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Methodologies and Tools to Ensure the Safe and Sustainable Re-entry of Spacecrafts

Clean Space Industry Days

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Methodologies and Tools for Satellite Re-Entry Analysis

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Why is satellite re-entry important?

Space debris is a serious problem that poses a threat to space operations and human activities

Mitigating this issue is critical for ensuring the sustainability and safety of space activities

Addressing the problem

- Develop **effective strategies** to reduce the amount of debris in orbit
- Identify and mitigate the **sources of debris**
- **Design for demise**

Solutions for mitigating space debris

- Relocating satellites to a safe orbit
- Disposing of satellites through re-entry into Earth's atmosphere

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Satellite re-entry types

- **Satellite re-entry** is the process of a spacecraft returning to Earth's atmosphere. At the end of its life, a satellite can be deorbited using its engines or by allowing it to naturally decay due to atmospheric drag.
- **Deorbiting** with engines involves using the satellite's engines to slow down and lower its orbit. Once the satellite is in a low enough orbit, it will re-enter the Earth's atmosphere and the surviving fragments will land in unpopulated areas.
- **Natural decay** due to atmospheric drag is a process that occurs over time as the satellite experiences resistance from the Earth's atmosphere. This resistance causes the satellite to lose altitude and eventually re-enter the atmosphere.

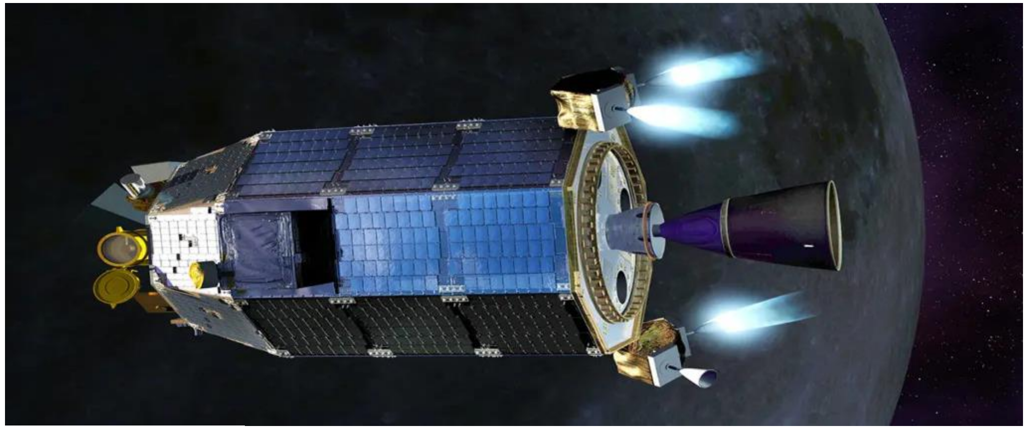
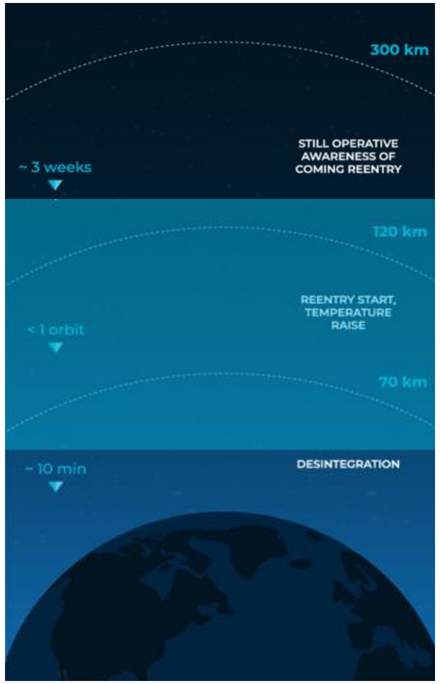


Photo credit: Valispace



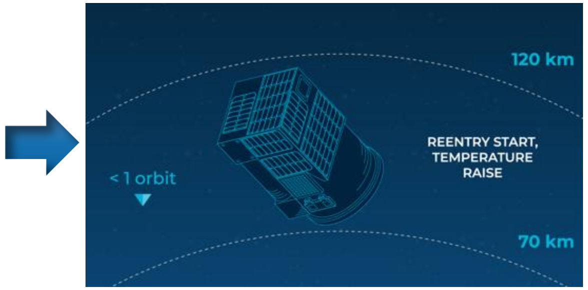


Photo credit: Satellogic

DRAMA Tool Overview

- All ESA missions must assess the casualty risk and comply with the **10^{-4} casualty risk requirement**.
- ESA-approved software tool **DRAMA** (Debris Risk Assessment and Mitigation Analysis) enables the assessment of
  - mitigation strategies for the operational and disposal phases of a mission, including
  - the risk due to mission's space debris and the effectiveness of an end-of-life strategy
- Using **DRAMA** enables aerospace engineers to evaluate a spacecraft's survivability during re-entry into the Earth's atmosphere and assess its risk on the ground.

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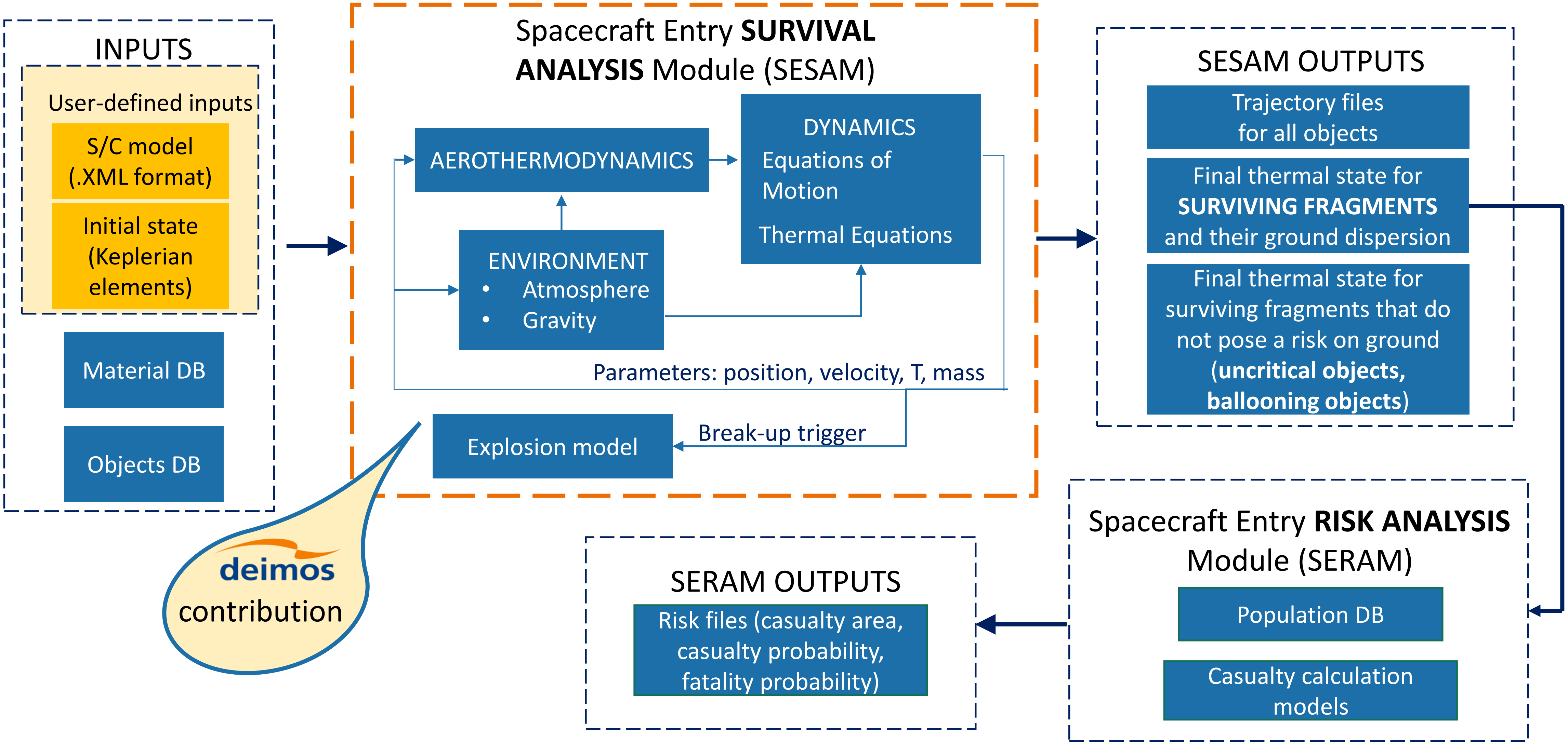
DRAMA (SARA) Workflow



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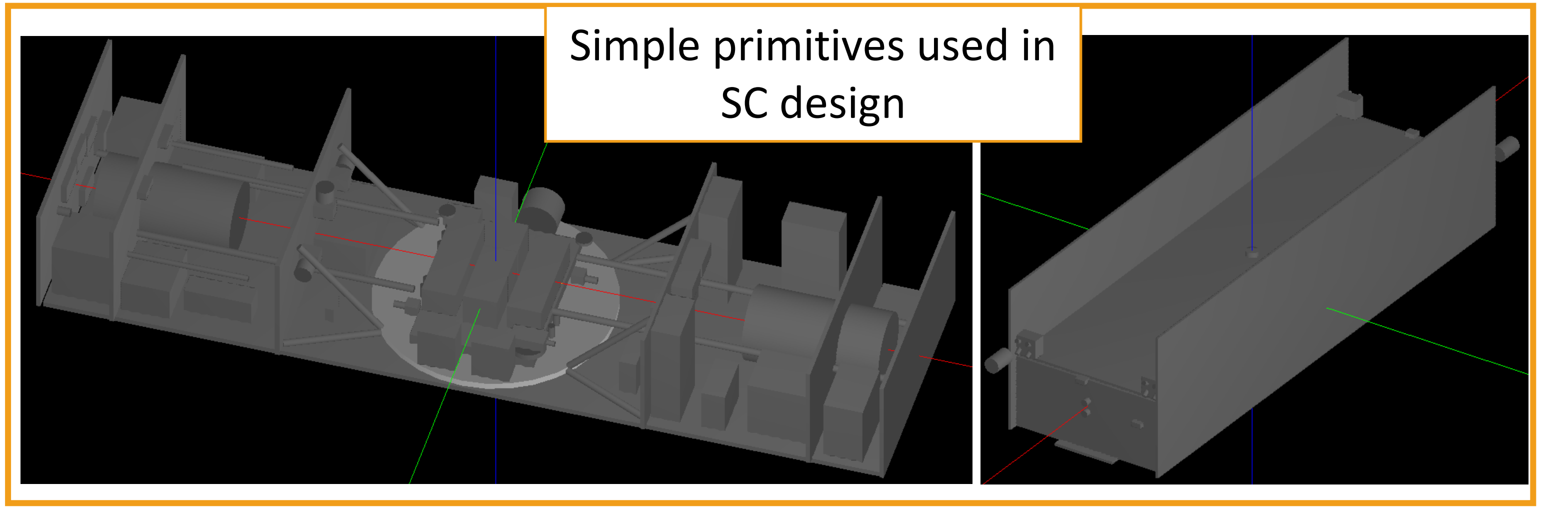
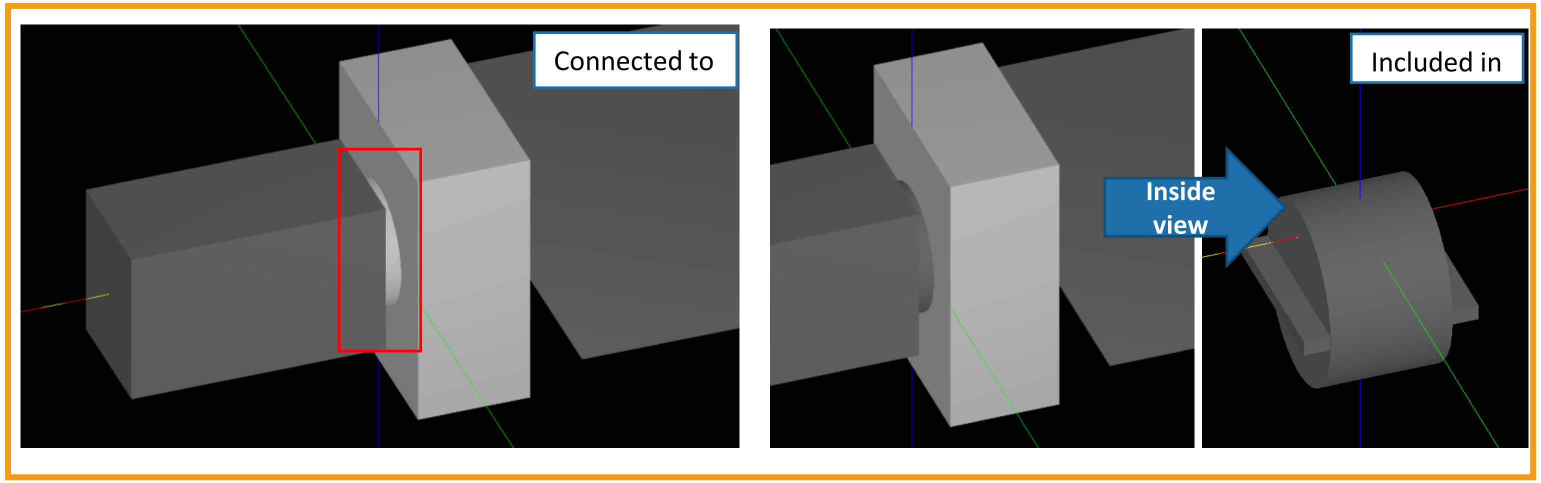
DRAMA Features

Modelling

- Spacecraft modelled as a combination of multiple primitives (**spheres**, **cones**, **cylinders**, **boxes** and **rings**).

- Relationship between the components:
  - "**included in**": one primitive is fully shielded by another one as in the parent-child concept
  - "**connected to**": two primitives are both partially exposed to the flow field and share a thermal conductive area.





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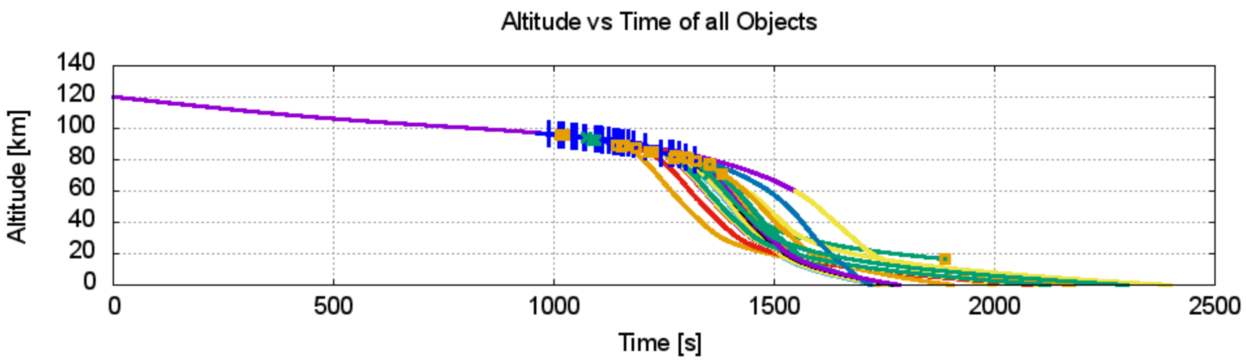
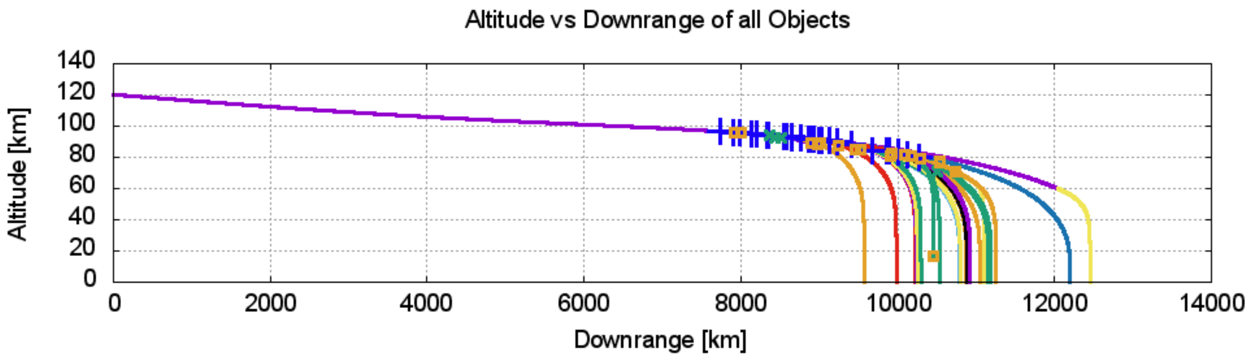
SESAM Features

<u>Analysis</u>

- Spacecraft fragmentation is a process, not a single event
- Influence of shadowing is taken into account
- Trajectories are propagated in 3DoF
  - Attitude modes: randomly tumbling and fixed attitude
- Re-entry starts below 120 km (propagation with OSCAR module above)
- Thermal analysis and dynamics are coupled; therefore, mass losses are considered during the trajectory propagation of the fragments
- Aerothermodynamic models are available for common simple geometrical shapes that are sphere, cylinder, box, cone or ring.





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Risk Computation in DRAMA

Re-Entry Analysis output:

- *Demised objects*: the mass of the object reached zero
- *Uncritical object*: the kinetic energy of the object dropped below 15 J
- *Ballooning object*: the wall thickness of the object dropped below 0.05 mm
- *Surviving object*: object that impacts the ground

Risk Analysis output computed for the surviving objects:

- *Total Casualty Area*: the equally circular area within which Ah (the vertical projection of a standing human with Ah = 0.36 m2) and Ai (the impact cross section of a fragment) must touch or intersect each other
- *Total Casualty Probability*: at a certain location it is determined from the impact probability Pi , the population density at this location ρP and the casualty area Ac → considered to assess compliance with casualty risk threshold 10^{-4}
- *Total Fatality Probability*: results from calculation of expectancy that an impact causes the death of a human

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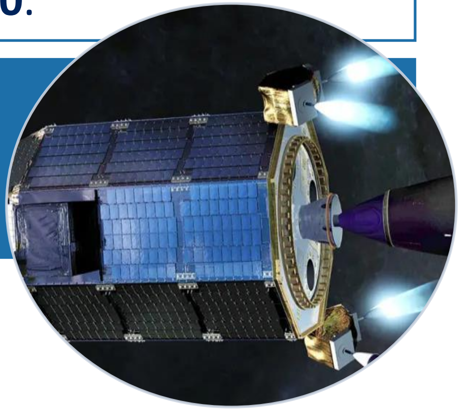
Satellite Re-entry Considerations

To ensure the safe disposal of spacecraft by re-entry into the Earth's atmosphere, **it is critical to maintain a casualty risk below 10^{-4}**. This can be achieved through:

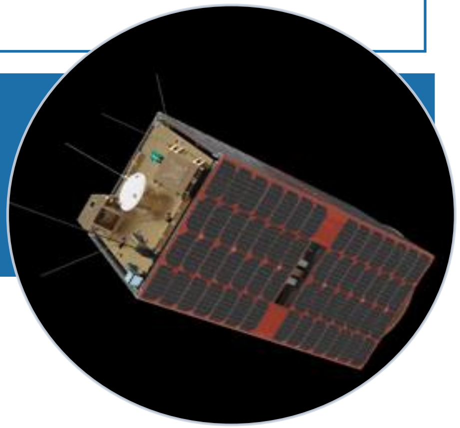
- the primary safety concern is **the size of the debris footprint** and the **impact location**
- controlled de-orbit guarantees a safe area, usually in the open ocean, with sufficient clearance of landmasses and traffic routes
- survivability of elements is not a significant concern, as the spacecraft is re-entering in a controlled manner, usually targeting SPOUA
- **the casualty risk must be 0**.

Controlled Re-entry



- the casualty risk requirement is directly linked to the survivability of debris fragments
- to minimize the casualty risk, it is crucial to reduce the number of surviving debris fragments that could potentially impact the ground
- **the casualty risk must be below 10^{-4}**.

Uncontrolled Re-entry



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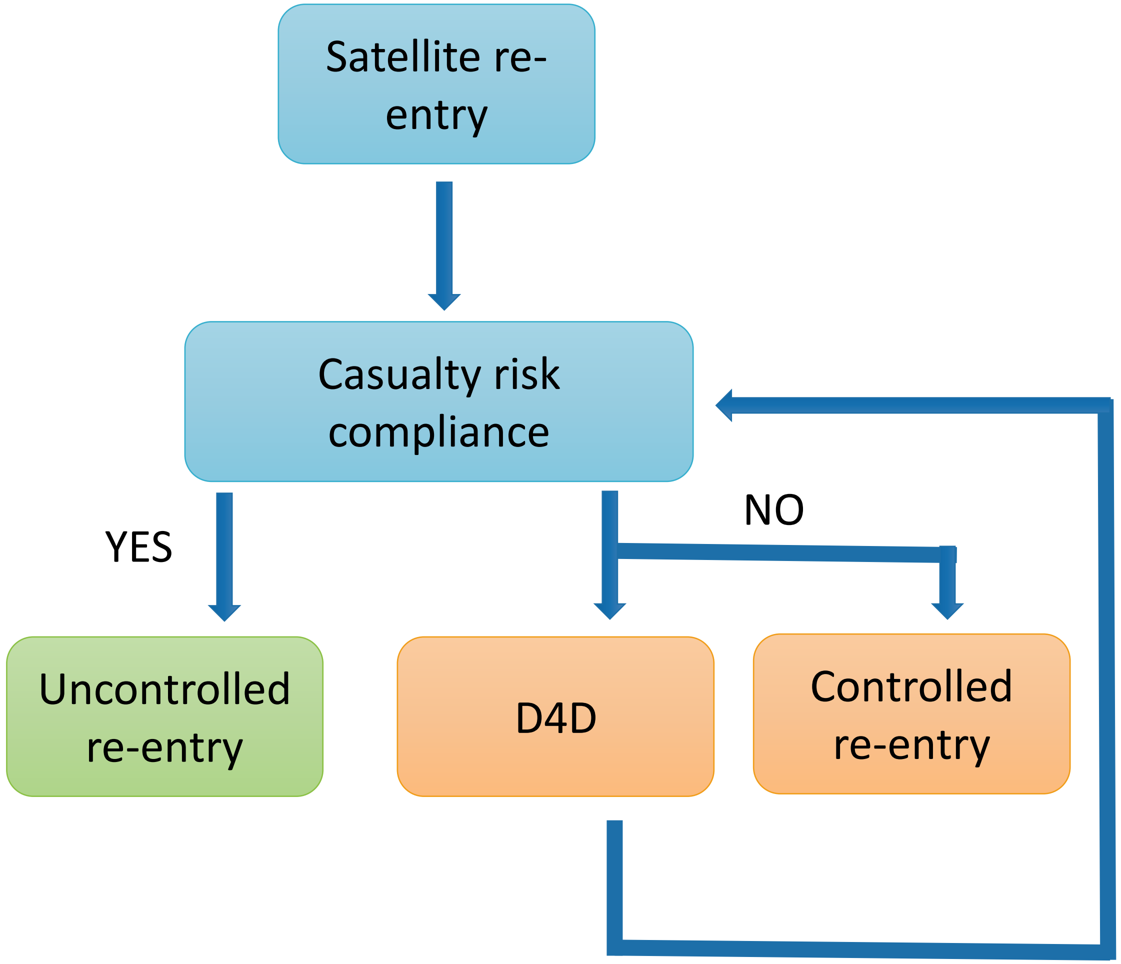
The importance of user experience



- **Better understanding of the results**: It is important for users to be able to understand the results in order to make informed decisions. An experienced user can visualize and interpret the data in a clear and concise way.
- **Explore different scenarios**: Tools can be used to explore different re-entry scenarios and to identify the best course of action to minimize risk. An experienced user can easily change parameters and run different simulations scenarios.
- **Make better decisions**: based on a better understanding of the outputs, an experienced user can make very good decisions.

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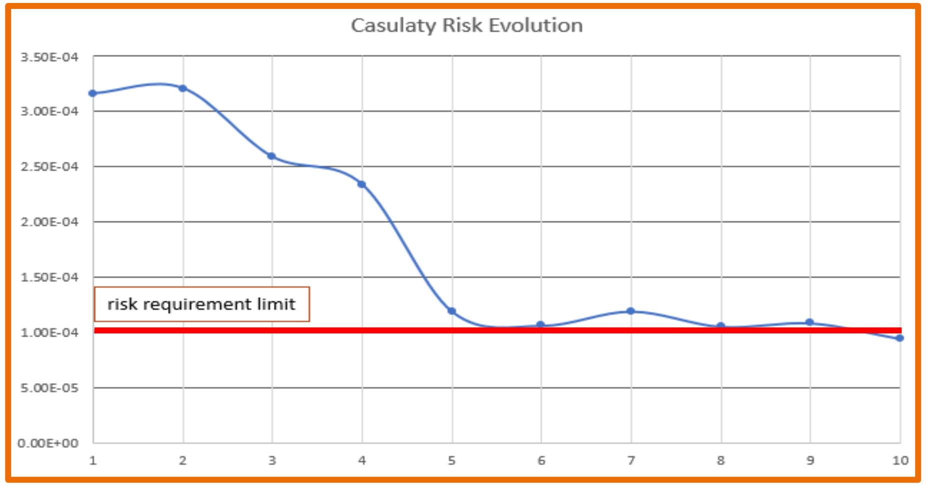
Examples – Uncontrolled Re-entry

NGGM mission – uncontrolled re-entry

NGGM represents ESA's Next Generation Gravity Mission and is part of a broader joint programme that seeks cooperation in the field of Earth Observation and intends to study the mass transport processes.



Design for Demise measures

- **Design for Demise** (D4D) measures are implemented to ensure that space debris is minimized during uncontrolled re-entry.
- Examples of D4D measures include the use of **lightweight materials** that are highly flammable, the inclusion of perforations in panels to increase heating rates, and the use of **thin-walled structures** that are prone to buckling.

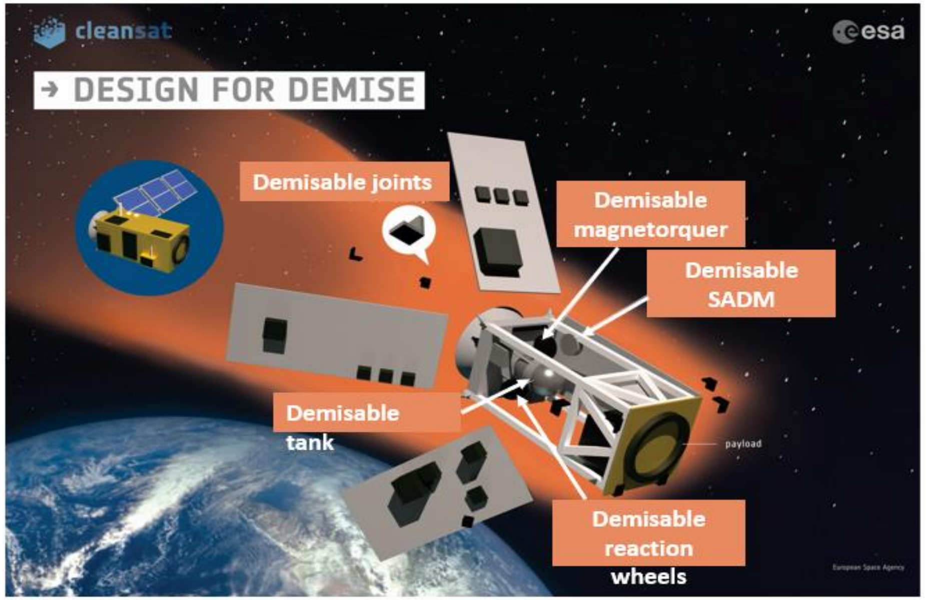


Photo credit: ESA

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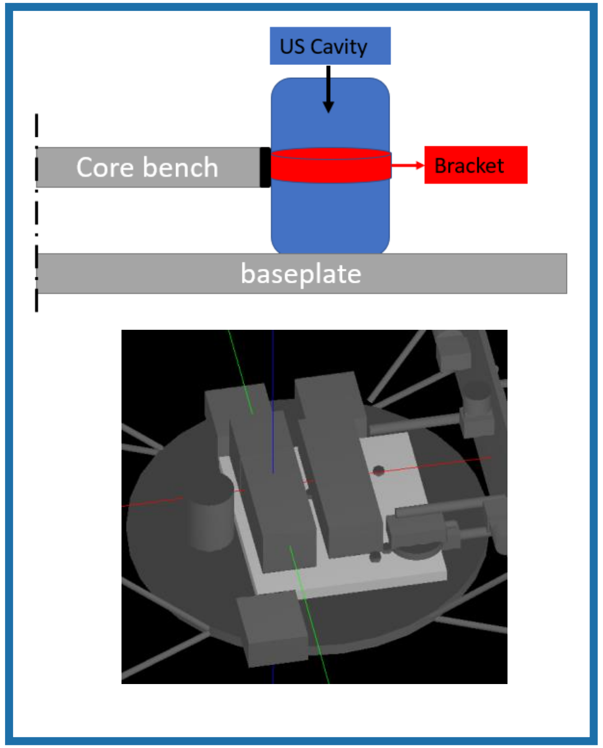
Examples - Design for Demise

Identifying the surviving fragments 'on the edge'	✓ Fragments represent high interest for further mitigations
Propose new connections	✓ Fragments surviving in big compounds, lowering the casualty area and therefore lowering the casualty risk
Propose new designs	✓ Fragments no longer surviving, lowering the casualty risk
Facilitate exposure to the direct heat flux	✓ Fragments no longer surviving, lowering the casualty risk
Look for alternative materials	✓ Fragments no longer surviving, lowering the casualty risk



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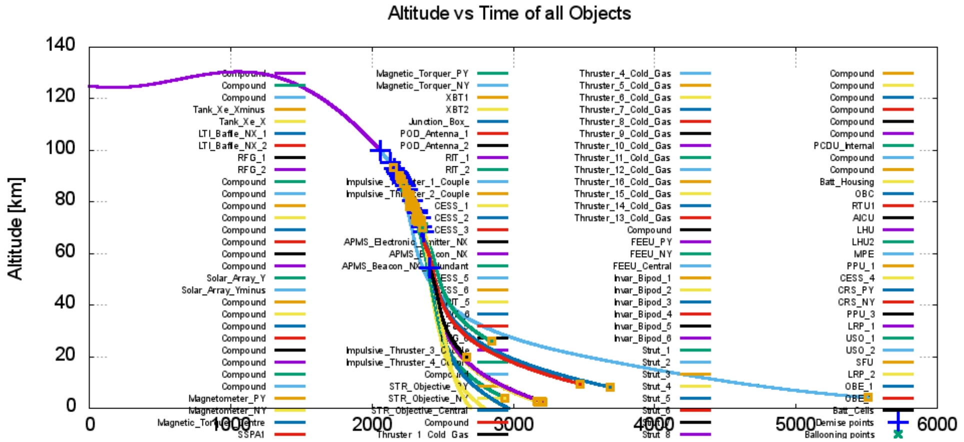
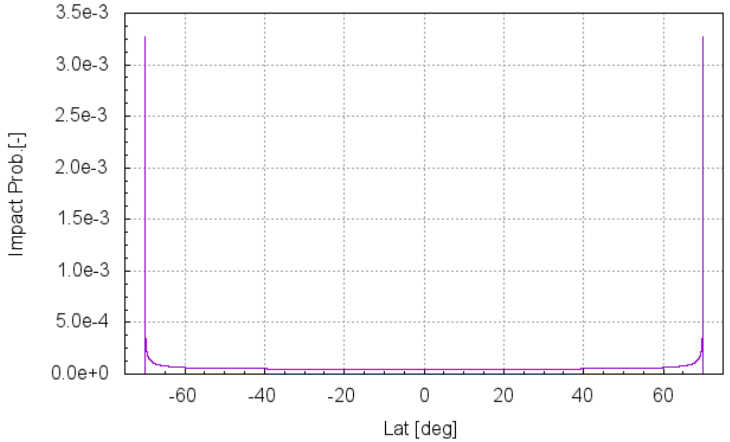
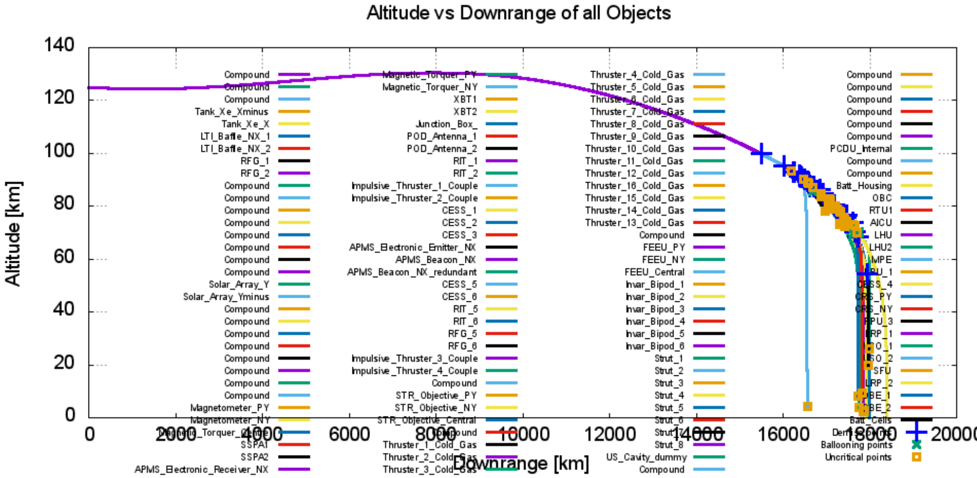
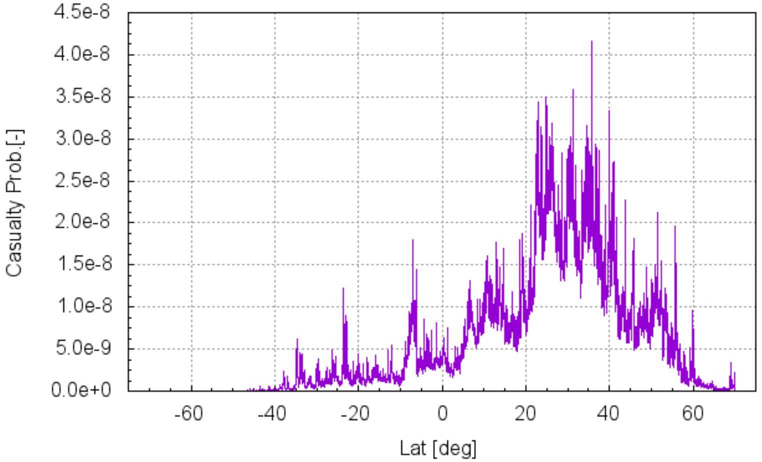
Examples - Results

Number of objects	Number of demised objects	Number of uncritical objects	Number of ballooning objects	Number of surviving objects	Number of surviving fragments
154	34	82	14	24	6









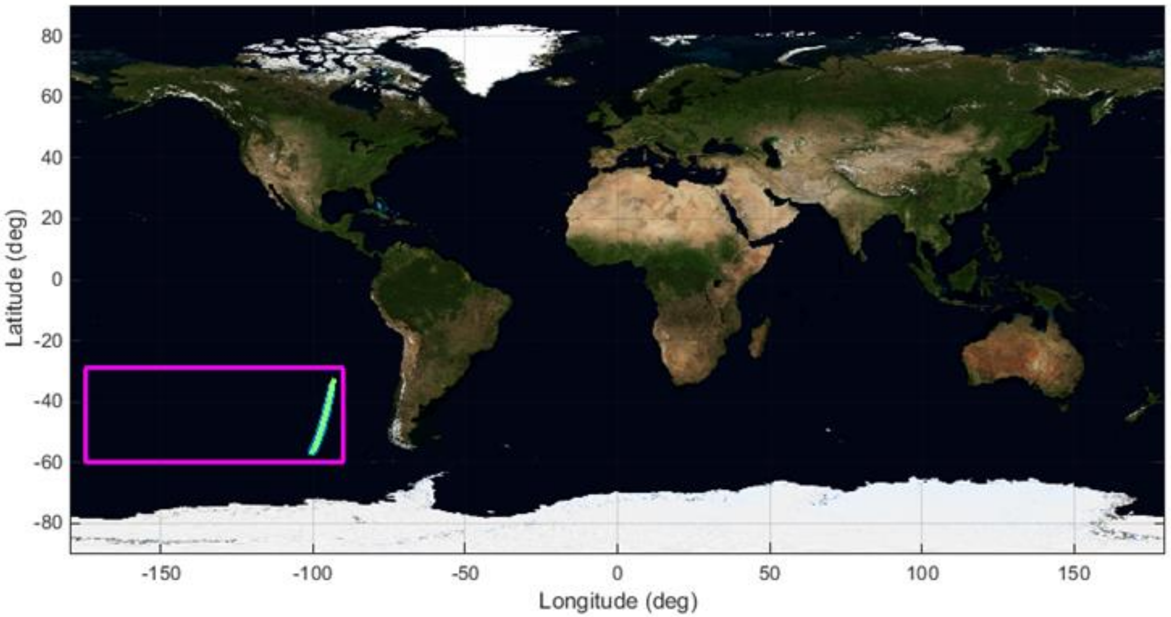
Examples – Controlled Re-entry

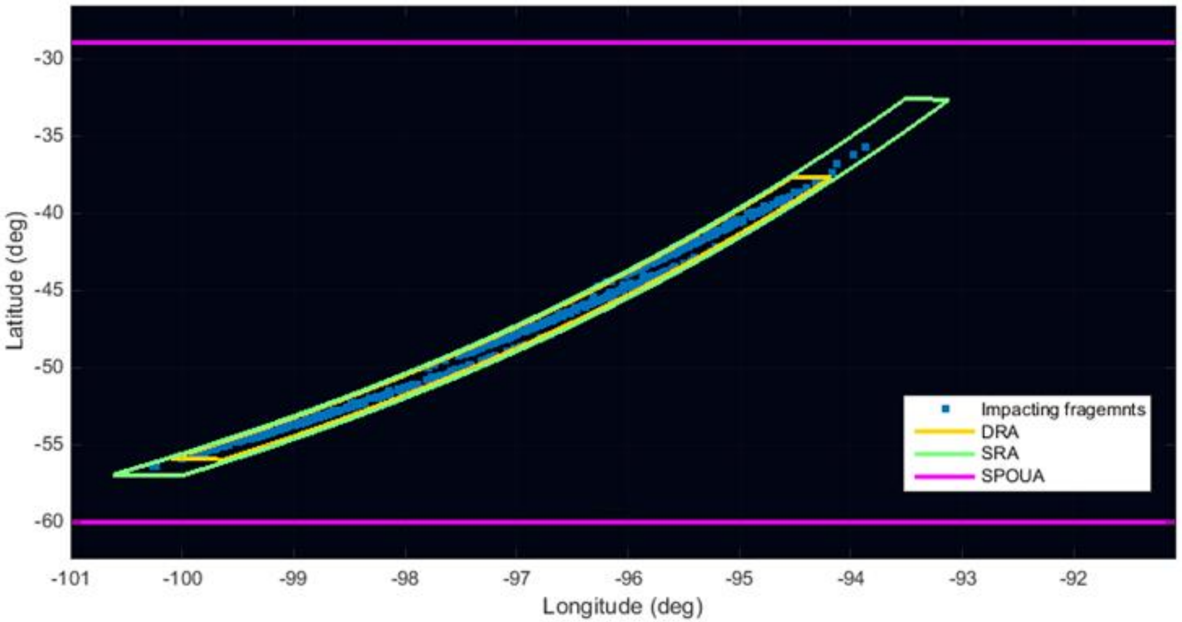
CHIME mission – controlled re-entry

CHIME (Copernicus Hyperspectral Imaging Mission for the Environment) is an ESA mission that will expand the current suite of Sentinel missions.

Based on the surviving fragments, statistical boxes are computed:

- DRA (**Declared Re-Entry Area**): area that encloses the debris with a 99% probability
- SRA (**Safety Re-Entry Area**): area that encloses the debris with a 99.999% probability





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Conclusions

- Satellite re-entry analysis is an essential activity for ensuring that satellites deorbit safely. By analysing the satellite's design, orbit, and other factors, engineers can identify potential risks and develop mitigation strategies.

- The findings of this presentation demonstrate that satellite re-entry analysis is a complex and challenging task. However, with careful planning and execution, it is possible to design satellites that will deorbit safely and completely, in accordance with the new zero debris trends promoted by ESA.

Photo credit: ESA

End of Presentation

Thank You!

Questions?

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