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Space systems — Structural design — Loads and induced environment

Systèmes spatiaux — Conception des structures — Charges et environnement induit

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Foreword

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International Standard ISO 14622 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Space systems — Structural design — Loads and induced environment

1 Scope

This International Standard defines the principles used to determine loads and the induced environment during the service life of a space flight vehicle and its components, taking account of the notions of probability, combined loads, corresponding safety factors and lifecycle.

2 Terms and definitions

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

2.1
space flight vehicle
combination of the launch system elements which leave the ground, i.e. the launch vehicle and the space vehicle(s) placed in orbit by the launch vehicle

2.2
launch vehicle
one or more space flight vehicle stages capable of launching one or more space vehicles and placing them in orbit

2.3
space vehicle
integrated group of subsystems and units capable of performing functions in space

NOTE Spacecraft is synonymous with space vehicle.

2.4
launch system
system including the space flight vehicle and corresponding installations, the ground equipment, hardware, software, procedures, services and personnel required for operations

2.5
load
response of a space flight vehicle to excitations encountered during its service life

2.5.1
static load
quasi-static load
load whose magnitude and direction are independent of time, or load which vary slowly and for which the dynamic response of the structure is not significant

NOTE This load can be induced by:

— steady winds;

— aerodynamic forces;

— thrust (constant or with slow variations);

— manoeuvres;

— spin stabilization.

2.5.2
transient load
load whose magnitude or direction varies with time and for which the dynamic response of the structure is significant

NOTE This load can be induced by:

— gusts;

— engine ignition or shutdown;

— separation;

— orbital docking;

— physical impact;

— deployment of appendages.

2.5.3
shock load
load applied in the form of shocks or percussion and for which the structure's dynamic response is significant

NOTE This load can be induced by:

— shockwave phenomena;

— pyrotechnic systems;

— physical impacts by deployed appendages;

— explosions.

2.5.4
oscillating load
load whose amplitude or direction varies within a frequency range for which the structure's dynamic response is significant

NOTE This load can be induced by:

— POGO effect;

— buffeting;

— vortex shedding due to ground wind;

— flutter;

— acoustic environment;

— rotation of parts;

— combustion instabilities in solid propellant stages.

2.5.5
limit load
maximum load that can be expected during the lifetime and in the presence of the environment

2.5.6
yield load
limit load multiplied by the yield safety factor J_E (2.10.1)

2.5.7
ultimate load
limit load multiplied by the ultimate safety factor J_R (2.10.2)

2.5.8
acceptance load
proof load
load applied during acceptance testing and which is equal to the limit load multiplied by an acceptance factor J_P

2.5.9
qualification load
load applied during the qualification tests and which is borne by the structure without failure or collapse

2.5.10
failure load
load determined experimentally and for which the structure fails, collapses through instability or exhibits excessive deformation

2.6 Pressure

2.6.1
limit pressure
maximum pressure differential that can be expected in service and in the presence of the environment (see 3.2.4) and includes:

- the operating pressure (due either to propellant combustion or to pressurisation);
- transient pressure;
- hydrostatic pressure;
- external pressure.

2.6.2
yield pressure
limit pressure multiplied by the yield safety factor J_E (2.10.1)

2.6.3
ultimate pressure
limit pressure multiplied by the ultimate safety factor J_R (2.10.2)

2.6.4
proof pressure
differential pressure applied during the proof pressure test and which is equal to the limit pressure multiplied by the proof pressure factor J_P (2.5.8)

2.6.5
hydrostatic pressure
pressure at a level below the liquid level in the tank, which is induced by the height of liquid above this level, plus quasi-static accelerations

2.6.6
transient pressure
pressure that varies with time and for which the characteristic variation time is of the same order of magnitude as the structure's significant time constant

2.7 Thermal definitions

2.7.1
calculated thermal flux
heat flux evaluated in the most unfavourable heat exchange condition

NOTE See 3.2.5.

2.7.2
design temperature
temperature of the structure once subjected to the harshest combination of load, pressure and temperature

2.8 Material properties

2.8.1
Young's modulus
E
constant ratio between the stress and the resulting strain

NOTE The average value of the Young's modulus determined at the design temperature shall be taken into consideration.

2.8.2 Allowable stresses

2.8.2.1
σ_E
uniaxial yield stress corresponding to 0,2 % residual strain (metallic materials only)

2.8.2.2
σ_R
uniaxial ultimate strength stress

NOTE 1 σ_R and σ_E have a statistical definition: they are equal to a value which has a 90 % probability of being exceeded, with a 95 % confidence level for unmanned space vehicles. In the case of manned space vehicles and/or launch vehicles, the values are 99 % and 95 % respectively.

NOTE 2 σ_R and σ_E correspond to the condition of the material when the structure is in service at the design temperature.

2.9
strength
ability of the structures to withstand the loads (or pressures) and the environment encountered during their service lifetime

2.10
safety factor
coefficient by which the limit load (or pressure) is multiplied so as to account for any inaccuracies in the known statistical distribution of the load (or pressure) and strength value

NOTE These inaccuracies are due to:

— the limited number of observations or tests used to estimate these distributions;

— calculation inaccuracies.

EXAMPLE If F represents the estimated statistical distribution of loads (or pressures) and R the estimated statistical distribution of strengths and that, relative to these estimated distributions, F_1 is the limit load and R_1 the allowable strength (ultimate or yield strength), the corresponding safety factor is:

$$J = \frac{R_1}{F_1}$$

2.10.1
safety factor at yield strength
J_E
ratio between the load (or pressure) at the material yield strength and the limit load (or pressure)

NOTE This factor can only be applied to metal structures.

2.10.2
ultimate safety factor
J_R
ratio between the allowable ultimate load (or pressure) and the limit load (or pressure)

NOTE A different approach can be used for defining a safety value when one has extensive experience of a given field of application. In this case, the authority will choose and set values for the safety factors.

2.11 Lifetime

2.11.1
envelope lifetime
lifetime of a structure determined on the basis of the structure having been subjected to the most unfavourable combination of events (load cycles, thermal cycles, etc.)

2.11.2
nominal lifetime
most probable lifetime determined by the authority on the basis of the envelope lifetime

2.11.3
design lifetime
lifetime used for designing structures, and in particular, for the damage tolerance studies

2.11.4
service lifetime
maximum period between the end of acceptance testing and the end of the structure's flight

3 Determination of loads and the induced environment

3.1 General input data

3.1.1 System inputs

To determine the loads, a space system shall be defined by:

- design trajectory;
- geometry;
- inertial data (masses, centre of gravity, inertia, unbalance);
- aerodynamic characteristics (global, local, distributed);
- thermal and thermo-optical coefficients;
- stiffness values (global, local);
- modal characteristics;
- propulsion characteristics;
- functional data concerning the control subsystem, the separation and jettison subsystems and the subsystems for deployment of appendages and other on-board devices.

3.1.2 Excitation sources

During its service life and along its design trajectory, a space system is exposed to various types of excitation:

a) Sources outside the system:

- wind and wind gradients on the ground and at altitude;
- gusting;
- atmospheric turbulence;
- solar and planetary thermal radiation and radiation pressure.

b) Sources generated by the system itself:

- differential pressures;
- operation of the propulsion subsystem;
- operation of the control subsystem;
- operation of separation and jettison mechanisms;
- operation of on-board mechanisms and other devices.

c) Intensity of each excitation source:

The intensity of each excitation source is the maximum value that the space system in question can encounter during its service life and in the presence of the environment. It is determined in the following way:

- When the statistical dispersion is known, the intensity of an excitation source shall be chosen such that the probability of it not being exceeded in service is 99 %, with a 90 % level of confidence.
- When the statistical dispersion is unknown, the intensity of an excitation source has to be determined on the basis of a rational estimate consistent with the dispersion of the parameters involved in determining it, when this dispersion is significant.

3.2 Determination of loading conditions

3.2.1 General

The load applied to a system is the sum of the responses of this system to excitations encountered during the pre-launch period and along its design trajectory.

These responses shall be determined using specific mathematical models. These models shall be validated following the appropriate activities, before the final design phase.

The loads and accompanying environments (vibratory and thermal in particular) correspond to the limit load level.

3.2.2 Types of loads

A structure can be exposed to the following types of loads:

- aerodynamic forces and moments;
- forces and moments due to the load factor (gravity or quasi-static accelerations);

- differential pressures;
- action of propulsion and control subsystems;
- temperature gradients;
- vibrations, shocks, acoustic noise;
- dynamic action of internal and external fluids;
- elongation due to different coefficients of expansion;
- various reactions exerted by connectors or supports;
- efforts associated with the operation of on-board devices.

During the structure design phase, consideration should be given to all the loads that can be expected to be exerted during the service life, as well as a history of these loads during the life of the structure.

The loads can be generally classified as:

a) mechanical loads;

b) limit pressure;

c) thermal loads.

3.2.3 Mechanical loads

These are forces and moments caused by the response of a system to all excitations acting on that system at a given moment in time. They may be occur in a section of the structure in the presence of the operating environment. Their intensity is such that the probability of not being exceeded in service is 99 %, with a confidence level of 90 %.

3.2.4 Limit pressure

The limit pressure (see 2.6.1) is determined by taking into account the different pressures likely to be exerted on the structure: pressurization pressure(s), hydrostatic pressure, pressure generated by propellant combustion, transient pressures, external pressure, pressure induced by compartment scavenging, etc.

If the statistical pressure dispersion is known, the limit pressure is to be set as the differential pressure which has a 99 % probability of not being exceeded in service, at the 90 % confidence level.

When the statistical pressure dispersion is not known, the limit pressure is to be set on the basis of an estimate accounting for the dispersion of the parameters used in determining it, when this dispersion is significant.

If the pressurization system of a liquid fuel propulsion system comprises a pressure-regulating device, the limit pressure shall be determined on the basis of the limit operating conditions of this device (maximum operating pressure), by taking into consideration the specified tolerances or the significant dispersions.

3.2.5 Thermal loads

Any thermal energy transfer affecting the material properties, the stress and/or strength distribution, is part of the thermal load.

These loads are frequently presented in the form of incoming heat fluxes (convection, conduction, radiation).

They are in particular due to the following:

— aerothermodynamic heating during the ascent and re-entry phases;

— heating by the propulsion gases;

— structural radiation and conduction;

— solar and planetary thermal radiation;

— use of cryogenic fuels;

— the action of pressurization systems;

— system internal heat transfers;

— the action of air-conditioning systems (ventilation).

3.2.6 Cases of loading

3.2.6.1 The cases of loading shall be specified for each structure by the authority. They concern the most unfavourable combinations of loads, pressures, thermal gradients and temperatures corresponding to specific times in the lifetime of the structure (see 2.11).

3.2.6.2 The cases of loading corresponding to missions identified as degraded, shall be covered by a reduced safety factor, the value of which shall be determined, justified and specified.

3.2.6.3 A structure shall be neither designed nor sized to withstand loads, pressures, thermal gradients and temperatures subsequent to the failure of another structure.

3.3 Safety factors

3.3.1 The safety factor shall be set so as to cover any dispersion and uncertainty arising under extreme conditions during service life or in material and manufacturing quality.

3.3.2 If the values of the safety factor are not set by the authority, they are to be determined as the ratio between the load (or pressure) to be borne by the structure and the limit load (or limit pressure):

$$J = \frac{R}{F}$$

The parameters R and F are probability values corresponding to a confidence level of V. The value V shall be determined and justified during preliminary structural calculations.

3.3.3 The following requirements shall be met:

a) The strength of the structure R shall be such that its probability, P, of being higher than the given value is above 99 %:

$$P\left(\frac{\Delta R}{R}\right) > 0{,}99$$

b) The loads on the structure F shall be determined such that the probability of their being exceeded in service is below 1 %:

$$P\left(\frac{\Delta F}{F}\right) < 0{,}01$$

NOTE For structural configurations whose strength cannot be defined with any great certainty, or if it can vary significantly, the level of confidence V will drop accordingly. The safety factor will therefore rise.

3.3.4 The value of the safety factor shall be determined and justified before being approved by the authority.

3.3.5 The value adopted should not, even partially, hide any lack of experience in the field of application.

3.3.6 In the case of mechanical loads and pressures, the lower limit values for a structure or assembly of structures are:

a) for an unmanned space flight vehicle:

$$J_R = 1,25$$

b) for a manned space flight vehicle or a space flight vehicle in which failure can possibly endanger the personnel:

$$J_R = 1,40$$

3.3.7 If the statistical data based on full-scale structural test results are known, the value of the safety factor can possibly be reduced.

3.3.8 No safety factor is applied to thermal loads or to mechanical loads due to thermal action on the structure.

3.4 Cases of design load

At the beginning of the design process, a register of the cases of design load is to be prepared by the person responsible for the structure. This register comprises the list of load combinations, defined in compliance with 3.2.6.1, which are to be taken into consideration for the design of the structure in question.

Special justification shall be provided to prove that the real and most unfavourable load combinations have been taken into account.

3.5 Calculated safety margins

3.5.1 In a critical area of a structure and for a given failure mode, the safety margin is defined as follows:

$$M_S = \frac{\sigma_{allow}}{J \cdot \sigma_{local}} - 1$$

where

σ_{allow} is the allowable stress for a given failure mode;

σ_{local} is the local stress corresponding to the combination of limit loads;

J is the safety factor (failure, yield strength).

3.5.2 The safety margin can sometimes be expressed as the ratio between the maximum allowable deformation at a critical point of the structure and the deformation at this same point due to the ultimate load or the ultimate combination of loads.

3.5.3 Any calculated safety margin shall be positive. The lowest values shall be checked by tests.

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