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Space engineering

Mechanical — Part 2: Structural

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This Standard has been prepared by the ECSS Mechanical Engineering Standard Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board.

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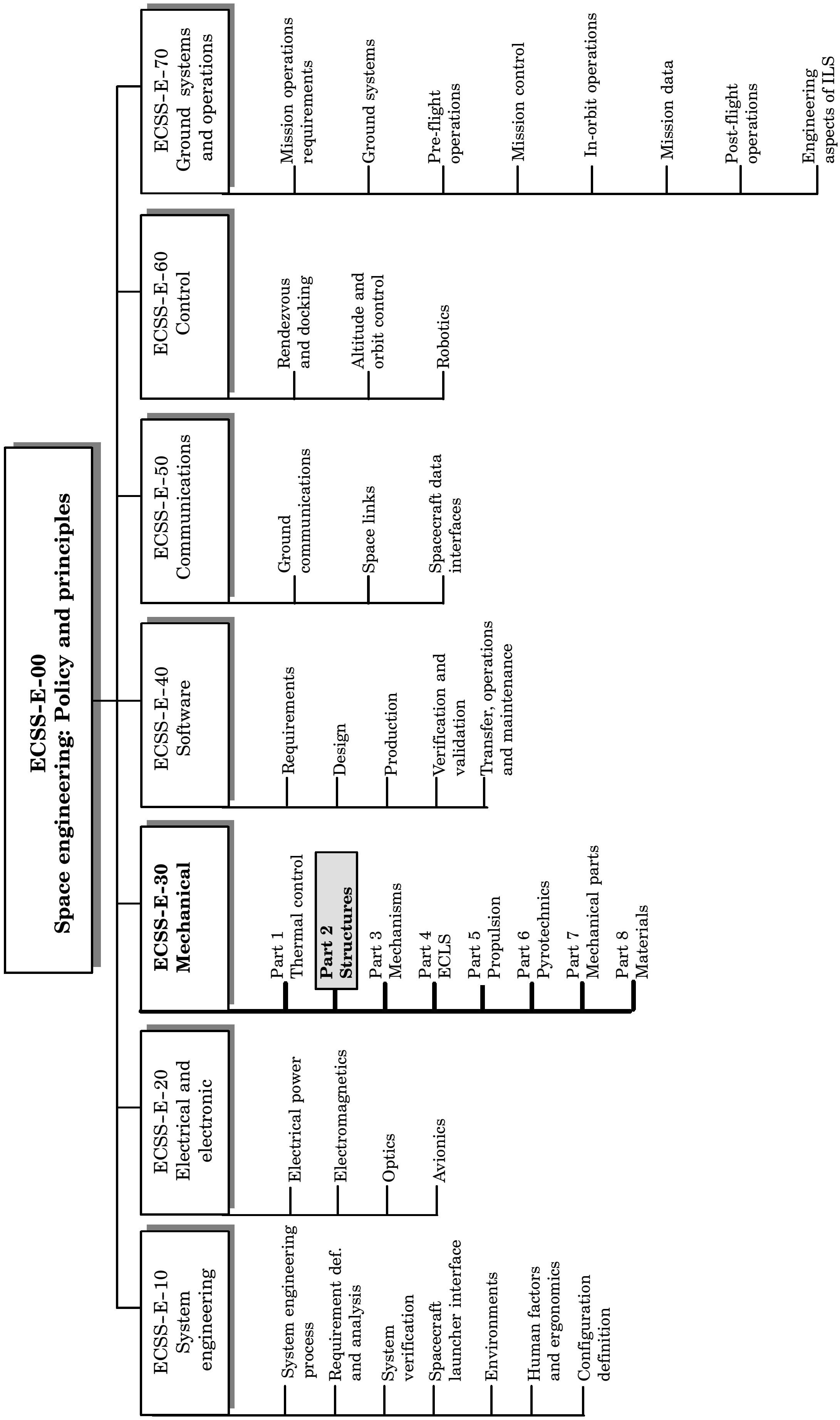

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Scope

Part 2 of ECSS-E-30 in the engineering branch of ECSS Standards defines the mechanical engineering requirements for structural engineering.

This Standard defines the requirements to be considered in all engineering aspects of structures: requirement definition and specification, design, development, verification, production, in-service and eventual disposal.

The Standard applies to all general structural subsystem aspects of space products and in particular: Launch vehicles, transfer vehicles, re-entry vehicles, spacecraft, landing probes and rovers, sounding rockets, payloads and instruments, structural parts of all subsytems.

When viewed from the perspective of a specific project context, the requirements defined in this Standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project.

NOTE Tailoring is a process by which individual requirements of specifications, standards and related documents are evaluated, and made applicable to a specific project by selection, and in some exceptional cases, modification of existing or addition of new requirements.

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

ECSS P-001	Glossary of terms
ECSS-E-10	Space engineering — System engineering
ECSS-E-30 Part 7	Space engineering — Mechanical — Part 7: Mechanical parts
ECSS-E-30 Part 8	Space engineering — Mechanical — Part 8: Materials
ECSS-Q-20	Space product assurance — Quality assurance
ECSS-Q-30	Space product assurance — Dependability
ECSS-Q-40	Space product assurance — Safety
ECSS-Q-70	Space product assurance — Materials, mechanical parts and processes

References to sources of approved lists, procedures and processes can be found in the Bibliography.

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Terms, definitions, abbreviated terms and units

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional with respect to those contained in ECSS-P-001.

3.1.1
A-value
mechanical property value above which at least 99 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE A-value is also called A-allowable.

3.1.2
allowable stress (load)
maximum stress (load) that can be permitted in a structural part for a given operating environment to prevent rupture, collapse, detrimental deformation or unacceptable crack growth

3.1.3
B-value
mechanical property value above which at least 90 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE B-value is also called B-allowable.

3.1.4
composite material
material that is made of two or more constituent materials

3.1.5
composite structure
structure composed of fibre-reinforced material, such as carbon, aramid or glass continuous aligned fibres in a resin, metallic or ceramic matrix

NOTE Fibre-reinforced plastic face sheeted sandwich panels containing light alloy or composite material cores are also defined as composite structures.

3.1.6
design load
limit load multiplied by relevant design factor

3.1.7
design parametres
physical features which influence the design performances

NOTE According to the nature of the design variables, different design problems can be identified such as:
- structural sizing for the dimensioning of beams, shells;
- shape optimization;
- material selection;
- structural topology.

3.1.8
dynamic load
time varying load with deterministic or stochastic distribution

3.1.9
factor of safety (FOS)
coefficient by which the design loads are multiplied in order to account for uncertainties in the statistical distribution of loads, uncertainties in structural analysis, manufacturing process, material properties and failure criteria

3.1.10
fail-safe
structure which is designed with sufficient redundancy to ensure that the failure of one structural element does not cause general failure of the entire structure with catastrophic consequences (e.g. loss of launcher, endangerment of human life)

NOTE Failure may be considered as rupture, collapse, seizure, excessive wear or any other phenomenon resulting in an inability to sustain limit loads, pressures or environments.

3.1.11
generalized mass
mass transformed by the mode shapes into the modal space (modal coordinates)

NOTE See annex B.

3.1.12
limit load
maximum load to be encountered in service with a given probability for a given design condition

3.1.13
margin of safety (MOS)
margin of the applied load multiplied by a factor of safety against the allowed load

3.1.14
maximum design pressure (MDP)
maximum pressure for which the system or component is designed

NOTE The MDP is always equal or larger than the MEOP.

3.1.15
maximum expected operating pressure (MEOP)
maximum pressure at which the system or component is expected to operate in a particular application

NOTE MEOP includes the effects of temperature, transient pressure peaks, vehicle acceleration and relief valve tolerance.

3.1.16
POGO
propulsion generated oscillations

3.1.17
primary structure
part of the structure that carries the main flight loads and defines the fundamental resonance frequencies

3.1.18
proof load
load applied during a proof test

3.1.19
random load
vibration load whose instantaneous magnitudes are specified only by probability distribution functions giving the probable fraction of the total time that the instantaneous magnitude lies within a specified range

NOTE Random load contains no periodic or quasi-periodic constituents.

3.1.20
safe life structure
structure which has no failure when subject to the cyclic and sustained loads and environments encountered in the service life

3.1.21
scatter factor
coefficient by which number of cycles or life time is multiplied in order to account for uncertainties in the statistical distribution of loads and cycles as well as uncertainties in fatigue analysis, manufacturing processes and material properties

3.1.22
secondary structure
structure attached to the primary structure with negligible participation in the main load transfer and the stiffness of which does not significantly influence the fundamental resonance frequencies

3.1.23
shock load
special type of transient load, where the load shows significant peaks and the duration of the load is well below the typical response time of the structure

3.1.24
(quasi) static loads
loads independent of time or which vary slowly, so that the dynamic response of the structure is not significant

NOTE (Quasi) static loads comprise both static and dynamic loads and are applied at a frequency sufficiently below the natural frequency of the considered part thus being equivalent to static loads for the structure.

3.1.25
stiffness
ratio between an applied force and the resulting displacement

3.1.26
structure
every physical part carrying loads or supporting or protecting other components

NOTE The structure is usually split into primary and secondary structures.

3.1.27
transient load
deterministic load which varies with time (magnitude or direction) and for which the dynamic response of the structure is significant

3.1.28
ultimate load
design load multiplied by the ultimate safety factor

3.1.29
ultimate strength
strength of a material in tension, compression, or shear, respectively, is the maximum tensile, compressive, or shear stress that the material can sustain

NOTE It is implied that the condition of stress represents uniaxial tension, uniaxial compression, or pure shear.

3.1.30
ultimate stress
engineering stress caused by the ultimate load

NOTE With this definition no relation exists with ultimate strength.

3.1.31
yield load
design load multiplied by the yield safety factor

3.1.32
yield strength
stress at which a material exhibits a specified permanent deformation or set

NOTE The set is usually determined by measuring the departure of the actual stress-strain diagram from an extension of the initial straight proportion. The specified value is often taken as a unit strain of 0,002.

3.1.33
yield stress
stress caused by the yield load

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

Abbreviation	Meaning
AIT	assembly, integration and tests
BIT	built-in testing
CAD	computer aided design
CAE	computer aided engineering
CAM	computer aided manufacturing
COG	centre of gravity
DRD	document requirements description

ECLS	environment control and life support
EMC	electromagnetic compatibility
FCI	fracture critical item
FEA	finite element analysis
FE	finite element
FMECA	failure mode, effects and criticality analysis
FOS	factor of safety
FSI	fluid structure interaction
MDP	maximum design pressure
MOI	moment of inertia
MOS	margin of safety
NDT	non-destructive test
NDI	non-destructive inspection
PFCI	potential fracture critical item
PFO	particle fall out
r.m.s.	root mean square

3.3 Units

For the implementation of this Standard SI-units and associated symbols system shall be used.

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4

Requirements

4.1 General

Structural design shall aim for simple load paths, maximize the use of conventional materials, simplify interfaces and easy integration.

4.2 Mission

4.2.1 Lifetime

a. All structural assemblies and components shall be designed to withstand applied loads due to the natural and induced environments to which they are exposed during the service-life and shall be able, in operation, to fulfil the mission objectives for the specified duration.

b. The service-life shall be defined taking into account all ground operations, such as transportation, handling, testing and storage as well as all phases of pre-launch, launch, operation and descent.

c. The phases and applicable loads and durations shall be determined based on

- the requirements of the structure (i.e. single mission, expendable, re-usable or long-term deployment),
- the effect of all degradation mechanisms upon materials used in the construction (i.e. both terrestrial and space environments and all loading regimes to be experienced), and
- experience with similar structures (e.g. qualification, problems identified in-service).

d. Service-life evaluations shall be applied to determine the inspection and maintenance requirements, when an item should be replaced (preventive maintenance), the inspection and repair procedures and intervals (corrective maintenance).

e. An envelope-lifetime consisting of the most unfavourable sequence of events (loading cycles, thermal cycles) to which the structure may be subjected during its defined service-life shall be defined as follows:

1. It shall commence at the start of manufacturing and shall end with the completion of the mission;

2. The envelope-lifetime shall be an envelope of all real lifetimes. If there are several variants in the real lifetime, the most severe shall be retained;
3. The envelope-lifetime shall define all lifetime phases and their chronology;
4. For each lifetime phase, the envelope shall take into account the maximum duration and the maximum number of cycles.

4.2.2 Natural and induced environment

a. All structural assemblies and components shall be able to withstand the environment loads and conditions to which they are exposed both during manufacture and their complete service-life.

b. Components and assemblies for space applications shall be compatible with the operational environment conditions and with the atmospheric conditions on earth in which they are manufactured and tested.

c. Consideration shall be given to effects of gravitation and exposure of sensitive materials to manufacturing and atmospheric environments; suitable provisions (e.g. gravitational compensation and purging) shall be made where necessary for the protection of sensitive equipment or components. The sensitivity of materials to the environment on earth can stipulate the requirements for quality control procedures.

NOTE 1 The natural environment generally covers the climatic, thermal, chemical and vacuum conditions, required cleanliness, levels of radiation and the meteoroid and space debris environment.

NOTE 2 The induced environments cover the mechanical loads induced by ground handling and pre-launch operations, launch, manoeuvres and disturbances, re-entry, descent and landing. Additional induced environments include static pressure within the payload volume, temperature and thermal flux variations and the electromagnetic and humidity environments.

4.2.3 Mechanical environment

a. The mechanical environment shall be defined by static and dynamic environment loads which shall be further defined in terms of constant acceleration, transient, sinusoidal and random vibration, acoustic noise and shock loads.

b. All loads shall be considered in the worst combinations in which they occur. The severest loads can be experienced during launch, ascent and separation, and, where relevant during re-entry, descent and landing. However, consideration shall also be given to the other loads which can effect the performance in an operational mode.

4.2.4 Microgravity, audible noise and human vibration

Structural requirements dictated by microgravity, audible noise and human vibration system level requirements shall be taken into account.

4.2.5 Corrosion effects

a. The selection of a material for corrosion resistance shall be in accordance with ECSS-Q-70 and shall take into account the specific environment, the design and fabrication of individual and assembled components, compatibility of dissimilar materials, susceptibility to fretting and crack initiation.

NOTE Corrosion can be regarded as any deterioration in the physical and chemical properties of a material due to the chemical environment.

b. In cases where the behaviour of a material in a specific environment is not known, corrosion tests of representative materials (composition and condition) shall be performed, either under appropriate service conditions, or in more severe conditions (accelerated testing). See ECSS-E-30 Part 8.

4.2.6 Ablation and pyrolysis

a. The structural design shall take into account the material changes due to ablation and pyrolysis.

b. In cases where an exact prediction of the behaviour of a material in a specific environment is not possible, ablation and pyrolysis tests of representative materials (composition and condition) shall be performed, either under appropriate service conditions, or in more severe conditions (accelerated testing).

4.2.7 Micrometeoroid and debris collision

a. Pressurized structures, tanks, battery cells, pipes, electronic boxes and other identified equipment shall be protected from micrometeoroid and debris impact in order to prevent the risk of catastrophic failures.

b. The selection and design of material and debris protection systems shall be based on a defined probability of survival. The probability of survival is influenced by the following:

- probability of impact;
- critical debris size;
- material response to hypervelocity impacts;
- impact face;
- back face (spalling);
- mission duration;
- spacecraft orientation;
- multiple impacts.

4.2.8 Venting and purging

a. Provision shall be made in the design of the structure for venting in order to avoid a build-up of excess pressure and to reduce the time necessary to evacuate the structure.

b. In cases where venting is not provided, the structure shall withstand build up pressure without violating other requirements such as strength or stability.

c. In areas where purging is required (e.g. to prevent contamination or risk of explosion), the openings required for venting shall be compatible with the purging system gas supply pressure and flow rate.

4.2.9 Mass and inertia properties

Mass and inertia properties of the structure shall be determined during all phases of the design applying estimation, calculation or measurement techniques.

NOTE The mass and inertia properties of a structure comprise its mass, the location of its centre of gravity, its moments and products of inertia and, where applicable, its balancing masses.

4.2.10 Load events

a. All relevant mechanical and thermal load events experienced throughout the service-life of the structure shall be identified.

b. Loads shall be defined according to their nature, static or dynamic, their level and time corresponding to the events during the lifetime, and as a minimum the following load events shall be considered:

1. Ground and test loads:
   - handling, transportation and storage loads;
   - assembly and integration loads;
   - ground test loads.
2. Launch loads:
   - launch preparation;
   - operational pressures;
   - engine ignition;
   - thrust build up;
   - lift-off;
   - thrust (constant or varying slowly);
   - aerodynamic loads;
   - heat flux from engine and aerodynamics;
   - gust;
   - dynamic interaction between the structure and propulsion system;
   - acoustic noise;
   - manoeuvres;
   - thrust decay;
   - pyrotechnics;
   - separation of parts (e.g. stage, fairing, spacecraft);
   - depressurization.
3. In-orbit loads:
   - operational pressures;
   - static and dynamic loads induced by thrusters;
   - shocks due to pyrotechnical operation and deployment of appendages;
   - thermo-elastic loads induced by temperature variations,- hygroscopic-induced load due to variations in moisture content;
   - micro-vibrations induced by moving elements (e.g. momentum wheels) and thrusters;
   - micrometeoroids and debris;
   - docking;
   - berthing;
   - crew induced loads (e.g. on handles, rails and by movements).
4. Re-entry, descent and landing:
   - aerodynamic loads and thermal fluxes;
   - parachute ejection and deployment shocks;
   - operational pressures;
   - landing loads;
   - impact loads.

4.2.11 Limit loads

a. The limit loads shall be derived as follows:

1. for cases where a representative statistical distribution of the loads is known, the limit load shall be defined as the load level not to be exceeded with a probability of 99% and a confidence level of 90% during the service-life.
2. for cases where a statistical distribution of the loads is not known the limit loads shall be based on conservative assumptions.
3. for pressurized systems, the maximum design pressure (MDP) shall be part of the defined limit loads.

b. For Gaussian distributed random loads for verification, with a zero mean value, the limit load contribution shall be derived as standard deviation multiplied by three, i.e. 3 × root mean square (r.m.s.).

c. Superposition of loads shall be defined according to the applicable load events.

4.2.12 Design loads

a. The design loads shall be derived by multiplication of the limit loads by relevant design factors.

b. Design factors shall be system defined due to project programmatic aspects e.g. proto flight approach, uncertainty in launcher environments, maturity of design, other design considerations.

4.2.13 Structural reliability

The structural dimensioning shall take into account the reliability aspects, generally through the use of safety factors and associated design and verifications approaches, including the following:

- upper bound values of loads;
- conservative material properties and failure criteria;
- application of approved analysis methodologies and tools;
- analysis of the failure modes and their criticality (FMECA);
- damage tolerance verification;
- application of mathematical models validated by tests;
- validation of selected technologies and manufacturing processes;
- inspections before, during and after manufacture;
- qualification tests;
- acceptance tests;
- implementation of maintenance plans.

4.3 Functionality

4.3.1 Strength

The structure shall be of adequate strength to withstand the design loads without yielding, failing or exhibiting excessive deformations that can endanger the mission objectives.

4.3.2 Buckling

a. The stability (no buckling) of the structure shall be verified for the design loads.

b. Local buckling shall only be tolerated, if it is reversible and on the condition that the resulting stiffness and deformations remain in conformance with the structural requirements without risk of general buckling being induced by local instability.

c. For composite materials microbuckling of fibres shall not be accepted

4.3.3 Stiffness

a. The structure shall be designed to meet the requirements for stiffness under the specified load and boundary conditions.

NOTE Stiffness is often expressed in terms of a minimum natural frequency requirement and is therefore related to the overall mass.

b. The stiffness of sub-assemblies and components shall be such that the structural and functional performance requirements are met, avoiding excessive deformations, leading to violations of specified envelopes, gapping at joints or the creation of inefficient load paths.

4.3.4 Dynamic behaviour

The resonant frequencies of a structure shall be restricted to specified bandwidths which have been chosen to prevent dynamic coupling with major excitation frequencies (e.g. launch vehicle fundamental frequencies).

4.3.5 Thermal

a. The design of space structures shall conform to the constraints imposed by thermal design as required to meet the mission objectives.

b. The temperatures and temperature variations and gradients that occur during all phases of a mission, including manufacturing and storage, shall be taken into consideration, both in the material selection and in the design in order to achieve the required functional and structural performance.

4.3.6 Pressure

a. The design, manufacturing, test, operation, and maintenance of metallic and non-metallic pressurized hardware which includes pressure vessels, pressurized structures, pressure components (e.g. valves, pumps, lines, fittings and hoses) and pressurized equipment (e.g. batteries, heat pipes, cryostats and sealed containers) shall conform to the specific requirements for structural design and verification of pressurized hardware (see ECSS-E-30-02).

b. The design of a pressurized items shall include the evaluation of:

1. inspectability;
2. pressures, including number of pressure cycles;
3. temperatures, including thermally induced loads;
4. environments (both internal and external), including contained substance, cleaning agents and humidity;
5. stresses imposed by internal, external or other sources to which the structure is exposed, including localized stresses, residual stresses imposed by the manufacturing process, e.g. welding, impact loads and dynamic loading from flight operations;
6. dimensional restrictions;
7. adequacy of structural interfaces, both with respect to stiffness, strength and damage tolerance;
8. requirements imposed by other disciplines.

4.3.7 Damage tolerance

c. To the extent possible damage tolerance design principles, e.g. fail-safe design (redundancy) of attachment points, and damage tolerant materials shall be applied.

d. The resistance of the structure against manufacturing defects and the result of accidental damage (low energy impact) shall be considered in the design.

NOTE A structure is considered to be damage tolerant if the amount of general degradation or the size and distribution of local defects expected during operation do not lead to structural degradation below limit-specified performance.

4.3.8 Fracture control

a. A fracture control programme shall be established and this shall become an integral part of the design and verification process and consists of several steps, including the following:

1. Hazard analysis and structural screening to identify potential fracture critical items (PFCIs);
2. the formulation of a non-destructive inspection (NDI) policy;
3. fracture mechanics analysis;
4. the identification of fracture critical items (FCIs).

NOTE Fracture control is the design and verification process applied to prevent or to demonstrate that a failure resulting in “catastrophic” or “serious” consequences does not occur. The definitions applied to “catastrophic” and “serious” for space systems are defined in ECSS-Q-40.

b. A fracture control programme shall be implemented in accordance with approved procedures (see ECSS-E-30-01).

4.3.9 Tolerances and alignments

a. The system of tolerances applied to the mechanical design shall be sufficiently accurate to guarantee conformance to geometrical interface requirements.

b. The angular and position tolerances shall be consistent with the requirements for alignment or pointing accuracy of the assembly necessary to achieve the required mission objectives.

c. In cases where alignment adjustability is required, either at assembly level or at spacecraft level, these provisions shall be included in the mechanical design together with the devices (e.g. alignment cubes) necessary for measurement or checking of the alignment.

4.3.10 Electrical conductivity

The required electrical conductivity of the structure shall be achieved, where necessary, by the provision of attachment points and bonding straps.

4.3.11 Lightning protection

The structure shall be designed such that it can dissipate static electrical charges, provide necessary electromagnetic protection and provide acceptable means of diverting electrical current arising from lightning strike so as not to endanger the vehicle.

4.3.12 Electromagnetic compatibility

Electromagnetic compatibility (EMC) of the structure shall be achieved by using adequate materials, material thickness and design.

4.3.13 Dimensional stability

a. Dimensional stability of the structure shall conform to mission specified system and payload requirements.

NOTE Dimensional stability requirements address the short, medium and long term alignment stability of a space structure under the operational environment.

b. The mechanical design of a structure shall ensure that no loss of alignment which jeopardizes or degrades the mission objectives can be caused by the action of applied loads (e.g. launch loads, deployment loads, thermal, moisture release).

c. Materials selected shall consider the stability of the material under the given environment.

4.4 Constraints

The constraints placed by the structure on the system or other subsystems shall be defined.

4.5 Interface

a. The design of structural assemblies shall be compatible with all interfaces, internal and external, which can affect, or can be affected by adjacent systems, subsystems or assemblies.

b. Consideration shall be given to the following:

1. Mechanical subsystem internal interfaces which include:
   - thermal control;
   - mechanisms;
   - ECLS;
   - propulsion;
   - pyrotechnics;
   - mechanical parts;
   - materials.
2. Interfaces controlled by system engineering which include:
   - system engineering process;
   - requirement definition and analysis;
   - system verification;
   - spacecraft-launcher interface;
   - environments;
   - human factors and ergonomics;
   - configuration definition.
3. Interfaces with the other engineering branches which include:
   - electrical or electronic engineering: interfaces with equipment, optics, avionics.
   - communication: ground communications, space link.
   - control systems: rendezvous and docking, attitude and orbit control and robotics.
   - ground system and operations: mission operation requirements, ground system, pre-flight operations, mission control, in-orbit operations, mission data, post-flight operations.

c. Interfaces shall be explicitly defined with respect to the following:
   1. design requirements, i.e. areas, volumes, alignments, surface finishing and properties, tolerances, geometry, flatness, fixations, conductibility, constraints imposed by design concepts (e.g. thermal, optical design), mass and inertia properties;
   2. external loads applied to the interfaces, including temperature effects;
   3. global and local stiffness of parts interfacing to the structure.

4.6 Design

4.6.1 Inspectability

a. To ensure structural integrity, consideration shall be given to the requirement to inspect a component, assembly or structure during the following:
   1. at various stages throughout manufacture;
   2. at various stages during assembly;
   3. after testing;
   4. in-service.

b. An efficient, consistent NDI policy shall be incorporated into the design process taking into account the inspectability of parts and access for inspection equipment and personnel.

c. For structures subject to fracture control the NDI policy shall be consistent with the assumption made for the fracture control verification.

4.6.2 Interchangeability

All parts or sub-assemblies identified by an item number shall be designed to be functionally and dimensionally interchangeable with items which are identically numbered.

4.6.3 Maintainability

a. The mechanical design shall require a minimum of special tools and test equipment to perform assembly, integration and repair and maintenance activities (see ECSS-Q-30).

b. The design shall minimize the maintenance required during storage and ground life.

c. The maintenance programme shall include a maintenance protocol and shall define measurable parameters for all pertinent operations, during all project phases, which shall include, but not be limited to the following:
   1. mean-time-to-repair;
   2. limited-life;
   3. fault detection and isolation capability;
   4. spares requirements;
   5. ground storage requirements.

d. The results of the maintenance programme evaluation shall influence the design and shall avoid costly, late alterations, or replacement of parts. The results of the maintenance programme evaluation shall also form the criteria with which various concept designs are evaluated.

e. Unaccessible structures shall require no maintenance during service.

4.6.4 Availability

a. In conjunction with the maintainability activity, on-ground and in-orbit readiness shall be studied to assess structure availability.

b. The objective of the study shall be to demonstrate how the user requirements are met and assist in determining the optimum structure production and storage.

4.6.5 Design concept

a. The following structural design aspects shall be covered:

1. The structural design shall lead to an item that is proven to be strong and stiff enough for the intended purpose throughout its intended lifetime;
2. Practices used in structural design shall be in accordance with those stipulated or agreed by the controlling bodies to permit certification and qualification of structures;
3. All structural design concepts shall include provision for verification of the structural integrity during design, manufacture and once in service;
4. The structural materials used shall have known, reliable and reproducible properties and shall have proven resistance to the environmental factors envisaged.
5. The structural materials shall not be hazardous to the operators, crew or mission;
6. The structure mass shall be minimized;
7. The design shall include balancing mass fixations;
8. The structure shall be cost effectively manufactured, by methods that do not alter the designed characteristics (mechanical or environmental resistance) in an unknown way, and by methods proven to be reliable and repeatable;
9. The generation of space debris by structural breakup shall be minimized.

b. Redundancy concepts (fail-safe) shall be considered whenever possible to minimize single-point failures. Where a single-point failure mode is identified and redundancy cannot be provided the required strength and lifetime shall be demonstrated (safe-life). See ECSS-E-10.

NOTE Many factors influence the definition and selection of the structural design concept (e.g. strength, stiffness, mass, resilience, resistance to corrosion and the environment, fatigue, thermal properties, manufacturing, availability and cost).
Structural design is an iterative process. The process starts with the conceptual design of possible alternatives which could be considered to satisfy the general performance requirements and are likely to meet the main mission constraints (e.g. mass, interfaces, operation and cost).
The various concepts are then evaluated according to a set of prioritized criteria in order to select the one or more designs to be developed further in detail. The main purpose of the evaluation is to identify the main mission requirements and to establish whether the selected concepts meet the requirements.
The selected concepts are evolved and evaluated in more detail against a comprehensive set of mechanical requirements and interface constraints which are “flowed down” from the main mission and functional requirements.

4.6.6 Material selection

Material selection shall be in accordance with ECSS-Q-70 and ECSS-E-30 Part 8.

4.6.7 Mechanical parts selection

Mechanical parts selection shall be in accordance with ECSS-E-30 Part 7.

4.6.8 Design optimization

The design of the structure shall be optimized whenever one or more design criteria have to be fulfilled to the best possible extent and all other requirements shall be respected at the same time.

NOTE Design optimization is the process of improving the design to reach the mission objectives. Where the optimum lies, depends on the prioritization of the requirements, but also on schedule and cost restraints. The structural optimization method combining mathematical programming techniques and analytic methods of structural analysis can help the designer identify and improve the promising design. Design and analysis iterations are necessary to evaluate the effects of design modifications.

4.6.9 Material allowables

a. For all structural materials allowable stresses shall be statistically derived, considering all operational environments. The scatter bands of the data shall be derived and allowable stresses defined in terms of fractions of their statistical distribution with prescribed levels of reliability and confidence.

b. For each type of test the minimum number of test specimens shall be ten to establish A-values, and five to establish B-values.

c. If the material is delivered in several batches, the allowables test programme shall consider the probability of variations from batch to batch. In such cases, preliminary allowable stresses may be based on the initially small sample size, and upgraded as the sample size increases by tests of newly arriving batches.

d. All material testing shall be performed in accordance with the requirements as defined in ECSS-E-30 Part 8.

NOTE 1 Probabilistic descriptions of the strength distribution of materials are usually based on the normal, log-normal or the Weibull distribution. Regardless of the kind of distribution, distribution curves and fractiles cannot be uniquely identified due to the data scatter. The values are assumed to lie within an interval bounded by upper and lower confidence limits. When allowables are deduced from a regression line based on a small number of test specimens the confidence in such allowables is low. Larger number of test specimens generally do not change the shape of the regression line, but the confidence in the statistical evaluation increases.
The position and shape of the confidence limits depend on the extent of the scatter, the correlation coefficient and on the sample size. For a given probability and confidence level the design allowable L is:

$$L = x - k\sigma$$

where

x denotes the mean of the distribution,

σ the standard deviation, and

k is a multiplier which size depends on probability, confidence level and sample size.

NOTE 2 As a rule, allowable stresses are defined not as points on a regression line, but as points on the upper confidence limit. Such values increase with increasing sample size, so that the definition of an adequate sample size involves a compromise between the maximization of allowables and associated experimental effort.

NOTE 3 The test database can be broadened by the inclusion of compatible data from acceptance and development tests as relevant.

4.6.10 Metals

a. All allowables for metals (yield, ultimate, shear, stress or strain) shall be defined by their A-values.

b. For redundant metal structures, allowables defined by their B-values should be used.

c. All other metal material properties, including fracture and fatigue properties, shall be defined by average values.

NOTE Metals are assumed to react to loads in an elastic-plastic manner.

4.6.11 Non-metallic materials

4.6.11.1 Glass and ceramics

Allowables shall be derived through a probabilistic approach, which adequately cover all size effects (see ECSS-E-30 Part 8).

NOTE For brittle materials such as glass and ceramics the lack of ductility results in very low failure strains. The large scatter observed in component testing is primarily caused by the variable severity of flaws distributed within the material (volume flaws) or flaws extrinsic to the material volume (surface flaws). The different physical nature of the flaws result in dissimilar failure response to identical external loading conditions. Due to the random distribution of flaws the failure of a complex structural part can be initiated not only at the point of highest stress.

4.6.11.2 Other non-metallics

a. All allowables, (stress or strain) shall be defined by their A-values.

b. For redundant structures, allowables (stress or strain) defined by their the B-values should be used.

c. All other material properties, including fracture and fatigue properties, shall be defined by average values.

4.6.12 Composite fibre reinforced materials

a. All allowables (stress or strain) shall be defined by their A-values.

b. For redundant structures, allowables (stress or strain) defined by their B-values should be used.

c. All other material properties, including fracture and fatigue properties, shall be average values.

NOTE The strength and stiffness of composite materials are functions of fibre properties, matrix properties, fibre content and orientation of fibres. The properties of composites are determined by both fibres and matrix. By placing fibres in different directions, the material properties can range from highly anisotropic to quasi-isotropic.

4.6.13 Adhesive materials in bonded joints

All allowables (stress or strain) shall be defined in accordance with approved standards (see ECSS-E-30-05 or other recognized standards).

4.6.14 Margin of safety (MOS)

a. Margins of safety (MOS) shall be calculated by the following formula:

$$MOS = \frac{(allowable\ load)}{(applied\ load) \times FOS} - 1$$

where:

allowable load: allowable load under specified functional conditions (e.g. yield, buckling, ultimate)

applied load: computed or measured load under defined load condition (design loads)

FOS: Factor of safety applicable to the specified functional conditions including the specified load conditions (e.g. yield, ultimate, buckling)

NOTE Margins of safety express the margin of the applied load multiplied by a factor of safety against the allowed load. Loads can be replaced by stresses if the load-stress relationship is linear.

b. All margins of safety shall be positive.

4.6.15 Factors of safety (FOS)

a. The selection of appropriate factors of safety for a specific structural element depends on parameters which are related to loads, design, structural verification approach and manufacturing aspects. Such aspects include the following:

- pressurized structures;
- human presence;
- flight hardware or ground support equipment;
- material type;
- joints, bearings, welds;
- verification by test;
- verification by analysis only;
- thermal loads;
- ageing effects;
- emergency loads;
- fail safe verification;
- dimensional stability.

b. Special factors, also called “additional factors”, can be applicable for joints, bearings and welds. Such additional factors shall be applied in combination with other factors of safety.

c. As opposed to the empirical approach applied in the definition of deterministic factors of safety, a probabilistic approach can be followed. Factors of safety are calculated based on a statistical description of loads, materials and geometry, combined with a failure probability requirement.

d. Factors of safety shall be determined considering the uncertainty of all relevant load, design, material, manufacturing and verification parameters.

e. The consistency of all assumptions regarding the loads, Factors of safety, materials and other factors shall be verified, following the guidelines given in annex D and annex E.

4.6.16 Scatter factors

Adequate scatter factors shall be used in fatigue analysis.

4.7 Verification

4.7.1 General verification

A general verification programme shall be implemented.

4.7.2 Verification by analysis

a. Analysis shall be based on reliable input data derived from appropriate tests or qualified methods.

NOTE Different analysis methods are available, such as handbook based calculations, analytical closed form solutions or numerical solutions. See ECSS-Q-20 and ECSS-Q-30.

b. It shall be proven that the analysis tools used are adequate for the intended purpose.

c. The qualifying authority shall exhibit a level of qualification allowing him or her to justify assumptions made in developing tools, methods and models and their representativity.

d. Nominal structure gauge (thickness) as specified in the design drawings shall be applied for analysis. Influence of tolerances (including overall dimensions, thickness), shall be used to evaluate the most critical condition.

e. Average material gauge (thickness) as specified in the design drawings shall be applied for all strength calculations, except for pressurized structures where minimum values shall be applied.

4.7.3 Modelling aspects

All mathematical models shall be checked for

a. the representativity of the anticipated application range, and

b. the applicability of the assumptions and boundary conditions with respect to the real physical behaviour.

NOTE 1 Analysis is based on mathematical models which are representative of the structural behaviour. These models help the designer to assess how the design fulfils structural requirements and gives an insight on how to improve the design.
The mathematical models allow preparation of experimental testing and verification of requirements not demonstrable by tests, e.g. through coupled analysis.
The mathematical models help in defining load cases or combination of load cases.

NOTE 2 Models can also give designers insight on sensitivity of the design with respect to uncertainties.

4.7.4 Static analysis

a. Static analysis shall be performed to verify the structural responses (e.g. displacements, forces, stresses, internal loads) to (quasi) static loads.

b. The static analysis shall consider representative load introduction, load distribution and boundary conditions.

c. The residual stresses due to the manufacturing process shall be taken into account.

4.7.5 Modal analysis

a. Modal analysis shall be performed to verify the frequency requirements and to determine associated modal characteristics (e.g. natural frequencies, eigenmodes, effective masses, participation factors, generalized masses).

b. When necessary, pretension and spin effects shall be included.

c. When necessary, for large lightweight structures, the effect of the surrounding air shall be considered.

4.7.6 Response analysis

a. Dynamic response analysis shall be used to verify the structural response due to force or motion inputs either in the frequency domain (sine and random) or time domain (transient) according to the definition of loads and information required.

b. Coupled loads analyses shall be performed to verify the loads resulting from dynamic behaviour of structural assemblies.

   1. The mathematical models applied in coupled analyses shall represent the structural assemblies by characterization of the dynamic parameters, namely fundamental frequencies and mode shapes, the associated effective masses and damping.

   2. The characterization of natural frequencies with small effective masses (e.g. multilayer insulation) shall not be performed if it can be shown that these modes do not significantly influence the overall dynamic behaviour.

4.7.7 Acoustics analysis

a. Acoustic analysis shall be used to calculate the characteristics of the pressure field due to acoustic sources.

b. Response analysis shall be performed to verify structural response to acoustic fields including acoustic fatigue.

4.7.8 Fluid structure interaction (FSI)

The structure shall be verified against the effects of the interaction with fluids (e.g. sloshing, POGO, cavitation effects, pressure fields).

4.7.9 Fatigue analysis

a. Fatigue analysis shall be performed to verify that fatigue crack initiation or propagation resulting in structural failure or functional degradation can not occur through out the service-life of the structure.

b. Effects of notches shall be taken into account.

c. The life of the structure shall be verified for the required envelope life multiplied by the required scatter factor.

d. All loads (alternate loads, permanent loads, acoustic loads) and their combination and sequence shall be considered.

e. Fatigue analysis shall be performed in accordance with established standards.

NOTE Fatigue analysis should use a cumulative damage approach which estimates fatigue life from stress time histories and fatigue material allowables (SN/Wöhler curves).

4.7.10 Fracture mechanics analysis

Fracture mechanics analysis shall be performed in accordance with established standards to determine crack propagation phenomena (crack propagation rate, critical crack size) on the basis of material properties and crack tip stress field.

4.7.11 Verification of composite structures

Analysis verification of composite structures shall be performed in accordance with agreed and established standards.

4.7.12 Buckling analysis

a. Buckling analysis shall be used to predict the loads at which the onset of structural instability occurs.

b. For cases where elastic fully reversible buckling is accepted, post-buckling behaviour shall be analysed.

c. Defects and geometrical imperfections in the structure shall be adequately taken into account.

4.7.13 Thermoelastic analysis

a. Thermoelastic analysis shall be used to verify stresses and deformations due to occurring temperatures.

b. Temperature distributions received from thermal analysis shall be mapped on the structural model.

4.7.14 Adhesive connections

a. The influence of the characteristics of the adhesive, the material of the adherents, their surface treatments, the dimensions of the bonded areas and the relative stiffness of the parts shall be taken into account in the mechanical characteristics of the bounded connections.

b. The analysis of adhesive joints shall be performed in accordance with approved standards and procedures (see ECSS-E-30-05 or other recognized standards).

4.7.15 Bolted connections

Bolted connections shall be analysed according to approved standards and procedures.

4.7.16 Welded connections

a. The analytical verification of welded joints shall take into account stress concentrations, type and quality of the weld, local maximum allowable geometrical defects as well as residual stresses and material characteristics changes due to local heating and cooling.

b. Welded connections shall be analysed according to recognized standards or procedures.

4.7.17 Riveted connections

Riveted connections shall be analysed according to recognized standards or procedures.

4.7.18 Insert connections

a. Standard insert connections shall be analysed according to approved standards and procedures (see ECSS-E-30-06 or other recognized standards or procedures).

NOTE Inserts are generally used in sandwich constructions with cores of low strength.

b. For inserts not covered by reference, other appropriate methods shall be used.

4.7.19 Aeroelasticity

Aeroelasticity analysis shall be used to verify the interaction between the aerodynamical flow and the structure.

4.7.20 Mass and inertia properties

a. The inertia properties shall be computed according to the specified accuracy using the adequate inertia matrix of individual components.

b. The quantities shall be monitored and presented in a mass budget report to be issued on a regular basis; a breakdown of mass to component level shall be given together with mass contingency estimates which shall be based on the design maturity.

c. The mass and inertia data shall include mass, centre of mass, moment of inertia with respect to specified coordinate frames as well as the principle moments of inertia and their orientation.

4.7.21 Alignments

The verification analysis shall assure that the design tolerances are adequate to meet the alignment requirements.

4.7.22 Dimensional stability

a. Short, medium and long term effects shall be taken into account as appropriate to determine the dimensional stability of the structure..

b. A stability budget shall be established and the contributors shall be identified, analysed and allocated (e.g. thermo-elastic, moisture release, in-orbit loads, Zero-gravity environment, micro-vibrations, material ageing (material property changes), material dimensional instability (invar), setting effect, spin effect).

4.7.23 Microgravity, audible noise and human vibration analysis

Verification of the microgravity and audible noise and human vibration requirements shall be performed by analysis.

4.7.24 Verification by test

a. Test verification for equipment shall be performed in accordance with approved standards and procedures (see ECSS-E-10-02 or other recognized standards).

b. The test objectives and success criteria shall be clearly defined.

c. The adequacy of the test procedure with regard to the test objectives shall be verified before the test.

d. Checking of the test conformance with regard to the test procedure shall be performed after the test. The impact of deviations on the adequacy of the test with respect to the test objectives shall be evaluated.

e. The test shall be representative with regard to operational conditions. Differences between test and operating conditions (e.g. boundary conditions, gravity, atmosphere) shall be identified and their effect with respect to test representativity shall be evaluated. If necessary, a correlated mathematical model shall be used to demonstrate representativity.

f. The test results shall be evaluated with respect to the requirements to be verified.

NOTE 1 Tests are used to

- characterize basic inputs for analysis, e.g. material properties and failure criteria,
- understand the behaviour of a structure as part of the development process,
- provide a basis for checking analysis assumptions as well as model validation,
- qualify the proposed design, and
- accept the structure for flight.

NOTE 2 Different types of tests are performed including

- sample tests performed in order to provide information required for the design,
- tests on structural parts or assemblies performed in order to verify and to understand the local behaviour or to validate analysis assumptions, and
- global tests.

4.7.25 Static test

a. Static test shall be applied to check the structural responses,(e.g. stresses and displacements) as well as integrity under constant loads.

b. Static rupture test shall be applied when knowledge of the rupture margins is necessary.

c. It shall be shown that the load distribution is representative.

d. The structural analysis of composite structures shall be confirmed by appropriate loadings of a fully instrumented structure or component. The static strength of the composite design shall be demonstrated through a programme of component ultimate load tests in the appropriate environment, unless experience with similar designs, material systems and loadings is available to demonstrate the adequacy of the analysis.

e. Test verification of composite structures shall be performed in accordance with recognized procedures.

4.7.26 Modal survey test

a. Modal survey tests shall identify dynamic characteristics as eigenfrequency, mode shapes, effective and generalized mass and modal damping.

b. Both phase resonance methods with appropriate exciter configurations or phase separation methods evaluating measured transfer functions may be applied.

c. The modal survey test shall be performed with different excitation levels in order to check the structural linearity.

4.7.27 Dynamic tests: sine, random, shock

a. Supported equipment and subsystems shall be represented with their mass, inertia and stiffness in accordance with the representativity requirements.

b. Sinusoidal vibration tests shall be performed, including sine sweep tests as relevant.

c. Random vibration tests shall be performed.

d. Shock tests shall be performed if relevant.

e. For equipment, the vibration levels and durations shall be in accordance with the values defined in approved space standards and procedures (see ECSS–E–10–03 or other recognized standards).

NOTE The purpose of applying dynamic loading to the structure is to verify its dynamic behaviour (internal and at the interfaces), if its stiffness requirements have been achieved (when they are defined in frequency term) and its strength and alignment stability under dynamic loads.

4.7.28 Acoustic test

a. Acoustic tests shall verify the ability of the structure and its equipment to withstand the vibrations induced by the specified acoustic field.

b. Acoustic tests shall verify the dynamic design environment for subsystems.

4.7.29 Fatigue and fracture test

a. Fatigue and fracture tests shall verify that the structure can survive, without unacceptable degradation, at least the predicted service-life cycles with the required scatter factor.

b. Fatigue tests shall verify that the cyclic loads do not cause cracks that endanger integrity of the structure or change the behaviour significantly.

c. Fracture tests shall verify that initial cracks present in the structure do not propagate, due to cyclic or constant loadings, up to a critical value which causes structural failure.

4.7.30 Microgravity, audible noise and human vibration tests

a. The conformance to requirements of vibration and audible noise sources of equipments shall be verified by test.

b. Structural and acoustic to structural transmissibilities shall be validated by test.

4.7.31 Non-destructive inspection and test

The structure shall undergo, non-destructive inspection to verify that no cracks larger than the size specified by life or leak requirements are present.

NOTE Non-destructive tests evaluate or quantitatively measure properties or detect defects in materials or structural components or whole structures which do not cause a permanent change to the item under test, e.g. visual inspection, ultrasonics, holography, eddy current, leak test.

4.7.32 Thermal stress and distortion test

a. The survival of the structure to thermal loads without failure shall be verified by thermal stress tests.

b. conformance of the structural distortion to specification shall be verified by thermal distortion tests.

4.7.33 Thermal cycling test

a. Thermal cycling tests shall verify that the structure is able to survive without failure all the thermal cycling loads expected during its service-life.

b. Adequate scatter factors shall be applied for the thermal cycling tests.

4.7.34 Ageing test

Where adequate data is not available, ageing tests shall be performed to identify possible variations of the material properties as a function of time and environment. These variations shall be taken into account in all verification phases.

4.7.35 Contamination test

Appropriate contamination tests shall determine the particle fall out (PFO) on specified spacecraft systems.

4.7.36 Mass and Inertia properties measurement

The mass and inertia properties of the structure shall be measured to the required accuracies.

4.7.37 Alignment checks

Alignment checks shall be performed in order to verify the relative position and movements between parts as relevant during all manufacturing, assembly and verification phases.

4.7.38 Dimensional stability tests

a. Appropriate tests shall be performed to verify the dimensional stability of the structure in the environment of the operational conditions.

b. the conformance of long term changes of material properties to specification (e.g. moisture release, ageing, creep) shall be verified by appropriate tests.

4.7.39 Geometrical control

Dimensions and tolerances shall be adequately controlled during and after manufacturing as necessary to meet all functional requirements.

4.7.40 Interface verification

Interface verification shall be performed by inspection (including geometrical control) of the manufacturing drawings and parts with respect to the interface requirements and, if necessary, with aid of fit checks of interfacing structural components.

4.7.41 Aerothermodynamic test

a. Aerodynamic and aerothermodynamic tests shall be performed to verify the behaviour of the vehicle or a part of it during flight in the atmosphere.

b. Tests performed with subscale models shall be verified for their representativity with respect to the flight item.

4.7.42 Aeroelasticity test

Aeroelasticity tests shall be performed to verify the analytically predicted behaviour for each flight configuration and to determine relevant application limits.

NOTE Aeroelasticity tests are performed on subscale and full-scale models and on flight vehicles on ground and in flight.

4.7.43 Lightning protection verification

A test and inspection procedure shall be established which ensures the satisfactory functioning of the lightning protection system.

4.8 Production and manufacturing

4.8.1 General aspects

The production of space structures includes the following:

- procurement, which covers:
  - materials,
  - components, and
  - parts.
- manufacturing/fabrication of components,
- assembly of components,
- assembly of substructures to form the final structure, either within the factory or for payloads and launch vehicles at the launch site.

The production engineering of space structures shall ensure that the structure, and all its component parts, can be manufactured in the way intended and shall be of acceptable quality, reliability and reproducibility.

4.8.2 Procurement

a. Quality assurance requirement for procurement defined in ECSS-Q-20 shall apply.

b. The successful design and manufacture of space structures relies on the guaranteed supply of materials and parts of specified and acceptable quality as confirmed by test or inspection. Factors to be evaluated during the design stages shall include the following:

   1. specification;
   2. acceptability for the application;
   3. sources identified.

c. Procurement shall be made to specifications derived by the user and in accordance with any relevant specifications or a fully detailed purchase order.

4.8.3 Manufacturing process

a. Quality assurance requirements for manufacture defined in ECSS-Q-20 shall apply.

b. Standard procedures shall be used to manufacture space components. These procedures shall form part of the overall product assurance requirements and shall conform to all applicable specifications

4.8.4 Manufacturing drawings

a. Manufacturing drawings derived from design drawings and established in accordance with the functional requirements shall be used .

b. Manufacturing drawings shall take into account the quality requirements, the manufacturing process and the various manufacturing steps.

4.8.5 Tooling

a. Requirements for tooling, including assembly jigs and fixtures, shall take into account the following:

   - materials to be used in manufacture;
   - geometry of the part(s);
   - number of parts required;
   - production rate.

b. Tooling design shall cover the acceptability of the finished components quality, size, shape and surface finish.

4.8.6 Component manufacture

a. During design development, manufacturing requirements shall be carefully considered through the input from the production engineering evaluation.

b. The manufacturing techniques used form part of the design and shall be considered when competitive designs are evaluated.

c. All manufacturing operations shall conform to product assurance requirements.

d. Quality assurance requirements for component manufacture defined in ECSS-Q-20 shall apply.

e. Special consideration shall be given to contamination and moisture for specified structures.

NOTE Manufacturing activities to be developed include

- samples for evaluation and testing,
- prototypes, components, representative sections or whole structures in order to prove manufacturing processes and procedures, test and evaluate, and determine and prove inspection procedures, and
- flight hardware, components and structure for use.

4.8.7 Assembly

a. Quality assurance requirements for assembly defined in ECSS-Q-20 shall apply.

b. Component assembly procedures shall involve, but are not limited to:

1. specifications of parts and materials,
2. assembly instructions which shall include:
   - preparation;
   - equipment;
   - parts and materials;
   - method;
   - cleaning.
3. inspection or test.

c. Major assembly shall be classified as the connection of either

- large sub-structures, e.g. launcher stage assembly, or
- final construction of the launch vehicle and its payloads, and the preparation for launch.

d. Major assembly operations shall be accompanied by inspection and mechanical and functional tests.

NOTE 1 The assembly includes component assembly and major assembly.

NOTE 2 Component assembly is the connection together of individual parts to form assemblies or sub-structures. Component may be large or small depending on the design of the structure.

4.8.8 Packaging, handling, transportation

The applicable quality assurance requirements according to ECSS-Q-20 for packaging, handling and transportation shall apply.

4.8.9 Storage

a. Storage conditions shall prevent the degradations of the structure.

b. To avoid all hazards to personnel or equipment, items that contain hazardous materials or those requiring special storage shall be marked according to recognized procedures.

c. For parts or components which cannot be inspected prior to flight and for which the possible structural degradation during storage is uncertain, adequate representative specimens (witness specimens) shall be stored together with the flight hardware. Prior to acceptance for flight, the samples shall be sufficiently inspected or tested for any structural degradation.

4.8.10 Cleanliness

Cleanliness requirements shall be defined and adequately controlled for all stages of manufacture, storage and transportation.

4.8.11 Health and safety

The health and safety aspects of all processes and materials shall be evaluated to ensure that they conform with all appropriate international, national and company safety policies.

4.9 In-service

4.9.1 Ground inspection

Ground inspection of integrated structures shall be part of pre-launch action and, for recoverable structures, those undertaken after its return.

NOTE Ground inspection techniques can generally be those which are applied during system integration or during assembly manufacturing stages.

4.9.2 In-orbit inspection

a. In-orbit inspection equipment shall be able to detect damage in a reliable and cost-effective way, whilst being portable and easy to use, without requiring specialist personnel, extensive resources and expert interpretation.

NOTE The role of in-orbit inspection is to inspect during the use that a structure has not so deteriorated, that further operation renders it unsafe.

b. Built-in-testing (BIT) systems shall be developed for continuous monitoring of long-term deployed structures, primarily where access is limited or the area is critical to the integrity and safety of the structure. BIT systems should identify damaged areas as they occur. Other appropriate techniques shall then be used to investigate local damage sites, as directed by the global monitoring system.

NOTE BIT systems monitor the condition of structures.

4.9.3 Evaluation of damage

a. When a defective or damaged area has been located its criticality with regard to the operations and safety shall be assessed.

b. The following factors shall be considered in determining criticality:

- defect size;
- location;
- propagation rate.

c. The above factors shall be evaluated taking into consideration the following:
   - operational conditions (loading and environment);
   - maintenance schedules;
   - as-designed structural requirements;
   - service-life of the structure.

d. Depending on the outcome of the evaluation of the damage , the options shall be to repair or replace the affected parts of the structure.

4.9.4 Maintenance

4.9.4.1 General maintenance requirements

a. All maintenance action shall be fully documented, including the specification of inspection methods, recording of results, category of damage, repair methods and compilation of service history documents.

b. The maintenance schedules shall be determined during design process, and procedures are specified for all of the action required.

4.9.4.2 Preventative maintenance

Preventive maintenance shall be applied to parts classified as, but not restricted to the following:

- critical to the safety and function of the structure;
- identified parts with low service-lives;
- high or low temperature use;
- moving parts experiencing wear;
- access points of structures (doors and hatches);
- surfaces experiencing general “wear-and-tear”.

NOTE Preventive maintenance includes the replacement of parts approaching the end of their stated lives, repainting, oiling and greasing moving parts.

4.9.4.3 Corrective maintenance

a. Corrective maintenance shall be applied to parts incurring damage and those undergoing higher then expected rates of deterioration. Depending on the criticality of the failure, procedures shall be required for on-orbit or on-earth action to be taken.

NOTE Corrective maintenance includes replacing or repairing parts and assemblies which have been damaged, either by accident or as a result of a higher than expected rate of deterioration.

b. Corrective maintenance shall involve the repair or replacement of damaged parts, the option to repair or replace depending upon, but being not limited to:
   - evaluation of damage: see subclause 4.9.3;
   - possibility to repair: to restore the as-designed mechanical and environmental performance for the remaining designed service-life, by known and proven techniques;
   - ability to replace: without causing intolerable levels of damage to surrounding structure;
   - remaining service-life.

4.9.5 Repair

a. On-earth or on-orbit repair procedures shall be defined as relevant.

b. All repair procedures shall consider the following factors:

1. structural classification;
2. damage category;
3. proven repair procedure (supported by mechanical and environmental testing programme);
4. accessibility to damaged parts (e.g. one or both sides);
5. availability of equipment (repair material and services, appropriate personal).

c. In-orbit repair procedures shall additionally consider the following factors:

1. requirements for extra-vehicular activity;
2. transportability of materials to space (e.g. current adhesive are unstable and could outgass, hazardous cleaning and preparation chemicals);
3. preparation of surfaces or damage removal (availability of appropriate hand-tools, control of dust, vapours and contamination, avoidance of space debris generation);
4. repair manufacture difficulties.

4.10 Data exchange

4.10.1 General aspects

a. All data exchange requirements shall be established in a data exchange specification. Wherever possible, electronic data exchange using established standards shall be used.

b. All data, regardless of the format, shall be accompanied by documentation containing detailed descriptions of the data, including the following:

1. format;
2. date and status of data;
3. software version used;
4. format of media (tape, back-up, operating system);
5. version of exchange format standard.

NOTE During the development process it is important to pass data safely and quickly exchanged within the project. This includes data exchange between all engineering disciplines including design, analysis, manufacturing and test, as well as physically separated teams and other subsystems.

4.10.2 System and structure subsystem

Data shall be exchanged by documents (specifications, interface control documents) or appropriate electronic formats (e.g. geometry CAD definition, system configuration).

4.10.3 Design and manufacturing

Data shall be exchanged by means of manufacturing drawings, documents or CAD/CAM files.

4.10.4 Design and structural analysis

a. Wireframe, surface and solid geometry shall be exchanged between CAD and CAE systems and analysis software through standard based or direct interfaces.

b. Other relevant data (materials, properties) shall be exchanged using documents or appropriate electronic formats.

4.10.5 Other subsystem and structural analysis

Interfacing software or data transfer by means of applicable documents should be employed.

NOTE The exchange of data with other subsystems (like thermal control, optical) can imply a mapping of entries or results between the different models and the use of extrapolation methods.

4.10.6 Tests and structural analysis

Exchanges of test and structural analysis data shall be based on the format of tables or files.

4.10.7 Structural mathematical models

a. Exchange of structural mathematical model data should be made at three levels:

   1. Physical models (i.e. finite element models, finite difference models): same software required and often same version of the software; in case of model transfer between different codes, translation problems and differences in capabilities of different software shall be considered. Accompanying documents shall clearly describe the model, the software, the version or release and any parameters being used,

   2. Mass, stiffness matrices: the model is reduced in size and restitution matrices shall be used,

   3. Mode components: the definition depends upon the method used (e.g. clamped or free).

b. Detailed numbering (nodes, elements) and modelling requirements shall be defined in a finite element model requirements document.

4.11 Product assurance

4.11.1 General

Product assurance shall be based on the creation and implementation of an effective programme of quality control, inspection and surveillance.

4.11.2 Model traceability

Traceability of CAD, CAE, CAM and finite element models, and the relationship between each other shall be ensured.

4.12 Deliverables

4.12.1 General

All products (hardware, software, models, documents) which are delivered during the course of a project shall be clearly specified at the beginning of a project.

4.12.2 Documents

The documents required for the control of materials shall include but not be limited to the documents listed in Table 1. Where applicable reference is provided to the document requirements definition (DRD) title and the DRD controlling standard.

A description of each document is given in annex A.

Table 1: Document requirements for structural

Term used in this Standard	Document title	DRD controlling reference
Design description	Design definition file	ECSS-E-10
Design justification	Design justification file	ECSS-E-10
Interface control document	Interface control document	
Manufacturing plan		
Mathematical model delivery document		
Procurement plan		
Design development plan	Systems engineering plan	
Structure alignment budget	Technical budget	
Structure mass summary		
Structure stability budget		
Design load summary	Analysis report	ECSS-E-10-02
Dimensional stability analysis report		
Fatigue analysis		
Fracture analysis		
Material allowables		
Mechanical part allowables		
Modal and dynamic response analysis		
Stress report		
Test prediction		
Test evaluation		
Test analysis correlation		
Mathematical model description		
Assembly integration plan	Assembly, integration and verification plan	
Test plan	Test plan	

Table 1: Document requirements for structural (continued)

Term used in this Standard	Document title	DRD controlling reference
Test procedure	Test procedure	ECSS-E-10-02
Test report	Test report	ECSS-E-10-02
Test specification	Test specification	ECSS-E-10-02
Verification plan	Verification control document	ECSS-E-10-02
Design development plan	Production plan	ECSS-M-30
Configuration item data list	Configuration item data list (description in ECSS-M-40)	ECSS-M-40
Fracture control plan and item lists	Critical item list	ECSS-Q-20-04
Fracture control plan and item lists	Fracture control plan	ECSS-Q-30
Failure mode effects and criticality analysis	Failure mode effects and criticality analysis report	
Declared materials list	Declared materials list	ECSS-Q-70
Declared mechanical parts list	Declared mechanical parts list	
Drawings	Drawings	ISO 128

Annex A (normative)

Document description list

a. Configuration item data list (document controlled by ECSS-M-40)

This document shall include the complete list of structural items and gives the denomination.

b. Design definition file (document controlled by ECSS-E-10)

This document shall describe the structural design by including drawings and design documents providing a detailed definition of the structure.

c. Design development plan

The description of the concept, plan, practice and procedures for achieving the necessary tasks under design, engineering, manufacturing, assembly, integration and verification constraints shall be presented in this document, taking into account the general sequence.

d. Design justification file (document controlled by ECSS-E-10)

The selected design concepts shall be justified. Emphasis shall be put on criteria applied during the design process. The results of performed trade-offs and optimization activities shall be reported.

e. Design load summary

The complete mechanical and acoustical environment applied in the structure design and verification shall be collected and clearly defined.

f. Dimensional stability analysis report

Dimensional stability requirements shall be verified and documented.

g. Drawings (document controlled by ISO 128)

Drawings shall be in accordance with the ISO 128 series of standards.

h. Fatigue analysis

Determination of load spectra and the fatigue analysis shall be described and the summary of results shall be provided.

i. Fracture analysis

The fracture analysis shall be described and the summary of results shall be provided.

j. Fracture control plan and item lists

The plan shall describe how the applicable fracture control requirements shall be implemented. Critical items shall be identified in relevant item lists (e.g. potential fracture critical items list, fracture critical items list, limited life items list).

k. Material allowables

This document shall collect mechanical allowables and properties of all applied structural materials.

l. Mathematical model delivery document

In this document data format, model characteristics and model checks of the delivered model shall be described.

m. Mathematical model description

This document shall include a detailed description of the mathematical model structure and of the performed quality checks.

n. Mechanical part allowables

This document shall collect mechanical allowables, physical properties and geometrical characteristics of mechanical parts.

o. Modal and dynamic response analysis

This document shall include mode shape description and related natural frequencies and effective masses. The results of dynamic response analysis shall be reported.

p. Stress report

The stress report shall include summary tables with the structure margins of safety. The computed stresses and displacements of the structure due to the design loads and failure analysis to determine structure allowables (e.g. buckling) shall be included in the report.

q. Structure alignment budget

The alignment between two or more locations of the structure shall be included and documented in this document. The estimated and measured quantities shall be compared with alignment requirements.

r. Structure mass summary

The mass properties of the structure shall be monitored and documented in this document. The estimated and measured mass values shall be compared with the mass requirements.

s. Structure stability budget

The stability of the structure shall be included and documented in this document. The estimated and measured quantities shall be compared with stability requirements.

t. Test and analysis

The mathematical model shall be modified to conform to the correlation criteria.

u. Test evaluation

The evaluation of the structure performance derived from the test data shall be performed in order to compare them with the test objectives.

v. Test prediction

The prediction by analysis of the behaviour of the structural parts under test shall be presented in this document. The definition of the specific parameters to be monitored during the test performance in order to minimize as far as possible damage risk, shall be part of this document.

w. Test procedure (document controlled by ECSS-E-10-02)

The test procedure shall include a summary of objectives to be attained by the test, a description of the test article configuration including locations and accuracy of the instrumentation, a description of the test set-up and the test conditions. A summary of the applied loads and their method of application and step sequence shall be included.

x. Test report (document controlled by ECSS-E-10-02)

The test report shall contain all the data acquired by the test. Test measurements shall be recorded and delivered as part of the documentation. The test data examination and the evaluation of the correctness of the measurements shall be documented.

y. Test specifications (document controlled by ECSS-E-10-02)

The test specification shall present the objectives, the item, the configuration and the success criteria of the test. This document shall include the input levels, the test conditions and their dedicated tolerances, the output types and tolerances.

z. Verification plan (document controlled by ECSS-E-10-02)

The verification plan shall define the verification methods used and the activities developed to demonstrate that the structure fulfils all the requirements.

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Annex B (informative)

Effective mass definition

A flexible structure is idealized with N degrees of freedom (N-dof). The interface dof are denoted by $\{q_R\}$ (R-set) and the internal dof with $\{q_I\}$ (I-set). The interface dof can describe properly the six motions as a rigid body. The interface dof constitute a determined interface.

The undamped linear equations of motion of the N-dof dynamic system are

$$[M]\{\ddot{q}\} + [K]\{q\} = \{F\}$$

where

$[M]$	the mass matrix
$[K]$	the stiffness matrix
$\{\ddot{q}\}$	the acceleration vector
$\{q\}$	the displacement vector
$[F]$	the external force vector

Partitioning the equations of motion into the R-set and the I-set results in the following equations:

$$\begin{bmatrix} M_{RR} & M_{RI} \\ M_{RI} & M_{II} \end{bmatrix} \begin{Bmatrix} \ddot{q}_R \\ \ddot{q}_I \end{Bmatrix} + \begin{bmatrix} K_{RR} & K_{RI} \\ K_{RI} & K_{II} \end{bmatrix} \begin{Bmatrix} q_R \\ q_i \end{Bmatrix} = \begin{Bmatrix} F_R \\ F_i \end{Bmatrix}$$

In case of a base excitation the dynamic responses of the structure are a superposition of the rigid body motions with respect to the R-set and the relative motions of I-set, assuming $\{q_R\} = \{\ddot{q}_R\} = \{0\}$, hence

$$\{q\} = [\Phi_R]\{\delta\} + [\Phi_E]\{\eta\} = [\Phi_R \Phi_E]\begin{Bmatrix} \delta \\ \eta \end{Bmatrix}$$

With

$[\Phi_R]$	matrix of rigid body modes
$[\Phi_E]$	matrix of elastic modes with relative to the R-set (R-set dof are constrained)
$\{\delta\}$	vector of R-set enforced displacements
$\{\eta\}$	vector of generalised coordinates (I-set)

The matrix of rigid body modes denoted with $[\Phi_R]$ can be expressed as follows:

$$[\Phi_R] = \begin{bmatrix} D \\ I \end{bmatrix} = \begin{bmatrix} -K_{II}^{-1}K_{IR} \\ I \end{bmatrix}$$

If the R-set dof are constrained the following eigenvalue problem can be achieved:

$$\left(-\omega_k^2[M_{II}] + [K_{II}]\right)\{\varphi_k\} = \{0\}$$

with

ω_k^2 the k-th eigenvalue

$\{\varphi_k\}$ the k-th eigenvector associated with ω_k^2

The matrix of elastic modes $[\Phi_E]$ is:

$$[\Phi_E] = \begin{bmatrix} \varphi_I \\ 0 \end{bmatrix} = \begin{bmatrix} \varphi_{I1} & \varphi_{I2} & \dots & \varphi_{IN} \\ 0 & 0 & \dots & 0 \end{bmatrix}$$

The equation of motions can be expressed in $\begin{Bmatrix} \delta \\ \eta \end{Bmatrix}$:

$$\begin{bmatrix} M_o & L^T \\ L & <_m> \end{bmatrix}\begin{Bmatrix} \ddot{\delta} \\ \ddot{\eta} \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & <_k> \end{bmatrix}\begin{Bmatrix} \delta \\ \eta \end{Bmatrix} = \begin{Bmatrix} f(t) \\ 0 \end{Bmatrix}$$

in which the matrix L the matrix of modal participation factors is called. The matrix of modal participation provide a coupling between the motion as a rigid body and the elastic motions.

The modal participation matrix is $[L]^T = [\Phi_R]^T[M][\Phi_E]$.

Introducing for the generalized coordinate η_k in ad hoc manner modal viscous damping, the equations of motion can be written as follows:

$$\ddot{\eta}_k(t) + 2\xi\omega_k\dot{\eta}_k(t) + \omega_k^2\eta_k(t) = \frac{-[L_k]\{\ddot{\delta}(t)\}}{m_k}, \quad k = 1, 2, \dots$$

The equation of motion as a rigid body can be written:

$$[M_o]\{\ddot{\delta}(t)\} + [L]^T\{\ddot{\eta}(t)\} = \{f(t)\}$$

After a Fourier Transformation of the last two equations of motion result in:

$$-\omega^2\hat{\eta}_k(\omega) + 2j\xi\omega\omega_k\hat{\eta}_k(\omega) + \omega_k^2\hat{\eta}_k(\omega) = \frac{-[L_k]\left\{\hat{\ddot{\delta}}(\omega)\right\}}{m_k}, \quad k = 1, 2, \dots$$

The generalized coordinate will be eliminated now and $\hat{\eta}_k(\omega)$will be expressed in $\left\{\hat{\ddot{\delta}}(\omega)\right\}$

$$\hat{\eta}_k(\omega) = H(\omega)\frac{-[L_k]\left\{\hat{\ddot{\delta}}(\omega)\right\}}{m_k}, \quad k = 1, 2, \dots$$

with

$$H(\omega) = \frac{1}{-\omega^2 + 2j\xi\omega\omega_k + \omega_k^2}, \quad k = 1, 2, \dots$$

Finally it is found:

$$[M_o]\left\{\hat{\ddot{\delta}}(\omega)\right\} - \omega^2\sum_k \frac{H_k(\omega)[L_k]^T[L_k]}{m_k}\left\{\hat{\ddot{\delta}}(\omega)\right\} = \left\{\hat{f}(\omega)\right\}$$

or

$$\left[[M_o] - \omega^2 \sum_k H_k(\omega)\tilde{M}_k(\omega) \right] \left\{ \ddot{\hat{\delta}}(\omega) \right\} = \left\{ \hat{f}(\omega) \right\}$$

$\left[\tilde{M}_k(\omega) \right]$ is the expression for the modal effective mass:

$$\left[\tilde{M}_k(\omega) \right] = \frac{[L_k]^T [L_k]}{m_k}$$

with the generalized mass $m_k = \{\varphi_k\}^T [M] \{\varphi_k\}$.

One can prove that $[M_o] = \sum_k \left[\tilde{M}_k(\omega) \right]$.

The interface dof (6) constitute a determined interface. The generalised modal interface (reaction) forces due to elastic vibration modes constrained at the determined interface are:

$$\{P_k\} = -\omega_k^2 [\Phi_R]^T [M] \{\varphi_k\} = -\omega_k^2 [L_k]^T$$

or

$$[L_k]^T = \frac{\{P_k\}}{-\omega_k^2}$$

An other expression for the modal effective mass matrix $\left[\tilde{M}_k(\omega) \right]$ becomes:

$$\left[\tilde{M}_k(\omega) \right] = \frac{[L_k]^T [L_k]}{m_k} = \frac{\{P_k\}\{P_k\}^T}{\omega_k^4 m_k}$$

One element in the 6*6 matrix $\left[\tilde{M}_k(\omega) \right]$, $\tilde{M}_{k,ij}(\omega)$ becomes:

$$\tilde{M}_{k,ij}(\omega) = \frac{P_{k,i} P_{k,j}}{m_k \omega_k^4}, \quad i,j = 1, 2, \ldots, 6$$

References

J.T. Chen, H. K. Hong and C.S. Yeh, Modal Reaction method for modal participation factors in support motion problems, Communications in Numerical Methods in Engineering, Vol 9, pages 479-490, 1995

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Annex C (informative)

Typical acronyms for loads and factors of safety

The following loads and factors of safety are defined in the present standard:

- acceptance load (AL)
- design load (DL)
- limit load (LL)
- qualification load (QL)
- ultimate load (UL)
- yield load (YL)
- design factor (FOSD)
- ultimate factor (FOSU)
- yield factor (FOSY)
- qualification factor (KQY)
- acceptance factor (KA)
- model factor (KM)
- project factor (KP)

Annexes D and E illustrate the usage and the relationship of those loads and factors within the frame of two typical projects for which related basic assumptions are recalled.

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Annex D (informative)

Spacecraft (STM approach) development assumptions

D.1 Development assumptions

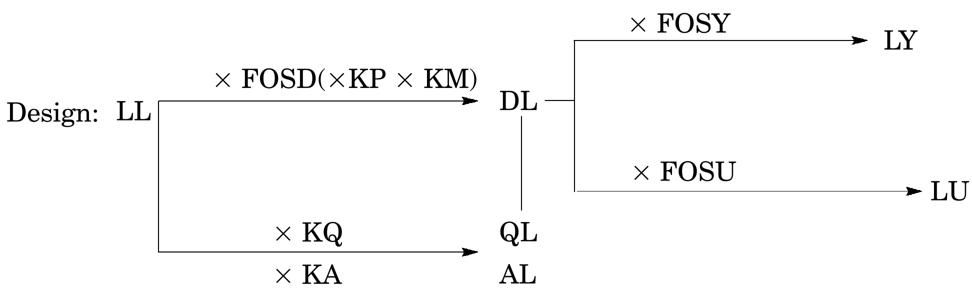
The development plan encompasses the following hardware models of the spacecraft:

- SM (Structural Model) to be qualification tested
- FM (Flight Model) to be acceptance tested.

The SM is re-used for a variety of qualification tests (static, dynamic sine or acoustic or modal identification, thermal, shock). Dynamic qualification includes test to a minimum interface acceleration level.

The conformance with alignment requirements is maintained through all the test sequence.

D.2 Loads and factors relationship



The following comments apply to this approach:

- The mechanical part of the LL is derived from the launcher manual (e.g. quasistatic loads, minimum requested test loads) either directly or indirectly (via adequate analysis, e.g. frequency response) and incorporate adequate engineering assumptions (e.g. notching) where relevant.
- The project factor KP accounts for possible mass increase at the start of the spacecraft design.
- The model factor KM accounts for the incertitude at the start of the spacecraft design with respect to mathematical model used to establish the de-

sign. While going through the design refinement loops, KM can be progressively reduced, expressing herewith the increasing fidelity of the mathematical model versus the actual hardware. Further to modal survey identification and mathematical model update KM can ideally be set to unity.

- The factor FOSD is the key factor ensuring the structural reliability objective is satisfied (0,999 at structural subsystem level)
- The structure shall be testable at the design load (DL).
- The factor FOSY ensures an acceptable risk of yielding during test at DL level, to enable re-utilization of the SM for a variety of tests according to programmatic requirements.
- The factor FOSU ensures an acceptable risk of ultimate failure during tests at DL level to enable re-utilization of the SM for multiple tests.
- The qualification load QL to be considered at the beginning of the programme should, as a minimum, be the DL loads, or a conservative TBD envelope of these loads.

As a result of the spacecraft-launcher coupled dynamic analysis (LCDA) performed during the project design and verification phases, the knowledge of the LL might be modified in the course of the project.

The DL and QL might follow this evolution.

Regarding the qualification loads QL and the acceptance loads AL, it is requested by the launcher authorities that these are as a minimum:

— KQ × LL final for qualification

— KA × LL final for acceptance

where LL final is the best knowledge of the LL as resulting from the LCDA (or an envelope thereof) approved by the launcher authorities.

- The above loads or factors relationship applies to the quasistatic and dynamic loads for general design and dimensioning, and testing.

The following factors are then commonly used:

- KM 1,1 to 1,0
- KP 1,3 to 1,0
- FOSD 1,4 to 1,5
- FOSY 1,1 to 1,25
- FOSU 1,25 to 1,5
- KQ 1,25 for ARIANE family
- KA 1,1 for ARIANE family

These assume the use of classical materials (metallic or composites) for which the coefficient of variation (COV) of the ultimate properties is lower or equal to 8 % for loads such as those encountered on ARIANE and STS types of launchers. In case the COV of a material exceeds this value, new adequate factors of safety need to be defined according to approved standards.

NOTE In case the ultimate COV is lower than 5 %, one can use FOSD = 1,25 without loss of structural reliability.

Annex E (informative)

Launcher structural element

E.1 Development assumptions

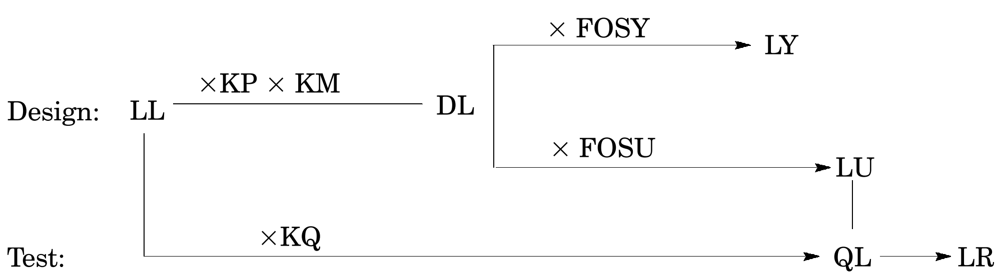
The development plan encompasses the following hardware models:

- M1 Static test model – test qualified
- M2 Dynamic test model – test qualified
- FM Flight Model(s) – not always test accepted.

The static model is used for qualification tests up to and including the ultimate load UL. Further it is often used in a final rupture test aiming at identifying the real hardware capability.

Dynamic testing mostly consists in modal identification considering the large size of launcher assemblies.

E.2 Loads and factors relationships



The following comments apply to this approach:

- LLs are derived from mission simulations including structures, propellants, payload, aerodynamic and environmental aspects, control system and other relevant aspects.
- The project factor KP accounts for possible mass increase at the start of launcher element design.
- The model factor KM accounts for the incertitude at the start of launcher element design with respect to mathematical model used to establish the design. While going through the design refinement loops, KM can be progressively reduced, expressing herewith the increasing fidelity of the mathematical model versus the actual hardware. Further to modal survey

identification and mathematical model update KM can ideally be set to unity.

- The factor FOSU is the key factor ensuring structural reliability objective is satisfied
- The structure shall be testable up to LU
- The factor FOSY ensures an acceptable risk of yielding at LL level during flight
- The qualification load QL to be considered at the start of the design shall be the LU loads or a conservative envelope of these. As a result of iterative design loops, the knowledge of the LL might be modified. The DL and QL might follow this evolution.

Regarding the QL, it is requested by the launcher authorities that these are at minimum KQ * LL final where LL final is the final best knowledge of the LLs.

The following factors are currently applied for the ARIANE family of launchers:

- FOSY 1,1
- FOSU 1,25
- KQ 1,25

where classical material (metal or composite) used are exhibiting less than 5 % scatter and ARIANE types of loads are considered.

Bibliography

The following list of informative references are provided to assist in the selection of approved lists, procedures and processes. These documents and references are cited at the appropriate places in the text.

ECSS-E-10-02	Space engineering — Verification
ECSS-E-10-03 [1)]	Space engineering — Testing
ECSS-E-30-01	Space engineering — Fracture control
ECSS-E-30-02 [1)]	Space engineering — Structural design and verification of pressure vessels
ECSS-E-30-04 [1)]	Space engineering — Structural materials handbook
ECSS-E-30-05 [1)]	Space engineering — Adhesive bonding handbook
ECSS-E-30-06 [1)]	Space engineering — Insert design handbook
ECSS-Q-00	Space product assurance — Policy and pinciples
ECSS-Q-60	Space product assurance — EEE components
MIL-STD-1522A	Standard General requirement for safe design and operation of pressurized missile and space systems [2)]

1) To be published.

2) To be replaced by ECSS-E-30-02: Space engineering - Structural design and verification of pressure vessels.

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ECSS Document Improvement Proposal

1. Document I.D. ECSS-E-30 Part 2A	**2. Document date** 25 April 2000	**3. Document title** Mechanical — Part 2: Structural
4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)		
5. Reason for recommendation		
6. Originator of recommendation		
Name:	Organization:	
Address:	Phone: Fax: e-mail:	**7. Date of submission:**
8. Send to ECSS Secretariat		
Name: W. Kriedte ESA-TOS/QR	Address: ESTEC, P.O. Box 299 2200 AG Noordwijk The Netherlands	Phone: +31-71-565-3952 Fax: +31-71-565-6839 e-mail: wkriedte@estec.esa.nl

Note: The originator of the submission should complete items 4, 5, 6 and 7.

This form is available as a Word and Wordperfect-Template on internet under
http://www.estec.esa.nl/ecss/improve/

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