ISO/DTR 18146:2025(E)

ISO TC20/SC14/WG7/TC 20/SC 14

Date: 2024-12-09

Secretariat: ANSI/AIAA

Date: 2025-04-04

Space systems — Space debris mitigation design and operation manual for spacecraft

Systèmes spatiaux — Conception de réduction des débris spatiaux et manuel d'utilisation pour les engins spatiaux

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO ~~documents~~document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This third edition cancels and replaces the second edition (ISO/TR 18146:2020), which has been technically revised.

The main changes compared to the previous edition are as follows:

— ~~—~~text has been updated to be aligned with ISO 24113:2023[1~~[1]~~;];

— ~~—~~ISO 16127 was cancelled and requirements relating to prevention of break-up have been transferred to ISO 23312[4~~ISO23312[4]. So that~~]; references to ISO 16127 ~~has~~have been replaced by ISO 23312[4~~to ISO23312[4] in this document.~~];

— ~~—~~ISO 16164 was cancelled and requirements relating to disposal of satellites operating in or crossing ~~Low~~low Earth ~~Orbit~~orbit have been transferred to ISO 23312[4~~ISO23312[4]. So that~~]; references to ISO 16164 ~~has~~have been replaced by ISO 23312[4~~to ISO23312[4] in this document.~~];

— ~~—~~ISO 23339 was cancelled and requirements relating to mass estimation for residual propellant for disposal manoeuvres have been transferred to ISO 23312[4~~ISO23312[4]. So that~~]; references to ISO 23339 ~~has~~have been replaced by ISO 23312[4~~to ISO23312[4] in this document.~~];

— ~~—~~ISO 26872 was cancelled and requirements relating to disposal of satellites operating at geosynchronous altitude have been transferred to ~~ISO23312[4]. So that~~ ISO 23312[4]; references to ISO

26872 hashave been replaced toby ISO 23312[4][4] and appendixISO 26872:2019, Annexes A, B, C and D of ISO 26872 have been transferred to this document,;

— — in 5.3.2sub-clause 5.3.2,, the rationale to restrict anti-satellite missile testing as a mean of intentional destruction has been added,;

— — in 5.3.4sub-clause 5.3.4,, the methods to assess the probability of break-up caused by impact of debris hashave been added corresponding to the requirement of ISO 24113:2023,[1][1], 7.3.1.2,;

— — characteristics of Space Debris Mitigation Plan hasthe space debris mitigation plan have been explained in detailed and Annexes EAppendix E and FF have been added to show the examples.;

— — other information relating to the changes in ISO 24113[1][1] has been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Coping with debris is essential to preventing the deterioration of the orbital environment and ensuring the sustainability of space activities. Effective actions are also taken to ensure the safety of those on the ground from re-entering objects that were disposed of from low -Earth orbit.

Recently, the orbital environment has become so deteriorated by debris that action isactions are taken to prevent damage due to the impact. Collision avoidance manoeuvres are taken to avoid large debris (e.g. larger than 10 cm, for example), which can be observed from the ground. Spacecraft design protects against micro-debris (even smaller than 1 mm) that can cause critical damage to vulnerable components.

This TR was designed to explaindocument explains the rationale of requirements in ISO 24113[1] of ISO24113[1] and provideprovides information ofon the process or works to comply withconform to those requirements. Clause 5 In Clause 5, informs the major space debris mitigation requirements are informed.

In Clause 6Clause 6,, the information of life-cycle implementation of space debris mitigation related activities is provided.

In Clause 7Clause 7,, the system level aspects stemming from the space debris mitigation requirements are highlighted; while in Clause 8Clause 8,, the impacts at subsystem and component levels are detailed.

This document provides comprehensive information on what ISO requires to do forthe requirements and recommendations from ISO documents on the design and operation of the launch vehicles, and where such requirements and recommendations are registered in a set of ISO documents.

Space systems — Design — Space debris mitigation design and operation manual for spacecraft

1 Scope

This document contains information on the design and operational practices for launch vehicle orbital stages for mitigating space debris.

This document provides information to engineers on what are required or recommended in the family ofdocuments on space debris mitigation standardsdeveloped by ISO/TC 20/SC 14 to reduce the growth of space debris by ensuring that spacecraft is designed, operated, and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime.

2 Normative reference

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminologicalterminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Symbols and abbreviatedAbbreviated terms

A/M	area-to-mass
AOCS	attitude and orbit control system
CDR	critical design review
CFRP	carbon-fibre-reinforced plastic
CNES	Centre National d'Etudes Spatiales
CSpOC	Combined Space Operations Center (USA)
DAS	debris assessment software (NASA)
COTS	commercial off-the-shelf
DRAMA	debris risk assessment and mitigation analysis (ESA)
EOMDP	end-of-mission (operation) disposal plan
ESA	European Space Agency
FDIR	failure detection, isolation, and recovery
FMEA	failure mode and effect analysis
GEO	geosynchronous Earth orbit
GPSR	global positioning system receiver

IADC	Inter-Agency Space Debris Coordination Committee
IRU	inertial reference unit
LEO	low Earth orbit
MASTER	meteoroid and space debris terrestrial environment reference
MIDAS	MASTER (-based) impact flux and damage assessment software
NOTAM	notice to airmen and notice to mariners
OLI	operation time limited item
ORDEM	orbital debris engineering model
PDR	preliminary design review
PNF	probability of no failures
QA	quality assurance
QR	qualification review
RCS	reaction control system
SDA	Space Data Association
SDR	system definition review
SDMP	space-debris-mitigation plan
STELA	semi-analytic tool for end of life analysis (CNES)
USSTRATCOM	United States strategic command
TCBM	Transparency and Confidence Building Measurestransparency and confidence building measures
TLE	two-line element set
TT&C	telemetry tracking and command
UN	United Nations

5 System-level activities

5.1 General

To accomplish comprehensive activities for debris mitigation and protection work, the following steps are considered:

a) a) identifying debris-related requirements, recommendations, and best practices.;

b) b) determining how to comply withconform to these requirements, recommendations, and best practices.;

c) c) Applyingapplying those methods early and throughout development and manufacturing to ensure sound debris mitigation capability in the final product.;

d) d) Applyingapplying appropriate quality assurance and qualification program to ensure complianceconformity with debris mitigation requirements;

e) e) Applyingapplying appropriate procedures during operation/utilisation and disposal to implement proper space debris mitigation and protection.

This subclauseclause provides information useful for taking comprehensive actionactions at the system level. More detailed information for action ofactions at subsystem and component levels is provided in Clause 6Clause 6.. The following specific subjects are emphasized:

— — limiting the release of objects in protected orbital regions;

— — preventing fragmentation in orbit (including intentional break-ups, and accidental break-ups caused by collision with trackable objects, impact of tiny debris, and stored energy);

— — proper disposal at the end of operation;

— — minimization of hazard on the ground from re-entering debris;

— — quality, safety, and reliability assurance.

5.2 Design for limiting the release of objects

5.2.1 Intents of requirements in ISO 24113[1 [1]]

ISO 24113:2023,[1][1], 7.1 requires avoiding the intentional release of space debris into Earth orbit during normal operations, including general objects such as fasteners, fragments from pyrotechnics, slag from solid rocket motors, etc.

The following objects are of concern from an orbital debris mitigation standpoint:

a) a) objects released as directed by mission requirements (not directorydirectly indicated in ISO 24113:2023,[1][1], 7.1.1.1, though);

b) b) mission-related objects, such as fasteners, apogee motor cases, etc. (ISO 24113:2023,[1][1], 7.1.1.1);

c) c) fragments and combustion products from pyrotechnic devices (ISO 24113:2023,[1][1], 7.1.2.1);

d) d) slag ejected from solid motors (ISO 24113:2023,[1][1], 7.1.2.2).

It implies that if objects are unavoidably released despite requirements in ISO 24113:2023,[1][1], 7.1.1.1, the orbital lifetime of such objects in LEO and interference with GEO is limited as described in ISO 24113:2023,[1][1], 7.1.1.3.

5.2.2 5.2.2 Work breakdown

Table 1Table 1 shows the work breakdown for the actions required to prevent the releasing of debris.

Table 1 — Work breakdown for preventing the release of objects

Process	Subjects	Major work
Preventive measures	Identification of released objects and design measures	a) a) In the mission, which releases objects required by mission objectives, the effect on the orbital environment and the expected benefit for the mission are assessed." b) b) Taking preventive design to avoid releasing objects turning into space debris (ISO 24113:2023,[1][1], 7.1). c) c) If objects might be released unintentionally, designers investigate design problems and take appropriate action during design phase (e.g. insulators).

Process	Subjects	Major work
		d) ~~d)~~ If release is unavoidable, designers estimate the orbital lifetime of released objects and check ~~compliance~~conformity with ISO 24113:2023,[1] 7.1.1.3. e) ~~e)~~ When applying the solid motors, the possible generation of slag and its risk posed to space activities are assessed.
Risk detection	Monitoring during operation	a) ~~a)~~ Confirming that the orbiting characteristics of released parts are as estimated, if needed. b) ~~b)~~ If an unexpected object is detected, the origin of the objects is confirmed.
Countermeasures	Preventive measures	If an object is released unexpectedly, it is investigated, and appropriate action is taken to avoid repeating the release in the following missions.

5.2.3 Identification of released objects and design measures

The designed parts that are released are identified. Their orbital lifetimes are estimated. The propriety of their release is determined.

a) ~~a)~~ Mission requirements that require dispersing objects

~~Assess~~Assessing the effects of proposed mission requirements on the environment. If the proposed mission can deteriorate the environment more than justified by its benefit, system engineering can suggest alternative approaches.

Examples are:

1) ~~1)~~ The experiment called "WESTFORD NEEDLES," conducted in *1961 and* 1963, scattered 480 million needles in orbit. More than 100 clumps of needles have been registered and many of them are still in orbit. NASA, JSC, Orbital Debris Quarterly News, Volume 17[2] reported that :"the legacy of Project West Ford can still be found in international policies, including the first major United Nations accord on activities in outer space that calls for international consultations before undertaking an experiment which might cause ~~"~~potentially harmful interference with activities of other State Parties in the peaceful exploration and use of outer space~~.~~."

2) ~~2)~~ Missions that conduct intentional fragmentation (one of the major causes of deterioration of the orbital environment).

b) ~~b)~~ Mission-related objects

Release of the following objects are avoided by appropriate mission and spacecraft design (ISO 24113:2023,[1] 7.1.1):

1) ~~1)~~ fasteners for deploying and holding devices for panels or antennas;

2) ~~2)~~ nozzle closures and igniters of solid motors;

3) ~~3)~~ clamp bands that tie spacecraft and launch vehicles (usually as launch vehicle components).

NOTE The structural elements which support upper spacecraft used in the multi-payloads launching missions can be released due to their unavoidability. Disposal orbits of these elements are ~~complied~~in accordance with ISO 24113:2023,[1] 7.1.1.2. (These elements usually belong to the launch vehicle, not the spacecraft.)

c) ~~c)~~ Fragments and combustion products from pyrotechnic devices

Devices are selected and/or designed to avoid the production and release of the fragments of parts or the combustion by-products. Employing vehicle components that trap all fragments and combustion products inside for segregation (ISO 24113:2023,[1] ~~[1],~~ 7.1.2.1).

d) ~~d)~~ Combustion products from solid motors

Solid motors are designed not to generate slag in both GEO and LEO protected regions (higher than the manned orbit ~~[=,~~ approximately 400 km~~])~~.) (ISO 24113:2023,[1] ~~[1],~~ 7.1.2.2)

5.2.4 Design measures

In general, only devices that do not release parts into the space environment are selected.

CSpOC sometimes detects released cases of the apogee kick motors. The solid motors are not used for the apogee kick motors if they generate slag. Furthermore, it is refrained from disposing the motor cases into the orbit crossing the GEO protected region.

If parts would be released due to unavoidable reasons, the orbital lifetime of the parts and the risk of impact on another spacecraft are assessed. The orbital lifetime can be assessed according to ISO 27852[3] ~~[3].~~, which does not designate a specific analysis tool but rather expects that the users employ their reliable techniques depending upon orbit regime, so that designers can select any tool(s) which adhere to ISO 27852[3] ~~[3]~~ approved techniques. Available simplified tools that can be used to estimate the long term orbital lifetime are, for instance: NASA DAS (https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html), ESA DRAMA (after creating an account at https://sdup.esoc.esa.int/ one can obtain a license before downloading), or CNES STELA (https://www.connectbycnes.fr/stela).

5.2.5 Monitoring during operation

The released objects, if they are larger than 10 cm, are confirmed with ground-based space tracking facilities to ensure that they are released as expected and that their orbital lifetimes are sufficiently short. The space situation report provided by the CSpOC provides a good reference.

5.2.6 Preventing failure

If objects are released unexpectedly, the origin of the objects can be identified to help prevent recurrence in future missions. Because such phenomena can indicate a malfunction, the situation is reviewed carefully, and appropriate action taken to prevent further abnormal conditions.

5.3 Prevention of break-up

5.3.1 General

ISO 24113:2023,[1] ~~[1],~~ 7.2 requires the prevention of break-ups caused by intentional behaviour, stored energy, collision with catalogued objects, and impact of debris or meteoroid. In 5.3.2~~5.3.2~~, the first two subjects are discussed. The collision with catalogued objects is addressed in 5.3.3~~5.3.3~~; and the impact of debris and meteoroid in 5.3.4~~5.3.4~~.

ISO 23312:2022,[4] ~~[4],~~ 6.2 provides ~~more~~ detailed requirements and procedures ~~for complying with them~~.

5.3.2 ~~5.3.2~~ Break-up caused by intentional behaviour~~,~~ or stored energy

5.3.2.1 Work breakdown for preventing orbital break-up caused by intentional behaviour~~,~~ or stored energy

Table 2~~Table 2~~ shows the work breakdown for preventing orbital break-up caused by intentional behaviour~~,~~ or stored energy.

Table 2 — Work breakdown for preventing orbital break-ups caused by intentional behaviour~~,~~ or stored energy

Process	Subjects	Major work
Preventive measures	Mission assessment	Mission which involves the intentional break-up is assessed to justify its intention is essential for peaceful use of space, and its effect on the environment can be controllable. However, according to the resolution of G7 2023 held in Hiroshima, it is recognised that destructive direct-ascent anti-satellite missile testing can be refrained in terms of preservation of orbital environment and TCBM.
	Identification of sources of breakup	Identifying components that can cause fragmentation during or after operation.
	Design measures	a) ~~a)~~ Missions that involve intentional break-ups are not designed. b) ~~b)~~ Taking preventive design to limit the probability of accidental break-up. Confirm it in FMEA. c) ~~c)~~ Providing functions for to prevent break-ups after disposal.
Risk detection	Monitoring during operation	a) ~~a)~~ Providing functions to monitor symptoms of break-up. b) ~~b)~~ Monitoring the critical parameters periodically. c) ~~c)~~ Taking immediate actions if the symptom of a malfunction that can lead to a breakup is detected.
Countermeasures	Preventive measures for break-up	Performing the disposal operations to eliminate the risk of break-ups.

5.3.2.2 Identification of the sources of break-up

For post-operation break-ups, ISO 23312:2022[4~~[4].~~] 6.2.2, identifies the following components as the most likely causes of the break-up of spacecraft:

a) ~~a)~~ batteries in the electrical subsystem;

b) ~~b)~~ propulsion mechanisms and associated components (such as engines, thrusters~~, etc.);~~);

c) ~~c)~~ pressurized components (such as tanks or bottles in the propulsion subsystems, or pneumatic control system, and heat pipes);

d) ~~d)~~ rotating mechanisms.

5.3.2.3 Design measures

a) ~~a)~~ Intentional break-up