# UPGRADE OF DRAMA
# ESA'S SPACE DEBRIS MITIGATION ANALYSIS TOOL SUITE

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## ABSTRACT

One decade ago ESA started the development of the first version of the software tool called DRAMA (Debris Risk Assessment and Mitigation Analysis) to enable ESA space programs to assess their compliance with the recommendations in the European Code of Conduct for Space Debris Mitigation. This tool was maintained, upgraded and extended during the last year and is now a combination of five individual tools, each addressing a different aspect of debris mitigation.

This paper gives an overview of the new DRAMA software in general. Both, the main tools ARES, OSCAR, MIDAS, CROC and SARA will be discussed and the environment used by DRAMA will be explained shortly.

Key words: ESA, DRAMA, risk assessment, spacecraft removal, cross section, re-entry analysis

## 1 INTRODUCTION TO DRAMA

The DRAMA tool is made for the use within space programs and provides several software modules to enable the assessment of debris mitigation strategies for the operational and disposal phases of a mission and the computation of the risk caused by debris for a mission or by objects surviving a re-entry.

The DRAMA tool is a combination of several software tools all operating independently:

| | |
|---|---|
| ARES: | Assessment of Risk Event Statistics |
| MIDAS: | MASTER(-based) Impact Flux and Damage Assessment |
| OSCAR: | Orbital Spacecraft Active Removal |
| CROC: | Cross Section of Complex Bodies |
| SARA: | (Re-Entry) Survival and Risk Analysis |

There is also an auxiliary tool included called CSTATE to convert different formats of orbit data. These tools can be controlled via the command line interface, but it might be more comfortable to use the re-developed graphical user interface (GUI). This GUI allows the user to create multiple DRAMA projects for a flexible use of the software suite.

### 1.1 What's new?

For each of the mentioned tools a lot of upgrade and maintenance work has been done. The following list gives a short overview what has been changed significantly:

- A new graphical user interface has been developed for the DRAMA software suite.
- Each software tool of DRAMA writes its own *gnuplot* driver files.
- An auxiliary tool called CSTATE can be used for state transformations.
- ARES makes use of MASTER-2009
- ARES makes now use of a customizable radar equation to simulate any catalogue system performance.
- The catalogue uncertainties used by ARES can be user defined or selectable among TLE or CSM type, which have been obtained from a detailed analysis of historical data.
- OSCAR now allows selecting different scenarios for future solar & geomagnetic activities.
- The use of drag augmentation devices as a disposal system has been implemented into OSCAR.
- The used methods for orbital lifetime prediction within OSCAR are now in line with the recommendations of ISO and ECSS.
- MIDAS allows the definition of user defined BLEs and makes use of MASTER-2009
- A new tool called CROC has been developed for cross section computation of user defined complex bodies for different aspect angle conditions.

### 1.2 The GUI of DRAMA

The new graphical user interface of DRAMA gives the user a fast access to the data required for the individual tools. More or less all required input is controlled by *sidebars*. The selection of the tool of interest can be done via a *toolbar*, which is part of and located on top of the sidebar as well. For general tasks like for example creating a new project, starting the execution, etc. the buttons of the *topbar* provide direct access. The results will be presented after the execution of the selected tool in the *results window*, where the DRAMA logo is

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shown before and during the execution. For a better visibility of the results (especially on small screens) the field including the *gnuplot* driver files and the data files as well as the sidebar can be faded out.

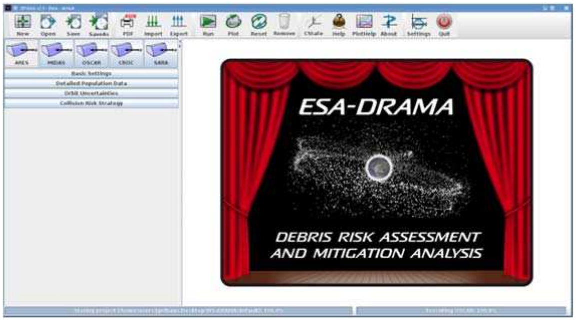

*Figure 1: Start window of the DRAMA software suite*

The underlying structure of the GUI is discussed in [7]. Especially for the CROC module, which included interactive panning, rotate and zooming capabilities the details are discussed in [6].

### 1.3 The DRAMA environment

During the first launch of DRAMA the user is requested to define a so called *workspace* folder. This workspace is used to store all related information. The user can easily make use of the DRAMA software in multiple projects by creating for example one *"DRAMA project folder"* for each of his projects. Doing so it is a simple task to switch between the data of different projects without using the *Import/Export* functionality (formally *Save* and *Save As* functionality [1]) or providing the input of all settings again at anytime. To have a clear overview also in the folder structure of the workspace the project folders will contain only the input data of those tools, which have been saved or executed as you can see in Figure 2.

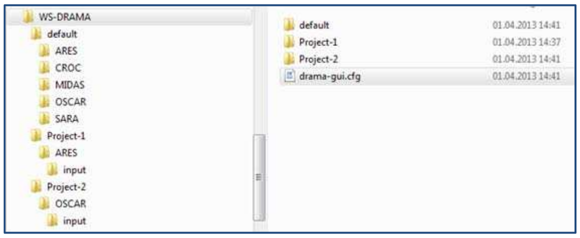

*Figure 2: Structure of the Workspace*

In this example of the workspace called *WS-DRAMA* it is shown that all tools have been used in the project *default*, while ARES and accordingly OSCAR are the only tools that have been saved within the projects *Project-1* and *Project-2.*

## 2 USE THE DRAMA TOOL SUITE

For the demonstration of the DRAMA tool suite the mission of a fictitious satellite shall be analysed. Therefore a LEO satellite will be designed first with the component CROC. The tool will be used to compute the along-track cross section. The software tool ARES is used in the next step to determine the annual collision probability. The impact of the debris and meteoroid environment onto the satellite is calculated with the software MIDAS and for the missions end the OSCAR software is used to analyse whether an EOL manoeuvre has to be performed to be in line with the mitigation standards or not. Finally the SARA component computes the re-entry of the satellite.

### 2.1 Designing the example satellite

The design of the satellite shall be kept very simple for this example. The satellite bus shall be of the size of one cubic meter. Two solar arrays shall be attached to the satellite each of the size 1x4.5m². The connection shall be realized by a cylindrical bar of 5cm in diameter allowing to have a spacing of 50cm between the solar arrays and the satellite bus. As an overview the design of the satellite is given in Table 1. A screenshot of the model is shown in Figure 3.

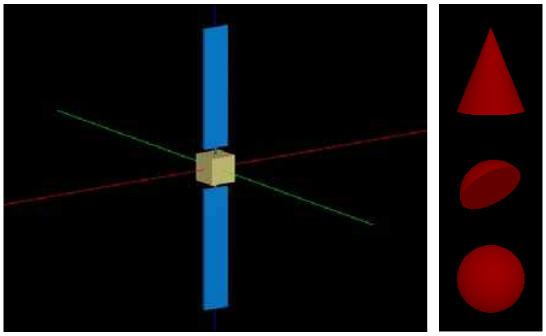

*Figure 3: Satellite designed by CROC (left) and additional shapes of the CROC module (right)*

| Component | Typ | Dimension [cm] | Position [cm] |
|---|---|---|---|
| Satellite Bus | Box | 100x100x100 | 0,0,0 |
| SA Connector | Cylinder | 5x200 | 0,0,-100 |
| Solar Array 1 | Box | 100x10x450 | 0,0, 300 |
| Solar Array 2 | Box | 100x10x450 | 0,0,-300 |

*Table 1: Definition of four elements for the example satellite.*

Besides the use of boxes and cylinders CROC also provides also the capability to define spheres, sphere caps as well as cones to realize the structures of more complex bodies. See [5] for more details on the CROC module.

After the design has been finished, the CROC component has been executed and the cross-section was calculated as seen from the aspect angle θ=0 and φ=0, which is the along-track direction.

| | Cross Section [m²] |
|---|---|
| F1: $\theta=0$ $\varphi=0$ | 10.05 |

*Table 2: Resulting cross section for a given aspect angle (along track) of the example satellite.*

To have more realistic comparison the values for a model of ENVISAT are shown in Table 3 for the function F3 (randomly tumbling satellite) and compared with the information given by ESA's DISCOS database:

| | DISCOS | CROC |
|---|---|---|
| Min. Cross Section [m²] | 20.250 | 22.023 |
| Average Cross Section [m²] | 63.034 | 65.062 |
| Max. Cross Section [m²] | 99.034 | 106.402 |

Table 3: Cross section for ENVISAT as model by CROC with 12 elements compared with the data given by ESA's DISCOS database [6]

## 2.2 Collision Risk, Impact and Damage Assessment

As a second step after the satellite has roughly been defined the impact of the debris environment shall be analysed. Therefore the DRAMA software suite provides two tools. On the one hand the ARES component can be used to assess collision avoidance manoeuvres. On the other hand the MIDAS tool can be used to assess collision flux and damage statistics.

As input for both tools it is required to define the orbit of the satellite. For this example it is assumed that the satellite is located on a Sun-synchronous orbit. This orbit is defined in Table 4.

| | |
|---|---|
| Epoch | May 1st, 2009 |
| Semi-major axis | 7160.0 |
| Eccentricity | 0.001 |
| Inclination | 98.55 |
| RAAN | 38.0 |
| Arg. of Perigee | 0.0 |
| True Anomaly | 0.0 |

*Table 4: Orbit definition*

### 2.2.1 Making use of ARES

For the computation of the annual collision probability (Functionality F1) ARES makes use of a radar equation. The parameters of this equation have to be defined by the user. Thus the user can define the sensitivity of a surveillance system to split the whole population provided by MASTER internally into known (detectable) and unknown objects:

$$D_{min}(h) = D_{ref}\left(\frac{h}{h_{ref}}\right)^{exp}$$

The used parameters for this equation are shown in Table 5. The resulting annual collision probability (ACP) for the detectable and the whole population as well as the related flux is shown in Table 6. The ACP for the whole population (objects larger 1cm have been considered) is nearly one order of magnitude larger than for the detectable population.

| | Branch 1 (Radar) | Branch 2 (Telescope) |
|---|---|---|
| Ref. Diameter [m] | 0.32 | 0.7 |
| Ref. Altitude [km] | 2000.0 | 36000.0 |
| Exponent | 2.0 | -0.5 |

*Table 5: Parameters for the definition of the radar equation.*

| | Detectable Population | Tot.Population (>1cm) |
|---|---|---|
| Flux [1/km²/yr] | 0.1972E+02 | 0.1910E+03 |
| Annual Coll. Prob. | 0.3013E-03 | 0.2042E-02 |

*Table 6: Results of ARES for the annual collision probability of the example satellite*

The spacecraft radius has to be provided to ARES. Therefore the computed cross section area of CROC can be used assuming a spherical body:

$$r_{sat} = \sqrt{\frac{A_{CROC}}{\pi}}$$

The collision probability is related to avoidance manoeuvres and a certain amount of fuel. To compute these parameters the functionality F4 ("Required Propellant") of ARES is used, which includes all other scenarios of ARES ("Annual Collision Probability", "Avoidance Schemes Assessment" and "Required Delta-V") as well. The uncertainties for the orbit of the potentially impacting objects are based on CSM-Data for this example and it is assumed that the event is predicted one day before it would occur. The uncertainties of the spacecraft are set to 200 meters along-track, 100 meters cross-track and 75 meters in radial direction.

| | ACPL |
|---|---|
| 1 | 1.0E-06 |
| 2 | 1.0E-05 |
| 3 | 0.5E-05 |
| 4 | 0.8E-05 |
| 5 | 1.0E-04 |
| 6 | 0.4E-04 |
| 7 | 0.5E-04 |
| 8 | 1.0E-03 |
| 9 | 1.5E-03 |
| 10 | 1.0E-02 |

| | $\Delta rev$ |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |
| 6 | 6 |
| 7 | 7 |
| 8 | 8 |
| 9 | 9 |
| 10 | 10 |

*Table 7: Settings for collision risk strategy*

The results are computed for ten different "Accepted Collision Probability Levels" (ACPL) and also for ten different values defining the number of revolutions between the manoeuver and the predicted event. These values are listed in Table 7. For an allowed minimum distance of 1.5km the risk for different total number of avoidance manoeuvres is shown in Figure 4. The remaining risk (blue line) is too large due to the large risk, which is not covered by the catalogue. This risk can not be diminished no matter, which avoidance strategies are implemented. On the contrary, the catalogued risk is very well diminished for low ACPL. In this case the number of avoidance manoeuvres would be high.

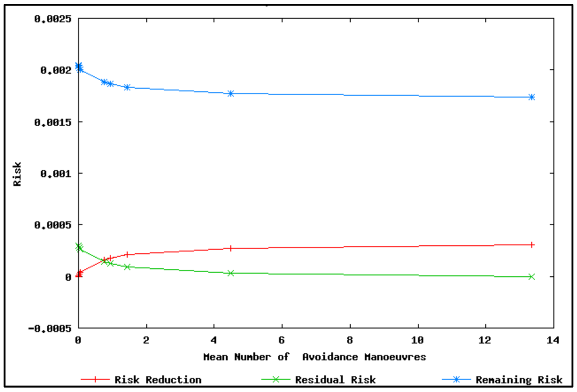

*Figure 4: Residual, Remaining and Reduced Risk related to the number of avoidance manoeuvers*

The number of avoidance manoeuvres is a direct consequence of the given ACPLs as ACPL indicates the threshold for raising a warning event. The smaller the ACPL values the more manoeuvers are computed. Related to the number of revolutions between the predicted event and the manoeuver the required propellant mass fraction decreases for larger time spans. Thus the required fuel mass is a function of the given ACPLs (giving the number of manoeuvres) and the number of revolutions until the predicted event occurs (given the intensity of the manoeuver) as shown in Figure 5.

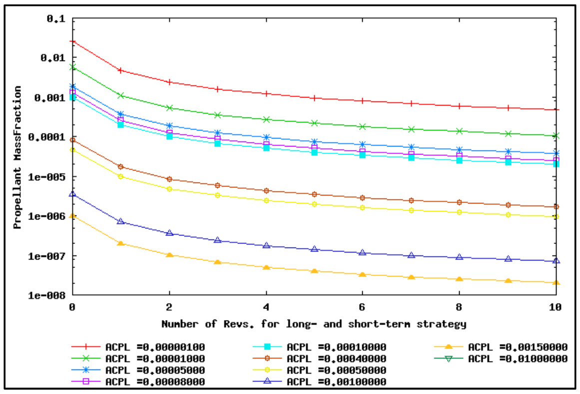

*Figure 5: Propellant mass fraction related to the given ACPLs*

For more detail on ARES please see [2] or [4].

### 2.2.2 Making use of MIDAS

The second part of risk analysis is related to the impact and damage risk caused by smaller debris particles. Thus, the upper limit is set to 5cm, which is related to the result of the radar equation for $h = 782km$. The lower limit is set to 100µm assuming that smaller particles would lead only to a degradation of the surface. All debris sources out of the Business-as-Usual scenario are considered and the analysis time interval is from May 1$^{st}$, 2009 to May 1$^{st}$, 2016 for a seven year lifetime of the satellite. The analysis made for this example shall be limited to the leading surface. It shall be calculated how many particles are going to impact and penetrate the surface. Therefore the surface will be designed as a double wall with two identical plates of aluminium with a thickness of 5mm. The shielding effect of this surface shall be analysed related to the spacing between the two walls from 5cm to 30cm in steps of 5cm.

For all wall definitions the multiple wall damage equation "ESA triple wall" has been used. This is one of four hard coded damage equations (two for single walls and two for multiple walls) that might be used to calculate the limiting particle diameter. Particles of larger diameters would penetrate the surface. The general equation for multiple walls is

$$d_{p,lim} = \left[ \frac{t_w + K_2 \cdot t_s^{\mu} \cdot \rho_s^{\nu_2}}{K_1 \cdot \rho_p^{\beta} \cdot \rho_w^{\kappa} \cdot \rho_s^{\nu_1} \cdot v_p^{\gamma} \cdot (\cos\alpha_p)^{\xi} \cdot S^{\delta}} \right]^{\frac{1}{\lambda}}$$

with the following parameters for the "ESA triple wall" equation:

| | $K_1$ | $K_2$ | $\lambda$ | $\beta$ | $\gamma$ | $\kappa$ | $\delta$ | $\xi$ | $\nu_1$ | $\nu_2$ | $\mu$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ESA multiple wall | | | | | | | | | | | |
| $v_n < v_1 = 3km/s$ | 0.3875 | 0.6458 | 1.056 | 0.5 | 2/3 | 0.0 | 0.0 | 2/3 | 0.0 | 0.0 | 1.0 |
| $v_n > v_2 = 7km/s$ | 0.2556 | 0.0 | 1.5 | 0.5 | 1.0 | 0.0 | -0.5 | 1.0 | 2/3 | 0.0 | 0.0 |

For the impactor diameter the number of penetrations and the probability of no penetration is shown exemplary in Figure 6 and Figure 7. It can be seen in the figures that the increase of the spacing (5cm to 30cm) between the two walls of 0.5cm thickness leads to a decrease of the vulnerability of the satellite.

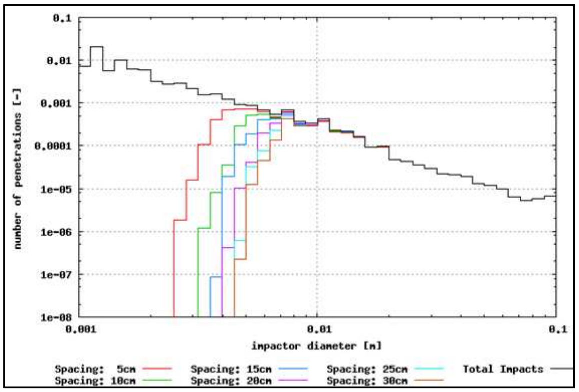

*Figure 6: Number of penetrations vs. impactor diameter*

Besides the "number of impacts" and the "probability of no penetration” also the “failure flux” as well as the “number of impacts” and the “probability of collision” are given as result by MIDAS. The results are also dumped as function of time and mass as well as cumulative respectively reverse cumulative plots.

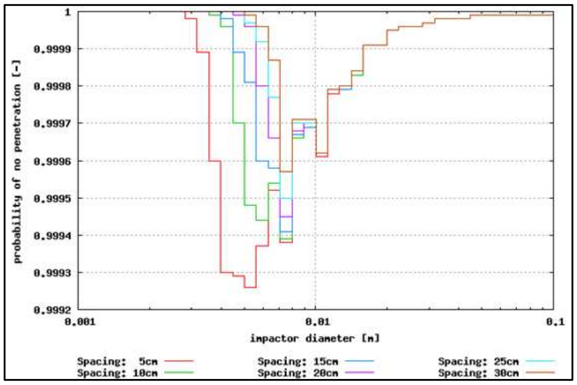

*Figure 7: Probability of no penetration vs. impactor diameter*

The user is also able to define additional limit equations matching the parameterized forms of the implemented single and multiple wall equations based on [3] (see also [2]). It is possible to define up to 10 surfaces, which can be oriented as “Earth Oriented”, “Sun Fixed” or “Inertial Oriented” surfaces. While the impact flux is also given in the mode “Damage Analysis” for a one square-meter sphere as reference, it is possible to performed only the “Impact Analysis” for a sphere or randomly tumbling plate of a favoured cross section.

### 2.3 End-of-Life Activities

After the mission has been finished successfully in the year 2016 seven years after launch it has to be ensured that the satellite will be re- or deorbited if the remaining orbital life time is larger than 25 years. Some additional parameters like the satellite dry mass or the cross section are required and listed in Table 8.

| | |
|---|---|
| Cross Section [m²] | 10.05 |
| Dry Mass [kg] | 500.0 |
| Drag Coefficient [-] | 2.2 |
| Reflectivity Coefficient [-] | 1.3 |

*Table 8: Additional Parameters*

The first analysis made by using the OSCAR tool is to calculate the remaining orbital lifetime of the satellite after the assumed EOL at May 1st, 2016. As shown in Figure 8 the satellite would be in orbit until the year 2132 for another 115 years. Thus a de- or re-orbit manoeuver is recommended. For the first approach a direct de-orbit shall be evaluated. Therefore only chemical propulsion systems are available. Out of a larger list three chemical propulsion systems shall be considered: cold gas ($I_{sp} = 60s$), solid rocket motor ($I_{sp} = 290s$) and a monopropellant propulsion system ($I_{sp} = 200s$).

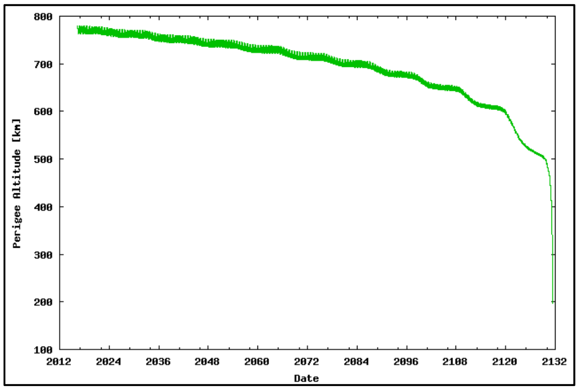

*Figure 8: Decay of the example satellite (perigee) after EOL at May 1st, 2016*

To achieve a direct de-orbit a perigee of $60km$ is required. Therefore it is required to reach a $\Delta v \geq 202{,}55km/s$. Reckoning only the fuel mass the solid rocket motor would be the lightest propulsion system as shown in Figure 11.

| | $I_{sp}[s]$ | $m_{fuel}\ [kg]$ |
|---|---|---|
| Cold Gas | 60 | 205.38 |
| Solid Motor | 290 | 36.90 |
| Monopropellant | 200 | 54.38 |

*Table 9: Direct Re-Orbit after EOL*

Considering these results one should not forget that typically a solid rocket motor is not on board a satellite. Thus another propulsion system, which is used also during the mission, might be more effective even if it consumes more fuel.

But because a direct de-orbit is typically not the manoeuvre of choice to fulfil the mitigation guidelines the delayed de-orbit will be analysed in the next step. The goal for the delayed deorbit is to find an orbit that is low enough to let the satellite re-enter during the next 25 years. The result therefore is that the satellite could be deorbited within 24.97 years if the perigee would be decreased to 564.32km. Therefore $\Delta v = 59.68\ m/s$ and the fuel mass as listed in Table 10 would be required for the same three propulsion systems.

| | de-orbit |
|---|---|
| Cold Gas | 53.35 kg |
| Solid Motor | 10.60 kg |
| Monopropellant | 15.44 kg |

*Table 10: Required fuel mass for delayed de-orbit*

Compared thereto, a drag augmentation device of $2000m^2$ (44.72m x 44.72m) would let the satellite decay within 2.51 years. This is much faster than the typically adopted 25 years to fulfil the mitigation guidelines. A new feature of OSCAR is now that the cross-section necessary to be in line with the UN guidelines is directly given as additional output. Thus the user is informed that for the given orbit and satellite a drag augmentation system with only about $52.177 m^2$ (7.22m x 7.22m) cross section would be sufficient. For different user given cross sections this value might vary slightly because of the iterative approach used for determining the optimal cross-section, which uses the user given cross-section as starting point.

For the day-to-day use of OSCAR there are a lot more propulsion systems provided for chemical and electrical propulsion systems by default. It is also possible to select between different solar and geomagnetic activities. The results made before are all made with the best guess scenario and the CSSI space weather data. Besides the effect that the remaining in orbit time and the required cross-section to be in line with the UN space debris mitigation guidelines is a function of the chosen start epoch (as shown in Figure 9), the result also depends on the chosen future solar and geomagnetic activity. Besides the "Best-Guess" option for the solar and geomagnetic activity there are also the options "Best-Case/Worst-Case", "Constant Solar Flux", "Sample Solar Cycle" as well as "Monte-Carlo Sampling". For details please refer to [5] and [2]

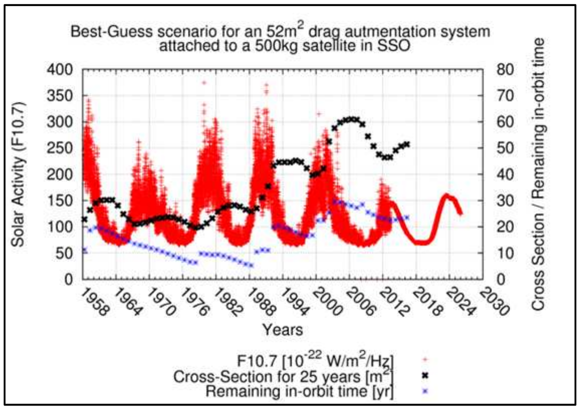

*Figure 9: Remaining orbital lifetime and required cross section as function of the start epoch.*

For the discussed fictitious satellite (see Table 4 and Table 8) the remaining in orbit lifetime and the required cross-section to decay within 25 years is shown in Figure 9 for the "Best-Guess" scenario using start epochs (equal to the end of life of the satellite) from 1958 to 2016. Additionally the used data for the solar activity is shown in the background of the figure. The increase and decrease of remaining in-orbit time and cross-section is linked directly to the solar activity. Both values increase significantly for start epochs after 1990 because of the low solar activity especially at the beginning of the 21st century but also in the future predictions.

A comparison of the "Best-Guess" results for 2016 with those of the other scenarios is shown in Table 11. This makes clear that the user has to be aware of the different scenarios and their effects on the orbit evolution.

| **Scenario for the Solar & Geomagnetic Activity** | **Remaining in-orbit time** |
|---|---|
| Best Guess | 23.53yrs |
| Best-Case (30%) | 20.65yrs |
| Worst-Case (30%) | 29.17yrs |
| Constant Solar Flux (Auto) | 11.96yrs |
| Sample Solar Cycle (ECSS) | 18.59yrs |
| Monte-Carlo Sampling (6) | 16.19yrs |

*Table 11: Results of different scenarios of solar & geomagnetic activity for an end of life of the example satellite at May 1st, 2016 (start epoch for simulation).*

For the scenario "Constant Solar Flux" values of $F_{10.7} = 128.72 \cdot 10^{-22} W/m^2/Hz$ and $A_P = 15$ have been used for the solar & geomagnetic activity. See [2] for more details.

## 2.4 Re-Entry Analysis

Finally the satellite will perform a re-entry in to the Earth's atmosphere. Therefore a detailed knowledge about the satellite components (shape, size, mass, material) has to be known. Thus, the example satellite is assumed to be in line with the default settings of the SARA component [1]. The satellite modelled contains 36 objects (27 boxes, seven cylinders, one plate and one sphere) out of four different materials, defined by their density, specific heat capacity, melting temperature, specific heat melting and the emission coefficient.

For the initial orbit the following parameters have been chosen based on the orbit used for the operational life time of the satellite (compare Table 4):

|  |  |
|---|---|
| Epoch | May 1st, 2016<br>at 06.00h UTC |
| Semi-major axis [km] | 6470.0 |
| Eccentricity [-] | 0.001 |
| Inclination [deg] | 98.55 |
| RAAN [deg] | 0.0 |
| Arg. Of Perigee [deg] | 0.0 |
| True Anomaly [deg] | 0.0 |

*Table 12: Initial orbit for Re-Entry Analysis*

As shown in Figure 10 five of the included 36 objects are impacting on ground. These impacts occur ~660s to ~960s after the start of the re-entry simulation. Within about five minutes the objects are impacting along the ground track. The distance between the first and the last impacting object is nearly 600km.

The global casual probability computed by the SARA component is shown in Figure 11. For a roughly defined world population of 7 billion people the risk is significant higher on the northern hemisphere because of the higher population density in that area. The maximum probability of nearly 3E-6 is still below the threshold of 1E-4 adopted by several space agencies [3].

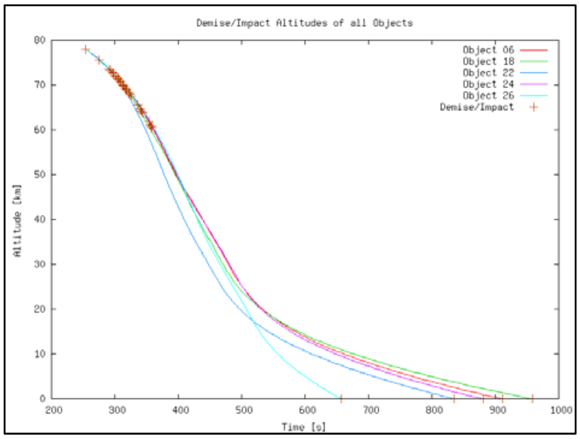

*Figure 10: Demise and Impact Altitude of all Objects*

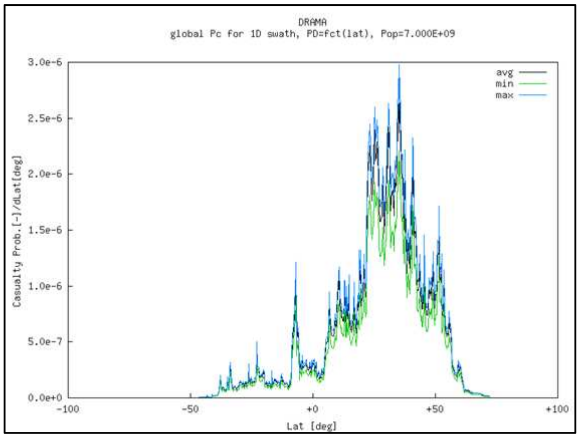

*Figure 11: Global casual probability*

The ground track of the impacting objects is shown in Figure 12. All objects are impacting into the Pacific Ocean at half the distance between Hawaii and the east costs of Asia.

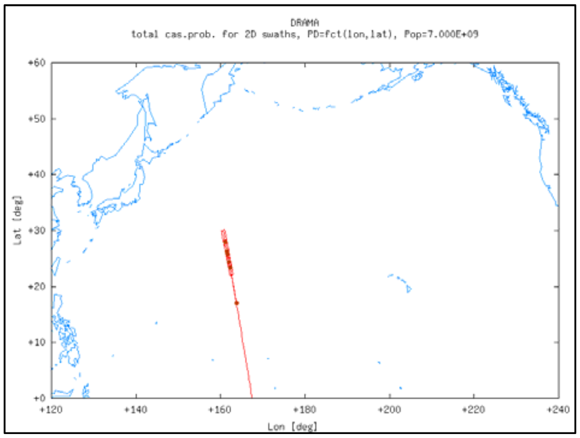

*Figure 12: Ground track of the re-entering objects*

## 3 CONCLUSION

The updated DRAMA software suite and its new features have been introduced. In general the software tool is now much more flexible to the users' needs, which is expected to increase the usage of the software within the community of space mission analysts and designers. Especially the ARES and OSCAR tools have been upgraded with several new features. The controlling element – the graphical user interface – can now provide a direct access to all necessary input data and settings and a comfortable display of the results has been realized. A direct modification of the *gnuplot* driver files to generate individual results is also possible now.

## 4 ACKNOWLEDGEMENT

The Upgrade of ESA's Debris Risk Assessment and Mitigation Analysis Software Suite has been under ESA contract 4000104977/11/D/SR. TUBS/ILR as prime contractor has been responsible for the upgrade of OSCAR, MIDAS and the GUI as well. DEIMOS Space S.L.U. was responsible for the ARES upgrade and the development of CROC. The SARA component was maintained by ESA/ESOC.

## 5 REFERENCES

[1] C. Martin, et.al., *"Final Report – Debris Risk Assessment and Mitigation Analysis (DRAMA) Tool"*, August 18th, 2005

[2] J. Gelhaus, N. Sánchez-Ortiz, et.al., *"DRAMA Final Report – Upgrade of ESA's Space Debris Mitigation Analysis Tool Suite"*, 2013

[3] H. Klinkrad, *"Space Debris – Models and Risk Analysis"*, ISBN 3-540-25448-X Springer-Verlag Berlin Heidelberg New York, 2006

[4] R. Domínguez-González, et.al., *"Upgrade of ESA DRAMA ARES: Comparison of envisaged collision alerts with operational statistics and impact of catalogue accuracy"*, 6th European Conference on Space Debris, Darmstadt, April 2013

[5] V. Braun, et al., *"Impact of Solar Flux Modelling on Satellite Lifetime Predictions"*, International Astronautical Congress, Naples, 2012

[6] N. Sánchez-Ortiz, et.al., *"Computation of Cross Section of Complex Body ESA's DRAMA Tool"*, 6th European Conference on Space Debris, Darmstadt, April 2013

[7] C. Kebschull, et.al., *"The software architecture of the upgraded ESA DRAMA software suite"*, 6th European Conference on Space Debris, Darmstadt, April 2013