

# ESABASE2 - Debris

## Software User Manual

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## Document Information

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#### IV. List of References

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- /19/ S. Stabroth, P. Wegener, H. Klinkrad, MASTER 2005, Software User Manual, M05/MAS-SUM, 2006.
- /20/ McNamara, H., et al. METEOROID ENGINEERING MODEL (MEM): A meteoroid model for the inner solar system
- /21/ PROTECTION MANUAL, Version 3.3, Inter-Agency Space Debris Coordination Committee, IADC-04-03, Revision April 04, 2004
- /22/ SWENET, ESA's Space Weather European Network, since 2004, <http://www.esa-spaceweather.net/swenet/>

## V. Glossary

Term	Description
Ballistic limit	The minimum particle diameter which is able to penetrate a given wall configuration.
Eclipse	Eclipse is an open source community whose projects are focused on providing an extensible development platform and application frameworks for building software. For detailed information refer to <a href="http://www.eclipse.org">http://www.eclipse.org</a> .
ESABASE	Unix-based analysis software for various space applications. For details refer to the ESABASE User Manual /4/.
ESABASE/Debris	ESABASE framework and the debris and meteoroid flux and damage analysis application.
ESABASE2	New ESABASE version running on PC-based Windows platforms (to be distinguished from the "old" Unix-based ESABASE).
Geometric(al) (analysis)	Flux and damage analysis of a full three-dimensional geometric model.
Georelay	Object pointing keyword: tracking of a GEO satellite.
Ground test	Evaluation of the results of a selected damage or failure equation.
MASTER 2001	ESA's Meteoroid and Space Debris Terrestrial Environment Reference Model. For details refer to the MASTER Upgrade Final Report /5/. ESABASE2/Debris uses the MASTER 2001 Standard application.
MASTER 2005	ESA's successor to MASTER 2001; now defined as standard application for space debris risk analyses.
NASA90	Simple analytical space debris engineering model established by NASA /16/.
NASA96 / ORDEM96	NASA's space debris engineering model. Successor of NASA90 and predecessor of ORDEM2000. For details refer to the ORDEM96 documentation /17/.
non-geometric(al) (analysis)	Flux and damage analysis of a plate, which can be specified as a randomly tumbling plate or an oriented plate.
ORDEM2000	NASA's latest space debris engineering model. For details refer to the ORDEM2000 documentation /15/.
STEP	Acronym which stands for the Standard for the Exchange of Product model data.

## VI. List of Abbreviations

Abbreviation	Description
GUI	Graphical User Interface
JVM	Java Virtual Machine
MASTER	Meteoroid and Space debris Terrestrial Environment Reference (Model)
MLI	Multi-layer insulation
NASA	National Astronautics and Space Administration
OCAF	Open CASCADE Application Framework (contains the ESABASE2 data model)
ORDEM	Orbital Debris Engineering Model
RTP	Randomly Tumbling Plate

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## 1 Introduction

ESABASE2 is a software application (and framework) for space environment analyses, which play a vital role in spacecraft mission planning. Currently (2009), it encompasses Debris/meteoroid /1/, Atmosphere/ionosphere /7/, Contamination/outgassing /5/, /6/ and Sunlight /8/ analyses; with this, it complements other aspects of mission planning like thermal or power generator design.

The application grew from ESABASE2/Debris, an application for space debris and micro-meteoroid impact and damage analysis, which in turn is based on the original ESABASE/Debris software /4/ developed by different companies under ESA contract. ESABASE2 adds a modern graphical user interface enabling the user to interactively establish and manipulate three-dimensional spacecraft models and to display the selected orbit. Analysis results can be displayed by means of the colour-coded surfaces of the 3D spacecraft model, and by means of various diagrams.

The development of ESABASE2 was undertaken by etamax space GmbH under the European Space Agency contract No. 16852/02/NL/JA. The first goal was to port ESABASE/Debris and its framework/user interface to the PC platform (Microsoft Windows) and to create a modern user interface.

From the start, the software architecture has been expressively designed to accommodate further applications: the solvers outlined in the first paragraph were added, and more modules like e.g. Radiation are to follow.

ESABASE2 is written in Fortran 77, ANSI C++ and Java 6. The GUI is built on top of the Eclipse rich client platform, with 3D visualisation and STEP import realised by Open CASCADE. Report and graphs are based on the JFreeReport/JFreeChart libraries.

This user manual is the **Debris handbook**. It complements the Framework user manual /1/, which explains the common functionality of all solvers (e.g. Debris, Sunlight, Atmosphere/Ionosphere, or COMOVA).

## 2 Debris Solver

After we have specified mission and spacecraft geometry /1/, the next step is to perform space environment analyses with these. One of the available solvers, ESABASE2/Debris, performs debris and meteoroid analyses within the framework.

Four space debris models (NASA90 /16/, ORDEM2000 /15/, MASTER 2001 /11/ and MASTER 2005 /19/) as well as three meteoroid models (Grün /14/, Divine-Staubach /13/, /18/, and MEM /20/) are currently available for flux and damage analysis.

For detailed information on the technical background of the space debris and micro-meteoroid simulation, please refer to the ESABASE2/Debris technical description /2/.

This debris solver chapter is structured as follows:

- *Debris Geometry*: Explains debris-specific additions to a S/C geometry.
- *Debris Input*: Describes the input parameters for Debris and meteoroid analyses.
- *Debris Analysis*: How to perform an analysis.
- *Debris Results*: How to interpret the analysis results.

### 2.1 Debris Geometry

The geometry editor defines a spacecraft geometry for all solvers available within the ESABASE2 framework /1/, including Debris. Solver-specific geometry parameters are defined using special pages in the shape wizard.

A dedicated Debris page is shown for each shape, allowing you to define the shielding configuration of any shape (both primary and secondary shielding). Classic surface material properties as defined by the Material page are not interpreted by the Debris solver.

Please note that the Debris page is only available if ESABASE2/Debris is part of your installation (it is also possible to have only ESABASE2/Atmosphere, for example, depending on your license).

To see the Debris page, open a geometry file, select a shape, then rightclick it and choose "Modify → Debris". A wizard page as shown in the figure below will be opened.

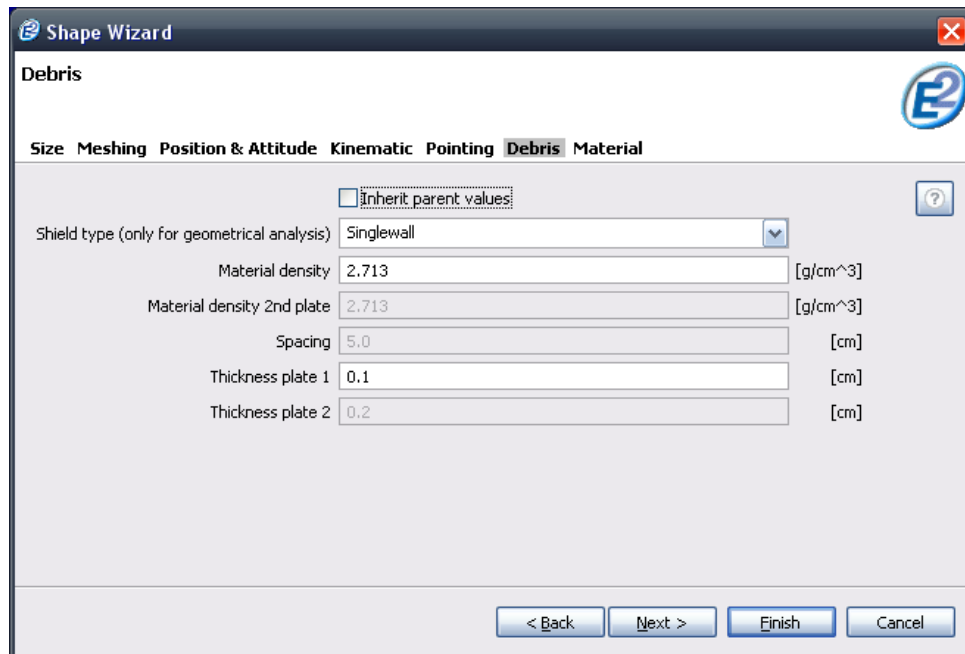


Figure 2.1: Geometry editor, Debris page

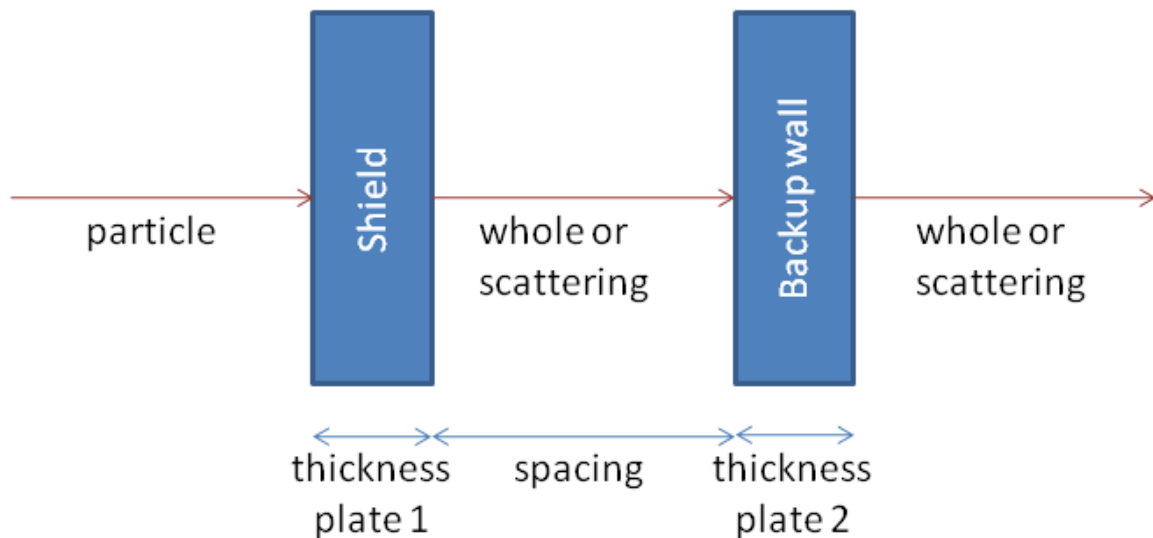
On this page, you can define shielding and material parameters that go beyond the Material page of the shape wizard.

The simplest option is to check the "Inherit parent values" checkbox, which takes over all Debris related values from the parent shape. This is possible for all shapes except the central body.

Below, the shield type can be chosen: Singlewall, multiwall (specified through double wall parameters /21/) or user subroutine (only for expert users with Fortran and/or C++ experience, see 2.2.1.5). Depending on single/multiwall choice, some fields are enabled or disabled.

In the screenshot above, you see "Singlewall" chosen, and thus material density and thickness of only one shield plate enabled. If you select "Multiwall" instead, you need to specify material density and thickness for the second shield plate or "back-up wall", as well as the spacing between both plates.

The figure below illustrates the parameters from the Wizard.



**Figure 2.2:** Debris shielding parameters

A particle hits the first shield wall, and the effect depends – besides the impact velocity, the impact angle and particle properties such as its diameter and material density – on the material density and thickness of the wall. The particle is either stopped, or penetrates the wall; it can remain whole or be scattered into smaller pieces due to the impact. If it penetrates, it travels the spacing between the walls; the same stop/penetration/scatter happens with the second wall. Depending on the remaining energy, the particle causes (a) a crater on or (b) a penetration of the device behind the wall.

In a single-wall scenario, the second wall does not exist, and the likelihood of a crater or penetration is considerably increased.

A failure equation determines whether a particle penetrates the wall configuration. A damage equation determines the size of the crater or hole (depending on no penetration/penetration) on the first wall (shield).

More information can be found in the ESABASE2/Debris technical description /2/ and in the IADC Protection Manual /21/.

This concludes the Debris specific additions to the geometry file.

## 2.2 Debris Input

Complementing the Debris parameters bound to the geometry (see previous section), the global Debris/Meteoroid input parameters are all specified in the Debris input editor. This editor is divided into three tabs:

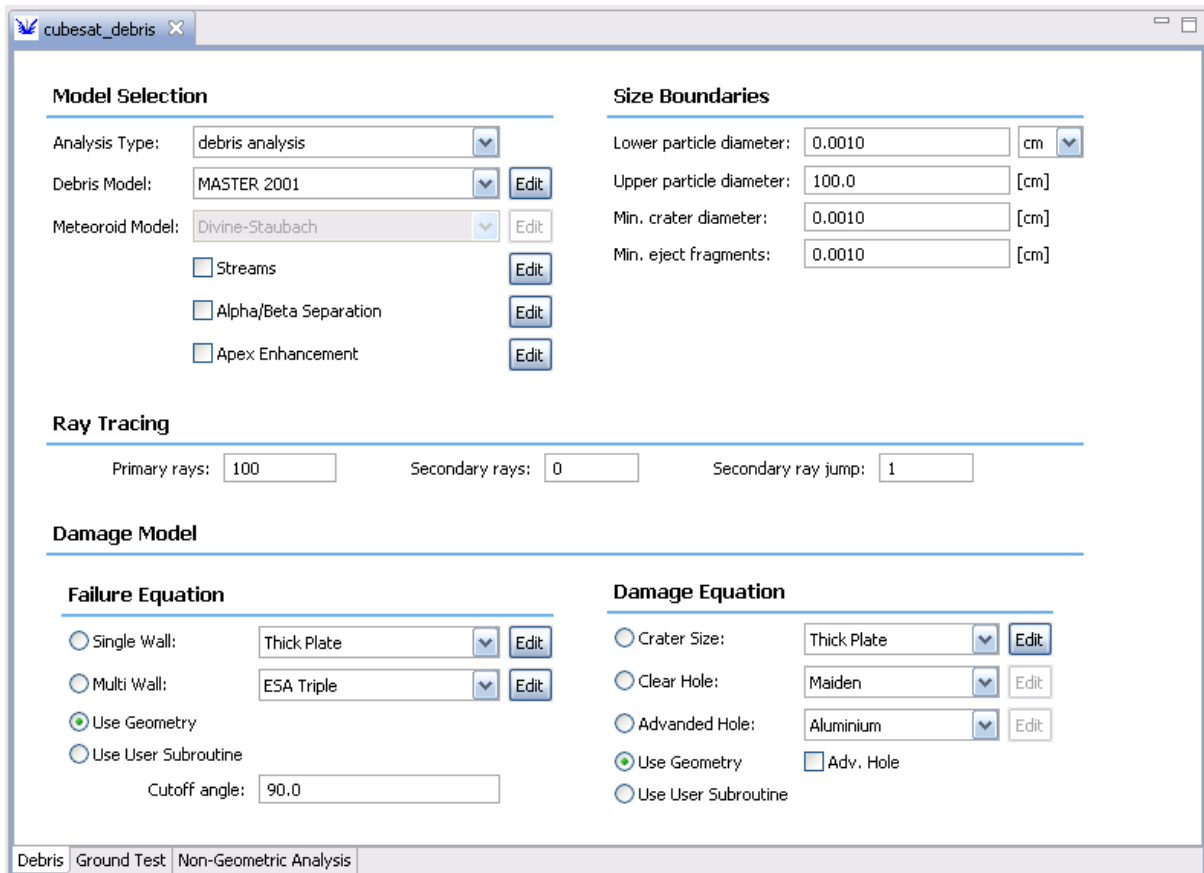
- *Debris Main Tab*: Specifies the parameters for the geometrical analysis.
- *Ground Test Tab*: An efficient way to test damage equations.
- *Non-Geometric Analysis Tab*: Allows a fast guess for the expected flux values on a specific orbit.

### 2.2.1 Debris Main Tab

The main tab of the Debris input editor contains four major blocks for specifying geometrical analysis input parameters:

- *Model selection*: Allows you to choose among debris and meteoroid models, and to edit dedicated model parameters.
- *Size boundaries*: Limits on the type of debris or meteoroids to be considered in the analysis.
- *Ray tracing*: Defines the accuracy of ray tracing results.
- *Damage Model*: Defines failure and damage equations for the Debris analysis.
- *User Subroutine*: How to define your own damage equation in a Fortran library.

The figure below shows the ESABASE2/Debris main tab within the Debris input editor.



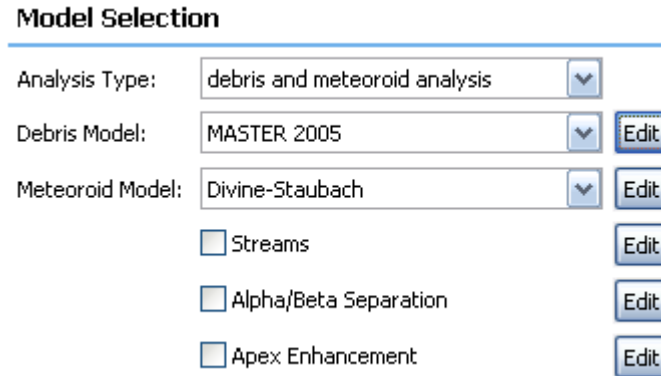
**Figure 2.3:** Debris input editor, main tab

At the bottom of the editor, you can see the "Debris", "Ground Test" and "Non-Geometric Analysis" tabs. This subsection is concerned with the main "Debris" tab.

In the following, the four sections of the main tab will be explained.

### 2.2.1.1 Model selection

Your first decision is which debris and meteoroid models you want to use. The following figure shows the model selection block within the Debris main tab.



**Figure 2.4:** Debris input editor, main tab, Model Selection

As a starting point to the Debris analysis, you have the choice between debris or meteoroid analyses, or both (see first combo-box: "Analysis Type"). Depending on your choice, the "Debris Model" or "Meteoroid Model" coboboxes will be enabled or disabled.

ESABASE2/Debris provides four Debris models (MASTER 2001, MASTER 2005, ORDEM 2000, NASA90) and three meteoroid models (Grün, Divine-Staubach, MEM). Most of the models accept detailed input parameters: Press the "Edit" button to the right of the model combo-boxes.

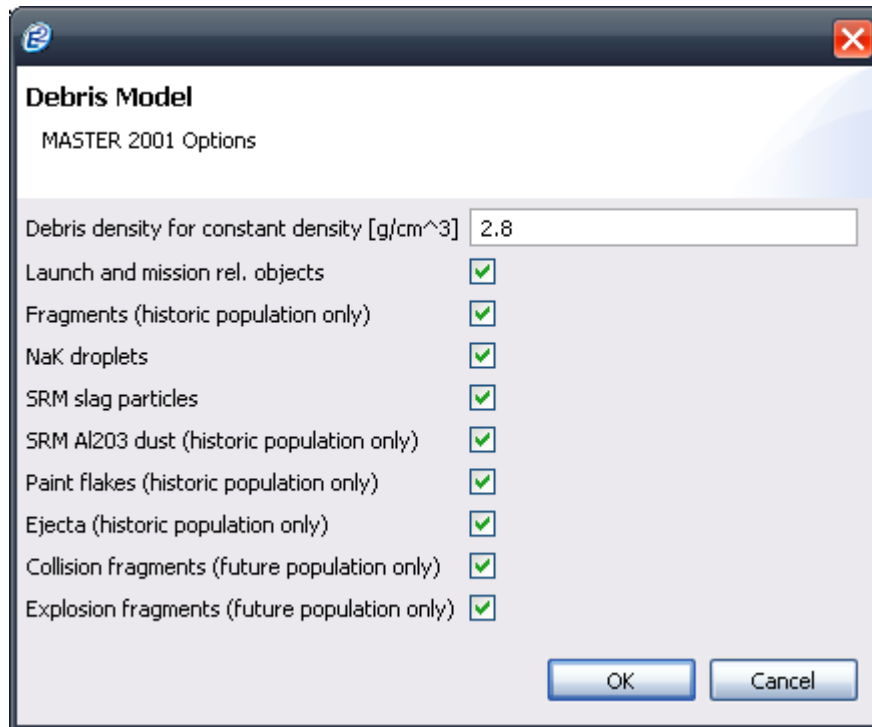
Additional parameters (Streams, Alpha/Beta Separation, and Apex Enhancement) are shown below; they are valid only for some models. Details are given in the sections 2.2.1.1.8, 2.2.1.1.9 and 2.2.1.1.10.

In the following, the available models will be described together with their associated parameters. This description is necessarily short; a full description can be found in the ESABASE2/Debris Technical Description /2/.



### 2.2.1.1.1 Debris model: MASTER 2001

MASTER 2001 /11/ is the 2001 version of ESA's meteoroid and space debris reference model; it is the forerunner of MASTER 2005 (see next subsection). When you click on the "Edit" button, a dialog with MASTER 2001 input parameters will open, as shown in the following figure.



**Figure 2.5:** Debris input editor, main tab, Model Selection, MASTER 2001

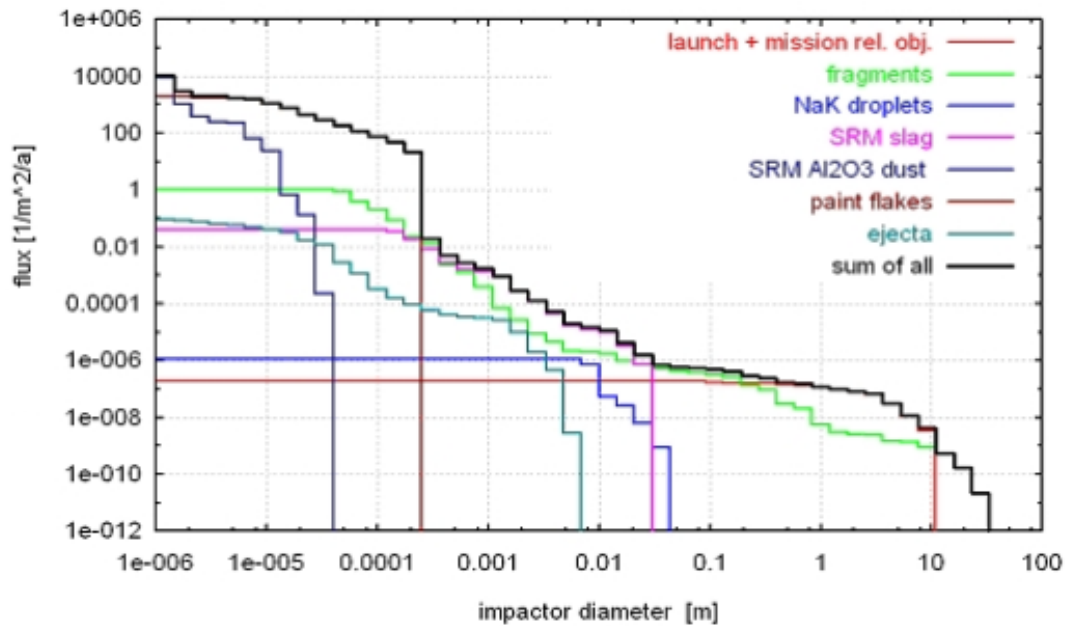
Apart from the assumed debris density (default: 2.8 g/cm<sup>3</sup> as material mix average), the MASTER 2001 model is based on numerical modelling of various population sources, which can be included or excluded from an analysis.

- Launch and mission related objects: payloads and satellites, upper stages, support structures. These are mostly larger, trackable objects.
  - Note that the Westford needles experiment is included as subpopulation and cannot be turned off with this flag.
- Fragments (collision and explosion) before reference epoch (2001-05-01): These are known fragment populations.
- NaK droplet releases: coolant droplets released from Russian RORSAT satellites.
- SRM (solid rocket motor) firing waste products:
  - slag produced in the final firing phase, mostly > 1 mm
  - Aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) dust

- Paint flakes are generated by surface degradation effects (mostly sunlight and thermal cycling)
- Ejecta are small fragments of the S/C created by the impact of debris or meteoroids.
- Collision (but not explosion) fragments after reference epoch; covers assumed collision rate of satellites with other bodies in the future.
- Explosion (but not collision) after reference epoch; covers assumed explosion rate of satellites in the future.

In the context of the MASTER 2001 model, "reference epoch" or "historic" means dates until 2001-05-01. The "future" are dates from 2001-05-01; note that from there, objects < 1 mm are not considered (this also means that paint flakes, ejecta and dust are not available, because they are always < 1 mm).

As an example of the effect of the various factors, the figure below shows the cumulative cross-sectional debris flux from different sources on an ISS-like orbit.



**Figure 2.6:** Cumulative flux vs. particle diameter for an ISS-like orbit (MASTER 2001)

MASTER 2001 provides realistic yearly population snapshots for the past and the future. The flux calculation is based on the analytic evaluation of the distributions of the size and the orbital elements of the particle population (MASTER 2001 Standard application).

The model considers the population asymmetry induced by the asymmetric distribution of the particle orbits argument of perigee.

MASTER 2001 covers the entire altitude range from LEO to GEO (150 km to 37000 km). Within the given altitude range there are no restrictions concerning the target orbit, so that highly eccentric orbits such as GTO can be analysed.

The MASTER population snapshots are available from year 1980 to 2020. Consequently, historic missions (e.g. LDEF) and future missions can be analysed using realistic population snapshots.

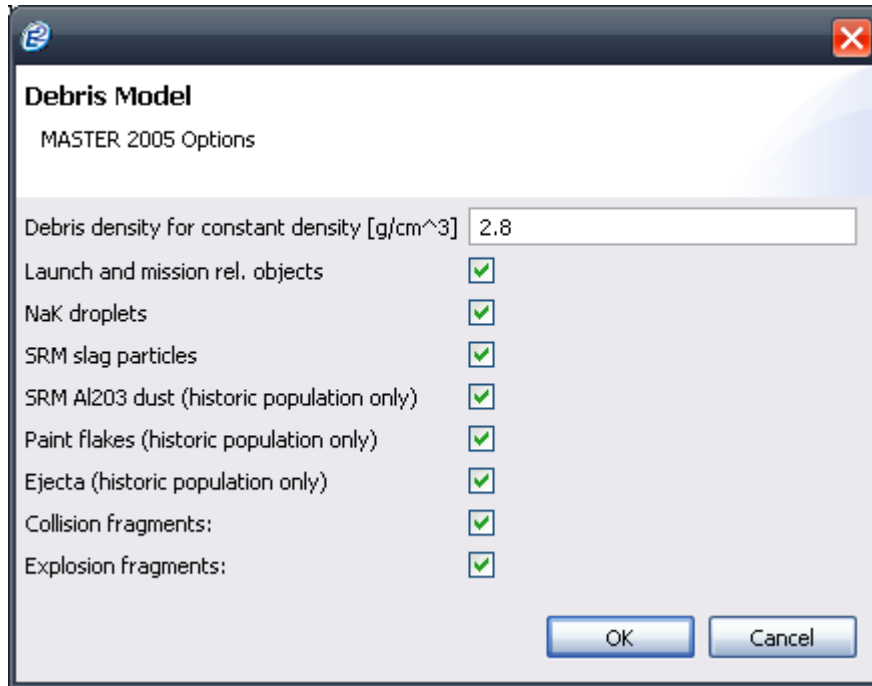
For the future evolution of the space debris environment the following assumptions have been applied:

- continuation of space activity (launches, explosions, solid rocket motor firings) at the same rate as in the recent past,
- no new satellite constellations deployed,
- no implementation of debris mitigation measures.

This corresponds to the MASTER 2001 future reference scenario.

### 2.2.1.1.2 Debris model: MASTER 2005

MASTER 2005 /19/ is ESA's meteoroid and space debris reference model, and the successor of MASTER 2001 (see previous subsection). When you click on the "Edit" button, a dialog with MASTER 2005 input parameters will open, as shown in the following figure.



**Figure 2.7:** Debris input editor, main tab, Model Selection, MASTER 2005


The MASTER 2005 options are similar to the MASTER 2001 options (see previous subsection). The following differences have to be noted:

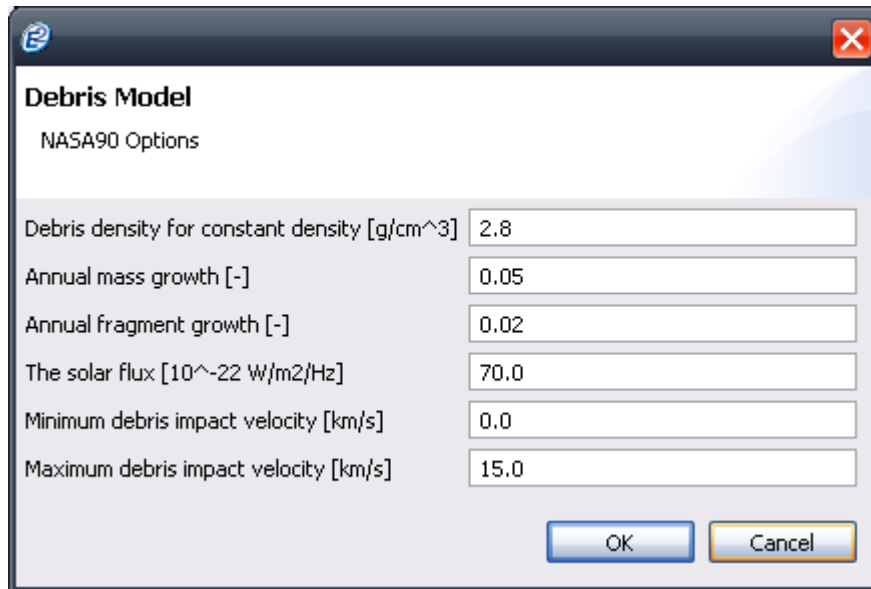
- Collision and explosion fragments cover both historic and future populations, not only future populations as in MASTER 2001.
  - This also explains why the "Fragments (historic)" option has vanished in comparison to MASTER 2001.

Like MASTER 2001, MASTER 2005 covers altitudes from 150 km to 37000 km. The "future" is from 2005-05-01 and in the future; objects < 1 mm are not considered.

### 2.2.1.1.3 Debris model: NASA90

NASA90 /16/ is an analytical debris model developed by NASA, which provides a simple and very fast debris flux calculation, but does not fully reflect the current knowledge of the Earth's debris environment, in particular the existence of a large number of particles on eccentric orbits.

Upon clicking the "Edit" () button, the NASA90 input parameters dialog is opened, as shown in the screenshot below.



**Figure 2.8:** Debris input editor, main tab, Model Selection, NASA90

As with all debris models, the average density of the debris material can be specified.

The debris mass (P) and fragments number (Q) annual growth rates are specified as percentage, where 1 = 100% growth. It is recommended to use the default values.

Solar flux is used to specify the solar activity; appropriate values for the mission duration can e.g. be retrieved using the publicly available SWENET database /22/.

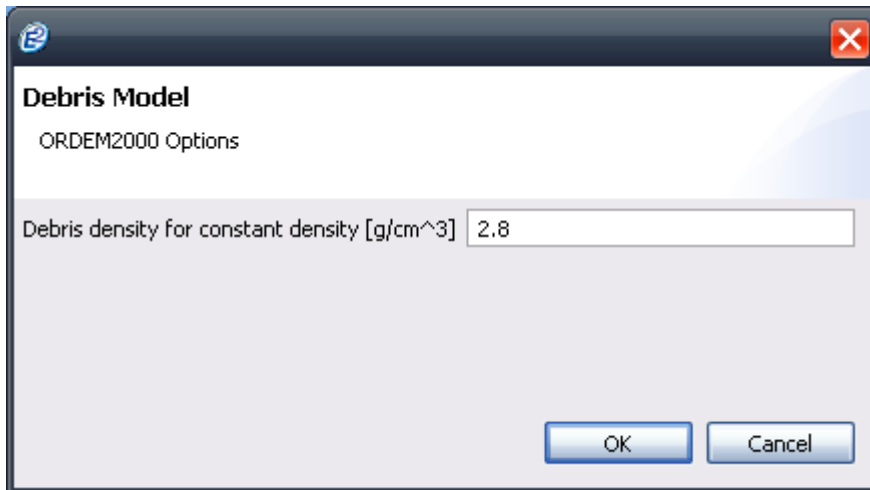
At the bottom, you see the debris velocity range, namely the minimum and maximum debris impact velocity to be considered. The default is from 0 to 20 km/s.

Please note that the NASA90 model is restricted to orbital altitudes below 1000km.

#### 2.2.1.1.4 Debris model: ORDEM 2000

ORDEM2000 /15/ is a debris model developed by NASA; it is the successor of NASA96, which in turn followed NASA90. The model describes the orbital debris environment in the low earth orbit region between 200 km and 2000 km altitude.

The only user-editable input parameter is the assumed debris material density (default: 2.8 g/cm<sup>3</sup>), as shown in the figure below.



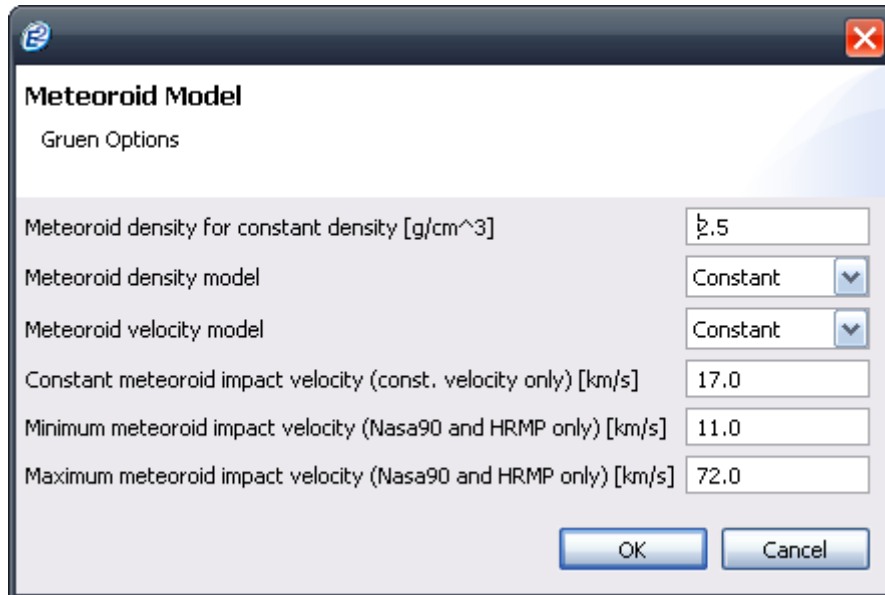
**Figure 2.9:** Debris input editor, main tab, model selection, ORDEM 2000

ORDEM 2000 is appropriate for engineering solutions requiring knowledge and estimates of the orbital debris environment (debris spatial density, flux, etc.). The model includes a large set of observational data (both in-situ and ground-based), covering the object size range from 10 µm to 10 m.

The analytical technique uses a maximum likelihood estimator to convert observations into debris population probability distribution functions; these functions then form the basis of the debris populations. A finite element model processes the debris populations to form the debris environment.

### 2.2.1.1.5 Meteoroid model: Grün

Gruen /14/ is an interplanetary flux model for sporadic meteoroid environment. When you press the "Edit" button, a dialog with the Gruen input parameters shown in the figure below appears.



**Figure 2.10:** Debris input editor, main tab, Model Selection, Grün

On top, you see the meteoroid density option. Below, choose between this constant meteoroid density and alternatively the NASA90 density distribution model (the latter choice will ignore your meteoroid density specification above).

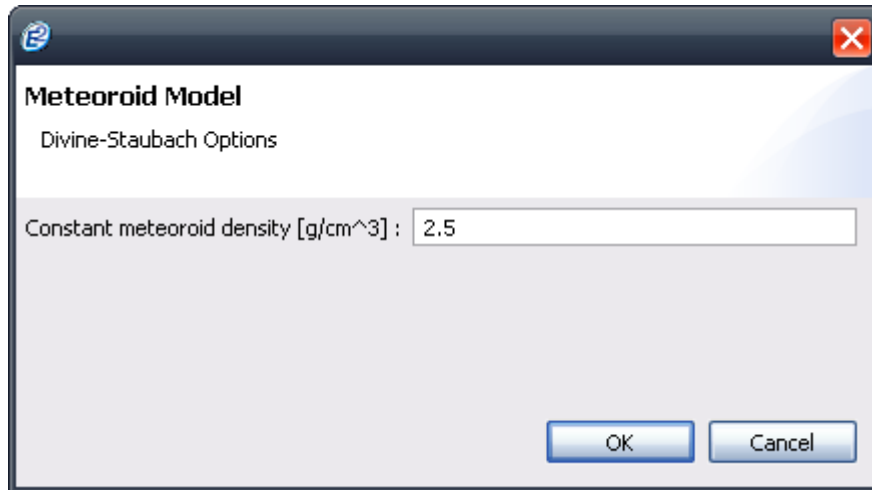
The next two lines are concerned with the meteoroid velocity distribution option:

- Constant meteoroid velocity; for this option, the default value is 17 km/s.
- The NASA90 velocity distribution. In most cases, this delivers the best results, and is thus the recommended option for the industrial user.
- The Taylor HRMP velocity distribution. This model is the most complex option.

The last two lines handle the meteoroid velocity range, namely the minimum and maximum meteoroid velocity to be considered. The default is 11 km/s and 72 km/s.

2.2.1.1.6 □ Meteoroid model: Divine-Staubach

Divine-Staubach /13/ /18/ is a meteoroid model which is also part of the MASTER 2005 model. When you press the "Edit" button, a dialog shows the the Divine-Staubach input parameters depicted in the screenshot below.



**Figure 2.11:** Debris input editor, main tab, Model Selection, Divine-Staubach

The only parameter is the material density of meteoroids. It is assumed to be constant.

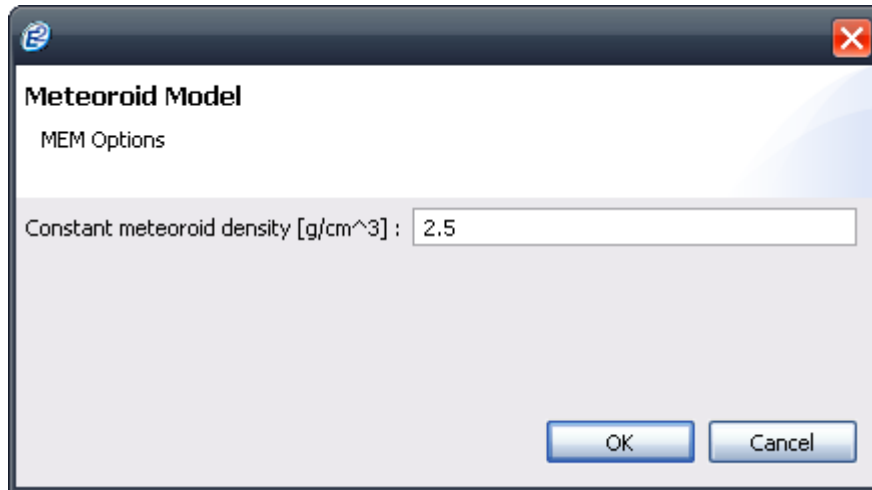
Divine-Staubach is based on the size and orbital element distributions of five meteoroid subpopulations, and thus provides directional information in the same way as the MASTER 2005 debris model.

Please note: Since the Divine-Staubach meteoroid model is implemented in the MASTER Standard application, one MASTER 2005 run covers both debris and meteoroid flux determination if the corresponding switches are set.



### 2.2.1.1.7 Meteoroid model: MEM

MEM /20/ is a meteoroid model developed by the University of Western Ontario, Canada. Upon pressing "Edit", a dialog with the MEM input parameters opens, as shown in the figure below.



**Figure 2.12:** Debris input editor, main tab, Model Selection, MEM

MEM has no options by itself, using a constant meteoroid density of  $1 \text{ g/cm}^3$ . The option available here is used to convert mass to diameter for damage computation. We propose to always use  $1 \text{ g/cm}^3$ .

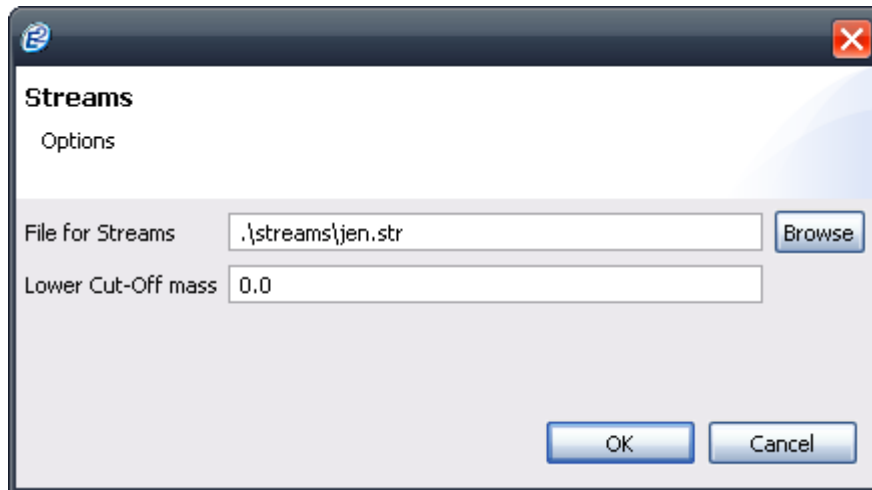
Please note that the default  $2.5 \text{ g/cm}^3$  is fitting only for the other meteoroid models – all models use the same parameter within the data model; this is the reason that the default in the GUI cannot be  $1 \text{ g/cm}^3$ .

MEM is a parametric model of the spatial distribution of sporadic meteoroids. The primary source is short-period comets with aphelia less than 7 AU. The model also considers the contributions from long-period comets to the sporadic meteor complex, and includes the effects of the gravitational shielding and focussing of the planets.

### 2.2.1.1.8 Jenniskens Stream Model

The above meteoroid models are describing the background meteoroid flux; the Jenniskens stream model adds annual meteoroid streams (e.g. the Perseids). The streams model can be used with or without another meteoroid model.

When pressing the "Edit" button, the dialog for the Jenniskens Stream Model input parameters appears, as shown in the figure below.



**Figure 2.13:** Debris input editor, main tab, Model Selection, Streams

The streams and possible interstellar sources are defined in an external input file, with a default `jen.str` being provided by ESABASE2. File locations are always relative to the ESABASE2 installation path.

Meteoroid particles with less mass than the lower cut-off mass are not considered in the analysis.

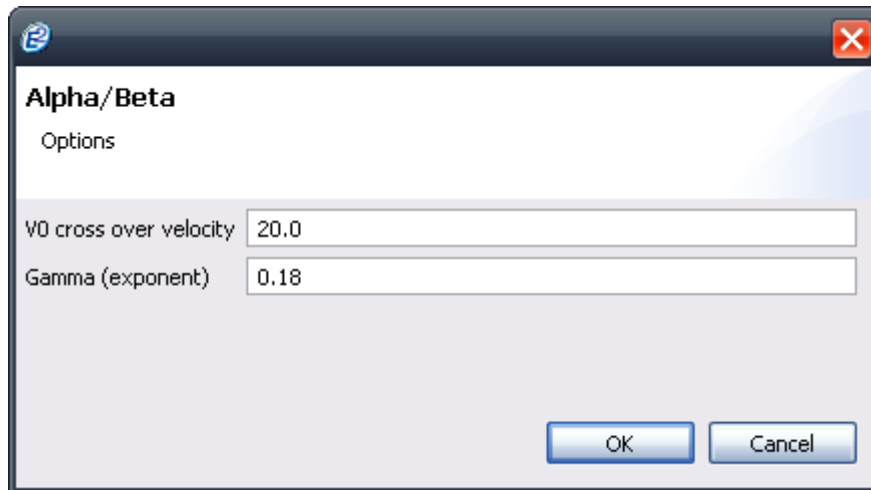
The Jenniskens stream model is based on observation data gathered over a 10 year period, and can be applied to flux and damage analysis. It also includes directional information on the streams.

Please note that for long mission durations, the directional effect is smeared out, and does not give any additional information than the Grün sporadic option. The stream option is best suited for the investigation of missions below 10 days where high stream activities are expected.

### 2.2.1.1.9 Alpha-Beta Separation

As an improvement to the Grün meteoroid model, the Alpha-Beta Separation divides the meteoroids in alpha particles (following the Grün sporadic omni-directional flux model) and smaller beta particles stemming from the sun.

When you press "Edit", the Alpha-Beta Separation options shown in the screenshot below appear in a dialog.



**Figure 2.14:** Debris input editor, main tab, Model Selection, Alpha-Beta Separation

The velocity distribution of the beta particles can be modified by specifying two parameters (for more details, see /10/):

- V0: cross-over velocity; default: 20.0 km/s
- Gamma (exponent); default: 0.18

The Alpha-Beta Separation obtains improved directional information by attempting to split off the beta meteoroids, which are driven away from the Sun into hyperbolic orbits by radiation pressure, from the alpha meteoroids.

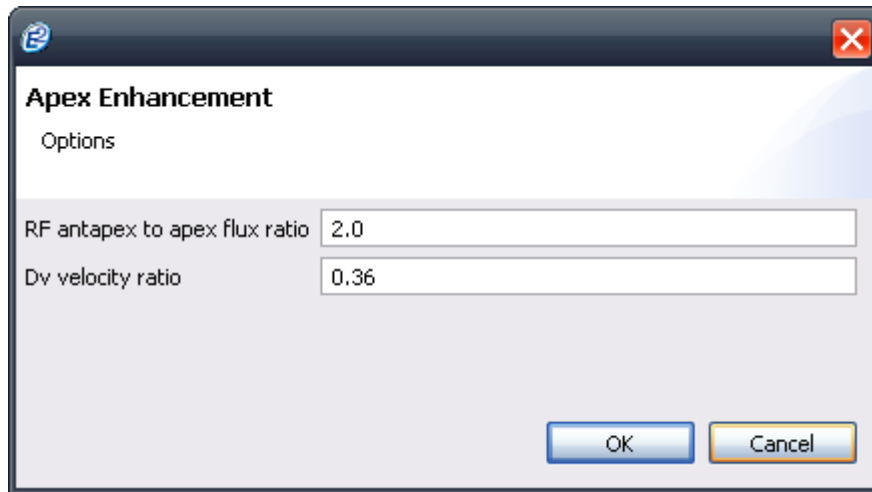
An apex enhancement of the alpha meteoroids and interstellar streams (see next subsection) may introduce further directional information.

We do not recommend using other values than the default values for this model, unless you have in-depth knowledge in astrophysics.

### 2.2.1.1.10 Apex Enhancement

As a modification to the Grün model, the Apex Enhancement describes the meteoroid flux enhancement caused by the earth's motion on its orbit around the sun (similar to the enhanced flux a spacecraft experiences in velocity direction).

If you press "Edit", a dialog shows the Apex Enhancement input parameters shown in the figure below.



**Figure 2.15:** Debris input editor, main tab, Model Selection, Apex Enhancement

Two parameters can be used to describe the ratio of flux and velocities between apex ("front") and antapex ("back") directions (see /10/ for more details):

- $R_f$ : antapex to apex flux ratio; default: 2.0
- $D_v$ : velocity ratio; default: 0.36

As with Alpha-Beta Separation, we do not recommend using other values than the default values for this model, unless you have in-depth knowledge in astrophysics.

### 2.2.1.2 Size Boundaries

The figure below shows the Size Boundaries section of the main tab in the Debris input editor. In this section, you specify limits on the type of Debris or Meteoroids to be used in the analysis.

**Size Boundaries**

Lower particle diameter:	<input type="text" value="0.0010"/>	<input type="button" value="cm"/> <input type="button" value="v"/>
Upper particle diameter:	<input type="text" value="100.0"/>	[cm]
Min. crater diameter:	<input type="text" value="0.0010"/>	[cm]
Min. eject fragments:	<input type="text" value="0.0010"/>	[cm]

**Figure 2.16:** Debris input editor, main tab, Size Boundaries

At the top, the minimum and maximum particle size limits can be input as mass [g] or diameter [cm]. The conversion between mass and diameter assumes spherical particles.

At the bottom, the minimum crater diameter and ejecta fragment size are defined in [cm]. Below these size limits, crater or ejecta fragment are not further considered in the analysis.

### 2.2.1.3 Ray Tracing

Ray tracing is the primary technique in ESABASE2 to determine whether Debris or Meteoroids hit the spacecraft geometry at a specific orbital point. Below, you can see a screenshot of the Ray Tracing section in the main tab.



**Figure 2.17:** Debris input editor, main tab, Ray Tracing

The "Primary rays" parameter governs the number of primary rays to be fired per element. For ESABASE geometric models, at least 250 rays per element are recommended, for non-geometric analyses 1000 rays.

In the middle, the "Secondary rays" parameter specifies the number of secondary rays to be fired from each impact point. Due to the high computational effort caused by this option it is recommended to choose fairly low values (< 100).

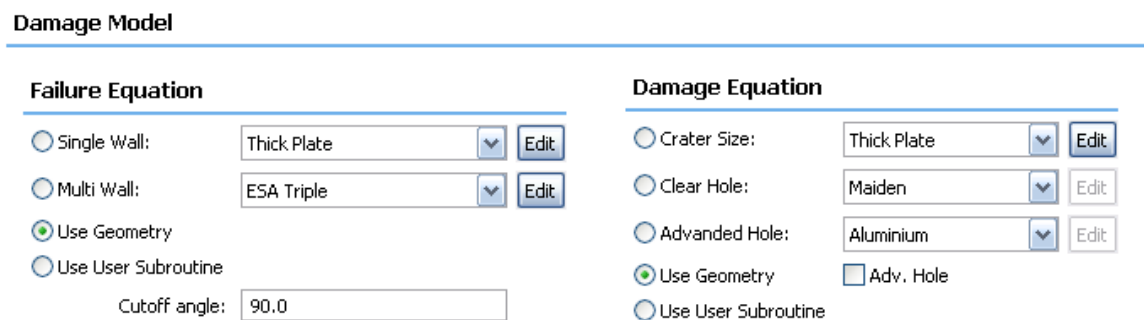
Another option to reduce computation time is to specify a "Secondary ray jump" which causes the program to skip the respective number of secondary rays.

### 2.2.1.4 Damage Model

There are two types of damage equations used during the analysis:

- The ballistic limit equations, which deliver the limit impactor diameter above which a structural failure of the analysed surface occurs. This limit diameter is used to compute the probability of a failure using the chosen flux models.
- The damage size equations, which compute the crater diameter of semi-infinite targets and the hole size of thin targets. Again, the flux models are then used to compute the total cratered or perforated area of the surface.

The figure below shows the damage parameters in the main tab.



**Damage Model**

---

<p><b>Failure Equation</b></p> <p><input type="radio"/> Single Wall: Thick Plate <input type="button" value="Edit"/></p> <p><input type="radio"/> Multi Wall: ESA Triple <input type="button" value="Edit"/></p> <p><input checked="" type="radio"/> Use Geometry</p> <p><input type="radio"/> Use User Subroutine</p> <p>Cutoff angle: <input type="text" value="90.0"/></p>	<p><b>Damage Equation</b></p> <p><input type="radio"/> Crater Size: Thick Plate <input type="button" value="Edit"/></p> <p><input type="radio"/> Clear Hole: Maiden <input type="button" value="Edit"/></p> <p><input type="radio"/> Advanced Hole: Aluminium <input type="button" value="Edit"/></p> <p><input checked="" type="radio"/> Use Geometry <input type="checkbox"/> Adv. Hole</p> <p><input type="radio"/> Use User Subroutine</p>
---	--

**Figure 2.18:** Debris input editor, main tab, Damage Model

The following convention is used in the software: for single wall surfaces, the single wall ballistic limit equation is used for the failure assessment, the crater size equation for the damage assessment (cratered area); for multiple wall surfaces, the multiple wall ballistic limit equation is used for the failure assessment, the clear hole equation for the damage assessment.

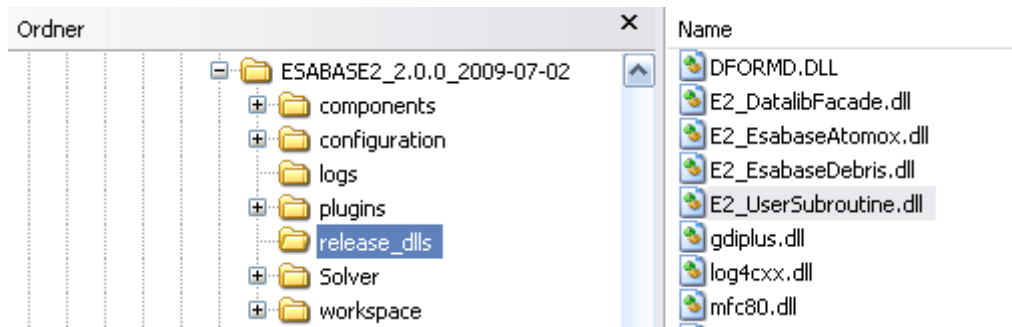
The damage equations of the ESABASE2/Debris analysis tool are defined in a parametric form, with editable parameters (constants and exponents).

For a detailed description of the user input of the damage equations, please refer to /10/. Up to seven entities can be defined: the damage equation preferences, the single wall ballistic limit equation, the multiple wall ballistic limit equation, the crater size equation, the parametric clear hole equation, the advanced hole equation and the user subroutine parameters.

### 2.2.1.5 User Subroutine

For expert users of the original ESABASE, the possibility to use your own damage equation subroutine is provided. This option requires the availability of a FORTRAN or C/C++ compiler and linker.

You need to rebuild the `E2_UserSubroutine.dll` (Dynamic Linked Library) located in the `release_dlls` directory of the installation, as shown in the figure below.



**Figure 2.19:** Finding the User subroutine DLL

ESABASE2 2.0.0 uses the Compaq Visual Fortran 6 compiler. It is highly advisable to use the same compiler. Also, while it is possible to use other languages (e.g. C++) to produce the subroutine DLL, compiler issues frequently occur.

Please note: When writing your own user subroutine in Fortran, take care to initialise all variables; otherwise, results can be erratic.

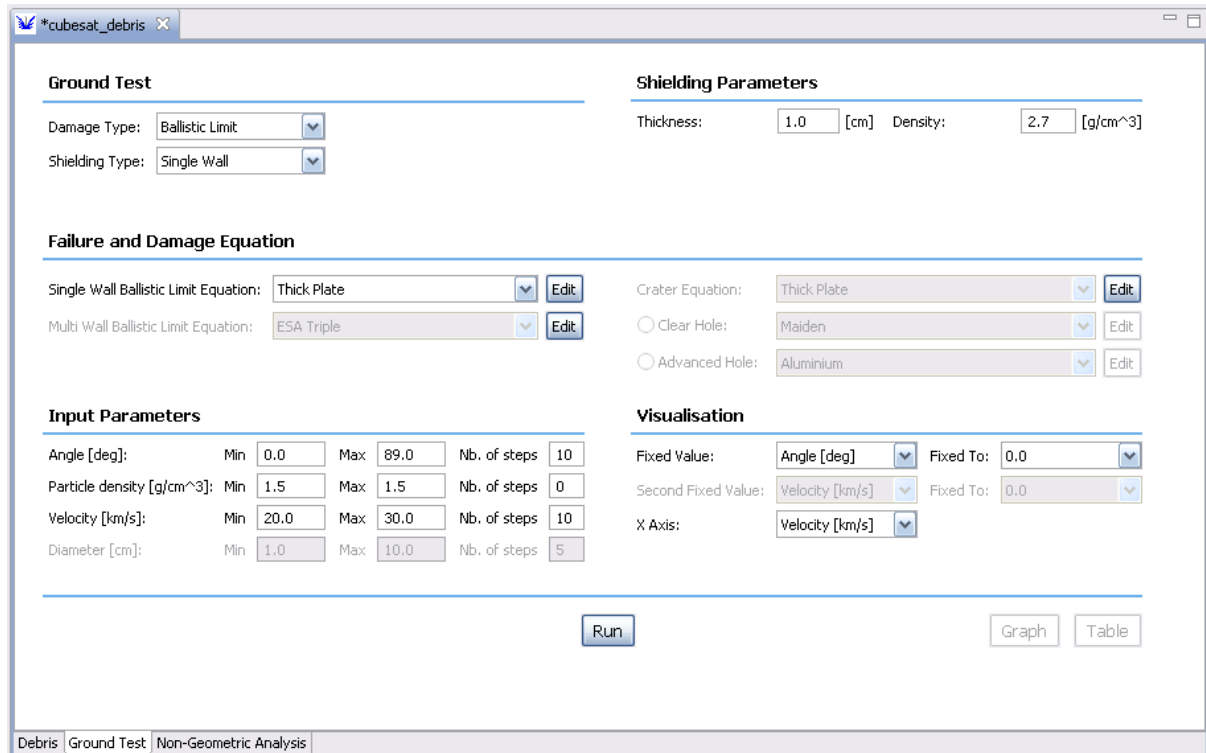
As a starting point, look at the Fortran file "user\_dam.f" in the Debris plugin directory (`plugins\eu.esa.estec.esabase2005.debris_2.0.0\user_subroutine`). In case of persisting issues, please contact the ESABASE2 development team using the email address provided on the website /3/.

To apply the subroutine to the entire model, choose "User Subroutine" as damage equation in the Debris input editor, as described above (subsection 2.2.1.4). To apply it only to parts of the S/C geometry, go to the geometry editor, modify a shape via wizard, and on the Debris page, choose "User Subroutine" as shield type (see also section 2.1).



## 2.2.2 Debris Ground Test Tab

At the bottom of the Debris input editor, the second tab leads to the "Ground Test" page, which is depicted in the figure below.



**Figure 2.20:** Debris input editor, Ground Test tab

The ground test option enables you to run the damage equations on their own, outside of the ESABASE2/Debris analysis; its purpose is to test and preview the results of the damage equations.

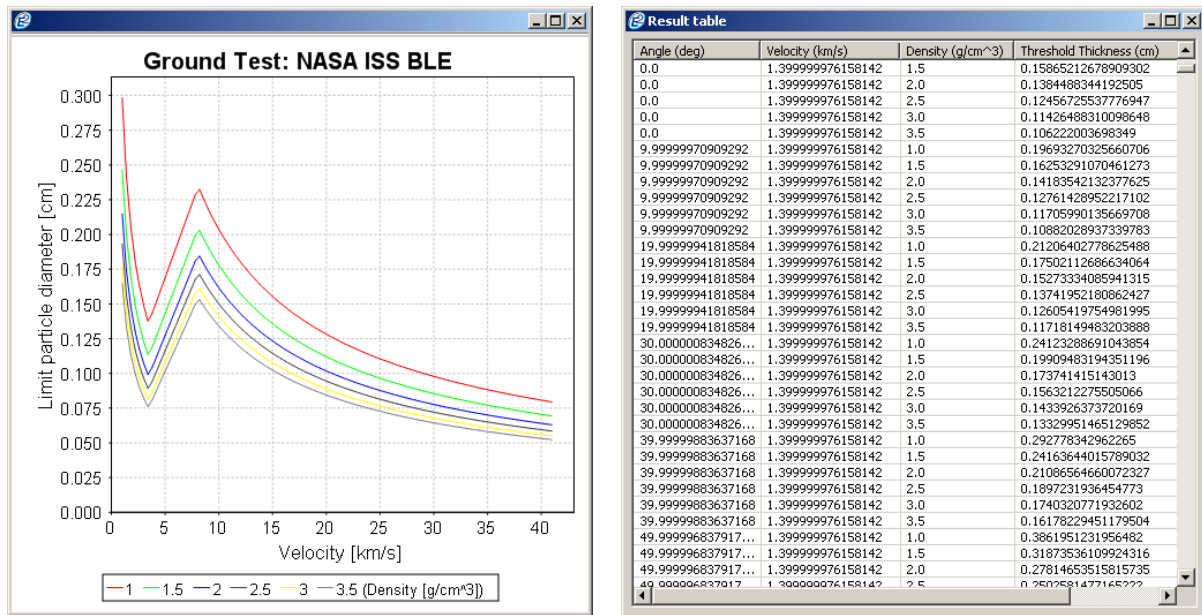
The following sections are available:

- *Ground Test:* Choose damage type (ballistic limit or crater size) and shielding type (single wall or multi wall).
- *Shielding Parameters:* Choose shield thickness and density (and spacing in case of double walls).
- *Failure and Damage Equation:* Choose the exact damage equation. Depends on the "Ground Test" choice made above.
- *Input Parameters:* Impact angle, density, velocity and diameter can be specified either as single values or as arrays of values. Each variable has three parameters: the minimum value, the maximum value and the number of steps. For single

shots, only the minimum parameter is used. For tabled data, when the variable is used as x-axis or y-curve parameter, all three parameters are used.

- *Visualisation:* Choose the axis on the result graph.

Unlike the normal Debris analyses, the ground test can be performed directly within the Debris input editor; for this purpose, press the "Run" button. Afterwards, the "Graph" and "Table" buttons at the bottom right are enabled, leading to the popup windows illustrated in the screenshot below.



**Figure 2.21:** Debris input editor, Ground Test tab, Run

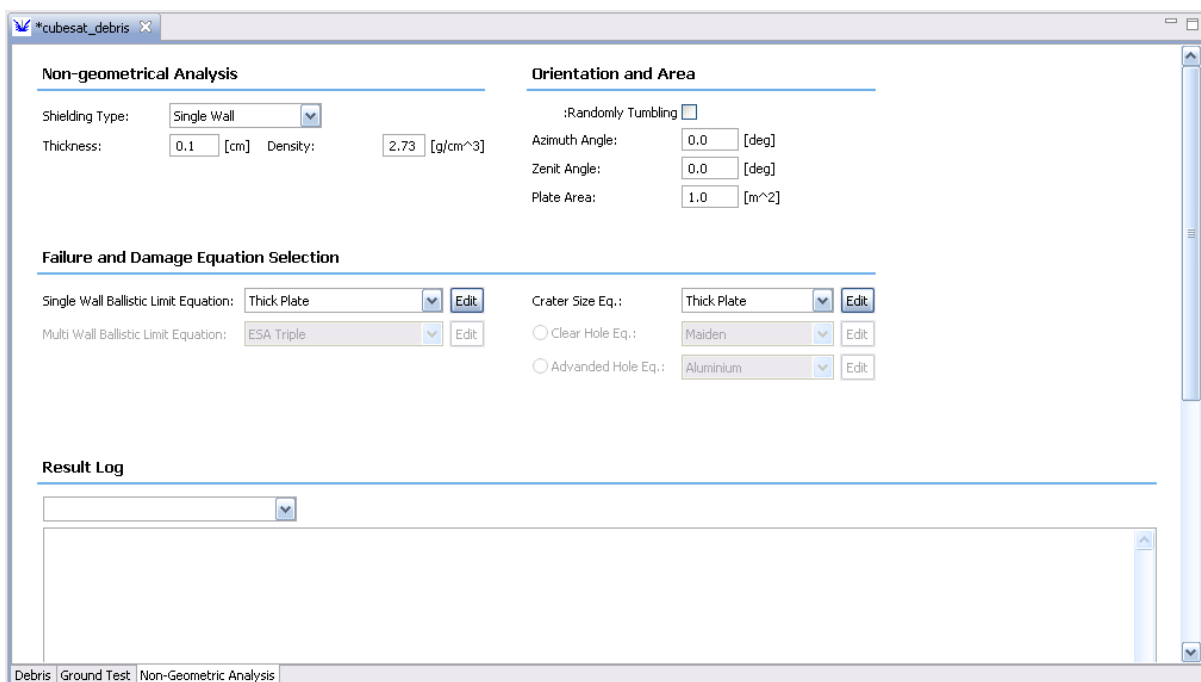
Graph and table show the same results.

### 2.2.3 Debris Non-Geometric Analysis Tab

The "non-geometric" analysis uses a simplified spacecraft geometry: A pointed or randomly tumbling plate. This mode is used to check an analysis environment consisting of the orbit specification, the environment models and the damage assessment parameters.

Using this mode is recommended for large spacecraft models with many elements, in order to iron out input errors without running a time-consuming full analysis. The ray tracing scheme is the same for both geometric and non-geometric analyses.

The following figure shows the Non-Geometric Analysis tab in the Debris input editor.



**Figure 2.22:** Debris input editor, Non-Geometric Analysis tab

In the tab, four sections are visible:

- *Non-geometrical Analysis:* Specifies shielding type as well as shield thickness and density (and spacing in case of double walls).
- *Orientation and area:* Specifies the plate size and its orientation or randomly tumbling property.
- *Failure and Damage Equation Selection:* Specifies the damage and failure equations, and their options.
- *Result Log:* Execution log of the analysis run (former listing file).

### 2.2.3.1 Non-Geometrical Analysis

The following screenshot shows the Non-Geometrical Analysis section (and the corresponding "Failure and Damage Equation Selection" section below it) for single and multi wall selection.

<p><b>Non-geometrical Analysis</b></p> <p>Shielding Type: <input type="text" value="Single Wall"/></p> <p>Thickness: <input type="text" value="0.1"/> [cm] Density: <input type="text" value="2.73"/> [g/cm<sup>3</sup>]</p> <p><b>Failure and Damage Equation Selection</b></p> <p>Single Wall Ballistic Limit Equation: <input type="text" value="Thick Plate"/> <input type="button" value="Edit"/></p> <p>Multi Wall Ballistic Limit Equation: <input type="text" value="ESA Triple"/> <input type="button" value="Edit"/></p>	<p><b>Non-geometrical Analysis</b></p> <p>Shielding Type: <input type="text" value="Multi Wall"/></p> <p>Thickness 1st plate: <input type="text" value="0.1"/> [cm] Density 1st plate: <input type="text" value="2.73"/> [g/cm<sup>3</sup>]</p> <p>Thickness 2nd plate: <input type="text" value="0.1"/> [cm] Density 2nd plate: <input type="text" value="2.73"/> [g/cm<sup>3</sup>]</p> <p>Space between: <input type="text" value="10.0"/> [cm]</p> <p><b>Failure and Damage Equation Selection</b></p> <p>Single Wall Ballistic Limit Equation: <input type="text" value="Thick Plate"/> <input type="button" value="Edit"/></p> <p>Multi Wall Ballistic Limit Equation: <input type="text" value="ESA Triple"/> <input type="button" value="Edit"/></p>
--	--

**Figure 2.23:** Debris input editor, Non-Geometric Analysis tab, Single and Multi wall

The input values correspond to the ones used in the geometry editor, in the Debris page of the shape wizards (see 2.1).

### 2.2.3.2 Plate Orientation and Area

The figure below shows the Plate Orientation and Area section within the Non-Geometric Analysis tab.

<p><b>Orientation and Area</b></p> <p>:Randomly Tumbling <input type="checkbox"/></p> <p>Azimuth Angle: <input type="text" value="0.0"/> [deg]</p> <p>Zenit Angle: <input type="text" value="0.0"/> [deg]</p> <p>Plate Area: <input type="text" value="1.0"/> [m<sup>2</sup>]</p>	<p><b>Orientation and Area</b></p> <p>:Randomly Tumbling <input checked="" type="checkbox"/></p> <p>Azimuth Angle: <input type="text" value="0.0"/> [deg]</p> <p>Zenit Angle: <input type="text" value="0.0"/> [deg]</p> <p>Plate Area: <input type="text" value="1.0"/> [m<sup>2</sup>]</p>
---	--

**Figure 2.24:** Debris input editor, Non-Geometric Analysis tab, Orientation and Area

The plate orientation can be one of the following.

- *Randomly tumbling*: This is the random tumbling plate (RTP) mode. It often corresponds to the environment models themselves, and is an effective way to get a quick first-order assessment of the micro-particle environment risk for a mission.
- *Oriented*: For this mode, azimuth and zenith angles of the plate normal can be defined.
  - The azimuth angle is the angle with respect to the velocity direction (0 deg corresponds to the ram direction, positive towards right).
  - The zenith angle is the angle to the space (zenith) direction (0 deg corresponds to the space direction).

In both cases, the area of the plate can be defined. Normally the default (1 m<sup>2</sup>) is used, but a specific area can be specified instead, e.g. in case of a detector or other special surface.

### 2.2.3.3 Failure and Damage Equation Selection

The failure and damage equations are the same as for the normal geometric analysis; please refer to subsection 2.2.1.4.

### 2.2.3.4 Result Log

The results of a non-geometrical analysis are displayed in the bottom part of the Debris input editor. You can select between four different sets of results:

- hits vs. crater size
- debris and meteoroid flux and damage results
- failures vs. ballistic limit
- orbit propagation results

All results will be presented in textual form (ASCII files).

The results listings are also available in the .ListingFiles folder of the corresponding project directory. The names of the listing files are composed from the string 'NonGeom', the analysis date and time and the type of listing (result set).

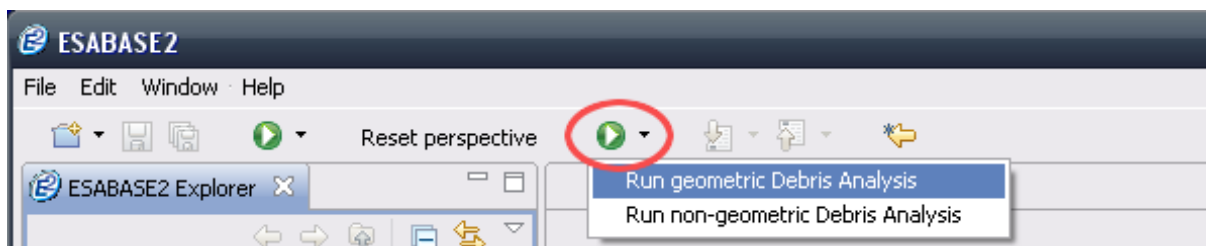
## 2.3 Debris Analysis

With both debris information within the spacecraft geometry and global debris input parameters specified, the time has come to perform a debris analysis. There are two type of analysis runs:

- *Geometric Analysis.* This is what you would normally expect: A mission and a spacecraft geometry are sent to orbit propagation and debris analysis.
- *Non-geometric Analysis.* Subtracts the S/C geometry from the analysis, instead taking a simple plate.

### 2.3.1 Geometric Debris Analysis

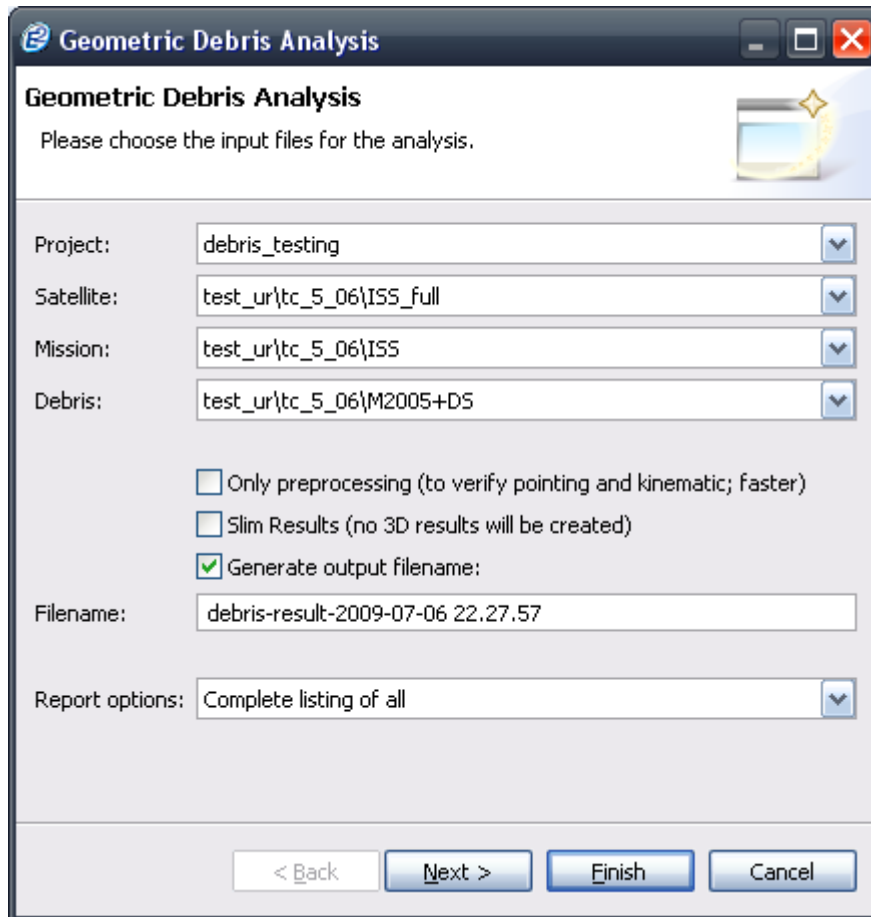
In the toolbar at the top of the application window, locate the "Run" button depicted in the following figure. Press the small down-arrow at the right of the button and a context menu will appear.



**Figure 2.25:** Geometric Debris analysis, Run button

Whenever you click directly on the Run button instead of the down-arrow to the right, the last selected run type will be repeated.

Choose the first entry, "Run geometric Debris Analysis". A wizard as illustrated by the following screenshot will appear.



**Figure 2.26:** Geometric Debris analysis, Run wizard

In the first line, you specify a project from your workspace; then, the next three combo-boxes will only show files from this project. A spacecraft geometry, a mission file and a debris input file must be chosen.

Activating the "Only Preprocessing" checkbox will stop the analysis after pointing and kinematics have been calculated. It is useful to check the correctness of the pointing and kinematics settings without running a complete and possibly time-consuming debris or meteoroid analysis.

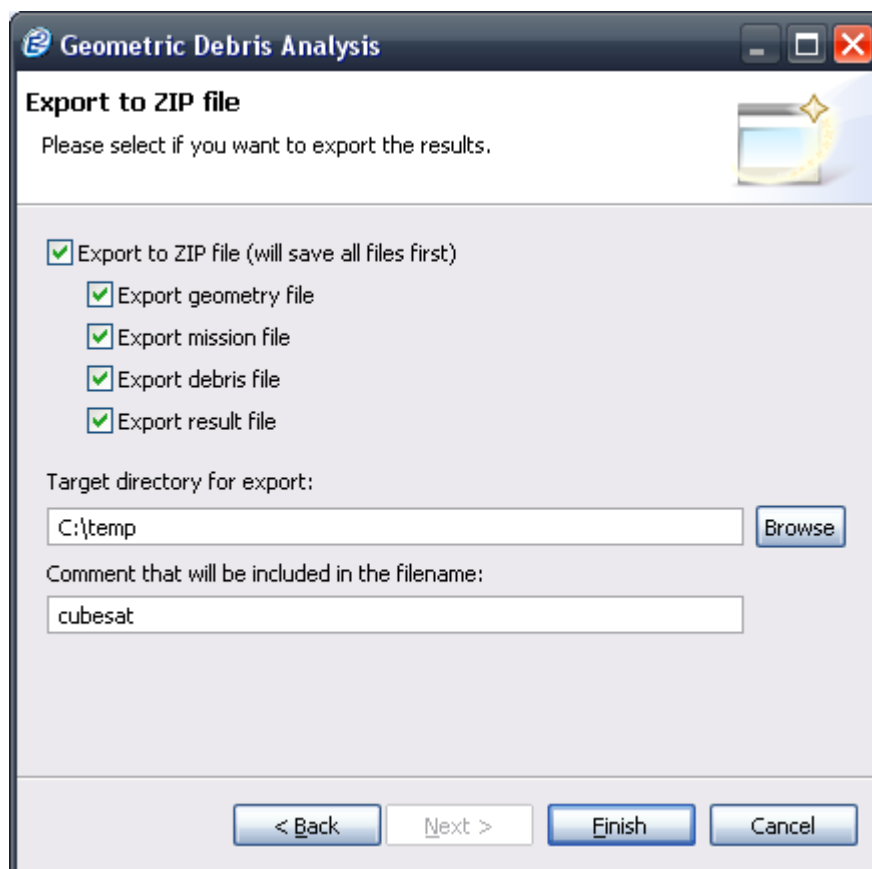
The "Slim Results" checkbox is a performance switch. With it, LIS\* files (as in the original ESABASE) and 2D graphs will be created as usual and with full information content (as specified in the "Report Options" box), but the only 3D geometry result will be for the entire mission; no orbital points or arcs will be available. For large models or many orbital points, this may be the only option to run ESABASE2/Debris within the available RAM of the executing computer.

Generating an output filename is highly recommended. The default filename contains the solver type (here: "debris") and the current date and time.

At the bottom, the "Report options" combo-box allows you to specify the content of the "Deb Met" listing (formerly \*.LISD, \*.LISM, \*.LISDM output files) within the Debris result file. You can choose between the following options:

- *Output of a summary of objects:* results on orbital arc and mission level, and on object and spacecraft level (no object/element summary, no orbital point related results and no element related results).
- *Output of header and summary all:* the same, but including object/element summary and element related results.
- *Complete listing of objects:* orbital point, orbital arc and mission related results on object and spacecraft level (no object/element summary, and no element related results).
- *Complete listing of all:* the same, but including object/element summary and element related results.

Optionally, you can press the "Next" button to go to the second page of the Debris analysis wizard, which is depicted in the figure below.



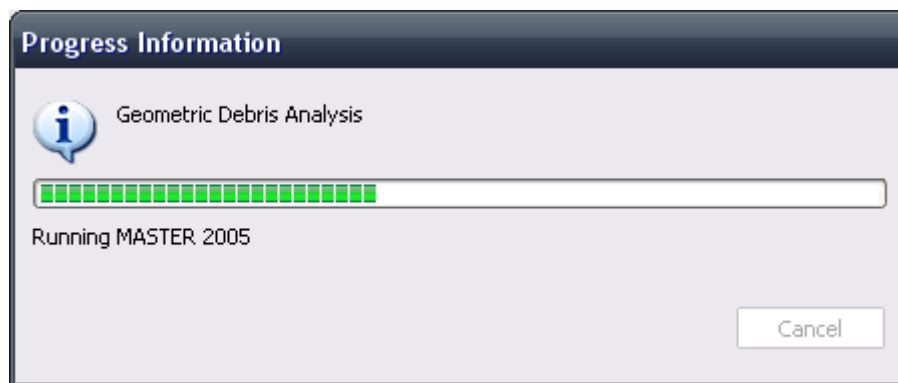
**Figure 2.27:** Geometric Debris analysis, Run dialog, export page



The debris result file will be saved into your workspace. This page allows you to additionally export the input and result files to a ZIP file suitable for transmission via email or other means.

Press the "Finish" button to launch the Debris analysis.

A progress bar will appear and keep you updated about the current state of the application. Depending on the number of elements in the S/C geometry and depending on the number of orbital points, an analysis might take a long time (i.e. several hours).



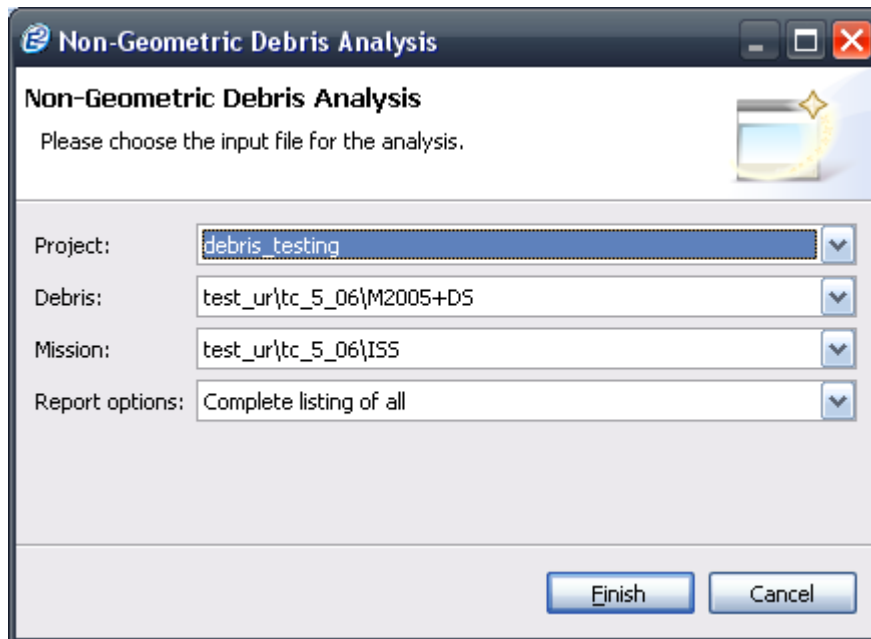
**Figure 2.28:** Geometric Debris analysis, Progress bar

After the run, a debris result file will be created in your workspace, and it will be automatically opened. If you are interested in its contents, skip to section 2.4; otherwise, the following subsection will explain the non-geometric debris analysis.

### 2.3.2 Non-geometric Debris Analysis

The non-geometric analysis uses a simple plate instead of a full spacecraft geometry; it is therefore considerably faster. As in the geometric debris analysis, locate the Run button and, this time, choose "Run non-geometric Debris Analysis".

The following figure shows the Run wizard for the non-geometric debris analysis.

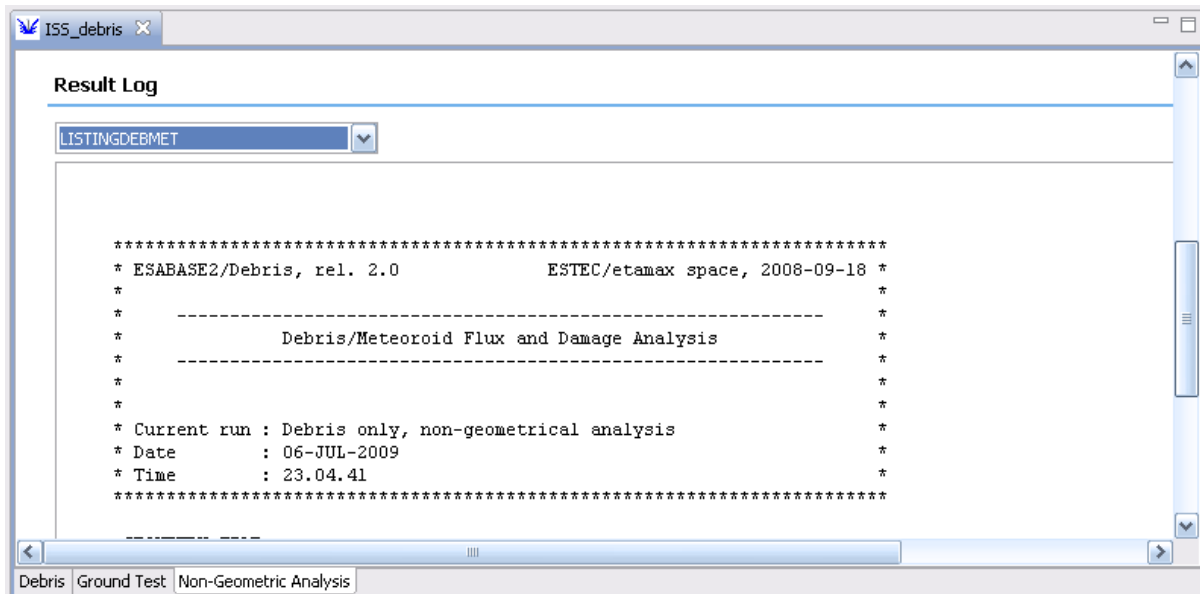


**Figure 2.29:** Non-geometric Debris analysis, Run wizard

Compared to the geometric Debris analysis, this wizard is considerably simpler. The spacecraft geometry input file is omitted and all options have been removed; only the report options remain.

No output file needs to be specified since the result listings are displayed in the "Result Log" section of the Debris input editor's "Non Geometric Analysis" tab. The content of the listings is stored within the debris input file.

The screenshot below shows the debris input editor, supplied with results from a non-geometrical debris analysis.



**Figure 2.30:** Non-geometric Debris analysis, results

In the "Result Log" section, the combo-box toggles between the output files, while the text area below shows the content of the selected file. Here, the Debris/Meteoroid listing ("LISTINGDEBMET") is shown.

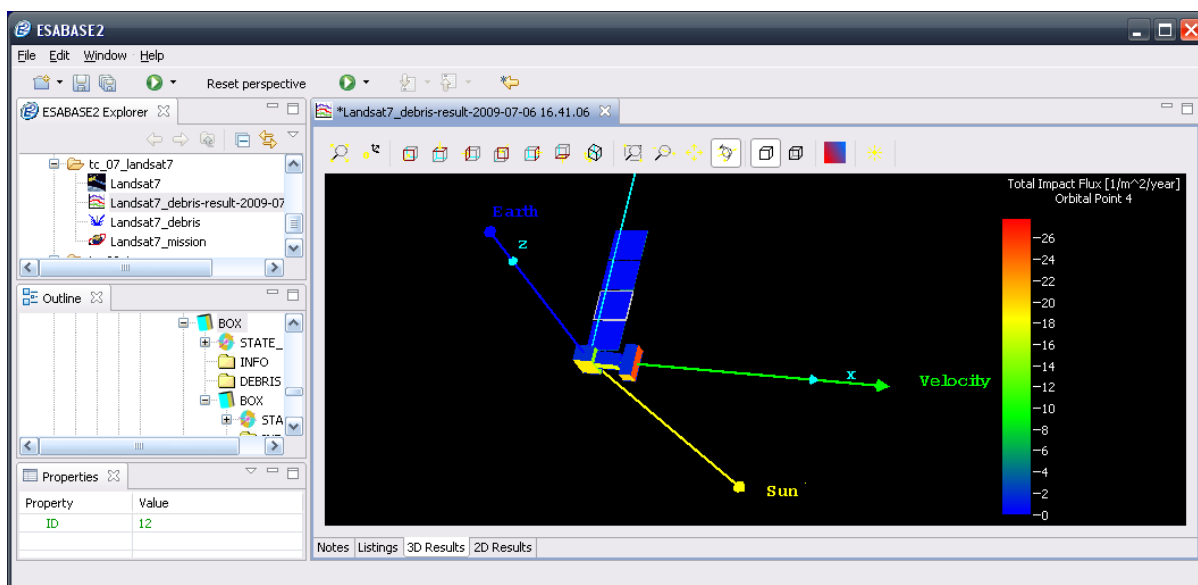
## 2.4 Debris Results

A geometric Debris analysis produces a debris result file, which is interpreted by the Debris result editor. The editor contains the following functionalities:

- *3D Results:* Shows the spacecraft geometry overlaid with the impact flux or other output parameters.
- *2D Results:* Graphs with different data about flux distributions at the orbital points as well as average flux distributions.
- *Listings:* In tradition of the original ESABASE, this tab shows the LIS\* files produced by the Debris solver.
- *Notes:* A blank text area for your own notes.

### 2.4.1 3D Results

The following figure shows the "3D Results" tab in a debris result editor.



**Figure 2.31:** Debris result editor, 3D Results

You can see a spacecraft geometry (Landsat7) with total impact flux, visualised by colour codes on the elements and decoded by the colour scale on the right. At the top of the editor, the same toolbar as in the geometry editor appears, allowing you to zoom, rotate and scroll around the spacecraft.

Additionally, you can rightclick into the 3D area to invoke the context menu, which contains the following options:

- *Colour*: Defines the result value to be laid over the S/C geometry; default is total impact flux.
- *Orbital Point*: Whether to show results for the entire mission, single orbital points or an orbital arc.
- *Coordinate Systems*: Whether to display coordinate systems alongside the S/C geometry.
- *Element Chart*: Shows the results for one single geometrical element (select one with Shift+Leftclick to enable).

### 2.4.1.1 Colour

Debris results come in multiple variables, e.g. impact flux or failure flux (and either per year or over the entire mission time). Only one of these variables at a time can be laid over the geometry model.

To choose a result set to be displayed, rightclick the 3D view to open the context menu, then choose "Colour → <Variable>", as shown in the following figure.

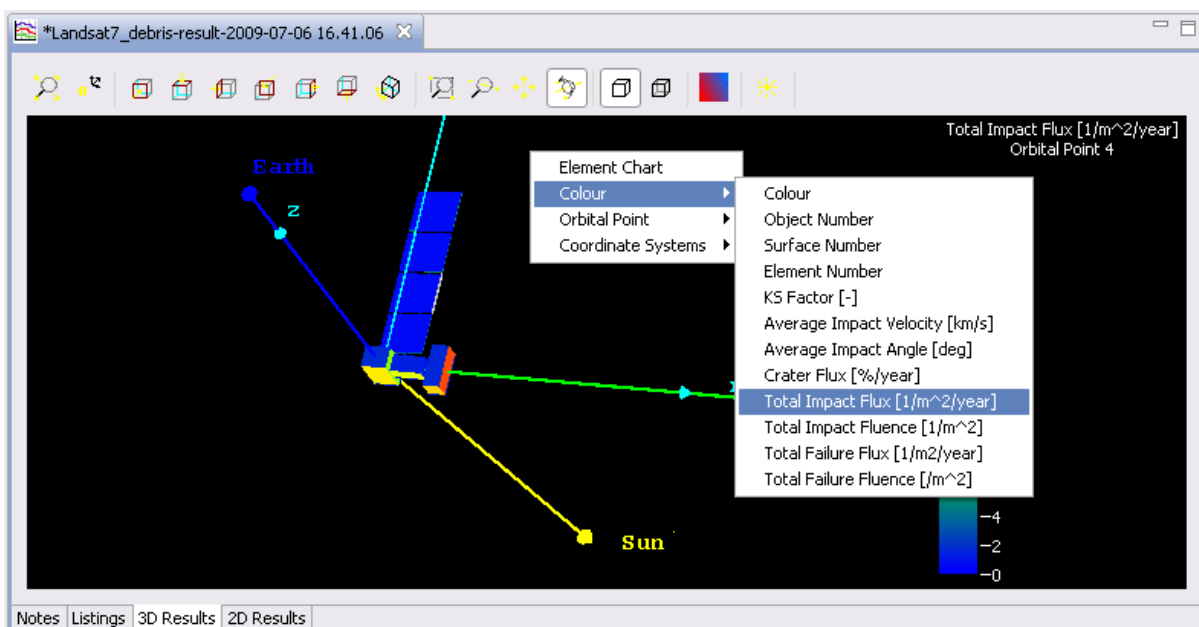


Figure 2.32: Debris result editor, 3D Results, colour context menu

The first 4 items (listed below) are not part of the Debris results; instead they are used to gain an overview of the spacecraft geometry, and particular its objects, surfaces and elements.

- *Colour*: Displays exactly the same object colour which was used in the geometry editor.
- *Object Number*: Each object is identified by an object number. In this overlay, this object number is mapped to colours.
  - Leftclick on an object in the 3D view to select it, and then look at the colour scale to the right. The appropriate colour will be marked, and the object number will be shown.
- *Surface Number*: Breaking down the objects, each surface is shown in a different colour.
  - Ctrl+leftclick on a surface in the 3D view to select it. The respective surface number is marked in the colour scale to the right.
- *Element Number*: Further breaking down the surfaces, each element is shown in a different colour.
  - Shift+leftclick on an element in the 3D view. The selected element number and color will be marked in the color scale.

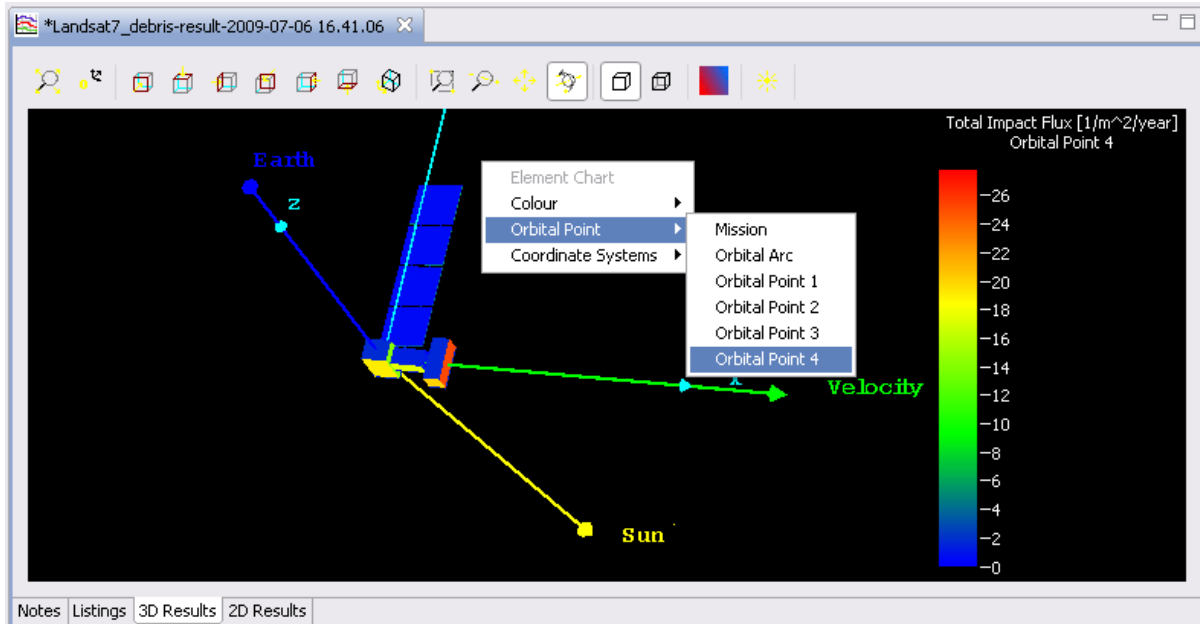
The following 8 items show the respective quantity (listed below) as colours on the elements of the geometry model. To see the exact value on an element, Shift+leftclick the element; the colour scale on the right will then show the quantity value.

- KS Factor
- Average Impact Velocity [km/s]
- Average Impact Angle [deg]
- Crater Flux [%/year]
- Total Impact Flux [ $1/m^2/year$ ]
- Total Impact Fluence [ $1/m^2$ ]
- Total Failure Flux [ $1/m^2/year$ ]
- Total Failure Fluence [ $1/m^2$ ]

If the secondary ejecta option was activated in the Debris input editor, it is now additionally possible to display the direct impact/failure flux/fluence and the ejecta impact/failure flux/fluence.

### 2.4.1.2 Orbital Point

When the debris result editor opens, it shows the analysis results for the entire mission. You can also view the results for each orbital point or for the orbital arc. Open the context menu and navigate to "Orbital Point", as shown in the following figure.



**Figure 2.33:** Debris result editor, 3D Results, Orbital Point context menu

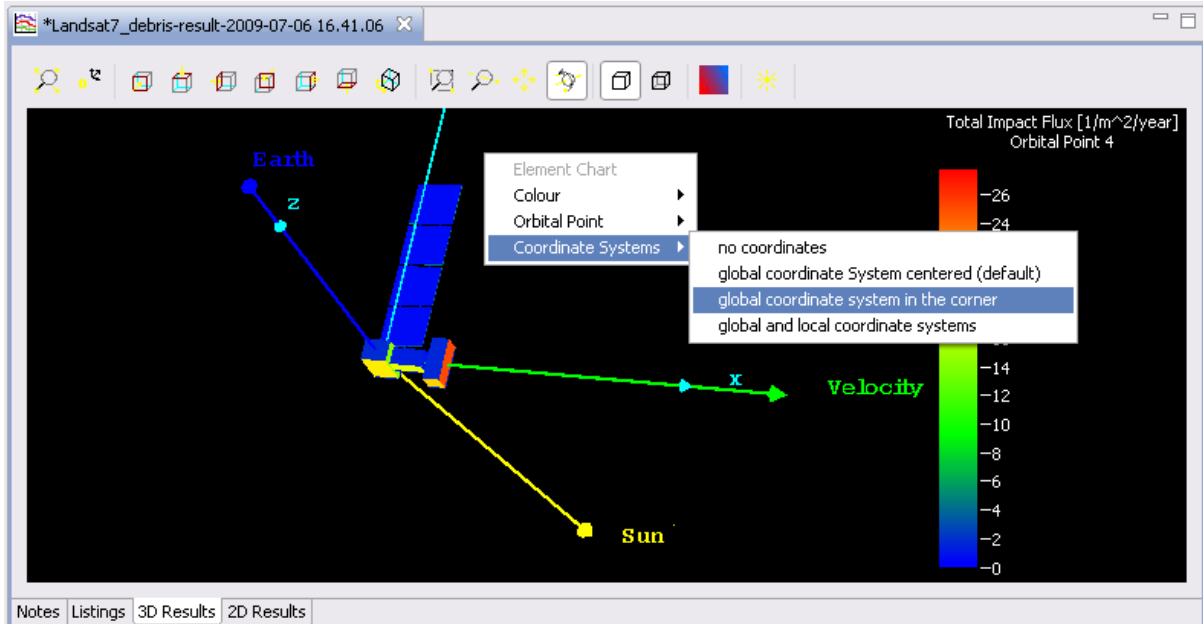
Choose one of the following:

- *Mission*: The entire mission duration.
- *Orbital Arc*: One orbital arc only.
- *One of the orbital points*: Results at a dedicated orbital point.

When you select an orbital point, then Earth, Sun and velocity direction are shown as depicted above. Note that the correct pointing (e.g. solar panel aligned towards the Sun) can only be shown at the orbital points, not for the whole mission or orbital arc.

### 2.4.1.3 Coordinate Systems

To visualise the coordinate system you used in the geometry editor, change the coordinate system by opening the context menu and navigating to "Coordinate Systems", as shown in the following figure.



**Figure 2.34:** Debris result editor, 3D Results, Coordinate Systems context menu

You can choose among the following coordinate system settings:

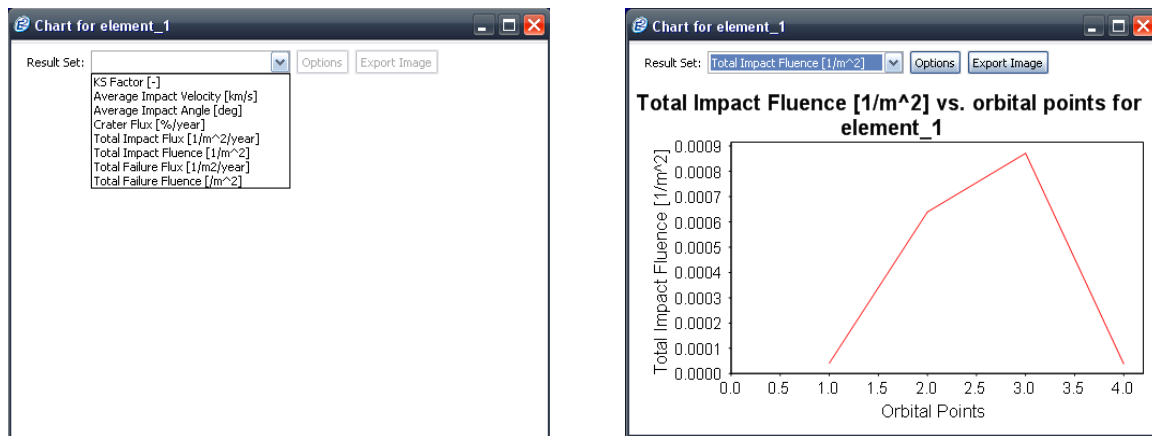
- *No coordinates*: Note that pointing vectors will also be deactivated.
- *Global coordinate system (centred)*: Shows the xyz-axis for the entire system.
- *Global coordinate system in the corner*: Same as before, but in the corner of the system, not centred.
- *Global and local coordinate systems*: Shows xyz-axis for each object. Detailed but probably slightly irritating for complex S/C geometries.



### 2.4.1.4 Element Chart

Different 2D graphs of the debris results can be shown for the entire spacecraft geometry using the "2D Charts" tab, as described in the next section (2.4.2). However it is also possible to show graphs of only one element.

Shift+Leftclick an element of the S/C geometry, then open the context menu and select "Element Chart". The following figure shows the resulting small popup window.



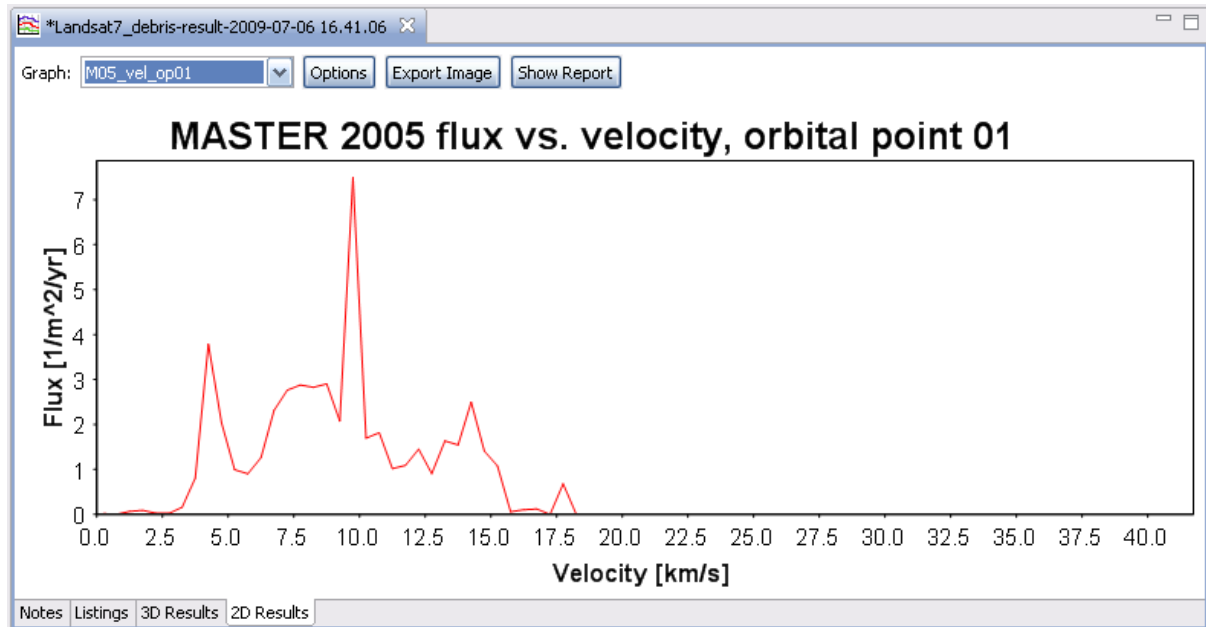
**Figure 2.35:** Debris result editor, 3D Results, Element Chart

From the "Result Set" combo-box, select a variable; the appropriate graph for the given element will be displayed, as shown on the right. These are the same values that are colour coded in the element in the 3D view.

You also have the possibility to adjust the appearance of the graph via the "Options" button or a context menu opening on rightclicking, and to export the image as PNG or JPG via the "Export Image" button (s. sections 2.4.2.1 and 2.4.2.2 for details).

## 2.4.2 2D Results

Complementing the "3D Results" tab described above, charts can show different flux distributions in the "2D Results" tab. An example is shown in the following figure:



**Figure 2.36:** Debris result editor, 2D Results

In the combo-box on the top left, you can select the chart you want to see. Which charts are available depends on the debris/meteoroid model used for the analysis, as shown in the following table.

Debris / meteoroid model	Flux distributions
NASA90	$F = f(d)$ (valid for all orbital points)
MASTER 2001	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
MASTER 2005	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
ORDEM2000	$F = f(d)$ , $F = f(\text{azimuth})$ for each orbital point
Grün	$F = f(m)$ (valid for all orbital points)
Divine-Staubach	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ for each orbital point
MEM	$F = f(m)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point

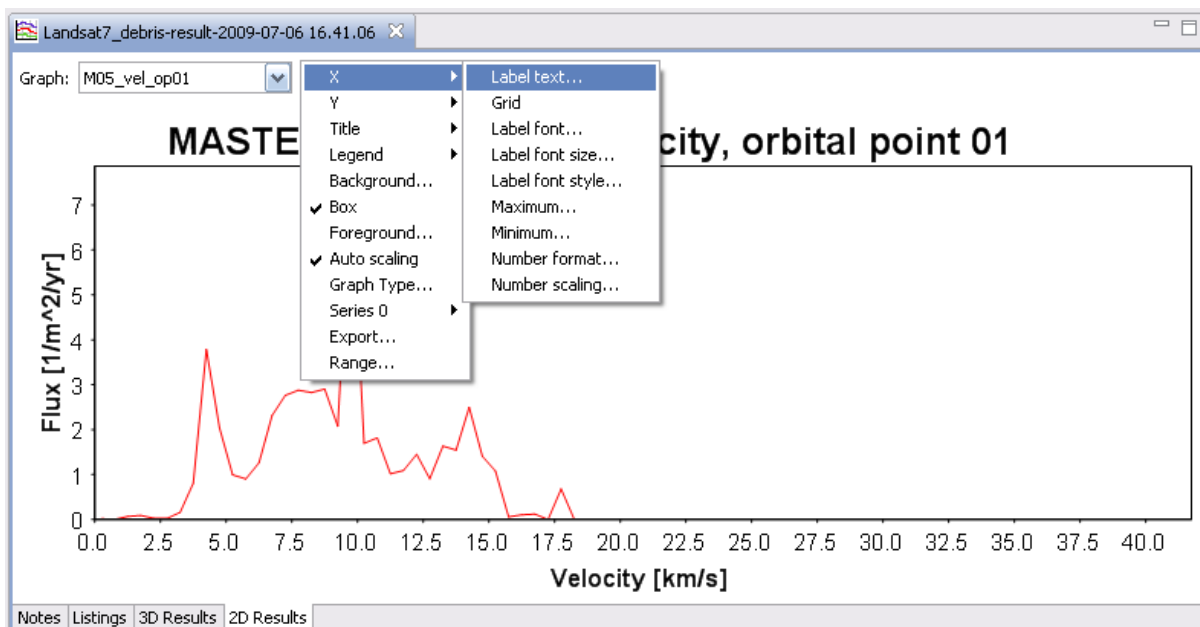
**Table 2.1:** Available 2D charts in dependency of the Debris/Meteoroid model

The "2D Result" tab offers additional functionality to work with the charts, represented by buttons to the right of the chart combo-box:

- *Options*: Allows you to customise the chart appearance.
- *Image Export*: Save the current chart to a PNG or JPG file.
- *Show Report*: Opens a print-ready report for a given chart.

### 2.4.2.1 2D Charts: Options

The "Options" button opens a context menu for a given chart, as shown in the following figure. It contains axis configurations as well as settings for the data lines.



**Figure 2.37:** Debris result editor, 2D Results, options

You can customize the following chart properties:

- x, y axis
  - *Label Text*: Changes the text of the axis label.
  - *Grid*: Displays horizontal/vertical dashed lines.
  - *Label font, Label font size, Label font style*: Changes the appearance of the axis label.
  - *Maximum, Minimum*: The value range that this chart shows

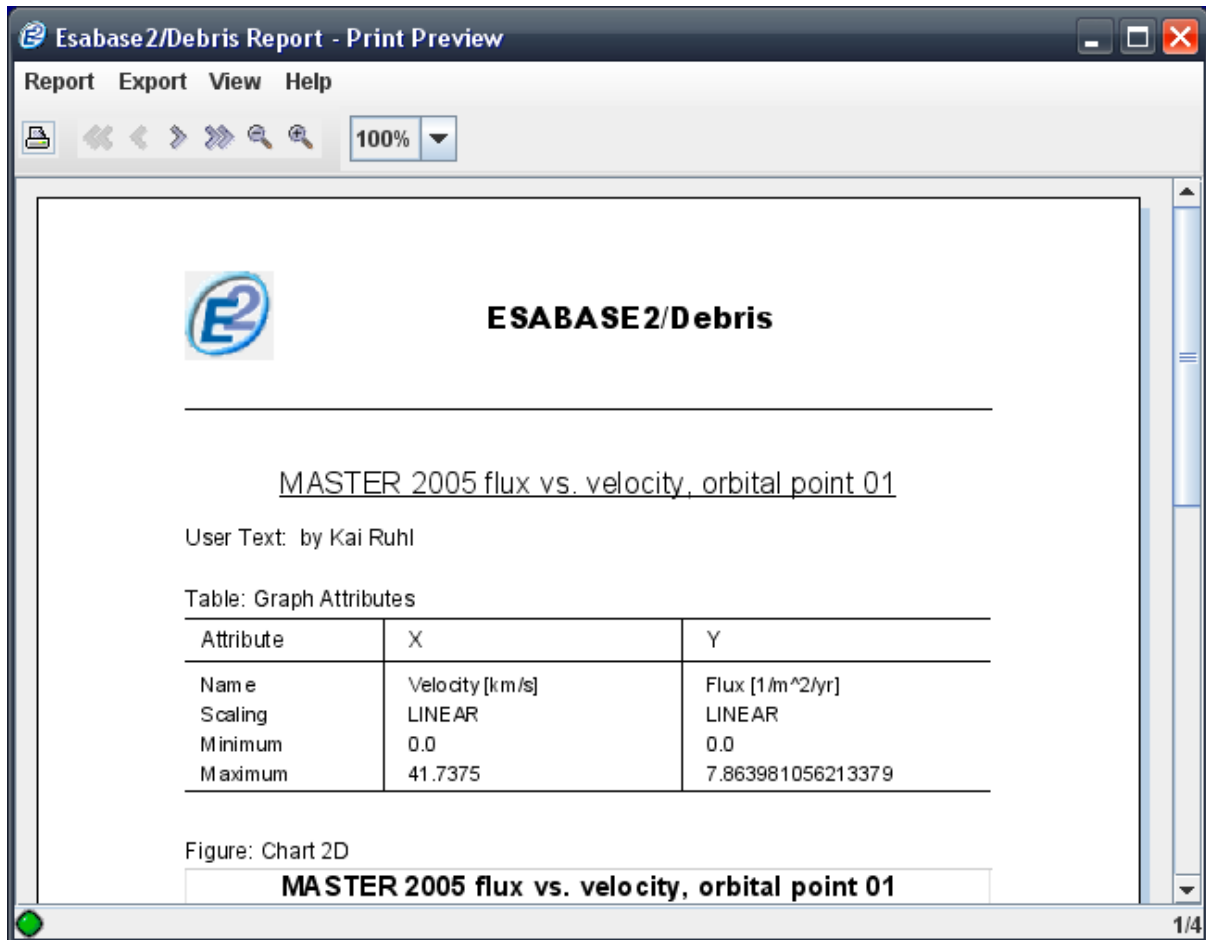
- *Number format*: The format of the number labels, e.g. the number of decimal places, can be specified.
- *Number scaling*: Choose between linear or logarithmic scale.
- Title
  - *Graph title*: The title text above the chart.
  - *Title visible*: Show or hide the title text.
  - *Title Font, Title Font Size, Title Font Style*: The appearance of the title text.
- Legend
  - *Legend*: Show or hide the legend.
  - *Legend Font, Legend Font Size, Legend Font Style*: The appearance of the legend.
- *Background*: The background color of the chart.
- *Box*: Shows or hides the box around the graph.
- *Axis and label colour*: The colour of the axis lines and the labels.
- *Major tick labels*: Shows or hides number labels at the major ticks.
- *Minor tick marks*: Display small ticks between the major ticks.
- *Ratio*: Set a fixed aspect ratio.
- *Auto scaling*: Re-scales the chart.
- *Graph Type*: Choose between line-, bar- and scatter chart.
- Series <num>:
  - *Linecolour, Linewidth*: Color and width of the line of this data series.
  - *Stroke*: Type of the line of this data series.
- *Range*: Set the X and Y range that the chart covers.

### 2.4.2.2 2D Charts: Image Export

Pressing the "Export Image" button opens a file dialog asking for a location to save to. PNG and JPG format are possible. The size of the image is the same as it is currently shown; resize the application window to get other image sizes.

### 2.4.2.3 2D Charts: Show Report

The chart can be embedded into a print-ready report; press the "Show Report" button to invoke it. After a dialog asking for a comment line has been confirmed, a report as shown in the following figure will appear in a popup window.



**Figure 2.38:** Debris result editor, 2D Results, reporting

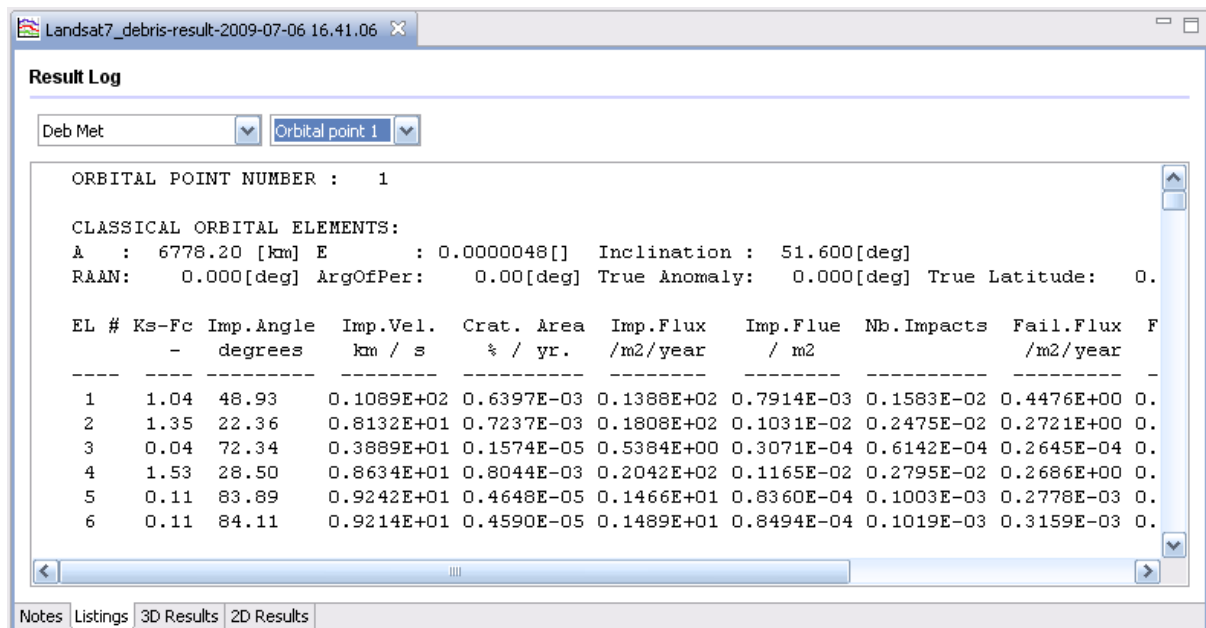
This report details the chart properties and below the chart itself, followed by the data values represented in the chart (on the second and following pages). It is thus a complete data description of a value pair's relation, suitable for distribution to your colleagues.

You may either print the report (press the print button) or choose "Export → Save as PDF" for electronic distribution.

## 2.4.3 Listings

The original ESABASE produced LIS\* files (or listing files), containing all debris results in one text file. This ability is also available in ESABASE2 in order to stay compatible to many post-processing tools.

The listings are shown on the "Listings" tab of the debris result editor, as shown in the figure below.



**Figure 2.39:** Debris result editor, 2D results, listings

In the result log, you can see the different LIS files; just select the appropriate LIS entry in the combo-box. For Debris/Meteoroid (Deb Met), you can jump to orbital point bookmarks using the second combo-box. The following LIS files are available:

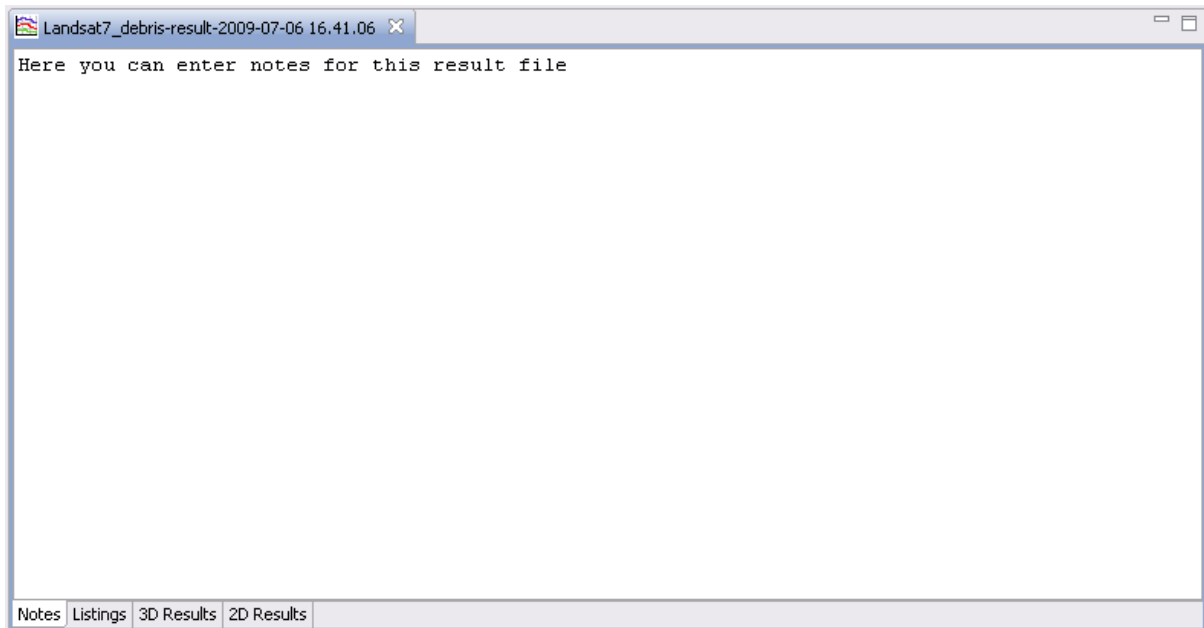
- Crater vs. Crater size
- Deb Met (Debris/Meteoroid)
- Failures vs. Ballistic Limit
- Kinematic
- Orbit

Detailed information about the contents of the listing files can be found in the original ESABASE user manual /4/.

Please note: The listing files are foremost saved as data nodes in the debris result file. Additionally, they are written in ASCII format to the "Listings" subfolder of the current project folder, in order to be more easily accessible to post-processing tools.

## 2.4.4 Notes

The figure below shows the "Notes" tab within the Debris result editor.



**Figure 2.40:** Debris result editor, 2D Results, notes

It consists of a simple text area, where you can write your notes concerning the debris results. Your text will be saved, and is available to whomever you may send the file.