PRESENTATION OF THE PC VERSION OF THE ESABASE/DEBRIS IMPACT ANALYSIS TOOL

A.Langwost (1), H.Sdunnus (1), D.Gunia (1), G. Drolshagen (2), J. Soerensen (2), S. Hauptmann

[(1)]eta_max space GmbH, Richard-Wagner-Str. 1, 38106 Braunschweig, Germany, a.langwost@etamax.de
[(2)] ESA/ESTEC, Keplerlaan 1, Postbus 299, 2200 AG Noordwijk, The Netherlands, gerhard.drolshagen@esa.int

ABSTRACT

ESABASE is a framework of space environment analysis tools known and accepted by European industry. It allows to predict the exposure of an orbiting spacecraft to its environmental conditions induced e.g. by sunlight, atomic oxygen, radiation and impacts from meteoroids and space debris

However, similar to other European tools in the space environment and also the thermal analysis domain, the ESABASE framework was ageing. Restrictions affecting the graphical capabilities, the data handling or the post processing became more and more evident and caused increasing user dissatisfaction. In view of that fact ESA took the initiative to port the debris application of ESABASE to PC platforms.

This paper provides an insight to PC ESABASE – the result of this activity. PC ESABASE is composed of an up-to-date framework based on Open Source components like the Eclipse Graphical User Interface or the OpenCascade CAD library, and the previously existing well established debris models like MASTER.

This paper introduces the capabilities of the ESABASE framework together with the debris application. It will demonstrate the modern user interface as well a new ray tracing algorithm and the integration of the ORDEM2000 debris model

1. INTRODUCTION

1.1. Introduction to ESABASE

Since its development in the late Eighties, ESABASE is a framework of space environment analysis tools well established and accepted by European industry. It allows predicting the exposure of an orbiting spacecraft to e.g. sunlight, atomic oxygen, radiation and impacts from meteoroids and space debris.
The ESABASE tool enables the user to construct a 3-dimensional analysis model. A built-in orbit propagator (SAPRE predicts the spacecraft orbit over a given time span. Several built-in physical models enable the user to perform a variety of space–specific analyses on this model along its orbital trajectory. The analysis model constructed with ESABASE incorporates the geometry of the system and other relevant data such as surface and material properties. In addition, kinematics and pointing information (e.g. Sun pointing) can individually be defined for singe spacecraft components (e.g. solar arrays). These features allow ESABASE to account for complex spacecraft geometries and mission profiles. The application of a ray tracing algorithm ensures the proper consideration of self shielding effects.

The ESABASE/DEBRIS impact analysis tool has been widely used by ESA and European industry and has been applied to basically all European modules of the International Space Station (Columbus, ATV, Cupola, ERA), but also to other missions like the Polar Platform, ISO, Eureca, HST, XMM, and other projects. The ESABASE/DEBRIS model has been kept up-to-date by the steady implementation of the most actual debris and meteoroid models like MASTER or ORDEM.

1.2. Motivation for PC ESABASE

However, similar to other European tools in the space environment and also the thermal analysis domain, the ESABASE tool was ageing. Its development started on VMS and UNIX systems. Restrictions from that time, affecting the graphical capabilities, the data handling or the post processing became more and more evident. The progressing usage of Windows and Linux operating systems also for demanding engineering purposes increasingly displaced ESABASE from the engineers' desktops.

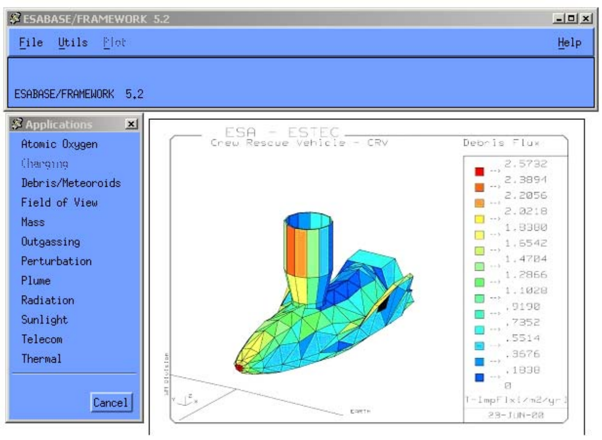

Figure 1 The UNIX based framework of the former ESABASE application was ageing

Note: for all images - click to magnify

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Efforts made by ESA in the meantime concentrated in the maintenance and extension of the scientific kernel of the application, rather than on the framework. In the current situation some tools are featuring state-of-the-art environment modelling capabilities coupled with outdated programming methods and data structures and almost archaic front- and back ends. As indicated by the screenshot of the former ESABASE application (Figure 1), ESABASE was one of the tools affected by this situation.

In view of the actual situation, ESA took the initiative to port the Debris application of ESABASE to PC platforms.

2. PRESENTATION OF PC ESABASE

2.1. General Concept

The roadmap to increase the acceptance of ESABASE by its users aimed at the provision of an open and state-of-the art solution avoiding proprietary limitations. Since the most severe shortcomings of the existing tools was in the framework of the tool, the roadmap for the enhanced version – PC ESABASE – in particular addressed these components. The approach of making PC ESABASE or parts of it Open Source was fostered. The roadmap includes the following steps:

- Replace the outdated UNIX version by a state-of-the art PC based version
- Provide a platform independent solution based on standard available software packages for the generation and display of geometry model, kinematics, pointing, meshing
- Make use of Open Source components
- Provide an open interface to external CAD/CAE tools as well as to former ESABASE versions
- Establish an attractive scheme for future maintenance, distribution and user support of the new tool

2.2. Components

The new PC ESABASE platform includes the following components:

- **Graphical User Interface → Eclipse**
  The acquisition of user input by means of the Eclipse platform (Java) (ref. [3]) ensures full availability to the features of the Java Standard Widget Toolkit (SWT). The SWT offers all features a user expects from an ergonomic framework, such as file selection dialogues, buttons, checkboxes, drop down boxes, trees, etc. .

  The Eclipse Project is an open source software development project dedicated to providing a robust, full-featured, commercial-quality, industry platform for the development of highly integrated tools. The Eclipse Platform is distributed under the Common Public License (CPL) intended to facilitate the commercial use of the program. Eclipse allows tool builders to independently develop modules that seamlessly integrate with third party tools.
  The Eclipse Platform is utilized to provide the top-level GUI framework of the ESABASE GUI. Eclipse supports a project oriented workflow, which means that the user assigns all kind of input (i.e. geometry, orbit, debris environment and mission characteristics) and also output data (i.e. analysis results) to a project, which he can store and exchange with other users.

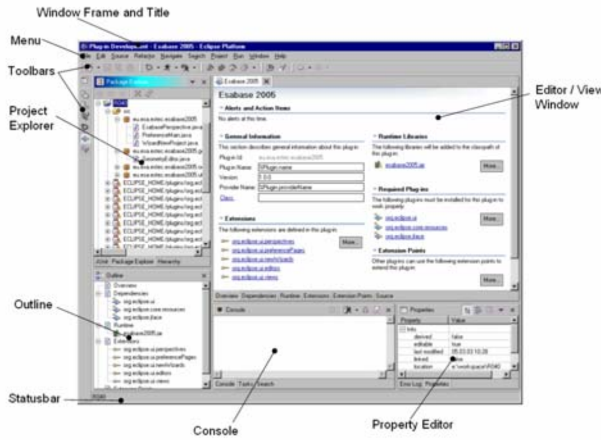

Figure 2 The Eclipse framework offers an state-of-the art user interface for PC ESABASE

- **Mode Builder/viewer → Open Cascade CAD lib**
  PC ESABASE comes with a built-in model editor that graphically supports the assembly of geometrical models in 3D. The model builder is based on the Open Source CAD library Open Cascade (OCC) (ref.[4]). The tool is distributed under the Open Cascade Public License. It provides a vast variety of modelling and visualisation capabilities and has already proven its applicability for many industrial and also space applications. Open Cascade 5.2 is a CAD library with open interfaces to several different programming languages. It is available on all major platforms (Win9x/NT/2000, Linux, Unix) and provides methods to import, edit and visualise CAD relevant data. It comes with its own data model (OCAF) that may be accessed from other languages and allows to manage hierarchical data structures where parts of the structure may be connected to geometrical objects.

Additionally, Open Cascade is STEP enabled regarding the application protocols AP 203 and AP 214 which opens the possibility to utilise a widely distributed CAD format for data exchange with other (commercial) applications. Open Cascade is already industry experienced and currently applied to space and aeronautical projects by EADS and Alcatel Space. An example of an OCC application is shown below:

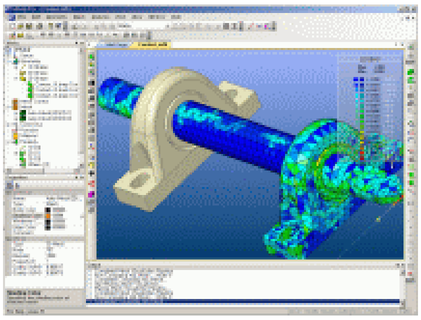

Figure 3 Application example of Open Cascade. Courtesy of Midas IT co.,Ltd.(ref [4])

- **Data visualization → VisAD**
  VisAD (Visualization for Algorithm Development) is a Java component library for interactive and collaborative visualization and analysis of numerical data (ref.[5]). It is distributed under the Lesser Gnu Public License (LGPL). It provides services to display any tabular result data in presentation ready charts. VisAD is able to generate a variety of different chart types (even combinations of different types) and allows the modification of all relevant chart components.
  Export options for visualised results into various formats are also provided. VisAD is an Open Source Software developed by programmers at the University of Wisconsin Space Science and Engineering Center (SSEC), at the Unidata Program Office and at the National Center for Supercomputer Applications (NCSA).

- **Report generation → JFree Report**
  PC ESABASE is also equipped with a report generator allowing to produce formatted reports upon user specification. The reports may contain text, tables, figures, etc. and are based on user defined templates. JFreeReport (ref. [6]) is distributed under the LGPL license. It allows for XML-based report definitions and output to the screen, printer or various export formats (PDF, HTML, CSV, Excel, plain text).

- **Ray tracing**
  In ESABASE, ray tracing is used to account for shielding/shadowing effects of the spacecraft geometry with respect to directional effects of e.g. the debris or meteoroid flux. The capabilities of the ray tracing algorithm implemented in ESABASE suffered from numerical and serious performance problems. In addition, the tools was affected by license restrictions. In case of larger spacecraft models the ray tracing algorithm took more then 90 percent of the calculation time. For this reason the ray tracer was replaced by a new one developed by eta_max space with the following characteristics:

  - The intersection algorithm is based on an algorithm design by Didier Badouel [7].
  - An adaptive octree datastructure has been implemented to increase the performance.
  - It is implemented in FORTRAN 90 but can be easily adapted to c++.

  The new solution is between ten and fifty times faster than the old one which has a great influence on the overall calculation time. The numerical problems are solved.

- **Mesher → NETGEN**
  The ESABASE analysis requires a subdivision of larger structures into planar elements. For this purpose, a surface meshing into triangular or quadratic surface elements is performed.
  For the PC ESABASE application two different meshing algorithms are used. Geometries created by the user by means of the PC ESABASE mode building capabilities are meshed by the meshing algorithm of the ESABASE kernel. For geometries imported from a STEP file, a STEP-conformant mesher is needed. Because of the open source approach of Open Frontier eta_max decided to take NETGEN as external mesher. NETGEN is an automatic tetrahedral mesh generator. It accepts STEP-files as input and has modules for mesh-optimization and mesh-refinement included. For PC ESABASE the STEP geometry is decomposed into objects, surfaces and triangular elements.

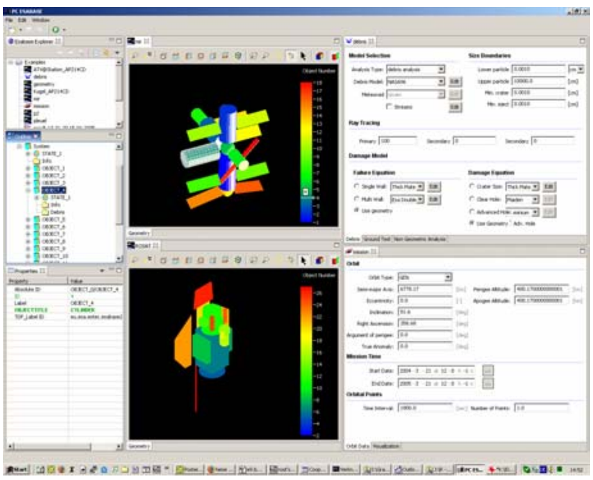

Figure 4 Screenshot of new PC ESABASE application

2.3. Handling

The general handling of PC ESABASE to a large extent profits from the excellent features in the domain of file handling and window management offered by the Eclipse platform. In conformance to the Eclipse philosophy, the PC ESABASE workflow is project oriented. An ESABASE project consists of four different files:

- Geometry file
- Mission file
- Debris (Application) file
- Result file

Files can be handled individually. This allows to easily combine one spacecraft geometry with different orbits or different debris parameters settings e.g. for analysis purposes. Files can be dumped to storage media and are easily exchangeable between different users. This feature is very valuable for distributed project teams.

For each input file the PC ESABASE application provides one or more specific editors or so called "wizards". These are custom made forms facilitating the acquisition of all kinds of user input.

- **Geometry file**
  The geometry file contains information on the spacecraft model, its kinematics and pointing. A spacecraft geometry may either be constructed from scratch or imported from external files. To construct a spacecraft from scratch the graphical geometry editor based on the Open Cascade CAD tool provides different possibilities. The creation of models is supported by "wizards" (see figure below) facilitating the definition of required information.

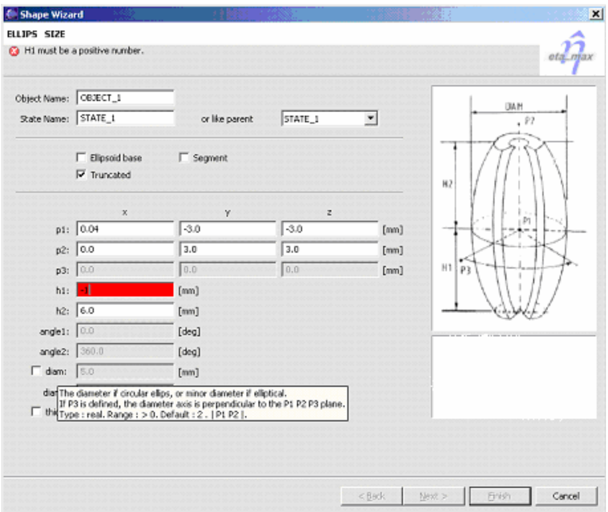

Figure 5 Wizards support the definition of geometrical primitives. Here:Ellipsoid

An important feature of PC ESABASE is its ability to import both, existing geometry models from its predecessors (*.BAS files) and geometries established by external CAD tools via its STEP interface. (see 2.4).

- **Mission File**
  The mission file contains data related to the space-craft mission. The user can specify the orbit, mission start and duration as well as the perturbations to be considered for orbit propagation. The orbit can be displayed in a 3D-view.

- **Debris File**
  According to the PC ESABASE workflow philosophy, parameters specifying physical models to be applied to the spacecraft are stored in dedicated application files.
  The debris file contains all parameters needed to specify the debris models to be applied. In addition to the parameters of debris and meteoroid models to be applied, the debris file contains information on the applicable damage and failure equations.

- **Result File**
  The result file contains all calculated values from the analysis. In case of the debris application this may include impact, crater and failure flux, average impact velocity and angle and others. Due to the fact that the result files mirrors the geometrical decomposition of the spacecraft, all results are available on element level, but can be integrated also to surface and object level.
  By means of the geometry viewer, the results can be projected onto the 3D-geometry and visualized with an interactice 3D-viewer (see Figure 7). VisAD opens different possibilities to create 2D charts.

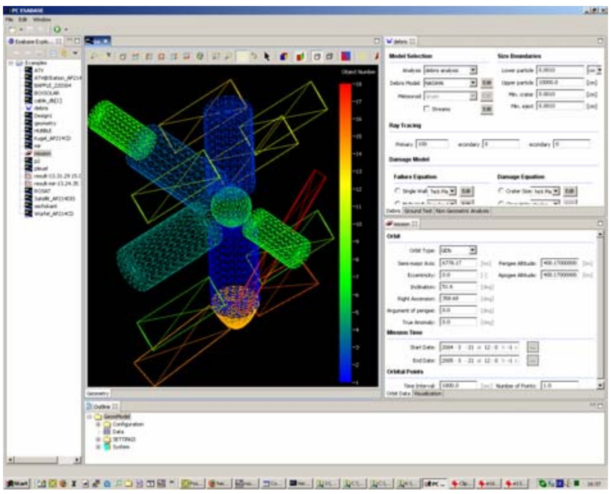

Figure 6 Dedicated editors support the definition of user input (here: Debris Editor, Orbit editor) and allow the visualization of constructed models.

2.4. The STEP data exchange format

STEP - the Standard for the Exchange of Product Model Data is an international product data standard (ISO 10303) to provide an complete, unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle. It is a much broader standard than data interchange standards such as IGES. STEP is already widely distributed in the domain of mechanical engineering and gets more and more support also in the aerospace domain. Within PC ESABASE, the application protocols AP 209 and AP 214 are supported. Further space oriented protocols such as STEP SPE are under preparation.

2.5. Available models

As shown by the following table summarising the models available in PC ESABASE, the tool offers access to all currently relevant debris and meteoroid models, including the ESA and the NASA reference models. This ensures the applicability of the tool to both, European and US satellite projects.

Debris Models	
	NASA 90 NASA 96 MASTER 2001 ORDEM 2000
Meteoroid Models	
Sporadics	Grün Cour-Palais Divine-Staubach
Streams	Jenniskens
Advanced (directional effects of the sporadic component)	Apex Enhancement α,β separation Interstellar Sources
Velocity Distribution	HRMP(also altitude dependant) Kessler
Secondary Ejecta	yes
Design Equations	
Single Wall **Multiple Wall**	▪ Commonly used equations are selectable ▪ Generic equations with user-editable parameters are available.
Damage Equations	
Craterisation **Clear Hole** **Advanced Hole**	▪ Commonly used equations are selectable ▪ Generic equations with user-editable parameters are available.

Table 1 Models contained in ESABASE

The most recent model implemented in PC ESABASE is the ORDEM 2000 model. Based on the software distribution package provided by the model authors (ref. [8]) the model was interfaced with the ESABASE framework

The design and damage equations implemented in PC ESABAE are in principle freely configurable by means of their relevant parameters. Some common equations with pre-defined parameters are offered via the debris editor.

- Single Wall Equations
  - Thick Plate, Thin Plate, MLI, Pailer-Gruen, McDonnell Sullivan, Gardner, McDonnell Collier, Frost, Naumann-Jex-Johnson, Naumann, McHugh Richardson, Cour Palais

- Multi Wall Equations
  - ESA double, Cour Palais, MLI, Maiden McMillan, ESA Triple, NASA ISS, NASA Shock, NASA Bumper

- Crater Size Equation
  - Ductile, Thick Plate, Shanbing, Sorensen, Christiansen, Brittle, Gault, Fechtig, McHugh Richardson, Cour Palais

- Clear Hole Size Equation
  - Maiden, Nysmith Denardo, Sawle, Fechtig

- Advanced Hole Size Equation
  - Aluminium, Silver, Gold, Beryllium Copper, Copper, Steel, Titanium

2.6. Results

This paper can only provide a very brief insight to the results provided by the new PC ESABASE tool. Results provided by the tool include impact, crater and failure flux (and fluence), average impact velocity and angle and others. All results are available on element level, but can be integrated also to surface and object level. The results can be mapped to the model geometry (see Figure 7) or can be analysed by means of 2D line charts or bar charts. The report generator allows to generate standardised reports based on user defined templates.
In order to verify the results provided by PC ESABASE, results were compared to the previous version and to results provided by the underlying models such as MASTER 2001, NASA 96 or ORDEM 2000.

Table 2 shows the total impact flux of a box on an ISS-like orbit, calculated with NASA96.

surface	1	2	3	4	5	6
PC ESABASE	0.513 E+03	0.246 E+03	0.498 E+01	0.247 E+03	0.656 E+01	0.800 E+01
Old ESABASE	0.513 E+03	0.246 E+03	0.498 E+01	0.247 E+03	0.652 E+01	0.798 E+01

Table 2 Result Validation

The small differences in the flux values calculated between the former ESABASE version and PC ESABASE may have different reasons:

- Higher precision in PC ESABASE because of using double precison variables
- Different handling of active and non-active surfaces
- The new ray tracing algorithm

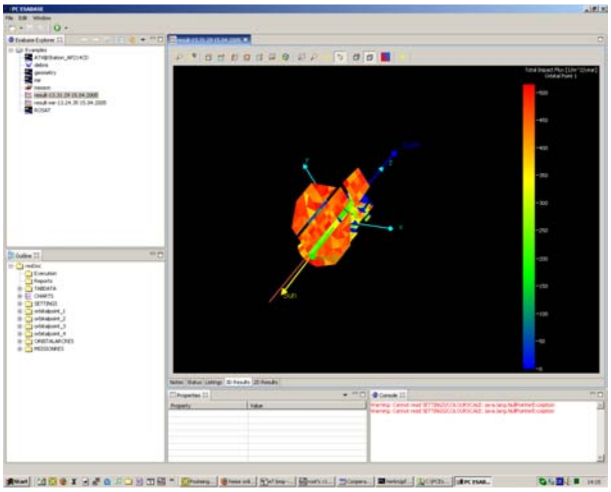

Figure 7 Total Impact Flux mapped to the satellite geometry. Here: Rosat (German X-Ray satellite)

2.7. System Requirements

A PC with a 1 GHz CPU, 500 MByte of free disc space and up-to-date graphics capabilities is recommended.

2.8. Maintenance and Distribution

Distribution of PC EABASE is done under the ESA Open Source license scheme. License fees will are charged for the maintenance and distribution of the tool, which is under the responsibility of eta_max space. Further information is available at the authors of this paper.

3. CONCLUSIONS AND OUTLOOK

After its porting to PC platforms, PC ESABASE now represents a state-of-the art space environment analysis framework. A highly intuitive user interface based on the Eclipse framework, a capable graphical model builder and viewer basen on Open Cascaded as well as post processing and viewing tools represent the backbone of the enhanced framework. Via a STEP AP 209/214 interface PC ESABASE offers access to external CAD/CAE tools

With the implementation of the ORDEM 2000 debris model, the already excellent modelling capabilities of former ESABASE releases were further enhanced. ESABASE now offers access to all state-of-the art debris and meteoroid models as well as to damage equations.

PC ESABASE distribution and maintenance as well as user support is provided by eta_max space.

4. REFERENCES

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