

RECENT EXTENSIONS OF THE ESABASE2/DEBRIS IMPACT RISK ASSESSMENT TOOL

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ABSTRACT

ESABASE2/Debris is ESA's tool to assess the probability of space debris and micro-meteoroid (MMOD) impacts and failures on spacecraft. It includes a high variety of capabilities, such as 3D modelling, consideration of different MMOD environment models, and various particle-wall interaction models.

A variety of MMOD environment models exist. To reflect the current understanding of micro-particle populations, it is important to use the most recent models in the risk assessments. Recently, ESABASE2/Debris has been updated, implementing NASA's most up-to-date space debris and micro-meteoroid models ORDEM 3.0 and MEM release 2 (MEMr2). The validation was performed by means of a result comparison of impact flux with the stand-alone model as well as impact flux and damage assessment results with NASA's Bumper application.

Moreover, the capabilities of ESABASE2/Debris have been extended to provide automated variation of calculation parameters and serial execution of multiple analyses.

1 INTRODUCTION

ESA's ESABASE2 software is composed of different applications. In the case of space debris and micro-meteoroids assessment, two applications are utilised: Debris application and the Framework.

The Debris application provides the means for the analysis of impact flux and damage on a 3-dimensional model of a spacecraft. It is described in detail in [1], [2], [11], and [12].

The Framework (application), on the one hand, allows the user to operate and control other applications of ESABASE2, e.g. Debris. On the other hand, it also provides the means for the definition of the 3-dimensional geometrical model. The model can be created by the use of the geometry editor within ESABASE2, based on a comprehensive palette of basic shapes. It is also possible to import an externally created model into ESABASE2 via the STEP interface or the GDML interface. A detailed description can be found in [2] and [3].

The results of the analyses are visualised in the Framework. The results (fluxes, impact, failure numbers etc.) are set as overlays on the 3D geometrical model or presented as 2D charts, alternatively. For further usage, the analysis results are stored as tabloid listings and the charts can be exported as images, additionally.

The initialisation of this activity is that NASA released updates of their space debris and micro-meteoroids models ORDEM and MEM, considering new events and newly available data, bug fixes and new features. Furthermore, user feedback indicates the need for additional capabilities of ESABASE2/Debris, e.g. serial execution of multiple analyses, automated variation of calculation parameters, a demo and a Linux version.

The main objectives of the activity described in this paper are

- the implementation of the new environment models ORDEM 3.0 and MEM release 2
- the extension of the capabilities considering the user feedback to allow serial execution of multiple analyses and automated variation of calculation parameters.
- the availability of a demo license, and
- the implementation of a Linux version

2 ENVIRONMENT MODELS

2.1 MEMr2

NASA's Meteoroid Engineering Model (MEM) is a parametric model of the spatial distribution of sporadic meteoroids within the inner solar system from 0.2 AU to 2.0 AU. Their primary source is considered to be short-period comets with aphelia less than 7 AU. Meteor storms and outbursts are not considered individually, but in an average sense. The effects of the gravitational focusing and shielding of the planets is also considered. Tailored versions for Earth and Moon vicinity exist.

MEM release 2 (MEMr2) is now, in contrary to the prior releases, a single product including the three individual sub-models:

- EarthMEM, for Earth orbiting spacecraft (S/C),
- LunarMEM, for Moon orbiting S/C, and
- MEM for interplanetary S/C.

The underrepresentation of particles with speed ranges of 40 km/s and higher is corrected in MEMr2. Furthermore, in MEMr2 three distribution resolutions are available (azimuth, elevation, velocity): 1 deg \times 1 deg \times 2 km/s, 4 deg \times 4 deg \times 4 km/s and 5 deg \times 5 deg \times 5 km/s, see [4], [5], and [6].

The implementation of MEMr2 in ESABASE2/Debris (E2/D) is based on the approach, which was used for the predecessors MEM and LunarMEM. These models are already contained in E2/D.

A more detailed approach description can be found in [1] and [12]. Here, model handling is organised via a single point interface and is based on two main branches.

One branch is approached prior to the geometrical analysis and prepares it. For this, it transfers all relevant input to MEMr2 input files and triggers the execution. The determination of the sub-model to use (EarthMEM or LunarMEM) depends on user's selection of the central body for the mission (Earth or Moon). The result files are parsed and stored in appropriate E2/D array data structures which in turn provide the micro-meteoroid environment data for the analysis.

The second branch is approached during the analysis. The provided micro-meteoroid flux spectra are utilised to generate a random impact direction.

In contrary to the predecessors, the output resolution of MEMr2 used is 4 deg \times 4 deg \times 4 km/s (azimuth, elevation, velocity).

2.2 ORDEM 3.0

NASA's most up-to-date Orbital Debris Engineering Model (ORDEM 3.0) is the successor of ORDEM2000. It incorporates data of many telescopes, radars (networks), hypervelocity tests, as well as returned hardware evaluations to define the population and its characteristics.

The space debris environment represented in ORDEM 3.0 is broken down by type and material density into five populations: Intacts, RORSAT NaK droplets, low-density, medium-density, and high-density fragments. The environment covers particle sizes from 10 μ m to 1 m for orbits between 100 km and 40,000 km altitude for the Earth vicinity. All data is composed to a yearly-interval input database for the time range from 2010 to 2035. The population database is accessed using the encounter igloo method for flux calculation. Additionally, some 2D results are provided, see [9].

The implementation approach of ORDEM 3.0 in E2/D correlates with the one of MEMr2. It is similarly divided into two branches, which are accessed before and during the analyses having the same purposes. The igloo-file data and the flux-particle size spectrum are

stored in appropriate E2/D arrays for further use. The 5 populations are reduced to three by merging the fluxes of Intacts and NaK droplets into the low-density fragments. The second branch (analysis) is extended. Firstly, the stored share distribution of the 3 populations is used to randomly define the particle kind. Finally, the stored space debris flux spectra are used to generate a random impact direction.

The finest available igloo resolution is used, which is 10 deg \times 10 deg \times 1 km/s (azimuth, elevation and velocity).

3 VALIDATION

3.1 General

For the validation of the newly implemented space debris and micro-meteoroids environment models, two tests suites are of special interest. One is used to compare angles and velocity distributions generated by E2/D implementation of the model to the stand-alone version. The second suite, called TestGrid, performs a number of tests forming a 'grid' out of input parameters. This allows one-by-one comparison of the fluxes of E2/D implemented to the stand-alone versions of the models. Due to the different model output formats and provided information, the test suites need to be modified for each model. However, the basic approach is kept.

The comparison of angles and velocity distributions needs to be adapted for the output format handling, while ensuring functionality. For this, both the environment model of the stand-alone version and the one implemented in E2/D are executed. For the E2/D version, rays are counted for the different angles and velocities and ray spectra over azimuth, over elevation, and over velocity are generated. These spectra are normalised with respect to the maximum as well as the generated fluxes spectra over azimuth, over elevation, and over velocities of the stand-alone version of the model. The according normalised spectra are then compared. This is done in the basic test suite layout for four Earth orbits:

- LEO: $a = 6800.0$ km, $e = 0.001$, $i = 51.6^\circ$,
- SSO: $a = 7069.0$ km, $e = 0.00205$, $i = 97.0^\circ$,
- GTO: $a = 24450.0$ km, $e = 0.73172$, $i = 10.5^\circ$,
- GEO: $a = 42371.0$ km, $e = 0.0$, $i = 0.0^\circ$,

with a as semi-major axis, e as eccentricity, i as inclination, and the complete available particle spectrum. The tests were performed with 100 rays, 500 rays, 1000 rays, 5000 rays, and 10000 rays. In the same way, tests were also applied for ORDEM 3.0. For MEMr2, they were additionally extended by two Lunar orbits,

- PLO: $a = 1838.0$ km, $e = 0.0$, $i = 90.0^\circ$,
- LLO: $a = 2038.0$ km, $e = 0.0$, $i = 30.0^\circ$,

since MEMr2 can be applied both for Earth and Lunar orbits. The tested orbits were: low-Earth orbit (LEO), Sun-synchronous orbit (SSO), GEO-transfer orbit (GTO), Geo-synchronous Earth orbit (GEO) for Earth, and polar Lunar orbit (PLO) as well as low-Lunar orbit (LLO) for Moon.

To compare the flux results with the TestGrid, the suite needs to be adapted to the provided input and output of the model. The basic idea is to use the orbits defined in the previously described suite, thus LEO, SSO, GTO and GEO for ORDEM 3.0 and LEO, SSO, GTO, GEO, PLO and LLO for MEMr2. All are combined with 6 mission dates: (May, 01) 2010, 2013, 2015, 2018, 2020, and 2025, for both models and with a number of different minimum particle thresholds. Results of the comparison between the E2/D and stand-alone version are written into formatted text files for each orbit. These files can be imported into a prepared Excel template where conditional formatting of the differences provide better overview of the results.

The following section summarises the results of the test suites.

3.2 MEMr2

According to the description in 3.1, 6 orbits were analysed for the validation of MEMr2 implementation, i. e. 4 Earth orbits and 2 Lunar orbits.

Figs. 1 to 3 visualise, as examples, the comparison results for LEO with 10,000 rays for azimuth, elevation and velocity, respectively. They reveal the very good compliance of all three distributions generated by the MEMr2 model and its E2/D implementation. Due to the minimised statistical effects, the distribution curve of E2/D results with 10,000 rays appears to be the smoothest.

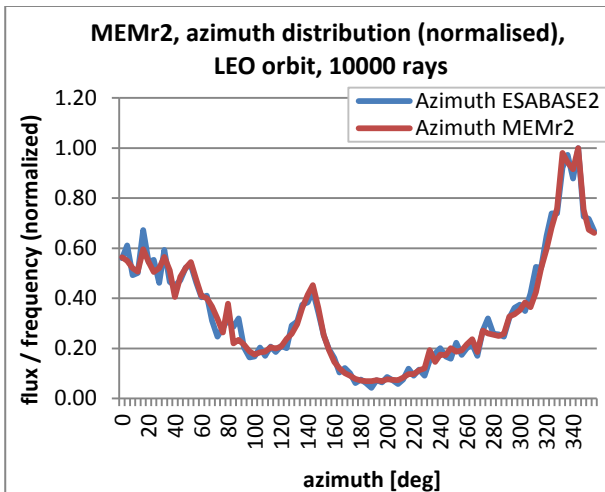


Figure 1. Normalised LEO azimuth distribution of the MEMr2 stand-alone and ESABASE2 applications

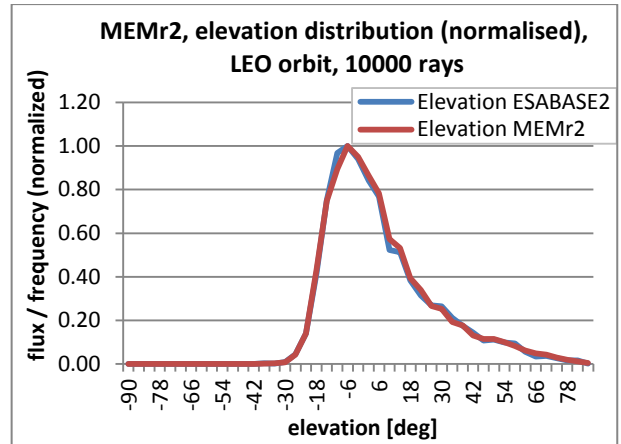


Figure 2. Normalised LEO elevation distribution of the MEMr2 stand-alone and ESABASE2 applications

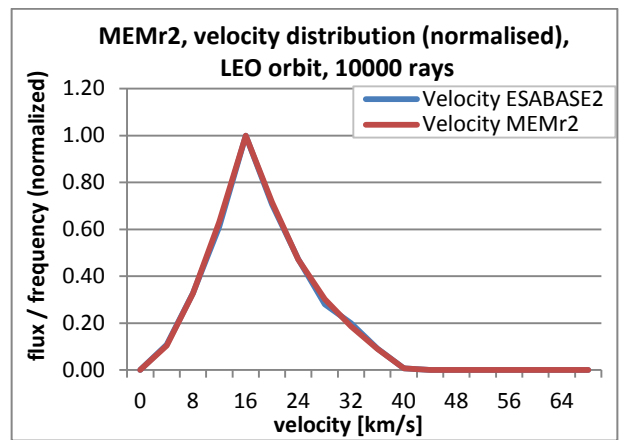


Figure 3. Normalised LEO velocity distribution of the MEMr2 stand-alone and ESABASE2 applications

For the TestGrid test suite of MEMr2, 8 mass thresholds is applied, i. e. in gram: 0.000001, 0.00001, 0.0001, 0.001, 0.01, 0.1, 1.0, and 10.0. The combinations result in 288 tests for MEMr2. The geometry for the flux results comparison is chosen to be a RAM and Nadir oriented cube with edge length of 1 m. MEMr2 provides flux results for all six cube sides, thus they can be directly compared with E2/D cube results. The overall compliance of the results showed to be excellent. The deviation between the E2/D implementation and stand-alone version is less than $\pm 2.5\%$ on each cube side for all of the 288 tests. The deviations for the individual orbits are:

- LEO: deviation $< \pm 1.4\%$,
- SSO: deviation $< \pm 2.5\%$,
- GTO: deviation $< \pm 1.6\%$,
- GEO: deviation $< \pm 1.6\%$,
- PLO: deviation $< \pm 2.2\%$,
- LLO: deviation $< \pm 2.1\%$.

3.3 ORDEM 3.0

The validation tests of ORDEM 3.0 were performed on the basis of the 4 Earth orbits as described in 3.1.

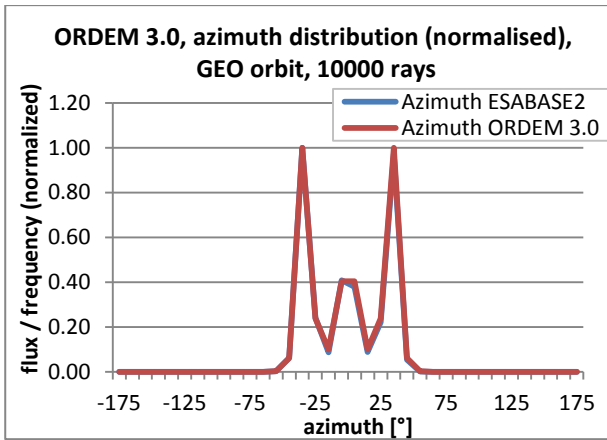


Figure 4. Normalised GEO azimuth distribution of the ORDEM 3.0 stand-alone and ESABASE2 applications

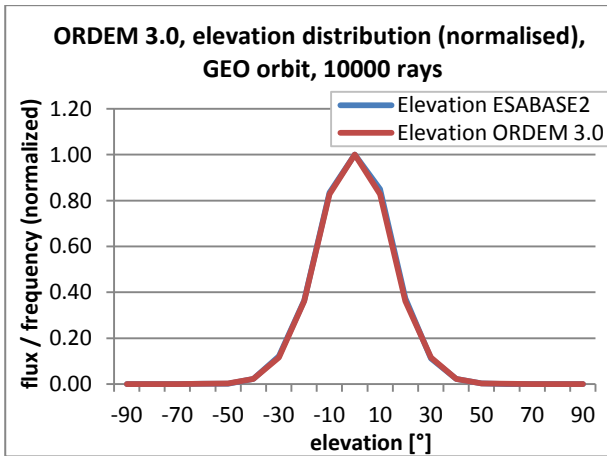


Figure 5. Normalised GEO elevation distribution of the ORDEM 3.0 stand-alone and ESABASE2 applications

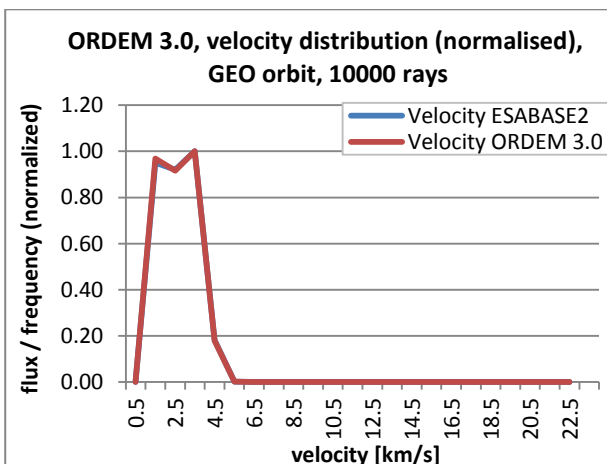


Figure 6. Normalised GEO velocity distribution of the ORDEM 3.0 stand-alone and ESABASE2 applications

Figs. 4 to 6 illustrate, as examples, the comparison results for GEO with 10,000 rays for azimuth, elevation and velocity, respectively. They show very good compliance of all three distributions generated by the stand-alone ORDEM 3.0 model and the E2/D implementation (with constant density consideration).

For the TestGrid test suite of ORDEM 3.0, 7 particle size thresholds are applied, in centimetre: 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, and 1.0. The combinations result in 168 tests for ORDEM 3.0. The geometry for the flux results comparison is chosen to be a sphere with a cross-section of 1 m², thus an area of 4 m². This is due to the fact that ORDEM 3.0 provides only the cross-sectional sphere flux, which is 4 times the impact flux of an overall sphere area. The overall compliance of the flux results showed to be excellent. The deviation between the stand-alone version of ORDEM 3.0 and the E2/D implementation (with constant density consideration) is less than $\pm 0.5\%$ for each of the 168 tests.

ORDEM 3.0 is implemented into E2/D in a way allowing the user to define a constant particle density or to consider the ORDEM 3.0 provided density distribution. Regarding the latter, the 5 sources defined in [9] are reduced to 3 sources (low-, medium- and high-density fragments) by combining the Intacts, NaK droplets, and low-density fragments to one source. The three sources can also be used individually for analyses or in the possible combinations (low-/medium-density fragments, low-/high-density fragments, medium-/high-density fragments). To validate the consistency of the implemented approach, an additional test suite was applied. For this, 8 analyses per orbit are performed, which include individual analyses for each source (3), analyses for each possible combination (3), analysis considering all three sources, and analysis considering the particles to have a constant density. The flux results of the individual source analyses are used to generate different sums to reflect all combined analyses. These sums were compared with the flux results of the combined analyses. For all orbits and all combinations, the differences of the impact flux are less than $\pm 0.2\%$. This holds even in the cases if the sum of all three individual sources analyses is compared to the analysis considering all three sources and to the analysis considering a constant particle density. This justifies applying the TestGrid suite only to the constant density configuration.

3.4 IADC test cases

3.4.1 General

IADC Protection Manual [10] provides a definition of calibration tests, which can be also used to validate the impact number and failure results by comparison with other tools.

ORDEM 3.0 and MEMr2 can be used, besides of E2/D,

also with Bumper application [7]. Bumper is NASA's tool for the impact flux and damage assessment. It uses the results outputs of the environment models in igloo format, which are prepared externally. Bumper results for both environments have been provided by [8]. For ORDEM 3.0 the finest resolution was used with its own orbit definition. In the case of MEMr2 4,000 samples were drawn out of 525,601 STK state vectors to calculate the igloo formatted distributions in a resolution of 5 deg × 5 deg × 5 km/s.

E2/D and Bumper are completely independent tools. The probability that different algorithms/ approaches are used by the tools for impact flux and assessment is very high.

3.4.2 Test definition

The definition of the test cases is given in [10]. The IADC Protection Manual defines five calibration cases:

- Number of impacts of particles with $d \geq 0.1$ mm
- Number of impacts of particles with $d \geq 1.0$ cm
- Number of impacts resulting in craters with depth $p \geq 1.0$ mm
- 'Single': number of penetration in single wall structure: 1 mm wall thickness
- 'Double': number of penetration in double wall structure: 2 mm shield thickness, 4 mm backwall thickness, 10 cm spacing

For these cases three geometric models are defined: cube, sphere and simple space station model. Also the orbit (ISS like) and the ballistic limit equations to be used are indicated. In agreement with NASA [8] the mission years were changed compared to the definition in [10]. The mission epoch for MEMr2 analyses is 27.12.2013 to 27.12.2014. For the ORDEM 3.0 based analyses the year 2018 was used. The orbits in E2/D were described by 8 orbital points.

3.4.3 MEMr2 results

In the case of MEMr2 two model characteristics need to be taken into account to achieve a better comparability.

First: Seasonal dependency of the micro-meteoroid flux is considered by the MEMr2. For Bumper this is averaged out by drawing a randomised number of samples over the whole mission time during the MEMr2 execution. To average out the seasonal dependency in E2/D, for each case the analyses with MEMr2 were run 12 times at different epoch of the year. The average of these 12 run results was compared with the Bumper results.

Second: MEMr2 model considers particles down to a minimum of 10^{-6} g. With the applied material density of 1 g/cm³ the corresponding minimum particle diameter is 0.124 mm. Thus MEMr2 does not cover the first calibration test: $d \geq 0.1$ mm. To achieve the impact

results for this case NASA [7] [8] scaled the results. This was already the case for the predecessors and the correction factor calculation can be found in [12]. The factor was established to be $f_{correct} = 1.74866$.

Tab. 1 lists and compares the results of Bumper with the results of E2/D for the IADC tests with the three geometries for MEMr2. For the calculation of the differences, Bumper results were used as reference.

Table 1. Cube, sphere and simple ISS results of Bumper [7] and ESABASE2 with MEMr2 (ISS like orbit, 1 year, 27.12.2013-27.12.2014)

	Test cases	ESABASE2	BUMPER	diff [%]
MEMr2 cube	$d \geq 0.1$ mm	1.935E+01	1.92E+01	0.79
	$d \geq 1.0$ cm	1.268E-06	1.28E-06	-0.94
	$p \geq 1.0$ mm	1.278E-01	1.30E-01	-1.68
	single	8.084E-01	8.27E-01	-2.25
	double	1.93E-05	1.98E-05	-2.62
MEMr2 sphere	$d \geq 0.1$ mm	1.288E+01	1.30E+01	-0.92
	$d \geq 1.0$ cm	8.440E-07	8.67E-07	-2.66
	$p \geq 1.0$ mm	8.120E-02	8.48E-02	-4.25
	single	5.158E-01	5.41E-01	-4.66
	double	1.21E-05	1.28E-05	-5.10
MEMr2 ISS	$d \geq 0.1$ mm	8.372E+01	8.23E+01	1.72
	$d \geq 1.0$ cm	5.485E-06	5.50E-06	-0.28
	$p \geq 1.0$ mm	5.489E-01	5.52E-01	-0.56
	single	3.476E+00	3.51E+00	-0.96
	double	8.26E-05	8.35E-05	-1.06

The impact results differences for all three geometries are less than 3% and the damage results differences less than 6%. Bearing in mind the use of different distribution resolutions for E2/D (cp. 2.1) and Bumper (cp. 3.4.1) the results show an excellent compliance.

Figs. 7 and 8 visualise results for the 'single' calibration case as example of the individual results. Fig. 7 show the results comparison on the 6 sides of a cube, where as Fig. 8 compares the results for the components of the simple ISS model. The results of the individual sides/components support the estimation of an excellent compliance of the results. The slightly higher deviation of the starboard and port sides of the cube applies for the cube damage cases. The probable reason of this deviation could be the mentioned use of different resolutions in the tools. This leads to different parameterisation of the incoming fluxes and can result in different accounting of impacts at ballistic limit thresholds.

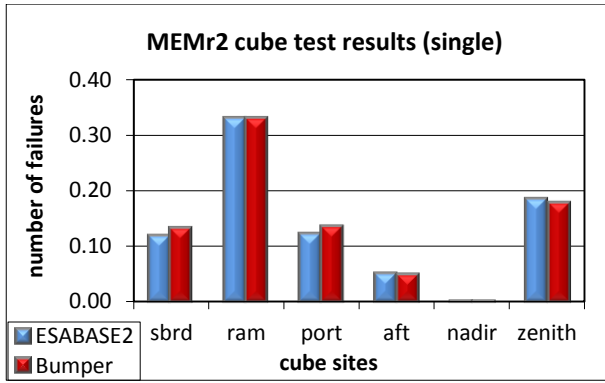


Figure 7. Comparison of ESABASE2 and Bumper results on the sides of a cube

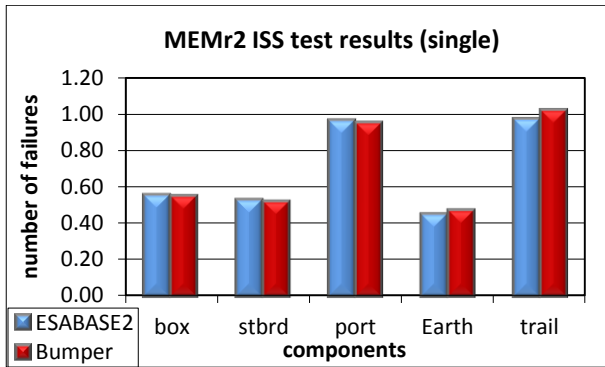


Figure 8. Comparison of ESABASE2 and Bumper results on the components of the simple ISS model

3.4.4 ORDEM 3.0 results

Tab. 2 lists and compares the results of Bumper with the results of E2/D for the IADC tests with ORDEM 3.0 for the three geometries. For the calculation of the differences, Bumper results were used as reference.

It is obvious that for all three geometries the compliance of the impact results is excellent, it is less than 2%.

In contrary, the results of the damage cases are considerably different. As previously mentioned Bumper and E2/D are completely independent tools and use most probably different approaches. In the case of ORDEM 3.0 consideration methods of different model characteristics can essentially influence the precondition for the damage calculations. These especially are: the applied particle size vs. flux resolution, the consideration method of the shares of the different populations (densities), how these distributions are linked, and probably the methods of interpolation between the reference data. The following can be seen as examples for probable reasons. Bumper relies on the igloo output files, which provide the results in 11 size classes and 5 density classes. Thus Bumper relies on this 11 size classes or interpolates between them. E2/D considers additionally the size vs. flux output file which provides a size resolution of 501 classes and interpolates

between them if required. As the flux test cases show, it is not a problem at reference points, but depending on the methods of Bumper for the consideration of particle sizes in-between the reference points, a considerable deviation of incoming potentially hazardous flux can be a result. Another point is the consideration of the shares of populations that define how many dangerous high-density particles are impacting. Especially in combination with the particle size consideration issue, this can also lead to considerable deviations. To identify the actually cause of these obvious differences further investigations are required.

Table 2. Cube, sphere and simple ISS results of Bumper [7] and ESABASE2 with ORDEM 3.0 (ISS like orbit, 1 year, 2018)

	Test cases	ESABASE2	BUMPER	diff [%]
ORDEM 3.0 cube	$d \geq 0.1$ mm	1.953E+01	1.94E+01	0.66
	$d \geq 1.0$ cm	3.411E-06	3.41E-06	0.02
	$p \geq 1.0$ mm	2.522E-01	3.90E-01	-35.34
	single	1.101E+00	1.41E+00	-21.95
	double	1.89E-05	1.74E-05	8.90
ORDEM 3.0 sphere	$d \geq 0.1$ mm	1.442E+01	1.46E+01	-1.23
	$d \geq 1.0$ cm	2.528E-06	2.55E-06	-0.86
	$p \geq 1.0$ mm	1.533E-01	2.53E-01	-39.41
	single	6.971E-01	9.02E-01	-22.72
	double	1.14E-05	1.10E-05	3.82
ORDEM 3.0 ISS	$d \geq 0.1$ mm	7.908E+01	7.77E+01	1.78
	$d \geq 1.0$ cm	1.385E-05	1.36E-05	1.85
	$p \geq 1.0$ mm	8.725E-01	1.41E+00	-37.94
	single	3.895E+00	5.04E+00	-22.72
	double	7.31E-05	6.31E-05	15.85

4 SCRIPTING AND BATCH MODE

The user requests and feedback revealed the need for serial execution of multiple analyses. A questionnaire, provided to the users to get better insight to their requirements, also indicates the demand for the possibility to vary some calculation parameters automatically. These extensions were addressed by the scripting mode and the batch mode, where:

- Batch mode is the capability of serial execution of multiple analyses without user interaction. It is mainly represented by the Batch Processor.
- Scripting mode is the capability to vary some calculation parameters automatically by creating a batch out of user provided information regarding value range and number of steps for the variation.

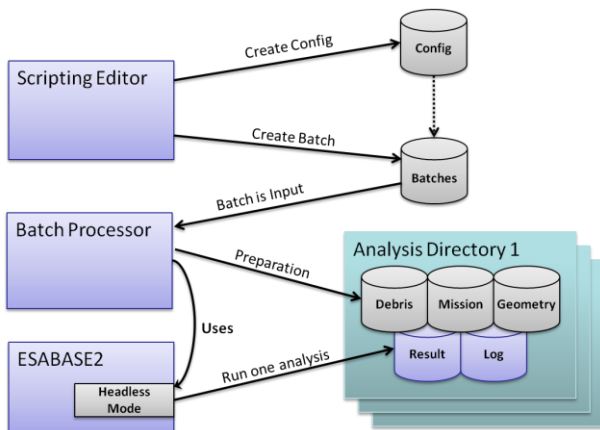


Figure 9. Scripting and batch mode utilisation workflow

Fig. 9 illustrates the utilisation work flow of the definition (scripting mode) and serial execution (batch mode) of multiple analyses.

The first part is covered by the Scripting Editor. It is used to define the required input for analyses. E2/D analysis uses three input files: geometry, mission, and debris file to define the respective information. In the Scripting Editor, existing files (e. g. default files) can be loaded into a scripting project. Loaded geometry files can be used only as is. Loaded mission and debris files can be modified by changing the individual values or, for some parameters, define a value range and number of steps to vary the parameter automatically. The loaded file and modified parameters can be stored as configuration of the according kind (e. g. mission). In this way multiple geometry (only links to files), mission, and debris configurations can be generated in a scripting project. In addition to the input sections, a scripting configuration section exists in Scripting Editor. Here, the user is able to freely define which configurations shall be combined to one batch, e. g. debris configuration 1 is to be used with mission configuration 2 and geometry 1, but in the same batch also debris 3 is to be used with mission 1 and geometry 1, where mission 1 could include scripted parameters. This is finally stored as a scripting configuration. In this way the user is able to define which parameters shall be varied automatically in three ways: by defining different input configurations, by scripting parameters in these configurations, and by combining these configurations to one batch. Storing the scripting configuration is not exactly the same as exporting as a batch file for the Batch Processor. The scripting configuration file is human-readable and lists the input as the user defined it, e. g. a definition of a value range and number of steps is listed exactly like this.

A batch, usable with the Batch Processor, can be exported. It is also human-readable, but it contains only the modifications as exact numerical values without the references to the loaded files. This means the scripted

values are resolved, i.e. there are no definitions that give a range or range step, but exactly all the combinations – each to be run as analysis, see Fig. 10. Such a batch file is loaded by the Batch Processor. It prepares the data structure for each run and copies/creates the input in the according directories. Then the E2/D analyses are performed using the new Headless Mode of E2/D while the results and logs are stored in the according directories. Thus, each analysis can be reproduced individually.

The Headless Mode of E2/D is a new capability, which is required to enable the implementation of a batch mode. It allows using E2/D via command line interface.

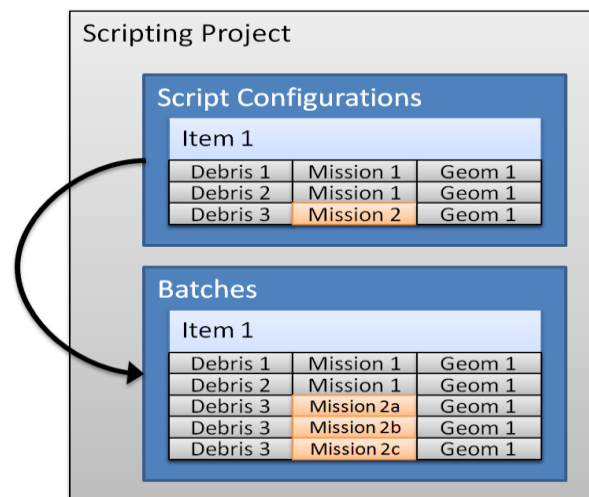


Figure 10. Schematical batch generation

5 VERSIONS

5.1 Demo Version

Beside additional capabilities, a demo version of ESABASE2 was requested frequently. For this purpose, the distribution approach of ESABASE2 was refactored. Being close to finalisation it will allow the provision of a demo version, as well as a sophisticated automated license management.

Fig. 11 depicts the workflow for the achievement of a demo version of ESABASE2. The user can register on the ESABASE2 website and request a demo version. The data of the filled form is provided to a data base and etamax staff is informed that a new interested person has registered and need an approval. After the check and approval by the etamax staff the database triggers the creation of the demo version (or for the requested tailored version) which is temporarily placed in a download area on a server, and a temporarily active download link is sent by the database to the requestor.

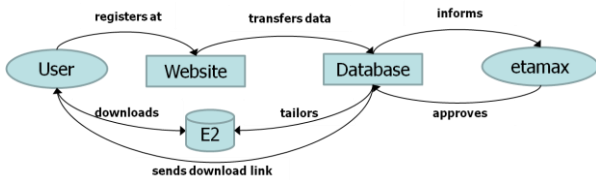


Figure 11. Work flow for demo version achievement

The requestor is then able to download the demo version. It includes nearly all ESABASE2 capabilities and allows comprehensive testing for 30 days. In the E2/D application, MASTER 2009 and ORDEM 3.0 space debris models are not included in the demo version.

5.2 Linux Version

A Linux version of ESABASE2/Debris is currently in development. The leading platform is 32 bit Ubuntu 14.04 LTS. The target platforms to be supported are Ubuntu, Debian, CentOS, and openSUSE. Multiple space debris and micro-meteoroid environments incorporated in E2/D are not available on Linux. To allow the execution of these models in the Linux version, it will rely on the “Wine” application. In this way, all capabilities of E2/D are planned to be made accessible on the Linux system.

6 SUMMARY AND CONCLUSIONS

ESABASE2/Debris now includes NASA’s most up-to-date space debris and micro-meteoroid environment models ORDEM 3.0 and MEM release 2, which can be used for the impact risk assessment. In case of ORDEM 3.0, it can be distinguished between three sources or a constant density for the complete flux.

Verification and validation tests were performed for all new integrated environment models comparing them with their stand-alone pendants. Additional validation was performed by comparison of the IADC calibration tests results of E2/D to NASA’s Bumper software for both models. The comparison of MEMr2 results revealed an excellent correlation of both impact and failure test results for all geometries. Analyses with ORDEM 3.0 showed also excellent agreement of the impact results, but the failure results are considerably different. To identify the cause of this, further investigations are required.

Beside the new environment models, E2/D was extended to allow serial execution of multiple analyses with automatic variation of calculation parameters. Additionally a demo version and a Linux version are introduced.

These new capabilities will be provided with the upcoming releases.

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