INTERNATIONAL STANDARD

ISO 16127

First edition
2014-02-15

Space systems — Prevention of break-up of unmanned spacecraft

Systèmes spatiaux — Prévention de l'éclatement des navettes sans pilote

Reference number
ISO 16127:2014(E)

Contents

Page

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 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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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

An ever-increasing number of man-made items are orbiting the Earth and bring with them ever-increasing risk of collisions. This can have implications on the operational requirements of both manned and unmanned spacecraft.

One potential source of space debris is the break-up of unmanned spacecraft both during and after the end of their operational lives. This break-up could be due either to external collisions or to internal factors caused by the existence of stored energy sources onboard the spacecraft. A cloud of debris from a single spacecraft having broken up poses a significantly greater threat of collision than the original spacecraft.

This International Standard defines the requirements to reduce the probability of a spacecraft breaking up, both during and after its operational life. It also defines the requirements for passivation of the spacecraft, which is the process by which all sources of stored energy are removed.

Space systems — Prevention of break-up of unmanned spacecraft

1 Scope

This International Standard defines the requirements to reduce the risk of in-orbit break-up of unmanned spacecraft, both during and after their operational lives. The aim would be met by reducing the possibility of a break-up caused by an unplanned internally caused event and by depleting to a safe level all the sources of stored energy at the end of a spacecraft's life. This International Standard is designed for use in planning, verifying, and implementing the prevention of break-up of a spacecraft.

This International Standard applies only to unmanned spacecraft operating in Earth orbit. It does not apply to manned space vehicles or launch vehicle orbital stages. Additionally, it does not cover nuclear power sources within spacecraft.

This International Standard is not applicable to fragmentation as a result of external particle impacts (which includes fragmentations triggered by external particle impact but powered by internal energy sources).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14623, *Space systems - Pressure vessels and pressurized structures — Design and operation*

ISO 24638, *Space systems — Pressure components and pressure system integration*

ISO 24113:2011, *Space systems — Space debris mitigation requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24113:2011 and the following apply.

3.1
acquiring organization
organization that plans and manages the development and acquisition contracts for the space system

Note 1 to entry: The responsibilities of the acquiring organization include the engineering and technical aspects of the space system's design and operations.

3.2
break-up probability
combined probability of the occurrence of all anomalous events, excluding meteoroid or debris impact, that leads to the generation of orbital debris

3.3
passivation
elimination of all stored energy on a space system to reduce the chance of break-up

Note 1 to entry: Typical passivation measures include venting or burning excess propellant, discharging batteries, and relieving pressure vessels.

4 Implementation

4.1 Design process

In accordance with ISO 24113, the spacecraft shall be designed to prevent break-ups while in orbit, both before end of life and after the end of life.

The spacecraft shall be designed to prevent break-ups while in orbit until its end of life, in accordance with probability levels defined in ISO 24113:2011, 6.2.2.1, and to enable passivation before its end of life. Calculations shall be performed to determine the accidental break-up probability. Annex A reports an example of an acceptable detailed evaluation approach.

The design process and the definition of the operations (including operational and disposal phases) shall prevent potential failures which could occur during operational life, but also after the end of life. All onboard sources of stored energy, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels, and momentum wheels, shall be depleted or safed and permanently deactivated once they are no longer required for the mission operation.

The spacecraft provider shall produce a break-up prevention plan. This plan shall be reviewed and updated as part of the normal spacecraft design review process. The acquiring organization/operator shall be involved with these design reviews and approve the proposed solutions. All management shall be done in accordance with ISO 24113.

When producing the break-up prevention plan, a system level risk assessment approach shall be used. Each source of stored energy shall be considered: what potential failure modes could result in an in-orbit break-up of the spacecraft (including post-disposal phase) and what can be performed to mitigate the risk in the design, operational, and disposal phases of the mission as well as after the end of life. Annex A provides further details regarding producing the plan.

The plan shall be developed by considering each item containing stored energy. The design shall take into account the following influences:

— the environmental extremes expected to be encountered during the operational life and following passivation, but excluding re-entry phase;

— mechanical degradation during the mission and following passivation;

— chemical decomposition;

— the effect of potential failure modes of the spacecraft during the mission, and what effect they would have on the ability to passivate the spacecraft.

The robustness of the design shall be confirmed during the design review process, to ensure that adequate reliability and quality control has been performed to inhibit any failure that could lead to a break-up event with a probability as defined in ISO 24113.

4.2 Verification

Throughout the ground phases of a mission, i.e. design, manufacture, AIT (Assembly, Integration, and Test), and launch, the implementation of the break-up prevention plan shall be reviewed. All the hardware and software designed specifically for the purpose of break-up prevention should be verified either by test, demonstration, analysis, or simulation (in that order of preference).

4.3 Prevention of break-ups until end of life

4.3.1 Monitoring during operations

For the operations of the spacecraft, procedures should be defined to allow monitoring of the relevant parameters of each subsystem, which has been identified as a possible source of space debris generation, in order to detect malfunctions.

The risk of potential malfunctions shall be considered within the break-up prevention plan, which shall include a contingency plan to mitigate against the risk of the malfunction causing a break-up.

The following items should, as a minimum, be monitored from the ground, if applicable:

— pressure and temperature in the tanks;

— parameters (temperature and voltage) of batteries to detect failures;

— parameters to detect failure modes of the orbit and attitude control system.

4.3.2 Debris mitigation measures in the case of malfunction

In the event of in-orbit malfunctions which could lead to 1) break-up or 2) the loss of operating function, possible debris mitigation measures should be studied and implemented (reduction of orbital lifetime or removal from a protected orbit region and passivation at the end of disposal).

At the time when satellite operation is concluded either purposefully or due to malfunction and other disposal actions have been completed, passivation shall be performed.

4.4 Prevention of break-up after end of life

Prevention of break-up after mission is guaranteed through the passivation process, which shall be completed at an appropriate point during the disposal phase. A passivation procedure shall be produced prior to the end of the design phase. Prior to the disposal phase, this shall be updated to take into account any failures that have occurred during the mission and that affect the ability to passivate the spacecraft.

No operations that will generate orbital debris of greater than 1 mm in size shall be performed during the passivation process, excepting the release of frozen propellant.

5 Stored energy sources

5.1 Systems storing energy

The following systems are most likely to cause the break-up of a spacecraft:

— electrical systems, especially batteries;

— propulsion systems and associated components;

— pressurized systems;

— rotating mechanisms.

It should be noted that this International Standard does not cover nuclear power sources on spacecraft.

5.2 Electrical systems

5.2.1 Batteries

The design of each battery pressure vessel and its margins of safety shall be in accordance with a standard that defines the safe in-orbit operation of this type of vessel. See Bibliography for examples of such standards.

Batteries should be adequately designed and manufactured, both structurally and electrically, to prevent break-ups and to allow the maximum reduction of the stored energy at the end of the disposal phase (unless these measures cause an excessive reduction of mission assurance). Pressure increase in battery cells and assemblies could be prevented by mechanical measures unless these measures cause an excessive reduction of mission assurance. At the end of operations, battery charging lines should be deactivated.

5.3 Propulsion systems

5.3.1 System design

The design of each propulsion pressure vessel and its margins shall be in accordance with a standard that defines the safe in-orbit operation of this type of vessel. See Bibliography for examples of such standards.

The break-up prevention plan shall detail the sources of stored energy within the propulsion system.

For a bipropellant propulsion system, especially with hypergolic propellants, tanks and lines should be so designed that any single-point failure will not cause the unplanned mixture or combustion of the propellants.

5.3.2 Propulsion system passivation

Before end of life, as part of the disposal phase, the spacecraft should have consumed or vented any residual liquid propellants and pressurized fluids, which are potential sources of break-ups.

Cold gas, liquefied gas, and xenon-based electric propulsion systems shall be vented through a vent port or thrusters. Completion of venting shall be monitored by proper means, such as on-board pressure sensors, fluid gauging systems, thermal sensing, attitude sensing, or any other demonstrable means.

If it is not possible to vent, a sufficient safety margin to ensure no break-ups under expected post-disposal environmental conditions should be adopted.

The venting system and process shall be designed to achieve passivation, even in the presence of propellant freezing.

The venting process should be defined to take into account any potential effects on the spacecraft's attitude or orbit and any ground visibility issues.

5.3.2.1 Tailoring of requirements for residual fluids

Some typical system designs do not allow for complete fluid venting during passivation. This limitation can typically (but not exclusively) be applicable in the following cases:

— bipropellant system pressurant gases which have been pyrotechnically isolated following main engine firings;

— ullage gases used in diaphragm/bladder/piston tanks;

— liquid propellant trapped within tanks or pipework that cannot be vented.

In these cases, the pressure vessel and all pressurized systems shall be designed in accordance with space industry pressure vessel/component standards.

Propellants or pressurants can be retained within the vessel/system provided that:

— The quantity of residual fluid is too small to cause break-up of the system.

— The pressure is below the level at which a crack can propagate under cycling due to pressure and/or thermal effects.

— No exothermal dissociation of the propellant occurs due to tank heating.

— No leak occurs that can cause the mixture of hypergolic propellants.

— The design of tanks (for example, leak-before-burst design) and the efficiency of thermal protection inhibit pressure build-up that can cause tank explosion.

— For composite vessels, account is taken of effects of the degradation of the composite materials.

— In case of vaporizing, freezing, or freeze/thaw cycling of liquid propellants, pressurized systems shall remain within their design constraints.

— There is no failure-relevant weakening of pressure vessels due to fluid-induced corrosion.

5.3.3 Solid rocket motors

Solid rocket motors can only be actuated in the case that there have been no sensor indications of motor degradation due to mission-induced damage or due to adverse environmental conditions.

5.4 Pressurized systems

5.4.1 Pressurized system design requirements

All pressurized systems shall be designed and qualified in accordance with the relevant requirements of ISO 14623 and ISO 24638.

5.4.2 Heat pipes/fluid loops

Fluid systems used for the thermal control of the spacecraft are typically not designed to be vented, hence no specific operations can be performed in the disposal phase. However, the design of thermal control fluid systems shall be in accordance with the relevant standards for safe in-orbit operation of pressurized systems.

5.5 Other energy sources

5.5.1 Rotating hardware

All rotating devices, for example flywheels, reaction wheels, momentum wheels, etc., shall be designed such that failure of the rotating part shall not cause break-up under normal mechanical environmental conditions.

All rotating parts shall be allowed to de-spin, or stopped by termination of the power supply, at the end of life.

5.5.2 Other devices

Any other energy sources shall be assessed to confirm that they do not cause break-up and generate fragments outside of the parent body. This shall cover pyrotechnically operated devices.

Annex A
(informative)

Procedure for estimating break-up probability

A.1 General

This procedure is informative as other methods can be proposed to estimate the probability of break-ups.

This International Standard is required to limit break-up probability to a level as specified in ISO 24113. This Annex provides analytical procedures to verify compliance with this requirement. The analysis covers the period up to the end of life of the spacecraft, i.e. the point at which the spacecraft is permanently turned off.

A.2 Background

Historical reports indicate that accidental break-ups of spacecraft have been caused by batteries and collisions with other space objects. On-board propulsion systems, both solid and bipropellant, have been suspected of causing spacecraft break-up. In addition, the orbital stages of launch vehicles have been broken up by the explosion of hypergolic (homogeneous) sets of propellants and ruptures of tanks due to the vaporization of cryogenic propellant.

A.3 Procedure

The steps in the recommended procedure are outlined below and discussed in more detail in the remainder of this Annex.

1) For each failure mode of interest, construct fault trees to identify the components associated with the failure mode and the functional relationship among these components (e.g. identify if components are connected in series, parallel, or using some other kind of functional connection). A Failure Modes and Effects Analysis (FMEA) can support this process.

2) For each component associated with the failure mode, the break-up probability should be inputs to the fault tree analysis to estimate the overall break-up probability if the failure mode of interest occurs. Probability data can be obtained through in-orbit heritage, design margins, analysis, or test. For example:

   a) For pressure vessels and other mechanical elements whose margins of safety are ensured by structural design, the break-up probability can be assumed to be zero.

   b) The break-up probability of a rotating mechanism in a container can be assumed to be zero, if designed to have sufficient margins of safety for the expected mechanical environment imposed during ground and orbital operation.

   c) Where the break-up event is at system level, i.e. the break-up is a symptom of one or more failures at system level, the break-up probability will be reviewed indirectly by its system reliability.

3) If the overall break-up probability is greater than or equal to a threshold defined in ISO 24113, identify corrective actions required to reduce this break-up probability to an acceptable level.

A.4 Fault tree analysis

A full system review, including historical failure data, should identify potential causes of break-up events. Consider only failure modes involving components having enough stored energy available to cause failures that would produce debris. Performing FMEAs in accordance with ISO 24113 will help ensure that all risk elements having the potential to generate debris are identified.

Examples include:

1) propellant tanks whose capacity is below the loading generated when propellants in the tanks are mixed and ignite,

2) a propulsion system whose capacity is below the loading generated when residual propellant (e.g. hydrazine) trapped in the system experiences a chemical reaction induced by mechanical shock, thermal heating, etc.,

3) a cryogenic propellant tank whose capacity is below the loading generated by the vaporization of cryogenic material in the tank, thus causing the tank to rupture, and

4) batteries whose break-up pressure is below the amount that could be generated when pressures inside the batteries are increased by electric failure and inadequate structural design or manufacturing.

The following cases can be excluded:

1) hardware whose stored energy is too small to damage its structural element or other components;

2) stored energy which will not lead to the ejection of fragments outside the spacecraft.

NOTE Fragmentations caused by external particle impacts are excluded from the scope of this International Standard.

Construct a fault tree to identify all the elements associated with the failure modes of break-ups as well as the functional relationship among these elements. Resulting fault trees should clearly show the functional relations among elements associated with the failure modes of break-ups. (See Figure A.1.)

The failure rate for each risk element should be identified and provided in a table with the fault tree for each failure mode.

A.5 Corrective action

If corrective action should be required, the design should be modified, and the risk assessment should be repeated starting at A.4.

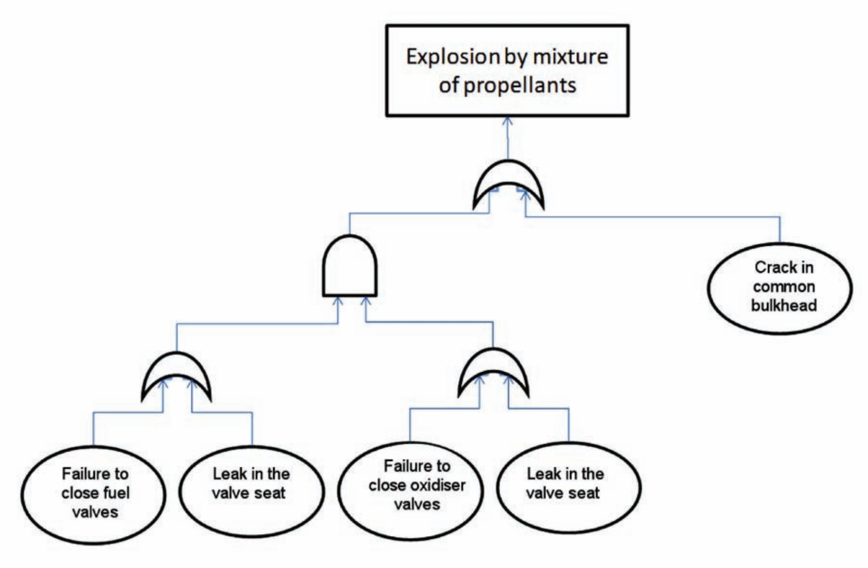

Figure A.1 — Fault tree analysis chart

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ICS 49.140

Price based on 9 pages