Zero Debris Technical Booklet

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Zero Debris Technical Booklet Overview

Purpose: answer to the call to define collaboratively how to reach Zero Debris by 2030, to achieve targets and principles of Zero Debris Charter:

- Focus on technical developments
- For the benefit of everyone
- Led by Zero Debris community stakeholders (ESA contributor and facilitator)
- Reinforcing the Zero Debris community

Received inputs from 36 organisations on initial draft

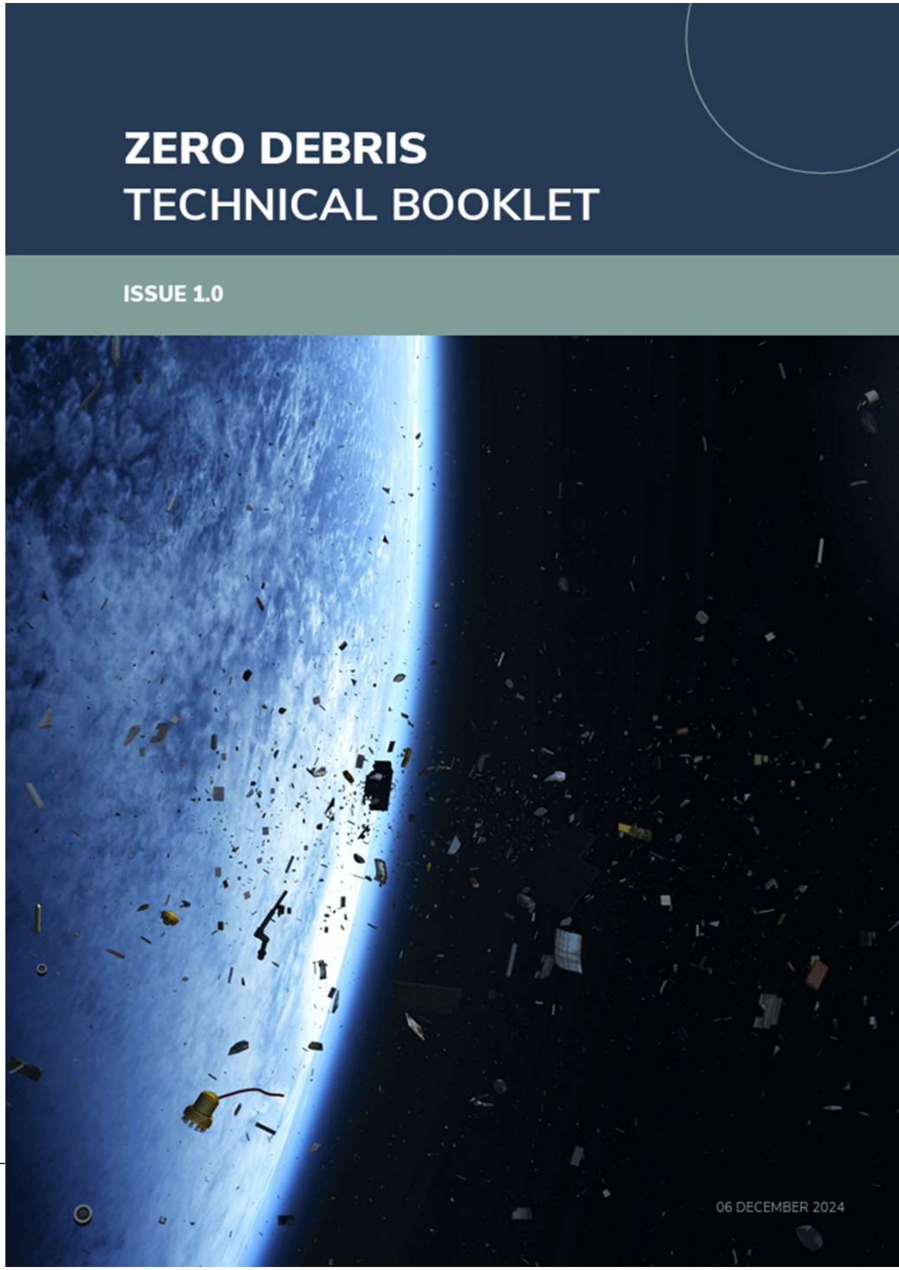
- 32 organisations in Europe, 2 in USA, 2 in Canada

Workshop held in ESOC on 26th/27th June 2024 to discuss technical content with >90 representatives from industry led to **Draft 1**

Work over the summer 2024 by Editorial Working Group

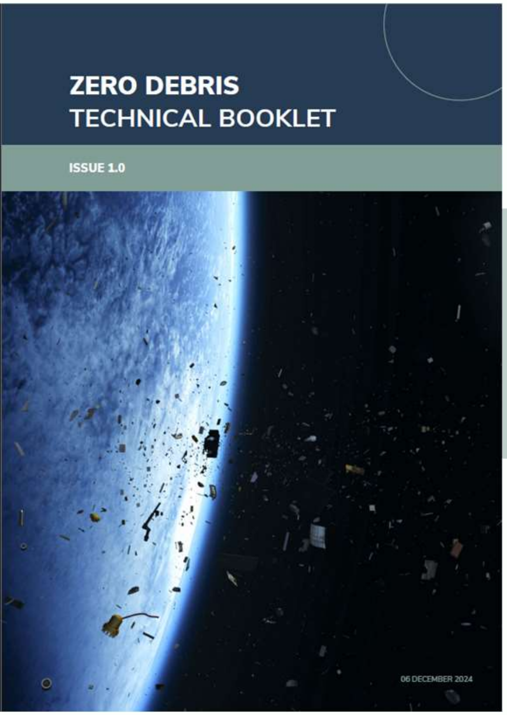
Final workshop held at ESTEC on 11th October 2024

First Issue of the Technical Booklet shared with Zero Debris Community at the end of 2024, **released to the public January 15th 2025**

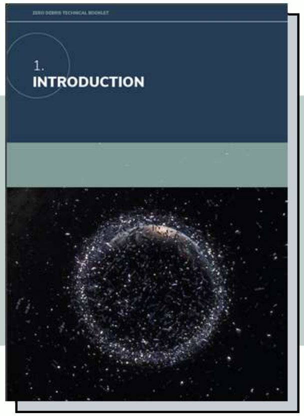


Technical Booklet Contents

- The Booklet is **technically focussed, non-binding,** and **collaborative.**
- The Booklet serves as a **resource to support the Zero Debris Community** in directing its resources **towards research and future technology developments.**

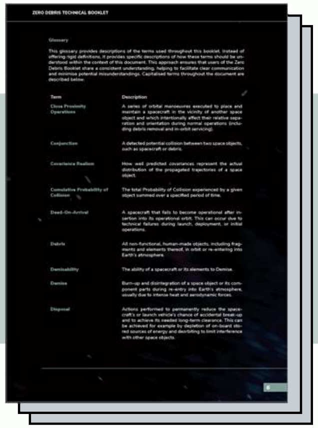


Introduction



Background and scope

Glossary



Description of terms used

Technical Chapters

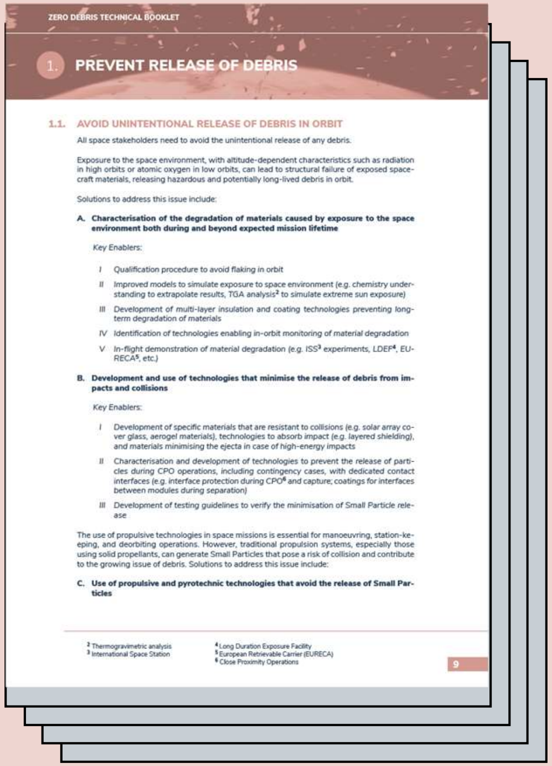
Needs, Solutions and Key Enablers

Vision for a Circular Economy in Space

Long-term vision

Technical Chapters

1. Prevent Release of Debris



ZERO DEBRIS TECHNICAL BOOKLET

1. PREVENT RELEASE OF DEBRIS

1.1. AVOID UNINTENTIONAL RELEASE OF DEBRIS IN ORBIT

All space stakeholders need to avoid the unintentional release of any debris.

Exposure to the space environment, with altitude-dependent characteristics such as radiation in high orbits or atomic oxygen in low orbits, can lead to structural failure of exposed spacecraft materials, releasing hazardous and potentially long-lived debris in orbit.

Solutions to address this issue include:

A. Characterisation of the degradation of materials caused by exposure to the space environment both during and beyond expected mission lifetime

Key Enablers:

- I Qualification procedure to avoid flaking in orbit
- II Improved models to simulate exposure to space environment (e.g. chemistry understanding to extrapolate results, TGA analysis[2] to simulate extreme sun exposure)
- III Development of multi-layer insulation and coating technologies preventing long-term degradation of materials
- IV Identification of technologies enabling in-orbit monitoring of material degradation
- V In-flight demonstration of material degradation (e.g. ISS[3] experiments, LDEF[4], EURECA[5], etc.)

B. Development and use of technologies that minimise the release of debris from impacts and collisions

Key Enablers:

- I Development of specific materials that are resistant to collisions (e.g. solar array cover glass, aerogel materials), technologies to absorb impact (e.g. layered shielding), and materials minimising the ejecta in case of high-energy impacts
- II Characterisation and development of technologies to prevent the release of particles during CPO operations, including contingency cases, with dedicated contact interfaces (e.g. interface protection during CPO[6] and capture; coatings for interfaces between modules during separation)
- III Development of testing guidelines to verify the minimisation of Small Particle release

The use of propulsive technologies in space missions is essential for manoeuvring, station-keeping, and deorbiting operations. However, traditional propulsion systems, especially those using solid propellants, can generate Small Particles that pose a risk of collision and contribute to the growing issue of debris. Solutions to address this issue include:

C. Use of propulsive and pyrotechnic technologies that avoid the release of Small Particles

[2] Thermogravimetric analysis
[3] International Space Station
[4] Long Duration Exposure Facility
[5] European Retrievable Carrier (EURECA)
[6] Close Proximity Operations

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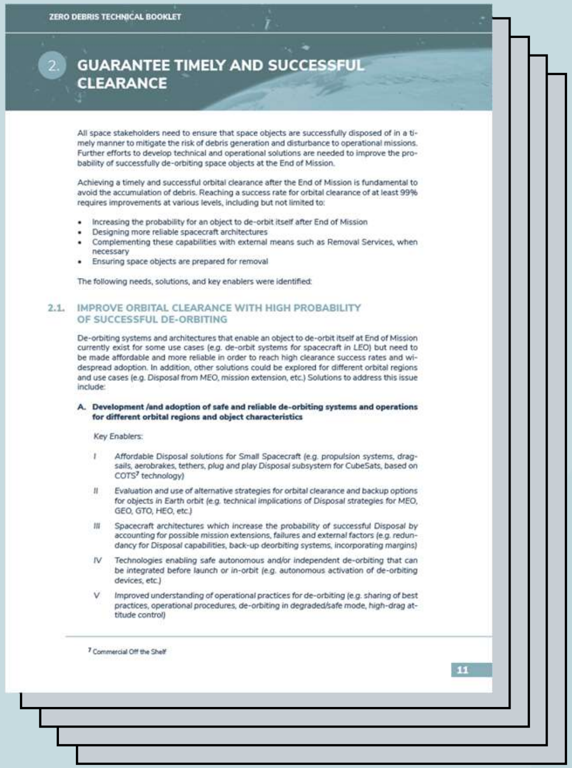
2. Guarantee Timely and Successful Clearance



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2. GUARANTEE TIMELY AND SUCCESSFUL CLEARANCE

All space stakeholders need to ensure that space objects are successfully disposed of in a timely manner to mitigate the risk of debris generation and disturbance to operational missions. Further efforts to develop technical and operational solutions are needed to improve the probability of successfully de-orbiting space objects at the End of Mission.

Achieving a timely and successful orbital clearance after the End of Mission is fundamental to avoid the accumulation of debris. Reaching a success rate for orbital clearance of at least 99% requires improvements at various levels, including but not limited to:

- Increasing the probability for an object to de-orbit itself after End of Mission
- Designing more reliable spacecraft architectures
- Complementing these capabilities with external means such as Removal Services, when necessary
- Ensuring space objects are prepared for removal

The following needs, solutions, and key enablers were identified:

2.1. IMPROVE ORBITAL CLEARANCE WITH HIGH PROBABILITY OF SUCCESSFUL DE-ORBITING

De-orbiting systems and architectures that enable an object to de-orbit itself at End of Mission currently exist for some use cases (e.g. de-orbit systems for spacecraft in LEO) but need to be made affordable and more reliable in order to reach high clearance success rates and widespread adoption. In addition, other solutions could be explored for different orbital regions and use cases (e.g. Disposal from MEO, mission extension, etc.) Solutions to address this issue include:

A. Development /and adoption of safe and reliable de-orbiting systems and operations for different orbital regions and object characteristics

Key Enablers:

- I Affordable Disposal solutions for Small Spacecraft (e.g. propulsion systems, drag-sails, aerobrakes, tethers, plug and play Disposal subsystem for CubeSats, based on COTS[7] technology)
- II Evaluation and use of alternative strategies for orbital clearance and backup options for objects in Earth orbit (e.g. technical implications of Disposal strategies for MEO, GEO, GTO, HEO, etc.)
- III Spacecraft architectures which increase the probability of successful Disposal by accounting for possible mission extensions, failures and external factors (e.g. redundancy for Disposal capabilities, back-up deorbiting systems, incorporating margins)
- IV Technologies enabling safe autonomous and/or independent de-orbiting that can be integrated before launch or in-orbit (e.g. autonomous activation of de-orbiting devices, etc.)
- V Improved understanding of operational practices for de-orbiting (e.g. sharing of best practices, operational procedures, de-orbiting in degraded/safe mode, high-drag attitude control)

[7] Commercial Off the Shelf

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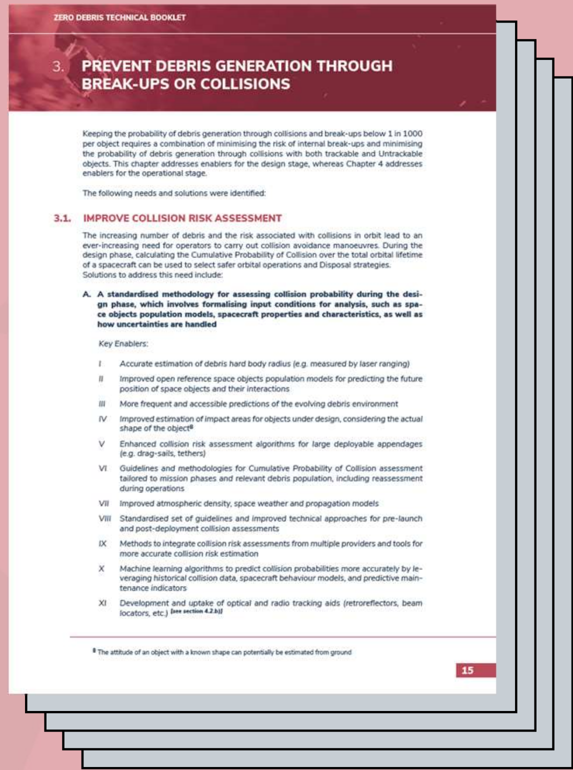
3. Prevent Debris Generation through Break-ups or Collisions



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3. PREVENT DEBRIS GENERATION THROUGH BREAK-UPS OR COLLISIONS

Keeping the probability of debris generation through collisions and break-ups below 1 in 1000 per object requires a combination of minimising the risk of internal break-ups and minimising the probability of debris generation through collisions with both trackable and Untrackable objects. This chapter addresses enablers for the design stage, whereas Chapter 4 addresses enablers for the operational stage.

The following needs and solutions were identified:

3.1. IMPROVE COLLISION RISK ASSESSMENT

The increasing number of debris and the risk associated with collisions in orbit lead to an ever-increasing need for operators to carry out collision avoidance manoeuvres. During the design phase, calculating the Cumulative Probability of Collision over the total orbital lifetime of a spacecraft can be used to select safer orbital operations and Disposal strategies. Solutions to address this need include:

A. A standardised methodology for assessing collision probability during the design phase, which involves formalising input conditions for analysis, such as space objects population models, spacecraft properties and characteristics, as well as how uncertainties are handled

Key Enablers:

- I Accurate estimation of debris hard body radius (e.g. measured by laser ranging)
- II Improved open reference space objects population models for predicting the future position of space objects and their interactions
- III More frequent and accessible predictions of the evolving debris environment
- IV Improved estimation of impact areas for objects under design, considering the actual shape of the object[8]
- V Enhanced collision risk assessment algorithms for large deployable appendages (e.g. drag-sails, tethers)
- VI Guidelines and methodologies for Cumulative Probability of Collision assessment tailored to mission phases and relevant debris population, including reassessment during operations
- VII Improved atmospheric density, space weather and propagation models
- VIII Standardised set of guidelines and improved technical approaches for pre-launch and post-deployment collision assessments
- IX Methods to integrate collision risk assessments from multiple providers and tools for more accurate collision risk estimation
- X Machine learning algorithms to predict collision probabilities more accurately by leveraging historical collision data, spacecraft behaviour models, and predictive maintenance indicators
- XI Development and uptake of optical and radio tracking aids (retroreflectors, beam locators, etc.) [see section 4.2.b)]

[8] The attitude of an object with a known shape can potentially be estimated from ground

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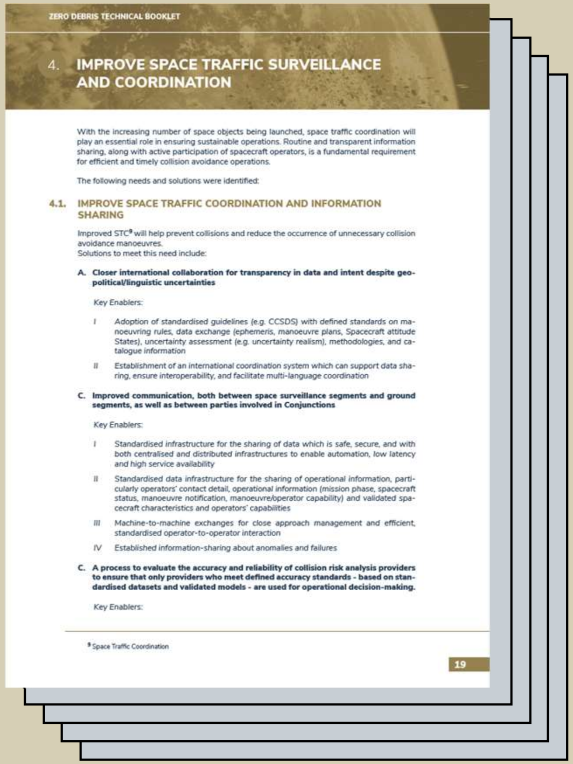
Technical Chapters

4. Improve Space Traffic Surveillance and Coordination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4. IMPROVE SPACE TRAFFIC SURVEILLANCE AND COORDINATION

With the increasing number of space objects being launched, space traffic coordination will play an essential role in ensuring sustainable operations. Routine and transparent information sharing, along with active participation of spacecraft operators, is a fundamental requirement for efficient and timely collision avoidance operations.

The following needs and solutions were identified:

4.1. IMPROVE SPACE TRAFFIC COORDINATION AND INFORMATION SHARING

Improved STC[8] will help prevent collisions and reduce the occurrence of unnecessary collision avoidance manoeuvres.
Solutions to meet this need include:

A. **Closer international collaboration for transparency in data and intent despite geo-political/linguistic uncertainties**

Key Enablers:

I Adoption of standardised guidelines (e.g. CCSDS) with defined standards on manoeuvring rules, data exchange (ephemeris, manoeuvre plans, Spacecraft attitude States), uncertainty assessment (e.g. uncertainty realism), methodologies, and catalogue information

II Establishment of an international coordination system which can support data sharing, ensure interoperability, and facilitate multi-language coordination

C. **Improved communication, both between space surveillance segments and ground segments, as well as between parties involved in Conjunctions**

Key Enablers:

I Standardised infrastructure for the sharing of data which is safe, secure, and with both centralised and distributed infrastructures to enable automation, low latency and high service availability

II Standardised data infrastructure for the sharing of operational information, particularly operators' contact detail, operational information (mission phase, spacecraft status, manoeuvre notification, manoeuvre/operator capability) and validated spacecraft characteristics and operators' capabilities

III Machine-to-machine exchanges for close approach management and efficient, standardised operator-to-operator interaction

IV Established information-sharing about anomalies and failures

C. **A process to evaluate the accuracy and reliability of collision risk analysis providers to ensure that only providers who meet defined accuracy standards - based on standardised datasets and validated models - are used for operational decision-making.**

Key Enablers:

[8] Space Traffic Coordination

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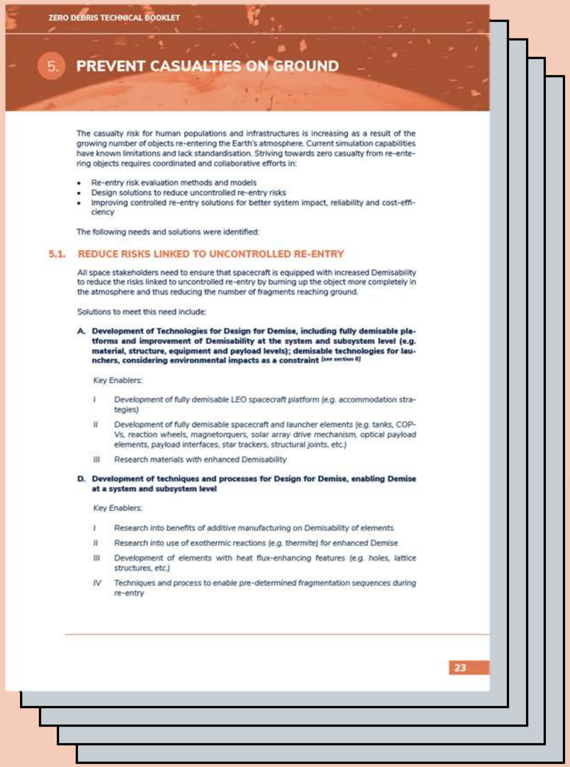
5. Prevent Casualties on Ground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5. PREVENT CASUALTIES ON GROUND

The casualty risk for human populations and infrastructures is increasing as a result of the growing number of objects re-entering the Earth's atmosphere. Current simulation capabilities have known limitations and lack standardisation. Striving towards zero casualty from re-entering objects requires coordinated and collaborative efforts in:

- Re-entry risk evaluation methods and models
- Design solutions to reduce uncontrolled re-entry risks
- Improving controlled re-entry solutions for better system impact, reliability and cost-efficiency

The following needs and solutions were identified:

5.1. REDUCE RISKS LINKED TO UNCONTROLLED RE-ENTRY

All space stakeholders need to ensure that spacecraft is equipped with increased Demisability to reduce the risks linked to uncontrolled re-entry by burning up the object more completely in the atmosphere and thus reducing the number of fragments reaching ground.

Solutions to meet this need include:

A. **Development of Technologies for Design for Demise, including fully demisable platforms and improvement of Demisability at the system and subsystem level (e.g. material, structure, equipment and payload levels); demisable technologies for launchers, considering environmental impacts as a constraint** [see section 6]

Key Enablers:

I Development of fully demisable LEO spacecraft platform (e.g. accommodation strategies)

II Development of fully demisable spacecraft and launcher elements (e.g. tanks, COPVs, reaction wheels, magnetorquers, solar array drive mechanism, optical payload elements, payload interfaces, star trackers, structural joints, etc.)

III Research materials with enhanced Demisability

D. **Development of techniques and processes for Design for Demise, enabling Demise at a system and subsystem level**

Key Enablers:

I Research into benefits of additive manufacturing on Demisability of elements

II Research into use of exothermic reactions (e.g. thermite) for enhanced Demise

III Development of elements with heat flux-enhancing features (e.g. holes, lattice structures, etc.)

IV Techniques and process to enable pre-determined fragmentation sequences during re-entry

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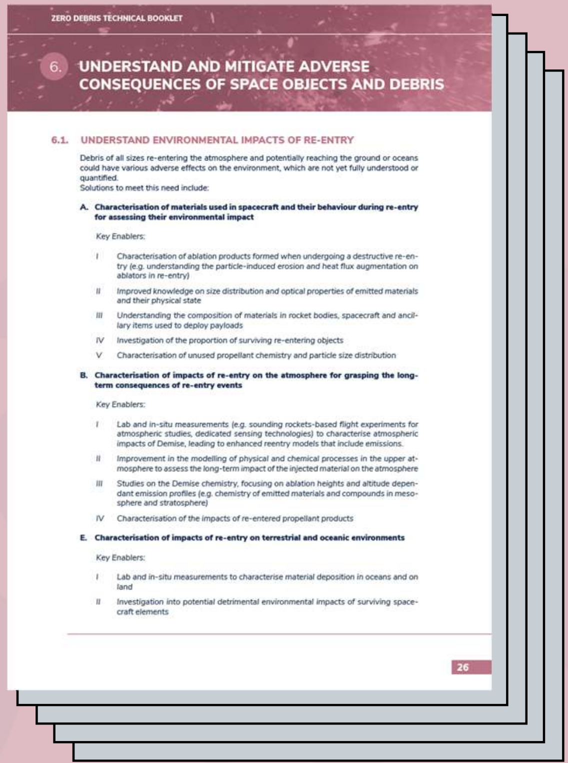
6. Understand and Mitigate Adverse Consequences of Space Objects and Debris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6. UNDERSTAND AND MITIGATE ADVERSE CONSEQUENCES OF SPACE OBJECTS AND DEBRIS

6.1. UNDERSTAND ENVIRONMENTAL IMPACTS OF RE-ENTRY

Debris of all sizes re-entering the atmosphere and potentially reaching the ground or oceans could have various adverse effects on the environment, which are not yet fully understood or quantified.
Solutions to meet this need include:

A. **Characterisation of materials used in spacecraft and their behaviour during re-entry for assessing their environmental impact**

Key Enablers:

I Characterisation of ablation products formed when undergoing a destructive re-entry (e.g. understanding the particle-induced erosion and heat flux augmentation on ablators in re-entry)

II Improved knowledge on size distribution and optical properties of emitted materials and their physical state

III Understanding the composition of materials in rocket bodies, spacecraft and ancillary items used to deploy payloads

IV Investigation of the proportion of surviving re-entering objects

V Characterisation of unused propellant chemistry and particle size distribution

B. **Characterisation of impacts of re-entry on the atmosphere for grasping the long-term consequences of re-entry events**

Key Enablers:

I Lab and in-situ measurements (e.g. sounding rockets-based flight experiments for atmospheric studies, dedicated sensing technologies) to characterise atmospheric impacts of Demise, leading to enhanced reentry models that include emissions.

II Improvement in the modelling of physical and chemical processes in the upper atmosphere to assess the long-term impact of the injected material on the atmosphere

III Studies on the Demise chemistry, focusing on ablation heights and altitude dependant emission profiles (e.g. chemistry of emitted materials and compounds in mesosphere and stratosphere)

IV Characterisation of the impacts of re-entered propellant products

E. **Characterisation of impacts of re-entry on terrestrial and oceanic environments**

Key Enablers:

I Lab and in-situ measurements to characterise material deposition in oceans and on land

II Investigation into potential detrimental environmental impacts of surviving spacecraft elements

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Example of Implementing the Zero Debris Approach

Conclusions and Next Steps

Navigating the Space Policy Quagmire

- We aim for **safe, secure, responsible,** and **sustainable** access to space
- For debris mitigation specifically, there is a broad range of **regulations, policies, guidelines,** and other **non-binding instruments,** each with their own **agenda, ambitions, priorities,** and **interpretations**

ZERO DEBRIS CHARTER

Towards a Safe and Sustainable Space Environment

…Establish this ***non-legally binding*** *Charter as a major contribution towards space safety and sustainability,* ***fostering a community*** *of proactive actors working collectively towards jointly defined* ***ambitious*** *and* ***measurable targets for 2030***

…Determined to ***lead by example***

ZERO DEBRIS TECHNICAL BOOKLET

ISSUE 1.0

…This Booklet presents a selection of ***technical needs, solutions*** *and* ***key enablers*** *that collectively provide the means to achieve the targets of the Zero Debris Charter*

…Technically-Focused, Non-Binding, Cross-Cutting, Collaborative, Complementary


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