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Space systems — Fracture and damage control

Systèmes spatiaux — Maîtrise des fissurations et des dommages

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Foreword

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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.

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Introduction

To prevent premature structural failure due to the propagation of cracks or crack-like defects during a structure's service life, fracture control policy is being imposed on space systems. These systems include civil and military space vehicles, launch systems, and their related ground support equipment. For manned space flight systems, most procurement agencies consider fracture control a mandatory human safety related requirement. For example, the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) require fracture control for all payloads using the NASA Space Shuttle (Shuttle) and all equipment items installed on the International Space Station (ISS). These systems have established specific fracture control requirements. These requirements are being implemented on all the payloads and equipment items using the Shuttle and ISS.

Recently, many procurement agencies and range safety authorities have imposed fracture control requirements on critical hardware items such as main propellant tanks of expendable launch vehicles (ELVs) and high-pressure gas bottles used in unmanned spacecraft in order to prevent loss of life and/or launch site facilities. Mechanical damage control is also being required by many range safety authorities on impact damage prone composite-overwrapped pressure vessels (COPVs). This International Standard provides uniform fracture and mechanical damage control requirements to the non-Shuttle and non-ISS hardware. It can be applied to safety and mission critical structures and other hardware items.

Space systems — Fracture and damage control

1 Scope

This International Standard establishes general requirements for the application of fracture control technology to fracture-critical items (FCIs) fabricated from metallic, non-metallic or composite materials. It also establishes mechanical damage control requirements for mechanical-damage-critical items (MDCIs) fabricated from composite materials. These requirements, when implemented on a particular space system, can assure a high level of confidence in achieving safe operation and mission success.

The requirements set forth in this International Standard are the minimum fracture control and mechanical damage control requirements for FCIs and MDCIs in general space systems, including launch vehicles and spacecraft. With necessary modifications, these requirements may also be applicable to reusable launch vehicles (RLVs). This International Standard is not applicable to the Shuttle and its payloads or the ISS and its equipment, since they already have a set of specific requirements suitable for their special applications.

This International Standard is not applicable to processing detected defects.

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 14623:2003, *Space systems — Pressure vessels and pressurized structures — Design and operation*

3 Terms and definitions

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

3.1
burst strength after impact
BAI
actual burst pressure of a pressure vessel after it has been subjected to an impact event

3.2
catastrophic hazard
potential risk situation that can result in loss of life, life-threatening or permanently disabling injury, occupational illness, loss of an element of an interfacing manned flight system, loss of launch site facilities, or long-term detriment to the environment

3.3
composite material
combination of materials which differ in composition or form on a macro scale

NOTE The constituents may retain their identities in the composite. Normally, the constituents can be physically identified, and there is an interface between them. A bonded structure such as metallic honeycomb sandwich is not considered as a composite structure in this International Standard.

3.4
composite-overwrapped pressure vessel
COPV
pressure vessel with a fibre-based composite system fully or partially encapsulating a liner

NOTE 1 The COPV containing a metallic liner is referred to as a metal-lined COPV while the COPV containing a nonmetallic liner is referred to as a nonmetal-lined COPV.

NOTE 2 The liner serves as a fluid permeation barrier and may or may not carry substantial pressure and external loads. The composite overwraps generally carry pressure and environmental loads.

3.5
critical flaw
specific shape of flaw with sufficient size such that unstable growth will occur under the specific operating load and environment

3.6
critical hazard
potential risk situation that can result in temporarily disabling but not life-threatening injury, or temporary occupational illness; loss of, or major damage to, flight systems, major flight system elements or ground facilities; loss of, or major damage to, public or private property, or short-term detrimental environmental effects

3.7
damage tolerance
ability of a material/structure to resist failure due to the presence of flaws for a specified period of unrepaired usage

3.8
damage tolerance threshold strain level
strain level below which no crack or damage propagation will occur when subjected to expected load or environmental conditions

3.9
design safety factor
design factor of safety
factor of safety
multiplying factor to be applied to the limit load and/or maximum expected operating pressure (MEOP), or maximum design pressure (MDP), for the purpose of analytical assessment and/or test verification of structural adequacy

EXAMPLE The design burst factor applied to the MEOP is the required design burst pressure for analysis or test.

3.10
fail-safe structure
structural item for which it can be shown by analysis or test that, as a result of structural redundancy, the structure remaining after the failure of any element of the structural item can sustain the redistributed limit loads with an ultimate safety factor of 1,0

NOTE It also can be shown that the structural item can withstand the fatigue loads for all the mission life for multi-mission applications.

3.11
flaw
local discontinuity in a structural material

EXAMPLES Crack, delamination or debonding.

3.12
fracture control
application of design philosophy, analysis method, manufacturing technology, verification methodology, quality assurance, and operating procedures to prevent premature structural failure caused by the propagation of cracks or crack-like flaws during fabrication, testing, transportation, handling and service

3.13
fracture-limited life item
any hardware item that requires periodic re-inspection or replacement to comply with damage tolerance requirements

3.14
fracture mechanics
engineering discipline that describes the behaviour of cracks or crack-like flaws in materials under stress

3.15
impact damage indicator
means for indicating the occurrence of an impact event

3.16
impact damage protector
physical device which can be used to prevent impact damage

3.17
initial flaw size
maximum flaw size, as defined by non-destructive evaluation (NDE), that is assumed to exist for the purpose of performing a damage tolerance (safe-life) analysis or testing

3.18
leak-before-burst
LBB
design concept which shows that, at maximum expected operating pressure (MEOP), potentially critical flaws will grow through the wall of a metallic pressurized hardware item or the metal liner of a composite-overwrapped pressure vessel (COPV) and cause pressure-relieving leakage rather than burst or rupture (catastrophic failure)

3.19
limit load
maximum expected external load or combination of loads that a structure can experience during the performance of specified missions in specified environments

NOTE When a statistical estimate is applicable, the limit load is that load not expected to be exceeded at 99 % probability with 90 % confidence.

3.20
maximum design pressure
MDP
highest pressure, as defined by maximum relief pressure, maximum regulator pressure and/or maximum temperature, including transient pressures, at which a pressure vessel retains two-fault tolerance without failure

3.21
maximum expected operating pressure
MEOP
highest differential pressure which a pressurized hardware item is expected to experience during its service life and retain its functionality, in association with its applicable operating environments

3.22
mechanical damage
induced flaw in the composite hardware item that is caused by surface abrasions, cuts or impacts

3.23
mechanical damage control
use of mechanical damage protection and/or indication system and appropriate inspection procedure to assure that no mechanical damage has been induced on a composite hardware item or if it has, the residual strength of the item still meets the minimum design ultimate load/pressure requirements for the required life

3.24
metal-lined COPV
composite-overwrapped pressure vessel which has a metallic liner

3.25
non-destructive evaluation
non-destructive examination
NDE
process or procedure for determining the quality or characteristics of a material, part, or assembly without permanently altering the subject or its properties

NOTE For the purposes of this International Standard, this term is synonymous with non-destructive inspection (NDI), and non-destructive testing (NDT).

3.26
pressure vessel
container designed primarily for the storage of pressurized fluid, which fulfils at least one of the following criteria:

a) contains gas or liquid with high energy level;

b) contains gas or liquid which will create a mishap (accident) if released;

c) contains gas or liquid with high pressure level

NOTE 1 **Pressurized structures** (3.27), pressure components and pressurized equipment including batteries, heat pipes, cryostats, and sealed containers are excluded.

NOTE 2 Energy and pressure level are defined by each project, and approved by the procuring authority (customer); if appropriate values are not defined by the project, the following levels are used:

— stored energy is 19 310 J or greater based on adiabatic expansion of perfect gas; or

— maximum expected operating pressure (MEOP) is 0,69 MPa or greater.

3.27
pressurized structure
structure designed to carry both internal pressure and vehicle loads

EXAMPLES Launch vehicle main propellant tanks, crew cabins and manned modules.

3.28
pressurized hardware
hardware items that contain primarily internal pressure

NOTE For the purposes of this International Standard, this term covers all pressure vessels and **pressurized structures** (3.27).

3.29
proof factor
multiplying factor applied to the limit load or maximum expected operating pressure (or maximum design pressure) to obtain proof load or proof pressure for use in the acceptance testing

3.30
residual strength
maximum value of load and/or pressure (stress) that a cracked or damaged structural item is capable of sustaining, considering appropriate environmental conditions

3.31
rotational machinery
device with a spinning part such as a fan and a rotor that has a high kinetic energy

EXAMPLES Control momentum gyroscopes and energy storage flywheels.

NOTE The energy level is defined by each project. If an appropriate value is not defined by the project, the value taken is 19 310 J or greater, based on 0,5 $I\omega^2$, where I is the moment of inertia (kg·m^2) and ω is the angular velocity (rad·s^{-1}).

3.32
safe life
required period during which a metallic hardware item, even containing a large undetected crack, is shown by analysis or testing not to fail catastrophically in the expected service load and environment

3.33
safe-life analysis
fracture mechanics-based analysis that predicts the flaw growth behaviour of a flawed hardware item which is under service load spectrum

NOTE For the purposes of this International Standard, safe-life analysis is synonymous with damage tolerance analysis.

3.34
safe-life test
test that determines experimentally the flaw growth behaviour of a flawed hardware item which is under service load spectrum

NOTE For the purposes of this International Standard, safe-life test is synonymous with damage tolerance test.

3.35
service life
period of time (or cycles) that starts with item inspection after manufacturing and continues through all testing, handling, storage, transportation, launch operations, orbital operations, refurbishment, re-entry or recovery from orbit, and reuse that may be required or specified for the item

NOTE For a metal-lined COPV, the service life starts with the autofrettage process during manufacturing.

3.36
stress-corrosion cracking
mechanically and environmentally induced failure process in which sustained tensile stress and chemical attack combine to initiate and propagate a crack or a crack-like flaw in a metal part

3.37
structural item
hardware item which is designed to sustain load and/or pressure or maintain alignment

EXAMPLES Spacecraft trusses, launch vehicle fairings, pressure vessels and pressurized structures; also fasteners, instrument housing and support brackets.