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Space systems — Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages

Systèmes spatiaux — Gestion du risque de la rentrée pour les étapes orbitales des véhicules spatiaux non habités et des lanceurs spatiaux

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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 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 on 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 the following URL: 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 second edition cancels and replaces the first edition (ISO 27875:2010) which has been technically revised. It also incorporates the Amendment ISO 27875/Amd1:2016. The main changes compared to the previous edition are as follows:

— revised 6.2;

— a Note 1 to entry was added to the definition of Ec;

— long sentences were divided into multiple sub-clauses with each sub-clause containing just one requirement.

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

According to international treaties, the “launching state” is liable for damage or injuries caused by unmanned spacecraft and launch vehicle orbital stages that re-enter the Earth's atmosphere. In addition, commercial operators are subject to the national safety regulations or laws of the launching country that relate to the re-entry of spacecraft and launch vehicle orbital stages. To minimise damage and injuries from re-entering spacecraft and launch vehicle orbital stages, all parties (i.e., developers, manufacturers, space service providers, satellite operators, and launch service providers) should take preventive measures during design and operations.

Space systems — Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages

1 Scope

This document provides a framework with which to assess, reduce, and control the potential risks that spacecraft and launch vehicle orbital stages (referred to hereinafter as "space vehicles") pose to people and the environment when those space vehicles re-enter the Earth's atmosphere and impact the Earth's surface. It is intended to be applied to the planning, design, and review of space vehicle missions for which controlled or uncontrolled re-entry is inevitable.

This document is applicable to following objects in assessing their risk to the ground:

a) objects re-entering from orbit in conformance with ISO 24113;

b) launch vehicles (including payloads, other objects separated during the ascent phase, etc.) that are mentioned in flight safety activities under ISO 14620-2[1]; and

c) interplanetary spacecraft returning to Earth.

This document complements ISO 14620-1 and ISO 17666.

This document is not applicable to spacecraft containing nuclear power sources[2].

NOTE 1 This document does not apply to Space Transportation Systems with wings and control functions intended for targeted landing.

NOTE 2 Useful background information for this document is available in ISO 24113.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14620-1, *Space systems — Safety requirements — Part 1: System safety*

ISO 17666, *Space systems — Risk management*

ISO 10795, *Space systems — Programme management and quality — Vocabulary*

ISO 24113, *Space systems — Space Systems Space debris mitigation requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10795, ISO 24113 and the following apply.

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

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

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

3.1
controlled re-entry
type of 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

Note 1 to entry: The designated area is usually an uninhabited region such as an ocean.

3.2
expected number of casualty
Ec
number of people who are predicted to be killed or seriously injured by an event

Note 1 to entry: The calculation of Ec is complex. Organizations use different processes to estimate Ec based on methods deemed applicable by the organizations. (see 5.5.1 and Annex C).

4 Re-entry risk management

4.1 General

Re-entry risk management shall be conducted according to ISO 17666, which is briefly explained in Annex B. This document mainly focuses on the estimation of the risk of casualty and partly on ground pollution. This document also presents requirements for when controlled re-entry would be conducted to reduce risk. This document acts as a part of a system safety programme based on ISO 14620-1.

4.2 Re-entry safety programme

In addition to the safety activities required by ISO 14620-1, a re-entry safety programme shall be established to ensure:

a) minimisation of damage and injuries caused by re-entering spacecraft or launch vehicle orbital stages; and

b) suggestions for corrective actions regarding risks assessed as exceeding safety requirements.

4.3 Re-entry safety oversight and management

As required in ISO 14620-1, safety representatives shall be appointed. Safety representatives shall be responsible for safety activities, have the right to access related data, and be authorized to reject any project document, stop any project activities, or interrupt hazardous operations. As required in ISO 14620-1, at each design or operation phase, a review committee should review the result of the safety assessment, review the plan for the next phase, and endorse the decision to proceed to the following phase. If there are requirements that cannot be met, a request for deviation or waiver is generated and reviewed, and the space vehicle is disposed according to ISO 14620-1.

4.4 Re-entry risk assessment and mitigation plan

4.4.1 Preparation of the plan

A Re-entry Risk Assessment and Mitigation Plan (RRAMP) shall be prepared and updated throughout the project life cycle as part of the safety data package specified in ISO 14620-1.

The RRAMP will define the work plan corresponding to each requirement in this document and detailed schedules for critical activities (design, analysis and testing reviews) throughout the life of the project. Typical contents of the RRAMP are given in Annex A.

4.4.2 Authorization of the plan

The RRAMP shall be approved by the safety representative, the head of project management, and the customers. The RRAMP will be changed and evolved as the project progresses.

4.5 Re-entry risk management concept

The scoring schemes for the severity of consequence of re-entry hazards are defined by the national authority. Based on ISO 17666, risk is assessed by the risk magnitude expressed as the combination of its severity and likelihood (see Annex B, and ISO 17666).

The scoring is typically related to the casualty area (see 5.5.1.2) in the case of casualty risk, damage of properties in the case of social risk, or pollution on the ground in the case of environmental risk (for example, see Table B.1, or ISO 17666). Generally, a risk index will be defined as a combination of severity and likelihood, and a risk magnitude will be defined for each risk index.

For assessing re-entry risk:

— In the case of natural re-entry, Ec is calculated as a function of the casualty area, orbital inclination, and population density. Since the re-entry cannot be avoided without control, likelihood is fixed as the probability of occurrence of 1,0, and the risk index is equivalent to the Ec. Sub-clause 5.5 describes assessment procedures for casualty risk in the case of natural re-entry. Sub-clause 5.6 for environmental risk.

— In the case of controlled re-entry, Ec is calculated in the same manner as for the natural re-entry (i.e., is a function of the casualty area, orbital inclination and population density), but the Ec is weighted by reliability of functions and sufficiency of propellants needed for controlling the re-entry. (See Annex B or ISO 17666). Sub-clause 7.4 describes assessment procedures for casualty risk in the case of controlled re-entry.

Proposed actions may be defined for each risk index (See Table B.3 and B.4, or ISO 17666.)

5 Risk assessment for the case of natural re-entry

5.1 General

A safety assessment shall be conducted to evaluate the risks associated with an uncontrolled re-entry and to determine the need for design improvements or a controlled re-entry. The safety assessment should include the following:

a) identification of the safety requirements;

b) identification of a standardized process and resources for analysis;

c) identification of system/mission dependent parameters;

d) estimation of risk; and

e) risk decision and actions.

NOTE Because the general concept for risk assessment is given in ISO 17666, this clause supplements specific requirements related to re-entry using terms (risk scenario, risk magnitude, risk decision and actions, etc.) defined in ISO 17666.

5.2 Identification of safety requirements

5.2.1 Identification of requirements

Specific re-entry safety requirements imposed contractually, voluntarily, or by national or international authorities shall be identified, and where possible, quantified with threshold parameters.

5.2.2 Risk assessment plan

Re-entry risk assessment actions (analyses, reports, etc.) shall be defined and scheduled, and a compliance matrix that correlates safety requirements against the system design and operation plan, which includes achieved quantitative results, threshold values, consequences of violating thresholds, and the probability that those consequences would be realized, shall be maintained.

The expected output is the assessment parameters (e.g., risk to people on the ground and its associated mathematical parameters) and their thresholds, or the concept for risk decision and the actions according to the severity of consequences and the likelihood of occurrence.

NOTE 1 Several national governments and space agencies adopt 0,000 1 persons as an acceptable upper limit for Ec.

NOTE 2 Generally, on-board radioactive substances, toxic substances, and any other hazardous materials are considered when evaluating and limiting the potentially adverse effects of re-entry on the Earth's environment.

5.3 Identification of standardized process and resources for analysis

A standardized process, to identify the safety requirements established by national or international authorities, shall be implemented by the entity which conducts the analysis. The standardized process shall designate methods, tools, models, and physical characteristics and properties of materials, as in the examples shown below.

a) Analysis tools, models, and approach, including:

1) algorithms for trajectory, aerodynamic, aerothermodynamic, and thermal analyses for re-entry trajectory and thermal analyses;

2) requisite physical characteristics, aerodynamic properties, and thermal properties for trajectory and thermal analyses;

3) Earth model and atmospheric model;

4) any constants or formulae for perturbations on the decaying trajectory;

5) human population distribution model;

6) definition of casualty area (see 5.5.1.2 for a typical definition of casualty area);

7) reduction in mass and size, and deformation due to ablation during re-entry; and

8) definition of the techniques and assumptions used to estimate the Ec (e.g., year of re-entry, population model, casualty area).

b) Analytic conditions, assumptions, or criteria for assessment

Due to the complexity of re-entry physics and material responses, detailed analyses will be necessary to obtain accurate estimates of aerodynamic and thermal phenomena. If there are technical uncertainties or insufficient resources, then simplified models, analytic conditions, criteria, or assumptions may be applied.

The following conditions may be assumed as given, for example:

1) attitude mode (e.g., tumbling, side-on stable, etc.);

2) contribution of oxidation to the heating rate;

3) standard conditions of the break-up process and sequence (e.g., de-facto altitude of the aerodynamic break-up point where the space vehicle is assumed to be disjoined into a set of components, a specific value acquired from the analysis, etc.);

4) initial temperature when the analysis starts;

5) criteria for eliminating any components from the risk analyses due to their low survivability; and

6) threshold for minimum impact energy that causes casualty.

5.4 Identification of system/mission dependent parameters

The following data shall be obtained from those organizations that are responsible for the design and operation of a space vehicle:

a) the object's physical characteristics, aerodynamic properties, and thermal properties;

b) orbital characteristics which define the initial point of re-entry analysis;

c) detailed characteristics of the space vehicle including its components (e.g., propellant tanks, pressurized vessels, major structural elements) and their architecture, mass, dimensions, shapes, connectivity, mutual shielding and nesting, and other factors (e.g., aerodynamic drag coefficient, coefficients for average heating); and

NOTE 1 Design data for deployment devices enable better estimation of the break-up point.

NOTE 2 It is important to list all of the components which are released when the space vehicle experiences break-up during re-entry. This is particularly the case for any components possibly surviving re-entry, and whose impact energy on the ground can be beyond the criteria defined in 5.3 b) 5).

d) properties of small but potentially surviving and hazardous objects that are likely to be released during re-entry.

5.5 Estimation of risk in the case of natural re-entry

5.5.1 Estimation of the number of casualties

5.5.1.1 Survivability analysis

A survivability analysis shall be conducted according to 5.3 and 5.4 to confirm compliance with the requirements in 5.2, and its result of the analysis shall include a list of objects that survive re-entry and impact on the ground.

5.5.1.2 Casualty area

5.5.1.2.1 Definition of casualty area

To estimate the risk of human casualty, a "casualty area" is typically defined as the average debris cross-sectional area plus a factor for the cross-sectional area of a standing individual which would have a "hazardous contact" with the "critical area of standing individual" ($A_{h\ critical}$). The total debris casualty area for a re-entry event is the sum of the debris casualty areas for all debris pieces surviving atmospheric re-entry. Here, "hazardous contact" is defined as contact that would cause casualty (injury or death); i.e., contact between an object which has an impact energy higher than the pre-defined threshold to prevent casualty and $A_{h\ critical}$ which is vulnerable to such a threshold for impact energy. Sub-clause C.2 shows one of the traditional methods for the calculation of casualty area.

5.5.1.2.2 Additional study for practical casualty area

It should be noted that methods presented in Annex C use an average cross-sectional area of a standing individual. The resulting "casualty area" does not necessarily represent the critical area which leads to fatal or serious injury. As one possible method to acquire a more practical value, a set of $A_{h\ critical}$ and threshold impact energies which cause casualty should be defined first. Next, "hazardous fragments" shall be selected as those whose impact energy are beyond said thresholds, and $A_{h\ critical}$ (the area of a skull, for example) and the projected area of hazardous fragments will be used to obtain the casualty area. Not limited to such a method, a space system developing entity should prepare adequate methods accepted by the authorities, and apply them to their analysis.

NOTE For a known re-entry location, the accuracy of the calculation of the casualty area is improved by considering the following conditions:

a) elongation (caused by factors such as wind);

b) secondary impact effects by fragments generated by the impact on the ground, or enlargement of casualty areas by multiple bounces on the ground; and

c) other factors that can enlarge the effective casualty area.

5.5.1.3 Expected number of casualties

If the safety requirement is defined by the expected number of casualties (Ec), it shall be calculated from at least the following values, and confirm conformance with the requirement:

a) sum of casualty areas of all the surviving objects;

b) predicted landing area defined by the latitude band corresponding to orbital inclination; and

c) number of residents in the predicted landing area at the time of the predicted landing event.

Sub-clause C.4 shows typical methods for calculation of Ec.

NOTE The probability of impact on the limited latitude band differs according to the latitude. In high latitude regions, the probability is relatively high, and in low latitude band, the probability is low. See Figure C.3.

5.5.2 Estimation and assessment of casualty risk

The scoring schemes for the severity of consequence will be defined by the national authority in accordance with the casualty area or Ec. (see Annex B).

The likelihood shall be scored in accordance with the probability of occurrence. In the simple case of natural re-entry caused by disposal from the operation orbit, the probability of occurrence is always 1,0 so that the risk magnitude will be defined by the score of the severity of consequence (see B.4).

Proposed actions would be defined in accordance with risk magnitude.

5.6 Assessment of environmental risk

In cases where there are on-board radioactive substances, toxic substances or any other environmental pollutants, a risk assessment for the effects on the Earth's environment, including human health, shall be conducted.

The scoring scheme for the severity of consequence would be defined by the national authority depending on the hazard level of on-board materials.

The likelihood would be scored as a function of the probability of occurrence considering the strength of containers and the location of impact on the Earth, i.e., whether it is on landmass or ocean.

