Evolution of ESA Space Debris Mitigation policy

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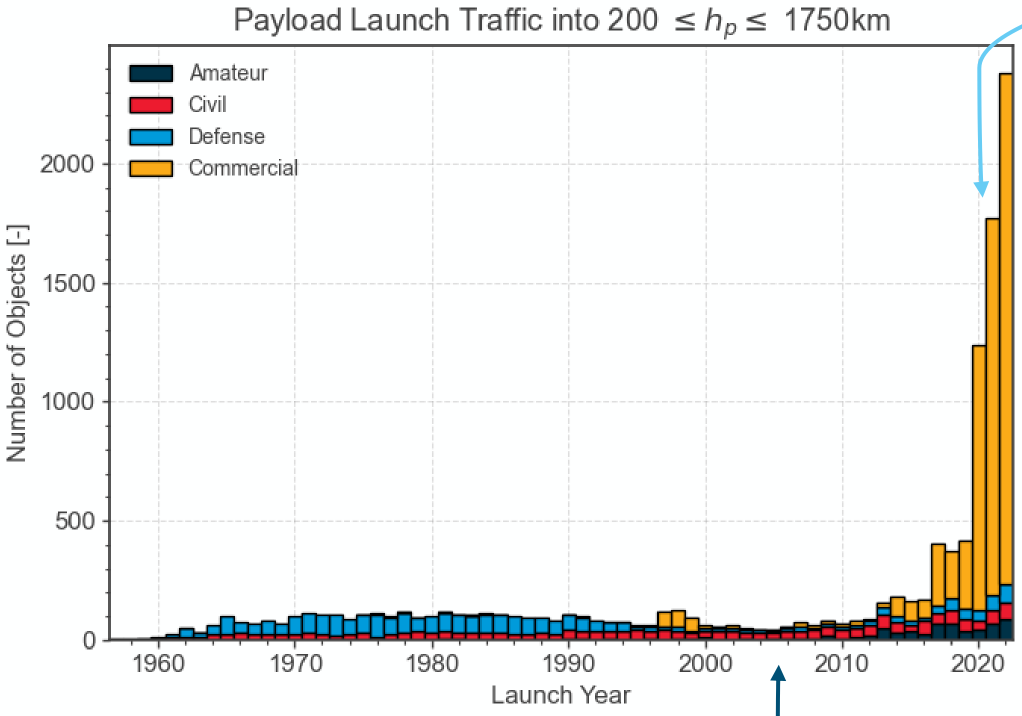
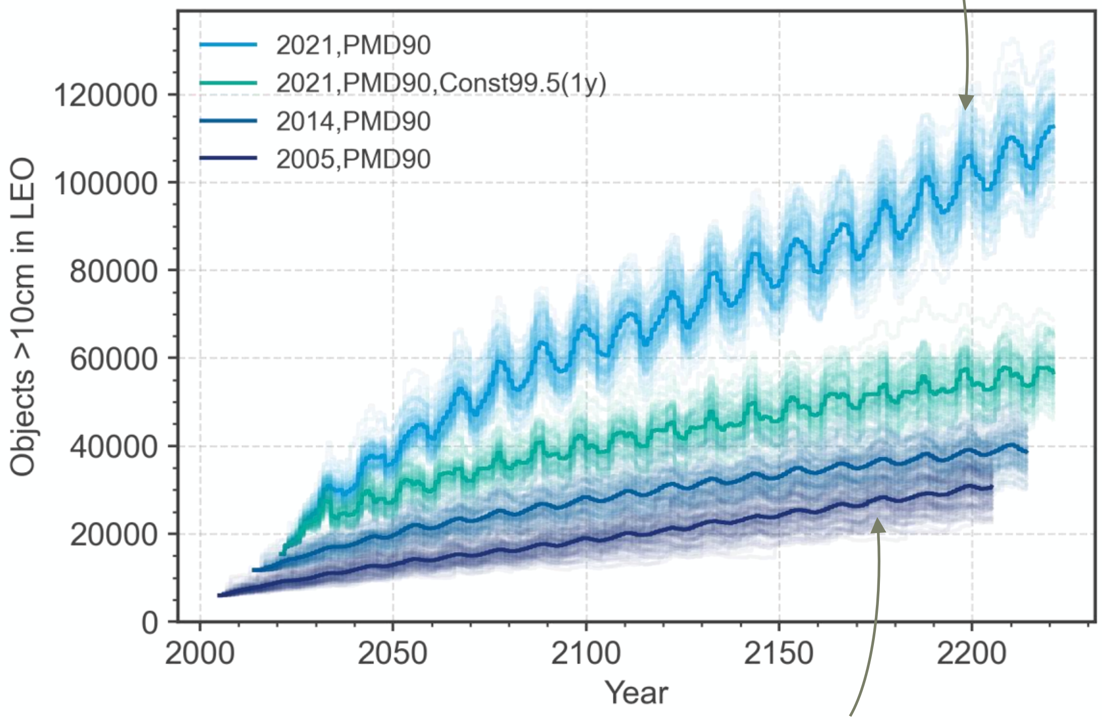
14/11/2023

Why do we need Zero Debris?

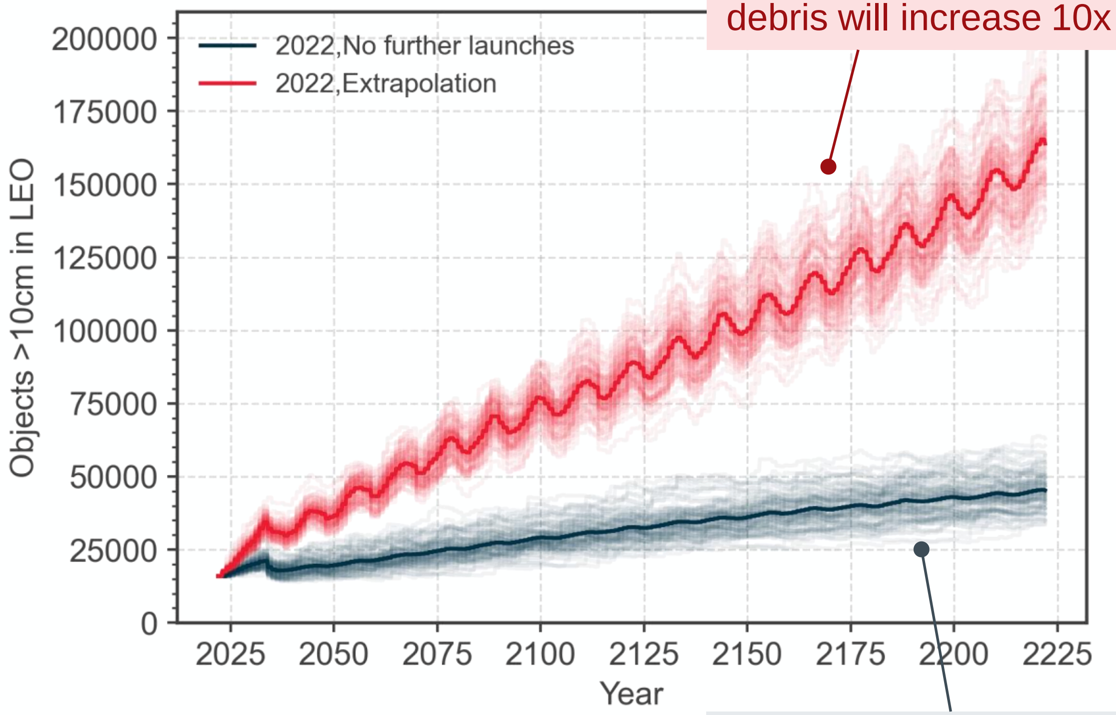




What PMD90(25y) means now: is this acceptable?

What PMD90(25y) meant when IADC drafted their recommendation

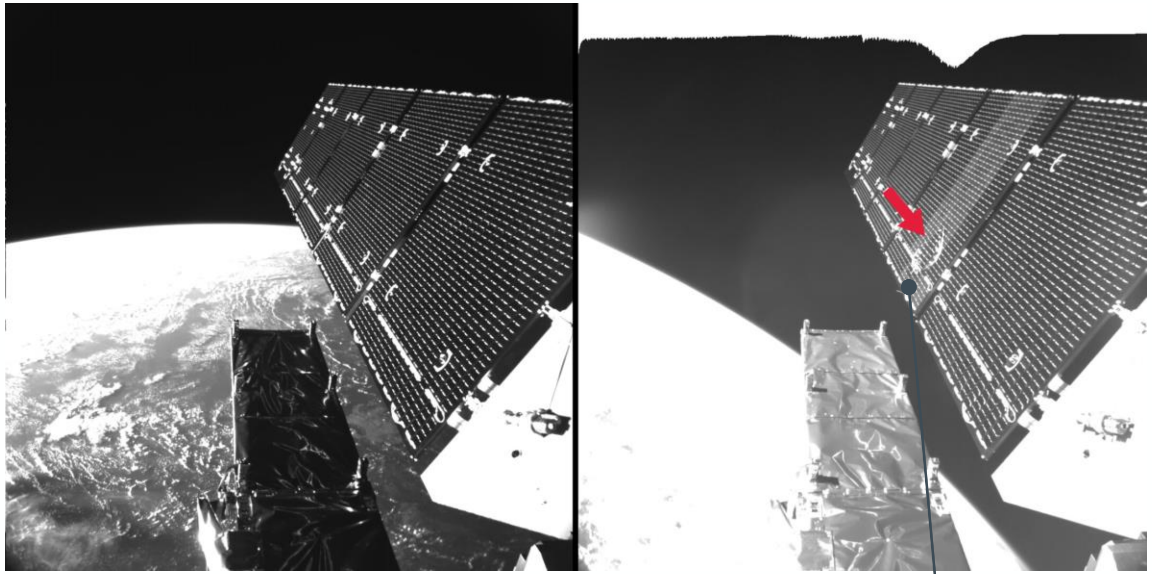
Why do we need Zero Debris?



If we keep the current behaviour, the amount of debris will increase 10x

Even if we stopped launching, the amount of debris would keep growing

Sentinel-1A



hit by ~5mm debris in 2016, resulting in 40 cm damage and at least 8 trackable debris (> 5cm)

Zero Debris initial recommendations

esa

1 Definition of valuable orbits

- Extend orbital protection to other earth orbits e.g., **GNSS operational orbits**

2 Guarantee successful disposal

- Improve probability of successful **self-disposal**
- **Prepare for removal**
- **Removal services**

3 Improve orbital clearance

- **Reduce time** left in protected regions
- Improve clearance in **other Earth orbits**

4 Avoid in-orbit collisions

- Improve **collision avoidance strategy**
  Adopt **cumulative collision probability** metrics
- Share **maneuver data**
- Improve **trackability**

5 Avoid internal break-ups

- **Mandatory** passivation features
- **Probability of successful passivation**

6 Prevent intentional release of space debris

- **Prevent release** of launcher related objects and interference with valuable orbits

7 Improve on-ground casualty risk assessment

- **Standardize** models and methods to assess demise
- **Impact on ground** of launcher related objects

8 Guarantee dark and quiet skies

- Mitigate impacts on **astronomy**

ESA “Zero Debris” mandate

“In ESA we are implementing a policy that by 2030, we have a ‘net zero pollution’ strategy for objects in space, by consistently and reliably removing them from valuable orbits around Earth immediately after they cease operations.
We need to **lead** by example here.”

Josef Aschbacher
ESA Director General

Lead is adopting an **own standard** for the global sustainability, where we can **steer** the process both in terms of **content** (advanced requirements) and **pace** (6 month drafting).

Lead is **not** proceeding in **isolation**. Engagement with **stakeholders** and intention to **flow-back** requirements into international standards in the upcoming years are in the mindset.

ESA Space Debris Mitigation Regulation status

Final Presentation Zero Debris CDF

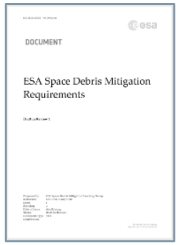
Operators Workshop

EB#154

ESB#64

Space Summit

October 2022 | **March 2023** | **April 2023** | **June 2023** | **August 2023** | **September 2023** | **October 2023** | **November 2023**



SDM WG Kick-off → WG drafting phase → **Draft standard** → Response to comments → **Final issue for endorsement**

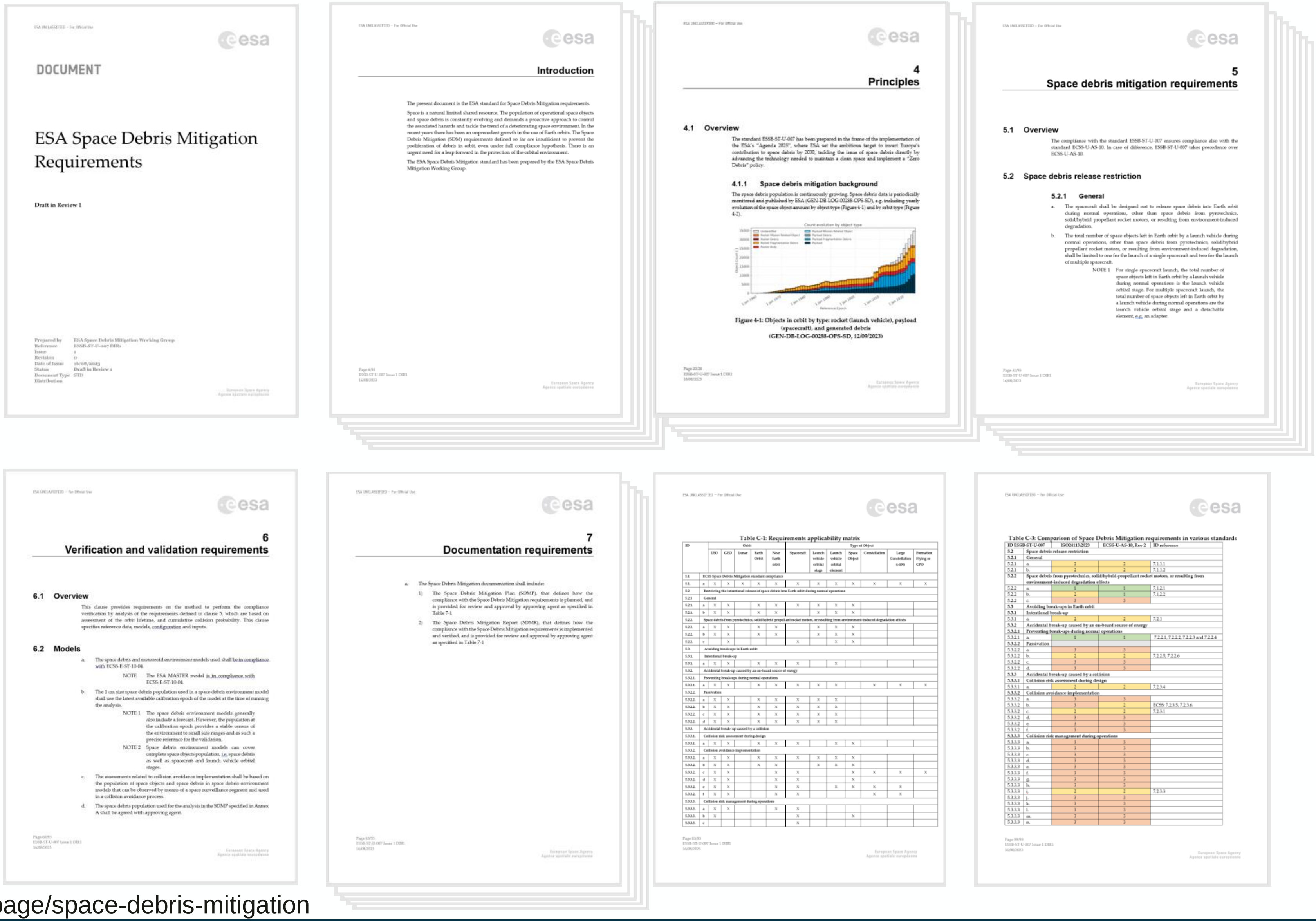
Provisional draft for ESA internal distribution

ESA review

Policy WG Kick-off → Policy drafting phase → **Final version for endorsement**

SDM: Space Debris Mitigation | WG: Working Group

The Document



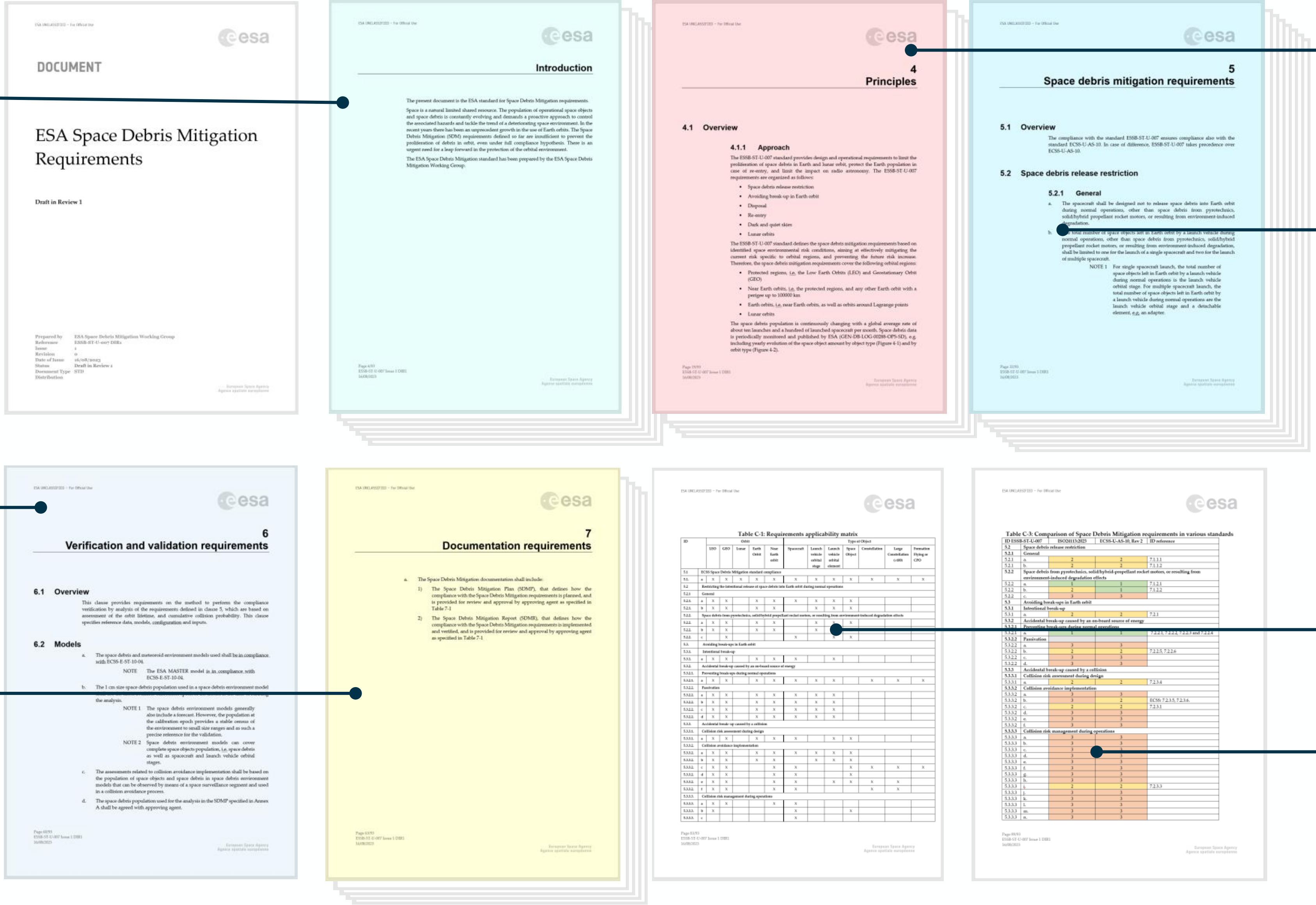
https://technology.esa.int/page/space-debris-mitigation

The Document

Frontmatter
Introduction, scope, definitions

Verification & Validation requirements
Indications on key models and data inputs for the required analyses (complementing ESSB-HB-U-002 ESA Space Debris Mitigation Compliance Verification Guidelines)

Documentation requirements
Including expected content for reporting



Principles
Rationale for each requirement

Space Debris Mitigation Requirements
Space debris release, Avoid breakups in Earth orbit, Disposal, Re-entry, Dark and quiet skies, Lunar orbits

Requirement Applicability Matrix
Requirement mapping based on orbital region and object type
Comparison wrt ISO24113:2023 and ECSS-U-AS-10

Requirements

Classical requirements with specified thresholds/**targets**

Pyrotechnics shall be designed not to release space debris larger than 1 mm in their largest dimension into Earth orbit.

Intentional break-up of a spacecraft or launch vehicle orbital element shall not be performed.

A spacecraft or launch vehicle orbital stage operating in Earth orbit shall be designed to guarantee a probability of successful passivation through to the end of life of:
1) At least 0,90
2) At least 0,95, when operating in the LEO protected region in an orbit with a natural orbital decay duration longer than 25 years
3) At least 0,95, when operating in the GEO protected region

Seed requirements i.e. request of quantification/assessment

During the design, the developer of a spacecraft operating in near Earth orbit with a recurrent manoeuvre capability shall quantify the operational impact during normal operations due to conjunctions.

The developer of a spacecraft or launch vehicle orbital element injected in near Earth orbit shall quantify:
- the expected number of conjunctions at 10^{-4} and 10^{-6} collision probability threshold,
- the estimated number of collision avoidance manoeuvres triggered thereby on other spacecraft

during normal operations and after end of life until re-entry or up to 100 years.

Seed requirements motivations

- Implement lessons learned
- Create awareness on known risks
- Develop quantifiable processes
- Define process towards threshold definition

ESSB-ST-U-007 rationale

LIFETIME

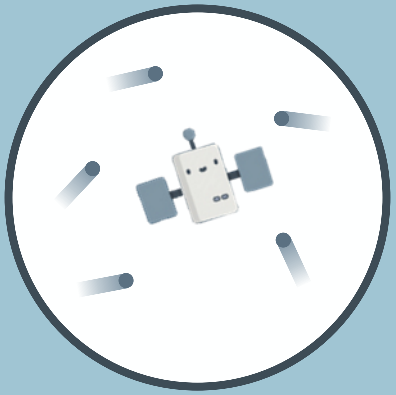
High risk
natural orbital decay duration
between 5 and 25 years

Medium risk
natural orbital decay up to 5 years
and crossing altitudes above 375 km

Very high risk
natural orbital decay duration
longer than 25 years

COLLISION PROBABILITY

Collision probability with **space debris** objects larger than **1 cm**



A space object in Earth orbit without capability of performing collision avoidance manoeuvres and with a cumulative collision probability with space objects larger than 1 cm above **1 in 1000** is considered **environmentally hazardous**.

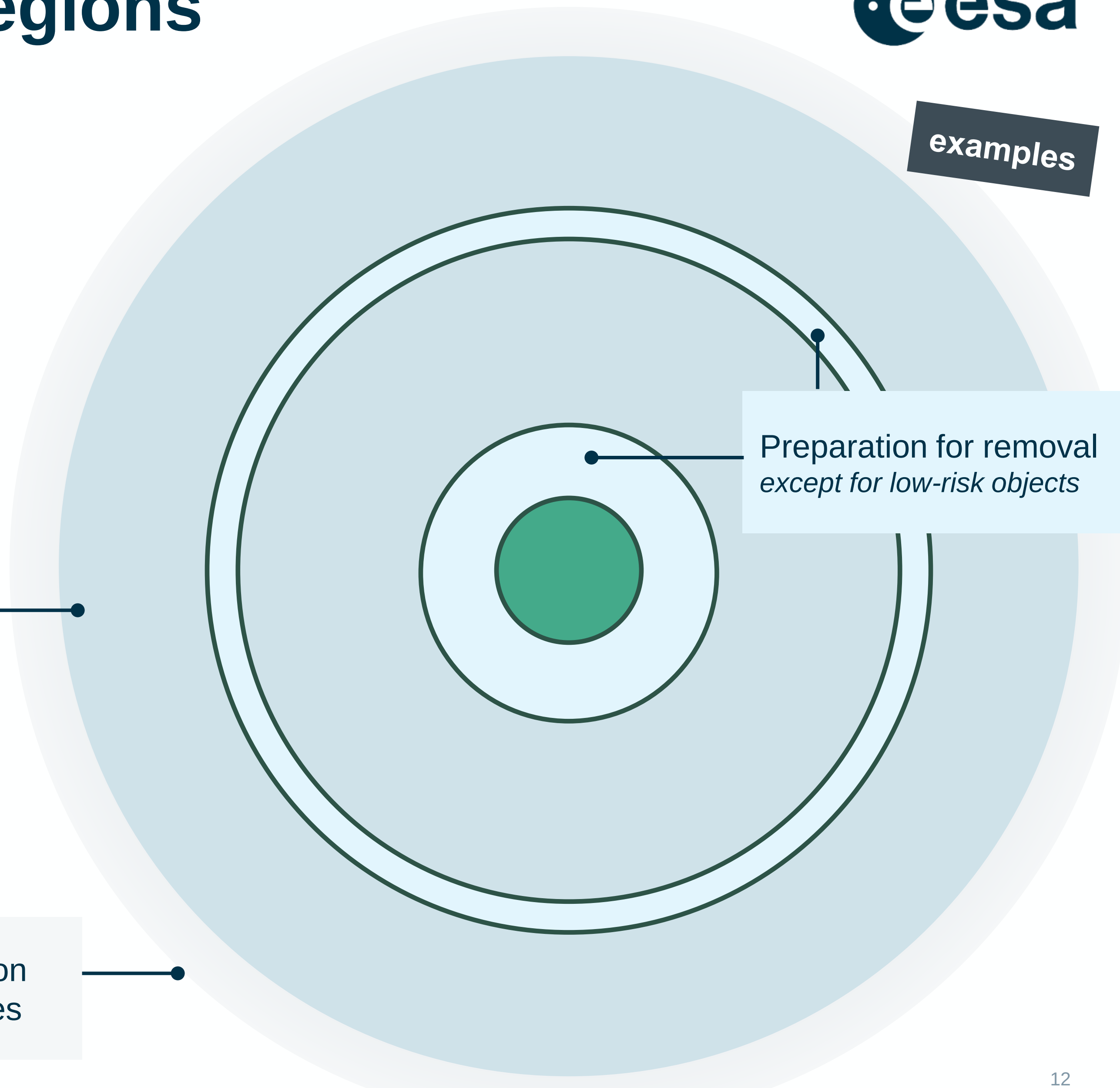
ESSB-ST-U-007 scope: orbital regions

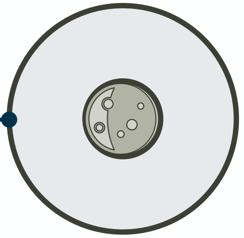
Protected regions (i.e. LEO and GEO)

Near-Earth orbits (perigee < 100000 km)

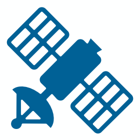
Earth orbits (including Libration Point Orbits)

Lunar orbits (including Libration Point Orbits)



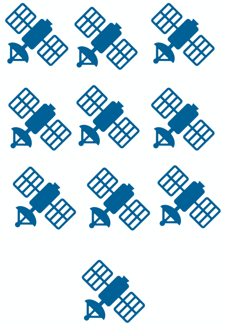


ESSB-ST-U-007 scope: space system type



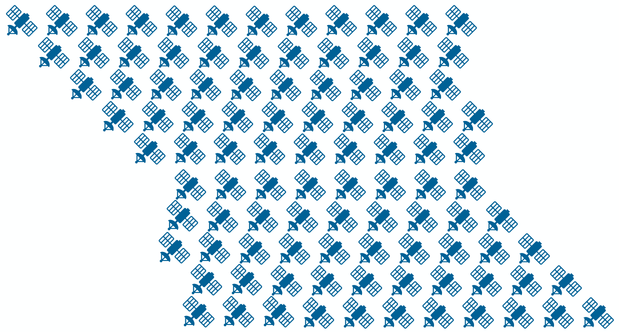
Single spacecraft

Request for collision avoidance capability in GEO and LEO if high or very high risk



Constellation
(> 10 spacecraft)

Request for collision avoidance capability in near-Earth orbit

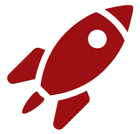


Large constellation
(> 100 spacecraft)

System reliability > 0.95

In LEO, disposal below 375 km and injection orbit with natural decay time < 5 years

Re-entry casualty risk per spacecraft < 1:10^6



Launch vehicle
(including elements, and orbital stages)

What's new? – some examples

Clearance criteria

- **5 years in LEO**
- Collision probability threshold
- Apogee below 375 km for constellations
- If graveyard, no crossing with known constellations

Probability of successful disposal

- ≥ 90% considering both **internal** (reliability) and **external** (impacts) factors
- ≥ 95% for large constellations
- Monitoring and reassessment

COLA & STM

- Encoding of current best practices (e.g. data sharing)
- Recurrent manoeuvre capability in GEO, in LEO for high and very high-risk objects, and for constellations
- Collision probability threshold for action ≤ 1:10000 (single conjunction)

Design for removal

- Preparation for removal for objects in the protected regions, except low-risk ones

Lunar orbits

- No MROs
- Break-up prob. < 1:1000
- Space traffic coordination
- Analysis of disposal options

COLA: Collision Avoidance | STM: Space Traffic Management

Probability of successful disposal

Probability of successful disposal > **0.9** including the contributions from **system reliability** and from **collisions** with space debris or meteoroids

System reliability > **0.95** for **large constellation** or **very-high risk** space objects in **LEO**

Implementation of failure **prognostic methods** for anticipating possible failures and wear-out trends (e.g. health monitoring, return of experience, …)

Collection of in-flight data and lessons learnt during operations for **constellation** management

Monitoring of spacecraft parameters for critical functions/equipment related to disposal actions

Re-assessment of probability of successful disposal in case of mission extension, anomaly, failures in similar platforms, changes in radiation/space debris environment, and half-way in the mission

COLA & STM

Ability to be **unambiguously identified** by a space surveillance segment within **1 day after injection**

Support by space surveillance segment able to provide **daily updated ephemerides** and **on-demand screening**

Use (generation & processing) of orbital produces (ODM, CDM) according to **CCSDS formats**

Operational procedures for the generation and **distribution** of **ephemerides**

Recurrent manoeuvre capability in GEO, in LEO for high and very high-risk objects, and for constellations

Ability to **generate ephemerides** within 1 day after injection

Ability to **perform CAMs** within 2 days after injection

Ability to **plan** a **CAM** if alert received at least 12 hours before TCA

Acceptable collision probability threshold below **10^{-4}** per conjunction.
If a CAM is executed, the probability should be reduced of at least **two order of magnitude**

CAM: Collision Avoidance Manoeuvre | CDM: Conjunction Data Message | ODM: Orbit Data Message | TCA: Time of Close Approach

COLA & STM

Example

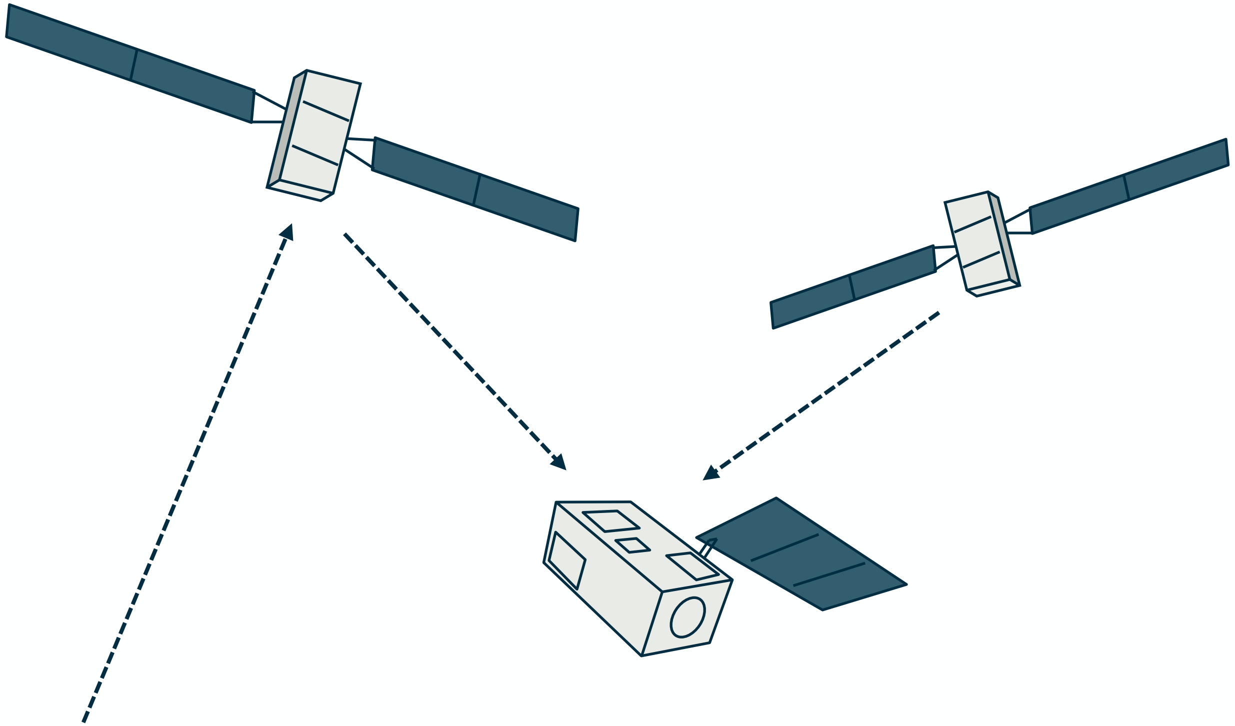
Development and test of late commanding paths and operations concepts

Trade-offs on split between

- on-ground and in-space processing
- Inter-Satellite Link and large ground station networks

Handling of platform constraints

Coordination mechanisms



CAM: Collision Avoidance Manoeuvre | CDM: Conjunction Data Message | ODM: Orbit Data Message | TCA: Time of Close Approach

Close proximity operations

Probability of **unintentional** contact < **1:10000**

Request for assessment of the probability of unintentional contact at **design** (e.g. considering failures and wear out/disturbances) and at **operations** level (including contingency and recovery procedures)

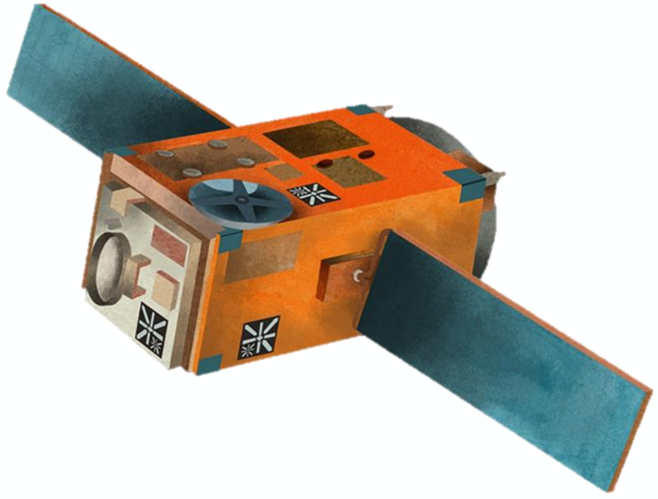
If during operations probability of unintentional contact > 1:10000, then **manoeuvre**

Compile (during design and operations) information for **relative navigation**

Design for removal

Applicable to GEO and LEO objects (unless re-entry casualty < 1:10000 AND low risk condition)

Spacecraft design & functions



- Passively ensure access to a **mechanical interface** compliant with capture, detumbling and removal mechanical loads
- Passively support the **relative navigation** of the space object performing the close proximity operations
- Passively enable **attitude reconstruction** on ground
- Limiting and damping the **spacecraft angular rates**
- System **modes** and operational procedures supporting the cooperative capture and removal

Assessment of the **long-term evolution** of the spacecraft **attitude** if in free drift

Next steps for SDM Regulations

Training

Development of training material on new ESA's process (internal)

Dissemination on expected verification/documentation of new requirements

Update

2024: Handbook for verification guidelines
2026: 2nd update of the SDM Standard
2030: 3rd update of the SDM Standard

Next steps for technical developments

Zero Debris implementation by 2030 relies on a roadmap of key technical developments:

Zero Debris compliant spacecraft platforms

- Interfaces for Removal,
- Demisable critical equipment,
- Improved Health Monitoring,
- Deorbit systems (e.g. 1U deorbit system for nanosats),
- Technologies to protect Dark and Quiet Skies.

Development & Demonstration of Removal Services

- Cameras, Robotics, Integrated capture payload bay
- Implement ADR & IOS missions like ClearSpace-1, SUNRISE, CAT-IOD, etc.
- Collect and share lessons learnt in standards and guidelines.

Technology improvement for SST and collision avoidance

- Small sized debris monitoring improvement,
- On-demand high accuracy measurements,
- Enhanced collision avoidance operations and coordination

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