DOCUMENT

# ESA Space Debris Mitigation Requirements


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| **Prepared by** | **ESA Space Debris Mitigation Working Group** |
| **Reference** | **ESSB-ST-U-007 Issue 1** |
| **Issue** | **1** |
| **Revision** | **0** |
| **Date of Issue** | **30/10/2023** |
| **Status** | **Approved** |
| **Document Type** | **STD** |
| **Distribution** | |

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| **Title** ESA Space Debris Mitigation Requirements | |
|---|---|
| **Issue** 1 | **Revision** 0 |
| **Author** ESA Space Debris Mitigation WG | **Date** 30/10/2023 |
| **Approved by ESB** | **Date 30 October 2023** |

# CHANGE LOG

| Reason for change | Ref/Issue | Revision | Date |
|---|---|---|---|
| First issue | ESSB-ST-U-007 Issue 1 | 0 | 30/10/2023 |

# CHANGE RECORD

| **Issue** 1 | **Revision** 0 | | |
|---|---|---|---|
| **Reason for change** | **Date** | **Pages** | **Paragraph(s)** |
| | | | |

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# Introduction

The present document is the ESA standard for Space Debris Mitigation requirements.

Space is a natural limited shared resource. The population of operational space objects and space debris is constantly growing and demands a proactive approach to control the associated hazards and tackle the trend of a deteriorating space environment especially around Earth. In the recent years there has been an unprecedent growth in the use of Earth orbits.

Compliance with Space Debris Mitigation (SDM) adopted so far in international and European standards, e.g. ISO and ECSS, national laws, and organisations is insufficient to prevent the future proliferation of space debris. Therefore, it has been identified the urgency for making a leap forward in the protection of the space environment around Earth by introducing specific requirements in the present standard. This urgency has been fully endorsed in the ESA's "Agenda 2025", where ESA set the ambitious target to invert Europe's contribution to space debris by 2030, tackling the issue of space debris directly by advancing the technology needed to maintain a clean space and implement a "Zero Debris" policy.

The ESA Space Debris Mitigation standard has been prepared by the ESA Space Debris Mitigation Working Group in line with the ESA "Zero Debris" policy.

# 1 Scope

The scope of this standard is to provide the Space Debris Mitigation requirements for ESA programmes and projects.

This standard defines the space debris mitigation requirements applicable to all elements of systems launched into, or passing through, Earth and Lunar space, including launch vehicle orbital stages, spacecraft and any part released.

This standard aims at meeting and exceeding the relevant international standards on space debris mitigation and space traffic coordination, in-line with state-of-the-art technology.

The ESA Space Debris Mitigation standard intends to improve the effectiveness of the removal in Earth and Lunar orbits of debris and their propagation, so that "zero debris" are left behind by space activities.

The ESA Space Debris Mitigation standard specifies design and operational measures through to the space object end of life to:

- Prevent space debris release and proliferation
- Control system break-up risk
- Control collision risk
- Control system failure risk
- Improve orbital clearance
- Assure safe re-entry
- Minimise impact on astronomy

# 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ESA Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. Parties to agreements based on this ESA Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

| | |
|---|---|
| ECSS-S-ST-00-01 | ECSS system – Glossary of terms |
| ESSB-ST-U-004 | ESA Re-entry Safety Requirements |
| ECSS-U-AS-10C Rev.2 | Space sustainability – Adoption Notice of ISO 24113: Space Systems – Space Debris Mitigation Requirements |
| ECSS-E-ST-10-04 | Space engineering – Space environment |
| ECSS-M-ST-10 | Space project management – Project planning and implementation |
| ECSS-E-ST-50-05 | Space engineering – Radio frequency and modulation |
| ISO 24113:2023 | Space systems — Space debris mitigation requirements |

# 3
# Terms and abbreviated terms

## 3.1 Terms defined in other documents

a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01, apply, and in particular for the following terms:

1. **risk**
2. **element**
3. **equipment**
4. **part**
5. **failure**
6. **launch vehicle**
7. **reliability**
8. **segment**
9. **space system**
10. **verification**

b. For the purpose of this Standard, the terms and definitions from ECSS-E-ST-10-04, apply, and in particular for the following terms:

1. **meteoroids**

c. For the purpose of this Standard, the terms and definitions from ESSB-ST-U-004, apply, and in particular for the following terms:

1. **casualty**
2. **casualty area**
3. **destructive re-entry**
4. **re-entry probability**

## 3.2 Terms specific to the present document

### 3.2.1 acceptable collision probability

collision probability threshold set by the approving agent per individual conjunction to determine the collision risk mitigation strategy

### 3.2.2 approving agent

entity from whom approval is sought for the implementation of space debris mitigation requirements with respect to the procurement of a spacecraft, or its launch, or its operations in outer space, or its safe re-entry, or a combination of those activities

[ISO 24113:2023]

### 3.2.3 break-up

event that completely or partially destroys an object and generates space debris

[ISO 24113:2023]

### 3.2.4 casualty risk

risk that a person is killed or seriously injured

NOTE The re-entry casualty risk is determined through the probability to cause death or serious injury, as specified in ESSB-ST-U-004.

### 3.2.5 close proximity operation

set of relative navigation-based manoeuvres performed by at least one out of two, or more space objects, to affect their relative separation and orientation during normal operations

NOTE During normal operations, close proximity operations can include intentional contact between two or more space objects involved. Unintentional contact is, instead, a collision.

### 3.2.6 collision avoidance

planning and execution of strategies to mitigate the risks associated with on-orbit conjunctions

### 3.2.7 conjunction

accidental close approach between a primary and a secondary space object that is predicted to occur because the secondary space object passes within a chosen geometric or statistical volume around the primary space object at a certain epoch

NOTE 1 Close proximity operations and formation flying are not considered conjunctions.

NOTE 2 Conjunctions with space objects can occur during operations of the space object.

### 3.2.8 constellation

group of space objects consisting of at least 10 spacecraft launched to form a system with the purpose of achieving mission objectives

NOTE The number of space objects of a constellation includes any spares and any planned enlargement of the number of spacecraft.

### 3.2.9 controlled re-entry

re-entry where the time of re-entry is sufficiently controlled so that the impact of any surviving debris on the surface of the Earth is confined to a designated area containing no more than the ground track of one revolution before the final return

NOTE The designated area is usually an uninhabited region such as an ocean.

### 3.2.10 cumulative collision probability

integrated probability of collision over time spent on orbit between two given epochs

NOTE Often the cumulative collision probability for a space object is computed from the release into Earth orbit or after the end of life until re-entry or a maximum upper bound.

### 3.2.11 demise

result of an ablation processes acting on elements, equipment, parts or components of a space object during an atmospheric re-entry event to the extent that the resulting fragments no longer pose a casualty risk

NOTE Common equipment of a space object that can cause a casualty risk include tanks, reaction wheels, magnetorquers.

### 3.2.12 design for demise

intentionally altering the design of a space object in such a way that it can improve the demise of its elements, equipment, parts or components

### 3.2.13 disposal

actions performed by a spacecraft or launch vehicle orbital stage to permanently reduce its chance of accidental break-up and to achieve its needed long-term clearance of the protected regions

NOTE Actions can include removing stored energy and performing post-mission orbital manoeuvres.

[ISO 24113:2023]

### 3.2.14 disposal phase

interval between the end of mission of a spacecraft or launch vehicle orbital stage and its end of life

[ISO 24113:2023]

### 3.2.15 Earth orbit

bound or unbound Keplerian orbit with Earth at a focal point, or Lagrange point orbit which includes Earth as one of the two main bodies

[ISO 24113:2023]

### 3.2.16 end of life

instant when a spacecraft or launch vehicle orbital stage is permanently turned off, nominally as it completes its disposal phase, completes its manoeuvres to perform a controlled re-entry, or can no longer be controlled by the operator

NOTE Adapted from ISO 24113:2023.

### 3.2.17 end of mission

instant when a spacecraft or launch vehicle orbital stage completes the tasks or functions for which it has been designed, other than its disposal, becomes incapable of accomplishing its mission, or has its mission permanently halted through a voluntary decision

NOTE Adapted from ISO 24113:2023.

### 3.2.18 ephemeris

set of trajectory parameters of a space object as function of epoch, including at least its position and velocity and the associated quantified uncertainties

NOTE Ephemerides can be generated for free drift and manoeuvre scenarios.

### 3.2.19 external removal service

service or vehicle, which is in charge of the removal or repositioning of a space object

### 3.2.20 formation flying

coordination of multiple space objects maintaining a desired relative separation and orientation during normal operations

NOTE The measurement of the inter-object distance is used to warrant the performance and the safety of the mission space segment elements.

### 3.2.21 free drift

evolution of an orbit of a space object solely subject to natural perturbations

NOTE The natural perturbations to model are given in ECSS-E-ST-10-04 and ESSB-HB-U-002-Issue 2.

### 3.2.22 geostationary Earth orbit

Earth orbit having zero inclination, zero eccentricity, and an orbital period equal to the Earth's sidereal rotation period

[ISO 24113:2023]

### 3.2.23 graveyard orbit

disposal orbit where the orbital parameters have a contained long-term variation not to interfere with populated orbital regions

NOTE A graveyard orbit is also known as a storage orbit.

### 3.2.24 inhabitable

space object suitable to sustain human life

NOTE It does not imply the presence of humans.

### 3.2.25 large constellation

group of space objects consisting of at least 100 spacecraft launched to form a system with the purpose of achieving mission objectives

NOTE 1 The number of space objects of a large constellation includes any spares and any planned enlargement of the number of space objects.

NOTE 2 A large constellation is a constellation.

### 3.2.26 launch vehicle orbital stage

complete element of a launch vehicle that is designed to deliver a defined thrust during a dedicated phase of the launch vehicle's operation and achieve orbit

NOTE Non-propulsive elements of a launch vehicle, such as jettisonable tanks, multiple payload structures or dispensers, are considered to be part of a launch vehicle orbital stage while they are attached.

[ISO 24113:2023]

### 3.2.27 lunar orbit

bounded or unbounded orbit with the Moon at a focal point, or orbits around the Earth-Moon Lagrange points

NOTE 1 A mission can be composed by Earth orbit phases, Lunar orbit phases, or other orbital regime phases, where the requirements applicability can be different.

NOTE 2 The Earth Moon Lagrange point (EML) orbits are defined both as Earth and Lunar orbits, therefore, both requirement sets for Earth orbit and Lunar orbit apply.

### 3.2.28 natural orbital decay

free drift ultimately leading to Earth atmospheric re-entry

### 3.2.29 near Earth orbit

Earth orbit with a perigee altitude below 100000 km

### 3.2.30 normal operations

execution of the planned tasks or functions for which a spacecraft or launch vehicle orbital stage was designed

NOTE Normal operations include the disposal phase.

[ISO 24113:2023]

### 3.2.31 orbit lifetime

elapsed time between an orbiting space object's initial or reference position and its re-entry

NOTE Examples of initial position are the injection into orbit of a spacecraft or launch vehicle orbital stage, or the instant when space debris is generated. An example of a reference position is the orbit of a spacecraft or launch vehicle orbital stage at the end of mission.

[ISO 24113:2023]

### 3.2.32 passivate

act of permanently depleting, irreversibly deactivating, or making safe all on-board sources of stored energy capable of causing an accidental break-up

[ISO 24113:2023]

### 3.2.33 probability of successful disposal

probability that a space object is able to complete all of the actions associated with its disposal

### 3.2.34 probability of successful passivation

probability that a space object is able to complete all of the actions associated with its passivation

NOTE The assessment of this probability can include consideration of the inherent reliabilities of subsystems that are necessary to conduct the passivation, monitoring of those subsystems, and operational remediation of any observed subsystem degradation or failure of the equipment.

### 3.2.35 prognostics

predictive approach to estimate the future performance of a component by assessing through various ways the extent of deviation or degradation of a system from its expected nominal operation

### 3.2.36 protected region

region in outer space that is protected with regard to the generation of space debris to ensure its safe and sustainable use in the future

[ISO 24113:2023]

### 3.2.37 re-entry

permanent return of a space object into the Earth's atmosphere

NOTE Several alternative definitions are available for the delineation of a boundary between the Earth's atmosphere and outer space.

[ISO 24113:2023]

### 3.2.38 recurrent manoeuvre capability

capability of a spacecraft to perform repeatable manoeuvres on-orbit that can cause a change to the orbit over a limited amount of time

NOTE The repeatability of the manoeuvres implies that multiple manoeuvres of a targeted accuracy can be implemented by a spacecraft.

### 3.2.39 space object

object of human origin which has reached outer space

[ISO 24113:2023]

### 3.2.40 space surveillance segment

segment responsible for the detection, tracking, monitoring, cataloguing and prediction of the motion of space objects, and the identification, and alerting of derived risks

### 3.2.41 space traffic coordination

cooperative planning, coordination, data and information sharing, and on-orbit synchronization of space activities

NOTE Space traffic coordination contributes to mitigate collision risks among active operators.

### 3.2.42 spacecraft

system designed to perform a set of tasks or functions in outer space, excluding launch vehicle

[ISO 24113:2023]

NOTE The addition of an instrument to the launch vehicle orbital stage that remains operational after the normal operations of the launch vehicle orbital stage implies this launch vehicle orbital stage is a spacecraft.

### 3.2.43 uncontrolled re-entry

type of re-entry that is not a controlled re-entry

## 3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

| Abbreviation | Meaning |
|---|---|
| **AOCS** | attitude and orbit control system |
| **CCSDS** | consultive committee for space data systems |
| **CDF** | concurrent design facility |
| **CDM** | conjunction data message |
| **DRD** | document requirements description |
| **ECSS** | European cooperation for space standardization |
| **FDIR** | failure detection isolation and recovery |
| **FIT** | failure in time |
| **GEO** | geostationary Earth orbit |
| **GNSS** | global navigation satellite system |
| **IADC** | Inter-agency space debris coordination committee |
| **LEO** | low Earth orbit |
| **MEO** | medium Earth orbit |

| Abbreviation | Meaning |
|---|---|
| **MEOR** | mission extension operations review |
| **ODM** | orbit data messages |
| **RDM** | re-entry data message |
| **RUL** | remaining useful lifetime |
| **SDMP** | space debris mitigation plan |
| **SDMR** | space debris mitigation report |

## 3.4 Conventions

### 3.4.1 Launch vehicle orbital element

The term launch vehicle orbital element refers to a launch vehicle orbital stage, or detachable space debris thereof, other than space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation.

### 3.4.2 GEO protected region

The GEO protected region is a segment of a spherical shell with the following characteristics:

a. lower altitude: geostationary altitude minus 200 km

b. upper altitude: geostationary altitude plus 200 km

c. latitude sector: 15° south ≤ latitude ≤ 15° north

where the geostationary altitude is 35786 km.

### 3.4.3 LEO protected region

The LEO protected region is a complete spherical shell extending from the surface of a spherical Earth with an equatorial radius of 6378 km up to an altitude of 2000 km.

### 3.4.4 Orbital regimes

Depending on the orbital regime a space object is in, different requirements can apply. The following cases are used in this standard:

- The wording "operating in" applies to spacecraft or launch vehicle orbital stage operating continuously or periodically within a certain orbital region before end of mission.
- The wording "crossing" applies to any space object crossing a certain orbital region at any point during the orbital lifetime.
- The wording "injected into" applies to any space object when launched or released in a certain orbital region.

### 3.4.5 Nomenclature

The following nomenclature applies throughout this document:

a. The word "shall" is used in this Standard to express requirements. All the requirements are expressed with the word "shall".

b. The word "should" is used in this Standard to express recommendations. All the recommendations are expressed with the word "should".

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

c. The words "may" and "need not" are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word "may". All the negative permissions are expressed with the words "need not".

d. The word "can" is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS "may" and "can" have completely different meanings: "may" is normative (permission), and "can" is descriptive.

e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

# 4 Principles

## 4.1 Overview

### 4.1.1 ESA Agenda 2025

The standard ESSB-ST-U-007 has been prepared in the frame of the implementation of the ESA's "Agenda 2025", where ESA set the ambitious target to invert Europe's contribution to space debris by 2030 with "Zero Debris", tackling the issue of space debris directly by advancing the technology needed to maintain a clean space and implement a "Zero Debris" policy.

### 4.1.2 Space debris mitigation background

The space debris population is continuously growing. Space debris data is periodically monitored and published by ESA (GEN-DB-LOG-00288-OPS-SD), e.g. including yearly evolution of the space object amount by object type (Figure 4-1) and by orbit type (Figure 4-2).

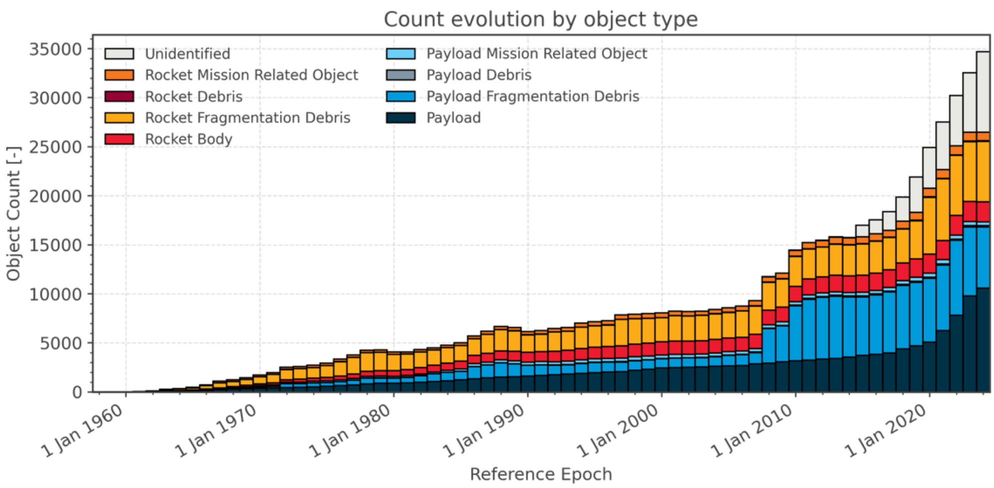


**Figure 4-1: Objects in orbit by type: rocket (launch vehicle), payload (spacecraft), and generated debris (GEN-DB-LOG-00288-OPS-SD, 12/09/2023)**

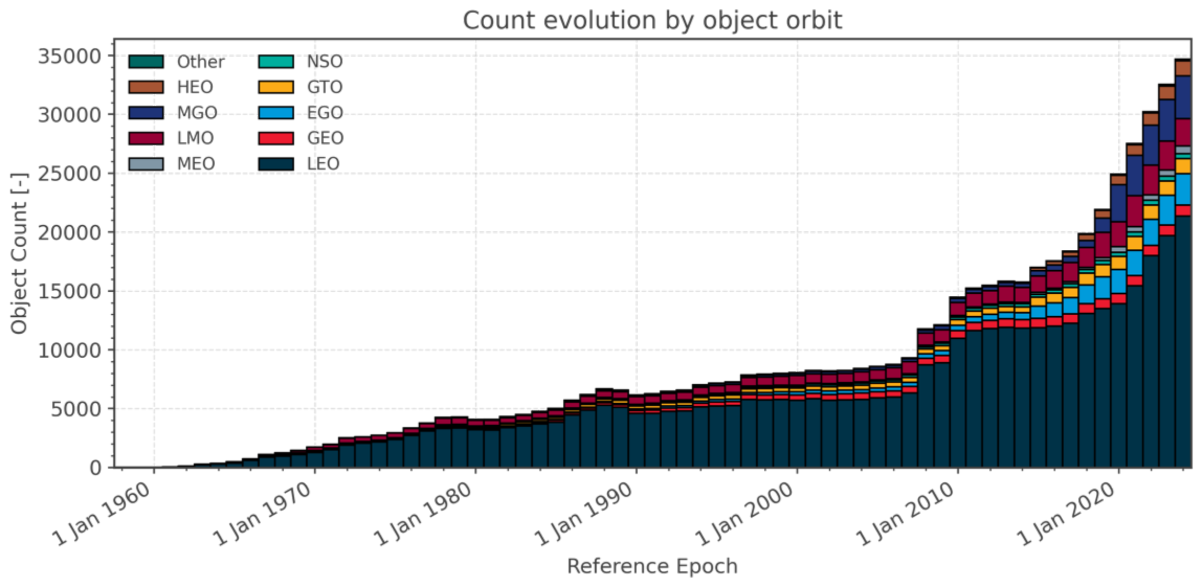


**Figure 4-2: Objects in orbit by region (GEN-DB-LOG-00288-OPS-SD, 12/09/2023)**

The current trends in the launch traffic and use of orbits, combined with spacecraft and launch vehicle orbital stages break-up events, limited post-mission disposal (PMD) success rate, and long time for orbital clearance, can lead to a cascade of collision events over the next centuries. It has been estimated that even in a case of no further launches into orbit, collisions among the existing space objects can lead to a further growth in space debris population (GEN-DB-LOG-00288-OPS-SD).

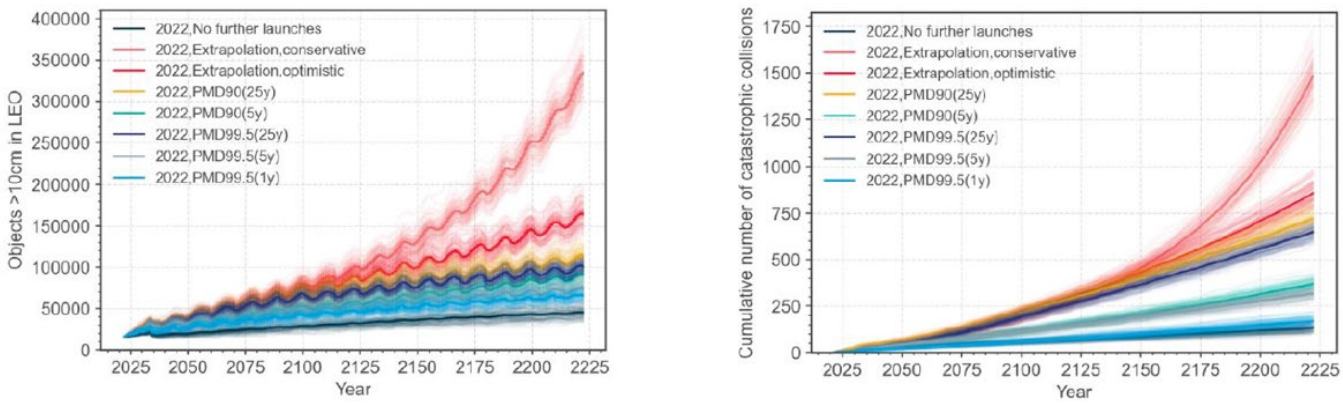


**Figure 4-3: Trends predicted in LEO for the space object amount and cumulative number of catastrophic collisions based on different possible scenarios (ESA "Zero Debris" CDF study, 2022).**

In the frame of the ESA Concurrent Design Facility (CDF) the study "Zero Debris" (2022) was performed. The trends for the space object amount and cumulative number of catastrophic collisions (involving complete destruction of an object), under different PMD and orbital clearance assumptions (Figure 4-3) were predicted over 200 years. The extrapolations were based on:

- On-orbit fragmentation rate noted in the period 2012-2022.
- Launch rate noted in the period 2017-2022, including constellations activity
- Average collision avoidance capability

### 4.1.3 Approach of the standard

The standard ESSB-ST-U-007 exceeds the standard ECSS-U-AS-10C Rev.2.
Specifically, the standard ESSB-ST-U-007:

- covers the requirements in ECSS-U-AS-10C Rev.2,
- has more stringent or additional requirements to ECSS-U-AS-10C Rev.2.

The standard ESSB-ST-U-007 provides design and operational requirements to limit the proliferation of space debris in Earth and Lunar orbit, protect the Earth population in case of re-entry, and limit the impact on astronomy.

In term of risk, the threats of space debris concern:

- Risks associated with increasing number of objects potentially involved in space debris generating events
- Risks associated with increasing number of collision avoidance operations that active operators have to cope with.

The standard ESSB-ST-U-007 defines the space debris mitigation requirements adapted to identified space environmental risk scenarios, which are based on cumulative collision probability and LEO clearance. This approach aims to effectively mitigate the current risks of specific orbital regions and prevents the future risk increase. Specifically, the following orbital regions are addressed by the standard:

- Protected regions, i.e. Low Earth Orbits (LEO) and Geostationary Orbit (GEO)
- Near Earth orbits, i.e. the protected regions, and any other Earth orbit with a perigee up to 100000 km
- Earth orbits, i.e. near-Earth orbits, as well as orbits around Lagrange points
- Lunar orbits

The risk scenarios defined in this standard are related with the impact that a space object can have on the space environment and consequently on other space objects.

The two elements to assess and mitigate the risks are the following:

**a. Cumulative collision probability threshold**

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.

The following points provide a rationale for the definition of this threshold:

- Environmentally driven criteria to foster long-term sustainability of the use of Earth orbits and prevent accumulation of disposed space objects in specific orbits.
- Environmentally driven criteria to foster Space objects with higher risk of break-up in orbit to implement more effective mitigation measures.
- At high orbital velocities, e.g. as common in LEO, the kinetic energy involved in a collision between two objects can result in the creation of a significant amount of space debris propagating into further collisions. 1 cm is commonly used as an approximation for the size above which space debris and meteoroids that can cause damage when impacting a space object (IADC-04-03). The kinetic energy of particles of these sizes is sufficient to penetrate structures and damage internal components preventing the disposal, even for collisions with impact velocity below 1 km/s, e.g. as possible in GEO.
- An IADC assessment (IADC-04-06) for LEO recommends that, with the current orbital traffic, in order to reach a sustainable space environment each object should guarantee a collision probability lower than "1 in 10000" per year, and lower than "1 in 1000" when extrapolated to a typical space mission orbital lifetime. Hence, this standard adopts the "1 in 1000" cumulative collision probability threshold to define sustainable disposal strategies for long-term sustainability in near Earth orbits.
- The cumulative collision probability calculation aims at preventing the generation of space debris and takes into account the operational configuration and design of the space objects, e.g. to assess the resilience to damages of different elements such as appendages.

**b. LEO clearance**

A space object in free drift in LEO represents an environmental risk depending on the time of its atmospheric re-entry. Three different risk scenarios are identified for LEO clearance:

- Very high-risk scenario, if the space object operates in an orbit with a natural orbital decay duration longer than 25 years.
- High risk scenario, if the space object operates in an orbit with a natural orbital decay duration between 5 and 25 years.

- o Medium risk scenario, if the space object operates in an orbit with a natural orbital decay duration of up to 5 years, while still crossing altitudes above 375 km

The following points provide a rationale for the definition of the LEO clearance risk scenarios:

- o Stricter Space Debris Mitigation requirements under higher risk scenario prevent the long-term degradation of the space environment more efficiently.
- o Debris generated by break-ups in higher risk scenario are on-orbit for longer time and cross highly populated orbits during their natural orbital decay, therefore, represent a higher risk for operational missions.
- o Different LEO clearance risk scenarios allow the definition of adapted disposal strategies for different missions (e.g. spacecraft constellations).
- o The long-term environmental evolution is unpredictable and longer timescales leads to a larger uncertainty of the risk that a given space object represents for the space environment.

In recognition of the fast-changing scenarios in space utilisation and evolving practices in space debris mitigation, this standard contains a set of requirements requesting specific analyses, but that do not set a numerical value to comply to. Specifically, the aim of the present standard is to:

- Implement lessons learned from past and current missions,
- Quantify, assess and document known risks,
- Develop methodologies such that these requirements can adopt a numerical threshold in future versions of the standard.

The requirements of clause 5 "Space Debris Mitigation Requirements" are organised in the following sub-clauses:

- 5.2 "Space debris release restriction"
- 5.3 "Avoiding break-up in Earth orbit"
- 5.4 "Disposal"
- 5.5 "Re-entry"
- 5.6 "Dark and quiet skies"
- 5.7 "Lunar orbits"

The clauses from 4.2 to 4.7 below provides the specific rationales of the requirements in the clauses from 5.2 to 5.7.

## 4.2 Space debris release restriction

### 4.2.1 General

Any debris left on orbit is a hazard in view of the relative velocity with other space object in case of collision. Therefore, restrictions in the possible release of debris in terms of number, size, source, and risk compatibly to the state-of-the-art technology are necessary.

The rationale for the requirements defined in ESSB-ST-U-007 includes:

- Limiting the generation of debris from space missions, i.e. mission-related objects, including, but not limited to: nozzle closures, lens caps, cooler covers, tethers, dummy masses, yo-yo weights and lines, and burst disks.
- Limiting the number of objects left in orbit from launch vehicles, i.e. launch mission-related objects, including, but not limited to: upper stages, kick-motor stages, dual launch structures, dummy masses, adapters, fairings, connectors, fasteners, separation bolts, clamp bands, and burst disks.

### 4.2.2 Space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation

The rationale for the requirements includes:

- Preventing the release of small particles (> 1 mm) in Earth orbit from pyrotechnics (e.g. cable cutters for solar array deployment, pyrovalves), which, although small, can damage other space objects.
- Preventing the release of small particles (> 1 mm) in Earth orbit from solid or hybrid propellant rocket motors, which, although small, can damage other space objects.
- Limiting the release of particles larger than 1 mm from degradation processes caused by the prolonged exposure to the space environment. In particular, multi-layer insulation is a known contributor to the space debris population in the GEO protected region.

## 4.3 Avoiding break-ups in Earth orbit

### 4.3.1 Intentional break-up

The rationale for the requirements includes:

- Preventing any deliberate generation of space debris in Earth orbit caused by destruction of a space object.

### 4.3.2 Accidental break-up caused by an on-board source of energy

#### 4.3.2.1 General

The rationale for the requirements includes:

- Reducing the risk of accidental break-up and consequent generation of space debris, caused by on-board sources of energy or failure of mechanical parts.

#### 4.3.2.2 Passivation

The rationale for the requirements includes:

- Depleting stored energy to prevent in-orbit break-ups caused by space objects that have completed their mission.
- Including passivation capabilities regardless of the de-orbiting strategy, possibly allowing to passivate and mitigate risk of internal break-up of the space object in case a failure prevents the successful de-orbit.
- Assessing risk associated to the design implementation and setting target for the probability of successful passivation.

### 4.3.3 Accidental break-up caused by a collision

#### 4.3.3.1 Collision risk assessment during design

The rationale for the requirements includes:

- Assessing accurately the collision risk of the spacecraft or launch vehicle orbital elements with debris and meteoroids, which can cause a break-up.
- Informing and improving the mission design against break-ups caused by:
  - Impact with space debris or meteoroids, typically smaller than 1 cm, on equipment storing energy, such as a pressurized vessel.
  - Impact with space debris or meteoroids with sufficient energy to damage or destroy the space object (i.e. using the 1 cm size approximation).

#### 4.3.3.2 Collision avoidance implementation

The rationale for the requirements includes:

- Defining criteria for collision avoidance capability, including recurrent manoeuvre capabilities and reaction thresholds.
- Defining collision probability thresholds to protecting inhabitable space objects, which could be in the vicinity of a space object releasing other space objects (e.g. a launch vehicle, or a space tug).
- Assessing and informing design of the impact of collision avoidance measures on other operations (e.g. in terms of resources and payload availability).

#### 4.3.3.3 Collision risk management during operation

The rationale for the requirements includes:

- Setting criteria for planning and executing collision avoidance manoeuvres.
- Setting criteria for space traffic coordination.
- Stating the fundaments for any operator of a spacecraft constellation to know exactly the location of their spacecraft with higher level of accuracy.

#### 4.3.3.4 Space surveillance and tracking

The rationale for the requirements includes:

- Providing design and operational measures perform collision avoidance manoeuvres timely and efficiently, including trackability of the space object from space surveillance segments.

## 4.4 Disposal

### 4.4.1 Successful disposal

#### 4.4.1.1 General

Active or passive disposal is planned and performed to mitigate the in-orbit collision risk associated with any space object left uncontrolled in orbit. The rate of successful space objects disposal (de-orbiting and passivation) at their end of mission has an important impact on evolution of the number of space debris in Earth orbits.

The rationale for the requirements provided in this clause includes:

- Ensuring a high rate of successful disposal, considering all contributors to potentially failing to dispose, including in-orbit collisions.
- Continuously monitoring the health throughout the operational lifetime to detect any early signs of failure or condition threatening the successful disposal.
- Preparing the space object for safe removal in case it fails to dispose while operating in high-risk scenarios.

#### 4.4.1.2 Probability of successful disposal

The rationale for the requirements includes:

- Ensuring through probability assessment that the highest possible number of space objects are successfully disposed (de-orbited and passivated) at their end of mission.
- Improving the disposal success rate by considering units for the critical functions that have predictable reliable behaviour along the whole mission duration.
- Including in the assessment all the events, which can affect the successful disposal (manoeuvre failures, impact with space debris and meteoroids, passivation failure, break-ups).
- Ensuring that the spacecraft and launch vehicle orbital stages' operations are conducted with limited risk of damages from impacts with space debris and meteoroids that can prevent the successful disposal.
- In view of the number of recurrent spacecraft and launch vehicle orbital elements, which can be part of the deployment of a constellation of spacecraft:
  - Mitigating the risk of creating space debris from recurrent spacecraft designs launched in large numbers (e.g. constellations of spacecraft).
  - Limit the severity of worst-case effects from a failure.

#### 4.4.1.3 Health monitoring

The rationale for the requirements includes:

- Anticipating the identification of possible failures during the operation in order not to compromise the capability for successful disposal at end of mission.
- Facilitating the planning and execution of safe life extension in compliance with the Space Debris Mitigation needs.
- Implementing continuous improvement to minimise occurrence of possible failures.
- Ensuring the disposal capability at any time.
- Implementing lessons learnt from similar space objects operating on orbit.
- Fostering communication between the relevant parties (i.e. developer and operator of the spacecraft) to enhance health monitoring operations.
- Fostering responsive reactions to any event that can prevent the successful disposal, e.g. critical equipment failure, loss of redundancies, system anomalies, major events in the space environment, etc.

#### 4.4.1.4 Preparation for removal

The rationale for the requirements includes:

- De-risking the possibility of the removal of space objects in high-risk scenario by an external servicer, in case it is unable to perform its own disposal directly.
- Defining a minimum set of design implementations that can allow the safe clearance of the space object by an authorized and reliable servicer space object.
- Mitigating the risk of accidental events leading to the generation of space debris during the execution of removal operations.

### 4.4.2 Earth orbit clearance

#### 4.4.2.1 General Earth orbit clearance

The rationale for the requirements includes:

- Defining disposal strategies for spacecraft and launch vehicle orbital elements operating continuously or periodically in any Earth orbit, mitigating risk of interference with other space objects and of space debris generation events.

#### 4.4.2.2 GEO protected region clearance

The rationale for the requirements includes:

- Introducing additional requirements for the disposal of space objects operating continuously or periodically in the GEO protected regions to reduce the number of possible collision events in a highly valuable and populated orbital region.

#### 4.4.2.3 LEO protected region clearance

The rationale for the requirements includes:

- Reducing the number of possible collision events by minimising the on-orbit presence of space objects after their operation time in the LEO protected region.
- Reducing the interference with the LEO protected region for missions operating outside of it, but crossing it after the end of life, for example under the effect of long-term perturbation forces.
- Avoiding the periodic crossing of operational orbits of other missions and inhabitable vehicles by the spacecraft of a large constellation after their disposal.

#### 4.4.2.4 Initial orbit insertion

The rationale for the requirements includes:

- Controlling the risk associated with possible infant mortality of spacecraft of a large constellation by testing their operational capability in lower risk scenario and defining orbit insertion criteria easing the disposal.

## 4.5 Re-entry

The rationale for the requirements includes:

- Defining criteria for safe planning and execution of the space object re-entry.
- Complementing the requirements in ESSB-ST-U-004 by specifying the methodology to deal with uncertainties in the verification process.
- Mitigating the constellation aggregate re-entry casualty risk in view of expected large number of re-entry events, especially from large LEO constellations.

## 4.6 Dark and quiet skies

The rationale for requirements includes:

- Limiting the optical and radio frequency interference of the space objects with ground and LEO astronomy.
- Informing the mission design of the brightness and promoting mitigation actions, in particular for large constellations.
- Enabling the protection of radio astronomy observations and radio quiet zones.

## 4.7 Lunar orbits

The rationale for the requirements includes:

- Defining actions and assessments for operation around the Moon, given the current and future progressive exploitation of Lunar orbits and considering the dynamics of the Moon's orbital environment.

# 5 Space debris mitigation requirements

## 5.1 Overview

The compliance with the standard ESSB-ST-U-007 ensures compliance also with the standard ECSS-U-AS-10C Rev.2. In case of difference, ESSB-ST-U-007 takes precedence over ECSS-U-AS-10C Rev.2.

## 5.2 Space debris release restriction

### 5.2.1 General

a. The spacecraft shall be designed not to release space debris into Earth orbit during normal operations, other than space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation.

b. The total number of space objects left in Earth orbit by a launch vehicle during normal operations, other than space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation, shall be limited to one for the launch of a single spacecraft and two for the launch of multiple spacecraft.

NOTE For single spacecraft launch, the total number of space objects left in Earth orbit by a launch vehicle during normal operations is the launch vehicle orbital stage. For multiple spacecraft launch, the total number of space objects left in Earth orbit by a launch vehicle during normal operations are the launch vehicle orbital stage and a detachable element, e.g. an adapter.

### 5.2.2 Space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation

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

b. Solid or hybrid propellant rocket motors shall be designed and operated not to release space debris larger than 1 mm in their largest dimension into Earth orbit.

NOTE The main aim of this requirement is to limit the generation of slag debris ejected into Earth orbit during the final phase of combustion.

c. A spacecraft or launch vehicle orbital element operating in the GEO protected region with a continuous or periodic presence shall be designed not to release space debris larger than 1 mm in their largest dimension resulting from the environment-induced degradation of adhesives and hook and loop fasteners for an orbit lifetime of 50 years including normal operations and after the disposal.

NOTE Environment-induced degradation mechanisms are based on electromagnetic radiation and the energetic particle environment, excluding impacting space debris and meteoroids. The objective is to minimise debris from multi-layer insulation, which is a known space debris source.

## 5.3 Avoiding break-ups in Earth orbit

### 5.3.1 Intentional break-up

a. In Earth orbit, intentional break-up of a spacecraft or launch vehicle orbital element shall not be performed.

NOTE Design for demise measures leading to a fragmentation during atmospheric re-entry are not considered intentional break-ups, provided it is demonstrated that they result in a reduced re-entry casualty risk, and they do not generate additional on-orbit collision risk.

## 5.3.2 Accidental break-up caused by an on-board source of energy

### 5.3.2.1 Preventing break-ups during normal operations

a. For accidental break-up during normal operations requirements 7.2.2.1, 7.2.2.2, 7.2.2.3 and 7.2.2.4 from ECSS-U-AS-10C Rev.2 shall be applied.

### 5.3.2.2 Passivation

a. A spacecraft or launch vehicle orbital stage operating in Earth orbit shall include passivation capabilities.

b. A spacecraft or launch vehicle orbital stage operating in Earth orbit shall be passivated before the end of life unless a successful controlled re-entry is performed.

c. 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

NOTE The probability of successful passivation takes into account all functions and units needed to passivate in a controlled and safe manner all the on-board sources of stored energy capable of causing an accidental break-up.

d. The passivation shall be executed by one of the following means, in order of preference:

1) Permanently and irreversibly deplete and prevent future loading

2) Demonstrate that a safe level is reached

NOTE 1 Guidelines for risk assessment are listed in Annex F of ESSB-HB-U-002-Issue2.

NOTE 2 Techniques for propulsion system passivation that do not induce torques to the spacecraft are preferable.

## 5.3.3 Accidental break-up caused by a collision

### 5.3.3.1 Collision risk assessment during design

a. The developer of a spacecraft or launch vehicle orbital element operating in Earth orbit shall quantify the probability that space debris or meteoroid impact causes the spacecraft or launch vehicle orbital element to break-up, including:

1) Impacts with space debris and meteoroids larger than 1 mm and smaller than 1 cm

2) Impacts with space debris and meteoroids larger than 1 cm

3) A free drift trajectory after orbit injection, end of mission, and disposal, and during normal operations, until re-entry or up to 100 years

NOTE 1 Mitigation options include the application of shielding, selection of optimised operation and disposal orbits, and collision avoidance manoeuvres.

NOTE 2 The assessment can be done statistically, as explained in ESSB-HB-U-002, with available space debris and meteoroid models described in ECSS-E-ST-10-04.

### 5.3.3.2 Collision avoidance implementation

a. The cumulative collision probability between a spacecraft or launch vehicle orbital stage intentionally releasing other spacecraft or elements in Earth orbit, and the released spacecraft or elements shall be below $10^{-6}$ for each possible conjunction, based on an assessment including:

1) Dispersion of the trajectories, including free drift and those associated with normal operations, of all space objects involved in the release event

2) 3-day time period coverage after on-orbit release

NOTE 1 It is considered that 3 days after on-orbit release, a spacecraft can take over possible collision avoidance manoeuvres.

NOTE 2 All possible conjunctions are derived from the combination of all pairs of released spacecraft or elements among each other as well as the spacecraft or launch vehicle orbital stage that released them.

b. The cumulative collision probability between a launch vehicle orbital stage in Earth orbit and each inhabitable space object shall be below $10^{-6}$, based on an assessment, including:

1) Dispersion of the trajectories, including free drift and those associated with normal operations, of all space objects involved in the release event

2) 3-day time period coverage after launch

NOTE This practice is also known as launch collision avoidance.

c. A spacecraft operating in near Earth orbit shall have a recurrent manoeuvre capability if it satisfies at least one of the following conditions:

1) It is operating in the GEO protected region
2) It is injected into an orbit crossing the LEO protected region with a natural orbit decay duration longer than 5 years
3) Its cumulative collision probability with space objects larger than 1 cm is above $10^{-3}$ through to its end of life
4) It is part of a constellation
5) It is performing close proximity operations, or formation flying

NOTE 1 In the context of close proximity operations, a serviced space object can be without manoeuvring capabilities.

NOTE 2 A method for verification of this requirement is presented in clause 6.

d. 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.

NOTE 1 Operational impact includes resources allocation for manoeuvres, planning and execution time for performing manoeuvres, payload outages to prioritize manoeuvres.

NOTE 2 Data input requirements are available in clause 6.

e. The developer of a spacecraft or launch vehicle orbital element injected into near Earth orbit shall quantify, during normal operations and after end of life until re-entry or up to 100 years:

1) The expected number of conjunctions at $10^{-4}$ and $10^{-6}$ collision probability threshold, and
2) The estimated number of collision avoidance manoeuvres triggered thereby on other spacecraft

NOTE 1 A methodology can be found in ESSB-HB-U-002-Issue 2.

NOTE 2 Data input requirements are available in clause 6.

NOTE 3 The assessment can support the identification of systematic conjunctions with space objects and constellations due to the nature of the operational orbit and hence identify risk reduction based on orbit optimisation or operational procedure among affected operators.

NOTE 4 It is good practice to separate the collision probability and resulting manoeuvres with respect to an inhabitable space object from other space objects when reporting.

NOTE 5 The assessment is informative. $10^{-4}$ and $10^{-6}$ are not collision avoidance manoeuvre thresholds for the spacecraft.

f. The assessment to quantify the expected number of conjunctions for spacecraft part of a constellation operating in near Earth orbit shall include the aggregated probability and resulting estimated manoeuvres at constellation level.

#### 5.3.3.3 Collision risk management during operations

a. During normal operations of a spacecraft in near-Earth orbit with a recurrent manoeuvre capability, the acceptable collision probability threshold shall be below $10^{-4}$ per conjunction.

NOTE The $10^{-4}$ collision probability threshold is considered absolute upper bound, and in practice lower threshold is often adopted to further reduce the collision probability, e.g. in the GEO protected region in combination with station keeping manoeuvres.

b. During the normal operations of a spacecraft in the LEO protected region with a recurrent manoeuvre capability, on an orbit with an average density of space debris larger than 1 cm above $10^{-7}$ km$^{-3}$, the acceptable collision probability threshold shall be the lower of the following values:

1) $10^{-4}$, and

2) The collision probability value such to reduce the annual collision probability by at least 90% with respect to not performing collision avoidance manoeuvres

NOTE 1 The $10^{-4}$ collision probability threshold is considered absolute upper bound, and in practice lower threshold is often adopted to further reduce the collision probability.

NOTE 2 The 0,90 relative risk reduction by adopting a given threshold accounts for the facts that not all space debris can be reliably tracked, and hence avoidable, and there are positional uncertainties associated with small space debris that can make avoidance manoeuvres unfeasible. A methodology is described in MIT-COL-MAN-00279-OPS-SD:2020 based on space surveillance segments performance as of 2023.

c. During normal operations, the cumulative collision probability of each spacecraft of a constellation in near Earth orbit with all other spacecraft of the constellation shall be below $10^{-4}$.

NOTE The cumulative collision probability considers probabilistically that any spacecraft of the constellation can fail during their normal operations and hence being not manoeuvrable.

d. The operator of a spacecraft operating in near Earth orbit with a recurrent manoeuvre capability shall perform the assessment of:

1) The resources allocation for the acceptable collision probability for individual conjunctions and its impact on the mission design

2) The response timeliness of the ground, space, and space surveillance segments to conjunction information

3) The accuracy and quality of the available data from a space surveillance segment

4) The combination of system failure probabilities that can lead to not being able to perform a collision avoidance manoeuvre

NOTE 1 Delta-v is the example of resource allocation.

NOTE 2 Collision probability thresholds can be applied to any type of mission and are dependent on the performance of associated attitude and orbit control systems, such as propellent availability and other system budgets, as well as the performance of the selected space surveillance segment.

e. The method used to evaluate the collision probability for each conjunction shall be probabilistic and model the uncertainties in the position and velocity of the involved space objects, the relative distance between the trajectories during the conjunction, the dimensions of the space objects when known, and space weather forecasts.

f. For a spacecraft operating in near Earth orbit planning a collision avoidance manoeuvre, the collision probability with space objects shall not exceed $10^{-4}$ for 4 days after the planned avoidance manoeuvre.

g. The space and ground segments associated with spacecraft operating in near Earth orbits shall be designed to have ephemerides available for collision avoidance purposes in less than 1 day after orbital injection.

NOTE 1 The ephemerides can be determined either by the operator's own means or by a space surveillance segment.

NOTE 2 The availability of the ephemerides can aid the unique identification of the space segment by a space surveillance segment.

NOTE 3 The requirement specifies the capability of the space and ground segments. During operations certain limitations, such as launch injection or support from a space surveillance segment, can result in not meeting the requested timeline.

h. A spacecraft with a recurring manoeuvre capability shall be able to implement a collision avoidance manoeuvre within 2 days when injected into a near Earth orbit with a natural orbital decay duration longer than 5 years.

NOTE A method for verification of this requirement is presented in clause 6.

i. For a spacecraft operating in near Earth orbit with a recurrent manoeuvre capability, if the collision probability with other space objects in a conjunction is assessed to be above the corresponding probability threshold set by the approving agent, then the operator of the spacecraft shall perform collision avoidance manoeuvres to reduce the collision probability by at least two orders of magnitude below the threshold.

NOTE 1 The reduction of the collision probability by two orders of magnitude includes a margin due to the limits of orbit accuracy and orbit evolution forecasting methods.

NOTE 2 In practice, the implementation of collision avoidance manoeuvres is subject to the quality and accuracy of the available space surveillance segment leading to variability in the risk assessment and mitigation. These aspects are generally addressed as part of operational procedures.

j. A spacecraft operating in near Earth orbit, after receiving a warning for a conjunction with a collision probability above the threshold during normal operations, shall perform a collision avoidance action, including:

1) Manoeuvres, if the warning is received up to 12 hours before the conjunction and the spacecraft is operational

2) Assessment in less than 4 hours after the warning

3) Actively communicating its status or ephemerides, if unable to perform manoeuvres

NOTE 1 Although not performing manoeuvres, a spacecraft without recurrent manoeuvre capability can still engage in space traffic coordination, e.g. by actively communicating its status or ephemerides.

NOTE 2 The mission operations plan specifies the detailed procedure and can include the capability or need for up-to-date information from a space surveillance segment.

k. For spacecraft operating in near Earth orbit the operator shall define an operational procedure for the distribution of the spacecraft ephemerides and mitigation actions against the collision risk.

l. The procedure specified in 5.3.3.3k shall include:

1) Planned manoeuvres and free drift, for space traffic coordination

2) Detailing functions, space surveillance segment, performance, collision avoidance strategy and associated timelines that can be adopted

NOTE 1 The distribution serves the purpose of informing other actors involved in a conjunction, e.g. another operator or the space surveillance segment, of operational scenarios and timelines to mitigate the risk.

NOTE 2 The system used for distribution is part of the ground segment design.

m. The part of the operational procedure for the spacecraft operating in near Earth orbit that details actions taken to mitigate the collision risk and associated timelines shall be available for distribution in case of a conjunction event during normal operations.

NOTE 1 The distributed data includes the manoeuvrability status and if end of life has been reached.

NOTE 2 The system used for distribution is part of the ground segment design.

NOTE 3 The distribution informs other actors involved in a close approach event, e.g. another operator or the space surveillance segment, of operational scenarios and timelines to mitigate the risk.

n. During normal operations, the operator of a constellation in near Earth orbit shall maintain a trajectory catalogue of its spacecraft and perform daily, automated, or on-demand, collision risk assessments.

o. During normal operations, the operator of a spacecraft in near Earth orbit shall implement, in case of a warning for a conjunction, the following actions in order of priority:

1) Establish a coordinated manoeuvre plan with the space object involved in the conjunction

2) For the spacecraft performing transiting operations, give way to on-orbit operations that maintain a fixed altitude, unless otherwise agreed when coordinating manoeuvres

3) Establish a manoeuvre plan in case no space traffic coordination can be established with the space object involved in the conjunction

NOTE Transiting operations include orbit lowering during disposal or orbit raising when manoeuvring towards to main mission orbit.

#### 5.3.3.4 Collision risk management for close proximity operations and formation flying

a. The probability of unintentional contact between space objects as a result of close proximity operations, or formation flying, in Earth orbit, shall be below $10^{-4}$.

NOTE The $10^{-4}$ probability of unintentional contact threshold is considered an absolute upper bound, but in practice, a lower threshold can be set by the approving agent.

b. The developer of a spacecraft involved in close proximity operations, or formation flying, in Earth orbit, shall quantify the probability of unintentional contact between the space objects involved, that includes:

1) The failure or combination of failures leading to exceeding the probability of unintentional contact threshold

2) Wear out modelling, disturbances, reliability and uncertainties in the space segment of those objects involved

3) All space objects involved in the close proximity operations, or formation flying, and the manoeuvres they are performing

NOTE Close proximity operations and formation flying can involve rendezvous, docking, berthing, capture or station keeping.

c. The operator of a spacecraft or launch vehicle orbital stage operating in Earth orbit performing close proximity operations, or formation flying, shall define an operational procedure detailing:

1) Functions, performance, and adopted collision avoidance strategy

2) Contingency and recovery operations to mitigate the probability of unintentional contact, and in case the on-orbit safety conditions are no longer met, and associated timelines

NOTE The procedure includes both actions triggered by the on-board failure detection isolation and recovery (FDIR) implementation and actions commanded by the ground segment.

d. A spacecraft or launch vehicle orbital stage involved in close proximity operations, or formation flying, in Earth orbit, shall have the resources to perform contingency and recovery operations.

NOTE Resources include space segment and ground segment resources.

e. During close proximity operations, or formation flying, in Earth orbit, if the probability of unintentional contact between the space objects involved is assessed to be above the set threshold, then the involved operators of the space objects shall perform a coordinated manoeuvre to reduce the probability of unintentional contact below $10^{-4}$ for 7 days after the manoeuvre.

NOTE This amount of time takes into account the time needed for ground segment to react to a non-nominal situation and to perform recovery or disposal action.

f. The developer and operator of a spacecraft or launch vehicle orbital stage involved in close proximity operations in Earth orbit shall compile, during the design phase, and update, during the operational phase, the information relevant for relative navigation for distribution to the spacecraft or launch vehicle orbital stage performing the close proximity operations.

NOTE 1 Relevant information includes possible or observed surface material properties, uncontrolled attitude motions, possible interface or capture points.

NOTE 2 It is good practice to store the information for potential non-cooperative removal in the future.

#### 5.3.3.5 Space surveillance and tracking

a. The developer of a spacecraft or launch vehicle orbital element injected into Earth orbit shall guarantee that it can be tracked by a space surveillance segment supporting collision avoidance processes.

NOTE Trackability for a space object generally means having at least one dimension larger than 10 cm when the perigee is within the LEO protected region and 50 cm when the perigee is outside. An analysis taking into account the specificity of the supporting space surveillance segment can be needed, e.g. for smaller space objects or those space objects in Lagrange point orbits.

b. The ground segment of a spacecraft or launch vehicle orbital stage injected into a near Earth orbit shall include a space surveillance segment.

NOTE 1 A space surveillance segment can be provided by an entity external to the operator, e.g. a proprietary network, or any other means to effectively monitor the orbit of the space object, and the space objects nearby.

NOTE 2 Even without a recurrent manoeuvre capability, an effective space surveillance segment ensures the coordination among operators, e.g. through the availability of points of contact.

c. During normal operations, the operator of a spacecraft in Earth orbit shall quantify the position and velocity accuracy of the combined ground, space, and space surveillance segment, for:

1) At least once every orbital revolution

2) A forecast of up to 7 days

NOTE 1 The accuracy is computed in terms of covariances resulting from the orbit determination process considering biases and measurement uncertainties, suitable for the mission's orbital geometry.

NOTE 2 The information is used to facilitate the identification of a space object from a space surveillance segment and to establish the accuracy of the ephemerides in case of conjunctions.

NOTE 3 Space surveillance segment and ground segment related uncertainties at the orbit determination epoch determine the uncertainties when propagated to the time of a conjunction and are accounted for when establishing collision probability thresholds. This process is heavily influenced by the specific orbital region dynamics and forecasting methods, which are under active research.

d. A spacecraft or launch vehicle orbital element injected into the protected regions shall guarantee that a space surveillance segment supporting collision avoidance processes can achieve a position accuracy during normal operations as well as after end of life higher than 100 m in the LEO protected region and higher than 1000 m in the GEO protected region along the orbit determination interval outside of manoeuvre periods.

NOTE 1 The position accuracy can be achieved, e.g. by means of on-demand tracking in the LEO protect region, passive optical measures in the GEO protect region for large space objects, or GNSS receivers during normal operations.

NOTE 2 The position accuracy is computed in terms of covariances resulting from the orbit determination process considering biases and measurement uncertainties, suitable for the mission's orbital geometry.

NOTE 3 The orbit determination interval covers at least one orbital revolution.

NOTE 4 The goal is to achieve a specified accuracy at the moment of a forecasted conjunction epoch, for which the starting accuracy is a major contributor.

NOTE 5 The accuracy target is an encompassing envelope covering all spatial directions.

NOTE 6 Compliance with the requirement can be achieved by the appropriated selection of the space surveillance segment.

e. The developer and operator of a spacecraft or launch vehicle orbital element injected into Earth orbit shall guarantee that it can be unambiguously identified by a space surveillance segment within 1 day after on-orbit injection.

NOTE 1 The ability to unambiguously identify a space object in Earth orbit after injection often involves a collaboration between launch, ground, space, and space surveillance segment operators.

NOTE 2 Compliance with the requirement can be achieved by the appropriated selection of the space surveillance segment, and potential modifications to the space segment.

f. The space surveillance segment supporting a spacecraft or launch vehicle orbital element normal operations in Earth orbit shall be able to provide:

1) Daily updated ephemerides on space objects potentially crossing the orbit of the space object, including position and velocity accuracy estimation, for up to 7 days

2) On-demand ephemerides screening with accuracy and timeliness levels subject to approval by the approving agent

NOTE 1 A space surveillance segment can be optimised in timeliness and accuracy requirements depending on the mission needs. However, this often requires a bespoke analysis as function of orbital regime and contributing sensors. This ultimately is a contributing factor in the definition of collision probability thresholds.

NOTE 2 It is good practice to have daily updated ephemerides, even without daily observations.

NOTE 3 The on-demand screening of ephemerides covers the functionality for a ground segment forecasted orbit for check against the space surveillance segment's best available forecast of the orbital environment, with the objective of finding conjunctions.

g. The operator of a spacecraft operating in near Earth orbit shall inform the space surveillance segment of any possible anomaly affecting a system or function necessary to reliably perform collision avoidance manoeuvres, after the anomaly resolution board.

NOTE Informing the orbital neighbours, through the space surveillance segment, about the incapability to manoeuvre is important to identify possible collision mitigation actions.

h. The ground segment of the spacecraft in near Earth orbit during normal operations shall be capable of performing an orbit determination and creating forecasted ephemerides, including accuracy metrics, for manoeuvres and free drift scenarios.

NOTE 1 The ground segment can implement a solution based on the actual spacecraft design, e.g. making use of on board GNSS receivers or tracking data, or make use of a space surveillance segments capabilities.

NOTE 2 Ephemerides can be based on ECSS-E-ST-10-04.

i. The ground segment of the spacecraft operating in Earth orbit shall be capable of generating and processing in CCSDS formats:

1) Ephemerides – Orbit Data Messages (ODM)

2) Conjunction data – Conjunction Data Message (CDM)

3) Re-entry information – Re-entry Data Message (RDM)

NOTE 1 CCSDS format data messages facilitate the exchange among operators during close approaches and re-entry events.

NOTE 2 The corresponding CCSDS standards are: CCSDS 502.0-B-3 (Orbit Data Message), CCSDS 508.1-B-1 (Re-entry Data Message), and CCSDS 508.0-B-1 (Conjunction Data Message).

NOTE 3 Compatibility with CCSDS 504.0-B-1 (Attitude Data Messages) is good practice for close proximity operations.

# 5.4 Disposal

## 5.4.1 Successful disposal

### 5.4.1.1 Probability of successful disposal

a. The overall probability of successful disposal of a spacecraft or launch vehicle orbital stage in Earth orbit shall be kept above 0,9 through to end of life, including the contributions from system reliability and from collisions with space debris or meteoroids preventing the successful disposal.

NOTE 1 The reliability calculation considers subsystems, units and functions used for the disposal only.

NOTE 2 If during the design the mission the operational orbit is only known within a given range of orbital parameters, the worst-case scenario is assumed for the assessment.

NOTE 3 The calculation of the probability of successful disposal can be based on reliability analyses performed according to ECSS-Q-ST-30, and ECSS-Q-HB-30 or any other methods set by the approving agent.

NOTE 4 MIT-COL-MAN-00309-OPS-SD:2021 provides a reference methodology on how the contribution of impacts with space debris or meteoroids to the reduction of the probability of successful disposal can be accounted for.

NOTE 4 Collisions on appendages are considered unless demonstrated that they do not affect the disposal functions.

NOTE 5 For launch vehicle orbital stages, probability of successful disposal above 0,98 can be achieved.

b. The contribution from system reliability to the probability of successful disposal of each spacecraft of a constellation in near Earth orbit shall be kept above 0,95 through to the end of life, if the spacecraft is:

1) Part of a large constellation, or

2) Operating in the LEO protected region in an orbit with a natural orbital decay duration longer than 25 years

NOTE Progressive increase of the probability of successful disposal of spacecraft part of a constellation is possible by integrating in the design return of experience from operations.

#### 5.4.1.2 Health monitoring

a. For health monitoring the requirements 7.3.1.3 and 7.3.1.5 of ECSS-U-AS-10C Rev.2 shall be applied.

b. The developer and operator of a spacecraft operating in Earth orbit shall implement failure prognostic methods for anticipating possible failures and wear-out trends.

NOTE Methods for failure prognostics are:

- health monitoring, to exploit telemetry as observed in-flight,
- return of experience and Bayesian techniques, to update and re-assess failure rate of units by exploiting on-orbit data and interpret anomalies and failures encountered by units, and their impacts on the mission and disposal,
- prognostics based on stochastic models, to predict statistically at any time the future status

of units and estimate their remaining useful lifetime (RUL),

- model-based prognostics, to predict quantitatively at any time, the future status of units and estimate their RUL from their engineering models,
- prognostics based on data trends, to identify degradation trends that cause the failure of units at the end of the RUL and to identify variation of telemetries with respect to the nominal condition,
- other methods, for agreement with the approving agent.

c. The operator of a constellation operating in Earth orbit shall collect in-flight data, lessons learned from spacecraft failures, and detected anomalies to integrate this information in the operational procedures for mission plan re-evaluation, and to perform the necessary design or operational updates.

NOTE Improvement of health monitoring features are considered for recurrent spacecraft based on the return of experience.

d. The condition of a spacecraft operating in Earth orbit shall be monitored during its operations to update the following parameters for all critical functions and equipment used in disposal operations:

1) Wear out data
2) Failure In Time (FIT) data

e. The probability of successful disposal of a spacecraft operating in Earth orbit shall be re-assessed during operations, including the updated reliability figures including wear out data, and in-flight collected telemetry based on return of experience or any other failure prognostics methods, which has been accepted by the approving agent.

f. The probability of successful disposal of a spacecraft operating in Earth orbit shall be re-assessed in the following occurrences, when affecting the disposal function:

1) Mission lifetime extension (before the start of the mission extension, as input to the Mission Extension Operations Review – MEOR)
2) Detected anomaly
3) Recorded failures from the same product family
4) Change in the radiation environment, when recommended by the radiation experts
5) Change in the space debris environment affecting the operational orbit or disposal approach when recommended by the space surveillance segment supporting the mission

6) As a minimum at 50% of the nominal mission lifetime, in case none of the occurrences above are triggered, unless agreed to be unnecessary between the approving agent and the spacecraft operator

NOTE 1 An example of change in the space debris environment is a catastrophic break-up.

NOTE 2 The frequency of the re-assessment depends on the mission needs and risk.

g. The developer and operator of a spacecraft in Earth orbit shall together define procedures to:

1) Assess the health status of the critical functions for the disposal operations

2) Update the probability of successful disposal based on in-flight collected telemetry

NOTE These procedures are an input to re-assess the mission plan and mission lifetime.

h. The operator of a spacecraft operating in Earth orbit shall maintain relevant system metrics for distribution each time the assessment of the probability of successful disposal is performed, including at least:

1) Adopted criteria for the mission continuation, termination, extension, or plan re-assessment

2) Updated probability of successful disposal based on on-orbit data

3) Number of collision avoidance manoeuvres foreseen up to the end of life, based on the updated space environment, and the respective Delta-v allocation

4) Re-assessment of the orbit lifetime and respective collision probability up to re-entry

5) Resources availability, Delta-v

NOTE The authorization for extending a mission beyond the initial duration is given after review of the risk assessment, including probability of successful disposal and status of the spacecraft.

#### 5.4.1.3 Preparation for removal

a. A spacecraft operating in the LEO protected region shall be prepared for removal by implementing measures that enable removal by external removal services, both in cooperative and un-cooperative condition, unless it always fulfils both of the following conditions:

1) The spacecraft in free drift from its operational orbit fulfils one of the following conditions:

(a) Natural orbital decay duration below 5 years

(b) Cumulative collision probability with space debris larger than 1 cm lower than $10^{-3}$ during the orbit lifetime

2) The spacecraft on-ground re-entry casualty risk is lower than $10^{-4}$ in case of uncontrolled re-entry.

NOTE 1 A method for verification of this requirement is specified in clause 6.

NOTE 2 Preparation for removal for spacecraft with an on-ground re-entry casualty risk higher than $10^{-4}$ is a remediation measure in case of failure to perform the controlled re-entry.

b. A spacecraft operating in the GEO protected region shall be prepared for removal by implementing measures that enable removal by external removal services, both in cooperative and un-cooperative condition.

c. A spacecraft, when prepared for removal, both in un-cooperative and cooperative scenario, shall have the following features or characteristics:

1) Passively ensure access to a mechanical interface compliant with capture, detumbling and removal mechanical loads

2) Passively support the relative navigation of the space object performing the close proximity operations

NOTE 1 It is good practice that the mechanical capture interface allows for capture before contact.

NOTE 2 It is good practice that the design of the support to the servicer relative navigation considers compatibility with different rendezvous sensors.

NOTE 3 The compliance with the requirement can be met if compatibility with at least one possible removal service interfaces is demonstrated. ESA-OPS-SC-RD-2023-001 provides a valid reference removal service Interface Requirements Document.

d. The developer of a spacecraft, when prepared for removal, shall perform an assessment of the long-term evolution of the spacecraft attitude if in free drift in its operational orbit.

e. A spacecraft operating in LEO protected region, when prepared for removal, in an uncooperative scenario, shall have the following features or characteristics:

1) Passively enable attitude reconstruction on ground

2) Limiting and damping the spacecraft angular rates

NOTE 1 The target accuracy for the attitude reconstruction from ground of the spacecraft angular rate vector magnitude is better than ±1 deg/s, and of the spacecraft direction vector magnitude is better than ±10 deg.

NOTE 2 The target for the evolution of the module of the spacecraft angular rates vector is convergence to values lower than 1 deg/s.

NOTE 3 Measures to limit and damp the angular rates include:

- use of angular rates damping system or device.
- orientation of appendages when in Safe Mode to minimise the torques resulting from solar radiation pressure.
- passivation of propulsion system not increasing spacecraft angular rates (e.g. through zero-torque venting pipe outlet).

f. A spacecraft, when prepared for removal, in a cooperative scenario, shall implement the following functions:

1) System modes and operational procedures supporting the cooperative capture and removal

2) Delivery of orbit and attitude data with the accuracy required by the removal service

NOTE 1 Considerations when defining system modes and operational procedures supporting cooperative capture and removal from a servicer include:

- orientation of appendages allowing the servicer approach and mechanical interface capture.
- stable angular rates allowing the servicer approach and mechanical interface capture.
- use of AOCS actuators that do not impact or impinge on the servicer relative navigation sensors and attitude control during the close proximity operations.
- prevention of AOCS from reacting against capture and manoeuvring by the servicer.

NOTE 2 The system Safe Mode attitude and configuration allow for a cooperative removal.

NOTE 3 The compliance with the requirement can be met if compatibility with at least one possible removal service interfaces is demonstrated. ESA-OPS-SC-RD-2023-001 provides a valid reference.

g. The operator of a spacecraft, when prepared for removal, shall compile and make available information regarding its preparation for removal functions and interfaces for distribution to the spacecraft or launch vehicle orbital stage involved in the close proximity and removal operations.

NOTE ESA-OPS-SC-RD-2023-001 provides a valid reference for the availability of minimum documentation to the removal service providers, if necessary.

### 5.4.2 Earth orbit clearance

#### 5.4.2.1 General Earth orbit clearance

a. The orbit clearance of a spacecraft or a launch vehicle orbital element in Earth orbit at its end of life shall be achieved by one of the following means, in order of preference:

1) Immediate Earth atmospheric re-entry after end of mission
2) Disposal in an orbit with a natural orbital decay that satisfies the orbit clearance requirements for the LEO protected region
3) If not operating in, nor crossing, the LEO protected region, disposal in a graveyard orbit that satisfies both following conditions:
   (a) Long-term perturbation forces do not cause it to cross the protected regions nor the operational orbits of known constellations that operate at a fixed operational altitude, within 100 years after its end of life
   (b) Its cumulative collision probability with space objects larger than 1 cm is below $10^{-3}$ for up to 100 years after the end of life

   NOTE 1 A method for verification of this requirement and related data sources are presented in Clause 6.

#### 5.4.2.2 GEO protected region clearance

a. The disposal of a spacecraft or launch vehicle orbital stage operating in the GEO protected region into a graveyard orbit shall be performed to satisfy, after disposal manoeuvres, at least one of the following conditions:

1) The graveyard orbit has an initial eccentricity less than 0,003 and a minimum perigee altitude $\Delta H$ (in km) above the geostationary altitude, in accordance with equation 1:

$$\Delta H = 235 + (1000 \cdot C_r \cdot A/m) \qquad (1)$$

   where $C_r$ is the solar radiation pressure reflectivity coefficient ($0 < C_r < 2$), and A/m is the aspect area to dry mass ration ($m^2 kg^{-1}$)

2) The graveyard orbit has a perigee altitude sufficiently above the geostationary altitude that long-term perturbation forces do not cause the spacecraft or launch vehicle orbital stage to enter the GEO protected region within 100 years after its end of life

   NOTE Equation 1 is derived to ensure that long-term perturbations do not cause a spacecraft to re-enter a protected zone of geostationary altitude plus 200 km.

### 5.4.2.3 LEO protected region clearance

a. The orbit clearance of a spacecraft or launch vehicle orbital element from the LEO protected region shall satisfy both following conditions:

1) the orbit lifetime is less than 5 years starting from either:

(a) The orbit injection epoch, if it is injected into an orbit crossing the LEO protected region and has no recurrent manoeuvre capability

NOTE Launch vehicle orbital elements without recurrent manoeuvre capability are considered within this category.

(b) The end-of-life epoch, if it operates in the LEO protected region and has a recurrent manoeuvre capability

2) the cumulative collision probability from its end of life until re-entry with space objects larger than 1 cm is below $10^{-3}$

b. The orbit clearance of a spacecraft or launch vehicle orbital element not operating in the LEO protected region, but crossing the LEO protected region after its end of life shall satisfy the following conditions:

1) the total orbit lifetime after end of life is less than 100 years

2) the cumulative collision probability from end of life until re-entry with space objects larger than 1 cm is below $10^{-3}$

3) the orbit lifetime starting from the epoch of first intersection with the LEO protected region is less than 25 years

c. The disposal orbit of spacecraft part of a large constellation operating in the LEO protected region shall have an apogee below 375 km.

### 5.4.2.4 Initial orbit insertion

a. Spacecraft of a constellation in Earth orbit shall be launched into an initial insertion orbit not crossing orbits of known constellations that operate at a fixed operational altitude.

NOTE The operational orbit of known constellations does not include orbits used for launch and early operations (LEOP) or disposal based on natural orbital decay.

b. Spacecraft of a constellation in Earth orbit shall be injected into an initial insertion orbit with a cumulative collision probability with space objects larger than 1 cm below $10^{-3}$ until re-entry or up to 100 years.

NOTE 1 This requirement can be relaxed if there is evidence that the system manufacturer follows quality assurance standards in line with ECSS-Q-ST-10 and ECSS-Q-ST-20, and to what extent, before agreement with the approving agent.

NOTE 2 A method for verification of this requirement is presented in clause 6.

c. Spacecraft of a large constellation in the LEO protected region shall be injected into an initial insertion orbit with a natural orbital decay duration lower than 5 years.

NOTE A method for verification of this requirement is presented in clause 6.

## 5.5 Re-entry

a. For re-entry the requirements in ESSB-ST-U-004 shall be applied.

b. The expected number of casualties per re-entry of a spacecraft or launch vehicle orbital stage, including elements thereof, shall be less than $10^{-4}$ through adopting design and operations practices in the following order of preference:

1) Design for demise
2) Controlled re-entry
3) Approval of any other design or operations practice by the approving agent

NOTE 1 The expected number of casualties is an objective-based requirement, but various methods exist to achieve this threshold.

NOTE 2 The goal of design for demise practices is to achieve full ablation of elements, equipment, parts and components of a space object.

NOTE 3 So called design for containment methods, i.e. reducing the number of impacting fragments by grouping them together, generally need demonstration by analysis or test.

NOTE 4 The calculation of the expected number of casualties per re-entry of a spacecraft or launch vehicle orbital stage in Earth orbit takes into account all objects released in orbit from the spacecraft or launch vehicle orbital stage, including elements thereof. For example, the expected number of casualties created by a dispenser detached by a launch vehicle orbital stage is summed up with the expected number of casualties of the launch vehicle orbital stage itself, even when not re-entering at the same moment in time.

c. The expected number of casualties per re-entry of a spacecraft or launch vehicle orbital stage, including elements thereof, shall be assessed probabilistically.

NOTE 1 When a probabilistic assessment does not result in a multi-modal distribution with a mode above the threshold, a median approach is often used to validate the threshold against at system level. In case of a mode above the threshold a bespoke assessment is often applied to assess compliance.

NOTE 2 To demonstrate the demise of an element, equipment, part or component of a space object, a 95% confidence level is often adopted as function of the re-entry trajectories and demise events likely be encountered by the space objects. A set of minimum uncertainties for re-entry casualty risk analysis is specified in ESSB-HB-U-002-Issue2, and further guidelines can be found in ESA-TECSYE-TN-018311.

d. Spacecraft part of a large constellation in Earth orbit re-entering shall either:

1) Have an expected number of casualties per re-entry below $10^{-6}$

2) Perform a controlled re-entry

NOTE The requirement can be met by implementing design for demise techniques and using a probabilistic assessment.

## 5.6 Dark and quiet skies

a. The developer of a spacecraft or launch vehicle orbital element in near Earth orbit shall quantify the visual brightness of the design.

NOTE UN COPUOS “Dark and Quiet Skies for Science and Society - Report and recommendations” identify the target visual magnitude of a space object to minimise negative impacts on astronomical observations by guaranteeing that all satellites appear fainter than 7,0 Vmag +2,5 × log(SatAltitude / 550 km) with a minimum value – corresponding to maximum brightness – of visual magnitude (Vmag) 7 during all flight phases.

b. The developer and operator of a constellation in near Earth orbit shall propose and implement design and operational mitigation actions to reduce the visual brightness of the spacecraft.

NOTE UN COPUOS “Dark and Quiet Skies for Science and Society - Report and recommendations” identify the target visual magnitude of a space object to minimise negative impacts on astronomical observations by guaranteeing that all satellites appear fainter than 7,0 Vmag +2,5 × log(SatAltitude / 550 km) with a minimum value – corresponding to maximum brightness – of visual magnitude (Vmag) 7 during all flight phases.

c. The developer and operator of a spacecraft or launch vehicle orbital stage operating in near Earth orbit shall protect the Radio Astronomy Service, in compliance with the ITU Radio Regulations and in compliance with requirements from clause 4 to clause 9 of ECSS-E-ST-50-05.

NOTE ECSS-E-ST-50-05 contains maximum power flux density values for different frequency bands to protect radio astronomy observations from spacecraft unwanted emission.

d. The developer and operator of a spacecraft or launch vehicle orbital element operating in near Earth orbit shall make available data on demand to support mitigation of impacts on astronomy, including brightness data, antenna diagrams, orbital profiles, and predicted and real-time orbital elements.

NOTE Data can be made available to the astronomy community and observatories to allow sufficient planning to avoid impacts and post-hoc analysis of incurred impacts.

## 5.7 Lunar orbits

### 5.7.1 Avoiding the creation of space debris

a. The spacecraft or launch vehicle orbital stage shall be designed not to release space debris into Lunar orbits during normal operations.

b. In Lunar orbit, intentional break-up of a spacecraft or launch vehicle orbital stage shall not be performed.

c. The accidental break-up probability of a spacecraft or launch vehicle orbital stage in Lunar orbit shall be less than $10^{-3}$ until its end of life.

d. The determination of accidental break-up probability of a spacecraft or launch vehicle orbital stage shall quantitatively model all known failure modes for the release of stored energy, capable of causing an accidental break-up, and those from external sources.

NOTE Failure modes from external sources include failures due to impacts with space debris and meteoroids.

### 5.7.2 Space traffic coordination

a. The space and ground segments associated with a spacecraft or launch vehicle orbital element shall be designed to have ephemerides available for space traffic coordination.

NOTE 1 The ephemerides can be determined either by the operator's own means or by a space surveillance segment.

NOTE 2 The availability of the ephemerides aids the unique identification of the space segment by a space surveillance segment.

b. The operator of a spacecraft or launch vehicle orbital element in Lunar orbit shall define a procedure to distribute its ephemerides, including planned manoeuvres and free drift, for space traffic coordination.

NOTE 1 The distribution serves the purpose of informing other actors involved in a conjunction, e.g. another operator or the space surveillance segment, of operational scenarios and timelines to mitigate the risk.

NOTE 2 The system used for distribution is part of the ground segment design.

### 5.7.3 Disposal

a. The overall probability of successful disposal of a spacecraft or launch vehicle orbital stage in Lunar orbit shall be kept above 0,9 through to end of life.

b. The disposal of a spacecraft or launch vehicle orbital element operating in Lunar orbits shall include one of the following means in order of preference:

1) Heliocentric orbit

2) Lunar impact, Earth re-entry, or a Lunar graveyard orbit

NOTE The selection of the disposal strategy, other than in heliocentric orbit, can be justified with the support of an orbit propagation analysis.

c. The free drift trajectories after disposal of a spacecraft or launch vehicle orbital element in lunar orbit shall be analysed for at least 100 years to evaluate:

1) Probability of Earth re-entry and its associated impact area

2) Probability of Lunar impact and its associated impact area

NOTE The suitability of possible impact area locations on the Moon surface are analysed with respect to points of interest such as space heritage artifacts, or operational assets on the lunar surface.

d. If the probability of an Earth re-entry does not lead to exceeding the casualty risk threshold specified in ESSB-ST-U-004, the associated impact area evaluation need not be performed.

e. The disposal of a spacecraft or launch vehicle orbital element into a Lunar graveyard orbit, shall meet the following conditions:

   1) An assessment is performed to identify tracking strategies and constraints for a space surveillance segment to track the spacecraft or launch vehicle orbital element after end of life

   2) The selected disposal orbit remains with bounded variations of its orbital elements for at least 100 years

# 6
# Verification and validation requirements

## 6.1 Overview

This clause provides requirements on the method to perform the compliance verification by analysis of the requirements defined in clause 5, which are based on assessment of the orbit lifetime, and cumulative collision probability. This clause specifies reference data, models, configuration and inputs.

## 6.2 Models

a. The space debris and meteoroid environment models used shall be in compliance with ECSS-E-ST-10-04.

NOTE The ESA MASTER model is in compliance with ECSS-E-ST-10-04.

b. The 1 cm size space debris population used in a space debris environment model shall use the latest available calibration epoch of the model at the time of running the analysis.

NOTE 1 The space debris environment models generally also include a forecast. However, the population at the calibration epoch provides a stable census of the environment to small size ranges and as such a precise reference for the validation.

NOTE 2 Space debris environment models can cover complete space objects population, i.e. space debris as well as spacecraft and launch vehicle orbital stages.

c. The assessments related to collision avoidance implementation shall be based on the population of space objects and space debris that can be observed by means of a space surveillance segment and can be used in a collision avoidance process.

NOTE 1 This information can be obtained from space debris environment models or generated by a space surveillance segment.

NOTE 2 Space object position covariance information needed for a probabilistic assessment at population level is often based on estimate rather than detailed per space object data from a space surveillance segment.

d. The space debris population used for the analysis in the SDMP specified in Annex A shall be agreed with approving agent.

e. The evaluation of the cumulative collision probability shall include:

1) Normal operations, including all orbits intended for use and with the space object geometry representing the on-orbit behaviour and AOCS modes

2) Free drift after end of life, with the space object geometry representing the on-orbit state and using either the long-term attitude motion or a random tumble motion

NOTE 1 The cumulative collision probability is computed considering the space objects that have a size above 1 cm such to create further space debris in case of a collision with the object under analysis. The contribution to the collision probability coming from objects of smaller size can be omitted.

NOTE 2 The cumulative collision probability is computed considering the complete space object geometry, including appendages, unless it is demonstrated that specific appendages can be hit by objects larger than 1 cm without generating space debris.

NOTE 3 A spacecraft can have various geometries during the analyses, e.g. the deployment of a drag sail to reduce orbital lifetime can be accounted only when deployed after end-of-life and if it creates debris when impacted.

NOTE 4 The ESA's MASTER model and ESA's DRAMA tool suite can be used for this assessment.

f. The orbit lifetime of a space object shall be assessed probabilistically, including at least the variability by moving the starting point through a full solar cycle.

NOTE 1 A solar cycle lasts an average 11 years. Depending on when the orbital lifetime assessment is started in the solar cycle, a large variability can be observed due to the associated atmospheric density.

NOTE 2 Atmospheric models capable of representing solar cycles are described in Annex A of ESSB-HB-U-002-Issue2.

NOTE 3 Other sources of uncertainty that can be considered in the probabilistic assessment are the space object physical characteristics and orbit accuracy.

NOTE 4 The cross-sectional area of the spacecraft or launch vehicle orbital element is determined based on the justified operational configuration.

g. For the orbit lifetime assessment, the following percentile shall be used:

1) 50th percentile for orbit with eccentricity below 0,3 at end of life

2) 90th percentile for orbit after with eccentricity above 0,3 at end of life

## 6.3 Inputs

a. The assessment of orbits containing known constellations or inhabitable space object shall be based on a regularly updated list available at the time of verifying the requirements in compliance with SDMP from Annex A approved by approving agent.

NOTE Such a list, suitable for verification, is available from https://discosweb.esoc.esa.int/

b. The assessment of conjunction statistics with operational spacecraft shall be based on a regularly updated list covering of the activity status of all spacecraft available at the time of verifying the requirements in compliance with an approved SDMP from Annex A approved by approving agent.

NOTE Such a list, suitable for verification, is available from https://discosweb.esoc.esa.int/

# 7 Documentation requirements

a. The Space Debris Mitigation documentation shall include:

1) The Space Debris Mitigation Plan (SDMP), in conformance with Annex A, specifies how the compliance with the Space Debris Mitigation requirements is planned, and is provided for review and approval by approving agent as specified in Table 7-1

2) The Space Debris Mitigation Report (SDMR), in conformance with Annex B, specifies how the compliance with the Space Debris Mitigation requirements is implemented and verified, and is provided for review and approval by approving agent as specified in Table 7-1

### Table 7-1: Space Debris Mitigation documentation

| Doc. | Delivery phase/review/event (see Note 1) | Content | Approval/ Review (see Note 2) | DRD |
|---|---|---|---|---|
| SDMP | Preliminary Requirements Review (PRR) | • Preliminary identification of the requirements, which are planned for implementation and specification of the related verification methods<br>• Preliminary analysis to support the planned compliance | Review | Annex A |
| SDMP | System Requirements Review (SRR) | • Final identification of the requirements, which are planned for implementation and description of the related verification methods<br>• Preliminary analyses to support the planned compliance | Approval | Annex A |
| SDMR | Preliminary Design Review (PDR) | • Requirements implementation and verification<br>• Detailed analyses to support the compliance verification | Review | Annex B |
| SDMR | Critical Design Review (CDR) | • Requirements implementation and verification<br>• Updated analyses to support the compliance verification | Review | Annex B |
| SDMR | Qualification Acceptance Review (QAR) / Ground Qualification Review (GQR) / Flight Acceptance Review (FAR) | • Requirements implementation and verification<br>• Updated analyses to support the compliance verification | Approval | Annex B |
| SDMR | Flight Readiness Review (FRR) | • Requirements implementation and verification<br>• Updated analyses to support the compliance verification | Review | Annex B |
| SDMR | Relevant on-orbit anomaly / environment change | • Updated requirements compliance status<br>• Updated analyses to support the compliance verification | Approval | Annex B |
| SDMR | Prior to mission change / extension | • Updated requirements compliance status<br>• Updated analyses to support the compliance verification | Approval | Annex B |
| SDMR | End of mission | • Updated requirements compliance status<br>• Updated analyses based on on-orbit status and operation plan | Approval | Annex B |
| SDMR | Prior to re-entry | • Updated requirements compliance status<br>• Updated analyses based on on-orbit status and operation plan | Approval | Annex B |
| 1. Phases and reviews are as defined in ECSS-M-ST-10, or equivalent (if named differently).<br>2. Review and approval are from the ESA Technical Authority for Space Debris Mitigation. | | | | |

# Annex A (normative) Space debris mitigation plan (SDMP) - DRD

## A.1 DRD Identification

### A.1.1 Requirement identification and source document

This DRD is called from ESSB-ST-U-007, clause 7.

### A.1.2 Purpose and objective

The Space Debris Mitigation Plan (SDMP) provides the plan for the implementation and verification of the Space Debris Mitigation requirements. The document is issued at Preliminary Requirements Review (PRR) for approval at the System Requirements Review (SRR) in order to define a stable baseline for the development and operations of the space system, e.g. spacecraft, launch vehicle, robotic or inhabitable space object.

## A.2 Expected response

### A.2.1 Scope and content

a. An SDMP shall contain:
   1) Introduction
   2) Scope
   3) References
   4) Applicable Documents
   5) Reference Documents
   6) Terms, definitions and abbreviated terms
   7) Terms and definitions
   8) Abbreviated terms

b. The SDMP shall contain the programme management overview, including:
   1) Identification of the ESA Directorate responsible for the project or mission
   2) Identification of the ESA Study Manager or Project Manager responsible for the preparation and maintenance of the SDMP
   3) Identification of any non-ESA participation in any phase of the mission
   4) Chronology of ESA project reviews and issues of the SDMP and SDMR

c. The SDMP shall contain the mission overview, including:

1) Description of the mission objectives

2) Schedule of the mission milestones from launch through end of mission, including the timeline of the planned orbital manoeuvres

3) Description of the mission profile, including type of orbit and orbital parameters

4) Description of the mission requirements for orbit injection, maintenance, and disposal

NOTE Example of mission requirements are type of orbit, ground track, constellation, close proximity operations, formation flying, etc.

5) Information on recurrent spacecraft, if multiple spacecraft or part of a constellation, including operational and disposal patterns

NOTE 1 Examples of type of orbit include LEO, MEO, HEO, GEO, SEL-1, SEL-2.

NOTE 2 For example, information on a spacecraft constellation includes: number of spacecraft; launch, disposal and replenishment timelines; injection, operational and disposal orbit parameters.

d. The SDMP shall contain the space system description, including:

1) Summary description of the space system including spacecraft, launch vehicle, robotic or inhabitable space object, spacecraft platform, payload instrumentation, and all appendages

NOTE Example of appendages are solar arrays, antennas, instrument booms, attitude control booms, etc.

2) Mass budget at launch and end of mission, including all propellants and fluids with details known at the present phase

3) Description of the propulsion system

4) Description of the power system

5) Description of the Attitude and Orbit Control System (AOCS)

6) Description of the Guidance, Navigation and Control (GNC) system

e. The SDMP shall contain the procured launch service description, including:

1) Identification of the launch service in case if the launch vehicle was not identified or procured yet, available information about launch constraints and launch vehicle opportunities)

2) Description of the launch vehicle mission profile, including all separation stages with all parking, transfer, and mission orbital parameters, apogee, perigee, inclination

3) Identification of the launch vehicle capabilities concerning de-orbiting of upper stages

4) Launch vehicle stages mass budget, including propellant before and after operation

5) Description of the propulsion systems for each stage, solid or liquid

f. The SDMP shall contain the Space Debris Mitigation implementation and verification plan, including:

1) Mission-related objects (MROs)

(a) Confirmation by design that MROs are not released

(b) Identification and description of any MRO (> 1 mm), if expected for release at any time after launch, including type, dimensions, mass, and material

(c) Rationale for release of each MRO

2) Small particles release

(a) Design approach to avoid on-orbit release of particles from solid or hybrid propellant rocket motor larger than 1 mm

(b) Design approach to avoid on-orbit release of particles from pyrotechnics larger than 1 mm

3) On-orbit break-up risk caused by the system

(a) Identification of all potential causes of break-up during deployment and mission operations

(b) Preliminary accidental on-orbit break-up risk analysis and monitoring approach

4) On-orbit break-up and vulnerability risk caused by impacts

(a) Identification of the methodology to assess on-orbit break-up and vulnerability risk

(b) Identification of strategies to prevent on-orbit impact with space debris and meteoroids resulting in break-up, or unsuccessful disposal of the spacecraft or launch vehicle orbital element

(c) Preliminary on-orbit break-up and vulnerability analysis for impact with space debris and meteoroids likely to cause break-up, or prevent disposal, or above 1 cm size

NOTE On-orbit break-up and vulnerability analysis is described in Annex C of ESSB-HB-U-002-Issue2.

5) On-orbit collision risk

(a) Identification of the methodology to assess on-orbit collision risk and preliminary on-orbit collision risk analysis

NOTE Methodology to assess on-orbit collision risk and preliminary on-orbit collision risk analysis is described in Annex C of ESSB-HB-U-002-Issue2.

(b) Identification of strategies to prevent on-orbit collisions through avoidance manoeuvres

(c) Information on space surveillance and trackability, including description of the space surveillance segment and assessment of trackability (identification, state accuracy)

6) Disposal

(a) Description of the disposal options and rationale for selection

NOTE Example of disposal options are controlled re-entry, uncontrolled re-entry, manoeuvres to a graveyard orbit, other means.

(b) Identification of all subsystems or components to accomplish any disposal manoeuvre

(c) Preliminary orbit propagation analysis assessing the orbit lifetime, or presence, after the disposal manoeuvres to identify a disposal orbit not interfering with the protected regions and not operational orbits of known constellations and with a cumulative collision probability with space objects, debris and meteoroids larger than 1 cm below $10^{-3}$ during the remaining orbit lifetime until the atmospheric re-entry or up to 100 years

NOTE Orbit propagation analysis is described in Annex C of ESSB-HB-U-002-Issue2.

(d) Preliminary probability of successful disposal analysis, including the system reliability and impacts with space debris or meteoroids, which is based on:

(1) subsystems, units and functions used for the disposal only, and

(2) worst-case space environment assumptions, if the mission orbit is defined within a given range

NOTE Probability of successful disposal analysis is described in Annex C of ESSB-HB-U-002-Issue2.

(e) When not in near Earth orbit, preliminary orbit propagation analysis assessing the probability of return to Earth orbit, or re-entry, in 100 years through the mission in case of failure or orbit instability, and after disposal manoeuvres, and determine the final state

NOTE Examples of final state are Lunar orbits, SEL-2, etc.

(f) Description of design for removal implementations and associated analyses

7) Passivation

(a) List of the components storing energy

(b) List of the components that are passivated at the end of the operation phase

(c) Description of the design measures and operations implemented for the passivation of the components

(d) List of the component that cannot be passivated at the end of the operation phase, and rationale

(e) Available options for passivation and the related additional impact on project cost, effort, and schedule in order to allow passivation of components that have not been planned for passivation

NOTE Example of options for passivation are new developments, or platform modification or changes.

8) Re-entry

(a) Preliminary re-entry casualty risk analysis for all elements likely to re-enter, including the list of components with mass, dimensions, shape, and material information used by the analysis

NOTE Re-entry casualty risk analysis is described in Annex D of ESSB-HB-U-002-Issue2.

(b) Identification of the re-entry scenario, including nominal and degraded cases

(c) Identification of the system functions that contribute to the controlled re-entry, if planned

(d) Identification of the methodology planned for use for the final re-entry casualty risk analysis

9) Hazardous materials

(a) Identification of hazardous materials on-board

NOTE Example of hazardous materials are toxic or radioactive substances.

10) Dark and quiet skies (for spacecraft)

(a) Preliminary assessment of the visual brightness of the spacecraft

(b) Description of the planned design and operational mitigation measures to reduce the visual brightness of the spacecraft

(c) Description of the planned design and operational measures to protect the Radio Astronomy Service

(d) Description of the planned data sharing approach

11) Contingency plan

g. The SDMP shall contain the compliance and verification information, including:

1) Preliminary Compliance and Verification Matrix, including identification of the applicable SDM requirements, statement of planned compliance with the SDM requirements, planned approach for compliance, and reference documents as specified in Table A-1

h. The SDMP shall contain the launch service compliance information, including:

1) Assessment of the compliance with the SDM requirements, if the launch service has been already selected

**Table A-1: Example of preliminary compliance and verification matrix**

| **Req. Id.** (see NOTE 1) | **Requirement** (see NOTE 2) | **Compliance Status (C/PC/NC/NA)** (see NOTE 3) | **Verification Method(s)** (see NOTE 4) | **Planned Approach** (see NOTE 5) | **Reference** (see NOTE 6) | **Close-out event** (see NOTE 7) |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |

1. Identification of the requirement from ESSB-ST-U-007.
2. Requirement text from ESSB-ST-U-007.
3. Status of planned compliance: Compliant (C), Partial Compliant (PC), Not Compliant (NC), Not Applicable (NA).
4. Verification methods: Test (T), Analysis (A), Review-of-design (ROD), Inspection (I).
5. Description of the planned approach to demonstrate compliance with the requirement (if the requirement is not applicable, provide a justification).
6. Reference to any documentation that demonstrates compliance with the requirement (e.g. section of the SDMP, reports, analysis, RFD/RFWs).
7. Information on when is planned the verification close-out, e.g. PDR, CDR.

# Annex B (normative) Space debris mitigation report (SDMR) - DRD

## B.1 DRD Identification

### B.1.1 Requirement identification and source document

This DRD is called from ESSB-ST-U-007, clause 7.

### B.1.2 Purpose and objective

The Space Debris Mitigation Report (SDMR) provides the status of the compliance of the space system, e.g. spacecraft, launch vehicle, robotic or inhabitable space object, with the Space Debris Mitigation requirements, including verification methods, reports, and close-out, starting from the Preliminary Requirements Review (PDR) through all the main project phases and reviews and submitted for the final approval at the Flight Acceptance Review (FAR).

## B.2 Expected response

### B.2.1 Scope and content

a. The SDMR shall contain:

1) Table of contents
2) Introduction
3) Scope
4) References
5) Applicable documents
6) Reference documents
7) Terms, definitions and abbreviated terms
8) Terms and definitions
9) Abbreviated terms

b. The SDMR shall contain the programme management overview, including:

1) Identification of the ESA Directorate responsible for the project or mission
2) Identification of the ESA Project Manager or Mission Manager responsible for the preparation and maintenance of the SDMR
3) Identification of any non-ESA participation in any phase of the mission
4) Chronology of ESA project reviews and issues of the SDMP and SDMR

c. The SDMR shall contain the mission overview, including:

1) Description of the mission objectives
2) Schedule of the mission milestones from launch to end of mission, including the timeline of the planned orbital manoeuvres
3) Description of the mission profile, including type of orbit and orbital parameters
4) Description of the mission requirements, operations, and means for orbit injection, maintenance, and disposal

   NOTE Example of mission requirements are orbit type, ground track, constellation, close proximity operations, formation flying, etc.

5) Information on recurrent spacecraft, if multiple spacecraft or part of a constellation, including operational and disposal patterns

   NOTE 1 Examples of type of orbit include LEO, MEO, HEO, GEO, SEL-1, SEL-2.

   NOTE 2 For example, information on a spacecraft constellation includes: number of spacecraft; launch, disposal and replenishment timelines; injection, operational and disposal orbit parameters.

d. The SDMR shall contain the space system description, including:

1) Summary description of the space system, including platform, payload, and all appendages

   NOTE 1 Example of space systems are spacecraft, launch vehicles, robotic vehicles, inhabitable space object.

   NOTE 2 Example of appendages are solar arrays, antennas, instrument booms, attitude control booms, etc.

2) Mass budget at launch and end of mission, including all propellants and fluids
3) Description of the propulsion system
4) Description of the power system
5) Description of the Attitude and Orbit Control System (AOCS)
6) Description of the Guidance, Navigation and Control (GNC) system

e. The SDMR shall contain the procured launch vehicle description, including:
   1) Identification of the launch vehicle service: provider, launch vehicle, launch site
   2) Description of the launch vehicle mission profile, including all separation stages with all parking, transfer, and mission orbital parameters: apogee, perigee, inclination
   3) Identification of the launch vehicle capabilities concerning de-orbiting of upper stages
   4) Launch vehicle stages mass budget, including propellant before and after operation
   5) Description of the propulsion systems for each stage, solid or liquid

f. The SDMR shall contain the Space Debris Mitigation implementation and verification, including:
   1) Mission-related objects (MROs)
      (a) Confirmation by design that MROs are not released
      (b) List of MROs, if released at any time after launch, including their characteristics:
         (1) type,
         (2) dry mass and fuel or fluids mass,
         (3) materials,
         (4) dimensions,
         (5) drawings
      (c) Rationale for release of each MRO and possible effects on debris generation
      (d) Time of release of each MRO with respect to launch time
      (e) Release or ejection velocity of each MRO
      (f) Expected orbital parameters, apogee, perigee, and inclination of each MRO after release
      (g) Analysis to determine the trajectory propagation and expected presence in the LEO or GEO Protected Regions of each MRO
   2) Small particles release
      (a) Review-of-design or test to verify that all engines do not release particles larger than 1 mm
      (b) Review-of-design or test to verify that pyrotechnics do not release particles larger than 1 mm
      (c) Review-of-design or test to verify that environment-induced degradation in GEO does not lead to the release particles larger than 1 mm
      (d) Assessment of the type and quantity of small particles larger than 1 mm expected for release during normal operations, including:
         (1) Type of particles

NOTE Example of particles can come from solid or hybrid propellant rockets (e.g. slags), pyrotechnics, multi-layer insulation (MLI).

(2) Size, mass and density ranges of the particles

(3) Conditions and orbit where released

3) On-orbit break-up risk caused by the system

(a) Identification of all potential causes of break-up during deployment and mission operations

(b) Accidental on-orbit break-up risk analysis

(1) Failure modes, and effects analysis for all credible failure modes which can lead to an accidental explosion or fragmentation

(2) Space system accidental on-orbit break-up probability through to end of life

(3) Accidental on-orbit break-up risk monitoring:

- space system health monitoring - parameters and approach for the control of the break-up risk,
- anomaly report - status during the operations, if relevant to break-up risk

4) On-orbit break-up and vulnerability risk caused by impacts

(a) Analysis to determine the probability of collisions with objects or debris over the launch, operation, and disposal phases

(b) Analysis to determine the probability of damage or failure due to collisions over the launch, operation, and disposal phases

(c) Assessment of the on-orbit break-up and vulnerability risk for tether systems -including:

(1) Analysis to determine the probability of catastrophic collisions with objects or debris over the launch, operation, and disposal phases

(2) Analysis to determine the probability of damage or failure due to collisions over the launch, operation, and disposal phases

NOTE On-orbit break-up and vulnerability risk analysis is described in Annex C of ESSB-HB-U-002-Issue2.

5) On-orbit collision risk

(a) Analysis to determine the expected number of conjunctions against trackable objects and definition of an appropriate reaction threshold

(b) Review of design to ensure that adequate resources, Delta-v, propellant mass are allocated for collision avoidance manoeuvres

(c) Consolidated measures to manage collision avoidance manoeuvres, including reference to operational procedures and data distribution systems where applicable, and assessment of their impact on other operations

(d) Information on space surveillance and trackability, including description of the space surveillance segment and assessment of trackability: identification and state accuracy

NOTE On-orbit collision risk is described in Annex C of ESSB-HB-U-002-Issue2.

6) Disposal

(a) Description of the disposal option

NOTE Example of disposal options are controlled re-entry, uncontrolled re-entry, manoeuvres to a graveyard orbit, other means.

(b) Identification of all subsystems or components to accomplish any disposal manoeuvre

(c) Plan of the manoeuvres to accomplish the disposal phase, including engine type, thrust level, manoeuvre or coasting sequence and duration, initial orbit parameters, intermediate or transfer orbits parameters, final orbit parameters, propellant mass, and Delta-v

(d) Orbit propagation analysis assessing the orbit lifetime, or presence, after the disposal manoeuvres to identify a disposal orbit not interfering with the protected regions and not operational orbits of known constellations and with a cumulative collision probability with space objects, debris and meteoroids larger than 1 cm below $10^{-3}$ during the remaining orbit lifetime until the atmospheric re-entry or up to 100 years including:

(1) Object physical and geometrical parameters and related dispersion margins:

- Cross-sectional area
- Drag coefficient
- Mass
- Ballistic coefficient
- Solar radiation pressure reflectivity coefficient

(2) Model assumptions:

- Atmospheric density
- Earth gravitational attraction
- Lunisolar attraction
- Solar activity, solar flux and geomagnetic index

(3) Initial conditions:

- Orbital parameters and epoch at the end of the operation phase
- Orbital parameters and epoch after the disposal manoeuvres

(4) Tool and methodology used

(5) Justification for the used methodology and assumptions

(6) Estimation of the presence in the LEO or GEO Protected Regions

(e) When not in near Earth orbit, preliminary orbit propagation analysis assessing the probability of return to Earth orbit, or re-entry, in 100 years through the mission in case of failure or orbit instability, and after disposal manoeuvres, and determine the final state Lunar orbits, SEL-2.

(f) Probability of successful disposal analysis and health monitoring:

(1) Analysis to determine the probability of successful disposal, including the system reliability and impacts with space debris or meteoroids, which is based on

- subsystems, units and functions used for the disposal only
- worst-case space environment assumptions, if the mission orbit is defined within a given range

(2) Space system health monitoring: parameters and approach for the control of the risk of degradation of the disposal operations

(3) Anomaly report: status during the operations, if relevant to risk of degradation of the disposal operations

(g) Description of design for removal implementations and associated analyses,

NOTE Orbit propagation analysis and Probability of successful disposal analysis are described in Annex C of ESSB-HB-U-002-Issue2.

7) Passivation - For each component storing energy, specify:

(a) Component type and subsystem

(b) Number of items

(c) Design measures allowing passivation

(d) Operational procedure allowing passivation

(e) Residual type and quantity of energy after the passivation operations

(f) Rationale if design measures or operational procedures do not allow full passivation

(g) Explosion risk and potential effects on space debris generation, if passivation is not fully accomplished

(h) Available options for passivation and the related additional impact on project cost, effort, and schedule in order to allow passivation of the components that have not been planned for passivation

NOTE Example of options for passivation are new developments, or platform modification or changes.

8) Re-entry

(a) Identification of the system functions that contribute to the controlled re-entry, if planned

(b) Identification of the re-entry scenario and related Fault Tree leading to nominal controlled, degraded controlled, and uncontrolled re-entry, and associated on ground risk

(c) Re-entry casualty risk analysis for all elements likely to re-enter (based on the most updated re-entry conditions, including:

(1) Object physical and geometrical assumptions at re-entry that is last orbit before fragmentation events:

- Model and design of the assembly
- Design details of components: shape, sizes, mass, material, accommodation

(2) Model assumptions:

- Atmospheric density
- Earth gravitational attraction
- Solar activity: solar flux and geomagnetic index
- Earth population model
- Ground impact probability
- Fragmentation model
- Controlled or uncontrolled re-entry approach

(3) Initial conditions

- Orbital parameters and epoch at re-entry, that is last orbit before fragmentation events
- Attitude at re-entry

(4) Tool and methodology used

(5) Justification for the used methodology and assumptions

(6) Results:

- Physical properties of each surviving fragments: size, shape, mass, material
- Dynamic properties of each surviving fragment: impact velocity, kinetic energy
- Casualty area of each surviving fragment
- Total casualty area
- Casualty risk
- Declared Re-entry Area (DRA) and Safety Re-entry Area (SRA)
- Floating or non-floating fragments

(d) Notification Plan for re-entry, that is schedule and procedure for the issue of the NOTAM, if controlled re-entry is planned

NOTE Re-entry casualty risk analysis is described in ESSB-HB-U-002-Issue2.

9) Hazardous materials – summary of the hazardous materials contained on the space object, including:

(a) Chemical and commercial name of the material

(b) Description of how material is hazard to humans: explosive, carcinogen, toxic, radioactive

(c) Material state gas, liquid, solid or powder and mass/volume and pressure at launch

(d) Material state gas, liquid, solid or powder and mass/volume and pressure at the operation phase

(e) Material state gas, liquid, solid or powder and mass/volume and pressure at end of mission / end of passivation

(f) Material state gas, liquid, solid or powder and mass/volume and pressure at released in the atmosphere at re-entry

(g) Material state gas, liquid, solid or powder) and mass/volume and pressure expected to survive at re-entry

10) Dark and quiet skies (for spacecraft)

(a) Assessment of the visual brightness of the spacecraft

(b) Description of the implemented design and operational mitigation measures to reduce the visual brightness of the spacecraft

(c) Description of the implemented design and operational measures to protect the Radio Astronomy Service

(d) Description of the implemented data sharing approach

11) Contingency plan

g. The SDMR shall contain the compliance and verification information, including:

1) Compliance and Verification Matrix, including identification of the applicable SDM requirements, status of the compliance with the SDM requirements, justification, close-out documents, and close-out status

2) List of events that can cause violation of the requirements and relevant consequences (e.g. description and characteristics of debris generated)

h. The SDMR shall contain the launch service compliance information, including:

1) Assessment of the compliance with the SDM requirements

**Table B-1: Example of compliance and verification matrix**

| **Req. Id.** (see NOTE 1) | **Requirement** (see NOTE 2) | **Compliance Status (C/PC/NC/NA)** (see NOTE 3) | **Verification Method(s)** (see NOTE 4) | **Justification** (see NOTE 5) | **Close-out Reference** (see NOTE 6) | **Close-out Status** (see NOTE 7) |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |

1. Identification of the requirement from ESSB-ST-U-007.
2. Requirement text from ESSB-ST-U-007.
3. Status of the compliance: Compliant (C), Partial Compliant (PC), Not Compliant (NC), Not Applicable (NA).
4. Verification methods: Test (T), Analysis (A), Review-of-design (ROD), Inspection (I).
5. Justification of the requirement applicability or not applicability and rationale for the statement of compliance.
6. Reference to any documentation that demonstrates compliance with the requirement (e.g. section of the SDMR, reports, analysis, RFD/RFWs).
7. Close-out status: open or closed.

# Annex C (informative) Requirements applicability matrix

## C.1 Scope

This Annex provides:

- A mapping of the requirements applicability to the different orbital regions and object types defined in ESSB-ST-U-007.
- A comparison of this standard with respect to the ISO24113:2023 and ECSS-U-AS-10C Rev.2 standards, including equivalent requirements, and modified, conflicting or new requirements introduced in this standard

## C.2 Orbital regions and object type applicability

Table C-1 provides the field of applicability of each requirement, depending on the Orbital Region and the Type of Object.

The specific terminology recalled in the requirements regarding orbital regions, i.e. "operating in", "crossing", "injected into", is specified in clause 3.4.4.

The specific requirements for constellations, large constellations and formation flying satellites are considered in addition to the ones for spacecraft.

**Table C-1: Requirements applicability matrix**

| ID | | LEO | GEO | Near Earth orbit | Earth orbit | Lunar orbit | Spacecraft | Launch vehicle orbital stage | Launch vehicle orbital element | Constellation | Large constellation | Close proximity operations / Formation flying |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5.1** | | **Overview** | | | | | | | | | | |
| **5.1.** | | X | X | X | X | X | X | X | X | X | X | X |
| **5.2** | | **Restricting the intentional release of space debris into Earth orbit during normal operations** | | | | | | | | | | |
| **5.2.1** | | | | | | | | | | | | |
| **5.2.1.** | **a** | X | X | X | X | | X | X | X | X | X | |
| **5.2.1.** | **b** | X | X | X | X | | X | X | X | X | X | |
| **5.2.2.** | | **Space debris from pyrotechnics, solid rocket motors, and degradation** | | | | | | | | | | |
| **5.2.2.** | **a** | X | X | X | X | | | X | X | | | |
| **5.2.2.** | **b** | X | X | X | X | | | X | X | | | |
| **5.2.2.** | **c** | | X | | X | | X | | X | X | X | |
| **5.3.** | | **Avoiding break-ups in Earth orbit** | | | | | | | | | | |
| **5.3.1.** | | **Intentional break-up** | | | | | | | | | | |
| **5.3.1.** | **a** | X | X | X | X | | X | | X | X | X | |
| **5.3.2.** | | **Accidental break-up caused by an on-board source of energy** | | | | | | | | | | |
| **5.3.2.1.** | | **Preventing break-ups during normal operations** | | | | | | | | | | |
| **5.3.2.1.** | **a** | X | X | X | X | | | X | X | | | X |
| **5.3.2.2.** | | **Passivation** | | | | | | | | | | |
| **5.3.2.2.** | **a** | X | X | X | X | | X | X | X | X | X | |
| **5.3.2.2.** | **b** | X | X | X | X | | X | X | X | X | X | |
| **5.3.2.2.** | **c** | X | X | X | X | | X | X | X | X | X | |
| **5.3.2.2.** | **d** | X | X | X | X | | X | X | X | X | X | |
| **5.3.3.** | | **Accidental break- up caused by a collision** | | | | | | | | | | |
| **5.3.3.1.** | | **Collision risk assessment during design** | | | | | | | | | | |
| **5.3.3.1.** | **a** | X | X | X | X | | X | | X | X | X | |
| **5.3.3.2.** | | **Collision avoidance implementation** | | | | | | | | | | |
| **5.3.3.2.** | **a** | X | X | X | X | | X | X | X | X | X | |
| **5.3.3.2.** | **b** | X | X | X | X | | | X | X | | | |
| **5.3.3.2.** | **c** | X | X | X | | | X | | | X | X | X |
| **5.3.3.2.** | **d** | X | X | X | | | X | | | X | X | |
| **5.3.3.2.** | **e** | X | X | X | | | X | | X | X | X | |
| **5.3.3.2.** | **f** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | | **Collision risk management during operations** | | | | | | | | | | |
| **5.3.3.3.** | **a** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **b** | X | | | | | X | | | X | X | |
| **5.3.3.3.** | **c** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **d** | X | X | X | | | X | | | X | X | |

| ID | | LEO | GEO | Near Earth orbit | Earth orbit | Lunar orbit | Spacecraft | Launch vehicle orbital stage | Launch vehicle orbital element | Constellation | Large constellation | Close proximity operations / Formation flying |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5.3.3.3.** | **e** | X | X | X | | | X | X | X | | | |
| **5.3.3.3.** | **f** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **g** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **h** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **i** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **j** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **k** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **l** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **m** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **n** | X | X | X | | | X | | | X | X | |
| **5.3.3.3.** | **o** | X | X | X | | | X | | | X | X | |
| **5.3.3.4.** | | **Collision risk management for close proximity operations and formation flying** | | | | | | | | | | |
| **5.3.3.4.** | **a** | X | X | X | X | | X | X | X | | | X |
| **5.3.3.4.** | **b** | X | X | X | X | | X | | | X | X | X |
| **5.3.3.4.** | **c** | X | X | X | X | | X | X | X | X | X | X |
| **5.3.3.4.** | **d** | X | X | X | X | | X | X | X | X | X | X |
| **5.3.3.4.** | **e** | X | X | X | X | | X | X | X | | | X |
| **5.3.3.4.** | **f** | X | X | X | X | | X | X | X | X | X | X |
| **5.3.3.5.** | | **Space surveillance and tracking** | | | | | | | | | | |
| **5.3.3.5.** | **a** | X | X | X | X | | X | | X | X | X | |
| **5.3.3.5.** | **b** | X | X | X | | | X | X | X | X | X | |
| **5.3.3.5.** | **c** | X | X | X | X | | X | | | X | X | |
| **5.3.3.5.** | **d** | X | X | | | | X | | X | X | X | |
| **5.3.3.5.** | **e** | X | X | X | X | | X | | X | X | X | |
| **5.3.3.5.** | **f** | X | X | X | X | | X | | X | X | X | |
| **5.3.3.5.** | **g** | X | X | X | | | X | | | X | X | |
| **5.3.3.5.** | **h** | X | X | X | | | X | | | X | X | |
| **5.3.3.5.** | **i** | X | X | X | X | | X | | | X | X | X |
| **5.4.** | | **Disposal** | | | | | | | | | | |
| **5.4.1.** | | **Successful disposal** | | | | | | | | | | |
| **5.4.1.1.** | | **Probability of successful disposal** | | | | | | | | | | |
| **5.4.1.1.** | **a** | X | X | X | X | | X | X | X | X | X | |
| **5.4.1.1.** | **b** | X | X | X | | | X | | | X | X | |
| **5.4.1.2.** | | **Health monitoring** | | | | | | | | | | |
| **5.4.1.2.** | **a** | X | X | X | X | | | X | X | | | X |
| **5.4.1.2.** | **b** | X | X | X | X | | X | | | X | X | |
| **5.4.1.2.** | **c** | X | X | X | X | | X | | | X | X | |

| ID | | LEO | GEO | Near Earth orbit | Earth orbit | Lunar orbit | Spacecraft | Launch vehicle orbital stage | Launch vehicle orbital element | Constellation | Large constellation | Close proximity operations / Formation flying |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5.4.1.2.** | **d** | X | X | X | X | | X | | | X | X | |
| **5.4.1.2.** | **e** | X | X | X | X | | X | | | X | X | |
| **5.4.1.2.** | **f** | X | X | X | X | | X | | | X | X | |
| **5.4.1.2.** | **g** | X | X | X | X | | X | | | X | X | |
| **5.4.1.2.** | **h** | X | X | X | X | | X | | | X | X | |
| **5.4.1.3.** | | **Preparation for removal** | | | | | | | | | | |
| **5.4.1.3.** | **a** | X | | | | | X | | | X | X | |
| **5.4.1.3.** | **b** | | X | | | | X | | | X | X | |
| **5.4.1.3.** | **c** | X | X | | | | X | | | X | X | X |
| **5.4.1.3.** | **d** | X | X | | | | X | | | X | X | |
| **5.4.1.3.** | **e** | X | | | | | X | | | X | X | |
| **5.4.1.3.** | **f** | X | X | | | | X | | | X | X | X |
| **5.4.1.3.** | **g** | X | X | | | | X | X | X | X | X | X |
| **5.4.2.** | | **General Earth orbit clearance** | | | | | | | | | | |
| **5.4.2.** | **a** | X | X | X | X | | X | | X | X | X | |
| **5.4.2.1.** | | **GEO protected region clearance** | | | | | | | | | | |
| **5.4.2.1.** | **a** | | X | | | | X | X | X | X | X | |
| **5.4.2.2.** | | **LEO protected region clearance** | | | | | | | | | | |
| **5.4.2.2.** | **a** | X | | | | | X | | X | X | X | |
| **5.4.2.2.** | **b** | X | | | | | X | | X | X | X | |
| **5.4.2.2.** | **c** | X | | | | | X | | | X | X | |
| **5.4.2.3.** | | **Initial orbit insertion** | | | | | | | | | | |
| **5.4.2.3.** | **a** | X | X | X | X | | X | | | X | X | |
| **5.4.2.3.** | **b** | X | X | X | X | | X | | | X | X | |
| **5.4.2.3.** | **c** | X | | | | | X | | | X | X | |
| **5.4.3.** | | **Re-entry** | | | | | | | | | | |
| **5.4.3.** | **a** | X | | X | X | | | X | X | | | |
| **5.4.3.** | **b** | X | | X | X | | X | X | X | X | X | |
| **5.4.3.** | **c** | X | | X | X | | X | X | X | X | X | |
| **5.4.3.** | **d** | X | | X | X | | X | | | X | X | |
| **5.5.** | | **Dark and quiet skies** | | | | | | | | | | |
| **5.5.** | **a** | X | X | X | | | X | | X | X | X | |
| **5.5.** | **b** | X | X | X | | | X | | | X | X | |
| **5.5.** | **c** | X | X | X | | | X | X | X | X | X | |
| **5.5.** | **d** | X | X | X | | | X | | X | X | X | |
| **5.6.** | | **Lunar orbits** | | | | | | | | | | |
| **5.6.1.** | | **Avoiding the creation of space debris** | | | | | | | | | | |

| ID | | LEO | GEO | Near Earth orbit | Earth orbit | Lunar orbit | Spacecraft | Launch vehicle orbital stage | Launch vehicle orbital element | Constellation | Large constellation | Close proximity operations / Formation flying |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5.6.1.** | **a** | | | | | X | X | X | X | X | X | |
| **5.6.1.** | **b** | | | | | X | X | X | X | X | X | |
| **5.6.1.** | **c** | | | | | X | X | X | X | X | X | |
| **5.6.1.** | **d** | | | | | X | X | X | X | X | X | |
| **5.6.2.** | | **Space traffic coordination** | | | | | | | | | | |
| **5.6.2.** | **a** | | | | | X | X | | X | X | X | |
| **5.6.2.** | **b** | | | | | X | X | | X | X | X | |
| **5.6.3.** | | **Disposal** | | | | | | | | | | |
| **5.6.3.** | **a** | | | | | X | X | X | X | X | X | |
| **5.6.3.** | **b** | | | | | X | X | | X | X | X | |
| **5.6.3.** | **c** | | | | | X | X | | X | X | X | |
| **5.6.3.** | **d** | | | | | X | X | | X | X | X | |
| **5.6.3.** | **e** | | | | | X | X | | X | X | X | |

# C.3 Requirements comparison

Table C-3 provides an overview of the evolution of the requirements with respect to ISO 24113:2023 and ECSS-U-AS-10C Rev.2, using the legend in Table C-2.

The "Comment" column in Table C-3 quotes the requirements from ISO 24113:2023 and ECSS-U-AS-10C Rev.2 corresponding to each ESSB-ST-U-007 requirement, where the ESSB-ST-U-007 requirement is an equivalent or modified requirement.

**Table C-2: Colour coding legend for requirements comparison**

| | |
|---|---|
| 1 | Equal or equivalent |
| 2 | Modified or Conflict: ESSB-ST-U-007 takes precedence |
| 3 | Not covered: ESSB-ST-U-007 new requirement |

**Table C-3: Comparison of Space Debris Mitigation requirements in various standards**

| ID ESSB-ST-U-007 | | ISO 24113:2023 | ECSS-U-AS-10C Rev.2 | Comment |
|---|---|---|---|---|
| **5.2** | **Space debris release restriction** | | | |
| **5.2.1** | **General** | | | |
| 5.2.1 | a. | 2 | 2 | 7.1.1.1 |
| 5.2.1 | b. | 2 | 2 | 7.1.1.2 |
| **5.2.2** | **Space debris from pyrotechnics, solid or hybrid propellant rocket motors, or resulting from environment-induced degradation** | | | |
| 5.2.2 | a. | 1 | 1 | 7.1.2.1 |
| 5.2.2 | b. | 2 | 1 | 7.1.2.2 |
| 5.2.2 | c. | 3 | 3 | |
| **5.3** | **Avoiding break-ups in Earth orbit** | | | |
| **5.3.1** | **Intentional break-up** | | | |
| 5.3.1 | a. | 2 | 2 | 7.2.1 |
| **5.3.2** | **Accidental break-up caused by an on-board source of energy** | | | |
| **5.3.2.1** | **Preventing break-ups during normal operations** | | | |
| 5.3.2.1 | a. | 1 | 1 | 7.2.2.1, 7.2.2.2, 7.2.2.3, 7.2.2.4 |
| **5.3.2.2** | **Passivation** | | | |
| 5.3.2.2 | a. | 3 | 3 | |
| 5.3.2.2 | b. | 2 | 2 | 7.2.2.5, 7.2.2.6 |
| 5.3.2.2 | c. | 3 | 3 | |
| 5.3.2.2 | d. | 3 | 3 | |
| **5.3.3** | **Accidental break-up caused by a collision** | | | |
| **5.3.3.1** | **Collision risk assessment during design** | | | |
| 5.3.3.1 | a. | 2 | 2 | 7.2.3.4 |
| **5.3.3.2** | **Collision avoidance implementation** | | | |
| 5.3.3.2 | a. | 3 | 3 | |
| 5.3.3.2 | b. | 3 | 2 | ECSS: 7.2.3.5, 7.2.3.6 |
| 5.3.3.2 | c. | 2 | 2 | 7.2.3.1 |
| 5.3.3.2 | d. | 3 | 3 | |
| 5.3.3.2 | e. | 3 | 3 | |
| 5.3.3.2 | f. | 3 | 3 | |
| **5.3.3.3** | **Collision risk management during operations** | | | |
| 5.3.3.3 | a. | 3 | 3 | |
| 5.3.3.3 | b. | 3 | 3 | |
| 5.3.3.3 | c. | 3 | 3 | |
| 5.3.3.3 | d. | 3 | 3 | |
| 5.3.3.3 | e. | 3 | 3 | |
| 5.3.3.3 | f. | 3 | 3 | |
| 5.3.3.3 | g. | 3 | 3 | |
| 5.3.3.3 | h. | 3 | 3 | |
| 5.3.3.3 | i. | 2 | 2 | 7.2.3.3 |
| 5.3.3.3 | j. | 3 | 3 | |
| 5.3.3.3 | k. | 3 | 3 | |
| 5.3.3.3 | l. | 3 | 3 | |
| 5.3.3.3 | m. | 3 | 3 | |
| 5.3.3.3 | n. | 3 | 3 | |
| 5.3.3.3 | o. | 3 | 3 | |

| ID ESSB-ST-U-007 | | ISO 24113:2023 | ECSS-U-AS-10C Rev.2 | Comment |
|---|---|---|---|---|
| **5.3.3.4** | **Collision risk management for close proximity operations and formation flying** | | | |
| 5.3.3.4 | a. | 3 | 3 | |
| 5.3.3.4 | b. | 3 | 3 | |
| 5.3.3.4 | c. | 3 | 3 | |
| 5.3.3.4 | d. | 3 | 3 | |
| 5.3.3.4 | e. | 3 | 3 | |
| 5.3.3.4 | f. | 3 | 3 | |
| **5.3.3.5** | **Space surveillance and tracking** | | | |
| 5.3.3.5 | a. | 3 | 3 | |
| 5.3.3.5 | b. | 3 | 3 | |
| 5.3.3.5 | c. | 3 | 3 | |
| 5.3.3.5 | d. | 3 | 3 | |
| 5.3.3.5 | e. | 3 | 3 | |
| 5.3.3.5 | f. | 3 | 3 | |
| 5.3.3.5 | g. | 3 | 3 | |
| 5.3.3.5 | h. | 3 | 3 | |
| 5.3.3.5 | i. | 3 | 3 | |
| **5.4** | **Disposal** | | | |
| **5.4.1** | **Successful disposal** | | | |
| **5.4.1.1** | **Probability of successful disposal** | | | |
| 5.4.1.1 | a. | 2 | 1 | 7.3.1.1 |
| 5.4.1.1 | b. | 3 | 3 | |
| **5.4.1.2** | **Health monitoring** | | | |
| 5.4.1.2 | a. | 1 | 1 | 7.3.1.3, 7.3.1.5 |
| 5.4.1.2 | b. | 3 | 3 | |
| 5.4.1.2 | c. | 3 | 3 | |
| 5.4.1.2 | d. | 2 | 2 | 7.3.1.4 |
| 5.4.1.2 | e. | 3 | 3 | |
| 5.4.1.2 | f. | 2 | 2 | 7.3.1.6 |
| 5.4.1.2 | g. | 3 | 3 | |
| 5.4.1.2 | h. | 3 | 3 | |
| **5.4.1.3** | **Preparation for removal** | | | |
| 5.4.1.3 | a. | 3 | 3 | |
| 5.4.1.3 | b. | 3 | 3 | |
| 5.4.1.3 | c. | 3 | 3 | |
| 5.4.1.3 | d. | 3 | 3 | |
| 5.4.1.3 | e. | 3 | 3 | |
| 5.4.1.3 | f. | 3 | 3 | |
| 5.4.1.3 | g. | 3 | 3 | |
| **5.4.2** | **General Earth orbit clearance** | | | |
| 5.4.2 | a. | 2 | 2 | 7.1.1.3, 7.3.2.1, 7.3.2.3, 7.3.3.2, ECSS 7.3.3.3 |
| **5.4.2.1** | **GEO protected region clearance** | | | |
| 5.4.2.1 | a. | 1 | 1 | 7.3.2.2 |
| **5.4.2.2** | **LEO protected region clearance** | | | |
| 5.4.2.2 | a. | 2 | 2 | 7.3.3.1 |
| 5.4.2.2 | b. | 2 | 2 | 7.3.3.1 |
| 5.4.2.2 | c. | 3 | 3 | |

| ID ESSB-ST-U-007 | | ISO 24113:2023 | ECSS-U-AS-10C Rev.2 | Comment |
|---|---|---|---|---|
| **5.4.2.3** | **Initial orbit insertion** | | | |
| 5.4.2.3 | a. | 3 | 3 | |
| 5.4.2.3 | b. | 3 | 3 | |
| 5.4.2.3 | c. | 3 | 3 | |
| **5.5** | **Re-entry** | | | |
| 5.5 | a. | 1 | 1 | 7.3.4.1 |
| 5.5 | b. | 2 | 2 | 7.3.4.3 |
| 5.5 | c. | 3 | 3 | |
| 5.5 | d. | 3 | 3 | |
| **5.6** | **Dark and quiet skies** | | | |
| 5.6 | a. | 3 | 3 | |
| 5.6 | b. | 3 | 3 | |
| 5.6 | c. | 3 | 3 | |
| 5.6 | d. | 3 | 3 | |
| **5.7** | **Lunar orbits** | | | |
| **5.7.1** | **Avoiding the creation of space debris** | | | |
| 5.7.1 | a. | 3 | 3 | |
| 5.7.1 | b. | 3 | 3 | |
| 5.7.1 | c. | 3 | 3 | |
| 5.7.1 | d. | 3 | 3 | |
| **5.7.2** | **Space traffic coordination** | | | |
| 5.7.2 | a. | 3 | 3 | |
| 5.7.2 | b. | 3 | 3 | |
| **5.7.3** | **Disposal** | | | |
| 5.7.3 | a. | 3 | 3 | |
| 5.7.3 | b. | 3 | 3 | |
| 5.7.3 | c. | 3 | 3 | |
| 5.7.3 | d. | 3 | 3 | |
| 5.7.3 | e. | 3 | 3 | |

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