
**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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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 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).