

# ESABASE2 - Debris

## Software User Manual

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## Document Information

### I. Release Note

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### II. Revision History

Version	Date	Initials	Changed	Reason for Revision
0.1	2009-08-03	KR	All	Split from common ESABASE2 handbook.
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0.9	2009-09-25	KB	All	Review for Final draft
1.0	2009-09-28	KR	All	Update after review
1.1	2009-12-14	KR	Section 2.1	Pos/negative side results.
1.2	2010-08-23	KB	Section 2.2.1.5, all	Description of the use of the User Subroutine extended; document layout update
1.4	2012-12-04	AG	Section 2.2	Modified BLE and Shielding handling
1.5	2013-04-19	AM	Sections 2.2.1.1, 2.4.2, 3	Extended for Lunar missions consideration.
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1.5.2	2013-11-07	AM	Section 2.4.3.1	Introduction of Crater vs. Crater size listing interpretation.
1.6	2014-03-19	AM	Sections 2.2.1.5, 3.1.2, 4	Extended for L1/L2 orbits consideration, change to Intel Fortran Compiler.
1.7	2014-07-24	AM	Sections 2.2.1.1, 2.4.2, 3.1.3.1, 3.1.4, 4.1.2	Extended for ORDEM 3.0 model use.
1.7.1	2014-11-20	AM	Sections 2.2.1.1	Introduction of notes for ORDEM 3.0 use.
1.8	2015-12-16	AM	Sections 2.2.1.1, 2.4.2, 3.1.3.2, 3.1.4, 4.1.1.2, 4.1.2	Extended for MEMr2 model use.
1.9	2016-10-17	MZ	Chapter 5	Introduction of Scripting Mode.
1.10	2016-11-08	AM	Section 2.4, Section 2.2	Extension of the Listings description, Indication of missing means to check the WINE availability.
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1.12	2017-12-21	FR	Section 6	Various text changes.
1.13	2018-01-19	FR	Section 6	Added CLI arguments section.
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1.17	2021-07-07	AM	Section 2.2	Include comments from ESA
1.18	2023-06-14	AM/TSC	All Sections	Extended for ORDEM 3.2 model use. Change of company name

### III. Distribution List

Institution	Name	Remarks
ESTEC	Mark Millinger	
etamax	ESABASE2 team	
various	ESABASE2 licensees	pdf format

### IV. List of References

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## 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.
IMEM	Interplanetary Meteoroid Environment Model. For details refer to /30/.
IMEM2	ESA's follow-up approach to IMEM. For details refer to /32/
LunarMEM	MEM version, which is tailored to orbits around the Moon.
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.
MASTER 2009	Successor of ESA's reference model MASTER 2005. For details refer to /24/.
MASTER 8	Successor of ESA's reference model MASTER 2009. For details refer to /28/.
MEM	Meteoroid Engineering Model, for details refer to /20/.
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/.
ORDEM 3.0	NASA's latest space debris engineering model. For details refer to the ORDEM 3.0 documentation /26/.

Term	Description
ORDEM 3.2	Update of NASA's ORDEM 3.0 model. For details refer to the ORDEM 3.2 documentation /36/.
STEP	Acronym which stands for the Standard for the Exchange of Product model data.

## VI. List of Abbreviations

Abbreviation	Description
ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
ECI	Earth Centred Inertial
GUI	Graphical User Interface
IAU	International Astronomical Union
JVM	Java Virtual Machine
LCI	Lunar Centred Inertial
MASTER	Meteoroid and Space debris Terrestrial Environment Reference (Model)
MJD	Modified Julian Day
MLI	Multi-layer insulation
NAIF	Navigation and Ancillary Information Facility
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
UTC	Coordinated Universal Time

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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 (2021), 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 FEV etamax 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.

Eight space debris models (NASA90 /16/, ORDEM2000 /15/, MASTER 2001 /11/, MASTER 2005 /19/, MASTER 2009 /23/, MASTER 8 /28/, ORDEM 3.0 /26/ and ORDEM 3.2 /36/) as well as eight meteoroid models (Grün /14/, Divine-Staubach /13/, /18/, /28/, MEM /20/, LunarMEM /25/, MEMr2 /27/, MEM 3 /35/, IMEM/30/, /31/ and IMEM2 /32/, /33/, /34/) 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 (see section 2.1).
- *Debris Input*: Describes the input parameters for Debris and meteoroid analyses (see section 2.2).
- *Debris Analysis*: How to perform an analysis (see section 2.3).
- *Debris Results*: How to interpret the analysis results (see section 2.4).

### 2.1 Debris Geometry

The geometry editor defines a spacecraft's 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.

For Debris, the following special pages and options are available:

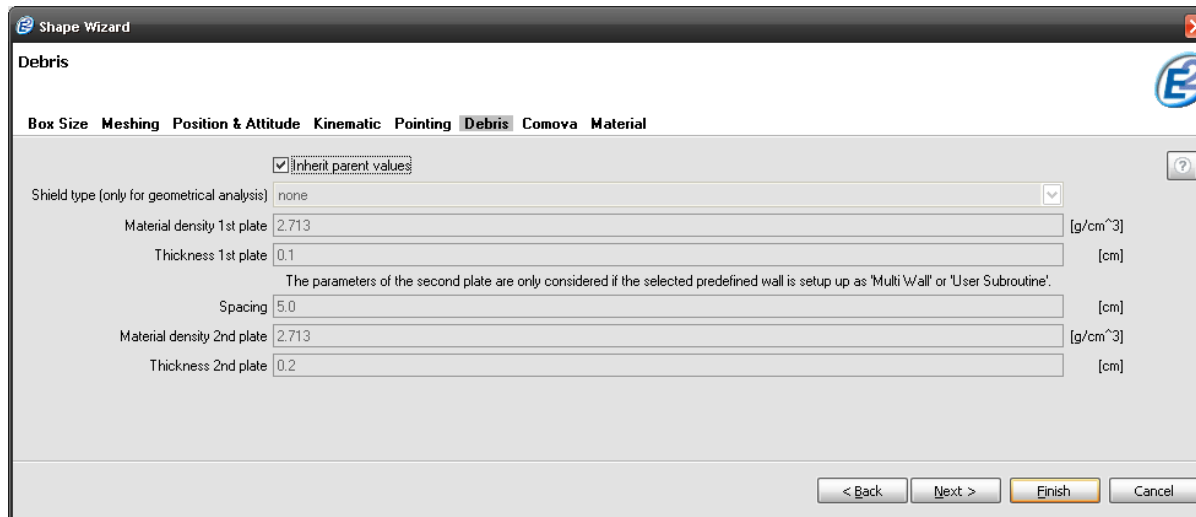
- *Debris Page*: Settings only applicable to the Debris solver, concerning material thickness and shielding (see section 2.1.1).
- *Meshing Page*: Positive/negative sides and meshing recommendations for Debris (see section 2.1.2).

## 2.1.1 Debris Page

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

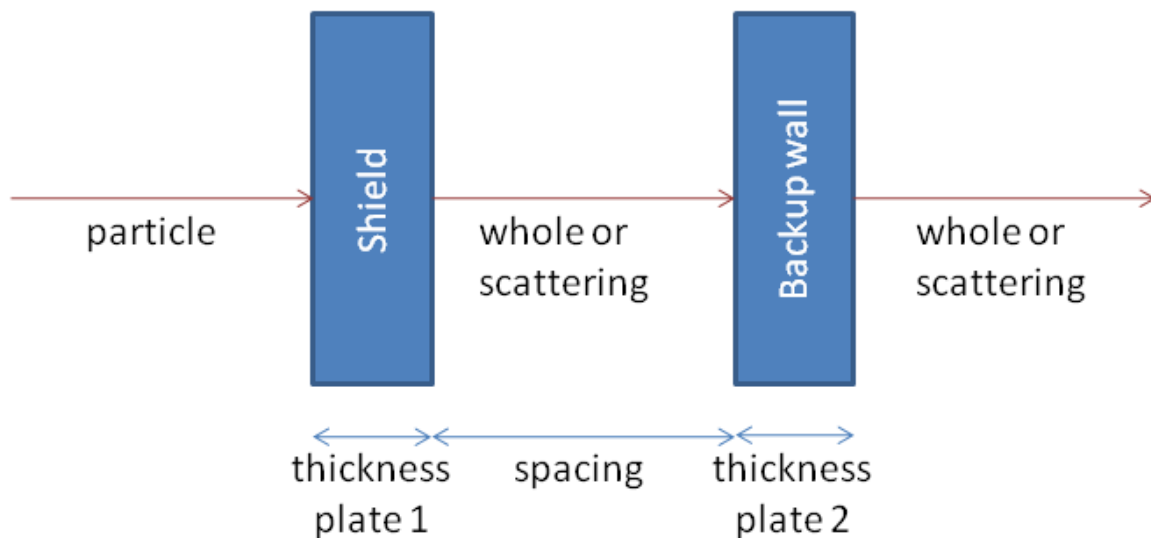
On this page, you can define shielding and material parameters that go beyond the Material page of the shape wizard.

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. One of the 15 predefined damage and failure equation combination can be selected here (Wall\_1 to Wall\_15, for setup see 2.2.1.4). The lower three parameters (spacing, Material density 2<sup>nd</sup> plate and Thickness 2<sup>nd</sup> plate) are only used if the selected wall is defined as multiwall.

In the screenshot above, you see "none" chosen and thus all further parameters are disabled.

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.

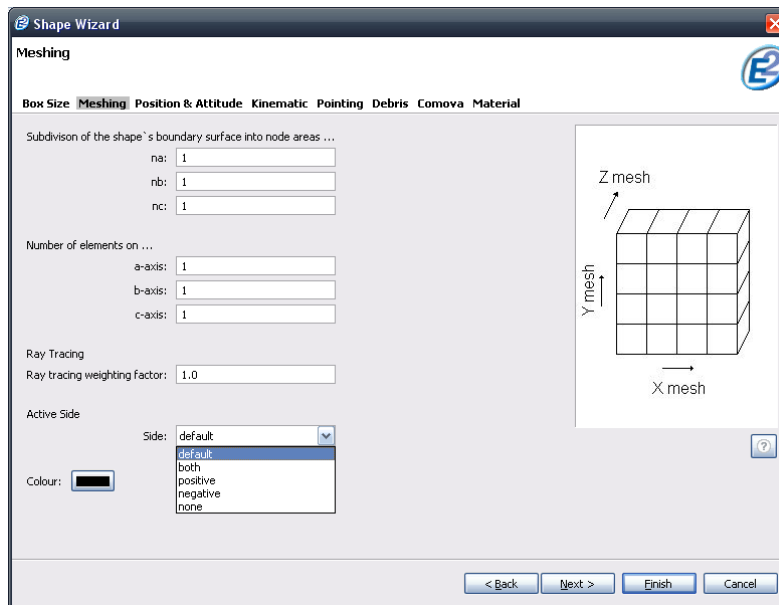
A failure equation determines whether a particle penetrates the wall configuration. A damage equation determines the size of the crater or hole (depending on no penetration/penetration) on the first wall (shield).

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



## 2.1.2 Meshing Page

Although the meshing page (shown below) is the same for all solvers, the effects of the settings may vary.



**Figure 2-3:** Geometry editor, Meshing page

Subdivisions of surfaces (i.e. "surface nodes") are not supported by Debris. We recommend using the "Number of elements on" settings for finer meshing.

Regarding active sides: Debris results always comprise both sides of an element (the solver sums them up). For volumes, this is uncritical, because only one side is ever affected. For surfacic shapes (e.g. plate), we recommend choosing only one active side, because the results can otherwise not be correctly assigned to an element side.

Please note: In NASA90, the average (instead of the sum) of both sides is taken. This is a known bug.

And with this, the geometry file is ready, and we can move to the Debris input editor.

## 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 (see section 2.2.1).
- *Ground Test Tab*: An efficient way to test damage equations (see section 2.2.2).
- *Non-Geometric Analysis Tab*: Allows a fast guess for the expected flux values on a specific orbit (see section 2.2.3).

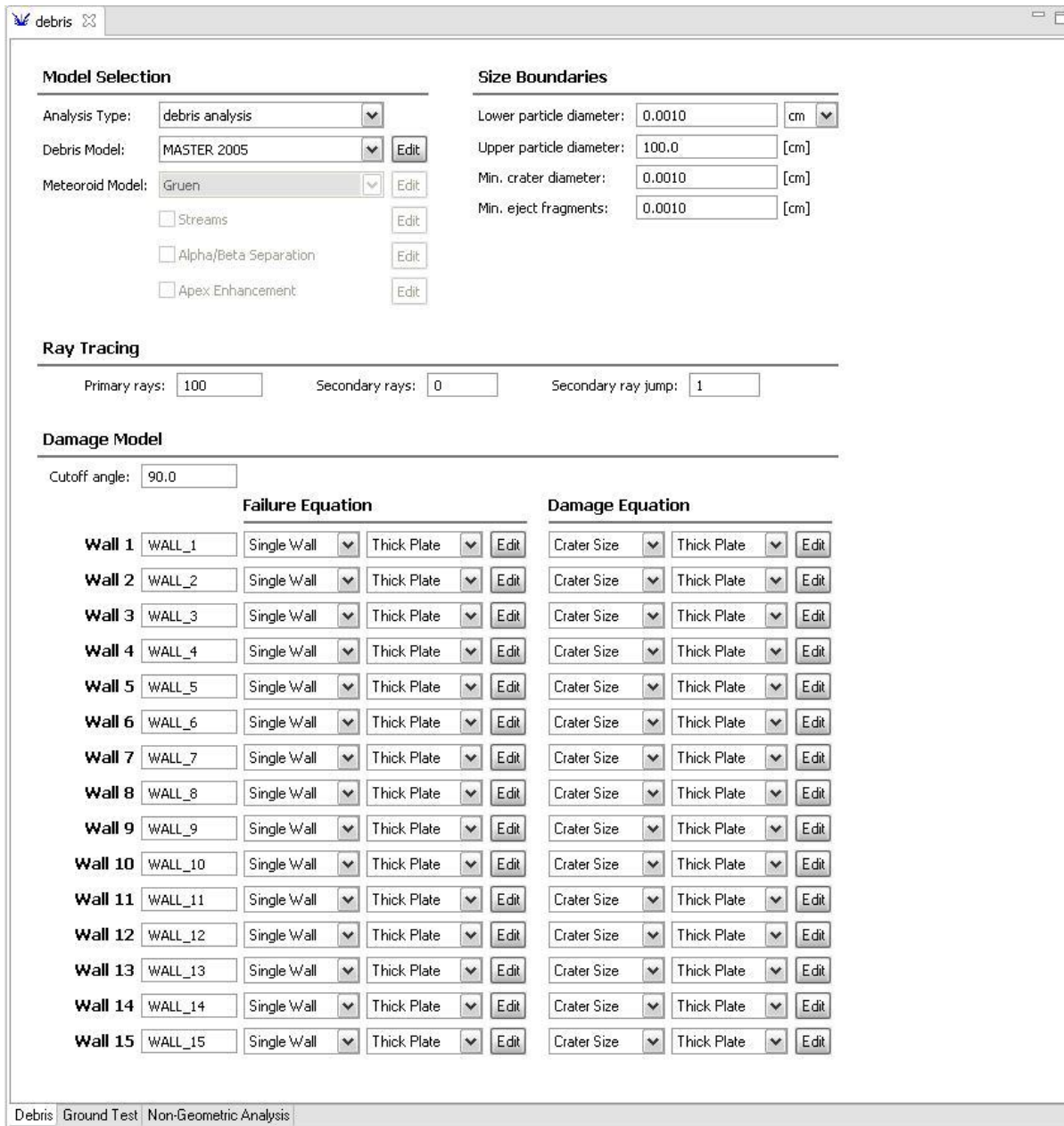
### 2.2.1 Debris Main Tab

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 (see section 2.2.1.1).
- *Size boundaries*: Limits on the type of debris or meteoroids to be considered in the analysis (see section 2.2.1.2).
- *Ray tracing*: Defines the accuracy of ray tracing results (see section 2.2.1.3).
- *Damage Model*: Defines a set of failure and damage equation combinations for the Debris analysis (see section 2.2.1.4).

Within the damage model block the option “user subroutine” can be selected. How to define your own damage equation in a Fortran library will be explained in section 2.2.1.5.

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



**Figure 2-4:** 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 2-5:** 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" combo boxes will be enabled or disabled.

ESABASE2/Debris provides eight Debris models (MASTER 2001, MASTER 2005, MASTER 2009, MASTER 8, ORDEM 2000, ORDEM 3.0, ORDEM 3.2, NASA90) and eight meteoroid models (Grün, Divine-Staubach, MEM, LunarMEM, MEMr2, MEM 3, IMEM, IMEM2). 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 2.2.1.1.17, 2.2.1.1.18 and 2.2.1.1.19.

For the analysis on lunar orbits only the meteoroid models Grün, MEM 3, MEMr2 and LunarMEM are applicable (no debris models will be accepted). In combination with a trajectory file the debris models MASTER 2009, MASTER 8, ORDEM 3.0/3.2 and the meteoroid models Grün and the different MEM versions are applicable. The use of models for lunar orbits or with a trajectory files other than listed here, causes a stop of the analysis execution informing the user about the invalid configuration.

For the analysis on interplanetary trajectories only the meteoroid models MEMr2, MEM 3, IMEM and IMEM2 are applicable (no debris models will be accepted). The use of models for interplanetary trajectories other than listed here causes a stop of the analysis execution informing the user about the invalid configuration. Currently, interplanetary functionalities, and the according models, are not available in the Linux version of ESABASE2.

### Note:

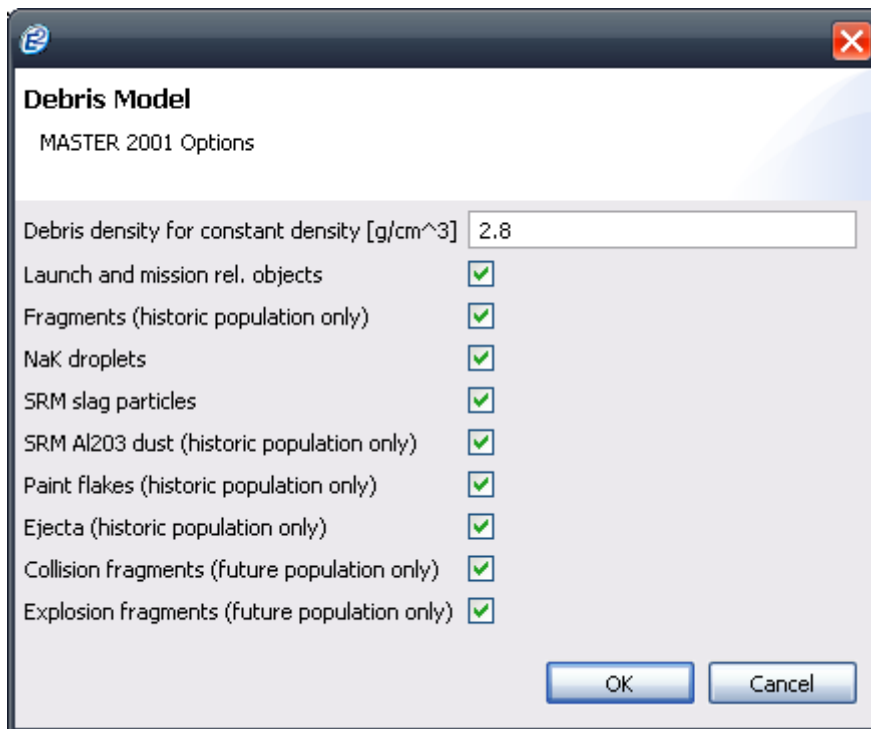
In the case you use the Linux version of ESABASE2, please make sure WINE is installed on your machine. The ORDEM and MEM environment models are executed by the means of WINE. Currently no means are available in ESABASE2 to detect if the WINE call was successful or not. Simultaneously if old results of the model are available, they are used for the damage assessment, thus you may get (reasonable looking) results while the environment analysis was not performed. This is a known (partially resolved) issue. For a user a possibility to recognise this problem, if the WINE installation was not checked, is the runtime of the environment models. If the runtime is one second or less (thus the whole analysis seems

to be too fast also) then it is very likely an incorrect run of the environment model due to missing WINE. Please install WINE to resolve this issue.

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.



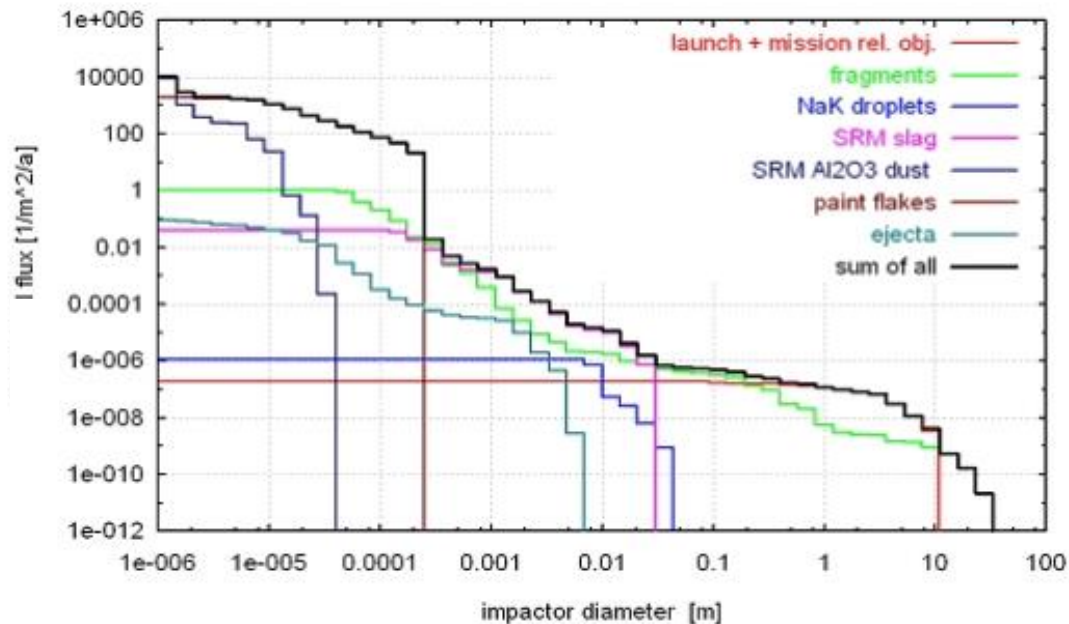
**Figure 2-6:** Debris input editor, main tab, Model Selection, MASTER 2001

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 2-7:** 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. The population snapshots of the May 1<sup>st</sup> of the mission start year are used for the analysis.

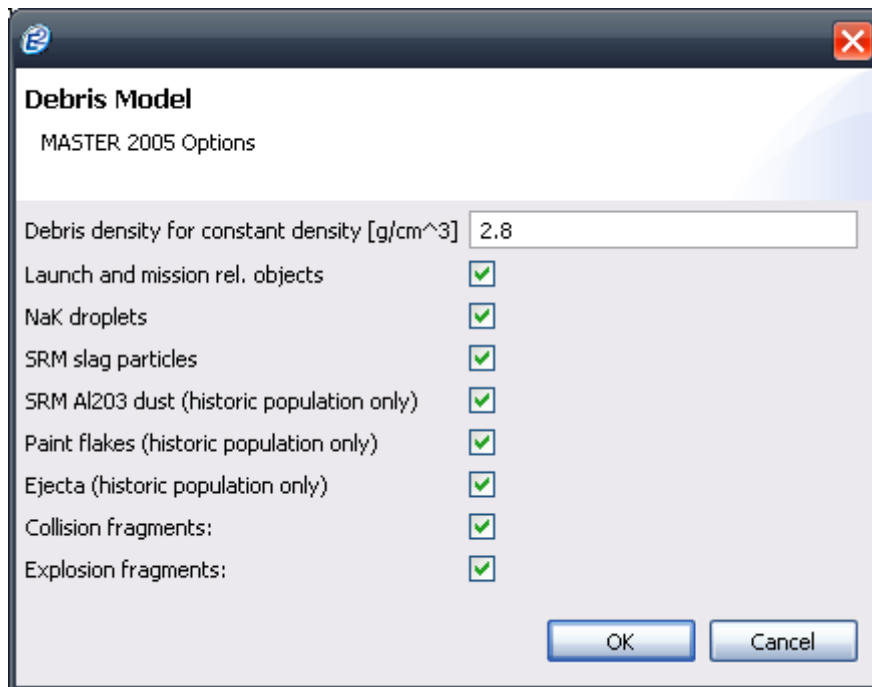
For the future evolution of the space debris environment the following assumptions have been applied:

- 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 2-8:** 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:

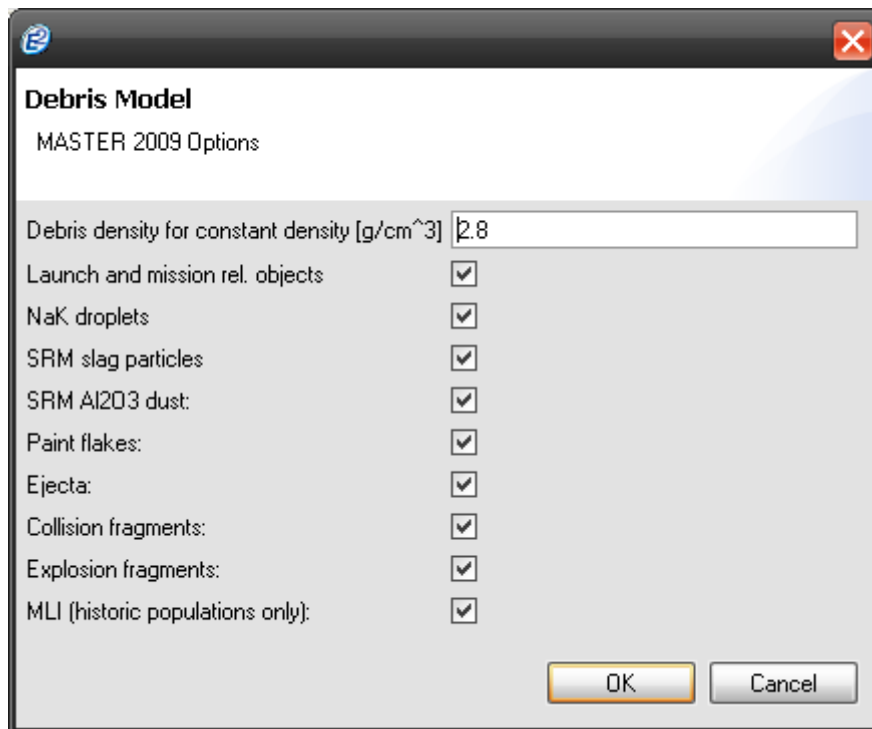
- Collision and explosion fragments cover both historic and future populations, not only historic populations as in MASTER 2001.
  - This also explains why the "Fragments (historic)" option has vanished in comparison to MASTER 2001.

Like MASTER 2001, MASTER 2005 covers altitudes from 186 km to 37000 km. The "future" is from 2005-05-01 and in the future; objects < 1 mm are not considered. The population snapshots of the May 1<sup>st</sup> of the mission start year are used for the analysis.



### 2.2.1.1.3 Debris model: MASTER 2009

MASTER 2009 [23] is ESA's meteoroid and space debris reference model, and the successor of MASTER 2005 (see previous subsection). When you click on the "Edit" button, a dialog with MASTER 2009 input parameters will open, as shown in the following figure.



**Figure 2-9:** Debris input editor, main tab, Model Selection, MASTER 2009

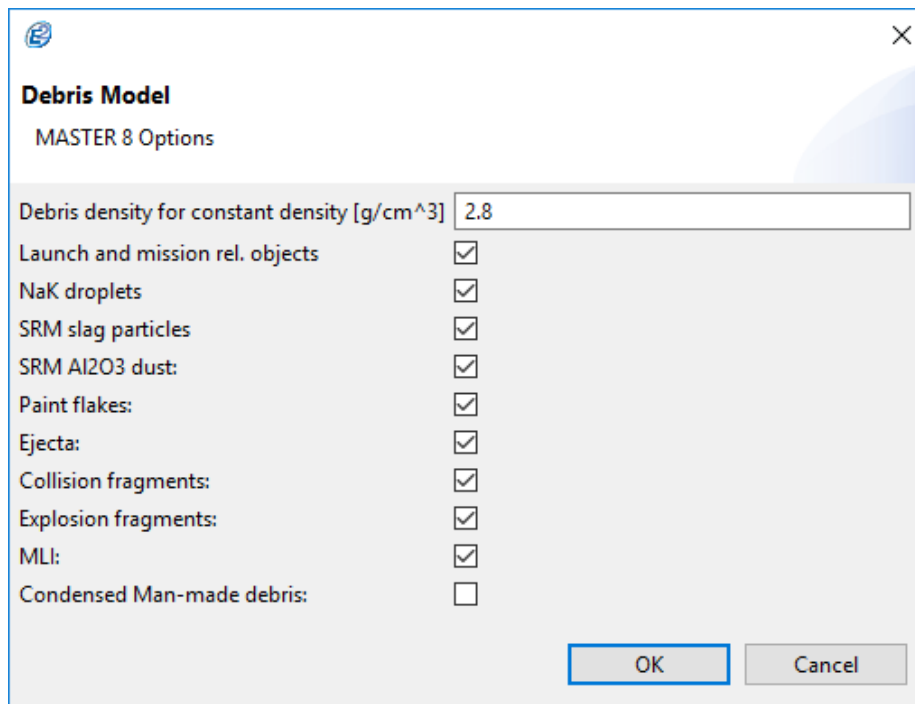
The MASTER 2009 options are similar to the MASTER 2005 options (see previous subsection). The following differences to MASTER 2005 have to be noted:

- Objects down to 1  $\mu\text{m}$  are considered for both the historic and the future populations (MASTER 2005 do not consider objects < 1 mm for future populations)
- Both historic and future populations for solid rocket motor dust are available  
→ absence of the hint 'historic populations only'.
- Both historic and future populations for paint flakes are available  
→ absence of the hint 'historic populations only'.
- Both historic and future populations for ejecta are available  
→ absence of the hint 'historic populations only'.
- The new source multi layer insulation (MLI) is introduced. Historic populations until the reference date are provided for this source.

The reference date of MASTER 2009 is the 2009-05-01. Dates after the reference date are considered as "future". MASTER 2009 covers altitudes from 186 km to ca. 37000 km. The population snapshots of the May 1<sup>st</sup> of the mission start year are used for the analysis.

## 2.2.1.1.4 Debris model: MASTER 8

MASTER 8 /28/ is ESA's meteoroid and space debris reference model, and the successor of MASTER 2009 (see previous subsection). When you click on the "Edit" button, a dialog with MASTER 8 input parameters will open, as show in the following figure.



**Figure 2-10:** Debris input editor, main tab, Model Selection, MASTER 8

The MASTER 8 options are similar to the MASTER 2009 options (see previous subsection). The following differences to MASTER 2009 have to be noted:


- Both historic and future populations for multi layer insulation (MLI) are available → absence of the hint 'historic populations only'.
- The new option Condensed Man-made debris is introduced. Which is not a new source, but the consideration of all sources at once by the application of the newly introduced condensed population files of MASTER 8. If this option is ticked, than it overrules other source options and is applied for the analysis.

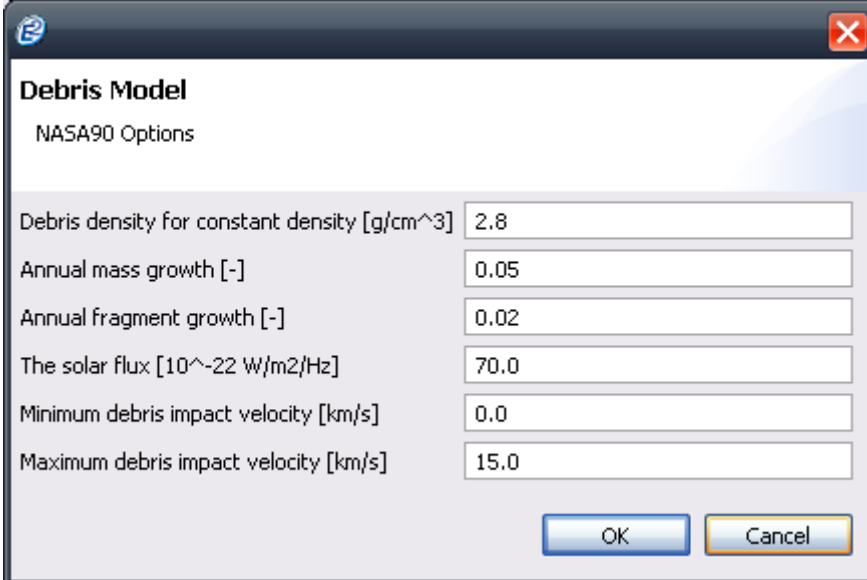
The reference date of MASTER 8 is the 2016-11-01. Dates after the reference date are considered as "future". MASTER 8 covers altitudes from 186 km to ca. 37000 km. The population snapshots have to cover the complete analysis epoch to allow to perform it, thus it is required to add them.

Please note that tests revealed some differences between the results with condensed source and the individual sources, especially with minimum sizes of 10 µm and 100 µm. According to ESA the results based on individual sources are most "reliable".

### 2.2.1.1.5 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.



Parameter	Value
Debris density for constant density [g/cm <sup>3</sup> ]	2.8
Annual mass growth [-]	0.05
Annual fragment growth [-]	0.02
The solar flux [10 <sup>-22</sup> W/m <sup>2</sup> /Hz]	70.0
Minimum debris impact velocity [km/s]	0.0
Maximum debris impact velocity [km/s]	15.0

**Figure 2-11:** 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/.

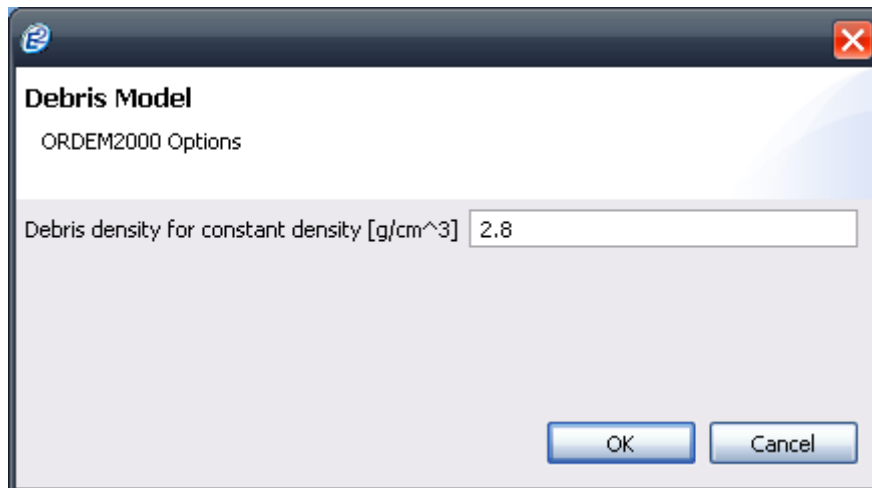
At the bottom, you see the debris velocity range, namely the minimum and maximum debris impact velocity to be considered. The default is from 0 to 20 km/s.

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

#### 2.2.1.1.6 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 2-12:** Debris input editor, main tab, model selection, ORDEM 2000

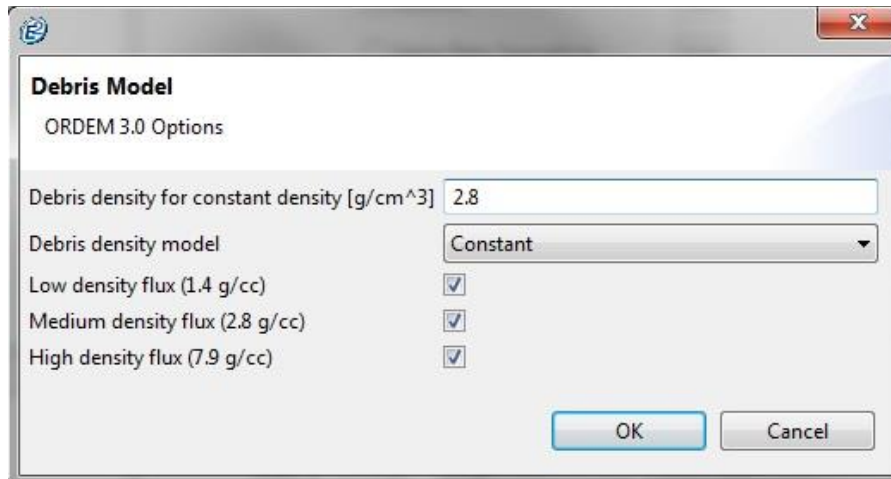
ORDEM 2000 is appropriate for engineering solutions requiring knowledge and estimates of the orbital debris environment (debris spatial density, flux, etc.). The model includes a large set of observational data (both in-situ and ground-based), covering the object size range from 10 µm to 10 m.

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.

## 2.2.1.1.7 Debris model: ORDEM 3.0

ORDEM 3.0 /26/ is a space debris engineering model developed by NASA; it is the successor of ORDEM2000.

When you click on the "Edit" button, a dialog with ORDEM 3.0 input parameters will open, as show in the following figure.



**Figure 2-13:** Debris input editor, main tab, model selection, ORDEM 3.0

The user can define the assumed debris material density (default: 2.8 g/cm<sup>3</sup>), as shown in the figure, which is used if a constant debris density model is applied.

In the drop-down menu "Debris density models" the "Low/Med/High" entry can be selected beside the "Constant" entry, as reflected in the figure. The "Low/Med/High" selection activates the discrimination of the particles in three fractions with different densities.

If impact flux shall be analysed only, the constant density option can be selected. For damage analyses it is recommended to use "Low/Med/High" option.

Note that the density distribution is size dependant, thus the defined lower particle diameter (s. 2.2.1.2) influences it, because it is used to define the reference distribution. Due to this link the definition of the lower particle diameter takes effect on the damage analyses results. It is recommended to define a lower particle diameter, which is not too different from the assumed ballistic limit.

The last three items allow including or excluding the fluxes with certain densities (low density, medium density or high density) from the analysis. These parameters are considered only, if the density model "Low/Med/High" is selected.

It is recommended to always include all density classes in the analysis.

Note that the 2D results visualise the results provided by the model executable, this means they reflect the results for the general flux (all three densities included) even if some density fluxes are excluded from the ESABASE2/Debris analysis.

The ORDEM 3.0 model describes the orbital debris environment for the Earth orbits between 100 km and 40000 km altitude and for the time range between 2010 and 2035.

ORDEM 3.0 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.

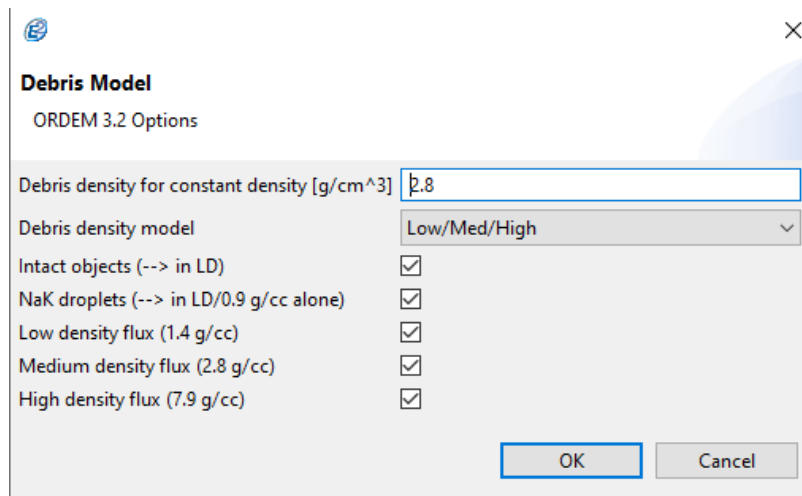
The analytical technique uses the Bayesian statistical model for population derivation. A finite element model processes the debris populations to form the debris environment.

Note that the runtimes of ORDEM 3.0 can be very long, especially for higher eccentricities. They can last from some minutes for LEO and more than an hour for GTO like orbits. The progress can be seen in the console where ORDEM 3.0 is running. Please consider the runtimes if you plan an analysis with ORDEM 3.0, especially if you use trajectory file, because then ORDEM 3.0 is executed for each orbital point individually.

## 2.2.1.1.8 Debris model: ORDEM 3.2

ORDEM 3.2 /36/ is an update of ORDEM 3.0, see section 2.2.1.1.7.

When you click on the "Edit" button, a dialog with ORDEM 3.2 input parameters will open, as show in the following figure.



**Figure 2-14:** Debris input editor, main tab, model selection, ORDEM 3.2

The user can define the assumed debris material density (default: 2.8 g/cm<sup>3</sup>), as shown in the figure, which is used if a constant debris density model is applied.

In the drop-down menu "Debris density model" the "Low/Med/High" entry or "Constant" entry can be selected. The "Low/Med/High" selection activates the discrimination of the particles in three fractions with different densities.

If only impact flux has to be analysed, the constant density option can be selected. For damage analyses it is recommended to use "Low/Med/High" option.

Note that the density distribution is size dependant, thus the defined lower particle diameter (s. 2.2.1.2) influences it, because it is used to define the reference distribution. Due to this link the definition of the lower particle diameter takes effect on the damage analyses results. It is recommended to define a lower particle diameter, which is not too different from the assumed ballistic limit.

The last five items allow including or excluding of the five available particle sources provided by ORDEM 3.2. However, Intacts, NaK droplets and low density flux are combined to "LD" for internal use and output. The 1.4 g/cm<sup>3</sup> are than applied for all three of them, except using NaK droplets alone renders its density to 0.9 g/cm<sup>3</sup>. These parameters are considered only if the density model "Low/Med/High" is selected.

It is recommended to always include all density classes in the analysis.

The ORDEM 3.2 model describes the orbital debris environment for the Earth orbits between 100 km and 40000 km altitude and for the time range between 2016 and 2050.

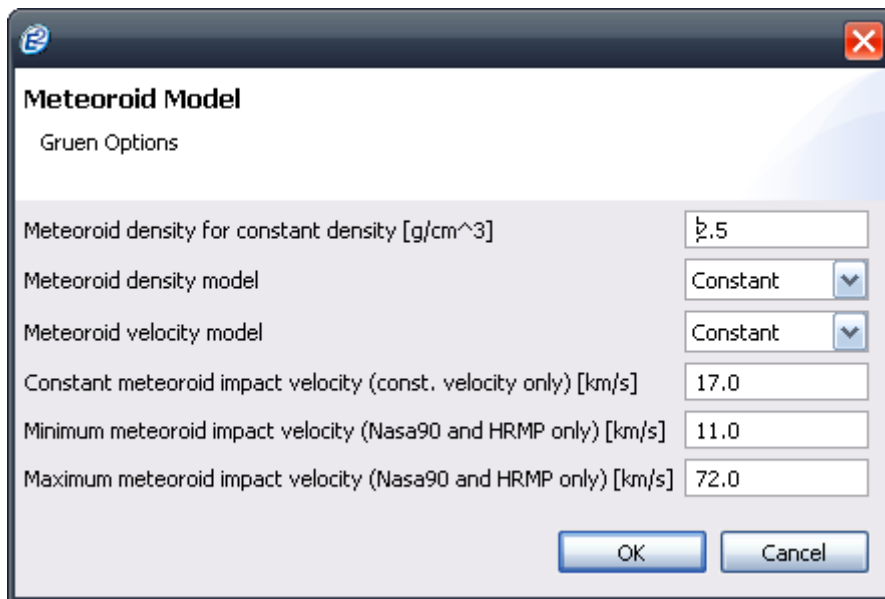
ORDEM 3.2 is appropriate for engineering solutions requiring knowledge and estimates of the orbital debris environment (debris spatial density, flux, etc.). The model includes a large set of observational data (both in-situ and ground-based), covering the object size range from 10 µm to 10 m.

The analytical technique uses the Bayesian statistical model for population derivation. A finite element model processes the debris populations to form the debris environment.

Note that the runtimes of ORDEM 3.2 can be very long, especially for higher eccentricities. They can last from some minutes for LEO and more than an hour for GTO like orbits. The progress can be seen in the console where ORDEM 3.2 is running. Please consider the runtimes if you plan an analysis with ORDEM 3.2, especially if you use trajectory file, because then ORDEM 3.2 is executed for each orbital point individually.

## 2.2.1.1.9 Meteoroid model: Grün

Grün /14/ is an omni-directional interplanetary flux model for sporadic meteoroid environment. It can be applied for Earth and lunar orbits. When you press the "Edit" button, a dialog with the Grün input parameters shown in the figure below appears.



**Figure 2-15:** 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).

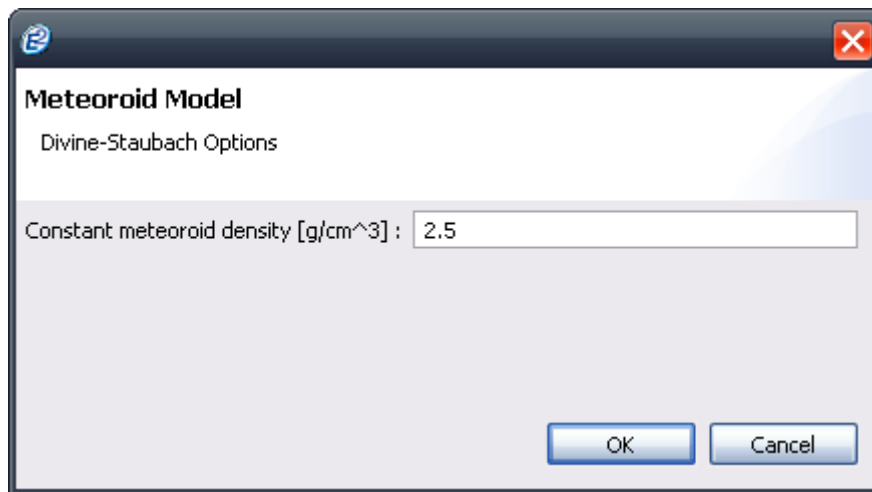
The next two lines are concerned with the meteoroid velocity distribution option:

- Constant meteoroid velocity; for this option, the default value is 17 km/s.
- The NASA90 velocity distribution. In most cases, this delivers good results, and is thus the recommended option for the industrial user. The NASA90 velocity distribution is not applicable to lunar orbits, due to the intended design for Earth orbits.
- The Taylor HRMP velocity distribution. This model is the most complex option. It is also applicable and recommended for the lunar orbits.

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.

## 2.2.1.1.10 Meteoroid model: Divine-Staubach

Divine-Staubach /13/ /18/ /28/ is a meteoroid model which is also part of the MASTER 8 model. When you press the "Edit" button, a dialog shows the the Divine-Staubach input parameters depicted in the screenshot below.



**Figure 2-16:** Debris input editor, main tab, Model Selection, Divine-Staubach

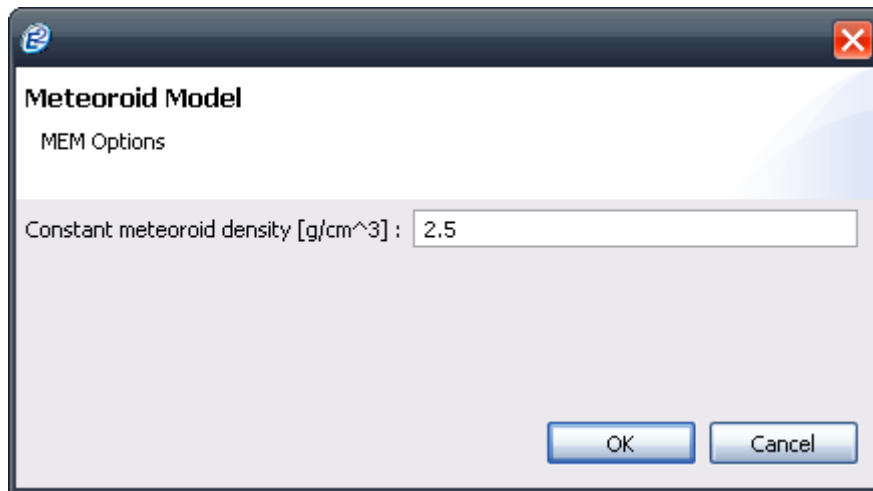
The only parameter is the material density of meteoroids. It is assumed to be constant.

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 8 debris model.



## 2.2.1.1.11 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.



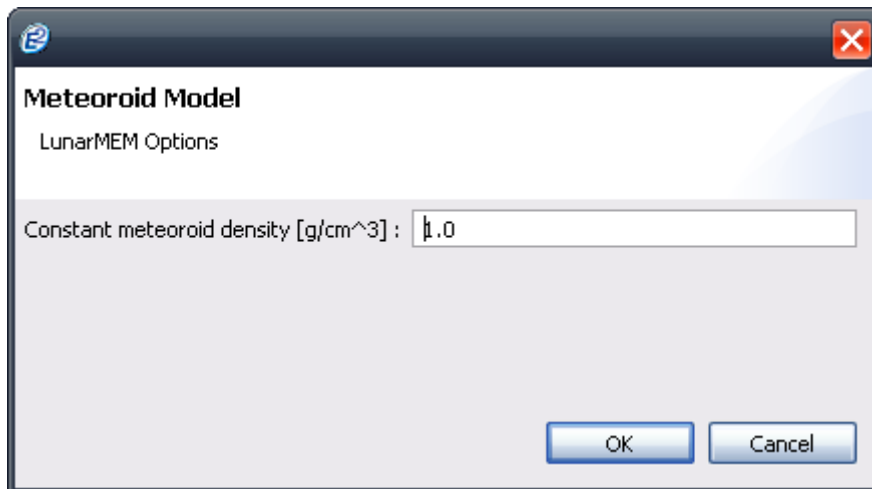
**Figure 2-17:** Debris input editor, main tab, Model Selection, MEM

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.

## 2.2.1.1.12 Meteoroid model: LunarMEM

LunarMEM is a MEM /20/ version, which is tailored to the vicinity of the Moon. Upon pressing "Edit", a dialog with the LunarMEM input parameters opens, as shown in the figure below.



**Figure 2-18:** Debris input editor, main tab, Model Selection, LunarMEM

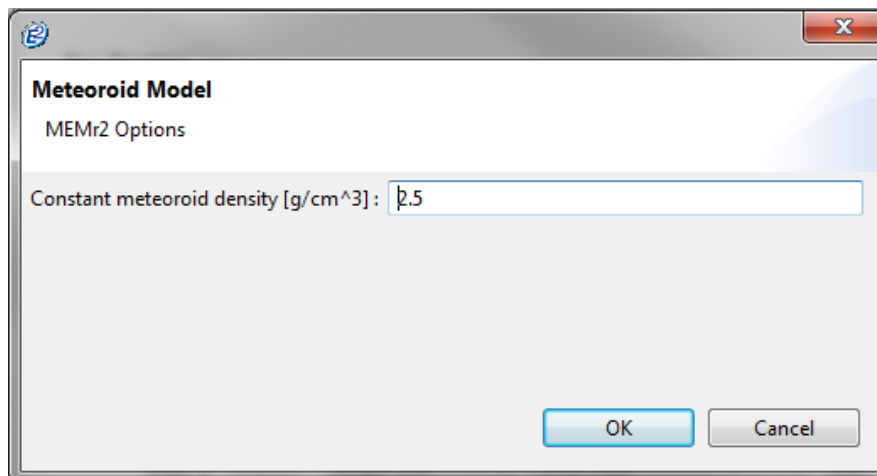
Since LunarMEM is a tailored version of MEM most model characteristics are coherent, as for the use of a constant meteoroid density of  $1 \text{ g/cm}^3$ . We propose to always use  $1 \text{ g/cm}^3$  also for LunarMEM. Please note that the default  $2.5 \text{ g/cm}^3$  is fitting only for the other meteoroid models – all models use the same parameter within the data model; this is the reason that the default in the GUI cannot be  $1 \text{ g/cm}^3$ .

For further information about LunarMEM please refer to /2/ or the MEM reference /20/.

## 2.2.1.1.13 Meteoroid model: MEMr2

MEMr2 /27/ is release 2.0 of MEM /20/, which is a meteoroid model developed by the University of Western Ontario, Canada.

Upon pressing "Edit", a dialog with the MEMr2 input parameters opens, as shown in the figure below.



**Figure 2-19:** Debris input editor, main tab, Model Selection, MEMr2

MEMr2 has no options by itself, using a constant meteoroid density of  $1 \text{ g/cm}^3$ , as it was already the case for MEM. 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  $1 \text{ g/cm}^3$ .

MEMr2, as the successor of MEM, keeps being 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.

Unlike prior releases, MEMr2 is a single product containing three individual environment sub-models

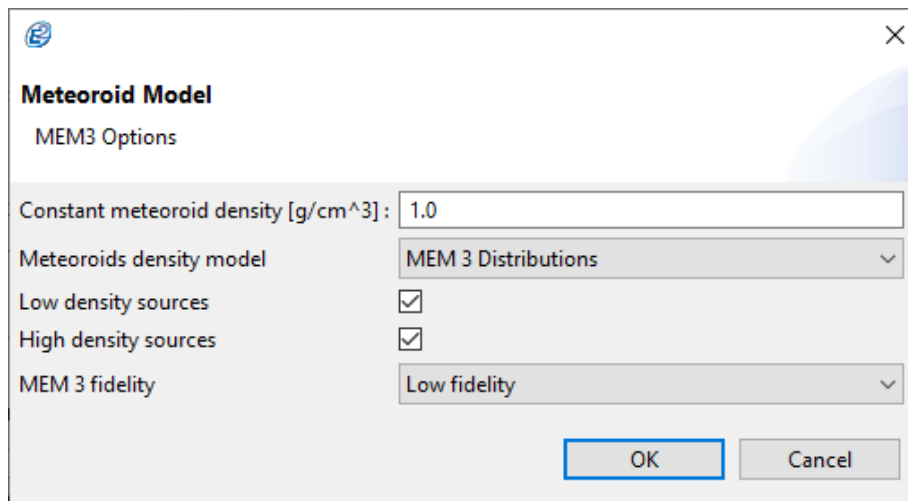
- For Earth Orbiting S/C
- For Moon Orbiting S/C
- For Interplanetary S/C

that describe the background meteoroid environment for spacecraft in orbit around the Earth, Moon, and in interplanetary space.

## 2.2.1.1.14 Meteoroid model: MEM 3

MEM 3 /35/ is the successor of MEMr2 /27/ and the 3<sup>rd</sup> main release of MEM /20/, which is a meteoroid model developed by the University of Western Ontario, Canada.

Upon pressing "Edit", a dialog with the MEM 3 input parameters opens, as shown in the figure below.



**Figure 2-20:** Debris input editor, main tab, Model Selection, MEM 3

MEM 3 is a highly reworked and extended version of MEM. A sounding change is the consideration of low- and high-density sources with according density distributions. The outputs are provided for the sources individually and no combined output is available. For the consideration in ESABASE2/Debris it is possible to select the appropriate approach for the performed analysis. The Meteoroid density model selection allows to select the use of a constant meteoroid density defined by the user in Constant meteoroid density field. In this case the defined density is applied for each particle for the combined results and the two check boxes are ignored. Alternatively, the consideration of the density distributions provided by MEM 3 can be used. Upon this choice, the sources to be considered can be selected via the two check boxes. If both are selected the results are combined, but only for the effects on the S/C, for the ray generation the individual distributions are considered.

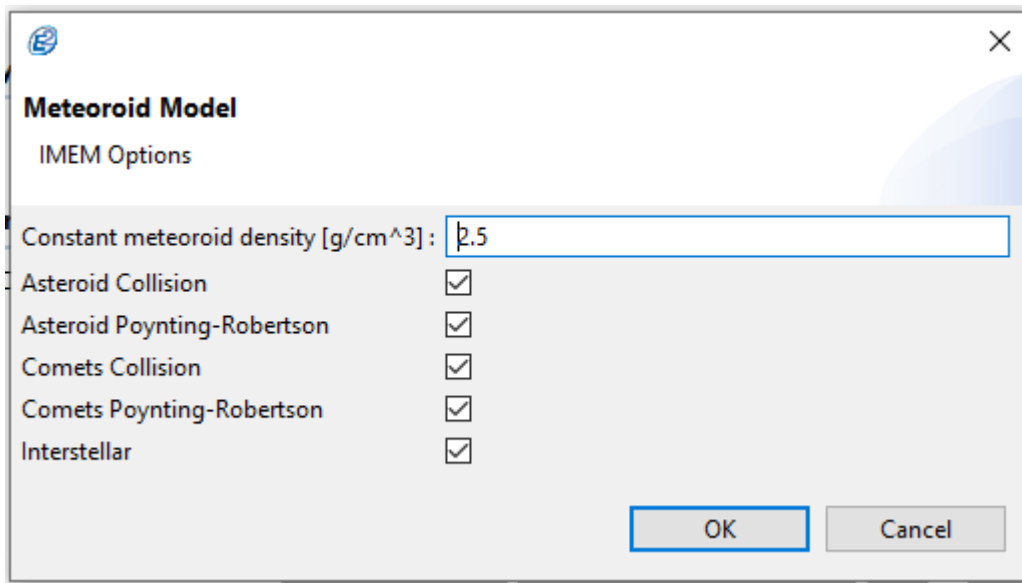
Please note that for the initial size conversion of the upper and lower particle consideration (if given as size) is done based on the default 1 g/cm<sup>3</sup>.

Furthermore, MEM 3 allow to select the level of fidelity for the environment definition. This selection is accessible also in ESABASE2/Debris.

For further information about MEM 3 please refer to /2/ or/and the MEM reference /20/ and /35/ (MEM 3).

### 2.2.1.1.15 Meteoroid model: IMEM

IMEM /30/, /31/ is an interplanetary meteoroid model developed by ESA. Upon pressing "Edit", a dialog with the IMEM input parameters opens, as shown in the figure below.



**Figure 2-21:** Debris input editor, main tab, Model Selection, IMEM

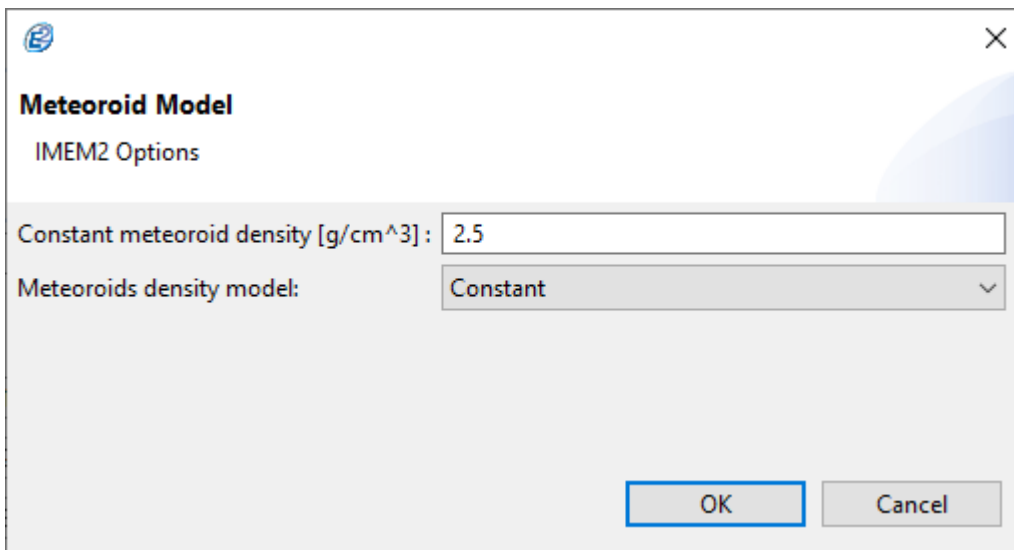
The first parameter is the material density of meteoroids. It is assumed to be constant. The IMEM model is based on numerical modelling of various population sources, which can be included or excluded from an analysis.

- Asteroid Collision: Asteroidal population of heavier ("collision dominated") group
- Asteroid Poynting Robertson: Asteroidal population of lighter ("Poynting-Robertson dominated") group
- Comets Collision: Cometary population of heavier ("collision dominated") group
- Comets Poynting-Robertson: Cometary population of lighter ("Poynting-Robertson dominated") group
- Interstellar: Interstellar population parametrized as mono-directional stream

IMEM models the orbits of particles from Jupiter-family asteroids and comets and was fitted largely to in situ data and infrared brightness measurements. The use of two different groups of asteroidal and cometary populations results in a discontinuity in the mass flux at around  $10^{-5}$  g. Modelled meteor observations were not used because they were found to be inconsistent with modelled infrared data. Please note that IMEM can only be used in combination with an "Interplanetary (SUN)" orbit defined in the mission file.

## 2.2.1.1.16 Meteoroid model: IMEM2

IMEM2 /32/, /33/, /34/ is the follow-up approach of ESA's IMEM to model meteoroids in the Solar System. Upon pressing "Edit", a dialog with the IMEM2 input parameters opens, as shown in the figure below.



**Figure 2-22:** Debris input editor, main tab, Model Selection, IMEM2

Here, the user selects the density settings for the analysis. With the drop-down menu at "Meteoroids density model", the user has the choice between using a constant density for the impact assessment and applying IMEM2's density distribution (3 bins: 1000 kg/m<sup>3</sup> for Halley type, 2000 kg/m<sup>3</sup> Jupiter family and 4000 kg/m<sup>3</sup> asteroid particles). For the constant selection, the value inserted in the text field is applied.

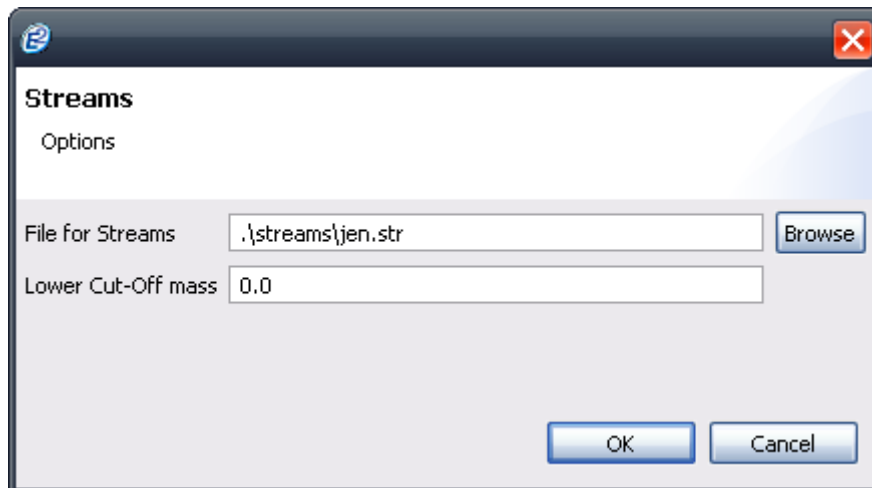
IMEM2 contains a dynamical engineering model of the dust component of the space environment using state-of-the-art knowledge of dust cloud constituents and their development under dynamical and physical effects /32/. The aim of IMEM2 was to improve on the IMEM model and to remove its step-wise mass flux by fully integrating the dynamics of particles of radii from 1 µm to 1 cm. The model is built based on knowledge of the orbital distributions of the dust parent bodies (cometary and asteroidal populations). The model is designed to match dust observations as closely as possible, including infrared data from the Cosmic Background Explorer (COBE), lunar microcrater counts, meteor orbit radar velocity, and orbital element distributions, as well as the flux of dust particles at the Earth.

Please note that IMEM2 can only be used in combination with an "Interplanetary (SUN)" orbit defined in the mission file.

## 2.2.1.1.17 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, only for the analyses on Earth orbits.

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



**Figure 2-23:** 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.

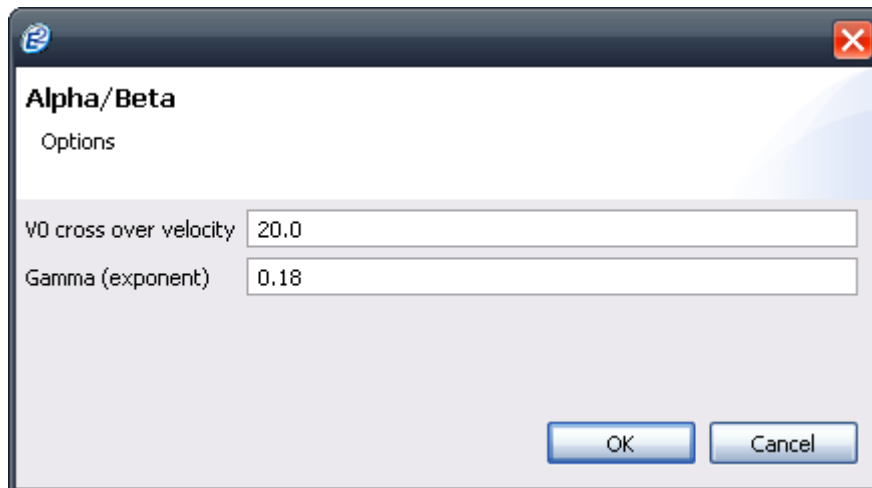
The Jenniskens stream model is based on observation data gathered over a 10 year period, and can be applied to flux and damage analysis. It also includes directional information on the streams.

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.

### 2.2.1.1.18 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 2-24:** 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. It is applicable only to Earth orbits.

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

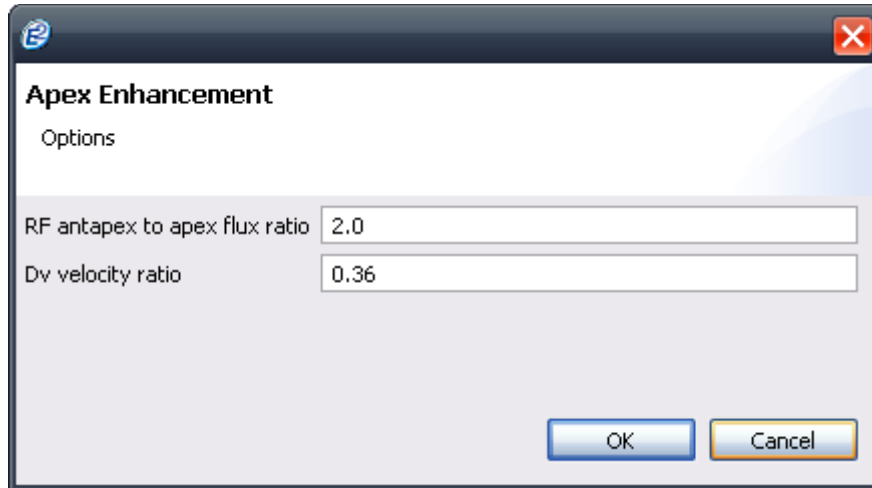
We do not recommend using other values than the default values for this model, unless you have in-depth knowledge in astrophysics.



## 2.2.1.1.19 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). It is applicable only to Earth orbits.

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



**Figure 2-25:** 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 2-26:** 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 2-27:** 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 500, better 1000 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

Up to 15 different damage models can be defined for damage assessment. Each model is defined by two types of damage equations which are used during the analysis:

- The ballistic limit equations (or failure equation), 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 model setup in the main tab.

**Damage Model**

Cutoff angle:

	Failure Equation			Damage Equation			
<b>Wall 1</b>	<input type="text" value="WALL_1"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 2</b>	<input type="text" value="WALL_2"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 3</b>	<input type="text" value="WALL_3"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 4</b>	<input type="text" value="WALL_4"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 5</b>	<input type="text" value="WALL_5"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 6</b>	<input type="text" value="WALL_6"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 7</b>	<input type="text" value="WALL_7"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 8</b>	<input type="text" value="WALL_8"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 9</b>	<input type="text" value="WALL_9"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 10</b>	<input type="text" value="WALL_10"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 11</b>	<input type="text" value="WALL_11"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 12</b>	<input type="text" value="WALL_12"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 13</b>	<input type="text" value="WALL_13"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 14</b>	<input type="text" value="WALL_14"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit
<b>Wall 15</b>	<input type="text" value="WALL_15"/>	Single Wall ▾	Thick Plate ▾	Edit	Crater Size ▾	Thick Plate ▾	Edit

**Figure 2-28:** Debris input editor, main tab, Damage Model

There are no conventions concerning the combination of failure and damage equation. Single wall as well as multi wall can be combined with crater or hole size equations.

Failure and damage equations of the ESABASE2/Debris analysis tool are defined in a parametric form, with editable parameters (constants and exponents). The parameters can be edited via the "Edit" buttons shown in Figure 2-2827.

Up to seven entities can be defined:

for failure equation:

- the single wall ballistic limit equation
- the multiple wall ballistic limit equation and
- the user subroutine parameters

for damage equation:

- the crater size equation
- the parametric clear hole equation

- the advanced hole equation and
- the user subroutine parameters.

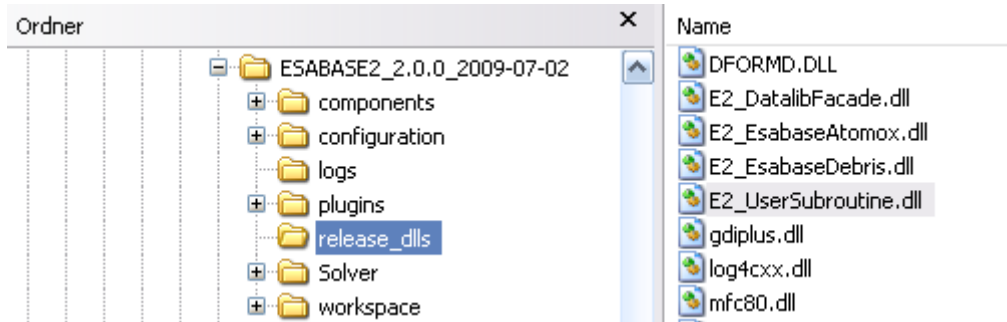
The user subroutine option is only for expert users with Fortran and/or C++ experience (see section 2.2.1.5).

For a detailed description of the user input of the damage equations, please refer to /10/.

## 2.2.1.5 User Subroutine

For expert users 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 2-29:** Finding the User subroutine DLL

ESABASE2 releases higher than 6.1.0 use the Intel Fortran 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`). A simple example file is shown in Figure 2-3029.

```

c---<kdb, etamax space>-----<2007-09-14>---
C
  SUBROUTINE USER_DAM (KFLAG, VPART, DPART, ALFA, RHOP, TB, RHOB,
&
  TS, RHOS, SPACE, X_OUT, D_USREQ)

C-----
C
C   Parameters of the calling sequence:
C
C   Input:
C   KFLAG: Calling Flag of the Routine :
C           1 - Routine called as ballistic limit equation
C           2 - Routine called as crater / hole size equation
C   VPART: Scalar impact velocity [km/s]
C   DPART: Particle diameter (for call as crater / hole size equation)
C   ALFA : Impact angle [deg]
C   RHOP : Particle density [g/cm3]
C   TB   : Back-up or Main Wall thickness [cm]
C   RHOB : Back-up or Main Wall density [g/cm3]
C   TS   : Shield cumulated thickness [cm]
C   RHOS : Shield average density [g/cm3]
C   SPACE: Cumulated spacing (shield to Back-up wall) [cm]
C
C   Output:
C   X_OUT: Routine output
C           Ballistic limit call: Particle limit diameter
C           Crater / hole size call: Crater / hole diameter
C
C   Input/Output:
C   D_USREQ: Parameters (up to 14) of the user failure and damage laws.
C-----
C   Purpose   : Specification of any user defined failure (ballistic
C               limit) and damage (crater size) equation.
C               +++ This is a simple example routine. +++
C-----
C   CALLS     : any user defined subroutine; to be included in
C               the UserSubroutine.dll
C-----
C   CALLED BY : DACRAHO, SH_BALDIV, RPRT_IMPA
C-----
C   COMMONS   : none
C-----
C ... Input/Output Variable declaration
  INTEGER KFLAG
  REAL VPART, DPART, ALFA, RHOP, TB, RHOB, TS, RHOS, SPACE,
&
  X_OUT
  REAL D_USREQ (14)

C ... USER_DAM internal variables
  REAL VNORM, ! Normal impact velocity
&
  FMAX, ! Ballistic limit 47ormalized to Dp**Lambda
&
  XDUM ! Dummy variable

c +++ Specification of d_usreq(1:14)
  D_USREQ(1) = 1.0d0
  D_USREQ(2) = 0.33d0
  D_USREQ(3) = 2.0d0
  D_USREQ(4) = 0.667d0
  D_USREQ(5) = 1.0d0
  D_USREQ(6) = 0.33d0
  D_USREQ(7) = 2.0d0
  D_USREQ(8) = 0.667d0
  D_USREQ(9) = 1.0d0
  D_USREQ(10) = 0.33d0
  D_USREQ(11) = 2.0d0
  D_USREQ(12) = 0.667d0
  D_USREQ(13) = 1.0d0
  D_USREQ(14) = 0.33d0

  VNORM = VPART * COS(ALFA)

  IF (KFLAG.EQ.2) THEN
C +++ Crater size equation
    XDUM = (DPART**1.056)*(RHOP**0.519)*(VNORM**0.66667)
    X_OUT = D_USREQ(11) * D_USREQ(12) * XDUM
  ELSE
C +++ Ballistic limit equation
    FMAX = D_USREQ(13)*D_USREQ(14) * (RHOP**0.519)*(VNORM**0.66667)
    X_OUT = (TB / FMAX)**(0.947)
  END IF

  RETURN
  END
C-----eof-----eof-----
C

```

**Figure 2-30:** Example user subroutine

After the variables specification, a block containing 14 parameters can be defined for the user damage equation.

The user sub-routine must be named `user_dam.f`.

The flag `KFLAG` indicates how the subroutine is called. When `user_dam` is called with `KFLAG = 1`, it is to be used as a ballistic limit equation, if `KFLAG = 2`, it is to be used as a crater / hole equation. Thus one subroutine can cover both types of equation.

It is possible to add further subroutines in the file `user_dam.f` which are called by the main user subroutine `USER_DAM`. Thus, the advanced user can build his own library of damage equations.

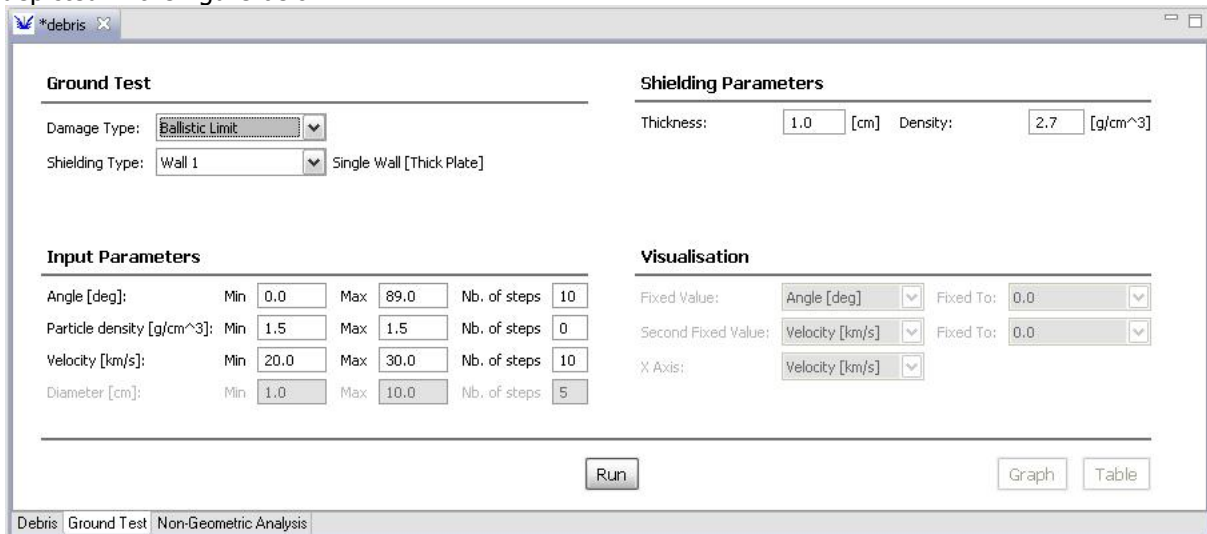
In case of persisting issues, please contact the ESABASE2 development team using the email address provided on the website /3/.

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.



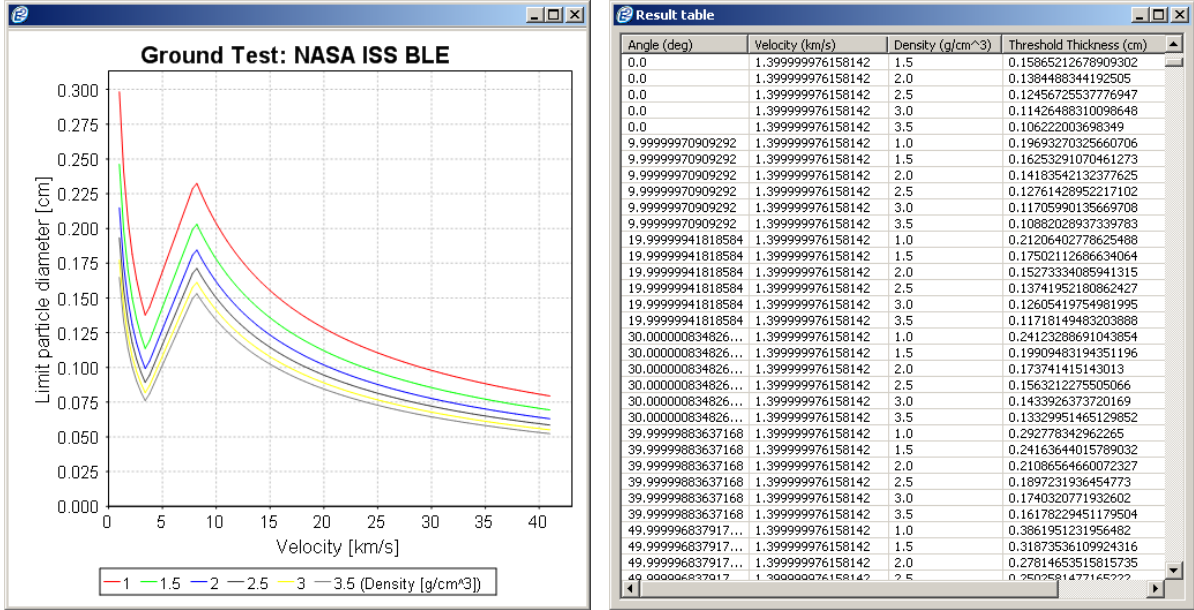
**Figure 2-31:** Debris input editor, Ground Test tab

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 (Wall\_1 to Wall\_15). To define the wall configuration see section 2.2.1.4.
- *Shielding Parameters:* Choose shield thickness and density (and spacing in case of double walls).
- *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 2-32:** Debris input editor, Ground Test tab, Run

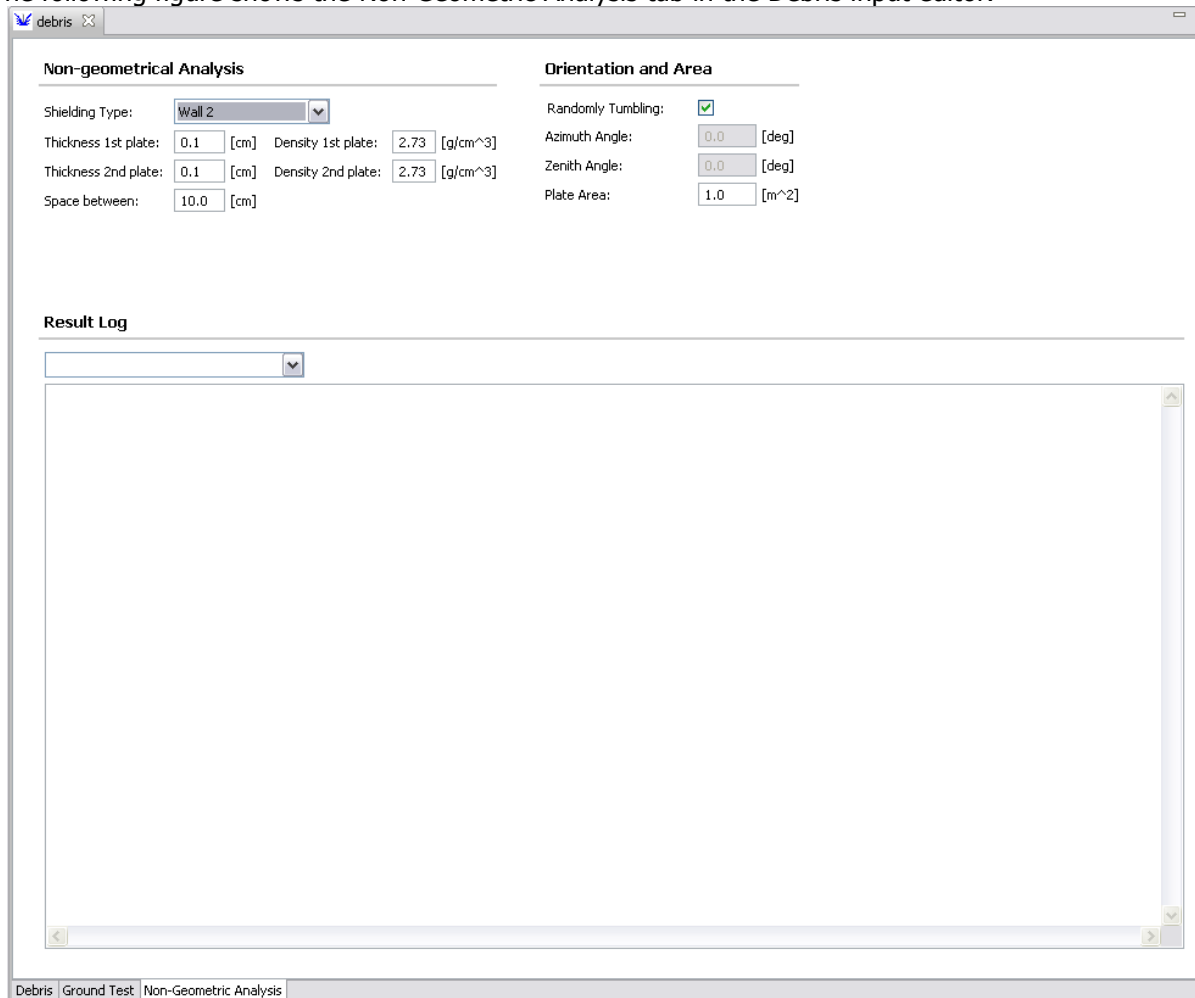
Graph and table show the same results.

## 2.2.3 Debris Non-Geometric Analysis Tab

The “non-geometric” analysis uses 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 2-33:** Debris input editor, Non-Geometric Analysis tab

In the tab, three sections are visible:

- *Non-geometrical Analysis:* Specifies shielding type (Wall\_1 to Wall\_15) as well as shield thickness and density (and spacing in case of double walls). To define the wall configuration see section 2.2.1.4.
- *Orientation and area:* Specifies the plate size and its orientation or randomly tumbling property.
- *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 for single (left) and multi wall (right) selection.

Non-geometrical Analysis		Non-geometrical Analysis	
Shielding Type:	Wall 1	Shielding Type:	Wall 2
Thickness:	0.1 [cm]	Density:	2.7 [g/cm <sup>3</sup> ]
Thickness 1st plate:	0.1 [cm]	Density 1st plate:	2.7 [g/cm <sup>3</sup> ]
Thickness 2nd plate:	0.1 [cm]	Density 2nd plate:	2.7 [g/cm <sup>3</sup> ]
Space between:	10.0 [cm]		

**Figure 2-34:** 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.

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

**Figure 2-35:** 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).

Please note that if the zenith angle is zero degree, the azimuth angle is irrelevant and the normal vector points in the space direction. The azimuth angle rotates the plate then only around the axis to nadir but due to the equal plate sides, this is irrelevant.

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 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).

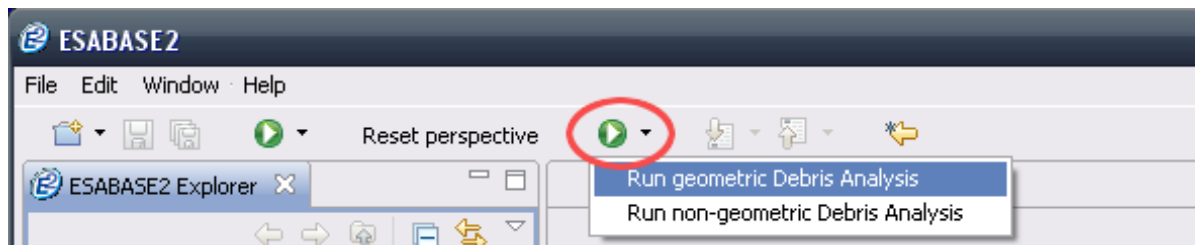
## 2.3 Debris Analysis

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 types 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 (see section 2.3.1).
- *Non-geometric Analysis*: Subtracts the S/C geometry from the analysis, instead taking a simple plate (see section 2.3.2).

### 2.3.1 Geometric Debris Analysis

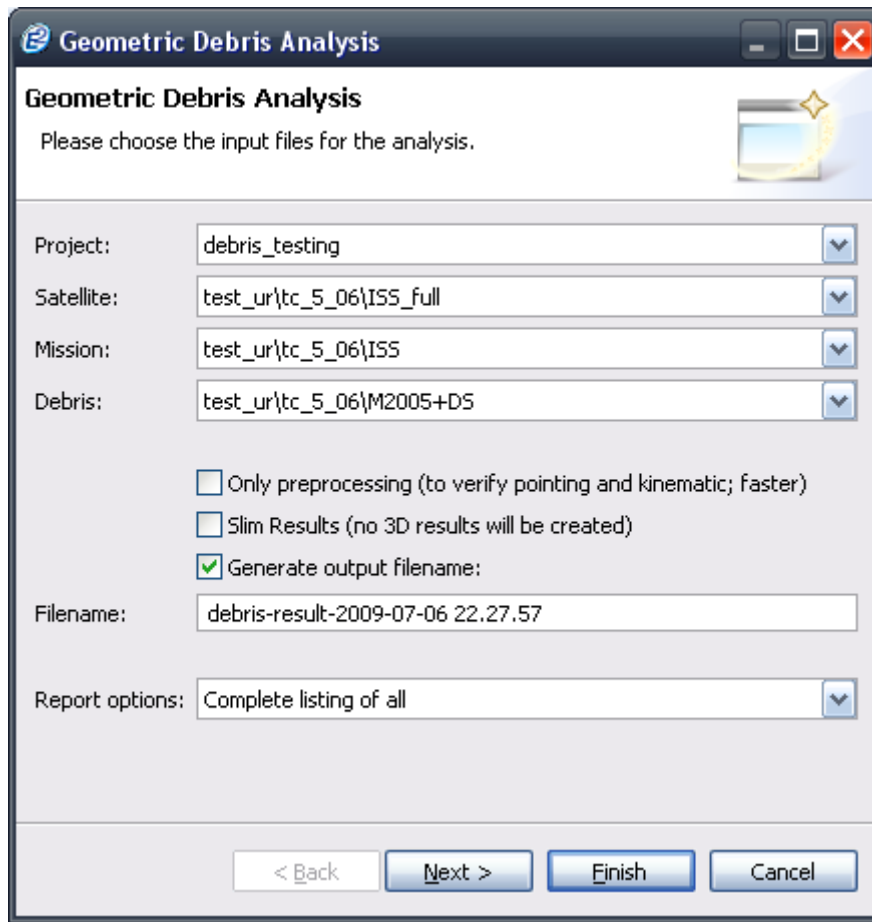
In the toolbar at the top of the application window, locate the "Run" button depicted in the following figure. Press the small down-arrow at the right of the button and a context menu will appear.



**Figure 2-36:** 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 2-37:** 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.

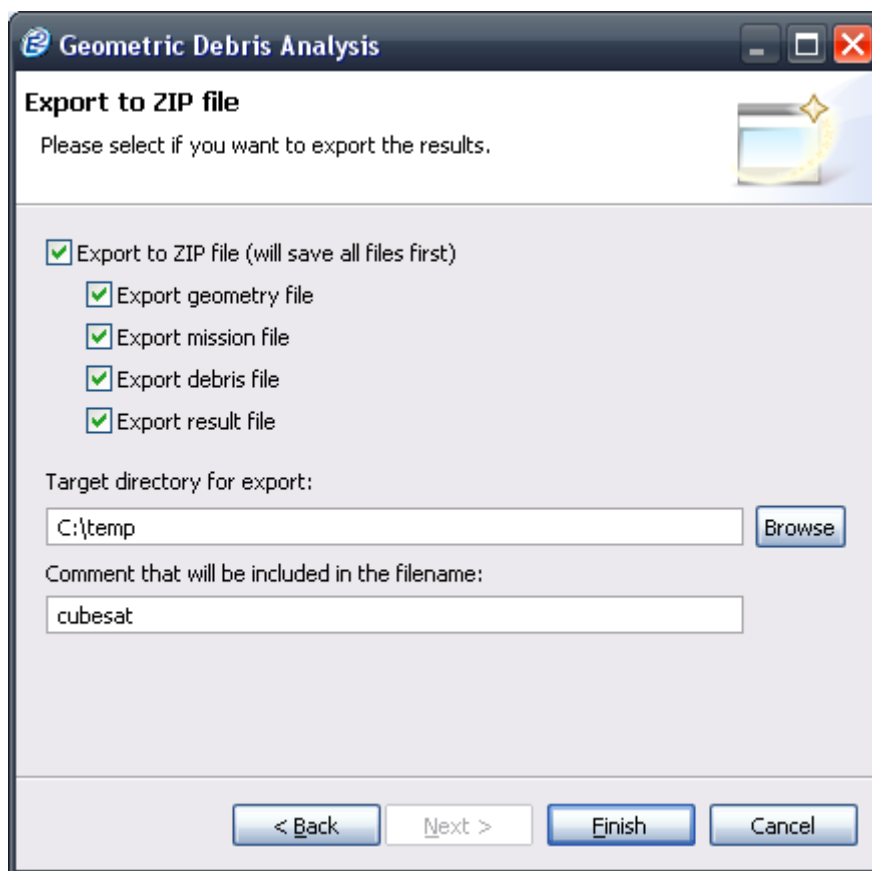
The "Slim Results" checkbox is a performance switch. With it, LIS\* files (as in the original ESABASE) and 2D graphs will be created as usual and with full information content (as specified in the "Report Options" box), but the only 3D geometry result will be for the entire mission; no orbital points 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.

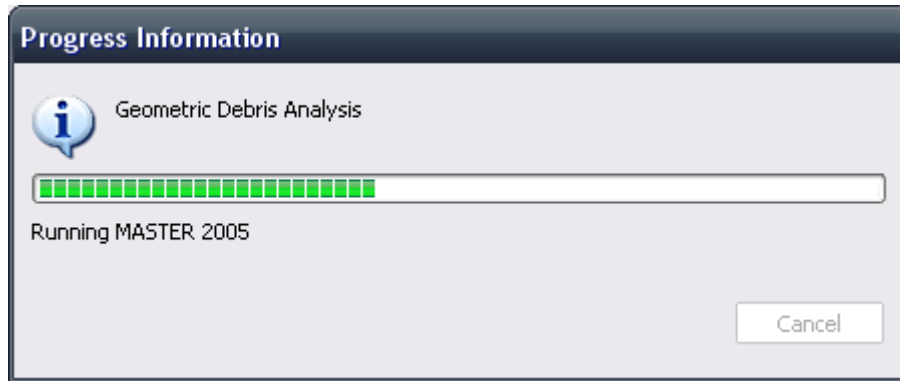


**Figure 2-38:** Geometric Debris analysis, Run dialog, export page

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 2-39:** Geometric Debris analysis, Progress bar

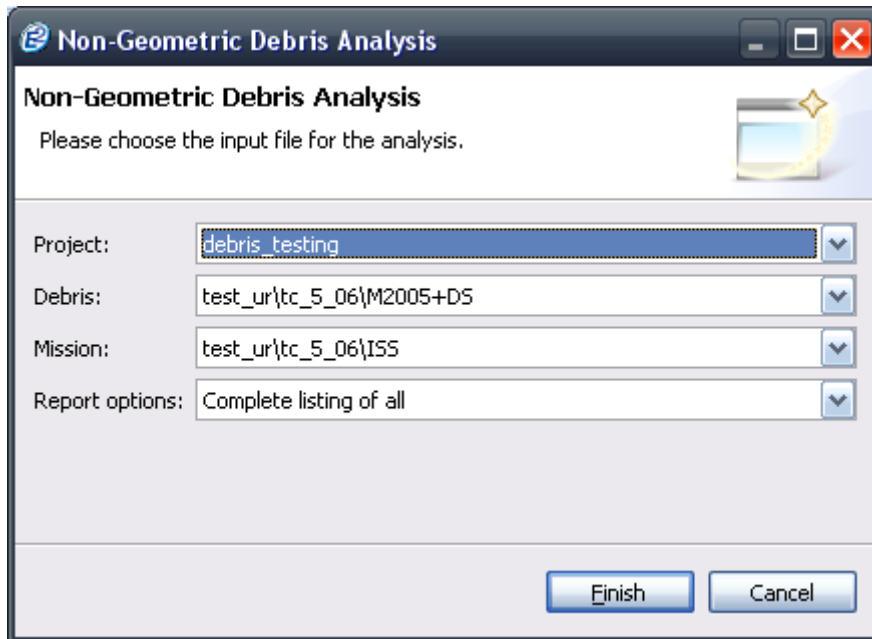
After the run, a debris result file will be created in your workspace, and it will be automatically opened. If you are interested in its contents, skip to section 2.4; otherwise, the following subsection will explain the non-geometric debris analysis.



## 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".

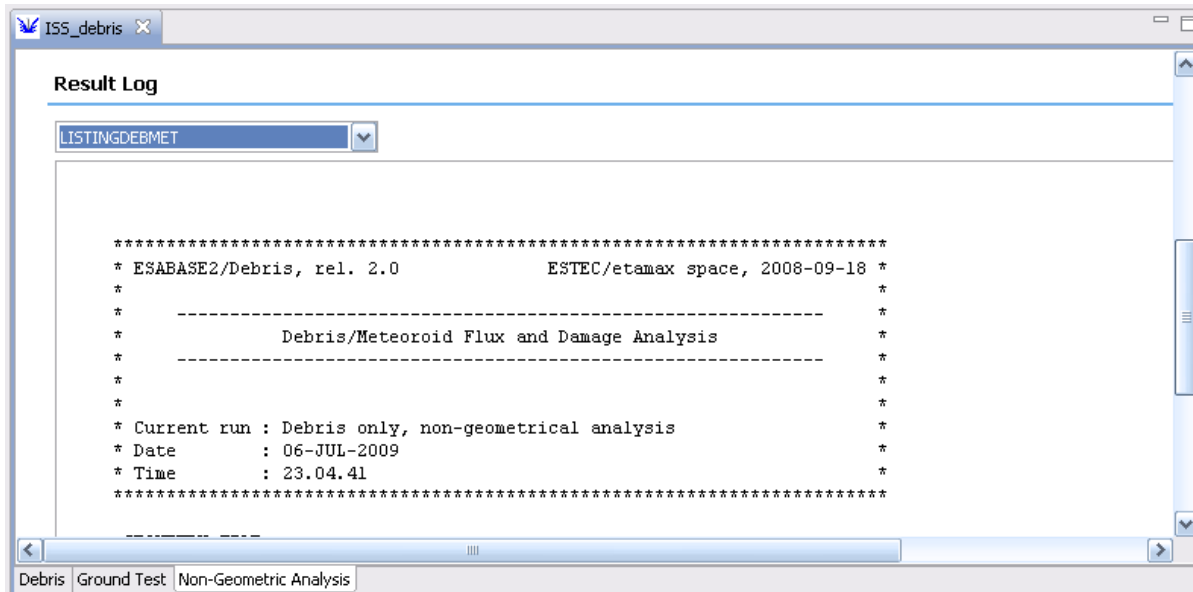
The following figure shows the Run wizard for the non-geometric debris analysis.



**Figure 2-40:** 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 2-41:** 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.

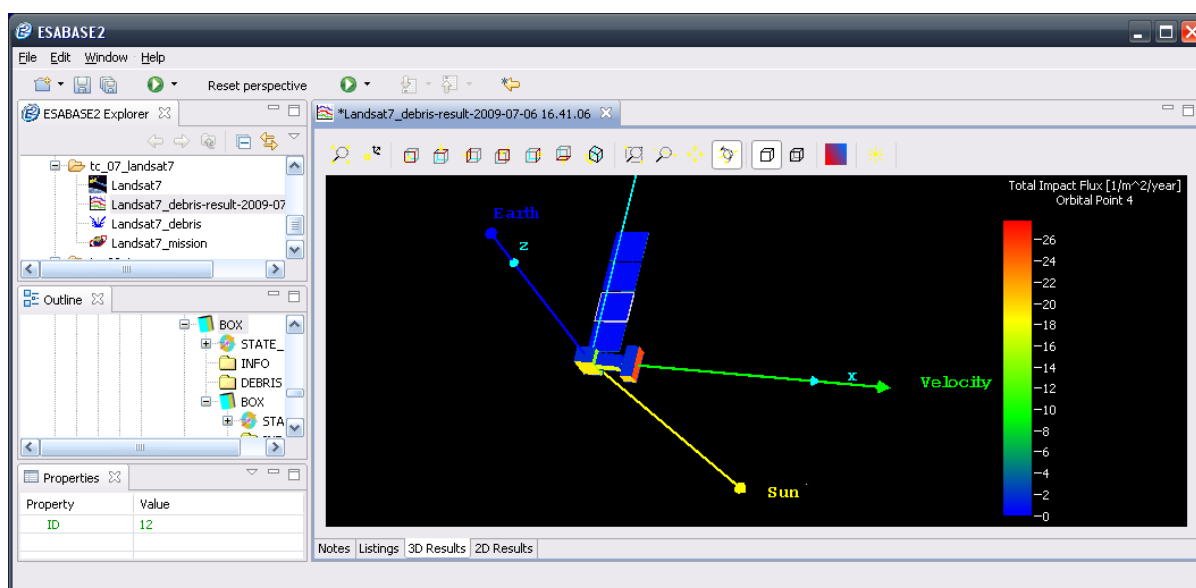
## 2.4 Debris Results

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 (see section 2.4.1).
- *2D Results*: Graphs with different data about flux distributions at the orbital points as well as average flux distributions (see section 2.4.2).
- *Listings*: In tradition of the original ESABASE, this tab shows the LIS\* files produced by the Debris solver (see section 2.4.3).
- *Notes*: A blank text area for your own notes (see section 2.4.4).

### 2.4.1 3D Results

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



**Figure 2-42:** 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.

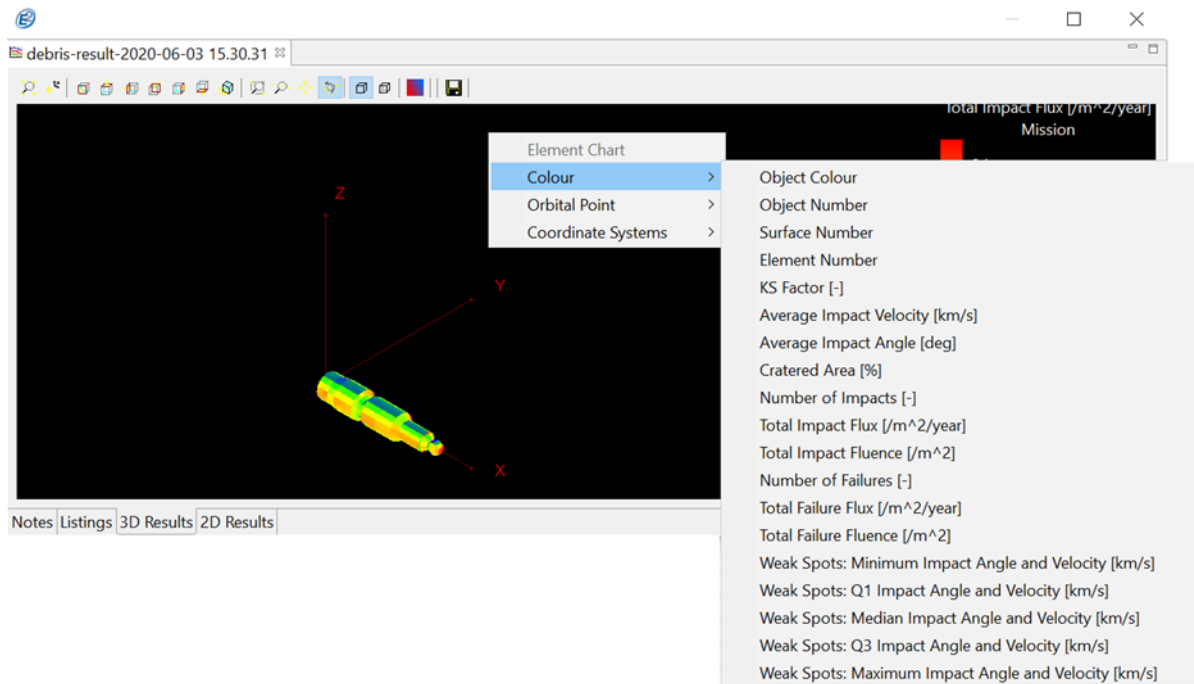
Additionally, you can rightclick into the 3D area to invoke the context menu, which contains the following options:

- *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 2-43:** 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 15 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]
- Number of Impacts [-]
- Total Impact Flux [1/m^2/year]
- Total Impact Fluence [1/m^2]
- Number of Failures [-]
- Total Failure Flux [1/m^2/year]
- Total Failure Fluence [1/m^2]
- Weak Spots: Minimum Impact Angle and Velocity [km/s]

- Weak Spots: Q1 Impact Angle and Velocity [km/s]
- Weak Spots: Median Impact Angle and Velocity [km/s]
- Weak Spots: Q3 Impact Angle and Velocity [km/s]
- Weak Spots: Maximum Impact Angle and Velocity [km/s]

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.

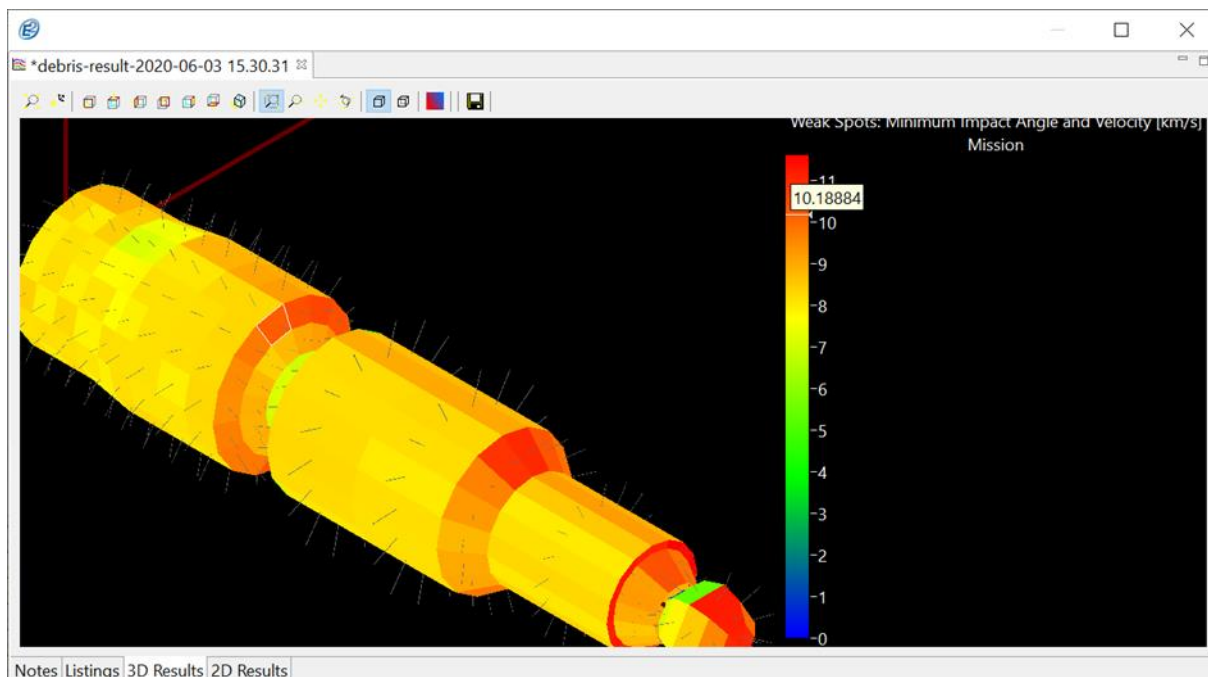
Please note that results always sum up both sides of all elements. A distinction between positive and negative side of an element is not possible.

For the weak spots the angular value is included in the results of the orbital points by grey arrows, as shown in Figure 2-4443. Please note that a choice of the orbital point via rightclick, "Orbital Point -> <Variable>" is only possible for an analysis without the analysis option "Slim Results". Furthermore, the properties view gives you more detailed information about the data contents in a file of the specific element.

For each selected surface element the following Weak Spot Properties are available

- IMPACTAZIMUTH: holds the minimum, Q1, medial, Q3, maximum impact azimuth angle in degree for the selected element
- IMPACTELEVATION: holds the minimum, Q1, medial, Q3, maximum impact elevation angle in degree for the selected element
- IMPACTVELOCITY: holds the minimum, Q1, medial, Q3, maximum impact velocity in km/s for the selected element

The median divides a sorted data set into two equal halves. The median is the value that stands exactly in the middle of the record. Equivalent to the standard deviations in the normal distribution, the quartiles are used here. Quartiles divide the dataset into four equally sized regions, where the second quartile boundary Q2 equals the median. Exactly 50% of the measured values lie between the first quartile boundary Q1 and the third quartile boundary Q3. For further information on the algorithm for the calculation of the quartile values please refer to the technical description /2/.



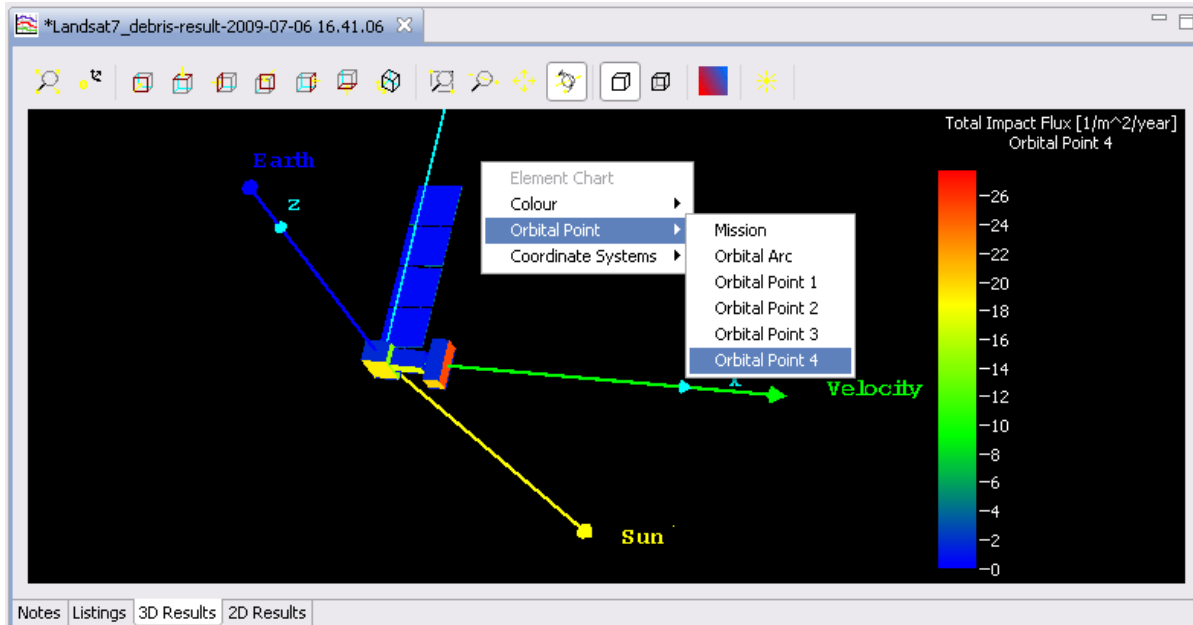
**Figure 2-44: Weak Spots: Minimum Impact Angle and Velocity**

S/C velocity is the reference direction for the angles. Azimuth is defined in the plane of velocity and rectangular to central body direction, with 0 deg starting at velocity and increasing according to the right-hand rule around the plane normal pointing away from central body. Elevation is 0 deg at velocity,

negative to the central body direction and positive away from the central body direction. Thus, an impact from "upper" RAM direction would have a positive elevation and azimuth around 0 deg or 360 deg. Due to the dependency on the velocity direction, which can vary over the orbital points, the visualisation of the impact direction cannot be done for the mission results. Thus, the impact directions are visualised for the orbital point results, only. However, the calculated values can be still seen in the properties and the coloured overlay concerning the impact velocities is available in mission and orbital point results.

## 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 2-45:** Debris result editor, 3D Results, Orbital Point context menu

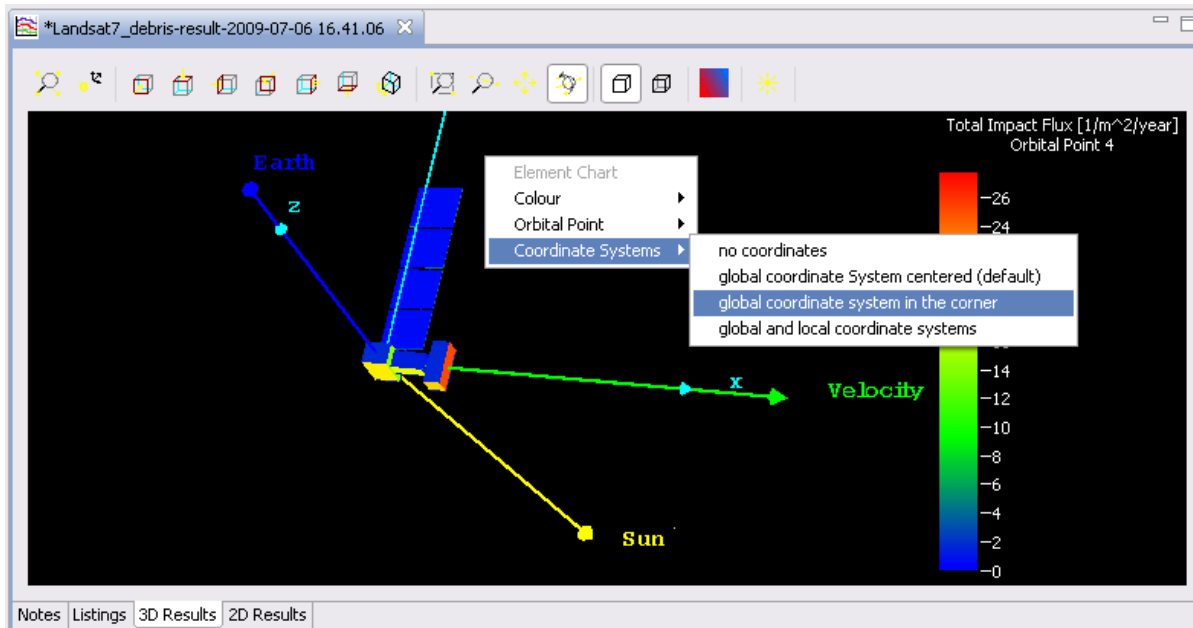
Choose one of the following:

- *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 2-46:** Debris result editor, 3D Results, Coordinate Systems context menu

You can choose among the following coordinate system settings:

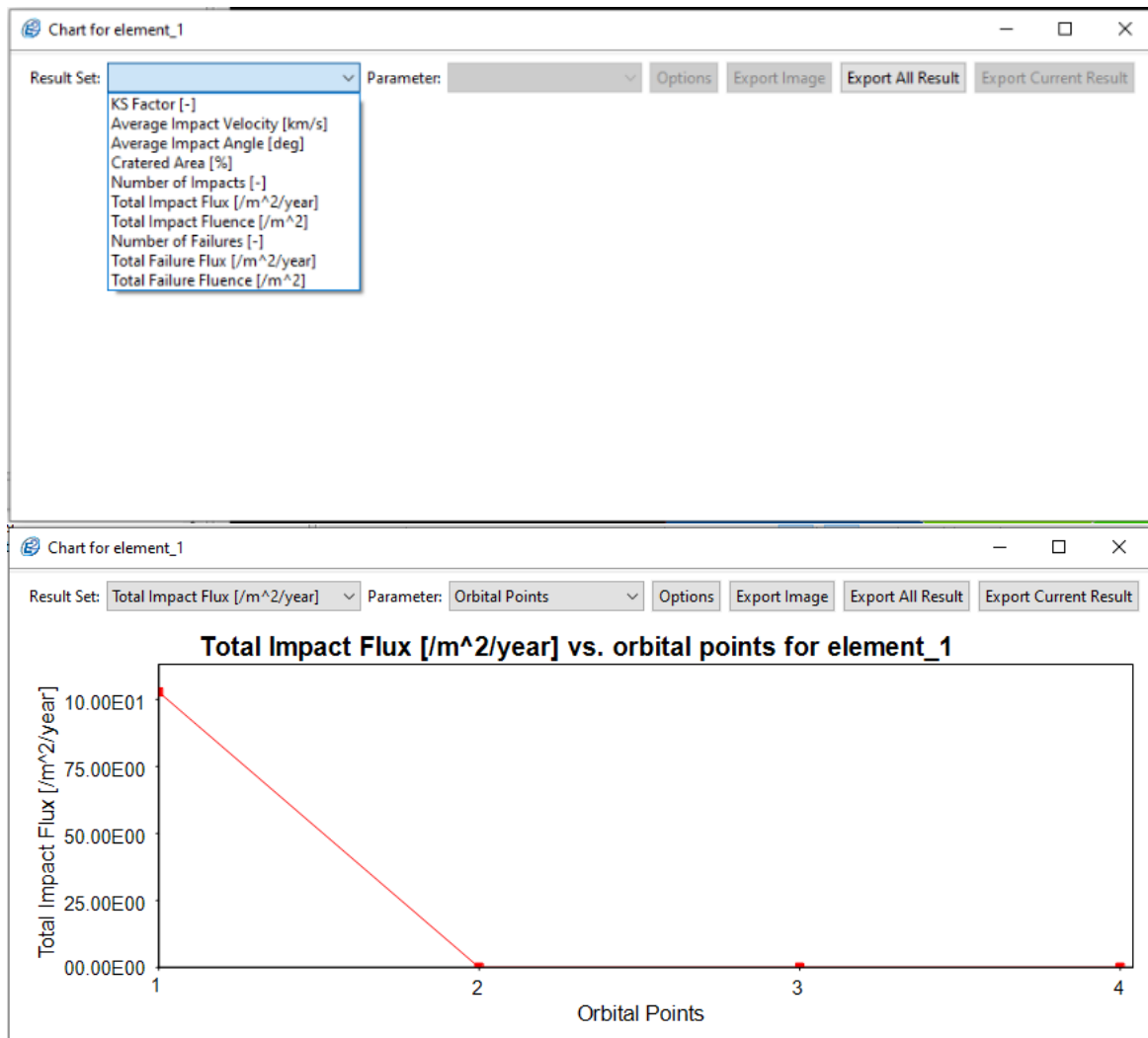
- *No coordinates*: Note that pointing vectors will also be deactivated.
- *Global coordinate system (centred)*: Shows the xyz-axis for the entire system.
- *Global coordinate system in the corner*: Same as before, but in the corner of the system, not centred.
- *Global and local coordinate systems*: 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.



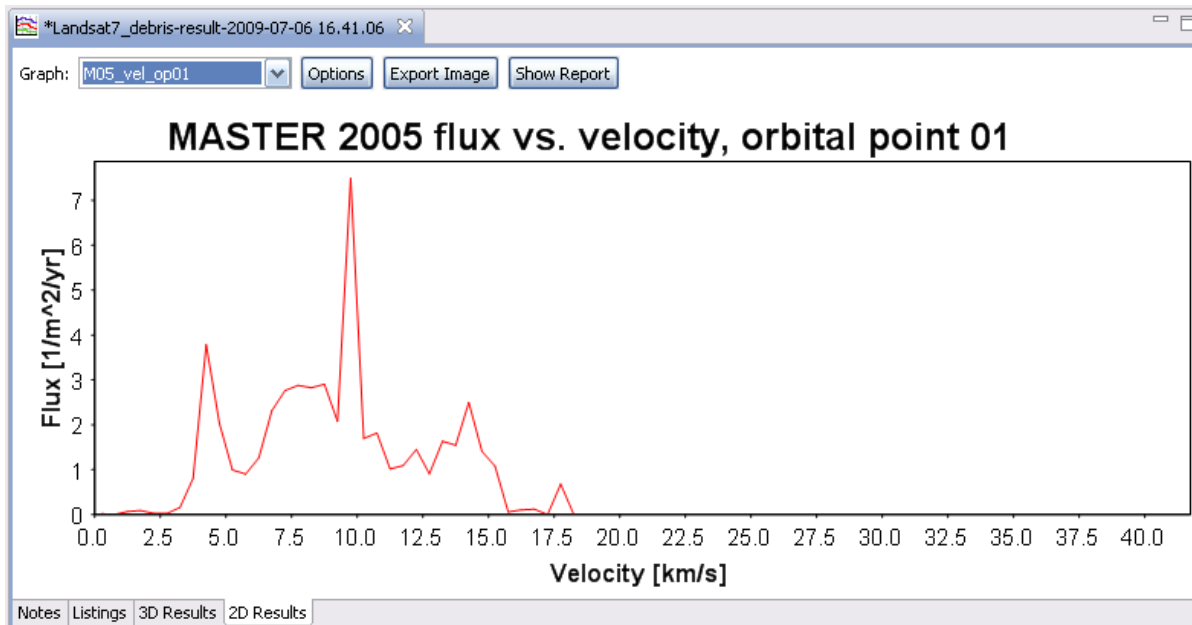
**Figure 2-47:** Debris result editor, 3D Results, Element Chart

From the "Result Set" combo-box, you select a variable for the y axis. From the "Parameter" combo-box, you select a variable for the x-Axis. Afterwards, the appropriate graph for the chosen element and parameter will be displayed, as shown on the bottom of Figure 2-4746. 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, 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) and to export the result of the current or all results in text format, via the "Export All Results" and "Export Current Result" buttons. The export in text format creates a folder with the name of the element's parent object in the indicated folder and all export files or the selected ones will be created under this directory.

## 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 2-48:** 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
MASTER 2009	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
MASTER 8	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
ORDEM2000	$F = f(d)$ , $F = f(\text{azimuth})$ for each orbital point
ORDEM 3.0	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
ORDEM 3.2	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ 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

Debris / meteoroid model	Flux distributions
LunarMEM	$F = f(m)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
MEMr2	$F = f(m)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
MEM 3	$F = f(m)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point and each source (low-, high-density)
IMEM	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ for each orbital point
IMEM2	$F = f(d)$ , $F = f(\text{azimuth})$ , $F = f(\text{elevation})$ , $F = f(\text{velocity})$ , $F = f(\text{density})$ (depending on user input) for each orbital point

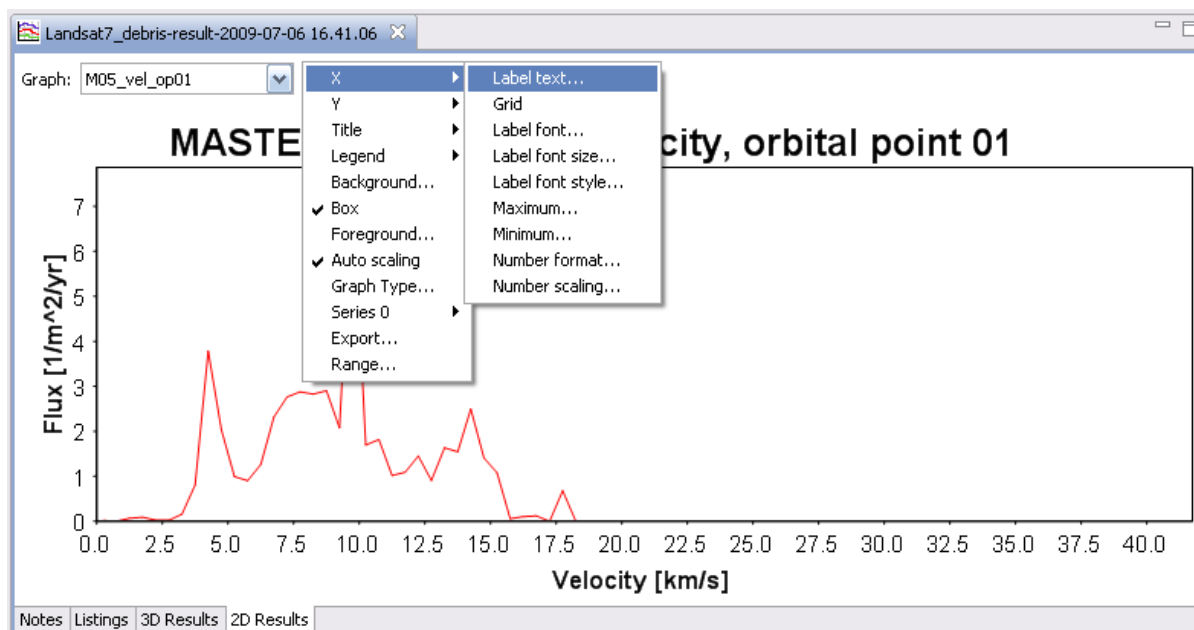
**Table 2-1:** Available 2D charts in dependency of the Debris/Meteoroid model

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 2-49:** Debris result editor, 2D Results, options

You can customize the following chart properties:

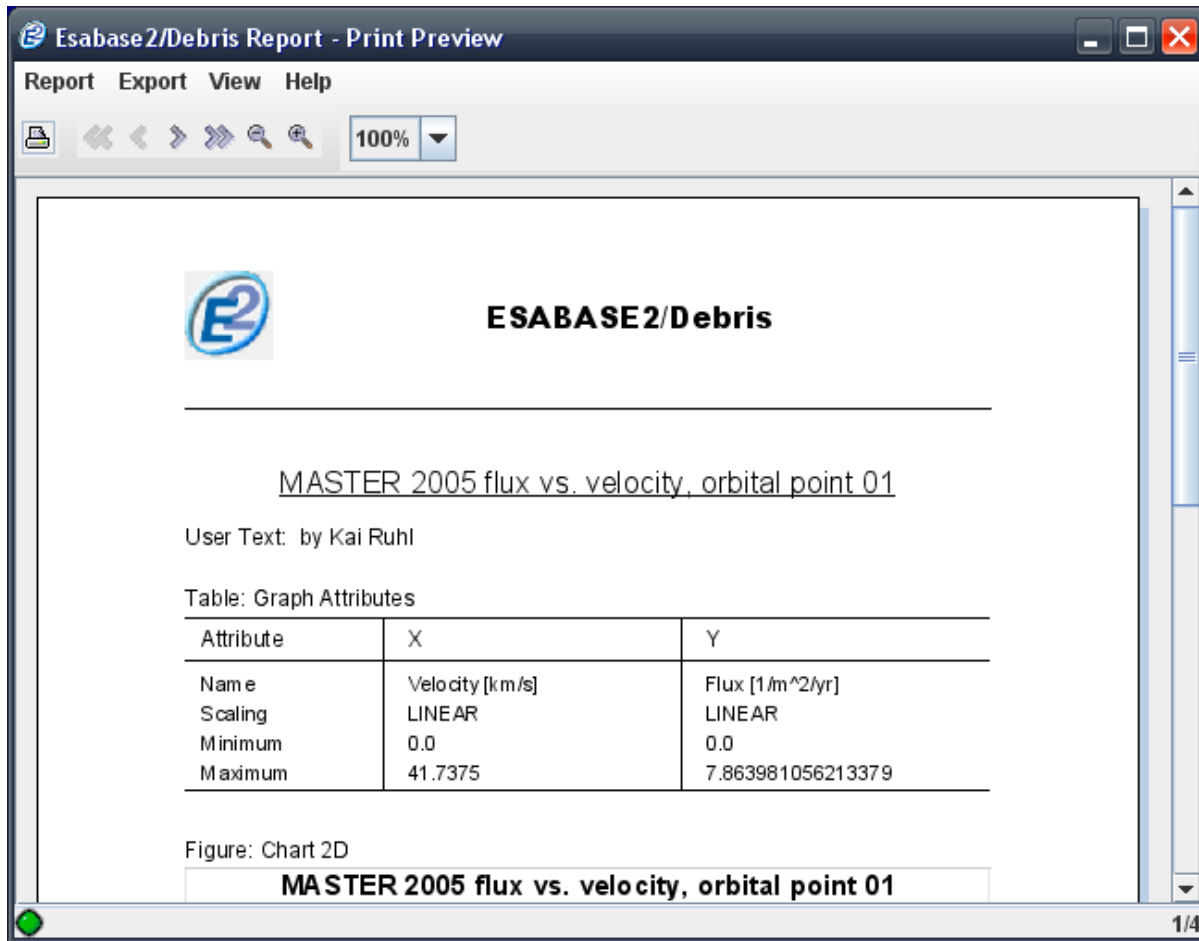
- x, y axis
  - *Label Text*: Changes the text of the axis label.
  - *Grid*: Displays horizontal/vertical dashed lines.
  - *Label font, Label font size, Label font style*: Changes the appearance of the axis label.
  - *Maximum, Minimum*: The value range that this chart shows
  - *Number format*: The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



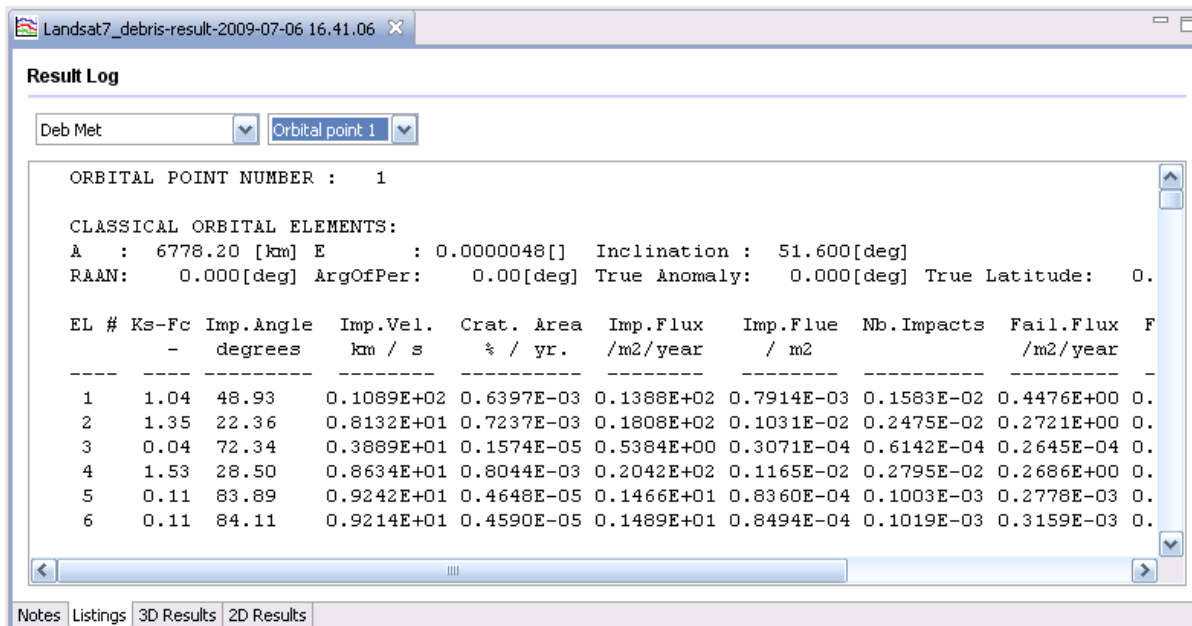
**Figure 2-50:** Debris result editor, 2D Results, reporting

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 2-51:** 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/Meteoroids)
- Failures vs. Ballistic Limit
- Kinematic (output of ESABASE2 Framework)
- Orbit (output of ESABASE2 Framework)

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.

Due to some confusion in the past the interpretation of the Crater vs. Crater size LIS file is described in the following section.

### 2.4.3.1 Crater vs. Crater size (Failures vs. Ballistic Limit)

Figure 2-5251 shows an example of a Crater vs. Crater size LIS file. The name indicates that it tabulates the number of craters again a crater size. The results are cumulative.

## Result Log

Crater vs. Cratersize

```
HITS vs CRATER SIZE File K:\ESABASE2_temp\ESABASE2_6.0.0\workspace\Example\ListingFiles\Plate-Grun_
-----
IELMT Elm Area .1000E-02 .1000E-01 .1000E+00 .1000E+01 .1000E+02 .1000E+03 .1000E+04
1      0.723 .17946E+03 .15043E+03 .32011E+01 .25539E-02 .53327E-06 .00000E+00 .00000E+00
2      0.723 .17573E+03 .14689E+03 .31543E+01 .25253E-02 .52793E-06 .00000E+00 .00000E+00
3      0.015 .17687E+01 .12261E+01 .19729E-01 .14002E-04 .28367E-08 .00000E+00 .00000E+00
4      0.015 .17803E+01 .12288E+01 .19631E-01 .13774E-04 .27809E-08 .00000E+00 .00000E+00
5      0.017 .27159E+00 .65109E-01 .29004E-03 .10363E-06 .76045E-11 .00000E+00 .00000E+00
6      0.017 .26408E+00 .64745E-01 .31146E-03 .11697E-06 .11308E-10 .00000E+00 .00000E+00
7      0.015 .17665E+01 .12030E+01 .18494E-01 .12609E-04 .25269E-08 .00000E+00 .00000E+00
8      0.015 .17978E+01 .12311E+01 .19380E-01 .13432E-04 .27029E-08 .00000E+00 .00000E+00
9      0.017 .29001E+01 .19323E+01 .29708E-01 .20618E-04 .41490E-08 .00000E+00 .00000E+00
10     0.017 .29610E+01 .20053E+01 .31162E-01 .21612E-04 .43512E-08 .00000E+00 .00000E+00
11     0.723 .26833E+02 .13917E+02 .17356E+00 .11468E-03 .22471E-07 .00000E+00 .00000E+00
12     0.723 .27332E+02 .14160E+02 .18190E+00 .12225E-03 .24117E-07 .00000E+00 .00000E+00
```

**Figure 2-52:** Example of Crater vs. Crater size LIS file.

The first column "IELMT" lists the elements of the model, thus the results of the Crater vs. Crater size LIS file are on the element level. The corresponding results on the object level are presented on the bottom of the Deb Met LIS file. Both LIS files provide the mission level of hits.

The second column lists the areas of the corresponding elements in [m<sup>2</sup>].

The columns 3 to 9 provide results (number of hits) for seven different crater size thresholds. This means the listed hit causes a crater that is equal or larger than the threshold crater size. The first (minimum) threshold is the *Min. crater diameter* defined by the user, see 2.2.1.2. Based on this value the other six thresholds are defined by raising the crater size threshold by one order of magnitude. This can be seen very well in the first line of the table in Figure 2-5251, which lists the values of the thresholds as head of the columns.

In the same way the LIS file Failures vs. Ballistic Limit can be interpreted. In this case the number of failures (instead of number of craters) is tabulated again the 'ballistic limit' (instead of crater size), which means thickness of the (back) wall. It uses the same principle and definition of the thresholds.

### 2.4.3.2 Deb Met (Debris/Meteoroids)

Figure 2-5150 shows an example of the main results (Debris/Meteoroids) listing the "~.LISDM". The extent of the file depends upon the user choice for the "Report options:" for the according analysis.

In the most extensive version the listing contains the following information:

- Reflection of used input files.
- Reflection of the input parameter (orbit, mission, applied environment models and equations).
- Reflection of the applied shielding for each object.
- Listing of the objects with their elements, identified by the element ID, and the element area in [m<sup>2</sup>].
- Results for each orbital point (Orbital Point Level)
  - Orbital elements of the point.
  - Results for each element (element level).
  - Results for each object (object level).
  - Results for the whole spacecraft (bottom of the object table).
- Results of one whole orbit (Orbital Arc Level)
  - The results of an object are provided followed by a list of the according element results. This is repeated for each object.
  - Spacecraft results.
- Results of the mission (Mission Level)
  - The results of an object are provided followed by a list of the according element results. This is repeated for each object.
  - Spacecraft results.
- Crater vs. Crater Size results on object level.

- Failures vs. Ballistic Limit results on object level.

The parameters that are analysed are the following:

- Ks factor,
- Average impact angle [deg] (only element level),
- Average impact velocity [km/s] (only element level),
- Cratered area [%],
- Impacts flux [ $\text{m}^2/\text{year}$ ],
- Accumulated impacts fluence [ $\text{m}^2$ ],
- Total number of impacts,
- Failures flux [ $\text{m}^2/\text{year}$ ],
- Accumulated failures fluence [ $\text{m}^2$ ],
- Total number of failures,
- Surface area [ $\text{m}^2$ ] (object level for 1. orbital point, arc and mission level),
- Probability of no failure (orbital level at mission level).

In the following short descriptions of the parameters are presented:

#### **Ks factor:**

The Ks factor is the combined value of the k factor (i.e. the impact flux ratio of the element to the flux of a random tumbling plate [for meteoroids: a fixed random tumbling plate, i.e. with  $V_{s/c} = 0$ ]) and the shading of the plate of Earth and neighbouring surfaces of the spacecraft.

#### **Average impact angle:**

The average impact angle is the average of all impact angles of all non-shaded rays.

**Average impact velocity:** The average impact velocity is the average of all impact velocity (amplitudes) of all non-shaded rays.

#### **Cratered area:**

The cratered area is the area of craters produced by the "possible real impacts" on each element. It is possible that this parameter exceeds the value 100, due to the fact that cases of two impacting particles generating two intersecting areas are not considered.

#### **Impacts flux:**

The impacts flux is the flux per  $\text{m}^2$  and year of impacting particles with diameter between the user defined minimum and maximum values (debris editor).

#### **Impacts fluence:**

The impacts fluence presents the particles per  $\text{m}^2$  of impacting particles with diameter between the user defined minimum and maximum values, calculated as: impacts flux \* DT1 (time step between orbital points).

#### **Total number of impacts:**

The total number of impacts is the total number of impacting.

#### **Failures flux:**

The failures flux is the number of failures per  $\text{m}^2$  and year.

#### **Failures fluence:**

The failures fluence is the number of failures per  $\text{m}^2$  calculated as: failures flux \* DT1.

#### **Total number of failures:**

The total number of failures.

#### **Surface area:**

The surface area is the object(S/C) surface area in  $\text{m}^2$ .

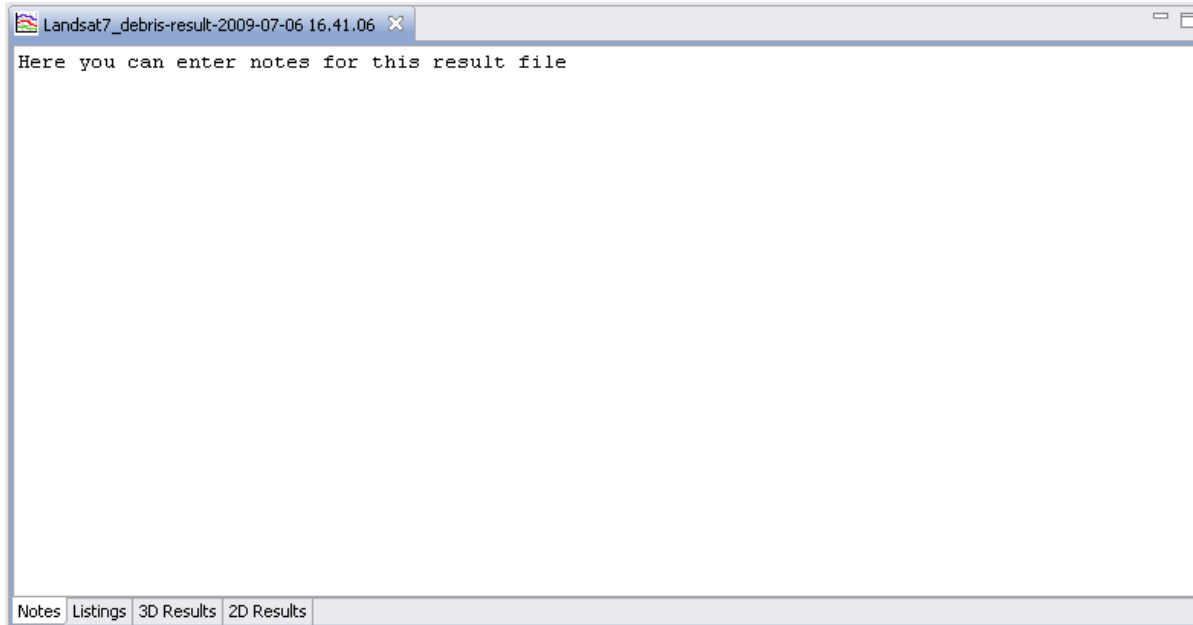
#### **Probability of no failure:**

The probability of no failure is the probability that no failure occurs during the mission time for the object respective spacecraft according to space debris and micro meteoroids environment effects.

## 2.4.4 Notes

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



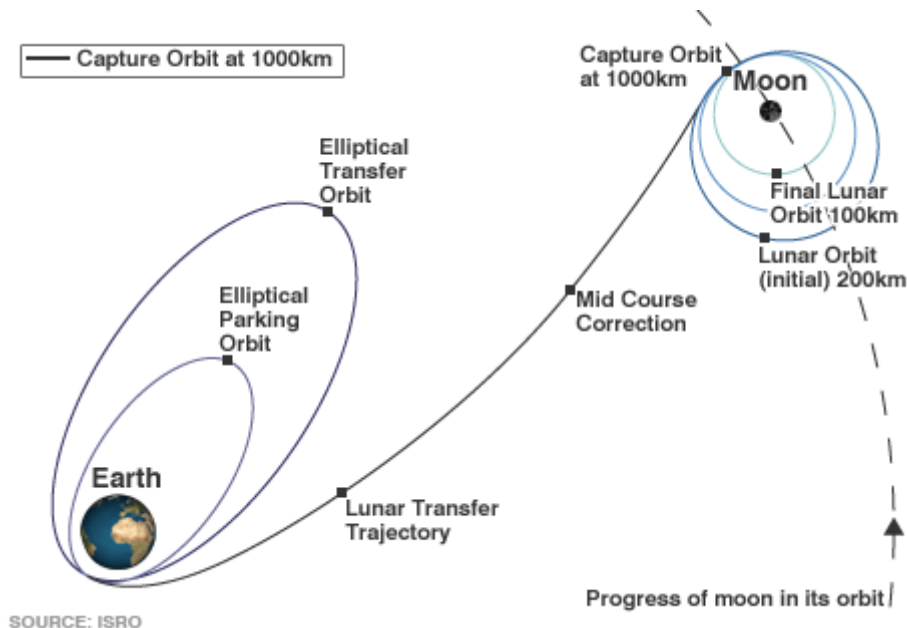


**Figure 2-53:** Debris result editor, 2D Results, notes

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.

### 3 Lunar Mission Debris Analysis

The intention of this chapter is to provide a small overview how a debris analysis for lunar mission can be performed.



**Figure 3-1:** Scheme of the lunar mission of Chandrayaan 1 (source: North East India News)

The Figure 3-1 displays an example of a trajectory of a lunar mission, as was used for Chandrayaan 1.

#### 3.1 Lunar Mission

Two different approaches can be used for an analysis of a lunar mission:

- Abstraction of the mission by splitting it into multiple orbits;
- Describing the mission with state vectors provided via a trajectory file.

In the first case the results of the individual orbits have to be post-processed manually to obtain the results for the whole mission.

The second case provides complete mission results. In this case, a trajectory file is used, describing the whole mission with up to 100 orbital points.

Both approaches for the mission definition are described in more detail in the following sections.

##### 3.1.1 Abstraction of the Lunar Mission

A lunar mission can be abstracted by the definition of multiple orbits. The simplest case includes three orbits (only the journey from Earth to Moon):

- A low Earth orbit (LEO), which is often called the parking orbit;
- A highly elliptical orbit (HEO), the transfer orbit, with a perigee at the parking orbit and the apogee at the orbit of the Moon;
- A low lunar orbit (LLO), which is the target orbit of the mission.

Each of the orbits represents one of the phases of a lunar mission. The three phases describe roughly the lunar mission; the first phase includes the mission time in the vicinity of the Earth, here it is represented by a LEO. The second phase is the transfer from Earth to Moon, represented by a HEO. The third phase of the mission is the motion of the S/C in the vicinity of the Moon, in this case a LLO.

The individual orbits generated in the following give only an outlook of possible tracks and are not combined to reflect a real mission. To abstract a real mission the used mission epochs and durations have to fit a meaningful timeline, i.e. the mission epochs have to form a continuous time interval (second track starts at the end of the first track etc.). Furthermore the start epoch and orbit parameters of the

transfer orbit have to be defined in a way that the Moon interferes with the transfer orbit and the S/C is at the according sector of the orbit at the particular moment. This implies also the usage of the correct orbital parameters, e.g. inclination, true anomaly at start etc.

Nevertheless, to get an impression of the result magnitudes to be expected and to get the feeling of the usage, three independent orbits can be used. This is also the case for the following orbit descriptions.

### 3.1.1.1 The Parking Orbit

Before the start of the journey to Moon the spacecraft is placed in an orbit around the Earth. A possibility is the low Earth orbit of the ISS. The basic values of such an orbit can be:

- Central body (centre of motion): Earth
- Semi-major axis = 6785 km
- Eccentricity = 0.001
- Inclination = 51.6 deg
- Other angles = 0.0 deg

The mission starts on January the 1, 2013 at 0:00. The orbital period of the orbit is ca. 92.7 minutes, let's say that 3 orbits are completed before starting the transfer, which means a mission duration of 278.1 minutes for the LEO. Thus the end epoch is January the 1, 2013 at 4:38 and 6 seconds.

The mission file can be created as described in /1/ section 3.1. The filename *ParkingOrbit* will be used in the text to identify the orbit. Figure 3-2 shows the mission editor with the parameters applied as introduced before.

**Figure 3-2:** Parking orbit parameters

Figure 3-1 shows that in a realistic scenario the first phase of a lunar mission is more complex than just one orbit. The mission phase is often composed of multiple orbits with different eccentricities and inclinations. Reasons for such an approach are the minimisation of the required propellant and also of the failure risk. This approach can be modelled by definition of new mission files, with according orbits and mission times, after each firing of the thrusters. The first phase of the lunar mission would be than described by multiple mission files, instead of one, the results of which have to be combined in the manual post-process.

### 3.1.1.2 Transfer Orbit

The transfer orbit is abstracted by a highly elliptic orbit around the Earth, with the perigee at the LEO orbit and the apogee at ca. the distance to the Moon.

Possible parameters for a representative HEO are:

- Central body (centre of motion): Earth
- Semi-major axis = 206585 km
- Eccentricity = 0.9671892
- Inclination = 28.5 deg
- Other angles = 0.0 deg

This trajectory has nearly the same perigee as the one of the LEO.

The start time for the transfer orbit is the mission end epoch of the LEO mission file, i.e. January the 1, 2013 at 4:38 and 6 seconds. A HEO with the introduced parameters has a period of ca. 10.82 days. Thus the half of the period (only the way to Moon) would be for a Hohmann transfer ca. 5.41 days. Let's say the transfer duration is more than 5 days but shorter than the duration of a Hohmann transfer. The end epoch for the second phase of the lunar mission, the transfer is thus arbitrary adjusted to January the 6, 2013 at 0:00.

The mission file can be created as described in /1/ section 3.1. The filename *TransferOrbit* will be used in the text to identify the orbit. The Figure 3-3 show the mission editor with the parameters applied as introduced before.

The screenshot shows a software window titled "TransferOrbit" with a tab icon. The main area is divided into several sections:

- Orbit:** Contains input fields for Central body (Earth), Orbit Type (GEN), Semi-major Axis (206585.0 [km]), Perigee Altitude (400.079 [km]), Eccentricity (0.9671892 [-]), Apogee Altitude (400013.641 [km]), Inclination (28.5 [deg]), RAAAN (0.0 [deg]), Argument of perigee (0.0 [deg]), True Anomaly (0.0 [deg]), Solar time (7.0 [hours]), and Geographic longitude (3.0 [deg]).
- Mission Time:** Includes Number of Orbits (1.0), Start Date (2013 - 1 - 1 at 4 : 38 h 6 s), and End Date (2013 - 1 - 6 at 0 : 0 h 0 s). A note states: "Please note: Number of orbits and end date may be used differently in different applications. Example: number of orbits must be 1 for Debris; mission end date is only used in Debris, not in Atmosphere, Ionosphere, Sunlight or COMOVA."
- Time Interval or Number of Orbital Points:** Includes Time Interval between Orbital Points (58403.48 [sec]) and Number of Orbital Points (16.0). A note states: "Please keep time interval and and number of orbital points in sync. Otherwise results can be mixed. Currently, the time interval will take preference."

**Figure 3-3:** Transfer orbit parameters

The Figure 3-1 indicates that correction manoeuvres can be performed during the transfer. Such case can also be modelled by defining different mission files with according orbits and durations before and after the manoeuvre.

### 3.1.1.3 Target Orbit

The target orbit is the desired trajectory around the Moon. Polar tracks with low altitudes are often aimed lunar orbits. Parameters for such orbit can be:

- Central body (centre of motion): Moon
- Semi-major axis = 1838 km
- Eccentricity = 0.0
- Inclination = 90 deg
- Other angles = 0.0 deg

The starting epoch of this phase of the lunar mission is the end epoch of the previous phase: January the 6, 2013 at 0:00. As already mentioned this is only an example, so let arbitrary say that the mission duration is one month, thus the end date is February the 6, 2013 at 0:00.

The mission file can be created as described in /1/ section 3.1. The filename *TargetOrbit* will be used in the text to identify the orbit. The Figure 3-4 show the mission editor with the parameters applied as introduced before.

The screenshot shows a software window titled "TargetOrbit" with a tab icon. The main content area is divided into three sections:

- Orbit:** Contains several input fields:
  - Central body: Moon (dropdown)
  - Orbit Type: GEN (dropdown)
  - Semi-major Axis: 1838.0 [km]
  - Eccentricity: 0.0 [-]
  - Inclination: 90.0 [deg]
  - RAAN: 0.0 [deg]
  - Argument of perigee: 0.0 [deg]
  - True Anomaly: 0.0 [deg]
  - Solar time: 7.0 [hours]
  - Geographic longitude: 3.0 [deg]
  - Perigee Altitude: 100.000 [km]
  - Apogee Altitude: 100.000 [km]
- Mission Time:** Contains:
  - Number of Orbits: 1.0
  - Start Date: 2013 - 1 - 6 at 0 : 0 h 0 s
  - End Date: 2013 - 2 - 6 at 0 : 0 h 0 s
- Time Interval or Number of Orbital Points:** Contains:
  - Time Interval between Orbital Points: 441.93 [sec]
  - Number of Orbital Points: 16.0 [ ]

There are "apply" buttons next to the time interval and number of orbital points fields. A note on the right side of the Mission Time section reads: "Please note: Number of orbits and end date may be used differently in different applications. Example: number of orbits must be 1 for Debris; mission end date is only used in Debris, not in Atmosphere, Ionosphere, Sunlight or COMOVA."

**Figure 3-4:** Target orbit parameters

The Figure 3-1 depicts that in fact the targeted orbit is not reached immediately. After the capture of the spacecraft by the Moon the trajectory is corrected and reached via multiple thrusters impulses. Thus also the last phase of the mission can be modelled in more detail by defining various mission files, which describes the orbits between the firings.

### 3.1.2 Trajectory File

The trajectory file allows the user, in contrary to the abstraction of a lunar mission, to define the whole track of the lunar mission in one file using the maximum of 100 orbital points / state vectors. If more orbital points than the maximum are contained in the file, only the first 100 points can be used. In this case a warning is shown in the console view.

The Figure 3-5 provides an example of a trajectory file, which represents the half of a highly elliptical orbit around Earth by 9 orbital points. The apogee is at the Moon distance and the last two points are in the in the sphere of influence of the Moon, thus they are interpreted as orbital points of lunar orbits.

```

*****
* Example trajectory file.
*
* Head defines the coordinate system and the epoch format:
* Possible origin bodies: (currently)
*   Earth
*   Moon
* Origin is optional, if it is missing, Earth is assumed to be the origin body
*
* Possible target bodies: (currently)
*   Earth
*   Moon
*
* Possible coordinate system:
*   ECI: Earth Centered Inertial (EME2000)
*   LCI: Lunar Centered Inertial (Moon_J2000) Mean pole (z),
*       IAU node of J2000.0 (x) System
*
* Possible epoch format:
*   MJD: Modified Julian Day 1950
*   UTC: CCSDS ASCII time code A: YYYY-MM-DDThh:mm:ss.d->d
*
* Body provides the state vectors with appropriate epoch
* Each state vector represents an orbital point
* Format: epoch X Y Z X_dot Y_dot Z_dot
*****
Origin: Earth
Target: Moon
Coordinates: ECI
Epoch: MJD
*****
$$BEGIN
19798.48806713   -5167.031478526992   -5714.255328231473   0.164960105913E-12   4.624454537551   -8.794028563774   -1.656573672415
19799.12152037   148315.109921829629   -29170.226320218550   -22994.538303340792   1.759254471321   0.138532715746   -0.215028620544
19799.75497361   226226.195277236839   -18725.302590315150   -32003.944520032528   1.165682717708   0.221179444868   -0.127063680752
19800.38842685   280398.370256302762   -6027.124364110680   -37620.677676406325   0.836727320480   0.238308397627   -0.081729838999
19801.02188009   319467.564641026722   7060.320356665809   -41203.360972652750   0.601124790635   0.238235389148   -0.050731326032
19801.65533333   347003.923373181664   19916.583080674551   -43295.770668876990   0.410462982675   0.230658389569   -0.026541351840
19802.28878657   364833.864160855301   32226.446256702318   -44175.831010104965   0.244018276115   0.218532860558   -0.006080424525
19802.92223981   373947.690921552770   43771.471716275177   -43999.897190881798   0.090479017080   0.202768322262   0.012248515984
19803.55569306   374834.343681340863   54355.372132761142   -42855.701921501168   -0.057725707849   0.183352046203   0.029440347424
*****
$$END

```

**Figure 3-5:** Trajectory file example

The trajectory file is composed of two parts (not considering the comments); the head and the body. The head of the file provides information about the mission. The keywords for the kind of information are 'Origin', 'Target', 'Coordinates' and 'Epoch'. They are required to indicate which information is given. The colon is required as a marker for the start of the input. No predefined order for the provision of the information exist, it can theoretically be placed everywhere in the head (before \$\$BEGIN), but it is recommended to group the inputs for better readability. The input is handled not case sensitive.

**Origin** provides the information of the starting celestial body. Possible inputs are **Earth** and **Moon**. This input is optional; if no origin is given Earth is used as default.

**Target** provides the information of the journey's destination. Possible inputs are **Earth**, **Moon**, **L1** and **L2**. It is mandatory.

For trajectories around one celestial body (only Earth orbit or only lunar orbit), the origin and the target must be equal. Except, if orbits at the Sun-Earth libration points L1 and L2 are targeted the origin must be **Earth** and the target **L1** or **L2**, respectively.

**Coordinates** provides the information of the coordinate frame that is used for the given state vectors. It is mandatory. Possible inputs are **ECI** and **LCI**. Thus the state vectors can be provided in Earth centred inertial (ECI) frame, which is EME2000, or in lunar centred inertial (LCI), sometimes also called Moon J2000. LCI is a mean pole (z-axis) IAU node (x-axis) at the epoch of J2000.0 system.

**Epoch** provides information of the time format used for the state vector epochs. It is mandatory. Possible inputs are **MJD** and **UTC**. MJD indicates that the epochs are given in the modified Julian day 1950 format, thus a decimal value DDDDD.d→d. UTC implies the use of the CCSDS ASCII time code A, i.e. YYYY-MM-DDThh:mm:ss.d→d, for the definition of the epochs.

The body of the file provides the state vectors of the trajectory. It must be placed behind the head and has to start with the key '\$\$BEGIN'. If the key '\$\$END' is not found, a warning is directed to the console view, which states that the trajectory file could be incomplete, but the analysis is continued.

The listed state vectors have to be preceded by the according epoch in the predefined format (MJD or UTC) and follow the format: X Y Z X\_dot Y\_dot Z\_dot. The state vector has to be in the predefined coordinate frame to get reasonable results.

Each state vector (with according epoch) is interpreted as an orbital point to be analysed. The maximum number of orbital points for the trajectory file is currently limited to 100.

The trajectory file can be modified with the ESABASE2 editor or every other text editor outside the application. To define a text file to be trajectory file and to be identified as such by ESABASE2 it must have the file type \*.trajectory.

#### Debris Input Limitation for Lunar Mission

The use of the Debris solver and the generation of a debris file are described in the chapter 2. The intention of this section is to introduce the limitations associated with the analysis of lunar mission or the use of a trajectory file.

### 3.1.3 Specifics for Abstracted Lunar Mission

In the case of an abstracted lunar mission the individual mission steps, represented by the mission files, are analysed independently. Thus, theoretically, for the analysis of orbits in the vicinity of the Earth all model possibilities, except LunarMEM, are available. But if the results of the individual mission steps are to be combined (manual post-processing), they have to be coherent. This means coherent models should be used throughout the analysis of the mission. The use of the debris and meteoroid models can be seen as independently.

For each mission file a debris file can be defined due to the individual analysis. More practicable is the definition of one debris file for the analysis of orbits around the Earth and one debris file for the analysis of orbits around the Moon. The debris file around the Earth should define the debris (if desired) and meteoroid model to be used, e.g. MASTER 2009 and MEM. The debris file around Moon should define the meteoroid model to be used, e.g. LunarMEM.

#### 3.1.3.1 Debris Models

Debris models are available only for the vicinity of the Earth and thus can be only applied to orbits around the Earth.

In the case that the debris environment should be considered only for the low Earth orbits than all debris models can be used. If the effects of the debris shall be considered for trajectories with semi-major axes about LEO (> 2000 km) also, then only the MASTER models and ORDEM 3.0/3.2 are applicable. This practically excludes NASA90 (target altitude < 1000 km) and ORDEM2000 (target altitude < 2000 km) models, because using them will lead to neglecting of the debris environment in the vicinity of the Earth for the transfer orbits.

Four versions of the MASTER model are available. MASTER 2001 is the oldest version and based on outdated data, but it is fast and thus can be handy sometimes. MASTER 2005 is the successor of MASTER 2001 and based on real data up to 2005. It is applicable to the vicinity of the Earth up to 1000 km above the geosynchronous orbit. The limitation of MASTER 2005 is the provision of mission (averaged) results only. Due to the averaged results it should be ensured that the examined mission part is in the range of validity of MASTER 2005, otherwise not existing debris fluxes will be provided. Furthermore the debris analysis results are not tailored to the considered arc of the track. MASTER 2009 is the successor of MASTER 2005 and is based on real data up to 2009. It also includes population development models, thus future populations down to 1 µm, for all sources except the MLI population it introduced. MASTER 8 model is the successor of MASTER 2009. It is based on the most up-to-date data (real data up to 2016) of the currently included models, provides future population data also for MLI, reflects the review of the implemented populations and introduces condensed population data that allows to base an analysis on a single condensed population considering all sources. Furthermore, as already MASTER 2009, it provides data for each orbital point, besides the averaged mission data. Thus data for individual points of interests can be extracted from the results. If only a part of a transfer orbit is considered and analysed using MASTER 2009 or MASTER 8 the desired results shall be extracted from the orbital points included in the arc. Also NASA's latest model ORDEM 3.0/3.2 (considers real data up to 2010/2016) allows the application up to 40000 km altitude about Earth, but it has the same problem as MASTER 2005 denying the possibility to divide the orbit in arcs. Furthermore the ORDEM 3.0/3.2 executable shows a very slow performance for high eccentric orbits (> 1h).

Summarising the properties of the debris models it can be concluded that MASTER 8 is the preferable choice due to its actuality (compared to 2009) and the range of validity for the abstracted lunar mission. If the transfer orbit is represented by only one mission file as in *TransferOrbit*, then also MASTER 2005 can be used, which show a better performance, also ORDEM 3.0/3.2 is an alternative due to its actuality, but with bad performance. If the transfer trajectory is represented by multiple mission files, then

MASTER 8 should be used and the results of individual orbital points included in the considered arc shall be combined to achieve the desired result for the arc.

### 3.1.3.2 Meteoroid Models

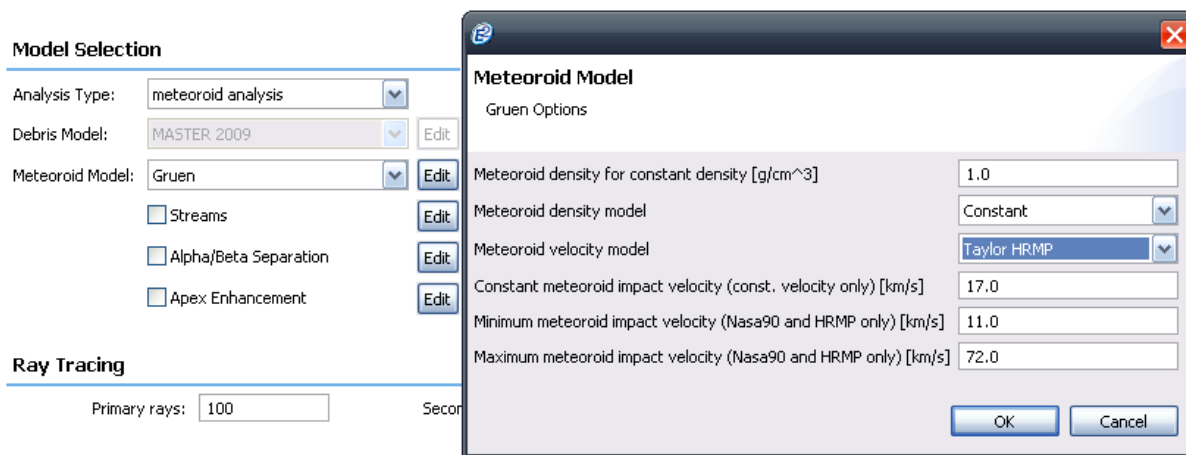
The ESABASE2/Debris application allows the use of several alternative meteoroid models; Grün, Divine-Staubach, MEM, MEMr2, MEM 3 and LunarMEM as well as IMEM and IMEM2. However, LunarMEM is a MEM version tailored to the vicinity of the Moon and MEMr2 is a newer release that combines MEM and LunarMEM. MEM 3 is the newest release of MEM considering the vicinities of Earth, Moon, Mercury, Venus and Mars.

For the analysis of orbits around the Earth the models Grün, Divine-Staubach, MEM, MEMr2 and MEM 3 are available. For the analysis of lunar trajectories Grün, MEMr2, MEM 3 and LunarMEM are available. To achieve coherent results for the whole track the models used for Earth and Moon vicinities shall be also coherent. Therefore, either Grün model or MEMr2 or MEM 3 models for both Earth and Moon part of the orbit or MEM for Earth and LunarMEM for Moon part of the orbit is recommended to be used. Additionally to the missing equivalent for the lunar trajectories, the Divine-Staubach model application is limited to 1000 km above the geosynchronous orbit.

If the Grün model is applied for the analysis of a lunar mission it is recommended to use the Taylor HRMP velocity distribution. It provides the most reasonable results compared with other models. The Figure 3-6 shows the activation of the Taylor HRMP velocity distribution for the Grün model via the 'Edit' button.

The available NASA90 velocity distribution is designed for the vicinity of the Earth.

The consideration of the focusing effect of the celestial body for constant velocity disregards the gravity constant of the body. This leads to overestimation of the flux for lunar orbits.



**Figure 3-6:** Taylor HRMP activation with the Edit button for Grün

### 3.1.4 Specifics for Trajectory File

The trajectory file can be combined with a limited number of models. The available models are selected according to the advantages and disadvantages described in 3.1.3.

Due to the possibility to tailor the results to desired arcs and handling a higher variety of orbits, the MASTER 2009 and MASTER 8 models are available for the debris analysis. As an alternative also ORDEM 3.0/3.2 are made available.

The models Grün, MEM, MEMr2, MEM 3 and LunarMEM can be combined with a trajectory file. Thereby the choice of MEM or of LunarMEM means the same to the software. It automatically switches from MEM to LunarMEM if the centre of motion is identified to be the Moon.

Since the debris and the mission files are independent, a try for each pair of files can be given. Non-compatible files will result in an error message, which should describe the problem.



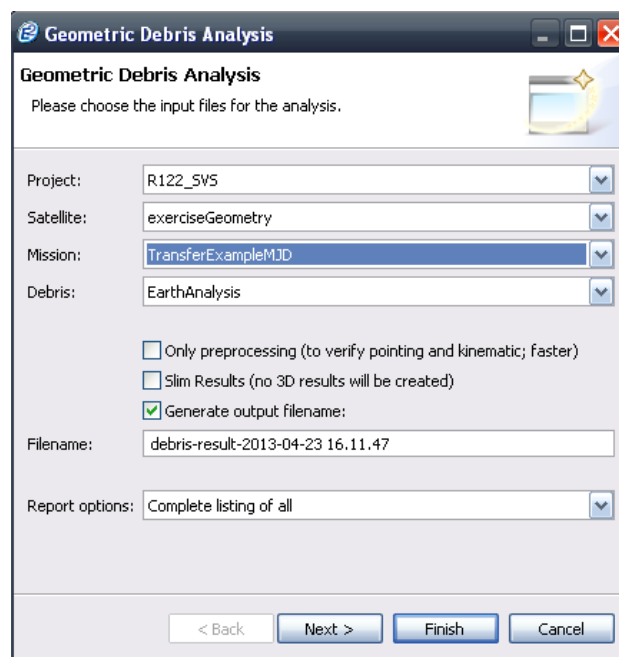
### 3.2 Perform an Analysis

Three mission files were presented in section 3.1 abstracting the lunar mission and two debris files were suggested (Earth: MASTER 2009, MEM and Moon: LunarMEM). Also a geometry is required for a geometrical analysis. A sample geometry is generated in the ESABASE2/Framework software user manual /1/ in section 3.2, which can be used for the analysis.

How to perform an analysis is described in section 2.3.1. For the case of an abstracted lunar mission three analyses have to be performed. Each with the same geometry but for the two analyses with *ParkinOrbit* and *TransferOrbit* mission files the debris file for orbits around the Earth has to be used. The last analysis is combined of the geometry the *TargetOrbit* and the debris files for the orbits around the Moon.

After the performance of all three analysis the results need to be combined in a manual post-processing to get the results of the whole mission.

To use a trajectory file it can be simply chosen in the drop down menu of the mission files as shown in Figure 3-7.



**Figure 3-7:** Choosing a trajectory file

## 4 Additional Information on Specific Debris Analyses

Debris analyses on special orbits can require specific configurations or have specific limitations. Such information is listed in the following. The current content of this chapter is:

- Specific information for analyses on L1/L2 orbits.

### 4.1 Specific Information for Analyses on L1/L2 Orbits

This section describes the specifics of configurations and limitations, which should be considered for the analyses of satellites at L1/L2 orbits. The information concerns the analyses using the

- Mission file, and
- Trajectory file.

#### 4.1.1 L1/L2 Orbits with Mission File

##### 4.1.1.1 L1/L2 Orbit Definition via Mission File

The mission file can be created as described in /1/ section 3.1. The central body "Earth" provides the orbit type options "L1" and "L2". The Figure 4-1 shows a defined L1 orbit.

The screenshot shows a web-based form for defining an L1 orbit. The form is titled "L1-orbit" and contains several sections:

- Orbit:**
  - Central body: Earth
  - Orbit Type: L1
  - Orbit defined by:  Semi-major Axis and Eccentricity,  Perigee Altitude and Apogee Altitude
  - Semi-major Axis: 1500000.0 [km]
  - Eccentricity: 0.0 [-]
  - Inclination: 23.45 [deg]
  - RAAN: 39.19 [deg]
  - Argument of perigee: 0.0 [deg]
  - True Anomaly: 0.0 [deg]
  - Solar time: 7.0 [hours]
  - Geographic longitude: 3.0 [deg]
  - Perigee Altitude: 1493621.860 [km]
  - Apogee Altitude: 1493621.860 [km]
- Mission Time:**
  - Number of Orbits: 1.0
  - Start Date: 2013 - 5 - 1 at 12 : 0 h 0 s
  - End Date: 2014 - 5 - 6 at 12 : 0 h 0 s
- Time Interval or Number of Orbital Points:**
  - Time Interval between Orbital Points: 3552000.0 [sec] [apply]
  - Number of Orbital Points: 10.0 [ ] [apply]

Additional text on the right side of the form includes a note: "Please note: Number of orbits and end date may be used differently in different applications." and an example: "Example: number of orbits must be 1 for Debris; mission end date is only used in Debris, not in Atmosphere, Ionosphere, Sunlight or COMOVA."

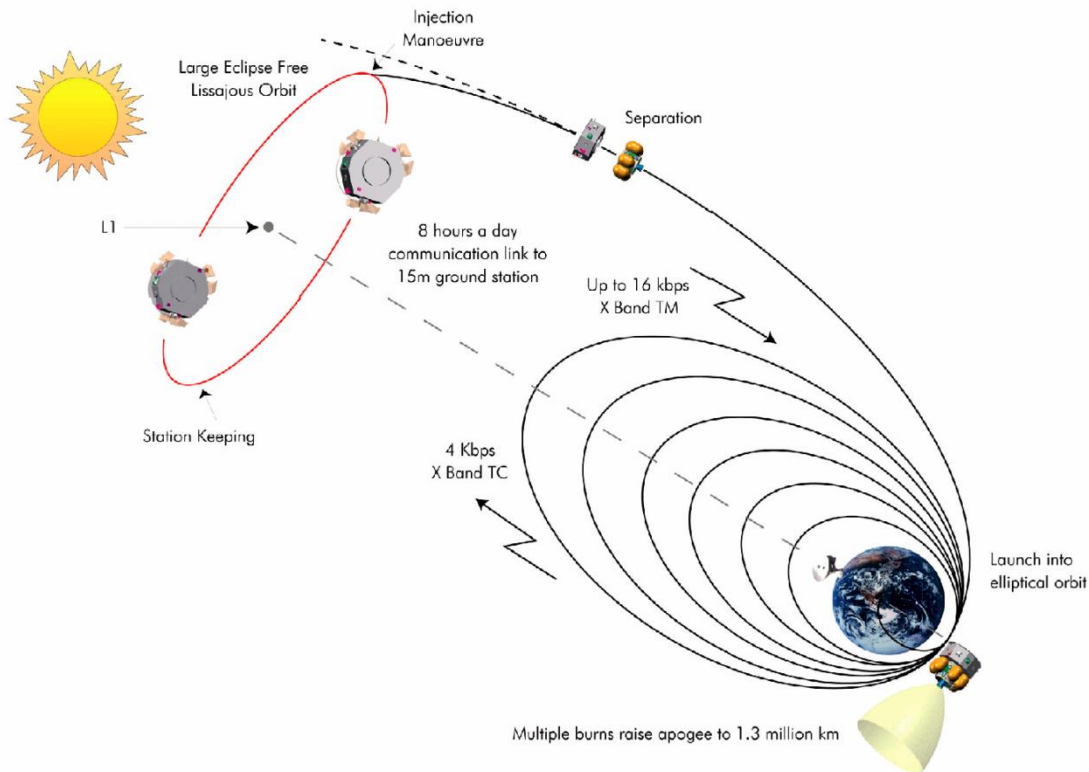
**Figure 4-1:** L1 orbit definition in the mission editor

The mission file allows choosing an orbit at one of the Sun-Earth libration points L1 respective L2. Due to the fix definitions of the orbits at libration points, the orbital parameters are not customisable, as can be seen in Figure 4-1.

The mission time is defined as described before, but the meaning of the orbital points number and their time intervals is different. In the case of L1/L2 orbits not one orbit is considered to estimate the orbital points, but the points are distributed over the whole mission time at equidistant time intervals, where the first orbital point is at mission start and the last orbital point is at mission end. This is also the reason, why the number of orbital points for the L1/L2 orbits needs to be an integer.

Figure 4-2 illustrates the concept for the transfer and operational orbit of the LISA Pathfinder. Defining a L1 or L2 orbit via the mission editor provides only the results for the mission part at the respective L1/L2 orbits. If the whole mission shall be analysed, an abstraction of the individual mission phases are

required. For this purpose the method as described in section 3.1.1 for lunar orbits can be applied by changing the target orbit to L1/L2 orbit.



**Figure 4-2:** LISA Pathfinder transfer and operational orbit concept (copyright: ESA)

#### 4.1.1.2 Model Limitations for L1/L2 Orbits with Mission File

The Sun-Earth libration points L1 and L2 have each a distance of ca. 1.5 Mio km from Earth. At this distance only analyses considering meteoroid environment can be performed. Furthermore, only the meteoroid models **Grün**, **MEM**, **MEMr2** and **MEM 3** are applicable with the L1/L2 orbits. The Divine-Staubach implementation of ESABASE2 is coupled to the most current MASTER model and thus only applicable up to a radius 1000 km about GEO radius. The LunarMEM model is a MEM model tailored to the Moon's vicinity. The IMEM and IMEM2 models are available in Interplanetary mode only. For these reasons the Divine-Staubach, the LunarMEM, the IMEM and the IMEM2 models are not applicable with L1/L2 orbits. In the case of MEMr2 it should be considered, that the "Earth" sub-model is used for the analysis and not "Interplanetary", since the latter one is currently not applicable in ESABASE2/Debris.

#### 4.1.2 L1/L2 Orbit Definition via Trajectory file

The Trajectory file and its use are already described in chapter 3 for the lunar missions. The given characteristic in that chapter are also applicable for the L1/L2 orbits. This means for example that the available environment models are **MASTER 2009**, **MASTER 8** and **ORDEM 3.0/3.2** for Debris and **Grün**, **MEM**, **MEMr2**, **MEM 3** and **LunarMEM** for the meteoroids, where LunarMEM is switched to MEM internally.

Beside the descriptions above the following information could be also of interest.

With the L1/L2 orbits analyses capability the "Target"s "L1" and "L2" were introduced, as listed in section 3.1.2. "L1" and "L2" can be used only as targets and "Earth" as origin is mandatory for this cases. Furthermore it is insignificant if you use "L1" or "L2" for the trajectory, except for the clarity of the track defined by the trajectory file for the user. The background is the following.

The orbits at the Sun-Earth libration points L1 and L2 are interpreted as Earth bounded orbits. In this case the configuration would be "Origin: Earth, Target: Earth". But such configuration would lead to an

abortion of the execution for a trajectory aiming at a libration point, because Earth's sphere of influence of hardly 1 Mio km is exceeded and the software is not able to interpret the state vectors any more due to missing central body. To avoid this problem "L1" and "L2" are introduced. Actually both options have the same functionality, they trigger a virtually extension of Earth's sphere of influence, and are not restricted to the listed state vectors of the file. (So you can use "L2" for state vectors of a L1 orbit and vice versa.)

The method behind is simple. For an Earth bounded path in the trajectory file which exceeds Earth's usual sphere of influence the "Target" "L1" (or "L2") is applied. During the parsing of the file *HEAD* this "L1" (or "L2") statement is interpreted as a trigger to extend Earth's sphere of influence to ca. 3 Mio km. After the extension the "Target" is reset to "Earth". In this way the state vectors in the trajectory file are interpreted as Earth bounded flying path, but the Earth is considered to be the central body for a very high distance.

## 4.2 Additional Available Celestial Bodies

Except Earth and Moon the following celestial bodies are available within ESABASE2: Mercury, Venus and Mars. They can be selected in the mission file to define a Keplerian orbit around it. They are not available for trajectory mode. If a more complex trajectory is required, please use the Interplanetary mode providing the trajectory via SPICE.

Mercury, Venus and Mars can be combined with MEM 3. Currently no other model incorporates the consideration of effects on the flux in the vicinity of these planets. In the case of MEM 3 these effects on the flux are also considered in the Interplanetary mode.

## 5 Scripting Mode

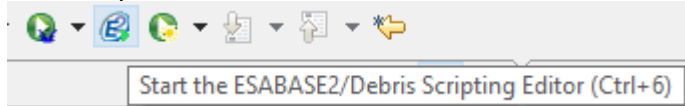
Since version 9.0, ESABASE2 provides facilities for automated debris analysis runs: You may provide ranges for mission- and debris-related parameters and a corresponding number of analysis runs will be executed automatically. So it is possible to perform analysis runs e.g. for a range of orbit parameters or for certain damage equations in one go.

### 5.1 Overview

The configuration process for scripted analysis runs is separated from the ESABASE2 GUI into two additional components:

- **The Scripting Editor** lets you define parameter ranges or simple parameter changes. From this input it will produce a batch of analysis runs that can be performed later on.
- **The Batch Processor** iterates over the generated batch of analysis runs and starts ESABASE2 for each item in the batch.

Both components are accessible from within the ESABASE2 GUI, see.



**Figure 5-1:** Start Button for the Scripting Editor in the ESABASE2 framework

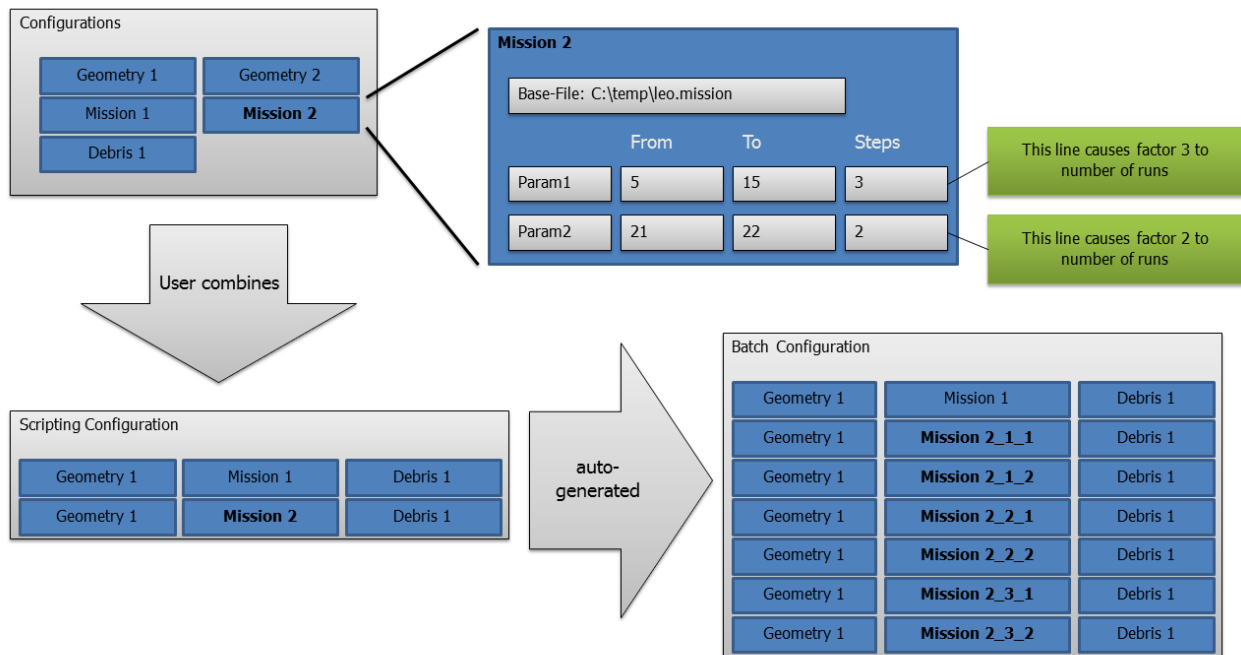
So in the first step, the scripting editor is used to prepare so-called configuration items. Such a configuration item refers to one existing file. This might be a mission-, a debris- or a geometry-file. Alternatively to a mission file, a trajectory file might be referenced. Now all the parameters of the referenced file with their current values are present in the configuration item.

For debris- and mission-configuration items, the scripting-functions are available. It is possible to either set a certain parameter to a certain value or to define a value range for this parameter. These functions are not available for geometry or trajectory configuration items.

When the geometry-, mission-, and debris-configuration items have been prepared, they need to be combined in a scripting configuration. Each scripting configuration item consists of one geometry-, one mission- and one debris configuration item. Configuration items can be shared amongst multiple script configuration items – e.g. the same geometry may be used in each scripting configuration item.

The last step is to generate the batch of run configurations from the scripting configuration. This is done automatically by the Scripting Editor. It executes the logic implied by setting value-ranges and transforms the possible combinations of scripted parameters into concrete run configurations.

This process is illustrated in Figure 5-2:

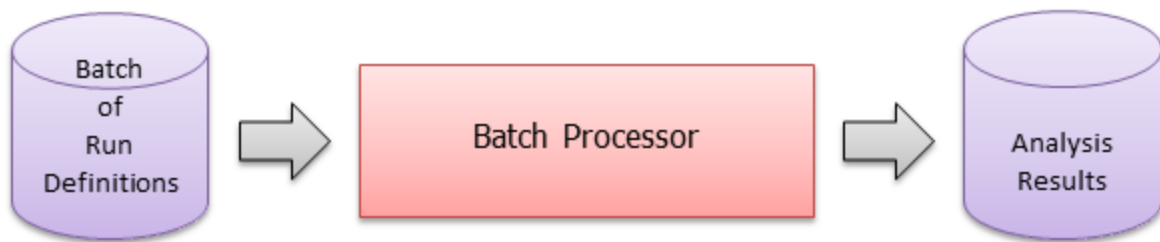


**Figure 5-2:** Workflow for creating a batch of analysis runs

The collection of configurations contains 5 entries in this example. The entry "Mission2" is shown in more detail. It refers to a base file "leo.mission" and contains all the parameters from this file by default. The virtual parameters "Param1" and "Param2" are scripted here by setting a value range for each of them, followed by a number of steps to fill this range. Every parameter combination will result in an own analysis run – so a certain attention needs to be paid here to not underestimate the number of generated runs.

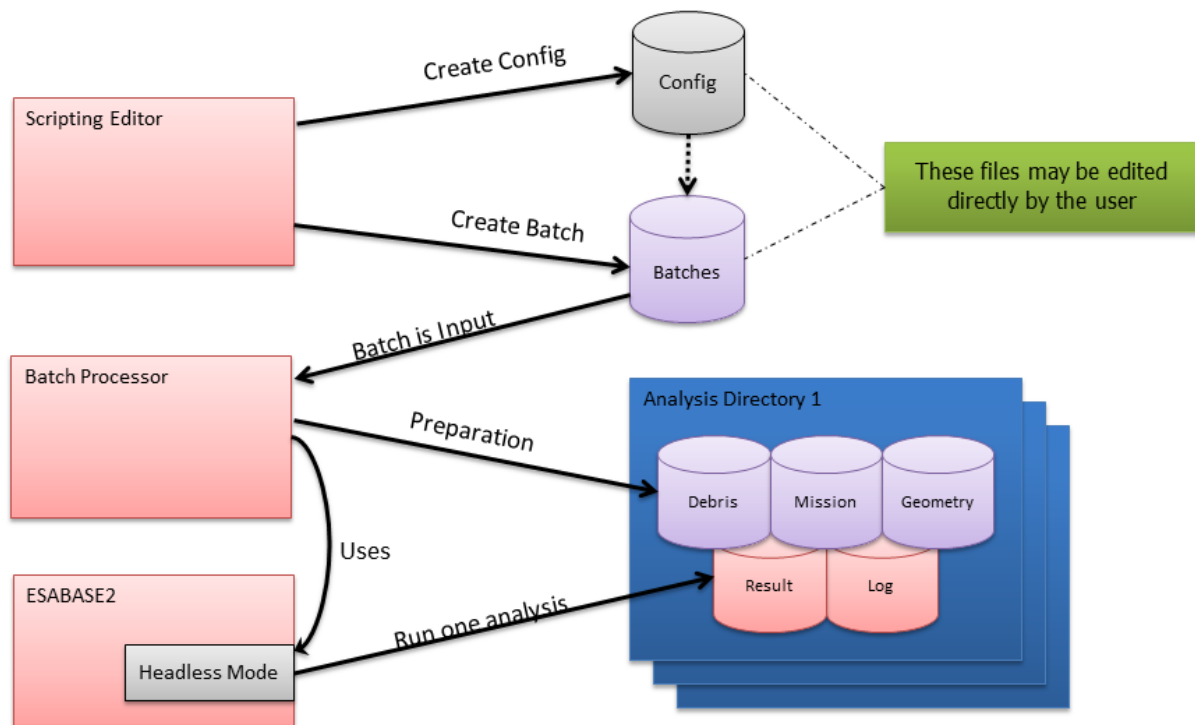
After defining the configuration items, the scripting configuration can be established. In this example, this scripting configuration consists of two items – each of them consisting of one geometry-, one mission-, and one debris item. The second scripting configuration item contains a scripted mission item: "Mission2".

In the final step, the scripting configuration is transformed into the batch of run configurations. Because the first scripting item does not contain scripting functionality in this example, a direct conversation is done. For the second scripting configuration item, Mission2 does contain a scripting. So for each combination of parameters being defined by value-ranges, an entry for the batch is generated. In this case, the second scripting configuration item results in (3 Steps x 2 Steps) = 6 run configurations. Now the batch is prepared for the Batch Processor. See Figure 5-3.



**Figure 5-3: Function of the Batch Processor**

The Batch Processor will accept the created batch of run configurations as input and create the corresponding analysis results with the help of ESABASE2’s command-line interface. Both components are accessible from ESABASE2, and the Batch Processor may be started directly from the Scripting Editor. So there is no need for you to care for the existence of separate tools. Nevertheless, **it is recommended to close ESABASE2 before a batch run** to avoid problems related to high memory consumption or accidental simultaneously accessing the same files or debris solvers. Figure 5-4 shows the involved components and their interactions:



**Figure 5-4: Component's Overview**

So the Scripting Editor creates the “Config”, consisting of geometry-, mission- and debris-configuration items as well as of the scripting configuration. Furthermore it creates the batch out of the scripting configuration. Both files are in XML format. So you may create or modify them manually. A XSD is provided, defining the structure of the XML files formally. This XSD may be loaded into a sophisticated XML editor to provide verification and code completion.

## 5.2 Scripting Editor

### 5.2.1 Starting the Editor

The Scripting Editor may be started in one of three ways:

- From ESABASE2 GUI: Click the button for Scripting Editor in the icon bar.
- From Windows Explorer: Double-Click on <ESABASE2 folder>/scripting.jar.
- Via command line:

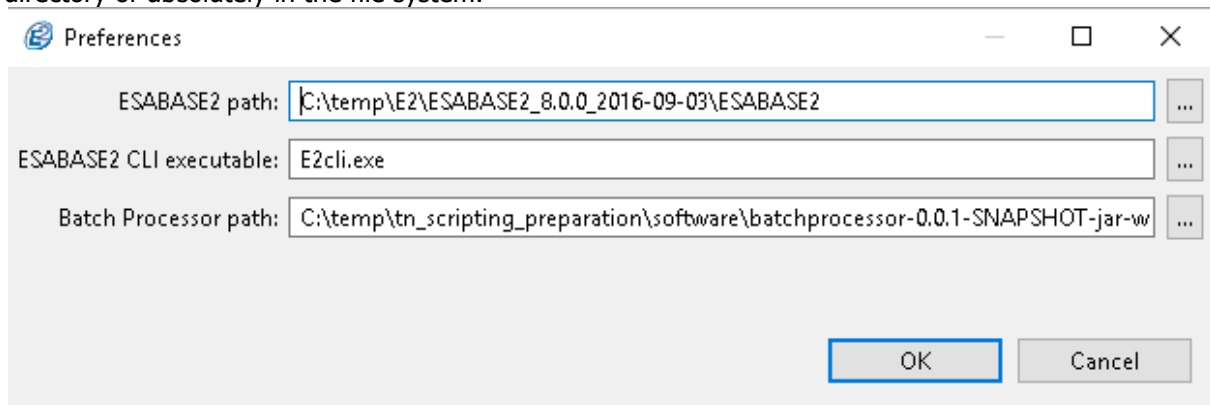
```
cd <ESABASE2 folder>/scripting
java -jar scriptingeditor.jar
```

Note that the scripting editor requires a 64 bit Java-(8)-Runtime environment. If your default JRE is not 8, the two latter ways of starting the editor could probably fail. In this case, you should explicitly call a java.exe of a 64 bit Java 8 environment. You could use the one which is delivered with ESABASE2:

```
cd <ESABASE2 folder>/scripting
<ESABASE2 folder>\components\Java\jre\bin\java.exe -jar
scriptingeditor.jar
```

## 5.2.2 Configuring Dependencies

The Scripting Editor makes use of ESABASE2's command-line interface and metadata definitions. The paths to these components are pre-defined and work as long as the relative paths of the components stay constant with respect to the scripting editor. If e.g. the scripting editor needs to be moved separately from the ESABASE2 installation, the stored paths can be adapted by opening the Preferences dialog from the File-menu. See Figure 5-5. The paths may be specified relatively to the Scripting Editor's directory or absolutely in the file system.

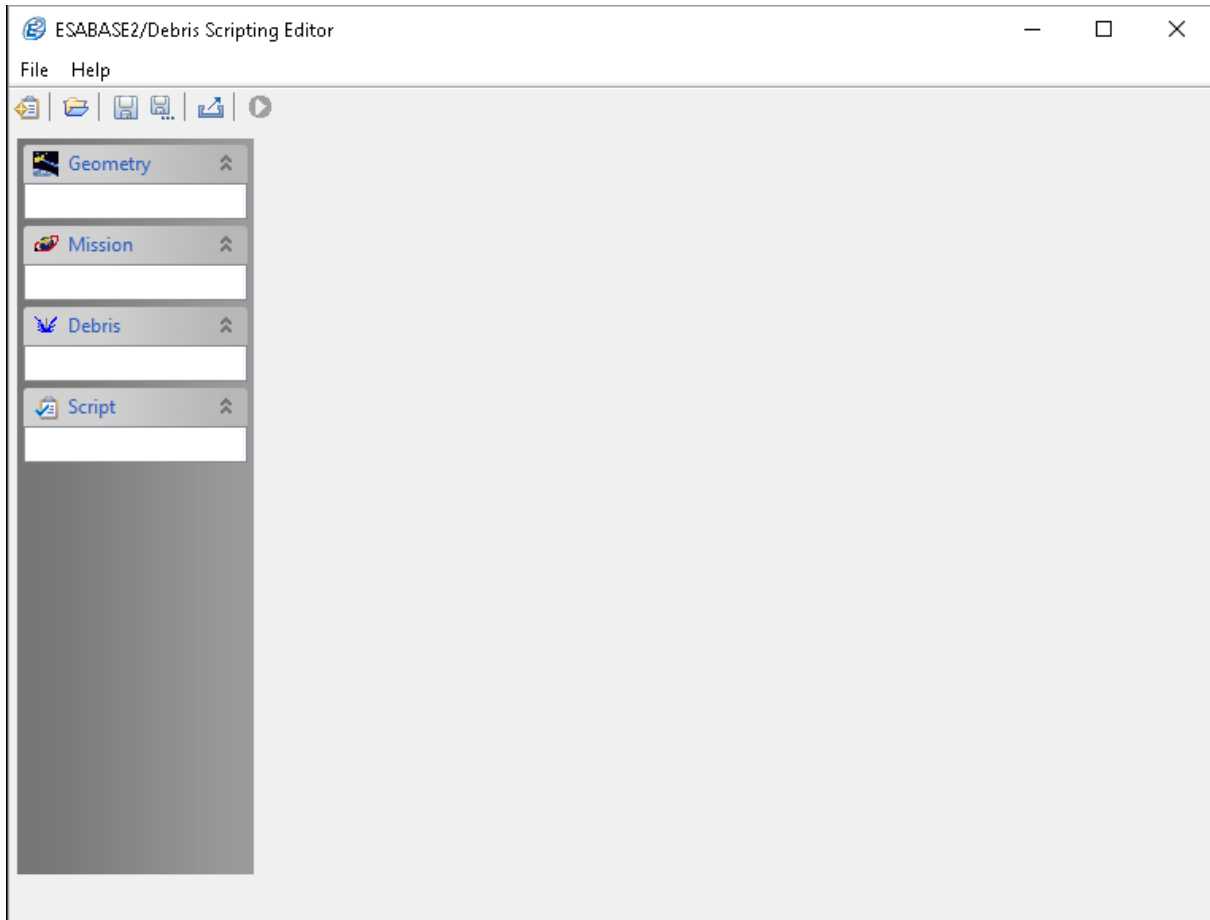


**Figure 5-5:** Scripting Editor's Preferences Dialog

## 5.2.3 Handling a Scripting Project

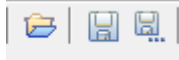
When starting the Scripting Editor, an empty scripting project is present which you can directly extend with configuration items (see Figure 5-6)





**Figure 5-6:** Scripting Editor

This project may be saved and loaded by the familiar buttons, provided in the editor’s tool bar:



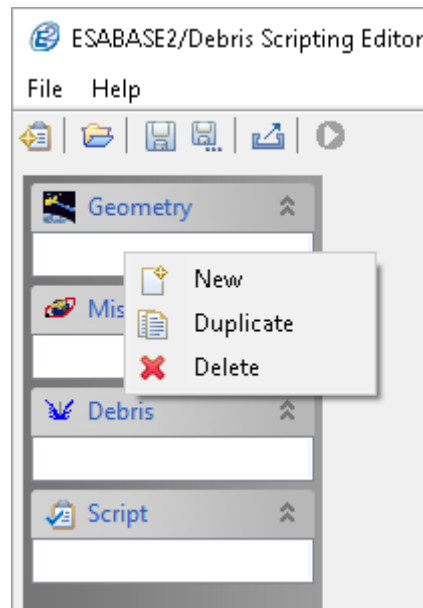
**Figure 5-7:** Scripting Editor – icons for loading and saving

The file format is XML, defined by an XSD file. So you may manipulate the files manually later on or even create complete files by hand. When loading a file, it will be validated against the XSD file and if formal errors exist, they will be reported.

In a scripting project, the user can define multiple items, and it is not necessary to include all of them in a scripting configuration. This also holds for scripting project files that were manually edited in XML.

### 5.2.4 Editing the Scripting Project

You may handle the entries of the sections via context-menu which appears after right mouse-click on an empty place in a section or on an existing entry:



**Figure 5-8:** Scripting Editor – Context Menu

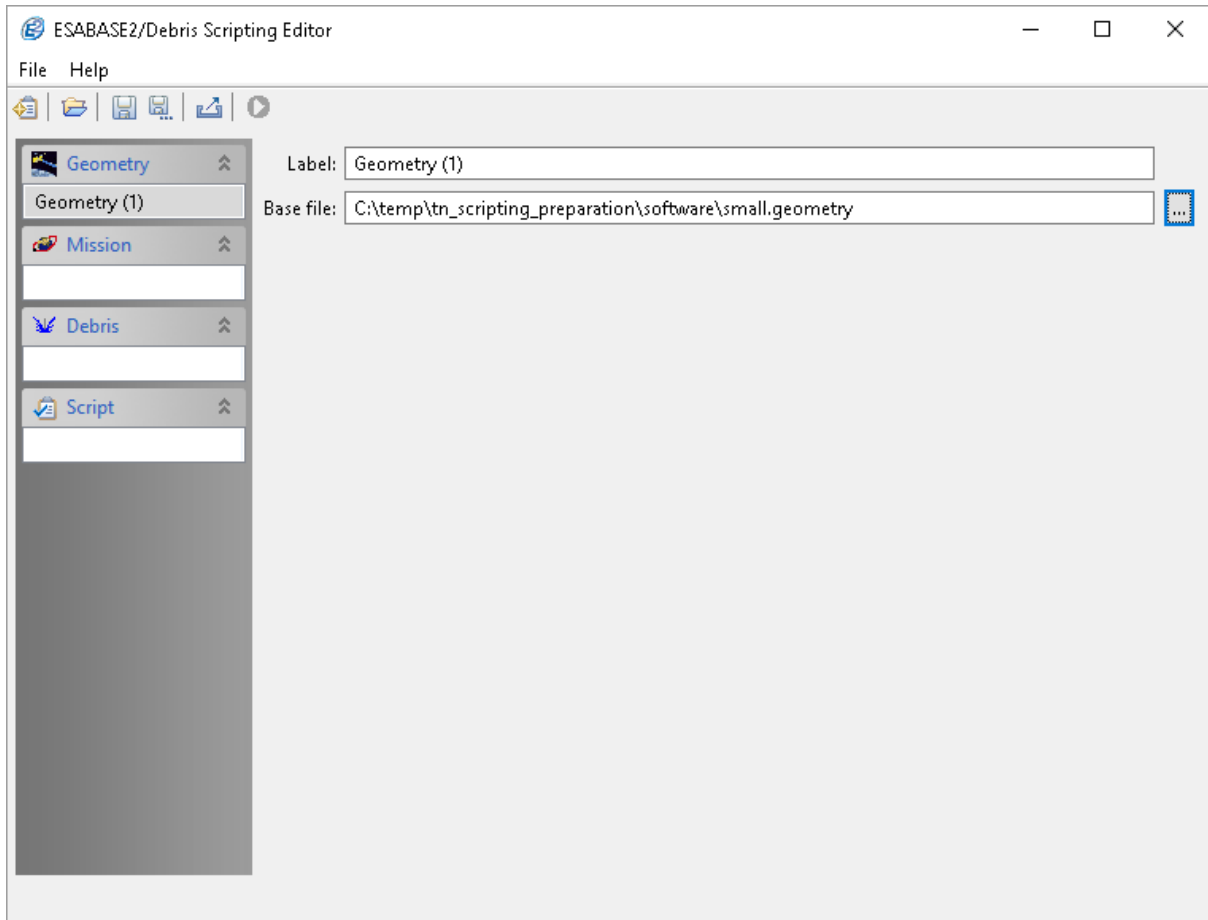
Figure 5-8 shows that the context menu offers the options to

- Create a new configuration item
- Duplicate the selected configuration item
- Delete the selected configuration item

### 5.2.5 Handling Geometry Configuration Items

The panel for editing geometry configuration items is shown in Figure 5-9. You may provide a descriptive label which appears in the items-overview on the left side as well as in the Batch Processor later on. Second, you shall specify the base file which must be a **meshed** geometry file. If the geometry file is not meshed, the batch processing later on will fail.

As usual, you may use the button next to the base file field to open a file-selector dialog that lets you navigate to your geometry file in a convenient way.



**Figure 5-9:** Scripting Editor – geometry editor panel

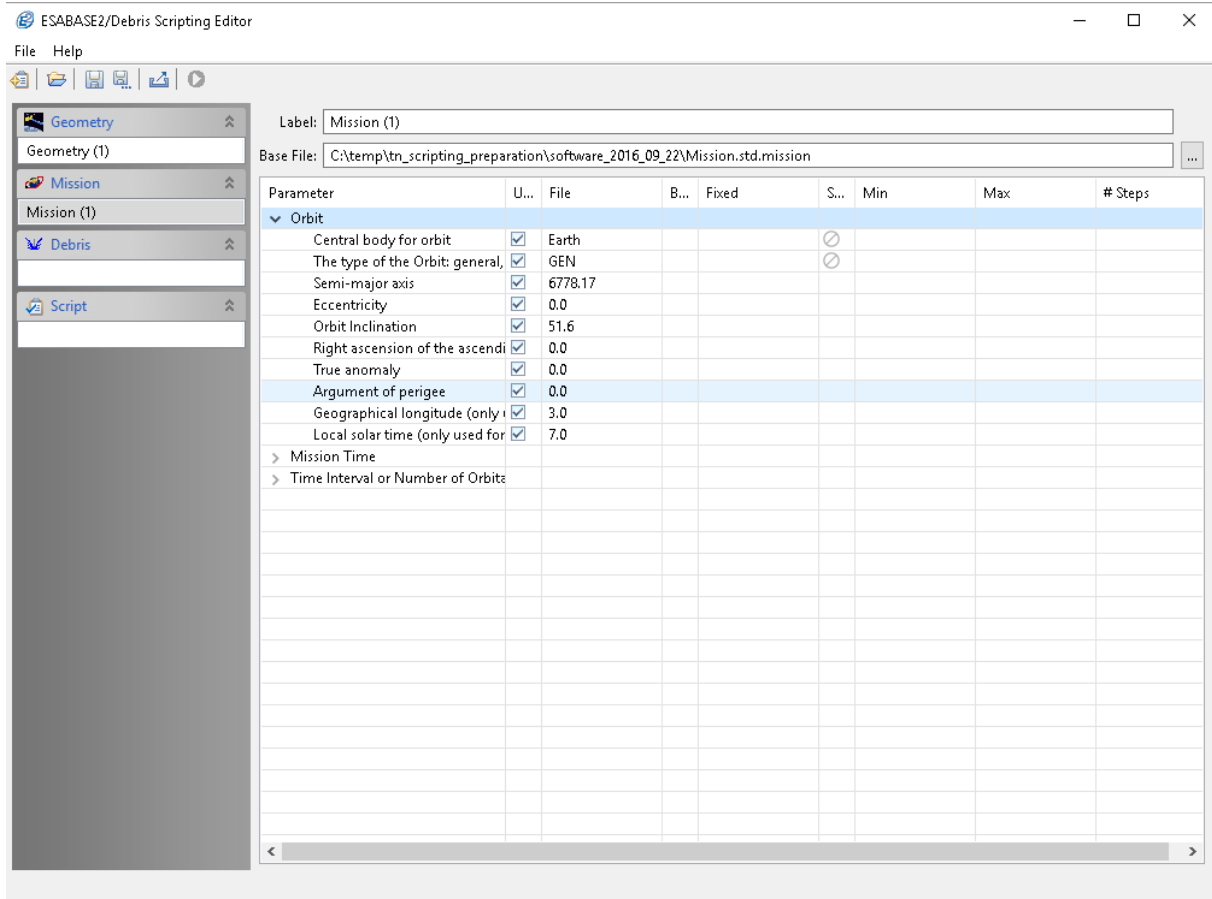
### 5.2.6 Handling Mission Configuration Items

When adding a new mission configuration, you may specify a descriptive label and you shall select a base file. After choosing a mission base file, the mission editor panel gets filled like shown in Figure 5-10. Here all relevant parameters are listed in table while being grouped thematically.

By default, the displayed values are taken from the base file. But of course, the purpose of the editor is to assist you in manipulating the parameter's values: For each displayed parameter, you may either set another value by typing into the "Fixed" column or you may specify a range by setting the "Min", "Max" and "#Steps" values. Check the corresponding box to mark which of the values shall be used. See Figure 5-11 for an editing example.

When specifying a value-range, you enter a minimum value and a maximum value. Because this range will be split into discrete runs later on, you need to specify the number of steps the range shall be split into. The minimum number of steps is 2. In this case just the minimum value and the maximum value of the edited parameter are taken into account. For a higher number of steps, a corresponding number of intermediate steps will be computed. The intermediate values will be equidistant.

If you wish to prepare multiple runs while iterating a parameter over a value range with non-equidistant steps, you need to prepare multiple configuration items with fixed parameter values.



**Figure 5-10:** Scripting Editor – mission editor panel

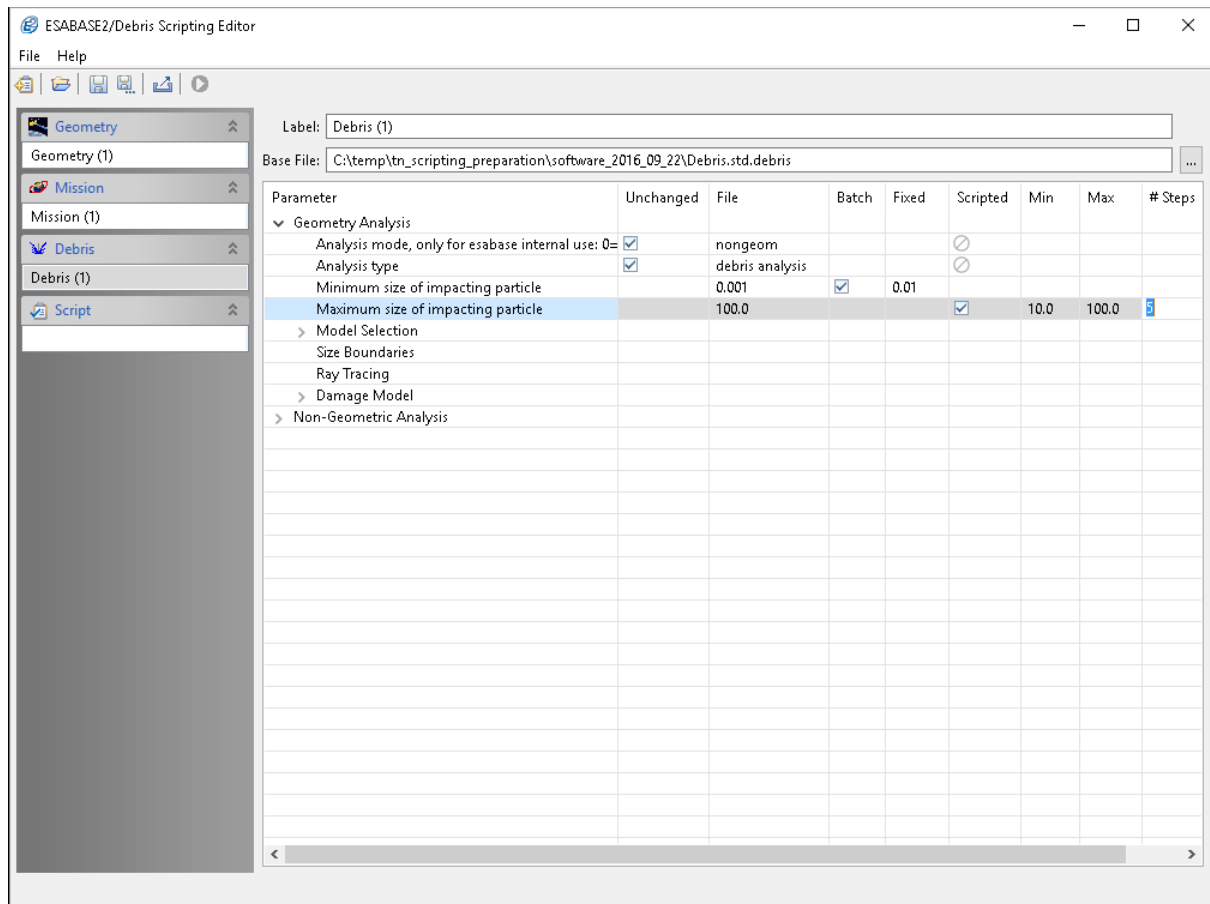
## 5.2.7 Handling Debris Configuration Items

The debris configurations are edited similar to the mission configurations. Therefore, please refer to chapter 5.2.6.

Figure 5-11 shows the debris editor of the Scripting Editor. In this example it is shown that the parameters "Analysis mode" and "Analysis type" are not available for scripting. So they can't iterate over a range of values, but they are allowed to be modified with a fixed value.

The "Minimum size of impacting particle" is modified to a fixed value.

The "Maximum size of impacting particle" is scripted. So there is the minimum value of 10.0 and the maximum value of 100.0. A total number of 5 steps means that there are 3 intermediate, equidistant steps to be computed. So the resulting values in this case will be 10.0, 32.5, 55.0, 77.5 and 100.0.

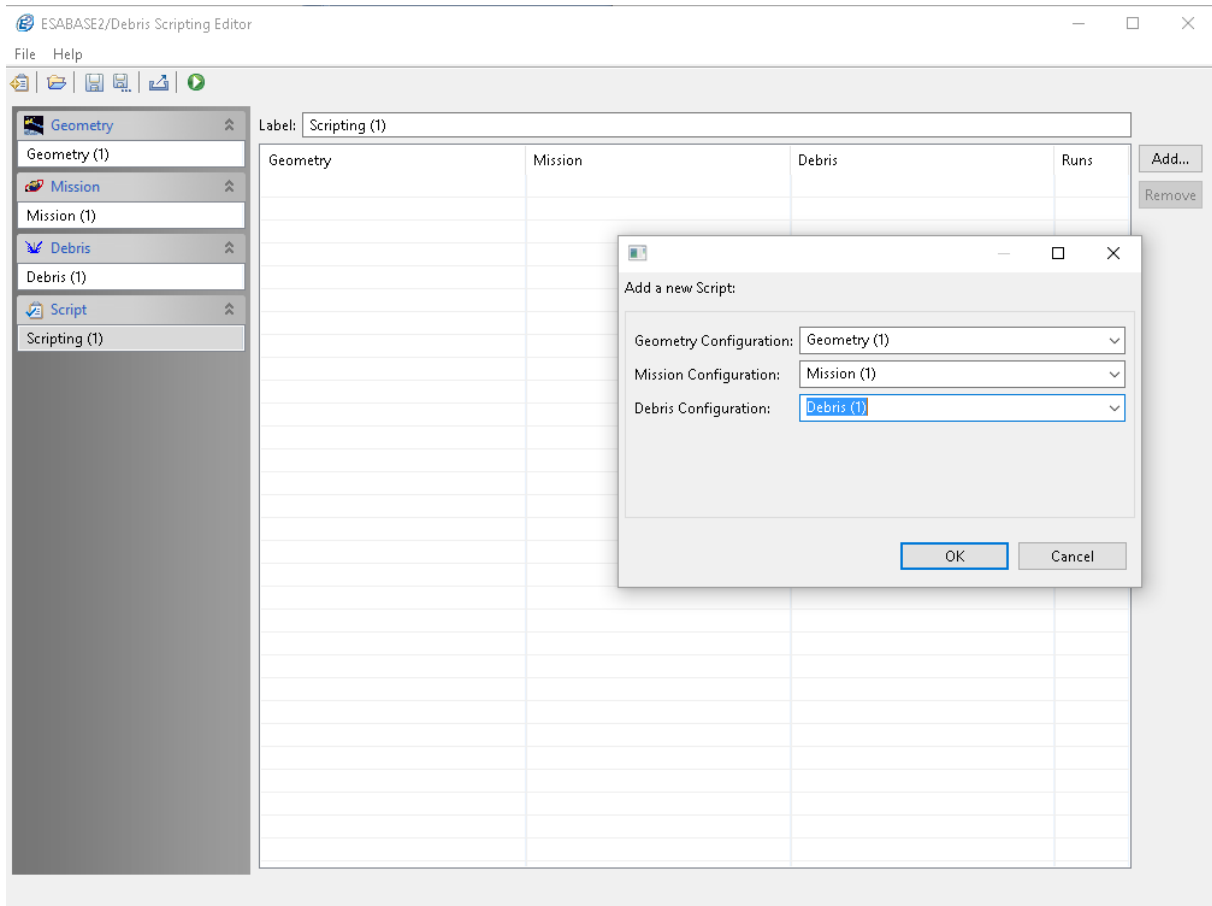


**Figure 5-11:** Scripting Editor – debris editor panel

## 5.2.8 Handling Scripting Configuration Items

Figure 5-12 shows the dialog which appears when pressing the “Add...” button in the scripting configuration. Each line of the table in the background represents one scripting configuration item which consists of one geometry-, one mission- and one debris-entry. In the shown dialog, you can select the corresponding entries for the new line in the table. You can change these values directly in the table later on.

In the case of a non-geometrical debris analysis, the geometry entry shall be set to “non-geom”.



**Figure 5-12:** Scripting Editor – adding a new scripting item

## 5.2.9 Creating the Batch

When the scripting configuration is done, it needs to be prepared for the batch analysis with the batch processor. Therefore an XML file needs to be computed that holds the specifications for each planned analysis run. You may decide to either explicitly generate this file by pressing the left button, shown in Figure 5-13, or you may decide to directly run the Batch Processor with the right button in this figure:



**Figure 5-13:** Scripting Editor – icons for creating a batch and running the Batch Processor

Independently of your choice, it is always a good idea to save your project before performing further actions.

## 5.3 Batch Processor

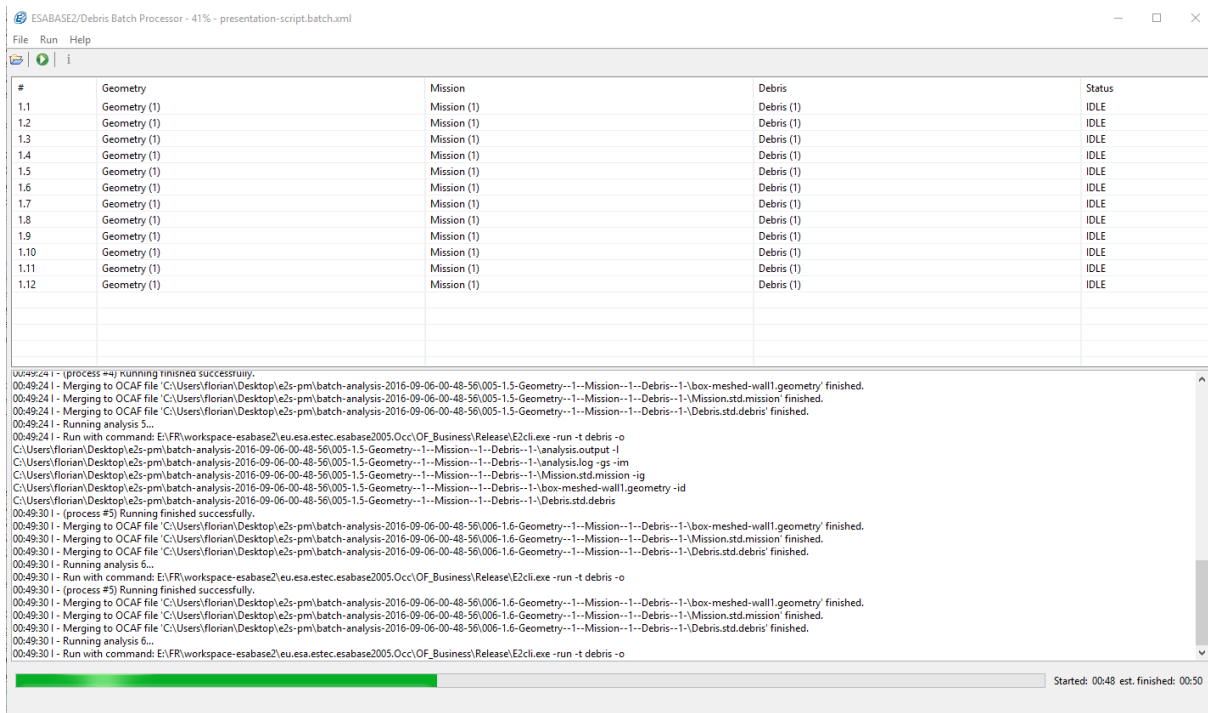


Figure 5-14: Batch Processor while processing a batch file

### 5.3.1 Starting the Processor

- From Scripting Editor: See Figure 5-13
- From Windows Explorer: Double-Click on <ESABASE2 folder>/scripting.jar.
- Via command line:

```
cd <ESABASE2 folder>/scripting
java -jar batchprocessor.jar
```

Note that the scripting program requires a 64 bit Java-(8)-Runtime environment. If your default JRE is not 8, the two latter ways of starting the Batch Processor could probably fail. In this case, you should explicitly call a java.exe of a 64 bit Java 8 environment. You could use the one which is delivered with ESABASE2:

```
cd <ESABASE2 folder>/scripting
<ESABASE2 folder>\components\Java\jre\bin\java.exe -jar
batchprocessor.jar
```

### 5.3.2 Handling Batch Files


You can load a batch file with the usual "load" button in the icon bar of the Batch Processor. A file selection dialog will appear that lets you navigate to your batch file which you created with the Scripting Editor in a previous step.

Another way of loading a batch file is specifying the path to the batch file as argument to the program. This makes only sense in the command-line call:

```
cd <ESABASE2 folder>/scripting
java -jar batchprocessor.jar C:\temp\myBatchFile.xml
```

When file is loaded successfully, the table of runs will be filled with all computed analysis run configurations that are part of the batch file.

### 5.3.3 Processing a Batch File

By pressing the play button  in the icon bar of the Batch Processor, the currently loaded batch file will be processed. This means, for each line in the table of runs, an analysis run will be executed calling a new instance of ESABASE2 via its command-line interface.

You will be informed about the progress by the progress bar at the bottom of the window as well as by the status column in the table. The output that is generated during the analysis runs is usually logged into files by ESABASE2. For convenience, it is also shown in the text pane at the bottom of the window and may be taken as an indicator whether the analysis runs perform as expected. See next chapter 5.3.4 for output files.

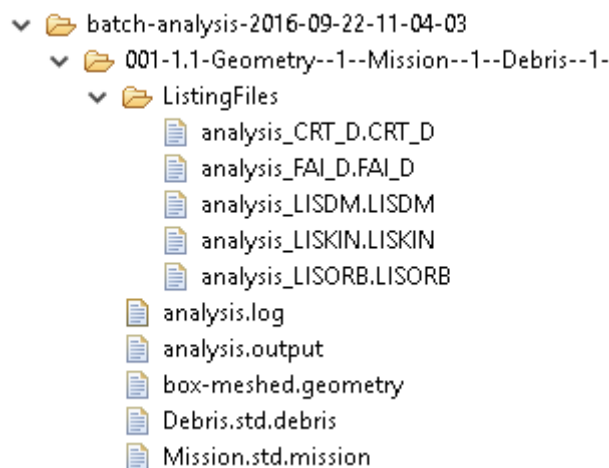
### 5.3.4 Output Structure

For each batch processing, a new directory will be created and be named with the current date and time. This avoids overwriting existing results by accident.

Inside this unique directory, for each analysis run a separate sub-directory will be created. The name allows identifying the originating batch item in the batch file. See Figure 5-15

Before the run is done, all required input files are copied into this sub-directory. In this example, the input files are "box-meshed.geometry", "Debris.std.debris" and "Mission.std.mission".

During the analysis, all result files, including a folder of listing files, and the log file are written into the sub-directory, too. This allows reproducing the results, easily loading all the files into a separate ESABASE2-project, repeating a single run with corrected parameters in the input files, and more.



**Figure 5-15:** Batch Processor's output structure

## 5.4 Command-Line Interface

In order to make use of ESABASE2 during the automated runs, ESABASE2 provides the so-called Headless Mode since version 9.0. It is accessible via E2cli.exe which is placed in the ESABASE2 installation directory – right next to ESBASE2.exe.

### 5.4.1 Usage

If you wish to use the CLI, open your command line. In Windows this is done by running the command "cmd" from start menu. Next, change the current working directory to the ESABASE2 installation directory. Prepare the environment variables by calling "e2cli\_env.bat" and next you can call E2cli.exe.

If you get messages about missing dlls, most probably you forgot to call e2cli\_env.bat before calling E2cli.exe.



```
Microsoft Windows [Version 10.0.10586]
(c) 2015 Microsoft Corporation. Alle Rechte vorbehalten.

K:\>c:

C:\>cd temp\ESABASE2

C:\temp\ESABASE2>e2cli_env.bat

C:\temp\ESABASE2>E2cli.exe
2016-09-14 15:45:25,128 INFO root: logging initialized
No valid command found. Try option -help

C:\temp\ESABASE2>
```

**Figure 5-16:** Calling ESABASE2 CLI

If you specify no further parameters, the program will complain about missing commands and suggest trying out "E2cli.exe -help". This will display the complete set of accepted parameters.

A convenient entry point is provided with the cliExample.bat. It generates the call to E2cli.exe and provides the paths to sample input files as parameters.

```
C:\temp\ESABASE2>cliExample.bat

E2cli.exe -run -t debris
-o C:\temp\ESABASE2\exampleFiles\output\analysis.output
-l C:\temp\ESABASE2\exampleFiles\output\analysis.log
-im C:\temp\ESABASE2\exampleFiles\short.mission
-ig C:\temp\ESABASE2\exampleFiles\box.geometry
-id C:\temp\ESABASE2\exampleFiles\debris.debris
```

**Figure 5-17:** Example for performing a debris analysis run with ESABASE2 CLI

The generated call is executed instantly.

## 5.4.2 Logging

You may adapt the amount of produced logging output by editing the file <ESABASE2>\configuration\eu.esa.estec.openfrontier\log4j.properties

The following line can be found in the mentioned configuration file

```
log4j.rootCategory=TRACE, CONSOLE, FILE
```

Currently it specifies that the log level is TRACE and the logging goes to console and to file. If you wish to deactivate one of the output targets, just remove it from the line.

If you wish to change the amount of output, replace the value of logging level. Valid values are

```
TRACE, DEBUG, INFO, WARN, ERROR, FATAL
```

The values are ordered by expected amount of output. TRACE produces the most detailed output, FATAL will report crashes only.

## 5.4.3 Further help

For further details on the command line, please refer to the output of the help command. Please note that not all commands and analysis types are implemented yet.

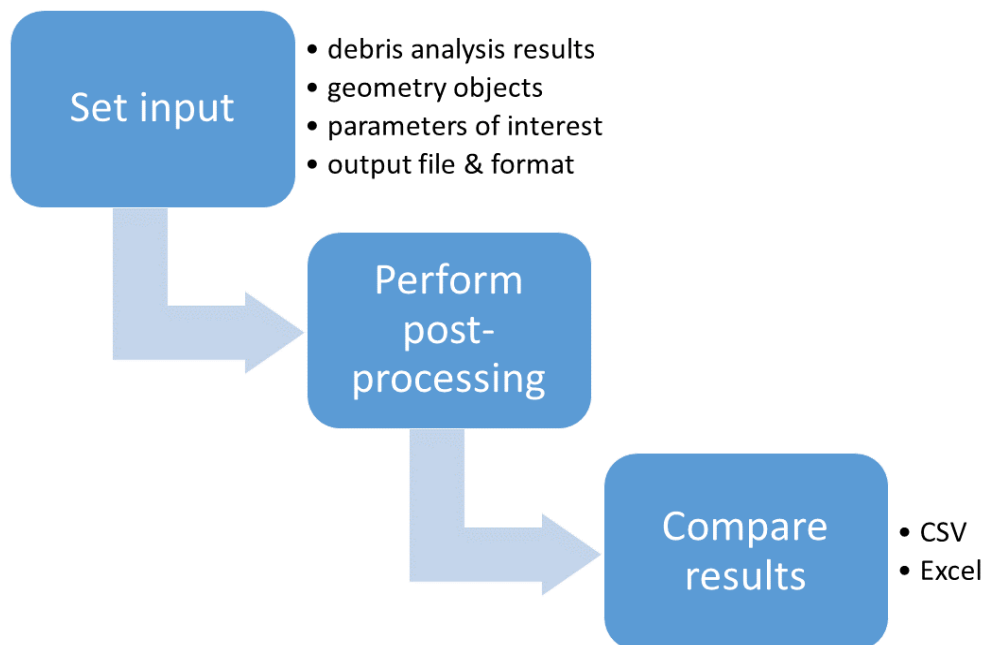
## 6 Post-Processing

The Post-Processor is a stand-alone application that enables the user to compare different debris analysis results with each other, depending on parameters of interest and selected geometry objects. The post-processing result can be exported to various formats, such as Excel and CSV output files.

This application requires an ESABASE2 installation in version 9 or newer. Usually, the Post-Processor is shipped as a standard component of that ESABASE2 version.

### 6.1 Overview

The Post-Process expects debris analysis results (see Section 2.4) as input files. These can be generated either manually by running an analysis within ESABASE2 (see Section 2.3), or using some scripted configurations by the Batch Processor (see Section 5.3).



**Figure 6-1:** The standard use case for the Post-Processor

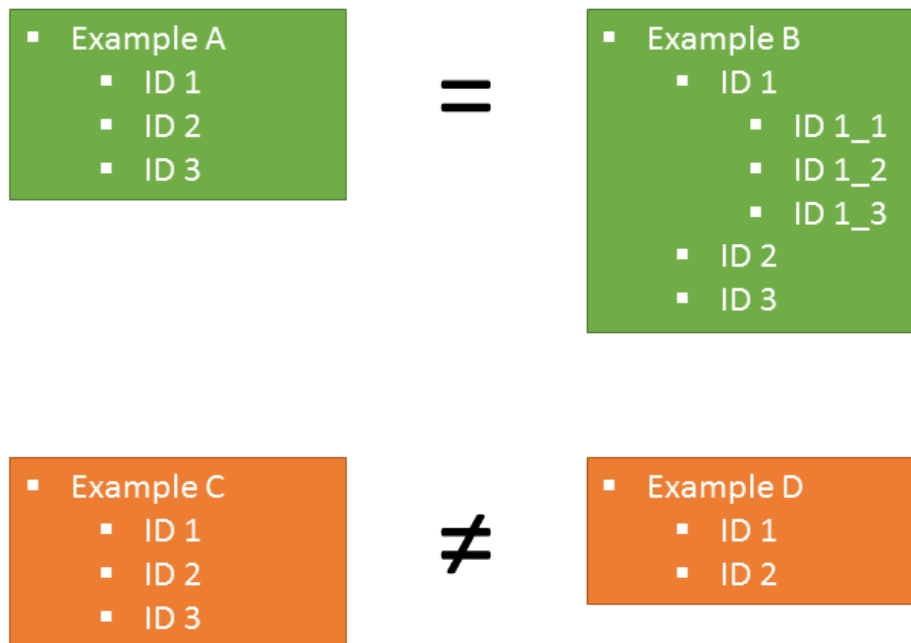
In both cases, a set of result files will be processed and compared with each other, see Figure 6-1. It is assumed that they all have the same geometry structure concerning the selected geometry objects to be analysed.

Before the processing, the user has to select debris analysis results, geometry objects, parameters of interest (e.g. total number of failures or probability of no failure), and an output file in a specified format. This can be either Excel or CSV in the standard edition of the Post-Processor, which is the only one currently available.

Once the application is finished with post-processing, the output directory is presented to the user. For this, the application opens the directory with Windows Explorer. Here the user can open the output file or select a number of files, if the format has generated more than one. The latter is the case for CSV format, where one CSV file is generated that lists all input parameters and one for each selected parameter of interest.

Due to performance reasons, the geometric compatibility is checked not until the processing of the second file. An overview of this concept is depicted in Figure 6-2. Here all geometry objects of Example A shall be compared to their corresponding objects in Example B and all of Example C to the ones in D. One can see that Example A matches Example B, even if the latter one has got sub-nodes defined for the node with ID 1. As Example C has three nodes defined, the geometry structure of Example D is incompatible to C, as D does not specify a node with ID 3. Moreover, for geometry objects not only the

OCAF IDs are checked but also their labels (i.e. value of sub-node OCAFTITLE). If the geometry structure does not match the one in the first file in the list of debris results, a warning message is presented to the user whether to continue anyway or to cancel.



**Figure 6-2:** Compatibility and Incompatibility of geometry objects for the Post-Processor.

## 6.2 Preferences

The preferences of the Post-Processor are stored in several files which should be shipped pre-configured:

- esabase2-template-settings.properties
- esabase2-postproc.preferences
- esabase2-postproc-template.xlsx

Each of these files serve an own purpose. Table 6-1 explains their purpose and content in detail.

File	Content description
<b>esabase2-postproc.preferences</b>	Stores the connection settings to ESABASE2 CLI, the environment parameters for CLI execution, and the shell command to open a directory with the default application.
<b>esabase2-template-settings.properties</b>	Stores the template settings for any output format (here: Excel and CSV), such as Excel template file path and CSV separator character, and their specific date format.
<b>esabase2-postproc-template.xlsx</b>	The Excel file used as template for generated Excel output. The first sheet will be used as template sheet containing a certain structure which can be specified in detail and in sync with attributes from esabase2-template-settings.properties.

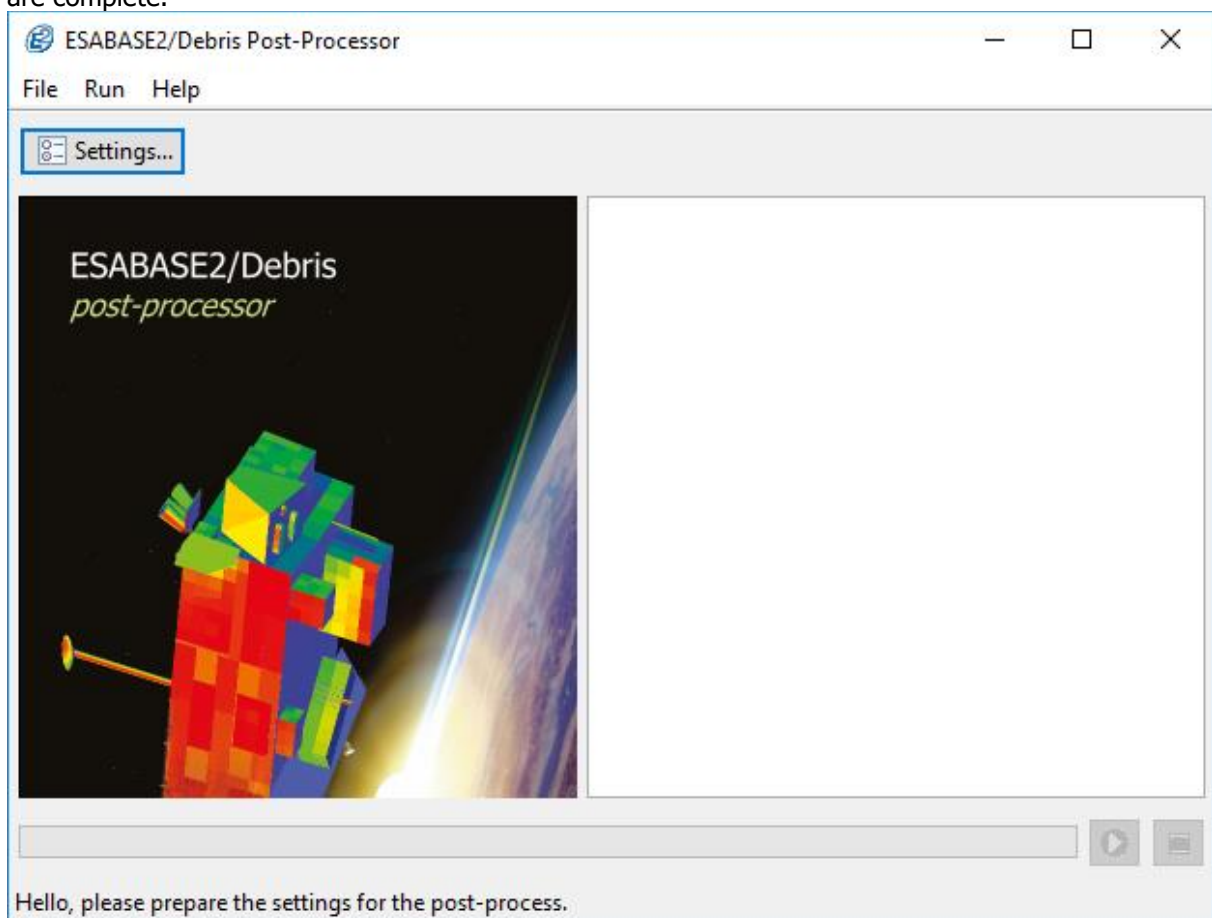
**Table 6-1:** Preferences are stored in several files, one for each purpose.

As these preferences are pre-configured, the user does not need to adjust the values. Only in certain situations, e.g. when the template shall be modified or when the Post-Processor path has changed independent from the location of the ESABASE2 installation, preferences have to be touched.

## 6.3 Starting the Post-Processor

The Post-Processor can be started by executing the batch script "postprocessor.bat". This ensures the usage of the correct Java Virtual Machine, i.e. the one shipped with ESABASE2 located in a sub-folder of the ESABASE2 installation directory.

The post-processor displays a main window containing a menu bar and a settings button at the top, a log area in the center, as well as a status bar and control buttons to start or cancel the post-processing at the bottom, see Figure 6-3. Depending on the settings, the start button will be enabled if the settings are complete.



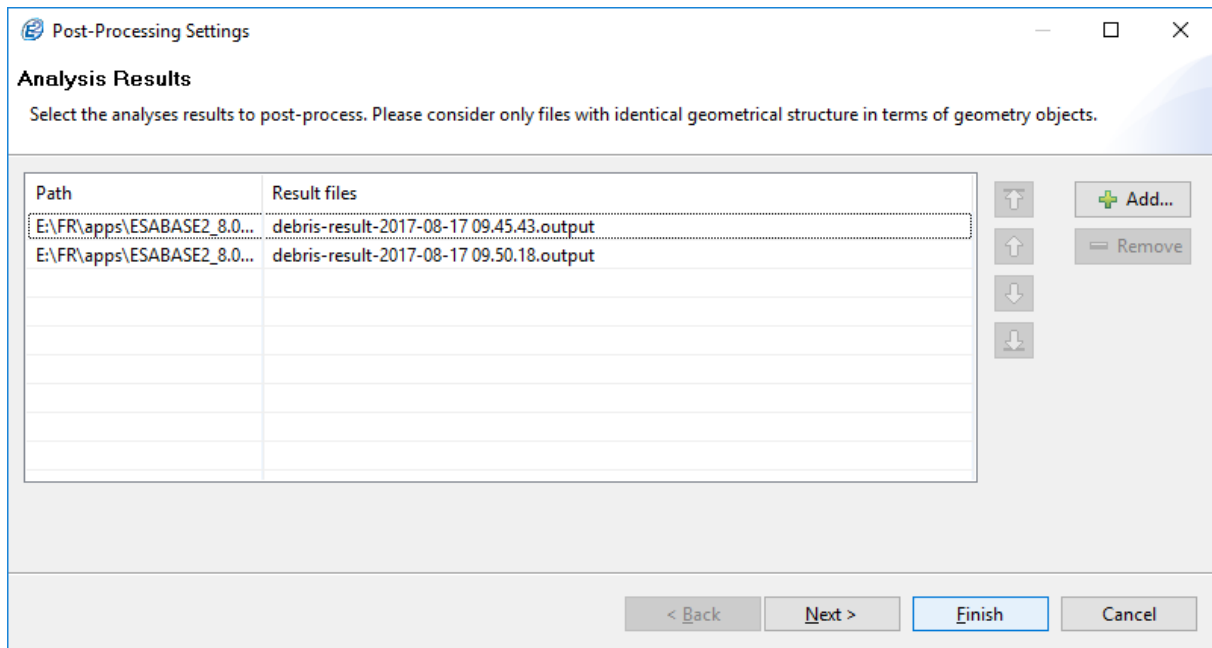
**Figure 6-3:** Post-Processor main window

## 6.4 Setting input

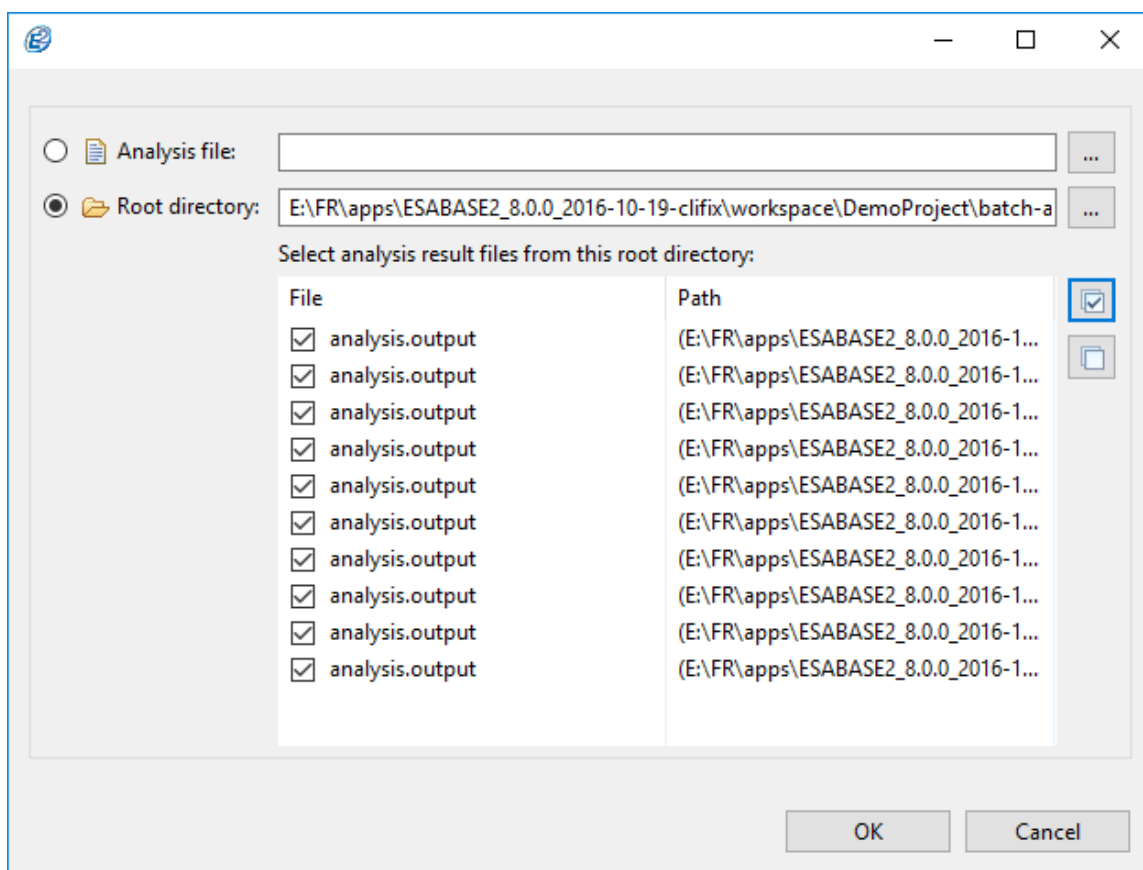
The input for post-processing can be easily set within a GUI wizard dialog and is divided into four steps:

1. Selecting debris analysis results
2. Selecting geometry objects of interest
3. Selecting parameters of interest
4. Selecting output file and format

The settings can be reached either via the menu entry „Run“ – “Settings...” or the “Settings...” button in the upper part of the main window, see Figure 6-3.



**Figure 6-4:** Selecting analysis results in the Post-Processor

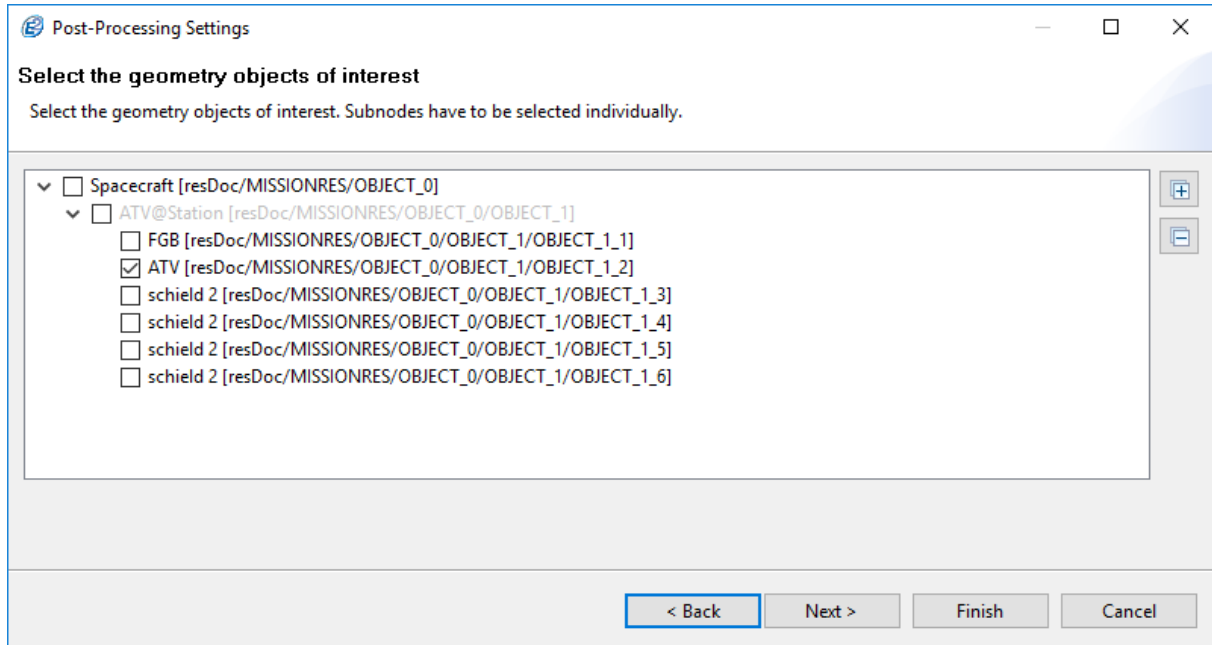


**Figure 6-5:** Adding single or multiple analysis results in the Post-Processor

In the first step, the settings require at least one analysis result to be added, see Figure 6-4. Click on the "Add..." button on the right to open a dialog for debris results selection, see Figure 6-5. In this window, the user can either choose to select a single file for addition or to select a root directory that will be automatically searched for debris results in all its sub-directories. The search result will then be

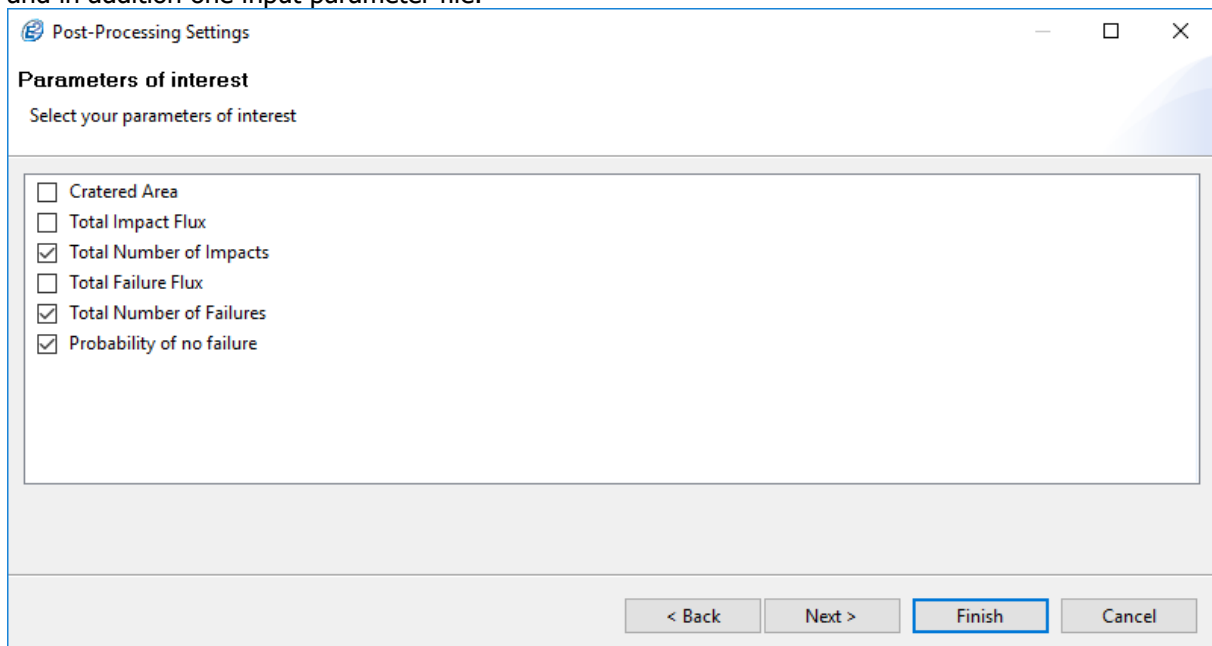
presented as a list below. After checking files of interest, they will be added to the list of analysis results when the user clicks on "OK" and closes this dialog.

In the second step, the user has to select the geometry objects of interest, see Figure 6-6. For this, the Post-Processor reads the geometry structure of the first analysis result in the list, assuming that the other results contain the same geometry structure concerning the IDs of the selected objects.



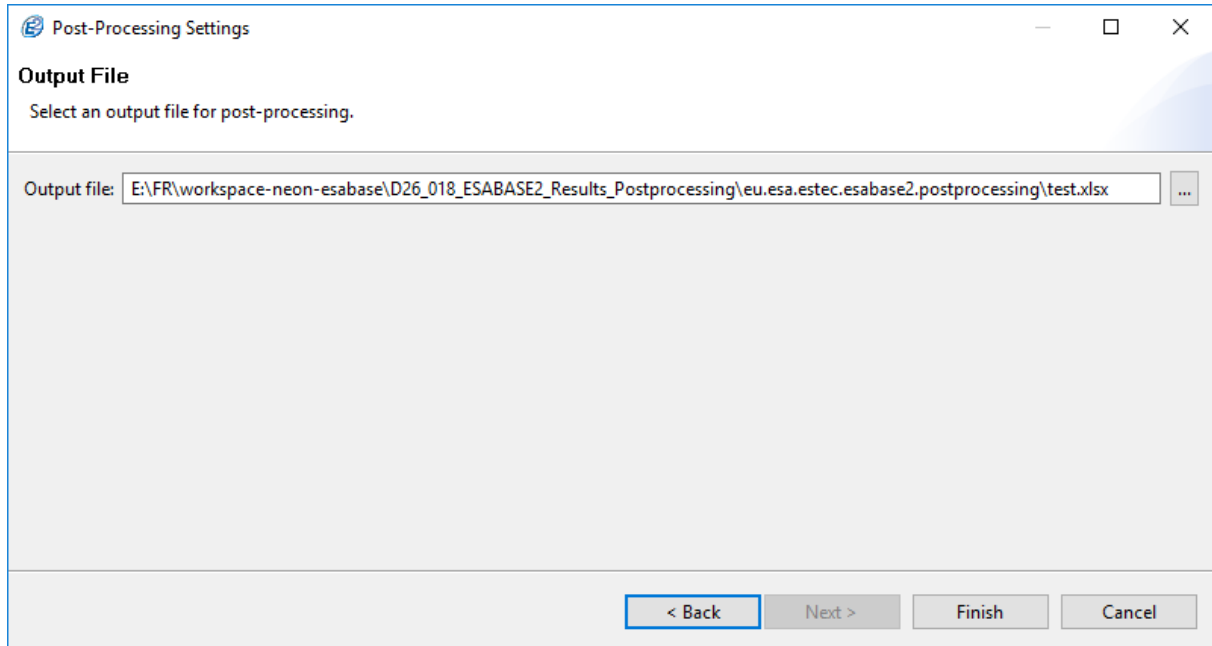
**Figure 6-6:** Selecting geometry objects in the Post-Processor

In the third step, the user selects parameters of interest whose values shall be presented in the output, see Figure 6-7. Multi-selection is possible. For each parameter, e.g. the Excel output format will create an own sheet within the document. The CSV output format will create an own file for each parameter, and in addition one input parameter file.



**Figure 6-7:** Selecting parameters of interest in the Post-Processor

Finally, in the fourth step of the settings wizard dialog, the user selects an output file and, by selecting a file filter, also the output format, see Figure 6-8. In the standard version of the Post-Processor, this can be either Microsoft Excel or CSV format.



**Figure 6-8:** Selecting output file and format in the Post-Processor

If all settings are complete, the user is allowed to finish the wizard dialog, i.e. to close it saving the settings. If the user wants to cancel, this is allowed anytime on any wizard page. Then, changes that has been done since opening the wizard will not be applied.

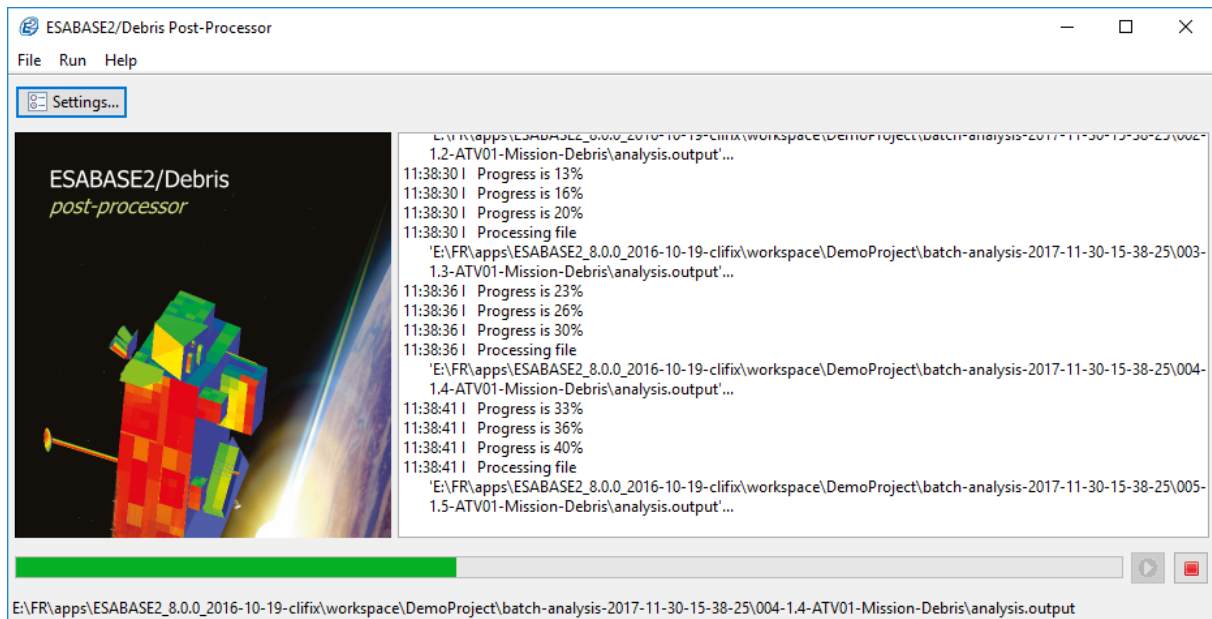
## 6.5 Executing the Post-Process

When all settings are finished and complete, the user is allowed to start the post-process by clicking on the "Run" button (icon with arrow in green circle) in the bottom right corner of the main application, see Figure 6-10. The start can also be executed via the menu item "Run" – "Run Post-Processor".

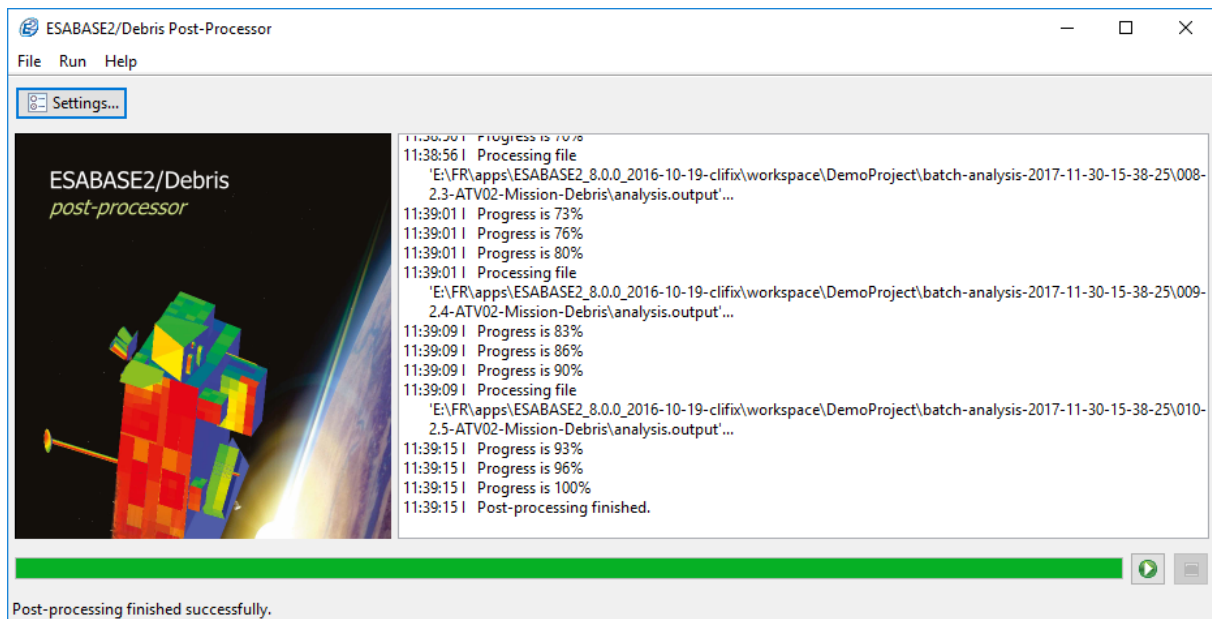
At the bottom of the window, the progress bar displays the current status of work in percent and the name of the current file to be analysed is displayed in the status line.

As soon as the post-process has been started, the "Run" button will be greyed out during execution, see Figure 6-9. Instead, the "Cancel" button (icon with red square) is activated unless the post-process is stopped. By clicking this button, the post-process will be cancelled immediately and the progress bar. During post-processing, the log area displays the current status and any warning or error that may occur.

If the process finishes successfully, the progress bar remains green at 100% (see Figure 6-10), otherwise it is marked red indicating an error or cancellation. Any error message will be immediately displayed to the user and written into the log file. This file is located in the "logs" sub-directory.



**Figure 6-9:** Running the post-process



**Figure 6-10:** Finished post-process successfully

## 6.6 Output

On success, the Post-Processor opens the directory that contains the output file (Excel) or multiple output files (CSV) for convenience. The user can now easily open the documents and compare the debris analysis results regarding the settings of the Post-Processor, i.e. analysis results, geometry objects, and (output) parameters of interest. Moreover for the Excel format, a chart is created for each run grouping the geometry objects in relation to the parameters of interest, see Figure 6-11. In this example, there is only one geometry object selected over 10 debris analysis results. Three sheets indicate the selected parameters of interest, which are here: total number of failures (displayed), total number of impacts, and probability of no failure.



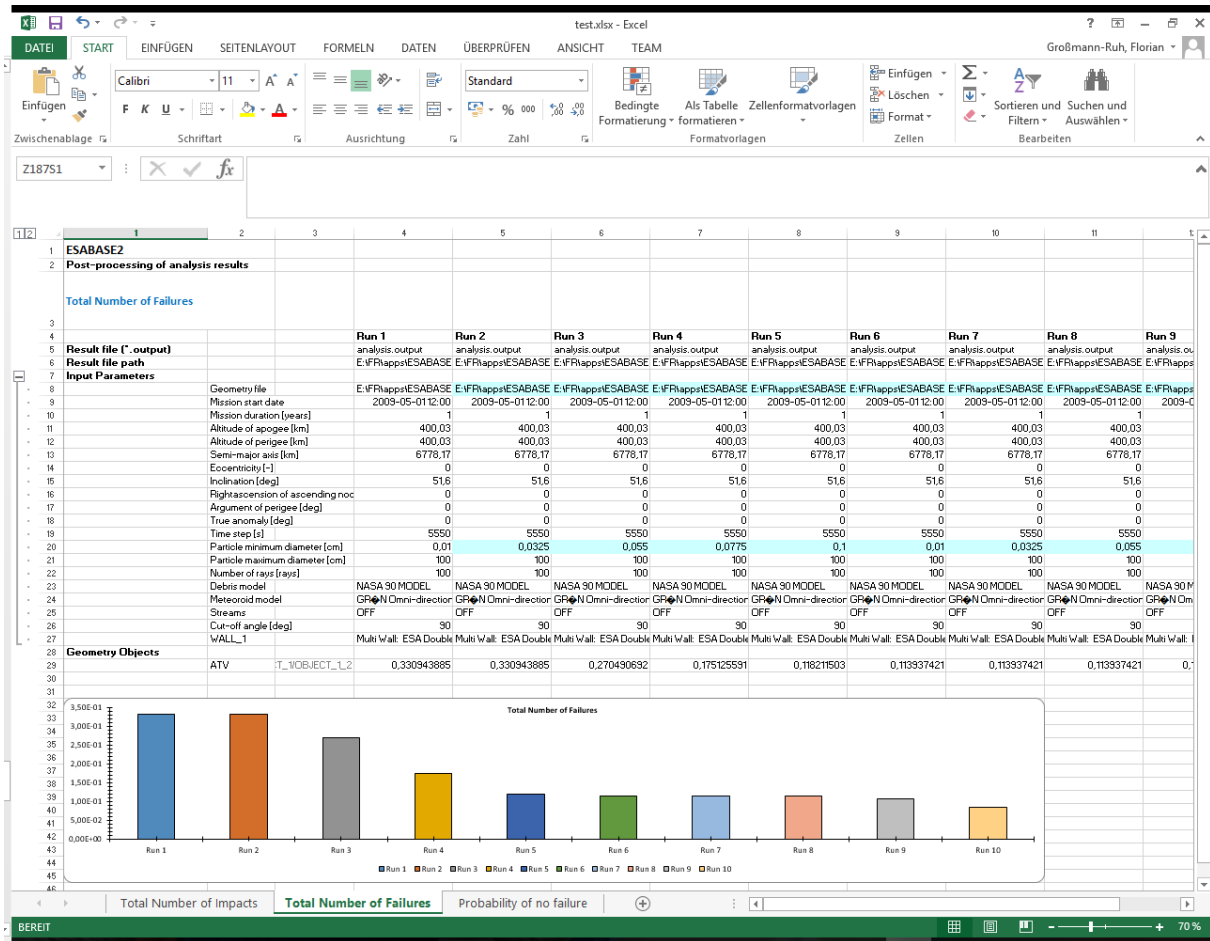


Figure 6-11: Output of the Post-Processor as Microsoft Excel document

## 6.7 Command-Line Interface

In order to automatically execute post-processing, a command-line interface (CLI) is introduced for the Post-Processor. By defining required and optional parameters, a user can run a setting instantly. The call of the application is extended by the CLI arguments as described in Table 6-2. An example call may be:

```
esabase2-postprocessor.jar -f analysis.output -g OCAF_ID -p NI;PNF -o output.xlsx
```

CLI key	argument	CLI argument value	Description
-f		file1;file2;...	debris analyses results
-g		OCAF_ID1;OCAF_ID2;...	geometry objects defined by their OCAF ID
-p		CA;FF;IF;NI;NF;PNF	the pre-defined set of all parameters of interest: CA: cratered area FF: failure flux IF: impact flux NI: total number of impacts NF: total number of failures

		PNF: probability of no failure
-o	output file	output file and format

**Table 6-2:** The list of CLI arguments for the Post-Processor