The Debris Mitigation Facility: A unified framework for DRAMA and MASTER

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ABSTRACT

As the number of satellites in orbit keeps increasing, the European Space Agency (ESA) has been improving and continuously developing their debris mitigation and modelling tools, MASTER (Meteoroid and Space Debris Terrestrial Environment Reference) and DRAMA (Debris Risk Assessment and Mitigation Analysis), to actively reduce the creation of space debris by offering analysis tools to all stakeholders in the space industry.

The development of DRAMA 4.0 started in 2020, under different Debris Mitigation Facility (DMF) activities, aimed at developing a new, mission-centric framework that integrates MASTER and DRAMA functionalities into one single software.

The latest extension, developed during the DMF-05 activity, included capabilities drawn from ESA's PROOF (Program for Radar and Optical Observation Forecasting) software, such as detectability and trackability features. These newest functionalities address the following use cases: to determine the trackability of space objects, and to assess the visible magnitude of a space mission, also allowing the comparison to Dark and Quiet Skies recommendations, as part of ESA's Zero Debris policy. The new software facilitates the compliance verification of satellite designs with new debris mitigation requirements.

The DMF-07 activity aims at unifying all the improvements and new implementations achieved during the previous DMF activities as well as updating compliance check capabilities. The updated compliance workflows allow for a unique turn-key solution to determine compliance with new ESSB-ST-U-007 requirements. These requirements include determining minimum maneuver capabilities, providing recommended Accepted Collision Probability Levels (ACPLs), determining interference with protected regions, evaluating the trackability of the mission as well as the resulting light pollution.

These improvements expand ESA's capabilities for comprehensive debris risk assessment and mitigation. This paper highlights the new functionalities related to Space Surveillance and Tracking capabilities developed during DMF-05 and all the technical advancements that are at the core of the new DRAMA 4.0 implementation achieved during the DMF-07 activity.

1 Acronyms

ARES	Assessment of Risk Event Statistics
CE	Coefficient Estimator
DMF	Debris Mitigation Facility
DRAMA	Debris Risk Assessment and Mitigation Analysis
DOF	Degree of Freedom
ESA	European Space Agency
GUI	Graphical User Interface
MASTER	Meteoroid and Space Debris Terrestrial Environment Reference
MIDAS	MASTER (-based) Impact Flux and Damage Assessment Software
OSCAR	Orbital SpaceCraft Active Removal
PROOF	Program for Radar and Optical Observation Forecasting
SARA	Re-entry Survival and Risk Analysis

2 Introduction

Space missions operate in a shared environment, requiring consideration of their impact on space debris evolution. The European Space Agency (ESA) has developed tools like the MASTER (Meteoroid and Space Debris Terrestrial Environment Reference) [1] and the DRAMA (Debris Risk Assessment and Mitigation Analysis) [1] tool suite to address space debris mitigation. Since 2014, ESA missions must comply with space debris mitigation requirements, similar to other countries' regulations. With a subset of activities called "The Debris Mitigation Facility (DMF)" [2] ESA aimed to unify software tools and procedures for space debris mitigation, integrating them with model-based system engineering (MBSE) to enhance spacecraft development and ensure interoperability with broader MBSE initiatives.

With the first activity DMF01 starting in 2020, DRAMA 4.0 was developed in which a unified framework was developed to integrate the DRAMA and MASTER functionalities in a more streamlined and mission centric approach. Moreover, as part of other DMF sub-activities, conducted in parallel, individual analysis modules and studies were conducted with the goal to integrate the outputs in the new DRAMA 4.0 framework. As an example, the DMF05 activity can be named which aimed to include the capabilities drawn from ESA's PROOF (Program for Radar and Optical Observation Forecasting) software, such as detectability and trackability features to be used in the new DRAMA framework.

The recent activity DMF-07 started and concluded in 2024 with the goal to update the DRAMA 4.0 framework to funnel the output of the predecessor DMF-activities and merge them into the new DRAMA framework under the software version DRAMA 4.1. Hereby, the back end of the framework was extended to incorporate new/updated analysis modules created in predecessor DMF-activities. Moreover, the existing DRAMA4.0 compliance verification workflows against international space debris mitigation requirement were updated to consider the new ESSB-ST-U-007 requirements. Lastly, the Graphical User Interface (GUI) was updated accordingly, to allow the user to interact with the new functionalities.

3 Software Updates

The following analysis modules were introduced/modified on back-end and frontend of DMF 4.0.

3.1 ARES

The ARES (Assessment of Risk Event Statistics) tool computes statistics related to collision events between an operational spacecraft and trackable objects orbiting the Earth.

In DRAMA 4.1, ARES supports the cross-section computation using a 6-Degree-of-Freedom (DOF) propagator (see Section 3.5). In the past, CROC was used to calculate the cross section. Moreover, ARES considers the following manoeuvre options:

- Drag augmentation and
- Electric propulsion.

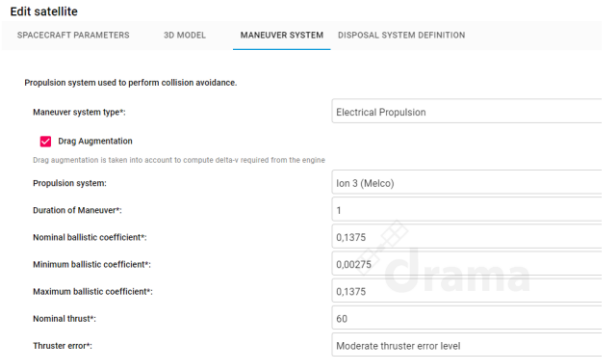

Figure 1. New manoeuvre options.

3.2 OSCAR

The OSCAR (Orbital Spacecraft Active Removal) tool is used to analyse different disposal strategies after the nominal end-of-life of a single spacecraft.

In DRAMA 4.1, the OSCAR module now can consider protected regions as well as the following new disposal options (as illustrated in Fig. 2):

- Circular Delayed De-Orbit,
- Elliptic Delayed De-Orbit,
- Re-Orbit, and
- Resonance based analysis.

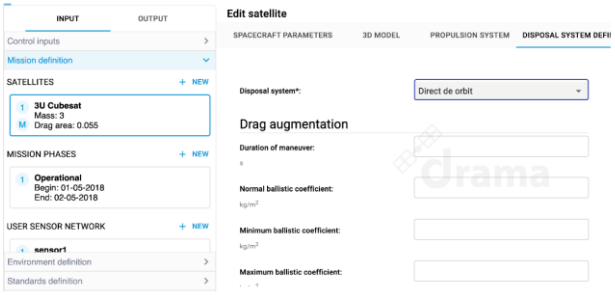

Figure 2. New disposal options.

Furthermore, it can also now consider 6-DOF attitude propagation for the analysis.

3.3 MIDAS

The MIDAS (MASTER-based Impact Flux and Damage Assessment Software) tool is used to model the collision flux and damage statistics for a mission.

In DRAMA 4.1, MIDAS now supports attitude-based

failure analysis by utilising a 6-DOF propagator. Furthermore, the output now contains the probability of penetration of each individual surface as well as the total one.

3.4 PROOF

To extend DRAMA with trackability, detectability and light pollution analysis capabilities, ESA's PROOF (Program for Radar and Optical Observation Forecasting) software was modified and integrated in the new DRAMA framework.

The PROOF software provides statistical pass characteristics of the non-deterministic space debris population and as well as the acquisition and pass characteristics of known objects for ground- and space-based radar and passive optical sensors. [1]

With this new addition, the use is able to perform a detectability analysis for their satellite by using predefined observation networks such as US-SSN.

On GUI level, the user has now the ability to select a sensor network and decide between their own network "user sensor network", or the US Space Surveillance Network (US-SSN) as shown in Fig. 3.

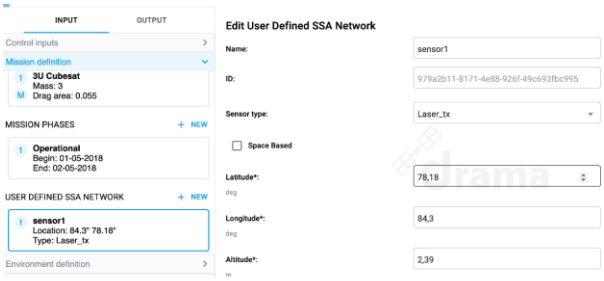

Figure 3. User defined SSA network.

3.5 Coefficient Estimator

The CE (Coefficient Estimator) is a newly added module in the DRAMA 4.1 framework. It provides a 6-DOF attitude simulation which enables the consideration of attitude evolution over an epoch for the new ARES, OSCAR and MIDAS analysis capabilities. Moreover, it is able of computing the attitude-based drag cross-section of the satellite. In case of conjunction events in ARES, it also calculates the effective satellite heard-body radius based on the conjunction geometry. Lastly, for the new detectability analysis, CE computes the required Radar and optical cross-section of the satellites.

The CE is accessible via the updated GUI as shown in Fig 4.

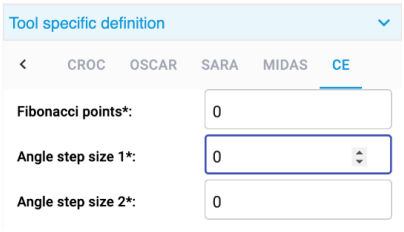

Figure 4. Coefficient Estimator interface.

3.6 SARA

SARA (Re-entry Survival and Risk Analysis) is used to calculate the satellite components which may survive the re-entry and the resulting casualty risk for both the controlled and uncontrolled scenarios.

In DRAMA 4.1, the SARA module was update to support both spherical and cylindrical tank shapes. Moreover, the database was extended for propellant and pressure gas materials. Lastly, the GUI was updated so the user can insert Brackets and lattice primitives as custom shape.

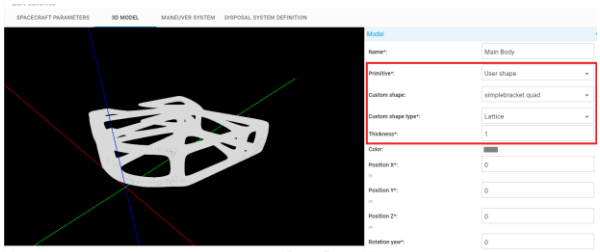

Figure 5. Lattice primitive as custom user shape.

3.7 Compliance Verification Workflow

In DRAMA 4.1, the compliance verification workflows have been adjusted according to reflect the latest version of "ESA Space Debris Mitigation Compliance Verification document" (ESSB-HB-U-002) [3]. These include:

- Workflow to check compliance with light pollution requirement,
- Workflow to check compliance with trackability requirement,
- Workflow to check for interference with LEO protected region,
- Workflow to check whether mission is compliance with manoeuvrability requirements, and
- Workflow to check whether a constellation is compliant with re-entry requirements.

3.8 MASTER Input

DRAMA 4.1 also support .sim file format as input for the MASTER tool.

4 Conclusion

The DRAMA 4.0 framework was successfully extended to incorporate analysis modules that have been created in other parallel DMF-activities. By that, the new DRAMA 4.1 framework is capable of attitude simulation and propagation, trackability and light pollution analysis, support of electric propulsion as part of collision avoidance assessment as well as extended material and 3D model features for re-entry assessment.

Lastly, the existing verification workflows were cross checked with latest changes to the underlying standards and requirements and updated were necessary.

5 Acknowledgment

The update of DRAMA 4.1 was accomplished under the ESA activity (Contract Nr. 4000133126/20/D/SR). We would like to thank to all institutions and individuals who have contributed to the predecessor DMF-activities, from which the outputs where integrated in this activity.

6 REFERENCES

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3. ESA Space Debris Mitigation Compliance Verification Guidelines (ESSB-HB-U-002): https://sdup.esoc.esa.int/documents/download/ESSB-HB-U-002-Issue214February2023.pdf