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Space systems — Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal

Systèmes spatiaux — Évaluation de la capacité de survie des véhicules spatiaux non habités face aux débris spatiaux et aux impacts de météoroïdes pour garantir une élimination efficace d'après-mission

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Foreword

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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*.

Space systems — Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal

1 Scope

This International Standard defines requirements and a procedure for assessing the survivability of an unmanned spacecraft against space debris and meteoroid impacts to ensure the survival of critical components required to perform post-mission disposal. This International Standard also describes two impact risk analysis procedures that can be used to satisfy the requirements. The procedures are consistent with those defined in References [1] and [2].

This International Standard is part of a set of International Standards that collectively aim to reduce the growth of space debris by ensuring that spacecraft are designed, operated, and disposed of in a manner that prevents them from generating debris throughout their orbital lifetime. All of the primary debris mitigation requirements are contained in a top-level International Standard.[3] The remaining International Standards, of which this is one, provide methods and processes to enable compliance with the primary requirements.

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 10795:2011, *Space systems — Programme management and quality — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10795:2011 and the following apply.

3.1
at-risk area
area of those parts of a surface on a component that are most vulnerable to impacts from space debris or meteoroids

Note 1 to entry: See A.1 for a more detailed explanation of at-risk area.

3.2
ballistic limit
impact-induced threshold of failure of a structure

Note 1 to entry: A common failure threshold is the critical size of an impacting particle at which perforation occurs. However, depending on the characteristics of the item being hit, failure modes other than perforation are also possible.

3.3
catastrophic collision
collision leading to the destruction by fragmentation of a spacecraft

3.4
critical component
component whose failure would prevent the completion of an essential function on a spacecraft, such as post-mission disposal

3.5
critical surface
<impact survivability> surface of a component which, when damaged by impact, will cause the component to fail

3.6
disposal
actions performed by a spacecraft to permanently reduce its chance of accidental break-up, and to achieve its required long-term clearance of the protected regions

[SOURCE: ISO 24113:2011, 3.4, modified]

3.7
impact survivability
ability of a spacecraft to function after being exposed to the space debris or meteoroid environment

Note 1 to entry: A measure of impact survivability is the Probability of No Failure (PNF).

3.8
lethal collision
collision leading to the loss of a critical component on a spacecraft

3.9
orbital lifetime
period of time from when a spacecraft achieves Earth orbit to when it commences re-entry

[SOURCE: ISO 24113:2011, 3.12, modified]

3.10
protected region
region in space that is protected with regard to the generation of space debris to ensure its safe and sustainable use in the future

[SOURCE: ISO 24113:2011, 3.14]

3.11
re-entry
process in which atmospheric drag cascades deceleration of a spacecraft (or any part thereof), leading to its destruction or return to Earth

[SOURCE: ISO 24113:2011, 3.15, modified]

3.12
space debris
orbital debris
man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional

[SOURCE: ISO 24113:2011, 3.17]

3.13
spacecraft
system designed to perform specific tasks or functions in space

[SOURCE: ISO 24113:2011, 3.18]

4 Abbreviated terms

BLE	ballistic limit equation
HVI	hypervelocity impact
IADC	Inter-Agency Space Debris Coordination Committee
ISO	International Organization for Standardization
M/OD	meteoroid/orbital debris
PNF	Probability of No Failure
PNP	Probability of No Perforation
S/C	spacecraft

5 Impact survivability assessment requirements

5.1 During the design of a spacecraft, if an assessment is required to determine the survivability of the spacecraft against space debris and meteoroid impacts for the purpose of achieving successful post-mission disposal, then the procedure in Clause 6 shall be followed.

5.2 The results of an impact survivability assessment, the methodology used, and any assumptions made shall be approved by the customer of the spacecraft.

6 Impact survivability assessment procedure

6.1 General

6.2 and 6.3 describe a procedure for assessing the space debris and meteoroid impact survivability of a spacecraft.

6.2 Definition of survivability requirement

6.2.1 Specify a requirement for the survivability of the spacecraft against space debris and meteoroid impacts for the purpose of achieving successful post-mission disposal.

6.2.2 Express the survivability requirement in terms of a minimum allowable value of impact-induced Probability of No Failure, PNF_{min}, over the operational phase of the spacecraft.

NOTE The operational phase of a spacecraft can be understood by referring to Annex B in Reference [3].

6.3 Impact risk analysis

6.3.1 Perform an impact risk analysis to determine and compare the impact-induced Probability of No Failure of the spacecraft, $PNF_{\mathrm{s/c}}$, with the minimum allowable value, PNF_{min}.

6.3.2 If $PNF_{\mathrm{s/c}} < PNF_{\mathrm{min}}$, then take appropriate steps to reduce the impact risk.

NOTE Clauses 7 and 8 describe two procedures for analysing and reducing the impact risk.

7 Procedure for performing a simple impact risk analysis

7.1 General

7.1.1 A procedure for performing a simple analysis of the risk that a spacecraft will not be able to complete a successful post-mission disposal, as a result of impacts from space debris and meteoroids, is illustrated in Figure 1. The procedure, which is based on that recommended in Reference [1], is used to determine whether impacts from small-size space debris and meteoroids could cause the failure of components that are critical for post-mission disposal. That is, the procedure is concerned with evaluating lethal collisions rather than catastrophic collisions. If the risk analysis shows that there is a significant probability of failure, then this indicates the need for a more rigorous analysis to determine and validate possible protection enhancements to the spacecraft, including the design of shielding. Clause 8 provides such an approach.

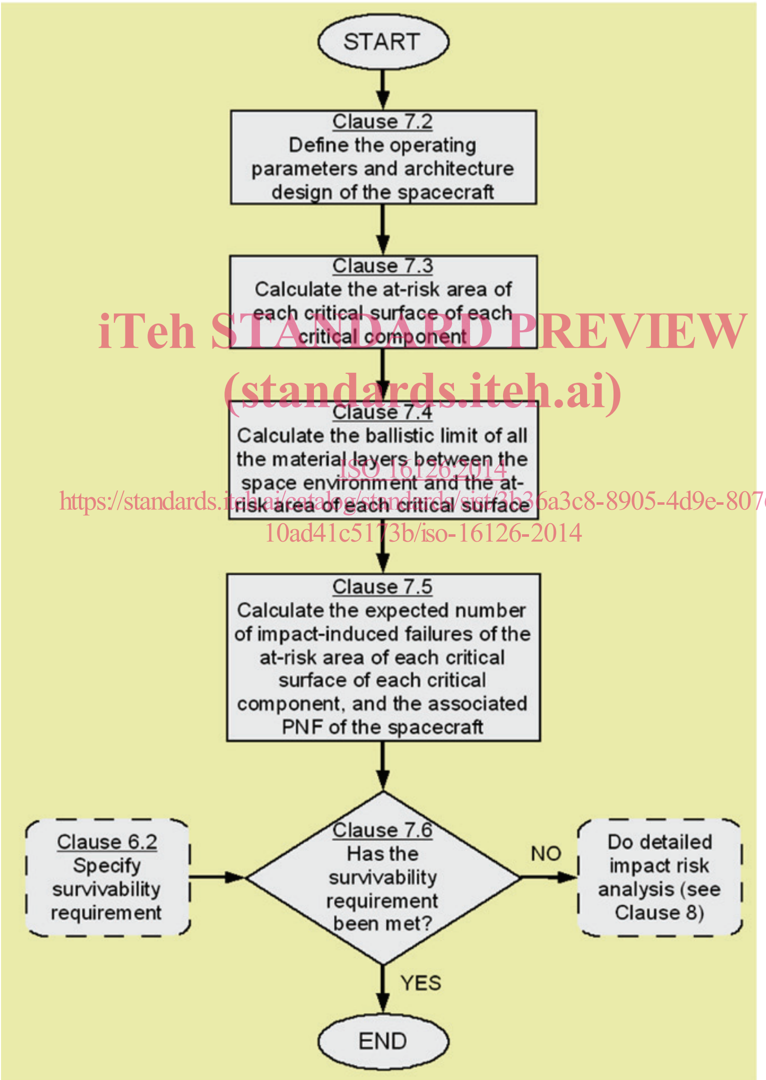

Figure 1 — Procedure for performing a simple analysis of the risk to a spacecraft from space debris and meteoroid impacts

7.1.2 7.2 to 7.6 describe each step in the procedure.

7.2 Spacecraft operating parameters and architecture design

7.2.1 Define the operating parameters of the spacecraft, such as its orbit and attitude orientation relative to the direction of motion.

7.2.2 Define the architecture design of the spacecraft, such as its configuration and dimensions, and the material properties of each of its surfaces, including any shielding.

7.3 Identification of critical components and surfaces

7.3.1 Identify every component on the spacecraft that contributes to post-mission disposal.

7.3.2 For each component identified in 7.3.1, determine its redundancy, impact damage modes, and failure criteria.

7.3.3 Use a reliability analysis technique, such as Fault Tree Analysis or Failure Modes and Effects Analysis, to identify the system-level consequences that might result when each of the components in 7.3.2 is damaged by impact.

7.3.4 Identify the critical components, i.e. those components which, when damaged by impact, would prevent post-mission disposal.

7.3.5 For each critical component, identify its most critical surface.

7.3.6 For each critical component, calculate the at-risk area of its most critical surface.

NOTE A.1 provides additional information on the calculation of at-risk area of a critical surface.

7.4 Ballistic limits

For each critical surface, do the following:

a) identify other elements of the spacecraft, e.g. components and structures that lie between the at-risk area of the critical surface and the space environment;

b) in the direction that has the least intervening material protecting the at-risk area of the critical surface from the space environment, identify the thickness and density of each layer of the material and hence its areal density;

c) in the direction that has the least intervening material protecting the at-risk area of the critical surface from the space environment, sum the areal densities of the material layers to obtain the total areal density between the at-risk area of the critical surface and the environment;

d) calculate the minimum diameter of space debris or meteoroid impactor that will penetrate the total areal density of material between the at-risk area of the critical surface and the environment.

NOTE A.2 provides additional information on the calculation of areal density and the minimum diameter of impactor that will penetrate a given areal density.

7.5 Failure probability analysis

7.5.1 For each critical surface, determine the expected number of impact-induced failures of the at-risk area of the critical surface.

7.5.2 Sum the expected number of impact-induced failures of the at-risk areas of all the critical surfaces to obtain the expected number of impact-induced failures of all the critical components.

7.5.3 Calculate the probability that one or more of the critical components will fail during the operational phase of the spacecraft as a result of impact with space debris or meteoroids, i.e. determine the impact-induced Probability of No Failure of the spacecraft, $PNF_{s/c}$, to achieve its post-mission disposal.

NOTE A.3 provides additional information on the calculation of the expected number of impact-induced failures and the probability of failure.

7.6 Completion of analysis

7.6.1 If $PNF_{s/c} \geq PNF_{min}$, then end the analysis.

7.6.2 If $PNF_{s/c} < PNF_{min}$, then perform a detailed impact risk analysis.

NOTE Clause 8 describes a procedure for performing a detailed impact risk analysis.

8 Procedure for performing a detailed impact risk analysis

8.1 General

8.1.1 A procedure for performing a detailed analysis of the risk that a spacecraft will not be able to complete a successful post-mission disposal, as a result of impacts from small-size space debris and meteoroids, is shown in Figure 2. Thus, the procedure is concerned with evaluating lethal collisions rather than catastrophic collisions. The procedure, which is based on that recommended in Reference [2], is used to provide a more accurate determination of the Probability of No Failure of the spacecraft, $PNF_{s/c}$, than that obtained in Clause 7. This is important when making decisions concerning the need for additional protection on the spacecraft and the design of that protection.

8.1.2 Figure 2 provides a simple illustration of the key steps in the procedure and the flow of information required between these steps. It is possible that the implementation of such a procedure in practice can be more complicated than that depicted in the figure.

8.1.3 8.2 to 8.6 describe each step in the procedure.

8.2 Spacecraft operating parameters and architecture design

8.2.1 Define the operating parameters of the spacecraft, such as its orbit and attitude orientation relative to the direction of motion.

8.2.2 Define the architecture design of the spacecraft, such as its configuration and dimensions, and the material properties of each of its surfaces, including any shielding.

8.3 Identification of critical components

8.3.1 Identify every component on the spacecraft that contributes to post-mission disposal.

8.3.2 For each component identified in 8.3.1, determine its redundancy, impact damage modes, and failure criteria.

8.3.3 Use a reliability analysis technique, such as Fault Tree Analysis or Failure Modes and Effects Analysis, to identify the system-level consequences that might result when each of the components in 8.3.2 is damaged by impact.

8.3.4 Identify the critical components, i.e. those components which, when damaged by impact, would prevent post-mission disposal.

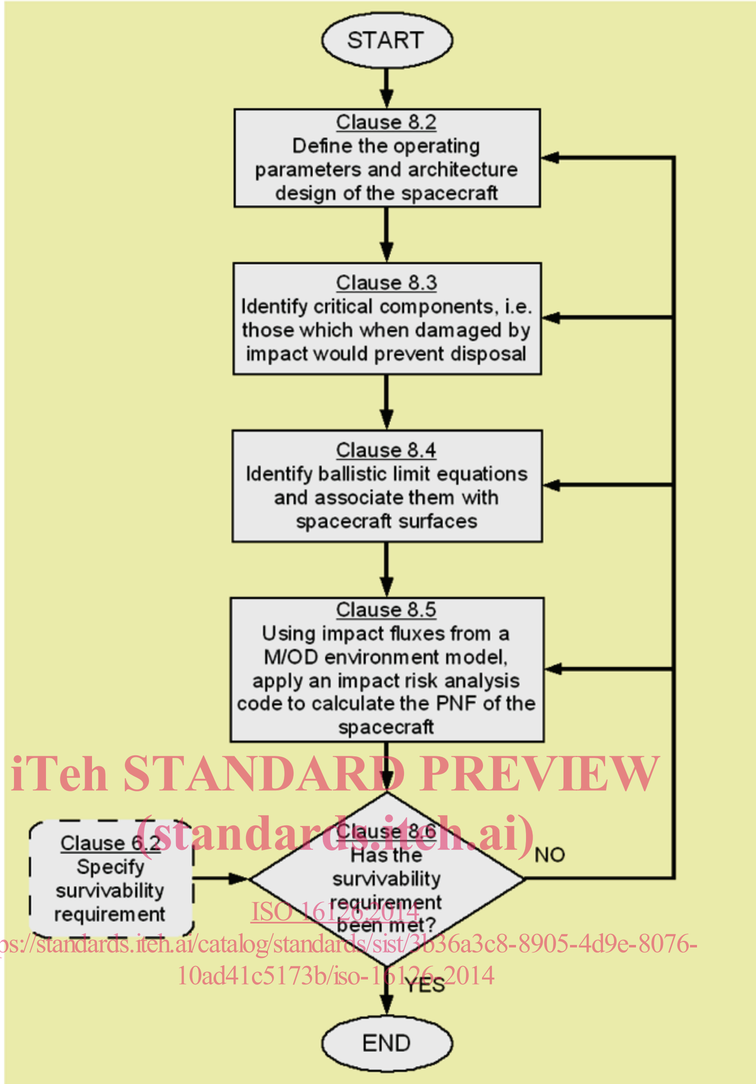

Figure 2 — Procedure for performing a detailed analysis of the risk to a spacecraft from space debris and meteoroid impacts

8.4 Ballistic limits

8.4.1 Identify existing ballistic limit equations (BLEs) that might be suitable for determining the ballistic limit of each surface or combination of surfaces on the spacecraft (including components).

NOTE Annex B identifies some commonly used BLEs.

8.4.2 If a suitable BLE cannot be identified for a particular surface or combination of surfaces, then adapt an existing formula or derive a new formula.

8.4.3 In satisfying 8.4.2, perform a set of hypervelocity impact (HVI) tests to derive a new BLE or verify the validity of an adapted BLE. Although the exact nature of the tests will depend on a range of factors, such as the configuration to be investigated, the following might be suitable for a variety of circumstances:

a) impact shots in each of the following three velocity ranges: the ballistic range (typically below ~3 km·s^{-1}), the transition range (typically between ~3 km·s^{-1} and ~7 km·s^{-1}), and the hypervelocity range (typically above ~7 km·s^{-1});