FRAGMENTATION EVENT MODEL AND ASSESSMENT TOOL (FREMAT) SUPPORTING ON-ORBIT FRAGMENTATION ANALYSIS

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1. Introduction

**FREMAT**

- The Fragmentation Event Model and Assessment Tool (FREMAT) project for ESA was carried out with the objectives of:
  - simulating on-orbit fragmentations
  - assessing their impact on the space population
  - evaluating the capability of identification of fragmentation events from existing surveillance networks.

- In the frame of the FREMAT activity, the implementation of several algorithms related to on-orbit fragmentation events was carried out.

- FREMAT encompasses three individual tools:
  - Fragmentation Event Generator (FREG)
  - Impact of Fragmentation Events on Spatial density Tool (IFEST)
  - Simulation of On-Orbit Fragmentation Tool (SOFT)
2. DESCRIPTION OF THE TOOLS

2.1 Fragmentation Event Generator (FREG)

- FREG has been conceived to simulate fragmentation events (explosion and collisions)
- MASTER 2009 NASA Breakup Model was employed as the baseline model for this tool
- The baseline model was enhanced in order to ensure the consistency of mass and momentum in the created fragment clouds.
- The user must specify the following inputs for the tool:
  - Type of event (explosion/collision)
  - Type of object (spacecraft/rocket body)
  - Mass of the parent(s) object(s)
  - State vector(s) of the parent object(s) at event epoch
  - Scaling factor (for explosion)
  - FREG also requires a discretization as input for the computation of representative fragments
- Its output is one or two clouds of fragments (original or representative) that can later be fed into IFEST or SOFT, or to any other propagator.
2. DESCRIPTION OF THE TOOLS

2.2 Impact of Fragmentation Events on Spatial density Tool (IFEST)

- IFEST (Impact of Fragmentation Events on Spatial density Tool) allows the evaluation of the impact of on-orbit fragmentations in the space debris population.
- It employs a fast semianalytic propagator (DSST from Orekit library) for computing the long-term evolution of the clouds of fragments (up to hundreds of years) obtained from FREG.
- Computes the 3D spatial density of the fragments (as a function of altitude and/or longitude and time).
- Allows defining discretizations for altitude and longitude.
- Computes the percent increase in the background spatial density obtained from MASTER.
- The computation of the spatial density within this tool is validated against results provided by ESA’s POEM tool.
2. DESCRIPTION OF THE TOOLS

2.3 Simulation of On-Orbit Fragmentation Tool (SOFT)

- SOFT simulates the identification of a fragmentation event when a space surveillance network detects a number of unexpected new objects and a fragmentation event is considered a possible cause.

- Uncertainties in the knowledge of the orbits of the fragments and the presence of foreign objects is also considered.

- Starting from a cloud with fragments the tool identifies a fragmentation event following these steps:

  - Determine type of fragmentation
  - Find parent using center of mass
  - Identify the parent from background catalogue

- The outputs are:
  - Type of fragmentation
  - Time and position of the event
  - Objects involved in the event, selected from a background catalogue
3. SIMULATION CASES

3.1 Collision Cosmos 2251-Iridium 33

Gabbard diagrams from FREG for collision at the event epoch, left plot corresponds to the Iridium 33 fragments, whereas right plot is associated to the Cosmos 2251 pieces.

Summary results from FREG:

<table>
<thead>
<tr>
<th>Type of event</th>
<th>Num. of fragments &gt; 1 cm</th>
<th>Num. of fragments &gt; 10 cm</th>
<th>Num. of representative fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iridium 33</td>
<td>35378</td>
<td>608</td>
<td>484 (&gt;1cm)</td>
</tr>
<tr>
<td>Cosmos 2251</td>
<td>50773</td>
<td>876</td>
<td>876 (&gt;1cm)</td>
</tr>
</tbody>
</table>

Percentage of re-entered objects for different altitudes of collision:
3. SIMULATION CASES

3.1 Collision Cosmos 2251-Iridium 33

Number of objects obtained for each colliding object as a function of the mass of one of the parent objects:

Evolution of the fragmentation clouds from Cosmos 2251-Iridium 33 collision. From left to right and from top to bottom, the:
1 day, 50 days, 200 days, 1000 days, 20 years and 96 years.

Spatial density as a function of altitude over 1 year (Cosmos-Iridium):
3. SIMULATION CASES

3.1 Collision Cosmos 2251-Iridium 33

Spatial density for Cosmos-Iridium as a function of altitude over 10 years (top) and over 100 years (bottom):
3. SIMULATION CASES

3.1 Collision Cosmos 2251-Iridum 33

The identification of the fragmentation event was simulated with SOFT using as input a catalogue with fragments from TLE data of 19 February 2009. According to SOFT the fragmentation happened on 2009-02-10 at 16:55:40.038 and the parents were correctly identified from the background catalogue.
3. SIMULATION CASES

3.2 Explosion of Breeze-M R/B

On 20 January 2016, at approximately 1900 UTC, the JSpOC (Joint Space Operations Center) identified a possible breakup of a Breeze-M R/B (NORAD id 41122) in GEO.

- Summary results from FREG:

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<th>Num. of representative fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breeze-M R/B</td>
<td>11056</td>
<td>248</td>
<td>136 (&gt; 10 cm) and 595 (&gt;1 cm)</td>
</tr>
</tbody>
</table>

- Gabbard diagrams for collision at the event epoch

- Variation of inclination for the fragments obtained from the explosion:
  - typical secular trend is produced by third-body perturbations: variation of inclination up to ±15 with a period of dozens of years.
3. SIMULATION CASES

3.2 Explosion of Breeze-M R/B

Spatial density and percent increases in background spatial density in the proximity of GEO altitude for Breeze-M R/B:

Spatial density as a function of longitude over 2000 days:
- Libration effect visible: part of the fragments that are oscillating around the stable point located at -105°.

Spatial Density over 10 (right) and 100 years (left) for Breeze-M R/B:
3. SIMULATION CASES

3.2 Explosion of Breeze-M R/B

The situations when the fragmentation clouds are incomplete (not all objects created in an event are detected) and inaccurate (the orbits of the fragments are known with a certain error) lead to considerable errors in the identification of the fragmentation event.
3. CONCLUSIONS

- The tools presented support the study of fragmentation events, either by simulating them or by using real orbital data obtained from a sensors network and also from TLE information.
- It is possible to study the long term effect of these events by means of the resulting spatial density, allowing comparison with the ESA MASTER tool.
- It is also possible to attempt to locate the position and orbit of the object(s) involved in the event in spite of having not complete clouds and poor accuracy.
- These tools can be used independently (in order to support studies such as the examples presented in this paper), or as part of a longer processing toolchain.
Thank you

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