General

DESIGN STANDARD

Micro-debris Impact Survivability Assessment Procedure

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Japan Aerospace Exploration Agency

This is an English translation of JERG-2-144. Whenever there is anything ambiguous in this document, the original document (the Japanese version) shall be used to clarify the intent of the requirement.

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Contents

1. Scope

This standard describes the assessment procedure for verifying the validity of the protection design of satellites and probes (hereinafter referred to as spacecraft) against risks of impact with micro-debris and meteoroid (hereinafter referred to as debris) which are 1 mm or less in size and whose impact probability and impact damage is not negligible.

2. Related documents

2.1 Applicable documents

N/A

2.2 References

Related references shall be as follows:

(1) IADC-04-03 Protection Manual (April 2011).

3. Terminology, Definition and Abbreviation

3.1 Terms and Definitions

The terms are defined as followings:

(1) Impact conditions: Characteristics of the impacting object (mass, dimensions, impact speed, material characteristics, impact angle) and characteristics of the impacted object

(2) Ballistic limit: The limit leading to harmful damage represented by the diameter of the debris for each subject to be assessed.

(3) Failure probability: Expected probability of harmful damages (defined in Paragraph (6)) caused by debris impact per unit of time. This value can be defied considering the debris impact probability causing harmful damage and the redundancy of portions vulnerable to impact. When the impact probability is a function of time, this is also a function of time.

(4) Ballistic limit equation: Used as a meaning of "impact damage equation" to represent the ballistic limit defined by the diameter of debris

(5) Debris impact survivability requirement: Definition of allowable probability of harmful damage incidence represented by PNF_{min} (minimum non-failure probability)

(6) Harmful damage: Damage caused by debris impact which disables the functions of the components to be assessed. Depending on the characteristics of the component, the harmful damage mode covers damages such as perforation, craters larger than a predetermined size and damages on the cable shielding. Thus, it shall be determined in accordance with the characteristics of the component to be assessed.

3.2 Abbreviation

(1) IADC: Inter-Agency Space Debris Coordination Committee

(2) PNF: Probability of Non Failure

4. Condition for assessment

To ensure the spacecraft mission in the environment of the micro-debris and meteoroid, the following points including the system design must be coordinated with JAXA during the progress of the development of the system from the Mission Requirements Definition Phase.

(1) Consideration of debris density when determine the operational orbit altitude

(2) Consideration of the distribution of debris impact probability when determine the shape of spacecraft

(3) Setting the policy concerning the allowable limit of impact risk (mission importance, relationship with other redundant elements, etc.)

(4) Assessment in view of system design including the influence of loss of mass and layout change of components associated with impact protection measures (including allocation of resources)

(5) Setting a contingency plan including impact detection, damage monitoring, recovering, reconstruction and isolation

This standard serves as guidance for impact protection design on the condition that the spacecraft has been defined in shape, dimensions, operational orbital characteristics and operational period considering above conditions.

5. Impact survivability assessment guidelines

5.1 Standard requirement

In the spacecraft design phase, impact survivability shall be assessed to decide the necessity of measures against risks of debris impact potentially preventing successful disposal after the completion of spacecraft operation. How the mission equipment to be protected shall be determined depending on the characteristics of project.

5.2 Impact survivability assessment procedure

The assessment flow shall be as follows: (See the assessment flow diagram in the appendix.)

(1) Preparation of information for spacecraft design architecture and operational parameters
(2) Identification of requirements for debris impact survivability
(3) Identification of components to be assessed and their failure modes
(4) Identification of ballistic limit
(5) Impact probability analysis
(6) Calculation of failure probability and non-failure probability
(7) Assessment of impact survivability

5.3 Confirmation of spacecraft design architecture and operational parameters

The debris impact probability differs depending on the altitude and inclination of operation orbit, operation period, shape of the spacecraft, and location of components in the spacecraft to be assessed. In this sub-clause, such information needed for analysis shall be collected as analysis conditions.

5.3.1 Operational parameters

The spacecraft’s operational parameters including orbital characteristics (altitude, orbital inclination, etc.), attitude respected to travelling direction, and operation period, shall be identified.

5.3.2 Spacecraft design data

Geometric information including the shape and dimensions necessary for creating a spacecraft structural model, and design data necessary for definition of the damage modes shall be prepared.

5.4 Setting of requirements for resistance to debris impact

The spacecraft's system minimum non-failure probability (PNF min) against debris impact shall be defined as a requirement for impact survivability.

The basic idea of the impact survivability assessment is to confirm that the relation between the system minimum non-failure probability (PNF min) and the system non-failure probability (PNF S/C) obtained by the analysis satisfies the following equation.

$$PNF_{S/C} \geq PNF_{\min}$$

Generally the non-failure probability (PNF) is obtained by the following equation using the operation period (t) and the failure probability p(t) calculated from the debris impact probability which causes damages exceeding the ballistic limit. In this process, if there were the redundant elements an adequate consideration shall be paid as in the case of the reliability analysis.

$$PNF = \exp\left[-\int_0^t p\ (t)dt \right]$$

If the failure rate (λ) during the operation period is assumed to be constant, the equation would be simplified as follows:

$$PNF = e^{-\lambda t}$$

5.5 Identification of components to be assessed and their failure modes

Vulnerable components subject to harmful damage due to debris impact shall be identified for assessment. At least the vulnerable components necessary for disposal operation shall be identified. Failure modes leading to harmful damage shall be identified using reliability analysis technology such as FMEA.

(Reference: The failure modes to be identified should include the damage of shielding for power cable leading to short circuit, and perforation in the propellant tank leading to blowout, etc. Details shall be determined according to the design concept of the spacecraft.)

5.6 Identification of ballistic limit

For the assessment of components identified in sub-clause 5.5, the minimum diameter of debris causing damage exceeding the ballistic limit shall be identified by collecting the design information (structural wall facing to the direction of debris impact, shielding materials, satellite structure panels and stand-off distance with them), identifying the adequate existing ballistic limit equation, and assuming the impact characteristics (including debris material, impact speed, and impact angle).

If an available ballistic limit equation cannot be obtained, it shall be coordinated with JAXA to apply the existing equation or derive a new equation by conducting a hypervelocity impact test and simulation analysis.

5.7 Impact probability analysis

The spacecraft structural shape shall be modeled based on the design information obtained in sub-clause 5.3. The impact probability of each surface of the spacecraft shall be understood from the operational parameters and operational period.

The impact probability of the entire spacecraft system shall be detailed to the impact probability with debris whose diameter exceeds the ballistic limit for each component to be assessed. The impact probability during the entire operation period shall be calculated by integrating the impact probability per unit period along the operation period with the projected area in the impact direction of the components to be assessed.

5.8 Calculation of failure probability and non-failure probability

For each component to be assessed or for the system including the component, the non-failure probability during the operational period shall be calculated from the failure rate obtained by the impact probability. In case that the redundant elements would be exist, the same method as the reliability analysis would be considered.

For all the components to be assessed, the non-failure probability shall be calculated and compiled to the system non-failure probability (PNF S/C).

5.9 Assessment

5.9.1 The non-failure probability is larger than requirement

If the following relation can be confired, then analysis can be completed.

$$PNF_{S/C} \geq PNF_{\min}$$

5.9.2 The non-failure probability is smaller than the requirement

If the following relation is obtained, measures must be taken.

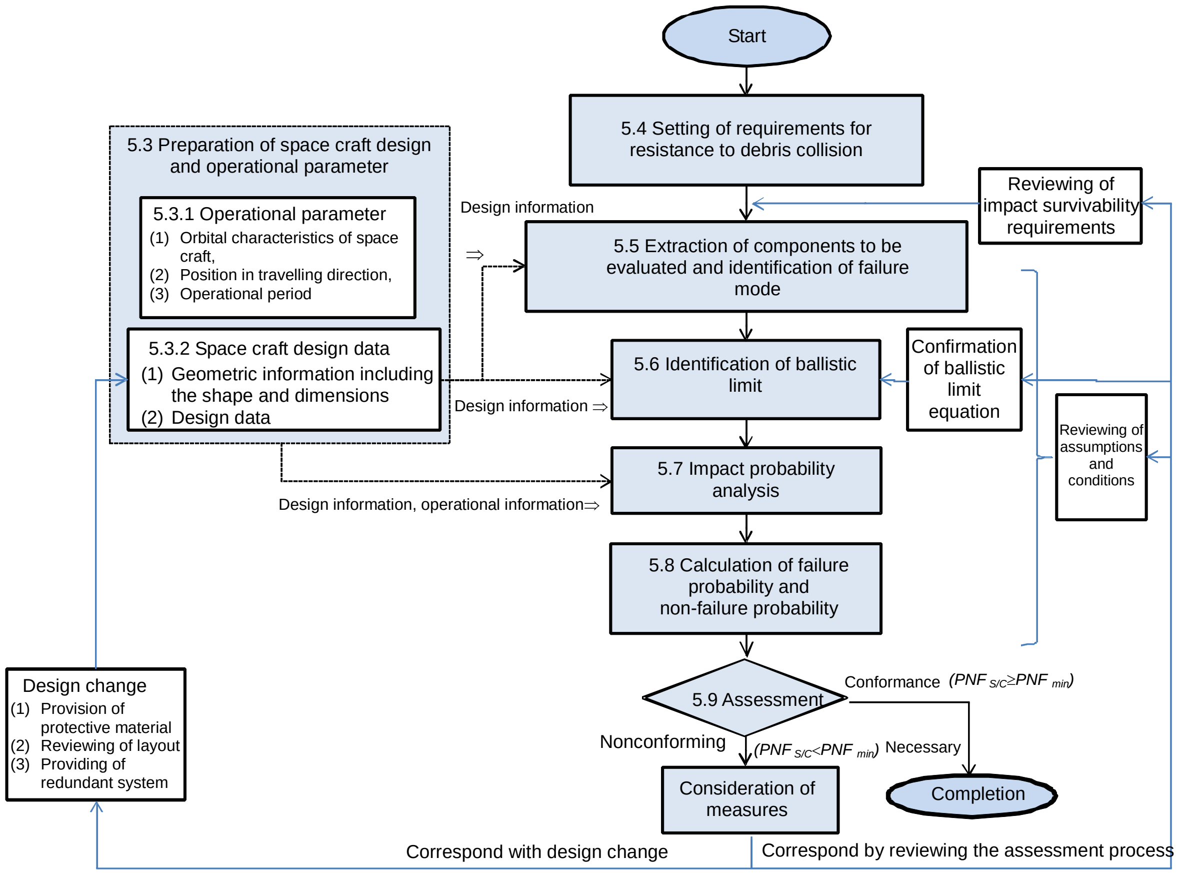
$$PNF_{S/C} < PNF_{min}$$

Proper measures shall be taken as follows:

(1) If the assessment process has any room for reviewing, it shall be performed.
  a) It shall be required to re-confirm whether the assumptions and conditions for analysis would be proper and whether the requirements would not be too excessive.
  b) If a large uncertainty of the ballistic limit equation would cause the problems, coordination shall be made with JAXA to improve the assessment accuracy by conducting impact test or simulation analysis.

(2) It shall be required to take measures for adding shielding materials, bumper installation, relocation of the component layout, and providing redundant design.

Appendix



Assessment flow diagram