) populations are assumed to consist of populations with randomized argument of perigee and RAAN, hence choosing a specific value for these orbital elements will not affect LEO fluxes (more than a fraction of a percent).
- Be aware that is possible to drive the ORDEM 3 console application with a PowerShell script. This makes it possible to generate parameter study results, such as the calculation of runtime as a function of circular orbit altitude shown in Figure 67.

5.12.3 Formal description

Refer to the Orbital Debris Program Office ORDEM 3 user guide [8] for the functional description of *ORDEM-GUI.exe*.

Table 16 and Table 17 are the formal description of the command line options and switches for the *procloo.exe* step of the "calculate with ORDEM 3.0 environment files operation."

Required Parameters – The *procloo.exe* command line interface options listed in Table 16 are required.

Table 16. *procloo.exe* Command Line Interface Options

Option	Default	Type
INPUT_FILENAME	none	A256
ROOT_OUTPUT_FILENAMES	none	A256

The INPUT_FILENAME command line option must be a string with 256 characters or less. If the filename includes spaces, then the INPUT_FILENAME string must be enclosed in double quotes.

The input file must be an ASCII text file with each line of characters terminated by a carriage return/line feed. The variables in each input file record are listed in the code block below.

```
start_year
duration
meanfile_1 sigmapop_1 sigmaran_1
meanfile_2 sigmapop_2 sigmaran_2
meanfile_3 sigmapop_3 sigmaran_3
...
meanfile_n sigmapop_n sigmaran_n
```

The first record is the starting year of the analysis. This is the start date in decimal year CE. January 1, 2014 would be entered as 2014.0.

The second record is the duration of exposure in decimal years. A two and a half year exposure would be entered as 2.5.

Records 3 through 3+n are the *ORDEM-GUI.exe* output files that will be processed by *procloo.exe*.

The ROOT_OUTPUT_FILENAME command line option must be a string with 256 characters or less. If the root output filename includes spaces, then the string must be enclosed in double quotes. This string is used as the filename of the .daf and the .key files.

***Optional Parameters* –** The *procloo.exe* command line interface switches listed in Table 17 are optional.

Table 17. *procloo.exe* Command Line Interface Switches

Switch	Default	Type
-h	none	A2
-v	none	A2
-b	none	A2

The –h help switch prints a command line help file to the screen and then continues executions of *procloo.exe*. The help screen is reproduced below.

```
'Combine multiyear ORDEM2010 IGLOOFLUX_SC.OUT files into a single fluence'
'formatted or direct access file for BUMPER.'
'USAGE:'
'  procloo [-hvb] [INPUT_FILENAME] [ROOT_OUTPUT_FILENAMES]'
'      -b switches from formatted output file to binary output file'
'      -h prints a help file'
'      -v prints the version number'
''
'<CR> to continue:'

' The format of the input file is'
'      start_year'
'      duration'
```

```
'     _SC.OUT_1 _SIGMAPOP.OUT_1 _SIGMARAN_SC.OUT_1'
'     _SC.OUT_2 _SIGMAPOP.OUT_2 _SIGMARAN_SC.OUT_2'
'     ...'
'     _SC.OUT_N _SIGMAPOP.OUT_N _SIGMA_RAN.OUT_N'
' An example of the input file is'
' # Comment lines begin with a hash in the first column'
' 2010.750'
' 3.1'
' # Another comment line'
' IGLOOFLUX_SC_1.OUT IGLOOFLUX_SIGMAPOP_SC_1.OUT IGLOOFLUX_SIGMARAN_SC_1.OUT'
' IGLOOFLUX_SC_2.OUT IGLOOFLUX_SIGMAPOP_SC_2.OUT IGLOOFLUX_SIGMARAN_SC_2.OUT'
' IGLOOFLUX_SC_3.OUT IGLOOFLUX_SIGMAPOP_SC_3.OUT IGLOOFLUX_SIGMARAN_SC_3.OUT'
```

The –v version switch prints a version number statement to the screen and then continues the execution of *procloo.exe*. The version number statement is reproduced below.

```
'procloo version 1.5.2 May 1, 2014'
```

The –b switch is deprecated.

Default options – There are no default command line options. All command line options are mandatory.

Parameter order and syntax – The command line options INPUT_FILENAME and ROOT_OUTPUT_FILENAME must be entered in the order INPUT_FILENAME ROOT_OUTPUT_FILENAME.

5.12.4 Examples

Calculating the ORDEM 3 environment files is a two-step operation. First, the ODPO program *ORDEM-GUI.exe* is used to create the *IGLOOFLUX_SC.OUT* file for each year and set of orbital parameters desired. Second, the HVIT program *procloo.exe* is used to combine and compress the files into two files; the filename.dat file and the filename.key file.

ORDEM 3 – *ORDEM-GUI.exe* accepts inputs from the user, sets up and performs a single run, and displays the results as on-screen plots. This example will calculate environment file for an orbit at ISS altitude and inclination for a 1.25-year exposure starting noon, July 1, 2014.

ORDEM 3 has two major assessment types. The first type is for spacecraft and mission designers. The second type gives orbital debris information as would be seen from a ground-based telescope or radar. Resultant plots and data files give estimates of population flux and velocity distributions.

The project window is the initial window on start-up. It shows the location of the user's current project directory. The project directory is the directory location chosen by the user to which all output files and GUI settings will be saved. It is designed to allow a user the ability to work with more than one project at a time. Figure 68 is a screen shot of the project window.

Example 10 has a start date of 2014.5 and an end date of 2015.75. Thus, two flux files are needed; one for the year 2014 and one for the year 2015. Note that the *ORDEM-GUI.exe* output filename is not user selectable. Therefore, two projects will be used for the computations to avoid overwriting the 2014 output file by the 2015 output file. The path to the first project is *…\EXAMPLE_10\2014* and the path to the second project is *…\EXAMPLE_10\2015*. Also note that *ORDEM-GUI.exe* cannot tolerate spaces in the path name, hence the underscore in *EXAMPLE_10.*

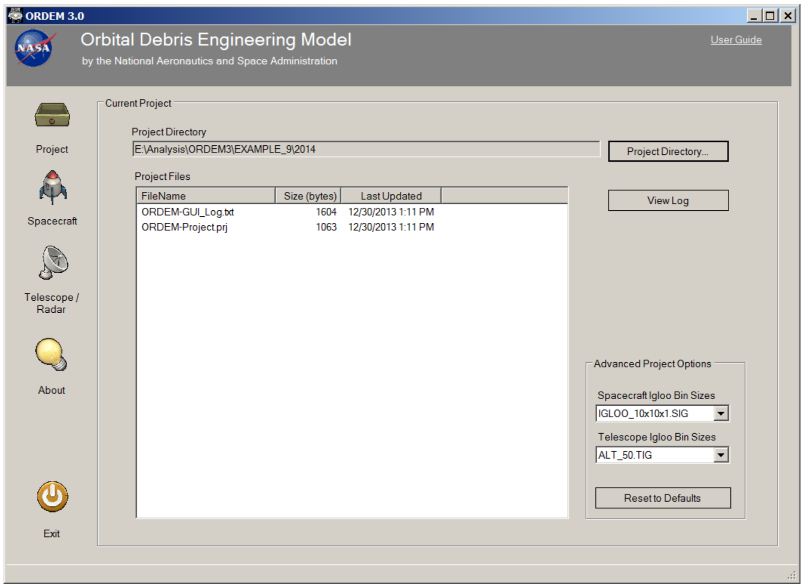


Figure 68. ORDEM 3 project window.

The top area of the project window displays the currently selected project directory. This directory is the location for all the computational output and GUI settings. The New button, when pressed, creates a new project (including the required ".prj" file) in another location that the user specifies. The application allows the user to save as many projects as desired. Note that creating a project directory by other means will NOT create the required ".prj" file, causing ORDEM 3 to reject that directory. To open a previously created project, the user selects the Browse button and chooses the desired directory. The Save button will save all the current values in the GUI to a file. The Save As button allows the user to save the current GUI values into another project directory. The Revert button resets all the GUI values to the last saved values.

Near the bottom of the window is a list of files in the current project directory. It provides a quick way to access and view any of the files. If double clicked, the file will be opened in another window for viewing. View Log will bring up a window allowing the user to view the log of past activity. Lastly, the Reset to Defaults button will reset all the GUI values to default values. This includes the currently known project directory in the project window and the system registry (used for loading the last used project on startup).

The spacecraft assessment window, Figure 69, is used for evaluating the orbital debris environment for spacecraft and missions. This window contains the input fields (at the top), and the runtime output window (at the bottom).

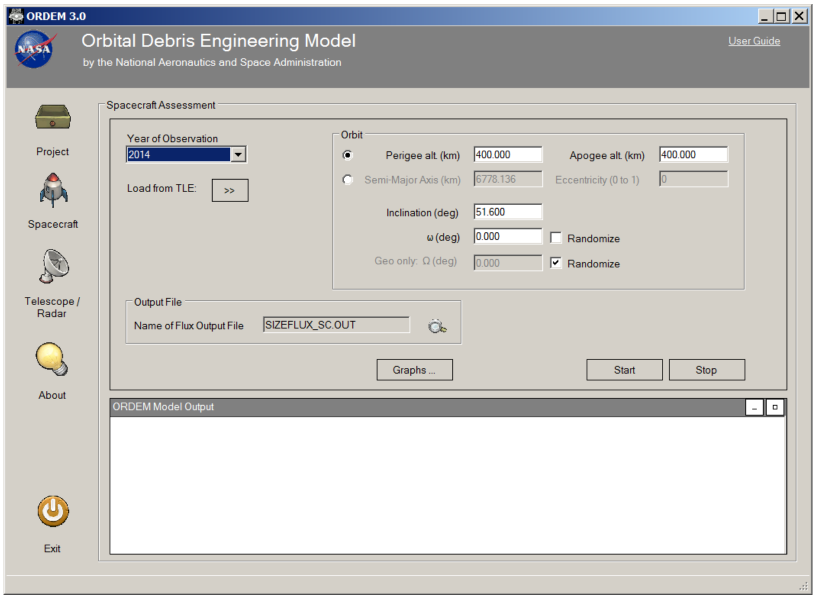


Figure 69. ORDEM 3 spacecraft assessment dialog.

The input orbit information can be entered as Keplerian-style orbit elements or as a Two Line Element set. When entering input information by hand, the user can define the orbit by perigee and apogee altitudes or by semi-major axis and eccentricity. RAAN may also be defined. It is also possible to choose a randomized value for the RAAN. The results will represent time-averaged fluxes over all possible values of the RAAN that are appropriate for long-term flux calculations in many cases. Note that the choice of RAAN only affects flux calculations in the GEO regime. The LEO populations are assumed to consist of populations with randomized RAAN, so the choice of spacecraft RAAN will not affect LEO fluxes.

After all input parameters are set in the spacecraft assessment window, the user may click the Start button to begin the computations. The Stop button is provided to abort a run. Immediately below the Start and Stop buttons is the ORDEM 3 Model Output area. After clicking the Start button, the model process will be started and the output messages will be redirected into this output area. Normal output messages from the model will appear in black text and error messages will appear in red text. The GUI will write other informative messages in blue text. (Note that the different-colored messages may not appear to be synchronized, as they come from different sources.)

The Keplerian elements for the ISS orbit are:

- 400.0 km perigee,
- 400.0 km apogee,
- 51.6 degrees inclination,
- 0 degree argument of perigee, ω,

which are the inputs shown in Figure 69. Perform the calculation for the years 2014 and 2015.

procloo – The program *procloo.exe* combines *IGLOOFLUX_SC.OUT* files and compresses the result into a single <ROOT_OUTPUT_FILENAMES>.DAF and an index file for decompressing the .DAF file called <ROOT_OUTPUT_FILENAMES>.KEY. *procloo.exe* reads its inputs from a file and not the command line. The input file for EXAMPLE 10 is:

```
2014.5
1.25
2014\IGLOOFLUX_SC.OUT 2014\IGLOOFLUX_SIGMAPOP_SC.OUT
2014\IGLOOFLUX_SIGMARAN_SC.OUT
2014\IGLOOFLUX_SC.OUT 2014\IGLOOFLUX_SIGMAPOP_SC.OUT
2014\IGLOOFLUX_SIGMARAN_SC.OUT
```

The inputs do not have to start in the first column. They may be preceded by blank characters.

1. The input lines may be up to 892 characters in length, but no more.
2. The start date and the duration do not have to be listed in the input file as reals. That is, the character string for the integer 2002 will be read as the real 2002.0.
3. The input files may have any number of comment lines or blank lines at any position in the file. A comment line begins with a hash (#), which can start anywhere in a line but not in data lines.

The program checks for the following:

- the years listed in the input file headers are continuous,
- the years listed in the input file headers are in order,
- that there are no gaps in the years in the headers,
- that there is an input file that covers the start year,
- that there is an input file that covers the end year.
    - The special case is covered where the elapsed time ends on a year boundary. For example 2010.25+2.75 = 2013; the user only needs to read in 2010, 2011, 2012, and not 2013.

The output of the program are the ROOT_OUTPUT_FILENAMES.daf file and the ROOT_OUTPUT_FILENAMES.key file.

The Example 10 *procloo.exe* analysis begins by changing directories to *EXAMPLE10*.

```
#> cd EXAMPLE10
```

Type the following at the console to use *procloo.exe* to process the ORDEM 3 files listed in the *input.txt* file into the *example9.daf* and the *example9.key* files.

```
#> procloo input.txt example10
```

The entire terminal session for Example 10 is shown in Figure 70.

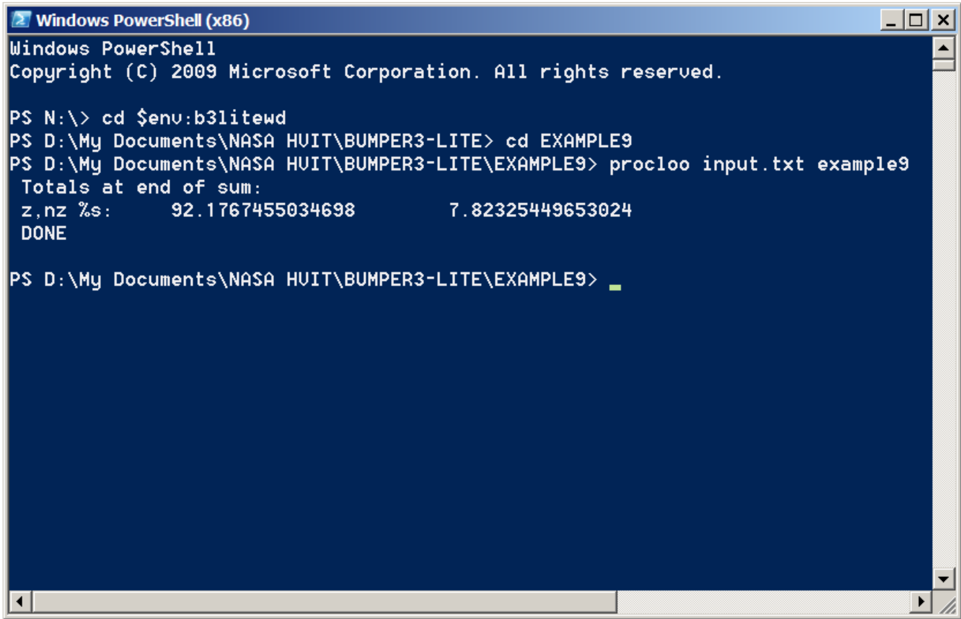


Figure 70. Output from the bumper *procloo.exe* app.

procloo.exe prints two numbers to the terminal; the 92.176… number indicates that 92% of the numbers in the *IGLOOFLUX_SC.OUT* file were zero. The 7.823… number indicates that 8% of the numbers in the *IGLOOFLUX_SC.OUT* file were nonzero

5.12.5 Possible error messages and causes

See the ORDEM 3 software user manual for the *ORDEM-GUI.exe* error messages.
The *procloo.exe* error messages are listed below:

- `'ERROR: ' [option)] ' is not a valid command line option'`
  - The only valid command line switches are -h, -v, and -hv.
- `'ERROR: Need two arguments following the options, input and output file names'`
  `' There are ',XXXX, ' space separated arguments following the options'`
  `' If you want to use spaces in the file name enclose the file name in double quotes'`
  - This error occurs when input and output filenames include spaces, but the filename is not enclosed in double quotes.
- `'ERROR: parsed a zero length input file name'`
  - This error occurs when the input and output filenames are not entered on the command line.
- `'ERROR: The input file name is the same as the output file name'`
  `'  input file name: ', [INPUT_FILENAME]`
  `' output file name: ', [OUTPUT_FILENAME]`
  - Use different names for the input file and the output file.
- `' Error opening input file ', [INPUT_FILENAME]`
  - The input file is not in the path. Check the spelling of the input filename.
- `'Couldn't parse the first line of input: '`
  - The first line of the input file could not be parsed into a decimal date. Make sure the start date is on the first line of the input file.
- `'Couldn't parse the second line: '`

    - The second line of the input file could not be parsed into a decimal duration. Make sure the duration of exposure is on the second line of the input file.
- `'Error reading input file header'`
    - An error occurred reading one of the first two lines of the input file. Check to determine the input file is not corrupted.
- `'Did not read any file names in the file name list'`
    - The input file does not contain text that can be parsed into filenames. Check to make sure there is a list of 3 filenames per record following the input file two line header.
- `' Error opening IGLOO file ', [IGLOOFLUX_SC.OUT]`
    - Could not open the *IGLOOFLUX_SC.OUT* file. Make sure it is in the path and spelled correctly.
- `' The igloo files are out of chronological order'`
  `' File # ' [IGLOOFLUX_SC_1.OUT] ' is for year ',YEAR_1, ' and'`
  `' file # ' [IGLOOFLUX_SC_2.OUT] ' is for year ',YEAR_2`
    - The *IGLOOFLUX_SC.OUT* records must be listed in the input file in chronological order and no date between the start and end date can be skipped.
- `'ERROR: start_date is less than the first year in the input file list'`
    - The start date from the first record in the input file is less than the earliest year listed in the header of the of *IGLOOFLUX_SC.OUT* files. Correct the start date or add the *IGLOOFLUX_SC.OUT* files to the input file list with the correct dates.
- `'ERROR: start_date+duration is greater than the last year in the input files'`
    - The sum of the start date and the duration of exposure from the first two records in the input file is greater than the latest year listed in the header of the of *IGLOOFLUX_SC.OUT* files. Correct the start date and/or duration or add the *IGLOOFLUX_SC.OUT* files to the input file list with the correct dates.

5.12.6 Cross references to other operations

1. Complementary operations
    a. None.
2. Predecessor operations
    a. Gather orbit parameters.
3. Successor operations
    a. Section 5.8 Calculate the number of spacecraft shield impacts or penetrations operation.

5.13 Calculate MEMCxP Environment Files Operation

The “Calculate with MEMCxP environment files operation” is mandatory for SHIELD calculations using the MEMCxP micrometeoroid environment. Note that MEMR2 is the most recent meteoroid environment. MEMR2 is recommended for new meteoroid impact risk analyses, and not MEMCxP. (MEMCxP is no longer in distribution and is only included in the *Bumper 3* code for those spacecraft programs, such as the Orion MPCV, whose environment specifications require performing meteoroid impact risk assessments with the MEMCxP meteoroid environment.)

5.13.1 Functional description

The "Calculate with MEMCxP environment files operation" is performed in two phases as shown in Figure 71.

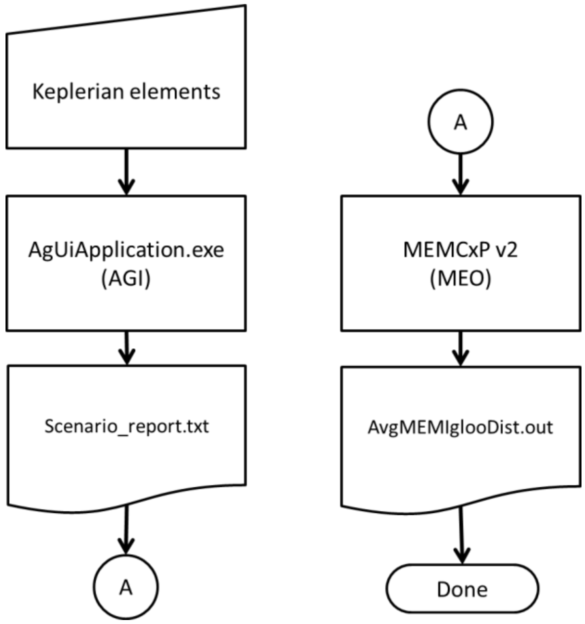


Figure 71. The two phases of the "calculate with MEMCxP environment files operation."

The first phase is performed with the Satellite Took Kit (STK) program *AgUiApplication.exe* marketed by Analytical Graphics, Inc. (AGI).[3] The Keplerian elements and the scenario start date and duration are input to the program and the program outputs the position and speed state vector components in Earth-centered inertial coordinates.

The second phase is performed with the HVIT program *procloo.exe* (supplied with the *Bumper 3* distribution). The program *procloo.exe* is used to combine the files into one compressed data file (the B3_input.dat file) and one file used to expand the compressed data file (the B3_input.key file).

MEMCxP is valid for all Earth orbiting missions and lunar transit missions out to the Moon's sphere of influence (~66,000 km radius from Moon). This tool is not capable of characterizing the meteoroid environment for spacecraft in orbit about the Moon; for those scenarios, LunarMEM is now available.

MEMCxP will generate an average environment file and a standard deviation from the average. The user can choose to either use just the average environment file or combine the standard deviation and average for a more or less conservative environment. Only one file should be read into the *Bumper 3* code, either the average or the resultant of combining the average and standard deviation variation. The output file format should not be changed as it is consistent with the format required for the *Bumper 3* code. All environment files contain the

[3] A reduced functionality version of Satellite Tool Kit (STK) is available for free from the AGI website: *http://www.stk.com/*. This version is capable of analyzing elliptical orbits.

information relative to the spacecraft motion as described in the state vector file. All environment files contain appropriate Earth shielding, gravitational focusing, and aberration.

To generate environment files for different missions, you must run the tool for each individual mission scenario (LEO, docked to ISS, lunar transit, etc.). This will require generating appropriate state vectors for each mission segment of interest. Do not assume that the environment for a 6-month mission docked to space station is adequate to define the short 4-day mission for lunar transit. The environment is highly dependent on the inclination of the orbit, the altitude of the orbit, where the spacecraft is in the orbit, and the orbit planes orientation with respect to the sun.

5.13.2 Cautions and warnings

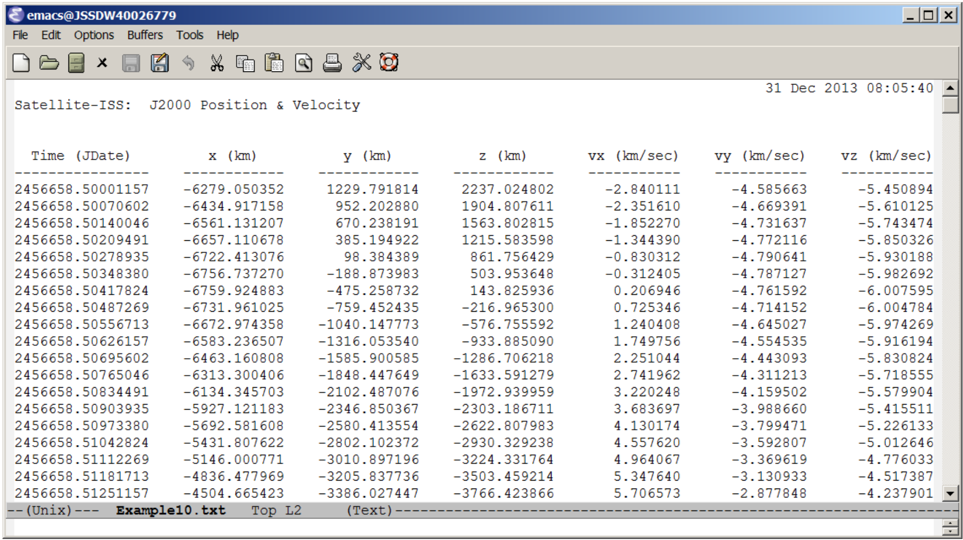
- Create the STK file using J2000 Cartesian coordinates.
- Create the STK file using the JDATE format for the time.
- Do use 4,000 or more draws from the STK file for a 1-year (or more) mission.
- Be aware that a 4,000 draw MEMCxP calculation will take about 2.5 Gigabytes of hard disk drive space. Make sure you have enough room before starting.
- MEMCxP uses the same seed for its random draws. So if you want a different set of random draws for the same orbit, you need to change the orbit in some way to change the state vectors in the draw file.
- Confirm that the limiting mass exponent value is -6 (i.e., 1 microgram micrometeoroids) before starting the MEMCxP calculation.
- Confirm that the 1,652 threat option is selected before starting the MEMCxP calculation. The *Bumper 3* code will not read any of the other options.

5.13.3 Formal description

The Satellite Tool Kit inputs are described in on-line resources at http://www.agi.com/resources/.

The MEM environment model is described in some detail in the reports [9] and [10]. The *MEMCxP.exe* help files are the software user manual. Consult the help files for a description of the MEM inputs.

STK 9 Outputs – An example AGI Satellite Tool Kit report file output is shown in Figure 72. The satellite position and velocity state vector components should be in a Cartesian Earth Centered Inertial J2000 coordinate frame. This is indicated by the second line of text stating “J2000 Position & Velocity.”


emacs@JSSDW40026779

File Edit Options Buffers Tools Help

31 Dec 2013 08:05:40

Satellite-ISS: J2000 Position & Velocity

Time (JDate)	x (km)	y (km)	z (km)	vx (km/sec)	vy (km/sec)	vz (km/sec)
2456658.50001157	-6279.050352	1229.791814	2237.024802	-2.840111	-4.585663	-5.450894
2456658.50070602	-6434.917158	952.202880	1904.807611	-2.351610	-4.669391	-5.610125
2456658.50140046	-6561.131207	670.238191	1563.802815	-1.852270	-4.731637	-5.743474
2456658.50209491	-6657.110678	385.194922	1215.583598	-1.344390	-4.772116	-5.850326
2456658.50278935	-6722.413076	98.384389	861.756429	-0.830312	-4.790641	-5.930188
2456658.50348380	-6756.737270	-188.873983	503.953648	-0.312405	-4.787127	-5.982692
2456658.50417824	-6759.924883	-475.258732	143.825936	0.206946	-4.761592	-6.007595
2456658.50487269	-6731.961025	-759.452435	-216.965300	0.725346	-4.714152	-6.004784
2456658.50556713	-6672.974358	-1040.147773	-576.755592	1.240408	-4.645027	-5.974269
2456658.50626157	-6583.236507	-1316.053540	-933.885090	1.749756	-4.554535	-5.916194
2456658.50695602	-6463.160808	-1585.900585	-1286.706218	2.251044	-4.443093	-5.830824
2456658.50765046	-6313.300406	-1848.447649	-1633.591279	2.741962	-4.311213	-5.718555
2456658.50834491	-6134.345703	-2102.487076	-1972.939959	3.220248	-4.159502	-5.579904
2456658.50903935	-5927.121183	-2346.850367	-2303.186711	3.683697	-3.988660	-5.415511
2456658.50973380	-5692.581608	-2580.413554	-2622.807983	4.130174	-3.799471	-5.226133
2456658.51042824	-5431.807622	-2802.102372	-2930.329238	4.557620	-3.592807	-5.012646
2456658.51112269	-5146.000771	-3010.897196	-3224.331764	4.964067	-3.369619	-4.776033
2456658.51181713	-4836.477969	-3205.837736	-3503.459214	5.347640	-3.130933	-4.517387
2456658.51251157	-4504.665423	-3386.027447	-3766.423866	5.706573	-2.877848	-4.237901

--(Unix)--- **Example10.txt** Top L2 (Text)----

Figure 72. STK 9 scenario report.

Notice that the time is displayed in Julian Day format, the position vector has units of kilometers and the velocity vector has units of kilometers per second.

MEMCxP Outputs – MEMCxP can output three resolutions of *AvgMEMIglooDist.out* environment files:

- 1,652 threats (5 degrees wide at the equator and larger at the poles) with 21 speed bins per threat.
- 2,576 threats (4 degrees wide at the equator and larger at the poles) with 21 speed bins per threat.
- 4,584 threats (1 degree wide at the equation and larger at the poles) with 51 speed bins per threat.

However, the *Bumper 3* code can only read the 1,652 threat *AvgMEMIglooDist.out* environment file.

MEMCxP produces a final set of seven output files. They are:

- Main Results file (name chosen by user)
- *AvgResults.out*
- *StdDevResults.out*
- *AvgSpdDist.out*
- *StdDevSpdDist.out*
- *AvgMEMIglooDist.out*
- *StdDevMEMIglooDist.out*

The *Bumper 3* code is only able to read the *AvgMEMIglooDist.out* file. Of course, the *StdDevMEMIglooDist.out* file can be added to the *AvgMEMIglooDist.out* file to obtain a more conservative environment for a probabilistic risk assessment.

The results files contain basic run information such as the limiting mass value that was selected, the state vectors that were selected from the random draw process and basic information of flux, speed, and a flux distributed by speed bin for each surface of a basic cube. Additionally, there is a total cross sectional flux (from all directions) and three other surfaces for evaluating the risk to equipment normally positioned on a sun/anti-sun-facing surface and Earth-facing surface. The main results file contains this table of basic information for each state vector evaluated from the random draw process.

The *AvgResults.out* file lists the fluxes of one microgram micrometeoroids on the faces of an oriented cube. These results are useful for the *Bumper 3* code software verification. Note that the *AvgResults.out* file is the average of all the fluxes computed from the state vector draws. Thus, if there were 1500 randomly drawn state vectors, then the *AvgResults.out* file would contain the average of the 1500 fluxes. For example, the Ram surface would show the average flux over the 1500 states, the average speed over the 1500 states, and an average distribution, the total cross sectional flux would be the average over the 1500 states etc. Furthermore, the *StdDevResults.out* file would be the standard deviation of the 1500 fluxes computed for each face of the cube. (Thus, the standard deviation results do not quantify the model uncertainty; they quantify the variation of the model flux along the trajectory.)

The *AvgSpdDist.out* file describes the flux distributed by speed bin for each 5 degrees by 5 degrees azimuth/elevation patch in local spacecraft coordinates. The first column describes the direction in elevation, the second column describes the direction in azimuth, and columns 3 through the end are the fractional flux in each speed bin. Each speed bin label represents the midpoint of the speed range. This information is useful when plotting an equal-angular projection of the flux map, as shown below:

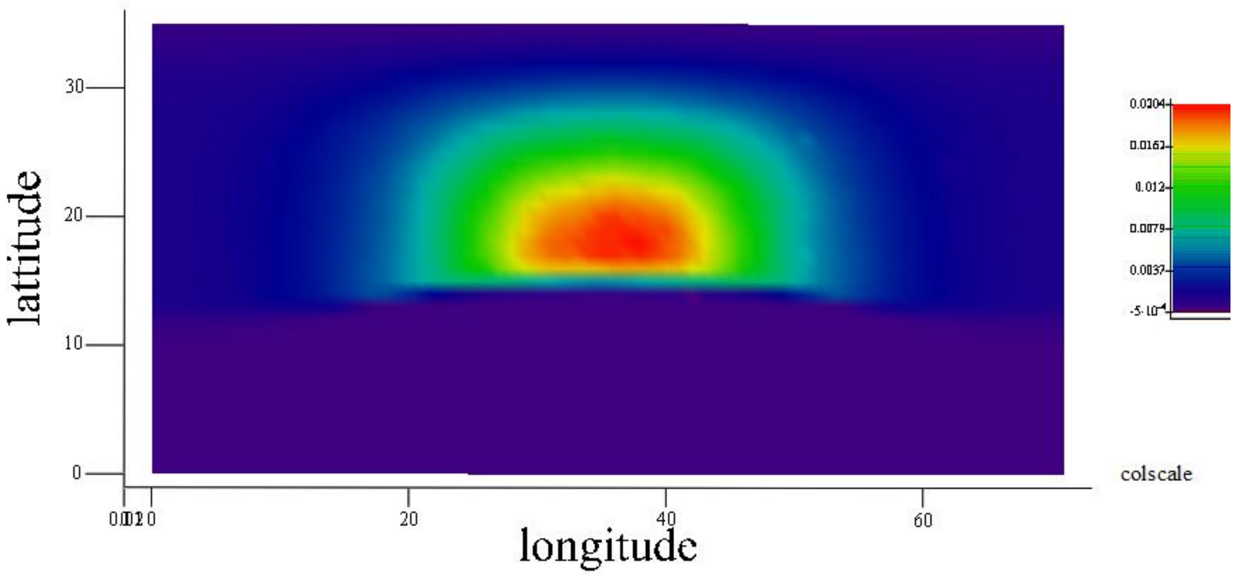
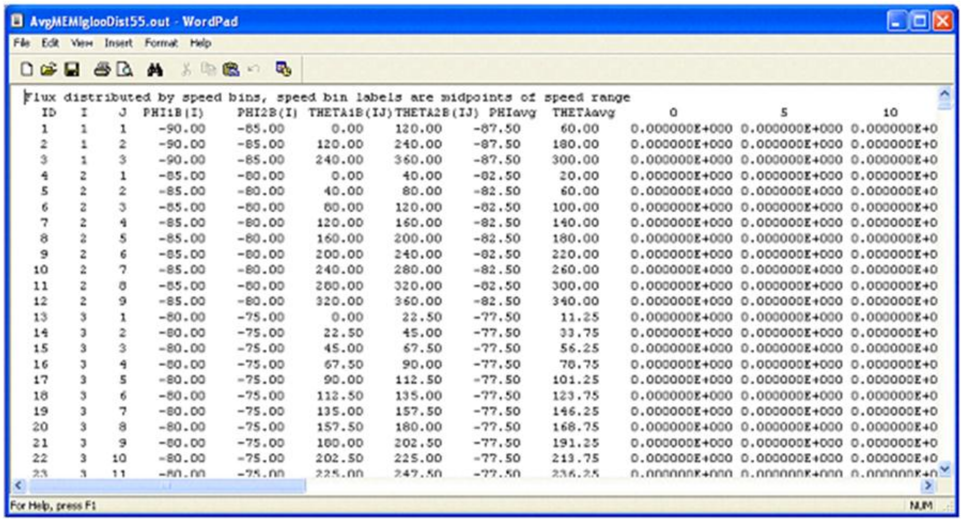


Figure 73. Typical AvgSpdDist.out flux map for 1 microgram micrometeoroids and the ISS orbit.

If the user chose an output MEM file resolution of 5 degree by 5 degree by 21 bins, then the *AvgSpdDist.out* file would increment azimuth and elevation in 5-degree bins and the flux would be distributed in 21 speed bins where each bin is 5 km/s wide. The speed bins start with bin label 0, 5, 10, 15, 20, …100 km/s. Speed bin 0 is the exception; it is not equal width as the others. Speed bin 0 covers meteoroid speeds > 0 and < 2.5 km/s and speed bin 5 covers meteoroid speeds of ≥ 2.5 km/s and < 7.5 km/s etc.

The *AvgMEMIglooDist.out* file and the *StdDevMEMIglooDist.out* file are quasi-equal area projections of the *AvgSpdDist.out* and *StdDevSpdDist.out* files. The *Bumper 3* code previously calculated threat igloos or quasi-equal area projections of the meteoroid threat and therefore this output file allows for the same format environment file as in the past.

Here is an example of a 5-degree quasi-equal area projection with 21 speed bins per direction. This file has 1652 threat directions with each direction containing the flux distributed in 21 speed bins 0, 5, 10, 15 …100 km/s.



AvgMEMIglooDist55.out - WordPad

Flux distributed by speed bins, speed bin labels are midpoints of speed range

ID	I	J	PHI1B(I)	PHI2B(I)	THETA1B(IJ)	THETA2B(IJ)	PHIavg	THETAavg	0	5	10
1	1	1	-90.00	-85.00	0.00	120.00	-87.50	60.00	0.000000E+000	0.000000E+000	0.000000E+0
2	1	2	-90.00	-85.00	120.00	240.00	-87.50	180.00	0.000000E+000	0.000000E+000	0.000000E+0
3	1	3	-90.00	-85.00	240.00	360.00	-87.50	300.00	0.000000E+000	0.000000E+000	0.000000E+0
4	2	1	-85.00	-80.00	0.00	40.00	-82.50	20.00	0.000000E+000	0.000000E+000	0.000000E+0
5	2	2	-85.00	-80.00	40.00	80.00	-82.50	60.00	0.000000E+000	0.000000E+000	0.000000E+0
6	2	3	-85.00	-80.00	80.00	120.00	-82.50	100.00	0.000000E+000	0.000000E+000	0.000000E+0
7	2	4	-85.00	-80.00	120.00	160.00	-82.50	140.00	0.000000E+000	0.000000E+000	0.000000E+0
8	2	5	-85.00	-80.00	160.00	200.00	-82.50	180.00	0.000000E+000	0.000000E+000	0.000000E+0
9	2	6	-85.00	-80.00	200.00	240.00	-82.50	220.00	0.000000E+000	0.000000E+000	0.000000E+0
10	2	7	-85.00	-80.00	240.00	280.00	-82.50	260.00	0.000000E+000	0.000000E+000	0.000000E+0
11	2	8	-85.00	-80.00	280.00	320.00	-82.50	300.00	0.000000E+000	0.000000E+000	0.000000E+0
12	2	9	-85.00	-80.00	320.00	360.00	-82.50	340.00	0.000000E+000	0.000000E+000	0.000000E+0
13	3	1	-80.00	-75.00	0.00	22.50	-77.50	11.25	0.000000E+000	0.000000E+000	0.000000E+0
14	3	2	-80.00	-75.00	22.50	45.00	-77.50	33.75	0.000000E+000	0.000000E+000	0.000000E+0
15	3	3	-80.00	-75.00	45.00	67.50	-77.50	56.25	0.000000E+000	0.000000E+000	0.000000E+0
16	3	4	-80.00	-75.00	67.50	90.00	-77.50	78.75	0.000000E+000	0.000000E+000	0.000000E+0
17	3	5	-80.00	-75.00	90.00	112.50	-77.50	101.25	0.000000E+000	0.000000E+000	0.000000E+0
18	3	6	-80.00	-75.00	112.50	135.00	-77.50	123.75	0.000000E+000	0.000000E+000	0.000000E+0
19	3	7	-80.00	-75.00	135.00	157.50	-77.50	146.25	0.000000E+000	0.000000E+000	0.000000E+0
20	3	8	-80.00	-75.00	157.50	180.00	-77.50	168.75	0.000000E+000	0.000000E+000	0.000000E+0
21	3	9	-80.00	-75.00	180.00	202.50	-77.50	191.25	0.000000E+000	0.000000E+000	0.000000E+0
22	3	10	-80.00	-75.00	202.50	225.00	-77.50	213.75	0.000000E+000	0.000000E+000	0.000000E+0
23	3	11	-80.00	-75.00	225.00	247.50	-77.50	236.25	0.000000E+000	0.000000E+000	0.000000E+0

For Help, press F1

Figure 74. MEM Igloo file from 5x5 degree bins.

The first column is just an index identification of the block number. The second column represents the igloo ring and the third column represents the block number in that ring. Phi1B and Phi2B and Theta1B and Theta2B represent the starting and ending latitude and longitude points of the block in the ring. Columns 8 and 9 represent the midpoint of the igloo block by Phi and Theta (latitude and longitude). The remaining columns 10 through the end are the flux distributed by speed bin. Depending on the resolution chosen, there can be 51 speed bins or 21 speed bins. Again, the speed bin labels represent the midpoints of the meteoroid speed range with the exception of the first speed bin 0, which is described above.

As with the other output file formats, the igloo also comes with a standard deviation version so that the two files can be combined if desired.

Random Draw Guidance – STK 9 typically outputs 1 state for every minute. This is 525,600 states for a 1-year orbit. MEMCxP would take 6 weeks to process this many states. Therefore, MEMCxP includes a feature that randomly selects state vectors from the STK 9 report file to cover the variation in meteoroid directionality, but reduce the time spent in computation. The number of random draws depends on the length of the scenario and the type of mission. The following guidelines have been established from the Meteoroid Environment Office and adequately cover the variation in directionality for the following basic missions:

- 1-year Mission Docked to ISS = 4000 random draws from input file
- 2-week Mission Docked to ISS = 1500 random draws from input file
- 4-day Lunar Transit Mission (based on typical Apollo trajectory) = 1500 random draws
    - Note this mission only goes out to the Moon's sphere of influence
- 3-day LEO Mission at 28.5° inclination and 300 km altitude = 1500 random draws

These guidelines were established from running thousands of state vectors for various missions and evaluating the flux, speed, and directionality of meteoroids relative to basic spacecraft surfaces. The number of random draws was chosen based on when the variation in flux on individual surfaces leveled out. If your mission is not mentioned above, use the above as guidance for choosing an appropriate number of random draws. Most short-term LEO missions can be adequately sampled by 1500 random draws, most 1-year missions need about twice as much (i.e., 3,000 to 4,000 random draws). These numbers are based on state vector files with 1 minute time steps. If you choose a larger time step the number of random draws for each mission should be changed.

Randomly selecting state vectors (or points in time) to evaluate the environment allows for some basic uncertainty calculations to be made. See the OUTPUTS section for discussion on the standard deviation output files.

Coordinates – All information displayed in the output files is relative to the spacecraft in local spacecraft coordinates. The figure below illustrates the coordinate frame.

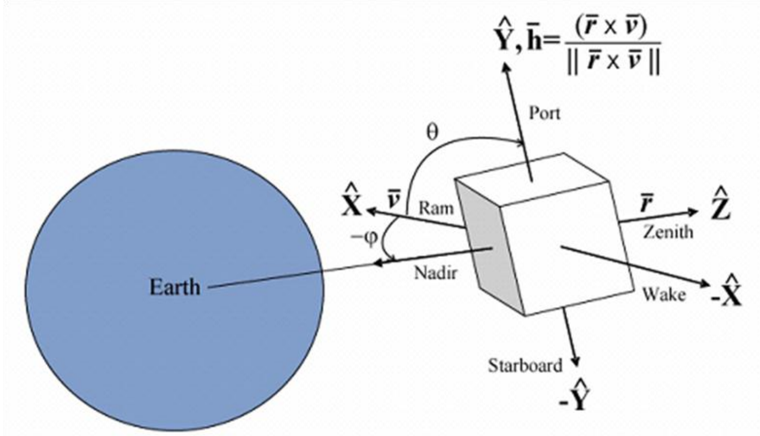


Figure 75. MEM coordinate system.

The spacecraft's velocity vector, $\vec{v}/\|\vec{v}\|$, defines the X unit direction. The Y unit direction is defined by the cross product of the position and velocity vectors, $(\vec{r} \times \vec{v})/\|\vec{r} \times \vec{v}\|$, or the angular momentum vector, $\vec{h}$. The Z unit direction is then defined by the cross product of the X and Y unit directions.

The elevation, φ, is measured from the spacecraft's velocity vector or X axis. Negative 90º points toward Earth or the nadir surface and positive 90º points toward space or the zenith surface, which is radially outward along the positive Z axis. The azimuth, ϑ, is measured positive counterclockwise from the velocity vector or X axis through the positive Y axis or port surface, in the XY plane. So 0º azimuth is the velocity vector, 90º azimuth is the port surface or positive Y axis, and 180º azimuth is the wake surface or negative X axis.

For a circular orbit, the $\vec{r}$ and $\vec{v}$ vectors are perpendicular, but for elliptical orbits they are not perpendicular; therefore, the unit vectors for the body fixed frame must be defined as above. For circular orbits, the main output file will show similar if not exact fluxes and speeds for certain surfaces (Earth surface and nadir, etc.).

5.13.4 Example

Example 11 computes the environment file for a SHIELD analysis using the MEM micrometeoroid environment. The spacecraft is assumed to be in the ISS orbit, 400 km circular orbit at 51.6 degrees inclination during the year 2014. The example requires two steps: first calculate the state vector component file using STK 9 and second compute the *Bumper 3* code igloo flux file using MEMCxP. The current version of STK is STK 10, so these dialogs may have changed; however, the inputs should be similar.

Creating the STK 9 Scenario and Report – To create the ISS orbit scenario using STK 9 follow these steps:

1. Create a new STK 9 scenario (File → New → Scenario).
2. Close the Insert Object dialog.

3. Right click on the scenario and select the properties browser, specify the desired mission start and end times.
4. Insert a satellite (Insert → New → Satellite → Define Properties).
5. Select the propagator (J2, J4 etc.) and then enter the Keplerian orbital elements or perigee/apogee information. This example uses the J4 propagator, apogee altitude = 400 km, perigee altitude = 400 km and 51.6 degrees inclination. For a long-duration orbit, the argument of perigee, right ascension of ascending node and true anomaly should not matter, so zero is used in all cases. For a short-duration orbit, they may matter, thus you should get the current values from the mission planning engineers supporting the program. Or, better yet, have the engineers provide an STK scenario report.
6. Coordinate type should be set to classical and coordinate system as J2000.
7. Click APPLY.

The satellite properties dialog should look like Figure 76 at the end of entering.

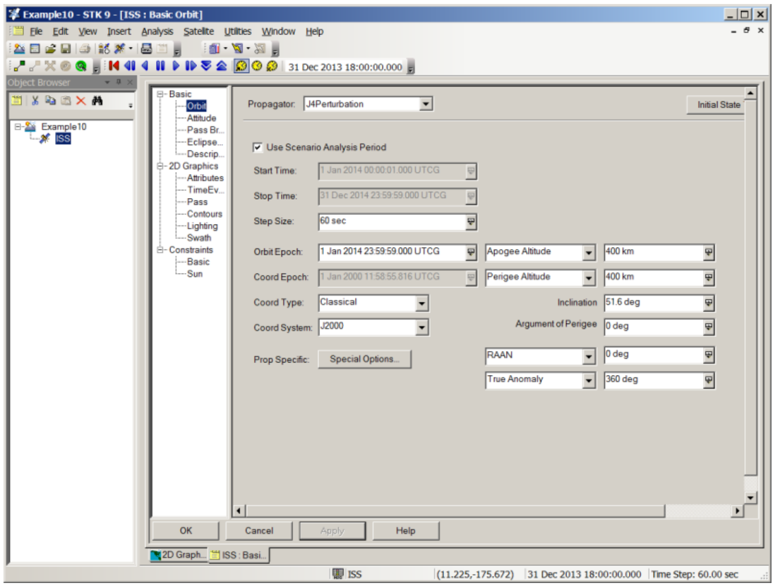


Figure 76. STK 9 satellite properties dialog for Example 11.

To generate an STK report, follow these steps:

1. Right click on satellite object in the Object Browser and select the Reports and Graph Manager option.
2. Click the J2000 Position Velocity report and click Generate… There are two J2000 Position Velocity entries in the styles list box. Select the one highlighted in Figure 77 – not the one that looks like a bar chart.

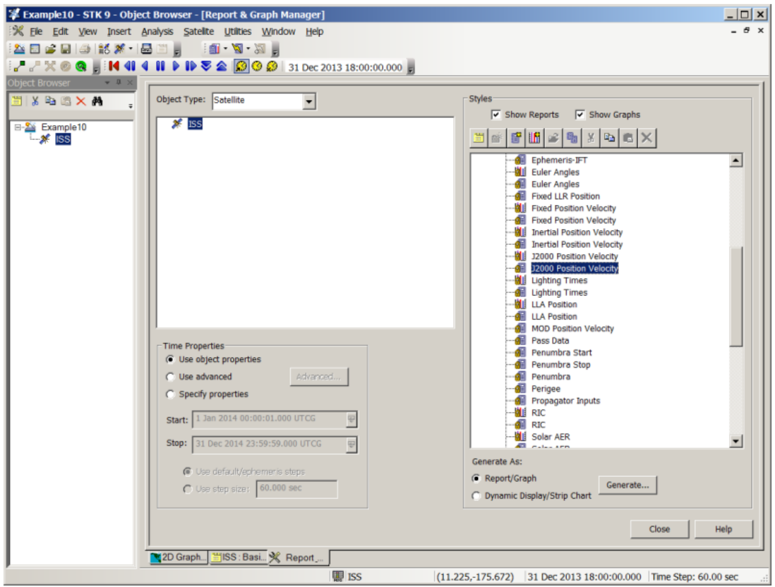


Figure 77. STK 9 Report & Graph Manager dialog for Example 11.

Wait a minute for the report to finish generating. The free version of STK 9 will default to reports using the wrong time format; the UTCG time format shown in Figure 78. MEMCxP will crash trying to parse a report with the UTCG time format. The next step is to select the JDATE time format and regenerate the report.

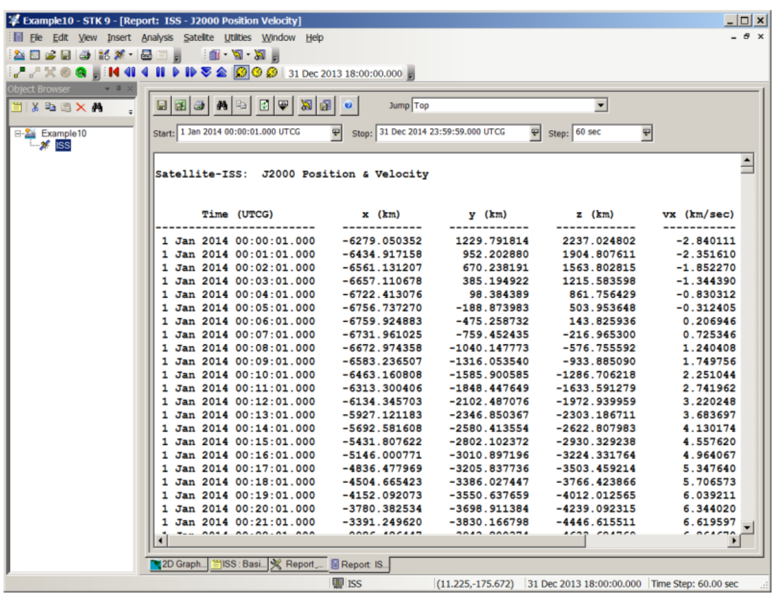


Figure 78. STK 9 scenario report with the default time format.

The author has not been able to set the default time format to JDATE using the free version of STK 9; therefore, the following step appears to be necessary. To reformat the report time units, click on the button pointed to by the yellow arrow in Figure 79. This calls up the Units dialog shown in Figure 79. Click on DateFormat to change the New Unit list box to time units and scroll down to the entry call Julian Date (JDATE). This entry is pointed to by the orange arrow in Figure 79. Click on JDATE to change the report time unit format. Click Apply and then click OK.

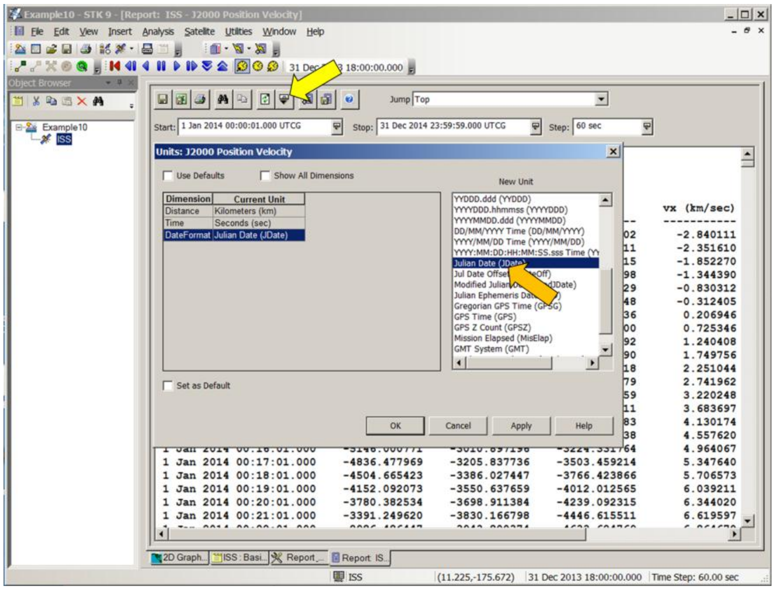


Figure 79. STK 9 units format dialog.

Wait a minute for the report to finish reformatting. The result should look like Figure 80.

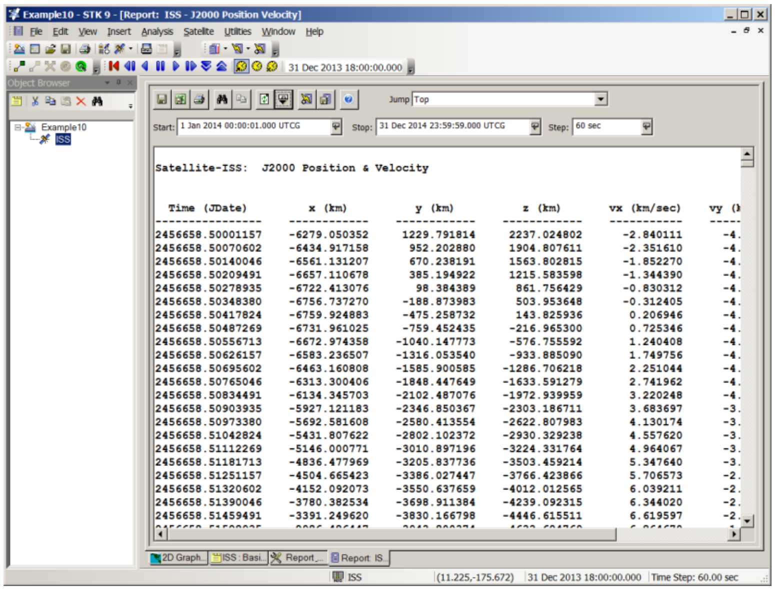


Figure 80. STK 9 scenario report with the JDATE time format.

To save the report as a text file, right click the report text pane and select Save As… . Browse to the desired folder and enter the desired filename in the edit box. Click OK to finish.

Creating the MEMCxP environment file – Use MEMCxP to process the STK trajectory state vector component file into a MEM environment file. The MEMCxP input dialog is shown below in Figure 81.

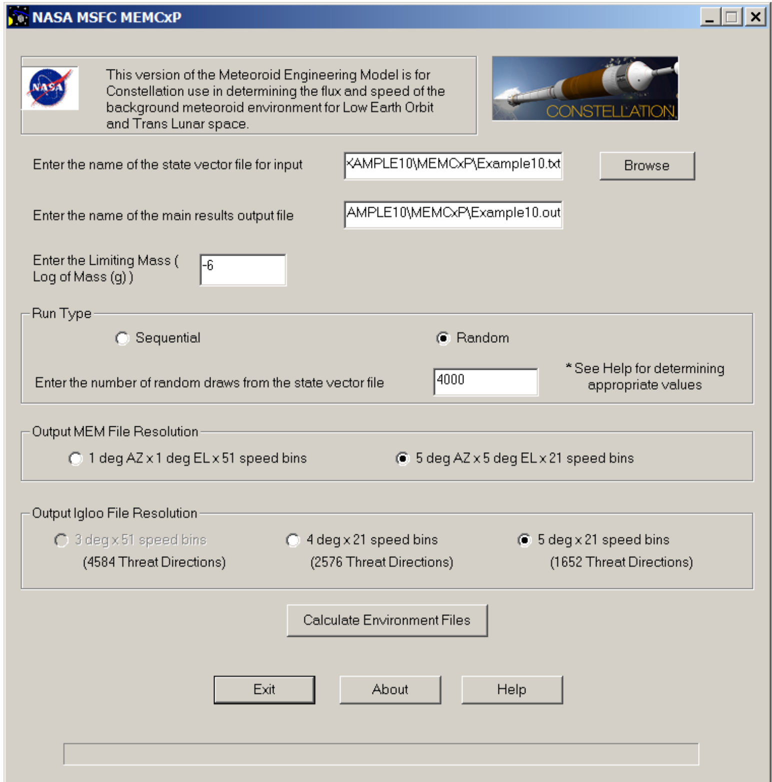


Figure 81. MEMCxP ver. 2 input dialog.

The topmost edit box is where you enter the name of a state vector input file. This file should reside in the same directory as the main program and its supporting files. MEMCxP will not run from the install directory on Windows 7 machine. Copy the executable and the population files to your working directory. The following files should be in your working directory

- MEMCxPv2.exe
- MEMCXP.HLP
- spcmtsbin.dat
- trcmtsbin.dat
- astbin.dat
- lpcmtsbin.dat

Next you specify the name of the main results output file, this should be a meaningful name that represents the environment you are creating. This file is appended to for each randomly drawn state vector so it will contain information relating to each state vector (or point in time). The name used for the example was *Example10.out*.

Next, confirm that the “Enter the Limiting Mass (Log of Mass (g))” edit box lists a value of -6. The *Bumper 3* code assumes that the environment file is for 1 microgram meteoroids, hence this box must say “-6” or the *Bumper 3* code analysis will generate fluxes that are too small. Integers or real numbers are acceptable. MEMCxP assumes a constant meteoroid density of 1.0 gram/cm^3.

After selecting the limiting mass for the meteoroid environment, you must specify a Run Type. Choose the “Random” radio button and enter 4000 into the number of random draws edit box. See the “Random Draw Guidance” for the justification for using 4,000 random draws.

Next you must confirm that the “5 deg AZ × 5 deg EL × 21 speed bins” radio button is set and the “5 deg × 21 speed bins (1652 Threat Directions)” radio button is set. The *Bumper 3* code will not be able to read the MEM output file for any other selections.

Click the “Calculate Environment Files” button and wait 8 hours for the computation to finish.

5.13.5 Possible error messages and causes

See the STK and MEMCxP documentation.

5.13.6 Cross references to other operations

1. Complementary operations
    a. None.
2. Predecessor operations
    a. Gather orbit parameters.
3. Successor operations
    a. Section 5.8 Calculate the number of spacecraft shield impacts or penetrations operation.

5.14 Calculate MEMR2 Environment Files Operation

The “Calculate with MEMR2 environment files operation” is mandatory for SHIELD calculations using the MEM micrometeoroid environment. MEMR2 is the recommended micrometeoroid environment for MMOD analyses.

5.14.1 Functional description

MEMR2 functions similarly to MEMCxP. See Section 5.13.1 for a functional description of MEMCxP. However, there is a major difference: MEMR2 now includes the functionality of LunarMEM and interplanetary MEM (IPMEM). The range of applicability of the three codes is

- Earth orbits – up to approximately 925,000 km from the Earth’s center.
- Lunar orbits – up to approximately 66,000 km from the Moon’s center.
- Interplanetary orbits – approximately more than 925,000 km from the Earth’s center and within 0.2 AU to 2.0 AU of the sun (between the orbits of Mercury and Mars). [10]

The MEM environment model is described in some detail in the reports [9], [10] and [11]. The *MEMR2.exe* help files are the software user manual. Consult the help files for a description of the MEM inputs.

5.14.2 Cautions and warnings

- Create the STK file using J2000 Cartesian coordinates.
- Create the STK file using the JDATE format for the time.
- Be aware that the *AvgMEMIglooDist.out* MEMCxP output file is not compatible with MEMR2 and vice versa.
- Do use 4,000 or more draws from the STK file for a 1-year (or more) mission.
- Be aware that a 4,000 draw MEMR2 calculation will take about 2.5 Gigabytes of hard disk drive space. Make sure you have enough room before starting.
- Be aware that a 4,000 draw MEMR2 calculation will take about 6 hours to complete.
- MEMR2 uses the same seed for its random draws. So if you want a different set of random draws for the same orbit you need to change the orbit in some way to change the state vectors in the draw file.

- Confirm that the limiting mass exponent value is -6 (i.e., 1 microgram micrometeoroids) before starting the MEMR2 calculation.
- Confirm that the 1,652 threat option is selected before starting the MEMR2 calculation. The *Bumper 3* code will not read any of the other options.
- Be aware that MEM writes its working files to the MEM installation directory. Therefore, it is not possible to run multiple instances of MEM from the same installation directory because they will overwrite each other's files. Therefore, when one wants to run multiple jobs at the same time, one must make multiple copies the installation directory and only run one instance from each copy.
- Be aware that MEM will not copy the *AvgMEMIglooDist.out* file to the project directory at the completion of the run. If you start a new instance of MEM before copying the *AvgMEMIglooDist.out* file to your project directory, the new instance will overwrite your file and you will need to rerun the analysis.
- Be aware
    - If one selects an IPMEM sequential run type, then an *AvgMEMIglooDist.out* file is produced and a modal "Program Finished Running!" dialog appears when the computation is complete.
    - If one selects an IPMEM random run type, then no *AvgMEMIglooDist.out* file is produced and no modal "Program Finished Running!" dialog appears when the computation is complete.

  The work around for the *Bumper 3* code users is to select the sequential run type whenever using IPMEM.

5.14.3 Formal Description

See Section 5.13.3.

5.14.4 Example

There are no example files for MEMR2.

Creating the STK 9 Scenario and Report – See Section 5.13.4.

Creating the MEMR2 environment file – Use MEMR2 to process the STK trajectory state vector component file into a MEM environment file. Upon opening MEMR2 the user is presented with the dialog shown in Figure 82.

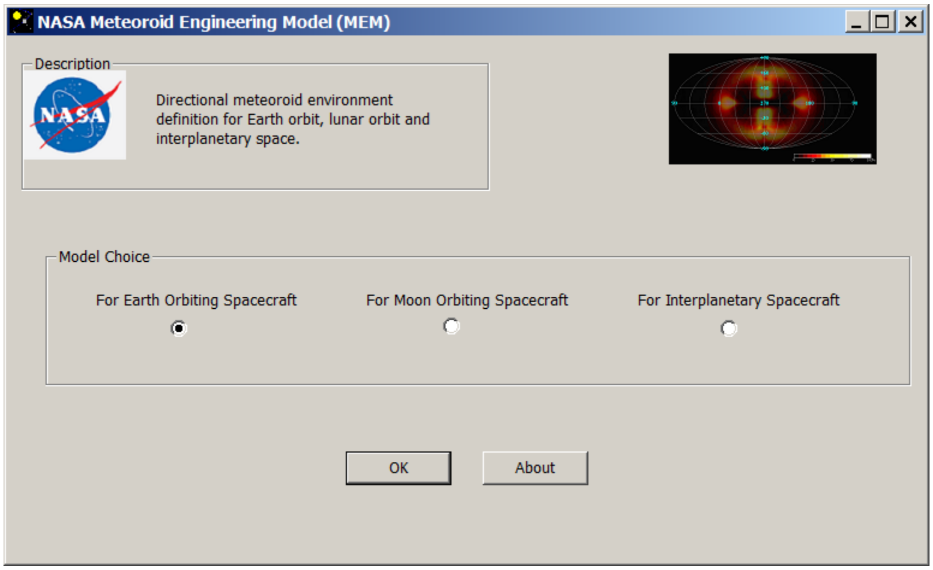


Figure 82. MEMR2 model choice dialog.

Select the radio button on the left labeled “for Earth Orbiting Spacecraft” for a spacecraft in Earth orbit within 925,000 km of the Earth’s center. Select the center radio button labeled “for Moon Orbiting Spacecraft” for a spacecraft within 66,000 km of the Moon’s center. Select the button on the right labeled “for Interplanetary Spacecraft” for a spacecraft within 0.2 to 2.0 AU of the sun.

Click the OK button to bring up the MEM inputs dialog. The dialog for a spacecraft in Earth orbit is shown in Figure 83.

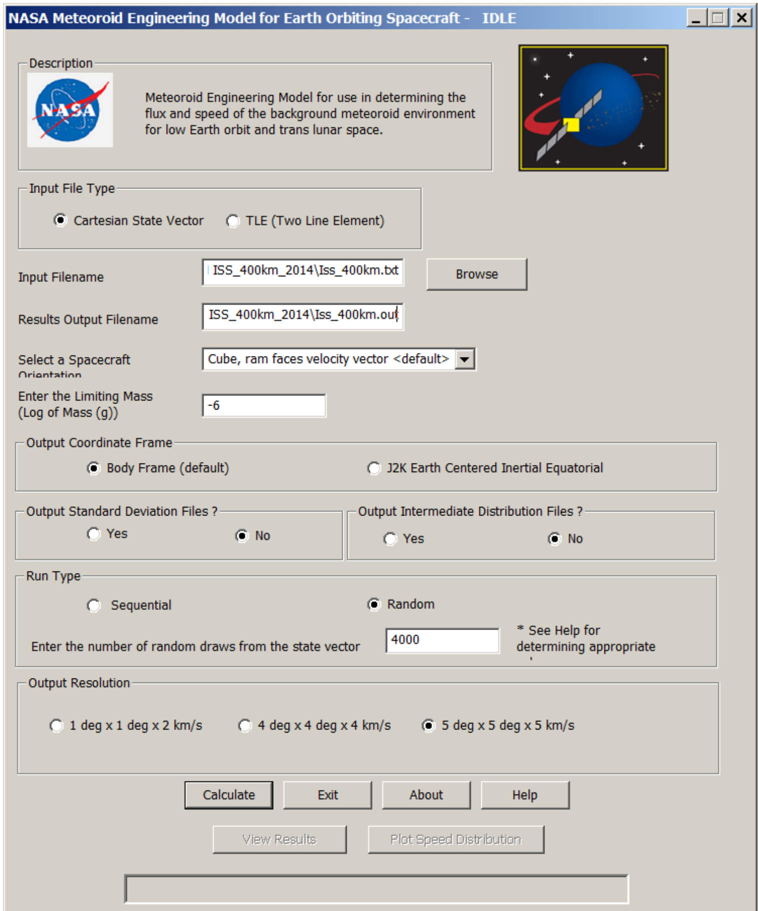


Figure 83. MEMR2 Earth orbit input dialog.

The “Input File Type” radio buttons identify the format of the STK input file. The example described in Section 5.13.4 “Creating the STK 9 Scenario and Report” uses the “Cartesian State Vector” option.

The topmost edit box is where you enter the name of a state vector input file.

Next, specify the name of the main results output file. This should be a meaningful name that represents the environment you are creating. This file is appended to for each randomly drawn state vector; therefore, it will contain information relating to each state vector (or point in time).

The drop-down list box labeled “Select a Spacecraft orientation” offers three choices

- Cube, ram faces velocity vector <default>
- Rotating about angular momentum vector
- Rotating about velocity vector

The first option is used for spacecraft with constant attitude in the VNC reference frame. This case also covers spacecraft in circular obits with fixed attitude in the local vertical local horizontal (LVLH) coordinate frame, such as the ISS. The second option is used for spin-stabilized spacecraft whose spin axis is parallel to the orbital momentum vector. The third option is used for spin stabilized spacecraft with their spin axis parallel to the spacecraft orbital velocity vector.

Next, confirm that the “Enter the Limiting Mass (Log of Mass (g))” edit box lists a value of -6. The *Bumper 3* code assumes that the environment file is for 1 microgram meteoroids, hence this box must say “-6” or the *Bumper 3* code analysis will generate fluxes that are too small. Integers or real numbers are acceptable. MEMCxP assumes a constant meteoroid density of 1.0 gram/cm^3.

The radio button group labeled “Output Coordinate Frame” offers two choices, “Body Frame (default)” and “J2K Earth Centered Inertial Equatorial.” The default option is used for typical BUMPER analyses (such as a spacecraft in a circular orbit with fixed attitude in the LVLH coordinate frame, such as the ISS). The second option might be useful for spacecraft that maintain a fixed orientation in inertial coordinates, such as a sun-pointing spacecraft.

The next two radio button groups “Output Standard Deviation Files?” and Output Intermediate Distribution Files?” default to No; it is common to keep the defaults for ISS analyses. The standard deviation files might be useful for a probabilistic risk assessment, and the intermediate distribution files might be useful for a spacecraft that changes orientation at different times in the orbit.

The “run Type” control group determines how many files will be saved. For missions lasting a year or more choose the “Random” radio button and enter 4000 into the number of random draws edit box. See the “Random Draw Guidance” for the justification for using 4,000 random draws.

Next you must confirm that the “5 deg AZ × 5 deg EL × 21 speed bins” radio button is set and the “5 deg × 21 speed bins (1652 Threat Directions)” radio button is set. The *Bumper 3* code will not be able to read the MEM output file for any other selections.

Click the “Calculate Environment Files” button and wait 8 hours for the computation to finish.

The dialog for spacecraft in lunar orbit is shown in Figure 84, the only difference is that it does not contain a “File Type” radio button group (and the coordinates are now centered on the Moon).

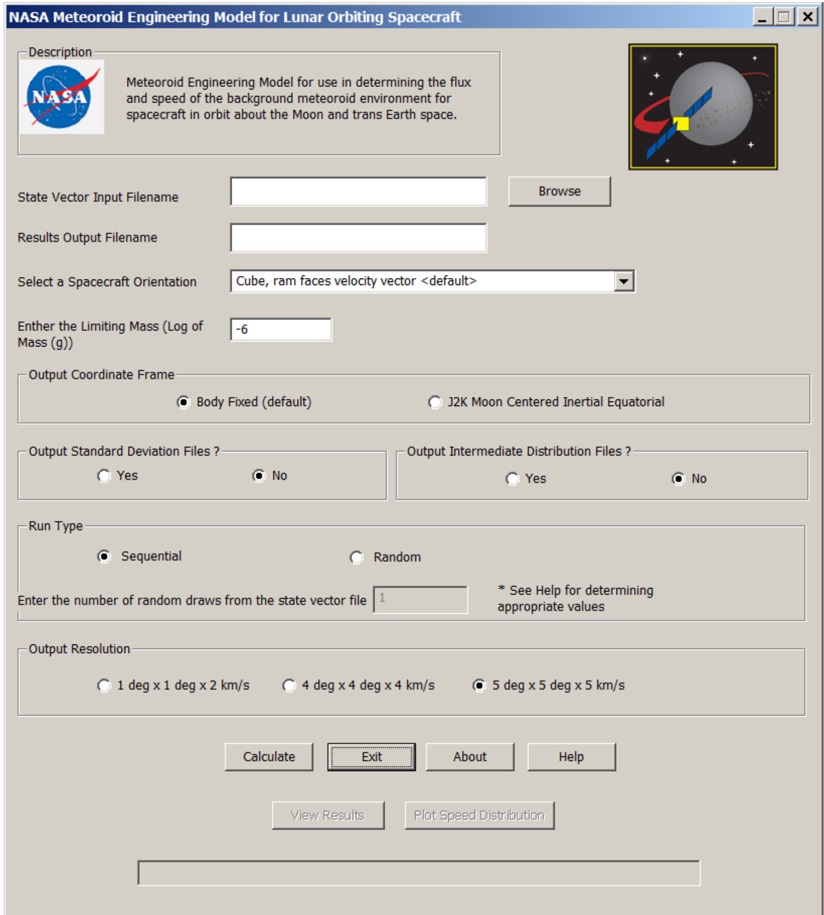


Figure 84. MEMR2 lunar orbit input dialog.

The dialog for spacecraft in solar orbit is shown in Figure 85, again the only difference is that it does not contain a “File Type” radio button group (and the coordinates are now centered on the sun).

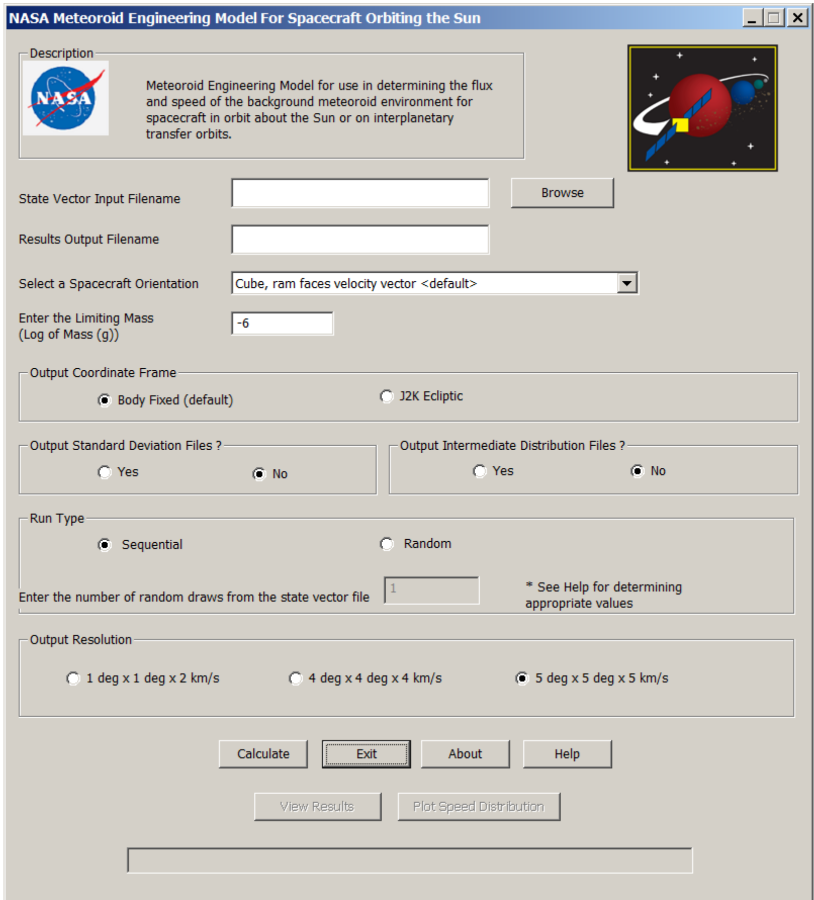


Figure 85. MEMR2 solar orbit input dialog.

5.14.5 Possible error messages and causes

See the STK and MEMR2 user manuals for a discussion of the error messages.

5.14.6 Cross references to other operations

1. Complementary operations
    a. None.
2. Predecessor operations
    a. Gather orbit parameters.
3. Successor operations
    a. Section 5.8 “Calculate the Number of Spacecraft Shield Impacts or Penetrations Operation.”

5.15 Advanced Topics

5.15.1 Calculate risk of failure of redundant components operation

The *Bumper 3* code calculates the probability of failure of independent components. If some of the components are redundant, then binomial statistics must be used to combine the *Bumper 3* code calculated values into the desired probability of failure of redundant components. This is usually done by using an Excel spreadsheet to combine the *Bumper 3* code results.

Example

A typical case for redundant components is fluid loops or heat pipes in a radiator. By way of example, assume the radiator has three loops: loop1, loop 2, and loop 3. Furthermore, assume that loops 1 and 2 have to leak before the radiator fails, or loops 2 and 3 have to leak. Also assume that there are no common mode failure mechanisms, hence the failure of loop 1 is independent of the failure of loop 2 and loop 3, etc. There are eight outcomes that can occur for this radiator after exposure to the MMOD environment. These are listed below in Table 18.

Table 18. Table of Radiator Failure Cases

case	Loop 1 fails	Loop 2 fails	Loop 3 fails	Radiator fails
1	no	no	no	no
2	no	no	yes	no
3	no	yes	no	no
4	no	yes	yes	yes
5	yes	no	no	no
6	yes	no	yes	no
7	yes	yes	no	yes
8	yes	yes	yes	yes

Now assume that the *Bumper 3* code was used to calculate the mean number of perforations of each loop and obtained μ_1 for loop 1, μ_2 for loop 2, and μ_3 for loop 3. The probability of occurrence of penetration has a Poisson distribution. Therefore, the probability of loop 1 not failing is $\exp(-\mu_1)$ and the probability of loop 1 failing is $1-\exp(-\mu_1)$ and analogous probabilities for the other two loops. If we're interested in the probability of the radiator not failing, then we're only interested in cases 1, 2, 3, 5, and 6. Building a table of the probabilities of each event for cases 1, 2, 3, 5, and 6 gives us Table 19.

Table 19. Table of Radiator Loop Probabilities of Failure or No Failure

case	Loop 1 probability	Loop 2 probability	Loop 3 probability
1	$\exp(-\mu_1)$	$\exp(-\mu_2)$	$\exp(-\mu_3)$
2	$\exp(-\mu_1)$	$\exp(-\mu_2)$	$1-\exp(-\mu_3)$
3	$\exp(-\mu_1)$	$1-\exp(-\mu_2)$	$\exp(-\mu_3)$
5	$1-\exp(-\mu_1)$	$\exp(-\mu_2)$	$\exp(-\mu_3)$
6	$1-\exp(-\mu_1)$	$\exp(-\mu_2)$	$1-\exp(-\mu_3)$

Since the column entries for each case are independent, we multiply them together to get the probability of occurrence of the case. We add the probabilities of each case together (binomial statistics) to get the total probability of no failure (PNF) of the radiator, accounting for the fluid loop redundancy.

$$PNF = \begin{cases} \exp(-\mu_1)\times\exp(-\mu_2)\times\exp(-\mu_3) \\ \quad +\exp(-\mu_1)\times\exp(-\mu_2)\times\{1-\exp(-\mu_3)\} \\ \quad +\exp(-\mu_1)\times\{1-\exp(-\mu_2)\}\times\exp(-\mu_3) \\ \quad +\{1-\exp(-\mu_1)\}\times\exp(-\mu_2)\times\exp(-\mu_3) \\ \quad +\{1-\exp(-\mu_1)\}\times\exp(-\mu_2)\times\{1-\exp(-\mu_3)\} \end{cases}$$

Multiplying out the terms gives

$$PNF = \begin{cases} \exp(-[\mu_1 + \mu_2 + \mu_3]) \\ \quad + \exp(-[\mu_1 + \mu_2]) - \exp(-[\mu_1 + \mu_2 + \mu_3]) \\ \quad + \exp(-[\mu_1 + \mu_3]) - \exp(-[\mu_1 + \mu_2 + \mu_3]) \\ \quad + \exp(-[\mu_2 + \mu_3]) - \exp(-[\mu_1 + \mu_2 + \mu_3]) \\ \quad + \{\exp(-\mu_2) - \exp(-[\mu_1 + \mu_2])\} - \{\exp(-[\mu_2 + \mu_3]) - \exp(-[\mu_1 + \mu_2 + \mu_3])\} \end{cases}$$

Combining terms gives

$$PNF = \exp(-\mu_2) + \exp(-[\mu_1 + \mu_3]) - \exp(-[\mu_1 + \mu_2 + \mu_3])$$

Clearly, the above formula does not apply to all cases of redundancy; however, the procedure applies to all cases with no common mode failures.

5.15.2 Spacecraft attitude

The *Bumper 3* code was developed to analyze spacecraft in circular Earth orbit with fixed attitude in the LVLH coordinate system; i.e., the ISS oriented for microgravity research. In recent years, the *Bumper 3* code solution space has expanded to include spacecraft in elliptical orbits about the Earth, Moon, or sun with fixed attitude in the VNC coordinate system. However, this is an uncommon attitude for spacecraft. The analysis procedure described in Section 0 must be adapted to provide meaningful results.

Experience has shown three significant use cases:

1. Spacecraft design.
2. Mission operations.
3. As-flown impact risk assessments.

Use case 1 is the sum of the analyses supporting system design from Preliminary Design Review to Critical Design Review and culminating in Qualification and Acceptance. Typically, these analyses are performed using a range of spacecraft attitudes and selecting the worst case for requirements verification. This approach gives mission operations the greatest flexibility in operating the spacecraft.

The second use case arises when mission operations requests advice on how to fly the spacecraft to minimize impact risk. This use case occurred for Shuttle operations and for ISS extravehicular activities. Again, these analyses were performed using a range of Shuttle and Extravehicular Mobility Unit attitudes and identifying the best-case attitudes.

Use case 3 is the most demanding attitude analysis. Each as-flown impact risk assessment involved factoring the as-flown attitude history into a set of 50 to 200 altitude, exposure and attitude triplets, calculating the MMOD impact risk for each triplet, and summing the results. The as-flown impact risk assessments were performed for the Shuttle windows, radiators, and reinforced carbon-carbon wing leading edge and were compared with the observed impact damage.

Worst-case attitude analysis

A worst-case attitude analysis should use the 24 attitudes from the Shuttle worst-case attitude analysis, or something comparable. The Shuttle worst-case attitude analysis used the pitch/yaw/roll (PYR) attitudes taken from Figure 4-5 in JSC-10511 REV D. These attitudes are reproduced in Table 20 as a set of rotations about body axes (columns 5, 6, and 7) and a set of rotations about spatial axes (columns 8, 9, and 10; i.e., the *Bumper 3* code rotation inputs).

Application to another spacecraft may involve developing a transformation from the spacecraft body coordinates to the Shuttle body coordinates.

The Shuttle body coordinate system is illustrated in Figure 86. The body X–axis is parallel to a line in the orbiter plane of symmetry, parallel to and 1016 cm (400 in.) below the payload bay centerline with positive sense toward the nose. The body Z–axis is parallel to the orbiter plane of symmetry and is perpendicular to body X-axis, positive down with respect to the orbiter fuselage. (Down refers to the direction of runway when the Shuttle has landed.) The body Y–axis completes the right–handed orthogonal system.

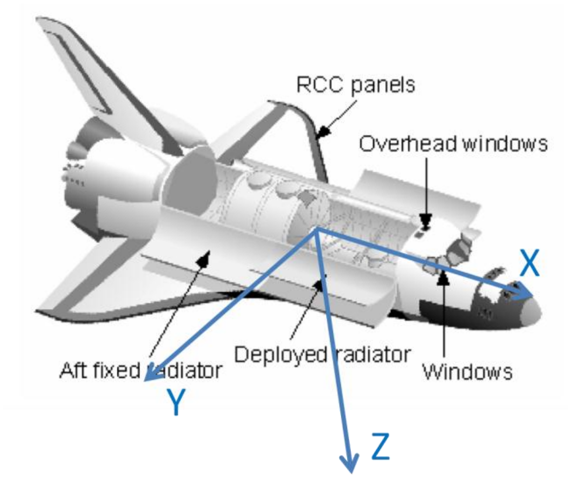


Figure 86. Shuttle body coordinate system (X,Y,Z).

The initial position of the Shuttle in the LVLH coordinate system before any PYR rotations are made is shown in Figure 87. Initially, the body X-axis points along the LVLH vehicle velocity (VV) vector and the Shuttle body Z-axis points along the LVLH local vertical (LV) axis.

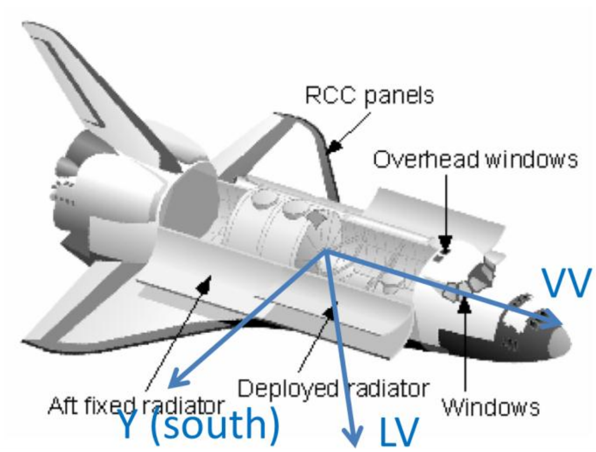


Figure 87. Shuttle with a PYR 0/0/0 attitude in the LVLH coordinate system (VV,Y,LV).

The initial position of the Shuttle in the *Bumper 3* code coordinate system (equivalent to the VNC coordinate system) before any rotations about the VNC axes is shown in Figure 88.

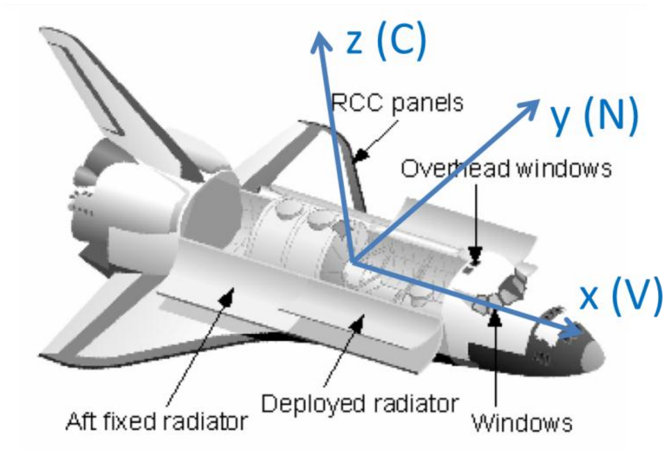
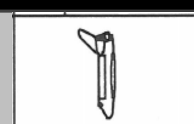
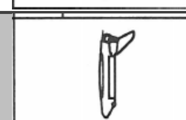
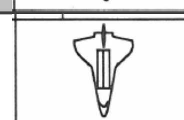
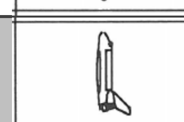
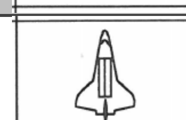
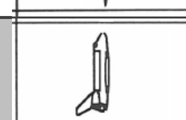
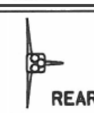
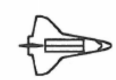
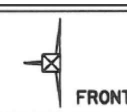


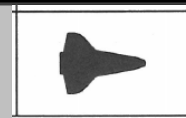
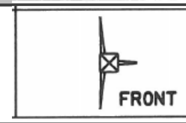
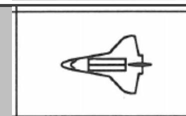
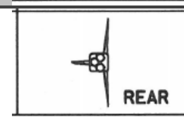
Figure 88. Shuttle with an XYZ 0/0/0 attitude in the *Bumper 3* code coordinate system (x,y,z).

Columns 8, 9, and 10 list the rotation angles that are input into the *Bumper 3* code. (See Section 5.4.3 and Figure 26.) The data in columns 1 through 7 are the data product received from the Attitude Timeline group. The MMOD analyst had to transform the data from columns 5, 6, and 7 into the data listed in columns 8, 9, and 10. Furthermore, any results produced with the *Bumper 3* code had to be transformed back to the Attitude Timeline group nomenclature to communicate the results in a format already familiar to the program.

Table 20. The 24 Attitude Analysis Case

Orbiter Orientation				PYR Euler rotations about the body axes			Rotations about the *Bumper 3* code axes.			Final Orbiter orientation
		Nose	Bay	Pitch	Yaw	Roll	x	y	z	
+XLV	-ZVV	earth	fwd	270	0	0	0	90	0	
+XLV	-YVV	earth	south	270	0	90	90	90	0	
+XLV	+ZVV	earth	aft	270	0	180	180	90	0	
+XLV	+YVV	earth	north	270	0	270	270	90	0	
-XLV	+ZVV	space	aft	90	0	0	0	270	0	
-XLV	-YVV	space	north	90	0	270	270	270	0	
-XLV	-ZVV	space	fwd	90	0	180	180	270	0	

Orbiter Orientation				PYR Euler rotations about the body axes			Rotations about the *Bumper 3* code axes.			Final Orbiter orientation
		Nose	**Bay**	**Pitch**	**Yaw**	**Roll**	**x**	**y**	**z**	
-XLV	+YVV	space	south	90	0	90	90	270	0	
+ZLV	+XVV	fwd	space	0	0	0	0	0	0	
+ZLV	-YVV	south	space	0	90	0	0	0	270	
+ZLV	-XVV	aft	space	180	0	180	0	0	180	
+ZLV	+YVV	north	space	0	270	0	0	0	90	
-ZLV	-XVV	aft	earth	180	0	0	180	0	180	
-ZLV	-YVV	north	earth	180	270	0	180	0	90	
-ZLV	+XVV	fwd	earth	0	0	180	180	0	0	
-ZLV	+YVV	south	earth	180	90	0	180	0	270	
+YLV	+XVV	fwd	south	0	0	90	90	0	0	
+YLV	+ZVV	south	aft	90	90	0	90	0	270	
+YLV	-XVV	aft	north	180	0	270	90	0	180	
+YLV	-ZVV	north	fwd	270	270	0	90	0	90	

Orbiter Orientation				PYR Euler rotations about the body axes			Rotations about the *Bumper 3* code axes.			Final Orbiter orientation
		Nose	**Bay**	**Pitch**	**Yaw**	**Roll**	**x**	**y**	**z**	
-YLV	-XVV	aft	south	180	0	90	270	0	180	
-YLV	+ZVV	north	aft	90	270	0	270	0	90	
-YLV	+XVV	fwd	north	0	0	270	270	0	0	
-YLV	-ZVV	south	fwd	270	90	0	270	0	270	

The figures in column 10 illustrate the relative attitudes following the PYR rotations. When the figure is substituted into the box in Figure 89, the figure gives the Shuttle attitude in LVLH coordinates.

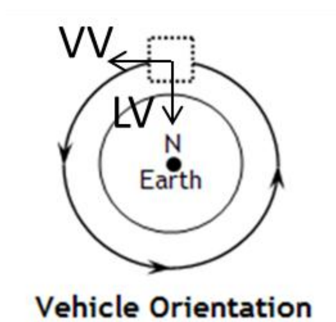


Figure 89. The LVLH coordinate frame for the figures in column 10.

Columns 1 and 2 of Table 20 list another way the Attitude Timeline group reported the Shuttle attitude. The nomenclature +XLV in the first column first row indicates that after the PYR rotations, the Shuttle body X axis is pointing in the LV direction in the LVLH coordinate frame and the second column –ZVV entry indicates that the Shuttle body –Z axis is pointing in the VV direction in the LVLH coordinate frame.

The port and starboard sides of the Shuttle are symmetric about the XZ plane, which makes 8 of the orientations in Table 20 redundant. In the case of port/starboard, Table 20 reduces to the 16 attitudes listed in Table 21.

Table 21. The 16 Attitude Analysis Case for Port/Starboard Symmetry

Orbiter Orientation				PYR Euler rotations about the body axes			Rotations about the the *Bumper 3* code axes.		
		Nose	**Bay**	**Roll**	**Pitch**	**Yaw**	**X**	**Y**	**Z**
+XLV	-ZVV	earth	fwd	0	270	0	0	90	0
+XLV	+ZVV	earth	aft	180	270	0	180	90	0
+XLV	+YVV	earth	north	270	270	0	270	90	0
-XLV	+ZVV	space	aft	0	90	0	0	270	0
-XLV	-YVV	space	north	270	90	0	270	270	0
-XLV	-ZVV	space	fwd	180	90	0	180	270	0
+ZLV	+XVV	fwd	space	0	0	0	0	0	0
+ZLV	-XVV	aft	space	180	180	0	0	0	180
+ZLV	+YVV	north	space	0	0	270	0	0	90
-ZLV	-XVV	aft	earth	0	180	0	180	0	180
-ZLV	-YVV	north	earth	0	180	270	180	0	90
-ZLV	+XVV	fwd	earth	180	0	0	180	0	0
+YLV	-XVV	aft	north	270	180	0	90	0	180
+YLV	-ZVV	north	fwd	0	270	270	90	0	90
-YLV	+ZVV	north	aft	0	90	270	270	0	90
-YLV	+XVV	fwd	north	270	0	0	270	0	0

The results of a typical Shuttle attitude risk analysis [12] are shown in Figure 90. The *Bumper 3* code and orbiter FEM were used to assess 16 distinct LVLH attitudes. The labels below each column in the plot indicate the attitude from columns 3 and 4 of Table 21 that corresponds to the critical risk value. The results are shown for a typical Shuttle mission to the ISS using a deprecated debris environment with a constant debris particle density of 2.8g/cc and the NASA SSP-30425 meteoroid environment [13] with a particle density that varies as a function of size. The results are also influenced by a number of other factors including flight year, orbital inclination, altitude, and exposure time. Note that the risk varies by a factor of 3 with attitude.

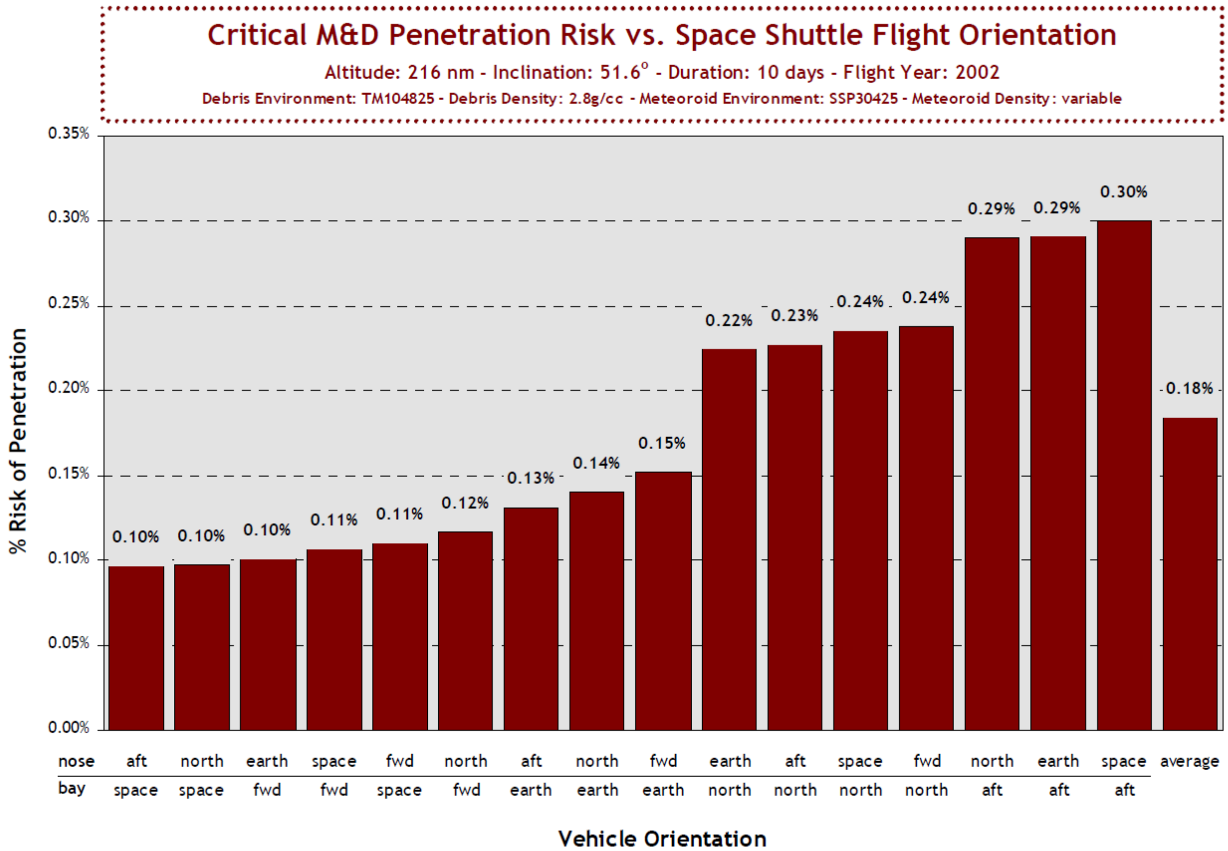


Figure 90. Vehicle worst-case attitude trade study.

As-flown attitude study

The as-flown MMOD threat assessment is made using actual attitudes, altitudes, and exposure times. The as-flown analysis can be performed to assess the Flight Readiness Review (FRR) products (critical risk, radiator leak, and window replacement). It can also be used to calculate the expected number of impacts on orbiter regions from specific particle diameters. When these “analysis” diameters are coordinated with observed damage, predictions and observations can be compared.

The typical Shuttle as-flown analysis produced four products:

1. Preflight and as-flown risk predictions vs. post-flight observations.
2. As-flown impact damage predictions vs. post-flight observations.
3. As-flown impact damage predictions vs. post-flight observations for a family of missions.
4. MMOD damage on windows and radiators vs. orbiter program history.

Analysis Procedure

The complete as-flown analysis procedure can be broken down into the following phases:

- Pre-processing – Collect and parse as-flown flight parameters.
- Calculation – Calculate risk assessment using the *Bumper 3* code.
- Post-processing – Merge output files and observed data.

Pre-processing

The pre-processing phase leverages orbit parameters with new post-flight data to create a mission profile that is used as input for the *Bumper 3* code risk assessment code. The Shuttle post-flight MMOD risk assessment was performed using as-flown data obtained from the following sources:

- Mission Event List
- Attitude Timeline (ATL)

As-flown ATLs were generated from quaternion data that were provided by the JSC Space Shuttle Vehicle Engineering Office. These ATLs were written to a resolution of 300 seconds, which means that the orbiter's attitude was defined in 5-minute time steps throughout the mission. The timeline files for each mission were imported into an Excel spreadsheet that performed a quaternion-to-Euler-angle conversion. Euler angle output from the spreadsheet is used as input for an ATL parsing program written in support of Shuttle FRR. The ATL parse program processes orbiter roll-pitch-yaw Euler attitudes into a discrete number of LVLH attitudes compatible with the *Bumper 3* code. The parse program categorizes similar attitudes in user-specified bins according to two criteria: The first is "dead band," which is the variability tolerance of each rotation angle that is used to describe an attitude. The second variable is the "cut-off time" in minutes, defined as the time below which miscellaneous attitudes (those that do not fall into a bin with similar attitudes) are not categorized.

The product of the timeline parse program is multiple sets of attitude cases that are used in the *Bumper 3* code program. Multiple dead band/cut-off time value pairs were examined in an attempt to determine an efficient number of attitude cases while keeping the percent contribution of miscellaneous attitudes to a minimum. For definiteness, consider the STS-111 flight. The "parsed" attitude timeline for the STS-111 as-flown assessment consisted of 55 discrete attitude cases spread out over three analysis groups with a total mission time of 19,855 minutes. The angle dead band was ±15 deg and the cut-off time was 10 minutes, yielded a 96.6-percent value for the "defined" attitudes. The remaining 670 minutes (3.4 percent) were equally distributed among the attitude groups.

Table 22 provides a summary of the relevant analysis parameters that were used for the previously documented preflight FRR calculations and the post-flight as-flown assessment that is the focus of this section. The primary differences between the preflight and post-flight assessments can be found in overall mission duration and the number of Orbiter attitudes.

Table 22. STS-111 Assessment Details

STS-111 Mission Parameters	Assessment Type	
	Preflight FRR	As-Flown
Mission Duration	11d 16.4h 280.44h	13d 18.9h 330.92h
Pre-dock Altitude (%mission time)	398 km	296 km (12.8%)
Docked Altitude (% mission time)		389 km (57.4%)
Post-dock Altitude (% mission time)		370 km (29.8%)
Orbit Inclination	51.6 deg	
Flight Year	2002	2002
Solar Flux ($F_{10.7}$)	ORDEM2000 default	
Distinct Attitudes	24 LVLH	55 LVLH
Finite Element Models	orb_v6.13: Orbiter @SSw/MPLM on Node 1 orb_v6.14: Orbiter w/MPLM in payload bay	
Orbital Debris Environment	ORDEM2000	
Orbital Debris Particle Density Meteoroid Environment	constant, 2.8 g/cc SSP30425, Rev. B	
Meteoroid Particle Density	constant 0.5 g/cc	
Meteoroid Velocity Distribution	variable, SSP30425	
Meteoroid Showers	basic shower enhancement factor included in SSP 30425	

Spin stabilize spacecraft

MEMR2 provides an option to compute the environment for a spin stabilized spacecraft. However, only two spacecraft spin axes are allowed

1. The spacecraft spin axis is parallel to the orbital momentum vector.
2. The spacecraft spin axis is parallel to the orbital velocity vector.

The applicability of these two options will vary with the mission design.

There is no option in ORDEM for spin stabilized spacecraft. However, if the spacecraft spin axis is oriented out of the orbital plane, then the orbital debris environment may rapidly average into an isotropic environment. This case can be approximated by averaging the results from the worst-case attitude study. Before an isotropic environment can be assumed, it is necessary to perform an analysis to show the spacecraft spin axis uniformly covers the sky over the duration of the mission.

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Appendix A Error Messages and Recovery Procedures

Serious errors that preclude the computation continuing result in an error message before the *Bumper 3* code comes to a stop. Each error message is assigned a number. To find the recovery procedure, read through Table 23, look for the error number and, when found, read across to find the recovery procedure. The error message is listed in constant width characters and the recovery procedure in proportional width characters. In some cases, *Bumper 3* adds text to the error message. This is indicated by bold text.

Some of the recovery procedures refer to the file *<unvFileName>.error*. This is the check model error file. The check model error file filename is constructed from the name of the Universal file (*<unvFileName>*) with the extension .error. The contents of this file are described in Section 5.3.

Table 23. Error Messages

Error Number	Error Message
10101	`The number of exposed elements > the number of total elements. The number of exposed elements =` **N1**. `The number of total elements =` **N2**. Indicates an error in the shadowing algorithm programming. Submit a software problem report.
10102	`Last attempt to decode format. Attempting to read as I-DEAS level IV!` Warning message generated by GEOMETRY on the last attempt to read the universal file by shifting to reading using an old file version format. Since it's unlikely you're using a 15 year old version of I-deas, the next message will be an error message stating that GEOMETRY can't read the universal file. Try using a different CAD program to write out the universal file.
10103	`Model file units not specified in meters, units=>` **UNITVAL**. *Bumper 3* assumes all Universal files are built using meters as the unit of length. Use I-deas to re-write the Universal file using meters as the unit of length.
10103	`Model file must have a unitary coord sys transformation matrix.` *Bumper 3* assumes that no rotation or translation of the model coordinates is to be applied after reading the nodal coordinates from the Universal file. Use I-deas to rebuild the model without any coordinate system transformations.
10104	`Model file has more than one coordinate system.` *Bumper 3* assumes the model is built in one coordinate system. Use I-deas to re-write the model in one coordinate system.
10105	`Element ,`**EID**`, is not a triangular or quadrilateral element. Bumper 3 will only process tri's and quad's. Use I-deas to change the offending elements to tri's and quad's. See the .error file for a full list of elements that need to be changed.` Element number **EID** is not a triangle or quadrilateral surface element. Use I-deas to rebuild the element out of triangles and or quadrilaterials.
10106	`UNV 2437 defined, PID labeling is a potential issue with this model in I-DEAS.`

Error Number	Error Message
10107	`Elements have wrong number of nodes see error output files, total =>` **N** A total of **N** elements are not triangles or quadrilaterals. The element numbers of the offending elements are listed in the *<unvFileName>.error* file. Use I-deas to rebuild the model with tri and quad elements.
10109	`Last attempt to decode format. Attempting to read as I-DEAS level IV!` See error 10102.
10110	`The property identifier (PID) is equal to zero for ELEM =>` **EID** The *Bumper 3* code assumes the smallest PID number is 1 or larger. Use I-deas to assign a PID with value greater than zero to element number **EID**.
10111	`No element data in UNV file, NELM=0` Universal file is malformed. Recreate the universal file in I-deas.
10112	`No nodal data in UNV file, NGRIDS=0` Universal file is malformed. Recreate the universal file in I-deas.
10401	`modelcheck FAILED. CHECK THE .ERROR FILE FOR DETAILS.` There are malformed elements in the Universal file. Consult the *<unvFileName>.error* file for the list of malformed elements. Repair the element using I-deas.
10402	`The BUMPER-II normal calculation can't do subNormalPlanarChecks.` Information message. You are using a version of *Bumper 3* that uses the BUMPER-II algorithm for computing the element normal. The checkModel test for element planarity requires the *Bumper 3* element normal algorithm, therefore this checkModel test is bypassed. No user intervention required.
10403	`There are elements that have normal vectors = NaN. See error file for full list.` There are malformed elements in the Universal file. Consult the *<unvFileName>.error* file for the list of malformed elements. Repair the element using I-deas.

20303	`The relative speed 'VR' is below the`
	`the response array bounds. The PNP(S) are being determined`
	`ignoring threat cases where the ratio of the relative`
	`velocity to the velocity increment is < 1.`
	`PNP(S) for the skipped threat cases is(are) assumed`
	`to be 100% due to the small relative speed.`
	In most cases this warning will lead to very small errors in the calculated number of impacts or penetrations. However, if the environment has a significant flux at low speeds, then significant errors may occur. Make a VBETA plot to determine how much of the flux is occurs at the lows speeds that are being ignored in the number of impacts/number of penetrations calculation.

20309	`critDia is NaN.` The computation of the projectile diameter at the shield ballistic limit failed in SHIELD. Typically this only occurs with the implicit BLEs. Try a different BLE.
20404	`The relative velocity 'VR' is above the response array bounds. VR (KMS) =` **VR** Indicates an error in the programming of the environment or the RTABLE bounds in rtableDataTypes Info data structure. Submit a software problem report.
20405	`The impact angle beta is outside the bounds of the response array.`

Error Number	Error Message
	BETA (DEGREES) = **BETA** This error message indicates an error in the programming of critDia. Submit a software problem report.
20406	No data exist for property ID **PID** in RTABLE when read by CRITDIA. The property ID **PID** cannot be found in the critDia table. Not enough PID numbers were entered into RESPONSE during automatic PID numbering or potentially a PID was missed when using PID renumbering. Check the .RSUM file for missing PIDs and rerun RESPONSE.
30101	GEM file needs more PIDs than are in the RSP file=> **,N1, N2,** in initializeSHIELD There are too few PIDs in the .RSP file (a total of N2) to cover all the PIDs required by the GEM file (a total of N1). Check the .RSUM file for missing PIDs and rerun RESPONSE.
30102	GEM file needs a larger PID than the max in the RSP file=> **PID1**, **PID2**, in initializeSHIELD The largest PID number in the GEM file, **PID1**, is larger than the largest PID number in RSP file, **PID2**. Check the .RSUM file for missing PIDs and rerun RESPONSE.
30103	PID missing from rsp file for element =>, **EID** The property ID for element **EID** does not occur in the .RSP file. Check the .RSUM file for missing PIDs and rerun RESPONSE.
30104	EID **EID** belongs to **N** ranges which is larger than the dimension of NEL2range in SHIELD. Increase the dimension nRanges in modParameters for NEL2range. No element can belong to more than 20 ranges in a SHIELD calculation. Reorganize the element ranges so that element **EID** belongs to less than 20 ranges or run SHIELD with fewer element ranges.
30201	Couldn't read first line of .GEM file header before allocating arrays for SHIELD. The GEM file format is incompatible with this version of *Bumper 3*. Recreate the GEM file from the Universal file using this version of *Bumper 3*.
52010	The number of materials is too large. The parameter IMATRLS in the modPARAMETERS must be reset. There are more than 25 materials in the *mat.prp* file. Reduce the number of materials in the *mat.prp* to a value less than 25 and rerun RESPONSE.
52011	The material properties data file was misread in INPUT_R_MATRL. The *mat.prp* file is corrupted. Repair the *Bumper 3* code installation from Start→Control Panel→Install a Program. Caution this will copy over any changes you've make to your *mat.prp* file, so back it up first.
53005	Environment type **NAME1** was specified in the geometry file, but the environment specified in the RESPONSE file was => **NAME2**. The GEM file was created assuming an environment that is incompatible with the environment that was assumed for the .RSP file. This indicates that the wrong filename was entered for the GEM file or the .RSP file to use for the SHIELD analysis or that the wrong GEM or .RSP file was built for the SHIELD analysis.
70101	Filename and path exceed 256 characters. Truncating filename; **FNAME**

Error Number	Error Message
	Windows cannot find files with filenames and paths that add up to more than 256 characters. You must decrease the path depth to the working directory or decrease the length of the filename to get the total path and filename length to a value less than 256 characters.
70202	`$BUMPERDIR is not defined.` The $BUMPERDIR Unix environment variable containing the path to the *Bumper 3* executable is not defined. Create the environment variable and set its value to the path to the *Bumper 3* executable. Not required for Windows.
70203	`$ENVFILESDIR is not defined` The $ENVFILESDIR Unix environment variable containing the path to the environment files is not defined. Create the environment variable and set its value to the path to the environment files. Not required for Windows.
70204	`APPDATA folder does not exist.` *Bumper 3* cannot find the user folder containing the *mat.prp*, *bumper.rc* and environment files. *Bumper 3* will default for looking for these files in the working directory.
70205	`Error code` **IRET** `when searching for APPDATA folder.` The file system has thrown an error with error code **IRET** when *Bumper 3* tried to read the %LOCALAPPDATA% folder. Resolve the error with your file system.
80101	`SSP30425OD analysis cannot start before the beginning of the year 1994! Current inputs use a start year of` **DATE** The SSP30425 orbital debris analysis cannot calculate the flux for years prior to 1994. Re-enter the start date in the SHIELD analysis.
80102	`SSP30425OD analysis cannot extend past the end of the year 2038! CURRENT INPUTS PROJECT THE ANALYSIS TO THE YEAR` **DATE+ETIME** The SSP30425 orbital debris analysis cannot calculate the flux for years after 2038. The start date **DATE** and the duration of exposure **ETIME** cannot add up to a value larger than 2038. Re-enter the start date or the duration of exposure in the SHIELD analysis.
80401	`ORDEM2000 analysis cannot extend past the year 2030! Current inputs project the analysis to the year` **DATE+ETIME** The ORDEM200 orbital debris analysis cannot calculate the flux for years after 2030. The start date **DATE** and the duration of exposure **ETIME** cannot add up to a value larger than 2030. Re-enter the start date or the duration of exposure in the SHIELD analysis.
80402	`ORDEM2000 was not designed for analysis > 15 years! Current inputs indicate a duration of` **ETIME** `years.` The ORDEM200 orbital debris analysis cannot calculate the flux for durations of exposure larger than 15 years. Re-enter the duration of exposure in the SHIELD analysis.
80404	`FRACTOT is greater than 1 =>` **,N** Warning message generated by ORDEM 2000 environment module. The warning indicates round off errors in the calculation of the closing speed probability density function. If the errors are large submit a software problem report.

80405	`XXX IS >1. XXX=` **X** `in modORDEM2000.`
	`Renormalizing XXX to 1.`
	Warning message generated by ORDEM 2000 environment module. The warning indicates round off errors in the calculation of the closing speed probability density

Error Number	Error Message
	function. If the errors are large submit a software problem report.
80406	`Spline failed in YOFX in modORDEM2000!` Warning message generated by ORDEM 2000 environment module. The warning indicates an error solving for the flux. Submit a software problem report.
80408	`There were too many iterations in SSP30425OD density calculation.` Use the constant density option, or adjust the BLE input parameters until the BLE critical diameter calculation converges.
80501	`MEMCxPv2 uses 1,652 threats, you specified=>` **NT** Warning message generated by the MEMCxPv2 environment module. The warning indicates a programming error in computing the number of threats. Submit a software problem report.
80506	`Too many lines in the MEM.DAT file. Are you using the correct file?` The MEMCxPv2 environment file is malformed. Use MEMCxPv2 to create a new *AvgMEMIglooDist.out* file
80507	`Too few lines in the MEM.DAT file. Are you using the correct file?` The MEMCxPv2 environment file is malformed. Use MEMCxP to create a new AvgMEMIglooDist.out file
80803	`xNew is not bounded by x0 in hermiteInterp in modORDEM3p0.` `x0(0)` **X1** `xNew` **X2** `x0(n0)` **X3** Warning message generated by ORDEM 3 environment module. The warning indicates a programming error solving for the flux. Submit a software problem report.
80404	`Initial x0 values are not in ascending order in hermiteInterp in modORDEM3p0` Warning message generated by ORDEM 3 environment module. The warning indicates a programming error solving for the flux. Submit a software problem report.
80901	`Conflicting values for number of threats between geometry and memr2 file ,NT,MEMCASES` The GEM file was created with a different number of threats than the AvgMEMIglooDist.out file. Rerun GEOMETRY or MEM R2 as appropriate.
80904	`Calculating the flux with diameter` **X** `which is less than 1.240701E-02. This may result in errors.` *Bumper 3* will not calculate the flux of particles less than 1 microgram in mass. Try a more robust shield to increase the meteoroid mass at the ballistic limit of the shield to values larger than 1 microgram.
80905	`The BLE needs to be changed to preclude values less than 1.240701E-02 cm for the MEMR2 environment.` *Bumper 3* will not calculate the flux of particles less than 1 microgram in mass. Try a more robust shield to increase the meteoroid mass at the ballistic limit of the shield to values larger than 1 microgram.
80906	`Number of velocity bins inconsistent in MEMR2.DAT file.` The *AvgMEMIglooDist.out* file is incompatible with *Bumper 3*. Rerun MEM R2 to create an *AvgMEMIglooDist.out* file with 5 deg by 5 deg by 5 km/s bins, 4 deg x 4 deg x 4 km/s bins, or 1 deg by 1 deg x 2 km/s bins.

Appendix B Software Problem Report Template

BUMPER Software problem Report	
date:	
title:	
symptoms:	List the *Bumper 3* code error messages and/or Fortran runtime error messages.
steps taken to produce the software problem	List the responses to the UI prompts that resulted in the software problem. Attach any input files (.GEM, .RSP) to the email that result in the software problem.
Complete the form and email to *JSC-BumperSupport@nasa.gov*.	

Appendix C Glossary and Acronyms

AGI	Analytical Graphics, Inc.
ASCII	The American Standard code for Information Interchange. A 7-bit encoding of the Roman alphabet. An older, more compact encoding than the 16 bit Unicode encoding used in many recent programs.
AR	aspect ratio
ATL	attitude timeline
BLE	ballistic limit equation
the *Bumper 3* code	NASA/Johnson Space Center/hypervelocity impact technology tool for computing risk of MMOD impact onto spacecraft.
bumper.rc	*Bumper 3* code runtime control file.
CS	Coordinate Systems
EID	element identification
FEM	finite element model
FRR	Flight Readiness Review
GEO	geosynchronous Earth orbit
GEOMETRY	Micrometeoroid and orbital debris analysis task that calculates a list of exposed elements from the finite element model for each threat and writes the results to the .GEM file.
HVIT	NASA/Johnson Space Center hypervelocity impact technology team.
I-deas	Finite element preprocessor software from Seimens NX
IPMEM	Interplanetary Meteoroid Engineering Model
ISS	International Space Station
ITAR	International Traffic in Arms Regulation
JSC	Johnson Space Center
JDATE	Julian date
J2000	J2000 epoch is a moment in time used as a reference point for some time-varying astronomical quantity, such as the celestial coordinates. The J2000 epoch is January 1 at 12h terrestrial time.
LEO	low-Earth orbit
LV	local vertical
LVLH	local vertical local horizontal coordinate system – coordinates used by the SSP30425 OD and the ORDEM 2000 orbital debris environments.
mat.prp	*Bumper 3* code material properties file.
MEM	Meteoroid Engineering Model
MEMCxP	Meteoroid Environment Office Meteoroid Engineering Model
MLI	multi-layer thermal insulation
MM	micrometeoroid
MMOD	micrometeoroid and orbital debris
MPCV	Orion Multi-Purpose Crew Vehicle
MS	Microsoft
NaN	Not a Number
OD	orbital debris
ODPO	NASA/Johnson Space Center Orbital Debris Program Office

ordem2k2bii	A program used to calculate the ORDEM 2000 environment and write the results to a file readable by the *Bumper 3* code.
ORDEM 2000	The past orbital debris engineering model.
ORDEM 3	The current orbital debris engineering model.
PATRAN	Finite element preprocessor software from MSC software.
PID	Finite element property identifier
PNI	probability of no impact
PNF	probability of no failure
PNP	probability of no penetration
procloo	A program used to compress the ORDEM 3 output into a format readable by the *Bumper 3* code.
PYR	pitch/yaw/roll
RAAN	right ascension of ascending node
RESPONSE	Micrometeoroid and orbital debris analysis task that calculates a table of micrometeoroid and orbital debris diameters from the ballistic limit curve and writes the results to the .RSP file.
RPLOT	Micrometeoroid and orbital debris analysis task that reformats the binary .RSP file into an ASCII text file that can be plotted with Excel.
SHIELD	Micrometeoroid and orbital debris analysis task that calculates the mean number of penetrations from the .GEM file and the .RSP file.
SSP30425 MM	The 1991 micrometeoroid model developed for Space Station Freedom.
SSP30425 OD	The 1991 orbital debris model developed for Space Station Freedom.
STK	Analytical Graphics, Inc. satellite took kit for computing spacecraft trajectories.
.GEM	File extension for the binary GEOMETRY output file. The spacecraft self-shadowing database.
.GSUM	File extension for the formatted GEOMETRY output file.
.RSP	File extension for the binary RESPONSE output file. The ballistic limit equation database.
.RSUM	File extension for the formatted RESPONSE log file.
.SUM	File extension for the formatted SHIELD output file.
UI	user interface
VNC	The velocity/normal (orbital momentum direction)/co-normal coordinate system. The coordinate system used by MEMCxPv2 and ORDEM 3 when analyzing elliptical orbits. vehicle/normal coordinates are the same as local vertical local horizontal coordinates for circular orbits.
VV	vehicle velocity

Appendix D Software Distribution File List

D.1 Executables

The following executables are copied to *folder %LOCALAPPDATA%\Programs*
NASA HVIT\bin\BUMPER3-LITE.exe
NASA HVIT\bin\ordem2k2bii.exe
NASA HVIT\bin\procloo.exe

D.2 Documents

The following executables are copied to folder %LOCALAPPDATA%\Programs\
NASA HVIT\BUMPER3-LITE\BUMPER Software User Manual.pdf
NASA HVIT\BUMPER3-LITE\bin\README.htm

The following environment files are copied to *folder %LOCALAPPDATA%\Programs\NASA HVIT\envFiles*

D.2.1 MEMCxP environment files

100 km altitude circular polar orbit around the Moon. Averaged over 5 years.
MEMCxPv2\LLOTimeAvgMEMIglooDist.out

400 km altitude circular orbit, inclined at 51.6°, around the Earth; the ISS orbit. Averaged over 5 years.
MEMCxPv2\MEMCxPv2_LEO_ISS.out

D.2.2 MEMR2 environment files

400 km altitude circular orbit, inclined at 51.6°, around the Earth; the ISS orbit. Averaged over 1 year.
MEMR2\MEMR2_LEO_ISS.out.

100 km altitude circular polar orbit around the Moon. Averaged over 1 year.
MEMR2\MEMR2_LLO_100km.out.

1 AU radius circular orbit around the sun, inclined 0 with respect to the ecliptic. Averaged over 1 year.
MEMR2\MEMR2_solar_1AU.out.

D.2.3 ORDEM2000 environment files

ORDEM2000 ver. 1.4 population files.
ORDEM2000\D101.ASC
ORDEM2000\D102.ASC
ORDEM2000\D104.ASC
ORDEM2000\D105.ASC
ORDEM2000\D106.ASC
ORDEM2000\SPHR.DAT
ORDEM2000\T101C.DAT
ORDEM2000\T101E.DAT
ORDEM2000\T102C.DAT
ORDEM2000\T102E.DAT

ORDEM2000\T104C.DAT
ORDEM2000\T104E.DAT
ORDEM2000\T105C.DAT
ORDEM2000\T105E.DAT
ORDEM2000\T106C.DAT
ORDEM2000\T106E.DAT
ORDEM2000\V101.ASC
ORDEM2000\V102.ASC
ORDEM2000\V104.ASC
ORDEM2000\V105.ASC
ORDEM2000\V106.ASC

ORDEM2000 PRA analysis files for shape and orientation effects.
ORDEM2000\TPS.DAT
ORDEM2000\TPS_Lc.dat
ORDEM2000\Whip.dat
ORDEM2000\Whip_Lc.dat
ORDEM2000 flux files for the ISS orbit and 15 year durations for RSCE.
ORDEM2000\O2K_1998.9-2012.9_400.dat
ORDEM2000\O2K_2014-2028_400.dat
ORDEM2000\O2K_2013-2027_400.dat

ORDEM2000 flux files for the ISS orbit, 1 year durations and every year that ORDEM2000 applies to.
ORDEM2000\O2K_1998_400.dat
ORDEM2000\O2K_1999_400.dat
ORDEM2000\O2K_2000_400.dat
ORDEM2000\O2K_2001_400.dat
ORDEM2000\O2K_2002_400.dat
ORDEM2000\O2K_2003_400.dat
ORDEM2000\O2K_2004_400.dat
ORDEM2000\O2K_2005_400.dat
ORDEM2000\O2K_2006_400.dat
ORDEM2000\O2K_2007_400.dat
ORDEM2000\O2K_2008_400.dat
ORDEM2000\O2K_2009_400.dat
ORDEM2000\O2K_2010_400.dat
ORDEM2000\O2K_2011_400.dat
ORDEM2000\O2K_2012_400.dat
ORDEM2000\O2K_2013_400.dat
ORDEM2000\O2K_2014_400.dat
ORDEM2000\O2K_2015_400.dat
ORDEM2000\O2K_2016_400.dat
ORDEM2000\O2K_2017_400.dat
ORDEM2000\O2K_2018_400.dat
ORDEM2000\O2K_2019_400.dat
ORDEM2000\O2K_2020_400.dat
ORDEM2000\O2K_2021_400.dat
ORDEM2000\O2K_2022_400.dat
ORDEM2000\O2K_2023_400.dat
ORDEM2000\O2K_2024_400.dat
ORDEM2000\O2K_2025_400.dat

ORDEM2000\O2K_2026_400.dat
ORDEM2000\O2K_2027_400.dat
ORDEM2000\O2K_2028_400.dat
ORDEM2000\O2K_2029_400.dat
ORDEM2000\O2K_2030_400.dat

D.2.4 ORDEM 3 environment files

ORDEM 3 flux files for the ISS orbit and 15 year durations for RSCE.
ORDEM3p0\OD3_2013-2027_400.daf
ORDEM3p0\OD3_2013-2027_400.key
ORDEM3p0\OD3_2014-2028_400.daf
ORDEM3p0\OD3_2014-2028_400.key

ORDEM 3 flux files for the ISS orbit, 1 year durations and every year that ORDEM 3 applies to.
ORDEM3p0\OD3_2010_400.daf
ORDEM3p0\OD3_2010_400.key
ORDEM3p0\OD3_2011_400.daf
ORDEM3p0\OD3_2011_400.key
ORDEM3p0\OD3_2012_400.daf
ORDEM3p0\OD3_2012_400.key
ORDEM3p0\OD3_2013_400.daf
ORDEM3p0\OD3_2013_400.key
ORDEM3p0\OD3_2014_400.daf
ORDEM3p0\OD3_2014_400.key
ORDEM3p0\OD3_2015_400.daf
ORDEM3p0\OD3_2015_400.key
ORDEM3p0\OD3_2016_400.daf
ORDEM3p0\OD3_2016_400.key
ORDEM3p0\OD3_2017_400.daf
ORDEM3p0\OD3_2017_400.key
ORDEM3p0\OD3_2018_400.daf
ORDEM3p0\OD3_2018_400.key
ORDEM3p0\OD3_2019_400.daf
ORDEM3p0\OD3_2019_400.key
ORDEM3p0\OD3_2020_400.daf
ORDEM3p0\OD3_2020_400.key
ORDEM3p0\OD3_2021_400.daf
ORDEM3p0\OD3_2021_400.key
ORDEM3p0\OD3_2022_400.daf
ORDEM3p0\OD3_2022_400.key
ORDEM3p0\OD3_2023_400.daf
ORDEM3p0\OD3_2023_400.key
ORDEM3p0\OD3_2024_400.daf
ORDEM3p0\OD3_2024_400.key
ORDEM3p0\OD3_2025_400.daf
ORDEM3p0\OD3_2025_400.key
ORDEM3p0\OD3_2026_400.daf
ORDEM3p0\OD3_2026_400.key
ORDEM3p0\OD3_2027_400.daf
ORDEM3p0\OD3_2027_400.key
ORDEM3p0\OD3_2028_400.daf

ORDEM3p0\OD3_2028_400.key
ORDEM3p0\OD3_2029_400.daf
ORDEM3p0\OD3_2029_400.key
ORDEM3p0\OD3_2030_400.daf
ORDEM3p0\OD3_2030_400.key
ORDEM3p0\OD3_2031_400.daf
ORDEM3p0\OD3_2031_400.key
ORDEM3p0\OD3_2032_400.daf
ORDEM3p0\OD3_2032_400.key
ORDEM3p0\OD3_2033_400.daf
ORDEM3p0\OD3_2033_400.key
ORDEM3p0\OD3_2034_400.daf
ORDEM3p0\OD3_2034_400.key
ORDEM3p0\OD3_2035_400.daf
ORDEM3p0\OD3_2035_400.key

D.3 BUMPER3-LITE example files

The following example files are copied to the folder *%USERPROFILE%\Documents\NASA HVIT\Examples* if the user does not change the path at install.

Section 4 Tutorial Example. (ORDEM 3 number of 1 mm deep craters in the faces of a cube made of 6061-T6 and covered with MLI.)
EXAMPLE1\example1.gsum
EXAMPLE1\example1.info
EXAMPLE1\example1.rsum
EXAMPLE1\example1.sum
EXAMPLE1\example1.txt
EXAMPLE1\example1.unv

GEOMETRY checkModel Example with a Malformed Cube FEM Example.
EXAMPLE2\example2.gsum
EXAMPLE2\example2.info
EXAMPLE2\example2.txt
EXAMPLE2\example2.unv
EXAMPLE2\example2.warn

GEOMETRY Analysis Example Using MEMR2 MM environment and a Cube FEM.
EXAMPLE3\example1.info
EXAMPLE3\example3.gsum
EXAMPLE3\example3.txt

RESPONSE Analysis Example Using MEMR2 MM environment and all 20 BLE Cases in BUMPER3-LITE.
EXAMPLE4\example4.rsum
EXAMPLE4\example4.txt

RPLOT Example Using Example 4 .RSP File.
EXAMPLE5\example5.rplot
EXAMPLE5\example4.txt
EXAMPLE5\PID 1 plot.xlsx

SHIELD Analysis Example Using MEMR2 MM Environment and Calculating the Number of 1 mm Deep Craters in the Faces of a Cube Made of 6061-T6 with no MLI.

EXAMPLE6\example6.sum
EXAMPLE6\example6.txt

VBETA plots of ORDEM 3 Number of 1 mm Impacts onto the Faces of a Cube Example.

EXAMPLE7\example 7 VBETA plots.xlsx
EXAMPLE7\example7.sum
EXAMPLE7\example7.txt
EXAMPLE7\example7_0001.vbeta
EXAMPLE7\example7_0002.vbeta
EXAMPLE7\example7_0003.vbeta
EXAMPLE7\example7_0004.vbeta
EXAMPLE7\example7_0005.vbeta
EXAMPLE7\example7_0006.vbeta

Contour Plots Example Using MEMR2 MM Environment and A SHIELD Analysis of the Number of 1 mm Impacts onto the Faces of a Cube.

EXAMPLE8\example8.sum
EXAMPLE8\example8.txt
EXAMPLE8\example8.uni

ordem2k2bii.exe Example.

EXAMPLE9\example9.txt
EXAMPLE9\ordem2k.dat

ORDEM-GUI.exe and procloo.exe Example.

EXAMPLE10\example10.daf
EXAMPLE10\example10.key
EXAMPLE10\input.txt
EXAMPLE10\2014\IGLOOFLUX_SC.OUT
EXAMPLE10\2014\IGLOOFLUX_SIGMAPOP_SC.OUT
EXAMPLE10\2014\IGLOOFLUX_SIGMARAN_SC.OUT
EXAMPLE10\2014\ORDEM.IN
EXAMPLE10\2015\IGLOOFLUX_SC.OUT
EXAMPLE10\2015\IGLOOFLUX_SIGMAPOP_SC.OUT
EXAMPLE10\2015\IGLOOFLUX_SIGMARAN_SC.OUT
EXAMPLE10\2015\ORDEM.IN

STK9.exe Example.

EXAMPLE11\MEMCxP\AvgMEMIglooDist.out
EXAMPLE11\MEMCxP\AvgSpdDist.out
EXAMPLE11\MEMCxP\EXAMPLE11.out
EXAMPLE11\MEMCxP\EXAMPLE11.txt
EXAMPLE11\MEMCxP\StdDevMEMIglooDist.out
EXAMPLE11\MEMCxP\StdDevResults.out
EXAMPLE11\MEMCxP\StdDevSpdDist.out
EXAMPLE11\STK9\Example11 STK ScenarioWB.wsp
EXAMPLE11\STK9\Example11 STK ScenarioWB.wsptb
EXAMPLE11\STK9\Example11.sc
EXAMPLE11\STK9\Example11.txt
EXAMPLE11\STK9\ISS.sa

Appendix E Index

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13. ABSTRACT *(Maximum 200 words)*

This Bumper 3 code software user manual is intended for all specialty engineering analysts tasked with determining the risk of a mission-ending impact by a micrometeoroid or orbital debris (MMOD) particle for a spacecraft in Earth orbit. This s manual applies to edition BUMPER3-LITE-3.0. The Bumper 3 code is used to aid developing requirements during the systems requirement phase and to assess spacecraft designs during the development phase. The BUMPER software project documentation was tailored for a small legacy project. The new user will want to read Section 2.0 for an introduction to the Bumper 3 code tasks. Installation instructions are given in Section 3.0. The new user will then want to run through the probability of penetration task tutorial to familiarize themselves with the basic features. Users familiar with prior versions of BUMPER-II will want to read Section 2.2 for a list of the changes and new features. Instructions for using the new features are given in Section 5.0. The user requirements document, this software user manual, and the software design documentation produced from the doxygen computer-aided software engineering tool are the sole design and use information for the Bumper 3 code software project.

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