# INTERNATIONAL STANDARD

# ISO 11227

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## Space systems — Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

*Systèmes spatiaux — Mode opératoire d'essai pour l'évaluation des éjectats de matériaux des véhicules spatiaux résultant d'impacts à hypervitesse*



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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11227 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.



 

# Introduction

Throughout its orbit lifetime, any spacecraft is exposed to the risk of collision with man-made space debris and natural micrometeoroids. Concentration of natural particles is nearly stable, but the amount of man-made debris is likely to increase over time. Details concerning this space environment can be found in the documents cited in the bibliography (see References [1] and [2]).

Damage caused by meteoroids or debris can result in total or partial mission failure and in a potential generation of small debris. Because of the large collision velocities (hypervelocity domain), even a small object produces upon impact a large amount of small particles, which are called ejecta. Ejecta can damage parts of the spacecraft itself and increase the population of space debris. The orbital lifetime of the ejecta depends on several factors such as size, initial velocity, and orbit altitude of the parent body. This population of space debris is already evaluated at a few percent of the total space debris population and it is likely to increase in the future[3][4][5]. It is therefore necessary, for the mitigation of such particles, to assess the mechanism of their production.

As shown by previous experimental studies[6][7][8], the amount of ejecta depends primarily on the type of material exposed directly to the space environment. It is greater for brittle materials than for ductile materials; it depends also on the size and on the velocity of impacting particles. Consequently, the best approach for assessing the process is to perform laboratory impact simulation using hypervelocity launchers.

The purpose of this International Standard is to describe a standard approach for assessing the behaviour, under orbital debris or meteoroid hypervelocity impacts, of the materials that are used on the external surfaces of spacecraft[9].

Results obtained from the standard tests carried out on as wide a range of materials as possible will be stored in a database created for this purpose, or incorporated into an existing one such as ECSS-Q70-71A (see Annex D and Reference [10]). This database will help designers choose spacecraft outer materials that mitigate the risk of space debris.

# Space systems — Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

## 1 Scope

This International Standard describes an experimental procedure for assessing the behaviour, under orbital debris or meteoroid impacts, of materials that are intended to be used on the external surfaces of spacecraft and launch vehicle orbital stages. This International Standard provides a unified method by which to rank materials. The ejecta production characteristics of different materials are compared under standardized conditions in which test parameters are fixed to one number. Optional tests with different parameters are also useful for the proper selection of materials in other conditions, and they could be performed as research items.

This International Standard establishes the requirements to be satisfied for the test methods in order to characterize the amount of ejecta produced when a surface material is impacted by a hypervelocity projectile. Its purpose is to evaluate the ratio of ejecta total mass to projectile mass, and the size distribution of the fragments. These are the necessary inputs for modelling the amount of impact ejecta that a surface material might release during its orbital lifetime, thereby helping to assess its suitability for space use while mitigating the production of small space debris.

The purpose of this International Standard is to provide data that need to be taken into account in the selection of outer spacecraft materials, though the selection is not based on these criteria alone.



The experimental procedure defines

— the type of facility to be used,



— the size, velocity and type of projectile to be used,

— the evaluation of impact ejecta released,

— the reporting of test results, and

— the quality requirements to be used.

It is anticipated that this International Standard will be the first of several test procedure standards aimed at characterizing the release of small debris from the external surfaces of spacecraft and launch vehicle orbital stages as the result of interaction with the space environment. It is applicable to spacecraft and launch vehicles operating in all types of Earth orbits.

## 2 Normative references

The following referenced documents are indispensable for the application 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 24113, *Space systems — Space debris mitigation requirements*

## 3 Terms, definitions, abbreviated terms and symbols

### 3.1 Terms and definitions

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

**3.1.1**
**brittle material**
material that breaks due to a propagation defect under the action of a stress

**3.1.2**
**ductile material**
material that can be plastically deformed without breaking under the action of a stress

**3.1.3**
**ejecta cone**
shaped spray of fine particles, comprising fragments and spalls that are released during a high-velocity impact.

**3.1.4**
**fragmentation**
process by which an orbiting space object dissociates and produces debris, such as break-up, exposure to space environment, and ageing

**3.1.5**
**hypervelocity impact**
impact occurring with a velocity greater than the velocity of sound in any given material

**3.1.6**
**impact crater**
damage left on a material, generally hemispherical in shape, after a projectile has hit its surface without going throughout the material

**3.1.7**
**light gas gun**
**LGG**
experimental device consisting of a powder gun that compresses a low-density gas to accelerate a projectile up to hypervelocities



**3.1.8**
**meteoroid**
particles of natural origin, resulting from the disintegration and fragmentation of comets and asteroids, which orbit the sun

**3.1.9**
**perforation**
hole created by an impact on a thin material in which there is no formation of a crater

**3.1.10**
**plasma gun**
experimental device that produces an accelerated plasma flow, which is compressed in a coil and then drags a projectile up to hypervelocities

**3.1.11**
**silica aerogel**
low-density solid material, made with a porous, silica-based structure, used for the retrieval of ejecta fragments in impact experiments

**3.1.12**
**spall**
piece of material broken and ejected upon high-velocity impact, usually by stress waves, mainly on brittle material

NOTE If the resulting tensile stress caused by the reflection of the compression wave on the surface (front or back) exceeds the tensile strength of the material, a thin sheet of material separates from the target and is ejected.

**3.1.13**
**specimen**
**target**
representative sample of a spacecraft material that is used in impact experiments

 

**3.1.14**
**stress**
force exerted on a body that tends to strain or to deform its shape.

**3.1.15**
**tensile strength**
power to resist tensile stress

NOTE The tensile strength of brittle materials is about two orders of magnitude less than the tensile strength of metals.

**3.1.16**
**tensile stress**
stress on a material produced by pulling forces along an axis, which tends to extend or break the material

**3.1.17**
**witness plate**
flat sheet of ductile material used in impact experiments to capture ejecta and characterize the resulting damage

### 3.2 Abbreviated terms

CFRP carbon-fibre-reinforced polymer

HVI hypervelocity impact

LGG light gas gun

MLI multilayer insulation

PVDF polyvinidylene fluoride



### 3.3 Symbols

$M_e$ total ejecta mass

$K$ material-type-dependent coefficient (ductile or brittle)

$\beta$ ratio of the mass ejected from the cone to the total ejected mass from the impact crater

$t$ thickness of test sample

$d$ diameter of projectile

## 4 General requirements

**4.1** If this International Standard is applied during the design of a spacecraft or launch vehicle orbital stage, then the test procedure and results shall be approved by approving agents and documented in accordance with the space debris mitigation plan specified by ISO 24113.

**4.2** Tests shall be performed at a hypervelocity impact facility that can fully satisfy the experimental procedure.

**4.3** Before performing the experimental procedure, a calibration of the hypervelocity impact facility shall be carried out to provide a reference data point for the subsequent tests at the facility.

**4.4** The calibration tests will be used to confirm the facility independencies of the test procedure.

# 5 Calibration

## 5.1 General

Subclauses 5.2 to 5.5 describe each step of a procedure for calibrating a hypervelocity impact test facility prior to it performing the experimental procedure described in Clause 6. The use of light gas guns or plasma guns to perform the tests is acceptable.

## 5.2 Impact parameters

**5.2.1** Perform a test shot using the following projectile parameters:

a) material: aluminium alloy Al 2017 or Al 2024; the choice is based on ISO 209-1:1989[11] or JIS H 4040:2006[12];

b) size and shape: 1 mm ± 0,1 mm diameter sphere;

c) impact velocity: 5 000 m/s ± 100 m/s is recommended;

d) impact angle of incidence relative to target normal: 0°.

**5.2.2** Use a target with the following characteristics:

a) size: 50 mm (± 1,5 mm) × 50 mm (± 1,5 mm);

b) material: synthetic fused silica glass (see Annex E for details);

c) thickness: 20 mm (± 1,5 mm);

d) attachment: fixed at the edges to a mounting plate.



NOTE The target material is fragile and it is recommended the target be placed in a small box with a window (hole) to prevent mass measurement error of the target after the impact test.

**5.2.3** Use a witness plate with the following characteristics to collect ejecta particles released from the front side of the target during impact:

a) size: 250 mm × 150 mm, with a circular hole (diameter not greater than 30 mm) cut in the centre in order to allow the projectile to go through;

b) material: copper; the choice is based on ISO 197-1:1983[13] or JIS H 3100:2006[14] (purity: 99,90);

c) chemical polishing is recommended[15];

d) thickness: 2 mm;

e) distance and position (angle) to the target: 100 mm in front of the target, parallel to the target;

f) attachment: by threaded rods and bolts, fixed on the target holding plate

NOTE See Annex C for details.

## 5.3 General environment

The general environment shall satisfy the following parameters:

a) operating temperature: room temperature (measurement accuracy: ±5 °C);

b) operating pressure: < 0,1 Pa (recommended).

 

### 5.4 Ejecta characterization

At a minimum, the following parameters shall be measured:

a) size distribution of diameter of craters created by front-side ejecta particles within the following ranges:

1) between 0,025 mm and 0,05 mm (mainly from the ejecta cone);

2) between 0,05 mm and 0,1 mm (mainly from the ejecta cone);

3) between 0,1 mm and 1 mm (mainly from spall);

4) > 1 mm (from spall).

NOTE More details for the ejecta characterization are given in 6.4 and in Annex C.

### 5.5 Report of calibration tests

The results shall be summarized in tabular form as shown in Table 1.

**Table 1 — Calibration tests**

| Date of test | Location | Type of facility | Reference of test | Projectile parameters: velocity, size | Target material | Total mass ejected<br>g | Size of crater on target<br>cm |
|---|---|---|---|---|---|---|---|
| xxx | xxx | xxx | xxx | xx, xx | xx | xx | xx |
| | | | | | | | |



## 6 Experimental procedure

### 6.1 General

This clause defines an experimental procedure for conducting tests in order to characterize the behaviour of materials upon hypervelocity impact and in particular to evaluate the amount of ejecta. The use of light gas guns or plasma guns to perform the tests is acceptable.

### 6.2 Impact parameters

**6.2.1** Perform the shots using the following projectile parameters

a) material: aluminium alloy Al 2017 or Al 2024; the choice is based on ISO 209-1:1989[11] or JIS H 4040:2006[12];

b) size and shape: 1 mm ± 0,1 mm diameter sphere;

c) impact velocity: 5 000 m/s ± 100 m/s;

d) impact angle of incidence relative to target normal: 0°.

**6.2.2** Use a target with the following characteristics:

a) size: at least 50 mm × 50 mm, in order to avoid edge effects upon impact;

b) material: representative of the material to be used on the spacecraft;

c) thickness: representative of the material to be flown;

NOTE The ejecta process depends on the ratio of target thickness to projectile diameter ($t/d$); in the case that there is a perforation of the sample under test, it is necessary to evaluate the amount of ejecta from the front side and from the rear side.

d) attachment: held in place by fixing at the edges only;

e) rear side left free to allow collection of ejecta if perforation or rear-side spall occurs.

**6.2.3** Use a witness plate with the following characteristics to collect ejecta particles released from the front side and from the rear side of the target during impact:

a) size: 250 mm × 150 mm, with a circular hole (diameter not greater than 30 mm) cut in the centre of the front witness plate in order to let the projectile go through;

b) material: copper; the choice is based on ISO 197-1:1983[13] or JIS H 3100:2006[14] (purity: 99,90);

c) chemical polishing is recommended[15];

d) thickness: 2 mm;

e) distance and position (angle) to the target: 100 mm in front of and parallel to the target plane;

f) similarly, a witness plate shall be placed behind the target;

g) attachment: by threaded rods and bolts, fixed on the target holding plate.

NOTE More details are given in Annex C.



## 6.3 General environment

The general environment shall satisfy the following parameters:



a) operating temperature: room temperature or defined by user (measurement accuracy: ± 5 °C);



b) operating pressure: < 0,1 Pa (recommended).

## 6.4 Ejecta characterization and evaluation

**6.4.1** To characterize and model the production of ejecta, it is appropriate to choose relevant parameters that are based on the physics of the impact process (more details are given in Annexes A and B).

**6.4.2** At a minimum, the following parameters shall be measured:

a) The total amount of ejecta, $M_e$, which is obtained by measuring the target mass before and after the test. Of course, part of the material ejecta comes from the projectile itself. This contribution is, however, small in comparison with material coming from the target (less than 1 %).

b) The size distribution of craters. On the witness plate used to characterize the ejecta, the size distribution of the diameter of craters formed by the front-side and rear-side ejected particles is determined within the following ranges:

   1) between 0,025 mm and 005 mm (mainly from the ejecta cone);

   2) between 0,05 mm and 0,1 mm (mainly from the ejecta cone);

   3) between 0,1 mm and 1 mm (mainly from spall);

   4) >1 mm (from spall).

NOTE 1 As an option, the average velocity of the ejecta can also be measured. At present, it is not possible to measure the ejecta velocity within each crater diameter range specified. Only the bulk velocity (of cone and spall fragments) can be measured using active velocity sensors or high-speed video recording.

 