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Space systems — Determination of test methods to characterize material or component properties required for break-up models used for Earth re-entry

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Foreword

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

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

New regulations require unmanned spacecraft and launch vehicle orbital stages, called space bodies in this document, to be designed and manufactured in such way that fragments generated during Earth re-entry cannot cause casualties, damage to property or environmental pollution on the ground (see ISO 24113).

Space bodies are submitted to high aero-thermodynamic fluxes, pressures and shear stresses that lead to their disintegration into fragments that can potentially reach ground after a re-entry. These fragments are generated by the effect of aero-thermal loads seen by components that constitute a space body. The assessment of the fragmentation and subsequent survivability of the fragments in terms of size and trajectory is based on simulation.

The methodology to determine the size of the debris is based on an idealized two-step process, called fragmentation and survivability.

— Fragmentation

  Based on the knowledge of the orbital (ballistic) trajectory of the space body and the knowledge of its design, the computation of temperature and stresses determine the most probable failure locations that will generate sub components. The breakup fragments prior to re-entry are termed debris.

— Survivability

  The objective is then to determine if debris can survive (no completely burned), and then if the final size and energy when touching down the Earth are in accordance with the international regulation.

  The computation of the final size and energy of the debris is based on generic geometry definition, homogenized properties and on the knowledge of their trajectories.

For both fragmentation and survivability, suitable thermal response models require a range of material properties for a full characterization of the material response.

Thermal tests used to determine material properties need to be well defined and shared between spacecraft manufacturers and regulation authorities.

There are a range of relevant spacecraft materials, from metals, organic and ceramics to composite materials.

As a result, the material or component properties used in break-up models is an essential model input.

Objects that separate during the ascent phase and impact the ground are addressed in ISO 14620-2.

Assessment, mitigating and control of potential risks created by the re-enter of objects from the orbit are addressed in ISO 27875.

Space systems — Determination of test methods to characterize material or component properties required for break-up models used for Earth re-entry

1 Scope

This document defines the elementary thermal tests to obtain thermal properties of materials and composite materials used to manufacture space body to support the fragmentation and survivability analysis.

This document does not apply to spacecraft containing nuclear power sources[1].

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1.1
ablation
chemical change and removal of surface *material* (3.1.12) due to the action of external high temperature heating

Note 1 to entry: Ablation can be a chemical process, addressing chemical reaction (gas-solid or gas-liquid);

Note 2 to entry: Ablation can be a physical process addressing vaporization, melting, fusion;

Note 3 to entry: Ablation can be a mechanical process addressing phenomena of erosive process (applied to solid or liquid surface) linked to pressure effect and wall shear stress due to high-speed motion.

[SOURCE: EN 16603-31:2014, 3.2.4.2, modified — Notes 1, 2 and 3 to entry have been added.]

3.1.2
break-up
event that completely or partially destroys an object and generates *space debris* (3.1.18)

Note 1 to entry: Debris generated during earth *re-entry* (3.1.16) can survive and fall to the ground.

[SOURCE: ISO 24113:2019, 3.2, modified — Note 1 to entry has been added.]

3.1.3
break-up altitude
altitude when the main structural fragmentation occurs leading several *components* (3.1.5)

Note 1 to entry: Altitude *break-up* (3.1.2) can occur on a wide range of values depending on trajectories and attitudes of the *spacecraft* (3.1.19).

3.1.4
ceramic
essentially inorganic and non-metallic *material* (3.1.12)

Note 1 to entry: The concept "ceramic" comprises products based on clay as raw material and also materials which are typically based on oxides, nitrides, carbides, silicides, borides, carbon etc.

[SOURCE: ISO 20507:2014, 2.1.7]

3.1.5
component
part
set of *materials* (3.1.12), assembled according to defined and controlled processes, which cannot be disassembled without destroying its capability and which performs a simple function that can be evaluated against expected performance requirements

[SOURCE: ISO 10795:2019, 3.48]

3.1.6
composite material

combination of *materials* (3.1.12) different in composition or form on a macro scale

Note 1 to entry: The constituents retain their identities in the composite.

Note 2 to entry: The constituents can normally be physically identified, and there is an interface between them.

[SOURCE: ISO 16454:2007, 3.6]

3.1.7
emissivity
ε
quotient of the radiant exitance of a radiator and the radiant exitance of a Planckian radiator at the same temperature, expressed by

$$\varepsilon = M/M_b$$

where M is the radiant exitance of a thermal radiator and M_b is the radiant exitance of a Planckian radiator (called hereafter black body) at the same temperature (ISO 80000-5)

Note 1 to entry: Emissivity of any surface is a function of wavelength, direction, temperature, and surface conditions.

Note 2 to entry: Emittance is a property of a particular object. It is determined by *material* (3.1.12) emissivity, surface roughness, of angle of incidence, oxidation, the sample's thermal and mechanical history, surface finish, and measured wavelength range. Although emissivity is a major component in determining emittance, the emissivity determined under laboratory conditions seldom agrees with actual emittance of a certain sample.

[SOURCE: ISO 80000-7:2019, item 7-30.1, modified — Notes 1 and 2 to entry have been added.]

3.1.7.1
total directional emissivity
total radiance, L_{Ω}, emitted by the considered surface, divided by total radiance emitted by the black body, $L°_{\Omega}$ at the same temperature

Note 1 to entry: Determined in the domain of near infrared (NIR) and middle infrared (MIR) of the *infrared radiation* (3.1.10).

[SOURCE: ISO 9288:1989, 5.8, modified — Note 1 to entry has been added.]

3.1.7.2
spectral directional emissivity
spectral radiance, $L_{\Omega\lambda}$, of the considered surface divided by the spectral radiance emitted by the black body, $L°_{\Omega\lambda}$, at the same temperature

Note 1 to entry: Determined in the domain of near infrared (NIR) and middle infrared (MIR) of the *infrared radiation* (3.1.10).

[SOURCE: ISO 9288:1989, 5.9, modified — Note 1 to entry has been added.]

3.1.7.3
total hemispherical emissivity
total hemispherical exitance, M, of the considered surface divided by the total hemispherical exitance of the black body, $M°$ at the same temperature

Note 1 to entry: Determined in the domain of near infrared (NIR) and middle infrared (MIR) of the *infrared radiation* (3.1.10).

[SOURCE: ISO 9288:1989, 5.10, modified — Note 1 to entry has been added.]

3.1.8
glass ceramic

inorganic *material* (3.1.12) produced by the complete fusion of raw materials at high temperatures into a homogeneous liquid which is then cooled to a rigid condition and temperature treated in such a way as to produce a mostly micro crystalline body

[SOURCE: ISO 7086-2:2000, 2.11]

3.1.9
glass transition temperature
*T*g
characteristic value of the temperature range over which the glass transition takes place

Note 1 to entry: Glass transition temperature characterizes the transition from true solid to very viscous liquid.

Note 2 to entry: The assigned glass transition temperature (*T*g) may vary, depending on the specific property and on the method and conditions selected to measure it.

[SOURCE: ISO 11357-2:2020, 3.1, modified — Note 1 to entry has been added.]

3.1.10
infrared radiation
electromagnetic radiation of wavelength between 780 nm and approximately 1 mm

Note 1 to entry: For infrared radiation, the range between 780 nm and 1 mm is commonly subdivided into:

— near infrared (NIR): 780 nm to 3 000 nm;

— middle infrared (MIR): 3 000 nm to 50 000 nm

— far infrared (FIR): 50 000 nm to 1 mm

Note 2 to entry: These limits are also specified in ISO 20473.

Note 3 to entry: For *break-up* (3.1.2) *models* (3.1.14), NIR and MIR are the must representative wavelength domains related to *re-entry* (3.1.16) phenomena.

[SOURCE: ISO 9488:1999, 3.9, modified — Notes 1, 2 and 3 to entry have been added.]

3.1.11
launch vehicle orbital stage
complete element of a launch vehicle that is designed to deliver a defined thrust during a dedicated phase of the launch vehicle's operation and achieve orbit

Note 1 to entry: Non-propulsive elements of a launch vehicle, such as jettisonable tanks, multiple payload structures or dispensers, are considered to be part of a launch vehicle orbital stage while they are attached.

[SOURCE: ISO 24113:2019, 3.13]

3.1.12
material
raw, semi-finished or finished purchased item (gaseous, liquid, solid) of given characteristics from which processing into a functional element of the product is undertaken

Note 1 to entry: Gas is not concerned for *break-up* (3.1.2) *models* (3.1.14).

[SOURCE: ISO 10795:2019, 3.148, modified — Note 1 to entry has been added.]

3.1.13
melting point
temperature at which solid changes state from solid to liquid

Note 1 to entry: At the melting point the solid and liquid phases exist in equilibrium for a single substance. The melting point of a solid depends on pressure and is usually specified at standard pressure.

Note 2 to entry: Solids, which differ from single substances and eutectics, do not have a sharp melting point because fusion occurs in a wide temperature range. Therefore, there is a temperature of beginning of fusion called solidus and an end temperature of fusion called liquidus.

Note 3 to entry: Amorphous solids (including many polymers) do not have a sharp melting point. When these pass from a solid to fluid state, they do so over a wide temperature range, centred roughly about the *glass transition temperature* (3.1.9).

Note 4 to entry: The determination method of the melting point used in the *break-up* (3.1.2) *model* (3.1.14) shall be mentioned if it is liquidus state, solidus state or even as an average of solidus and liquidus.

Note 5 to entry: By conservatism, liquidus is preferred in order to state that no solid debris can fall on ground.

Note 6 to entry: Carbon does not melt at any temperature under standard pressure; instead it sublimes around 4 000 K.

3.1.14
model
physical or abstract representation of relevant aspects of an item or process that is put forward as a basis for calculations, predictions, or further assessment

Note 1 to entry: The term "model" can also be used to identify particular instances of the product, e.g. flight model.

[SOURCE: ISO 10795:2019, 3.155]

3.1.15
pyrolysis
chemical change caused by heat

Note 1 to entry: Sometimes used in a more restricted sense to describe chemical changes resulting from heat treatment in the absence of oxygen.

[SOURCE: ISO 11074:2015, 6.4.33]

3.1.16
re-entry
return of a *spacecraft* (3.1.19) or other space object into the Earth's atmosphere

Note 1 to entry: Several alternative definitions are available for the boundary between the Earth's atmosphere and outer space.

[SOURCE: ISO 10795:2019, 3.197]

3.1.17
reversible specific heat capacity
specific heat capacity determined with DSC where all heat contributions (endothermic and exothermic) due to chemical transformation of the *material* (3.1.12) are not taken into account to measure the specific heat capacity

3.1.18
space debris
non-functional fragments of, or residue from, a space segment element, or launch segment element, in Earth orbit or re-entering the Earth's atmosphere

[SOURCE: ISO 10795:2019, 3.219, modified — The deprecated term has been removed.]

3.1.19
spacecraft
manned or unmanned vehicle designed to orbit or travel in space

[SOURCE: ISO 10795:2019, 3.224, modified — The abbreviated term and Note 1 to entry have been removed.]

3.2 Abbreviated terms

DSC differential scanning calorimetry

LFA laser flash analysis

TGA thermogravimetry analysis

4 Methodology of material characterization

4.1 General

Unmanned spacecraft and launch vehicle orbital stages are made with different components based on metals, polymers, ceramics and composite materials made with polymers, metals and ceramics.

The test matrix (type of test and environmental experimental conditions) shall be determined with respect to the complexity of the break-up model and the re-entry mode that provides the temperature range.

4.2 Temperature range

Depending on the type of re-entry (controlled versus natural) of the spacecraft, one can define two temperature domains associated with high dynamic pressure and aerothermal loads or high energy, respectively.

For controlled re-entry, the entry speed is maximized when the flight path angle allows the temperature to reach over 1 500 K and below approximately 2 500 K.

