

BS EN 16603-32:2014



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Space engineering — Structural general requirements

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Foreword

This document (EN 16603-32:2014) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-32:2014) originates from ECSS-E-ST-32C Rev. 1.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015, and conflicting national standards shall be withdrawn at the latest by February 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 14607-2:2004.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

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1

Scope

ECSS-E-ST-32C (Space engineering – Structural) defines the mechanical engineering requirements for structural engineering.

This Standard specifies 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 including: launch vehicles, transfer vehicles, re-entry vehicles, spacecraft, landing probes and rovers, sounding rockets, payloads and instruments, and structural parts of all subsystems.

This Standard may be tailored for the specific characteristics and constraints of a space project in conformance with ECSS-S-ST-00.

2

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 publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system– Glossary of terms
EN 16603-32-01	ECSS-E-ST-32-01	Space engineering – Fracture control
EN 16603-32-02	ECSS-E-ST-32-02	Space engineering – Structural design and verification of pressurized hardware
EN 16603-32-10	ECSS-E-ST-32-10	Space engineering – Reliability based mechanical factors of safety
EN 16602-70-36	ECSS-Q-ST-70-36	Space product assurance – Material selection for controlling stress-corrosion cracking
EN 16602-70-37	ECSS-Q-ST-70-37	Space product assurance – Determination of the susceptibility of metals to stress-corrosion cracking

Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

3.2 Terms specific to the present standard

3.2.1 A-basis design allowable (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 %

3.2.2 B-basis design allowable (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 %

3.2.3 buckling

not stable equilibrium of a structure under loads applied statically or dynamically

NOTE Buckling include snapping of slender beams, buckling of flat plates, buckling of cylindrical panels, three dimensionally curved shells, rib crippling, and skin buckling of a sandwich.

3.2.4 composite material

combination of materials different in composition or form on a macro scale

NOTE 1 Composite materials provide improved characteristics not obtainable by any of the original components acting alone

NOTE 2 The constituents retain their identities in the composite.

NOTE 3 Normally the constituents can be physically identified, and there is an interface between them.

NOTE 4 Composites include

- fibrous (composed of fibres, usually in a matrix),

- laminar (layers of materials), and
- hybrid (combinations of any of the above).

NOTE 5 Composites material can be metallic, non-metallic or a combination thereof.

3.2.5 composite structure

structure fully or partially made of composite materials

3.2.6 contributing loads

loads which decrease the margin of safety.

3.2.7 damage tolerance

capability of a structure to resist failure due to the presence of flaws, cracks, or other damage for a specified period of usage without inspection or repair.

3.2.8 design allowable

statistically based strength capability with respect to a failure mode

NOTE For example in terms of load resistance, stress resistance, or strain limit with respect to rupture, collapse, detrimental deformation.

3.2.9 design factor

factor used in the determination of DLL to account for uncertainties

NOTE Design factor accounts for uncertainties related to loads, models and project programmatic aspects (i.e. protoflight approach, uncertainty in launcher environment, maturity of design, growth potential and other design considerations).

3.2.10 design limit load (DLL)

limit load multiplied by a design factor

NOTE Design factors are defined in ECSS-E-ST-32-10.

3.2.11 design load (DL)

design limit load or design yield load or design ultimate load

3.2.12 design parameters

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.

3.2.13 design ultimate load (DUL)

design limit load multiplied by the ultimate safety factor

3.2.14 design ultimate stress

stress caused by the design ultimate load

NOTE With this definition no relation exists with ultimate strength.

3.2.15 design yield load (DYL)

design limit load multiplied by the yield safety factor

3.2.16 design yield stress

stress caused by the design yield load

NOTE With this definition no relation exists with yield strength.

3.2.17 detrimental deformation

structural deformation, deflection or displacement that prevents any portion of the structure or other system from performing its intended function or that reduces the probability of successful completion of the mission

3.2.18 dynamic load

time varying load with deterministic or stochastic distribution

3.2.19 effective mass

measure of the mass portion associated to the mode shape with respect to a reference support point

3.2.20 factor of safety (FOS)

factor by which design limit loads are multiplied in order to account for uncertainties of the verification methods, and uncertainties in manufacturing process and material properties

NOTE 1 Factor of safety is synonym of safety factor.

NOTE 2 FS and SF are also recognized abbreviations used for factor of safety

NOTE 3 The factor of safety is a combination of factors according to various sources of uncertainties. Its magnitude is based on proven processes and verification methods for analyses, tests and manufacturing. To account for uncertainties of analysis, higher values of factor of safety are normally used for verification by analysis only. Higher values of factors of safety are also used if higher reliability is desired than was taken in the limit load determination.

3.2.21 failure

rupture, collapse, degradation, excessive wear or any other phenomenon resulting in an inability to sustain design limit loads, pressures (e.g. MDP) and environments

3.2.22 fail-safe structure

structure designed with sufficient redundancy to ensure that the failure of one structural element does not cause failure of the entire structure

NOTE No factor of safety is applied to design limit loads in the failure analysis.

3.2.23 flaw

local discontinuity in a structural material

NOTE For example: scratch, notch, crack, void or pores in case of metallic and homogenous non metallic material; delamination or porosity in case of composite material.

3.2.24 generalized mass

mass transformed by the mode shapes into the modal space (i.e. modal coordinates)

3.2.25 limited service life items

hardware item that requires periodic re-inspection or replacement

3.2.26 limit load (LL)

maximum load(s), which a structure is expected to experience with a given probability, during the performance of specified missions in specified environments

3.2.27 maximum design pressure (MDP)

pressure equal to $MEOP \cdot K_m \cdot K_p$

NOTE 1 MDP correspond to design limit loads

NOTE 2 MDP is equal or larger than MEOP.

NOTE 3 K_m is a factor which takes into account the representativity of the mathematical models predicting MEOP and it is defined by the entity defining MEOP (for definition of K_m see ECSS-E-ST-32-10 'Factors of safety').

NOTE 4 K_p is the project factor (for definition of K_p see ECSS-E-ST-32-10 'Factors of safety')

3.2.28 maximum expected operating pressure (MEOP)

highest pressure that a system or component is expected to experience during its mission life in association with its applicable environment

NOTE 1 For mission life see definition in 3.2.29.

NOTE 2 MEOP corresponds to limit loads.

NOTE 3 MEOP includes effects of temperature and acceleration on pressure, maximum relief pressure, maximum regulator pressure and effects of failures within the system or its components. The effect of pressure transient is assessed for each component of the system and used to define its MEOP.

NOTE 4 MEOP includes effects of failures of an external system (e.g. spacecraft), as specified by the customer ,on systems (e.g. propulsion) or components.

NOTE 5 MEOP does not include testing factors, which are included in ECSS-E-ST-32-02 'Structural design and verification of pressurized hardware' and ECSS-E-ST-10-03 'Verification'.

3.2.29 mission life

life cycle from delivery to disposal

3.2.30 primary structure

part of the structure that carries the main flight loads and defines the overall stiffness

3.2.31 proof load

load applied during a proof test

3.2.32 proof test

test of flight hardware under the proof load or pressure, to give evidence of satisfactory workmanship and material quality or to establish the initial crack sizes in the hardware

3.2.33 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.

3.2.34 relieving loads

loads which increase the margin of safety

3.2.35 residual stress

stress that remains in a structure after processing, fabrication, assembly, testing or operation

3.2.36 safe life

fracture control design principle, for which the largest undetected defect that can exist in the part does not grow to failure when subjected to the cyclic and sustained loads and environments encountered in the service life

3.2.37 safe life structure

structure designed according to the safe life design principle

3.2.38 scatter factor

factor by which the number of cycles or life time is multiplied in fatigue analysis, fracture analysis, thermal cycling analysis and test in order to account for uncertainties in the statistical distribution of loads and cycles

3.2.39 service life

interval beginning with the last item inspection or flaw screening proof test after manufacturing, and ending with completion of its specified life

3.2.40 secondary structure

structure attached to the primary structure with negligible participation in the main load transfer and overall stiffness

3.2.41 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

3.2.42 (quasi) static loads

loads independent of time or which vary slowly, so that the dynamic response of the structure is not significant

3.2.43 stiffness

ratio between an applied force and the resulting displacement or between an applied moment and the corresponding rotation

3.2.44 structural design

set of information defining the structure, or the process used to generate it

NOTE Structural design is an iterative process. The process starts with the conceptual design of possible alternatives which can 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 prioritised criteria in order to select the designs to develop in further 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.

3.2.45 structure

set of mechanical components or assemblies designed to sustain loads or pressures, provide stiffness or stability, or provide support or containment

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

3.2.46 transient load

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

3.2.47 ultimate strength

the maximum load or stress that a structure or material can withstand without incurring rupture or collapse

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

3.2.48 yield strength

maximum load or stress that a structure or material can withstand without incurring a specified permanent deformation or yield

NOTE The yield 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.

3.3 Abbreviated terms

For the purpose of this standard, the abbreviated terms of ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
AIT	assembly, integration and tests
AOCS	attitude and orbit control system
BIT	built-in testing
CAD	computer aided design
CAE	computer aided engineering
CAM	computer aided manufacturing
COG	centre of gravity
DDF	design definition file
DJF	design justification file
DL	design load
DLL	design limit load

DOF	degree of freedom
DRD	document requirement definition
DUL	design ultimate load
DYL	design yield load
ECLS	environment control and life support
EMC	electromagnetic compatibility
FCI	fracture critical item
FEA	finite element analysis
FE	finite element
FM	flight model
FMECA	failure mode, effects and criticality analysis
FOS	factor(s) of safety
FOSU	factor(s) of safety at ultimate
FOSY	factor(s) of safety at yield
FSI	fluid structure interaction
LCDA	launcher coupled dynamic analysis
LL	limit load
MDP	maximum design pressure
MEOP	maximum expected operating pressure
MOS	margin of safety
NDT	non-destructive test
NDI	non-destructive inspection
OTM	Output Transformation Matrix
PFCI	potential fracture critical item
PFO	particle fall out
POGO	propulsion generated oscillations
r.m.s.	root-mean-square
SEP	system engineering plan

4

Requirements

4.1 Overview

The structural engineering produces a structural product which conforms to its functional and performance requirements by:

- aiming for simple load paths,
- maximizing the use of conventional materials,
- simplifying interfaces, and
- providing easy integration.

4.2 Mission

4.2.1 Lifetime

- a. Structural assemblies and components shall be designed to withstand applied loads due to the mechanical environments to which they are exposed during the service-life.
- b. Structural assemblies and components shall fulfil, in operation, the mission objectives for the specified duration.
- c. The service-life shall include the expected events, with at least:
 1. transportation, handling, testing and storage, and
 2. all phases of pre-launch, launch, operation and descent.

NOTE Usually handling tools are provided such that manufacturing, transportation, assembling, testing and storage are not dimensioning cases of the structure.

- d. The phases, applicable loads and duration shall be determined using:
 1. the requirements of the structure (i.e. single mission, expendable, re-usable or long-term deployment),
 2. the effect of all degradation mechanisms upon materials used in the construction (i.e. both terrestrial and space environments and all expected loading regimes), and

3. experience with similar structures (e.g. qualification and problems identified in-service).
- e. Service-life evaluations shall determine:
 1. the inspection and maintenance requirements,
 2. the item replacement procedure (preventive maintenance), and
 3. the inspection and repair procedures and intervals (corrective maintenance).

4.2.2 Natural and induced environment

- a. Components and assemblies for space applications shall be compatible with the natural and induced environments, including:
 1. the on ground, launch and operational environment conditions,
 2. the atmospheric conditions on earth in which they are manufactured, stored and tested, including corrosion effects,
 3. the effects of gravitation, and
 4. the exposure of sensitive materials to manufacturing and atmospheric environments .
- b. Provisions (e.g. gravitational compensation and purging) shall be made for the protection of equipment or components.

NOTE 1 The sensitivity of materials to the environment on earth can determine the requirements for quality control procedures.

NOTE 2 The natural environment generally covers the climatic, thermal, chemical and vacuum conditions, cleanliness, levels of radiation and the meteoroid and space debris environment.

NOTE 3 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, thermal and dynamic environment loads.
- b. The static and dynamic environment loads shall be defined in terms of constant acceleration, transient, sinusoidal and random vibration, acoustic noise and shock loads.
- c. Loads shall be used in the worst combinations in which they can occur.

NOTE The severest loads are experienced during launch, ascent and separation, and, where relevant during re-entry, descent and landing.

- d. Definition of the mechanical environment shall include the loads which can affect structural integrity and functional performance.

4.2.4 Microgravity, audible noise and human induced vibration

- a. Structural requirements derived from microgravity, audible noise and human induced vibration system level requirements shall be identified.

4.2.5 Load events

- a. The relevant mechanical and thermal load events expected throughout the service life of the structure shall be identified.
- b. Loads shall be defined according to their nature, (i.e. static or dynamic) and their level, occurrence time and duration.
- c. As a minimum the following load events shall be used:
 - 1. Ground and test loads:
 - (a) handling, transportation and storage loads,
 - (b) assembly and integration loads, and
 - (c) ground test loads.
 - 2. Launch loads as defined by the launch services supplier and including:
 - (a) launch preparation,
 - (b) operational pressures,
 - (c) engine ignition,
 - (d) thrust built-up,
 - (e) aborted launch
 - (f) lift-off,
 - (g) thrust (constant or varying slowly),
 - (h) aerodynamic loads,
 - (i) heat flux from engine and aerodynamics,
 - (j) wind and gust,
 - (k) dynamic interaction between the structure and propulsion system,
 - (l) thrust decay,
 - (m) acoustic noise,
 - (n) manoeuvres,

- (o) pyrotechnics,
 - (p) separation of parts (e.g. stage, fairing and spacecraft), and
 - (q) depressurization.
3. In-orbit loads:
- (a) operational pressures,
 - (b) static and dynamic loads induced by thrusters,
 - (c) shocks due to pyrotechnical operation and deployment of appendages,
 - (d) thermo-elastic loads induced by temperature variations,
 - (e) hygroscopic-induced load due to variations in moisture content,
 - (f) micro-vibrations induced by moving elements (e.g. momentum wheels) and thrusters,
 - (g) micrometeoroids and debris,
 - (h) docking,
 - (i) berthing, and
 - (j) crew induced loads (e.g. on handles, rails and by movements).
4. Re-entry, descent and landing:
- (a) aerodynamic loads and thermal fluxes,
 - (b) parachute ejection and deployment shocks,
 - (c) operational pressures,
 - (d) landing loads, and
 - (e) impact loads.

4.2.6 Combined loads

- a. Load combination rules shall be defined according to specified load events by establishing the loads to be combined, their level and mathematical combination procedures

NOTE For example mathematical combination procedures like linear superposition or root of the sum of the squares.

- b. Load application sequence shall be defined.

NOTE For example to account for any non-linear effect depending on load application sequence.

- c. Factors of safety for combined loads shall be defined at yield and ultimate level, and for the tests.

- d. Relieving loads which are independent from contributing loads shall be combined at their minimum operating value without any design factor nor FOS.

NOTE This requirement aims at avoiding overestimation of relieving effects due to combination of loads.

4.2.7 Limit loads

- a. The limit loads are 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 being 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 agreed with the costumer.

NOTE It is good practice to determine the loads using conservative assumptions.

- 3. For pressurised systems, the maximum expected operating pressure (MEOP) shall be part of the 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. $3 \times \text{root-mean-square (r.m.s.)}$.

4.2.8 Design limit loads

- a. The design limit loads shall be derived by multiplication of the limit loads by the design factors.
- b. Design factors shall be system defined.
- c. For pressurised systems, the maximum design pressure (MDP) shall be part of the design limit loads.

4.3 Functionality

4.3.1 Overview

For the design, manufacturing, verification, operation and maintenance of metallic and non-metallic pressurized hardware see the requirements of ECSS-E-ST-32-02. For fracture control programme see ECSS-E-ST-32-01.

4.3.2 Strength

- a. The structure shall withstand the design limit loads without failing or exhibiting permanent deformations that can endanger the mission objectives.

4.3.3 Local yielding

- a. For metal structures or metal structure components local yielding may exist, provided it does not cause overall permanent set, instability or fatigue failure of the structure

4.3.4 Buckling

- a. The stability (i.e. no buckling) of the structure shall be verified for the design loads.
- b. Local buckling shall be prevented unless:
 - 1. the buckling is reversible, and
 - 2. the resulting stiffness and deformations still conform to the structural and functional requirements, and
 - 3. a post-buckling investigation (by analysis or test) demonstrates positive margins against failure.

4.3.5 Stiffness

- a. Stiffness requirements under the specified load and boundary conditions shall be identified.

NOTE Stiffness is often expressed in terms of a minimum natural frequency requirement.

- b. The stiffness of subassemblies and components and interfaces shall be such that the structural and functional performance requirements are met

NOTE For example avoiding deformations leading to violations of specified envelopes, gapping at joints, the creation of inefficient load paths and dynamic coupling with other subsystems e.g. Attitude and Orbital Control System.

4.3.6 Dynamic behaviour

- a. The natural frequencies of a structure shall be within specified bandwidths preventing dynamic coupling with major excitation frequencies

NOTE For example launch vehicle fundamental frequencies.

4.3.7 Thermal

- a. Constraints imposed by the thermal design and impacting the structure shall be identified.
- b. The temperatures and temperature variations and gradients during all phases of a mission, including manufacturing and storage, shall be used,

both in the material selection and in the design in order to achieve the specified functional and structural performance.

4.3.8 Damage tolerance

- a. Damage tolerance design principles shall be applied.

NOTE Design principles can include fail-safe design (redundancy) of attachment points, and damage tolerant materials.

- b. The resistance of the structure against manufacturing defects and the result of accidental damage (e.g. low energy impact) shall be taken into account in the design.

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

4.3.9 Tolerances and alignments

- a. The accuracy of the tolerances applied to the mechanical design shall guarantee conformance to geometrical interface requirements.
- b. The impacts of the assembly alignment and pointing accuracy requirements on the angular and position tolerances shall be identified.
- c. In cases where alignment adjustability is specified, 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) for measurement or checking of the alignment.

4.3.10 Electrical conductivity

- a. Structural requirements derived from electrical conductivity requirements shall be identified.

4.3.11 Lightning protection

- a. The structure shall be designed to
1. dissipate static electrical charges,
 2. provide electromagnetic protection, and
 3. provide means of diverting electrical current arising from lightning strike so as not to endanger the vehicle.

4.3.12 Electromagnetic compatibility

- a. Structural requirements derived from electromagnetic compatibility requirements shall be identified.

4.3.13 Dimensional stability

- a. Impact of system requirements on dimensional stability of the structure shall be identified.

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 caused by the action of applied loads and material stability can jeopardise or degrade the mission objectives.

NOTE Structure stability can be affected for example by launch loads, deployment loads, thermal and moisture release.

4.4 Interface

- a. The design of structural assemblies shall be compatible with internal and external interfaces, which can affect or be affected by adjacent systems, subsystems or assemblies.
- b. Mechanical subsystem internal interfaces shall include:
 - 1. thermal control,
 - 2. mechanisms,
 - 3. ECLS,
 - 4. propulsion,
 - 5. pyrotechnics,
 - 6. mechanical parts, and
 - 7. materials.
- c. External interfaces shall include:
 - 1. spacecraft-launcher interface,
 - 2. human factors and ergonomics
 - 3. interfaces with equipment, optics and avionics,
 - 4. rendezvous and docking, robotics,
 - 5. ground support equipment for pre-flight and post-flight operations, and
 - 6. support equipment for in-orbit operations.
- d. Interfaces shall be explicitly defined with respect to the following:
 - 1. Design requirements.

NOTE These include areas, volumes, alignments, surface finishing and properties, tolerances, geometry, flatness, fixations, conductivity, constraints

imposed by the launcher (e.g. geometric, static and dynamic envelopes) and by design concepts (e.g. thermal and optical design), mass and inertia properties.

2. External loads applied to the interfaces, including temperature effects and overfluxes caused by adjacent structures.
3. Global and local stiffness.
4. Electrical, magnetic and radio frequency aspects, where applicable

4.5 Design

4.5.1 Inspectability

- a. To ensure structural integrity, the requirement to inspect a component, assembly or structure shall be met during the following:
 1. at various stages throughout manufacture,
 2. at various stages during assembly,
 3. after testing, and
 4. in-service.
- b. An NDI policy shall be defined and incorporated into the design process using 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, and as specified in ECSS-E-ST-32-01.

4.5.2 Interchangeability

- a. All parts or subassemblies identified by an item number shall be functionally and dimensionally interchangeable with items which are identically numbered.

NOTE It is not guaranteed that parts or subassemblies which are match drilled during assembly are interchangeable.

4.5.3 Maintainability

- a. The mechanical design shall be performed in such a way that assembly, integration and repair and maintenance activities can be carried out with tools and test equipment agreed with the customer.

NOTE It is good practice to minimize the number of special tools and equipment to minimize cost.

- b. The maintenance activity during storage and ground life should be avoided.
- c. The maintenance programme shall
 - 1. include a maintenance protocol, and
 - 2. define measurable parameters for all operations, and during all project phases, including at least the following:
 - (a) mean-time-to-repair,
 - (b) limited-life,
 - (c) fault detection and isolation capability,
 - (d) spares requirements, and
 - (e) ground storage requirements.
- d. The results of the maintenance programme evaluation shall
 - 1. avoid alterations and replacement of parts,
 - 2. form the criteria with which various concept designs are evaluated.
- e. Structures that are not accessible shall be maintenance free during service-life.

4.5.4 Dismountability

- a. The mechanical design shall enable removal and replacement of:
 - 1. secondary structures,
 - 2. equipment, and
 - 3. payload.

4.5.5 Mass and inertia properties

- a. Mass and inertia properties of the structure shall be determined during all phases of the design

NOTE Mass and inertia properties can be estimated, calculated or measured.

- b. Mass and inertia properties shall be compliant with the mass budget allocation.

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.

4.5.6 Material selection

4.5.6.1 Overview

For requirements on material selection, see ECSS-Q-ST-70 and ECSS-E-ST-32-08.

4.5.6.2 Corrosion effects

- a. The material selected for corrosion resistance shall be compatible with:
 1. the specific environment,
 2. interaction with contained fluid,
 3. design, fabrication, storage of individual and assembled components,
 4. interactions with dissimilar materials, and
 5. 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 environment to which they are exposed.

- 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 the service conditions, or in more severe conditions (accelerated testing).
- c. For alloys, and their weldments, not included in table “Alloys with high resistance to stress–corrosion cracking” of ECSS-Q-ST-70-36, their characteristics on susceptibility to stress-corrosion cracking shall be demonstrated by test in conformance with ECSS-Q-ST-70-37.

NOTE 1 These materials have been tested and demonstrated to have a high resistance to stress-corrosion cracking and therefore can be used for this purpose.

NOTE 2 Metals, alloys and weldments not present in table “Alloys with high resistance to stress–corrosion cracking” of ECSS-Q-ST-70-36 can be approved for structural applications by means of the stress-corrosion evaluation form specified in the Annex A of ECSS-Q-ST-70-36.

4.5.7 Mechanical parts selection

For requirements on selection of mechanical parts, see ECSS-Q-ST-70.

4.5.8 Material design allowables

- a. For structural material, design allowables shall be statistically derived covering all operational environments.

- b. The scatter bands of the data shall be derived and design allowables defined in terms of fractions of their statistical distribution with A-basis or B-basis specified levels of reliability and confidence.
- c. For each type of test the minimum number of test specimens shall be:
 - 1. ten (10) to establish A-values, and
 - 2. five (5) to establish B-values.
- d. If the material is delivered in several batches, the design allowables test programme shall evaluate the variations from batch to batch by performing sample tests at regular intervals during the production sequence.
- e. In the cases specified in d) above, preliminary design allowables may be based on the initially small sample size, and upgraded as the sample size increases by tests of newly arriving batches.

NOTE 1 For material testing requirements, see ECSS-E-ST-32-08 and ECSS-E-HB-32-20.

NOTE 2 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 design allowables are deduced from a regression line based on a small number of test specimens the confidence in such allowables is low. Larger numbers of test specimens generally do not change the shape of the regression line, but the confidence in the statistical evaluation increases.

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

4.5.9 Metals

- a. All design allowables for metals shall be defined by their A-values.
- b. For unpressurized metal structures, B-values may be used in redundant structure in which the failure of a component can result in a safe redistribution of applied loads to other load-carrying structures.
- c. All other metal material properties shall be defined by average values.

4.5.10 Non-metallic materials

4.5.10.1 Glass and ceramics

- a. Design allowables for glass and ceramics shall be derived through a probabilistic approach, covering all size effects.

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.

4.5.10.2 Non-metallics other than glass and ceramics

- a. Design allowables for other non-metals, (stress or strain) shall be defined by their A-values.
- b. For unpressurized non-metallic structures, B-values may be used in redundant structure in which the failure of a component can result in a safe redistribution of applied loads to other load-carrying structures.
- c. The material properties other than those specified in 4.5.10.2a and 4.5.10.2b shall be defined by average values.

4.5.11 Composite materials

- a. All design allowables for composite materials (stress or strain) shall be defined by their A-values.
- b. For unpressurized structures in composite materials, B-values may be used in redundant structure in which the failure of a component can result in a safe redistribution of applied loads to other load-carrying structures.

NOTE For structures made in composite materials, a progressive failure analysis methodology can be used to demonstrate that the material is intrinsically redundant, i.e. it maintains the required load carrying capability after initial damage or failure of one component (e.g. after failure of the most critical lamina).

- c. All the material properties other than those specified in 4.5.11a and 4.5.11b shall be defined by their average values.

NOTE The strength and stiffness of composite fibre reinforced 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.

4.5.12 Adhesive materials in bonded joints

- a. All design allowables for adhesive materials in bonded joints (stress or strain) shall be defined according to standards agreed with the customer.

4.5.13 Ablation and pyrolysis

- a. Impact of material changes due to ablation and pyrolysis shall be identified.
- b. In cases where the behaviour of a material in a specific environment is not known, ablation and pyrolysis tests of representative materials (composition and condition) shall be performed, either under the service conditions, or in more severe conditions (accelerated testing).

4.5.14 Micrometeoroid and debris collision

- a. Pressurised structures, tanks, battery cells, pipes, electronic boxes and other specified equipment shall be protected from micrometeoroid and debris impact in order to prevent loss of functionalities.
- b. The selection and design of material and debris protection systems shall be based on a specified probability of survival.

NOTE For a given hardware design and configuration, the probability of survival is influenced by the probability of impact, critical debris size, material response to hypervelocity impacts, impact face; back face (spalling), mission duration, spacecraft orientation and multiple impacts.

4.5.15 Venting

- a. Provision shall be made in the design of the structure for venting.

NOTE In order to prevent a build-up of excess pressure and to reduce the time to evacuate the structure, a minimum ratio of venting-area to enclosed-volume is usually needed for venting.

- b. In case that provision a. is not made, the structure shall withstand build-up pressure (including safety factors).
- c. The openings for venting shall be compatible with the purging system gas supply pressure and flow rate.

NOTE The openings for venting can be used to prevent contamination or risk of explosion.

4.5.16 Margin of safety (MOS)

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

$$MOS = \frac{\text{design allowable load}}{\text{design limit load} \times FOS} - 1$$

NOTE Loads can be replaced by stresses if the load- stress relationship is linear.

- b. All margins of safety shall be positive.
- c. The margins of safety for combined loads shall be computed by the following procedure:
1. define the load combination applied at a certain design level (limit, yield or ultimate), according to the specified FOS for combined loads;
 2. calculate the margin of safety as:

$$MOS = \lambda - 1$$

where λ , called reserve factor, is the ratio between design allowable and design load.

- d. MOS shall be computed by accounting for interactions of different types of failures (e.g. failure of a bolt due to shear and tension)

NOTE The following “interaction equation” is normally used to compute λ for interacting failure types:

$$\lambda^\alpha R_1^\alpha + \lambda^\beta R_2^\beta + \lambda^\gamma R_3^\gamma + \lambda^\delta R_4^\delta \dots = 1$$

where α , β , γ , and δ are experimental exponents and R_i are the ratios between the i-th DLL $\times$ FOS and the allowable load (which causes the failure if the i-th load is applied alone)

4.5.17 Factors of safety (FOS)

4.5.17.1 Overview

The selection of appropriate factors of safety for a specific structural element depends on parameters, which are related to loads, design, structural verification approach, model philosophy 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 structure verification, and
- dimensional stability.

4.5.17.2 FOS requirements

- a. Factors of safety shall be determined considering the uncertainty of loads, design, material, manufacturing and verification parameters
- b. Factors of safety listed in ECSS-E-ST-32-10 and ECSS-E-ST-32-02 shall be applied.

4.5.18 Scatter factors

- a. A scatter factor of four (4) shall be used in fatigue analysis.

NOTE 1 The scatter factor is applied to the number of cycles of a certain load level in order to cover the uncertainties of loads and material properties. Usually for metallic materials a scatter factor of 4 is applied. However, for specific applications (e.g. pressure vessels and low cycle fatigue) higher values are commonly used (e.g. 5 for pressure vessels).

NOTE 2 For composite materials in some cases a factor on the stress (e.g. 1.15) is defined instead of a scatter factor on the load cycles"

NOTE 3 The number of cycles can be based on the number of possible repetitions of tests (e.g. 1 qualification vibration plus 3 possible repetitions) specified by the project.

4.6 Verification

4.6.1 Overview

For general requirements on verification, verification programme and verification methods, see ECSS-E-ST-10-02.

4.6.2 Verification by analysis

4.6.2.1 General

- a. Analysis methods shall be agreed between customer and supplier.
 - NOTE Different state of the art analysis methods are available, such as handbooks, standards or validated numerical solutions.
- b. A mathematical model (e.g. finite element model) shall be developed for primary and secondary structure.
- c. A mathematical model shall be developed and delivered for launcher coupled dynamic analysis (LCDA).
- d. It shall be demonstrated that the analysis tools used are adequate for the intended purpose.
- e. A justification of assumptions made in tools, methods, models and input data shall be provided.
- f. The influence of tolerances (including overall dimensions and thickness) shall be assessed whenever potentially critical.
- g. All analysis data shall be traceable, and the organization responsible for the analysis shall provide procedures to ensure data traceability during the life of the product.

4.6.2.2 Modelling aspects

- a. It shall be demonstrated that the mathematical models is adequate to perform the foreseen analysis.
 - NOTE 1 Finite element mathematical models meet the requirements detailed in ECSS-E-ST-32-03.
 - NOTE 2 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.
 - NOTE 3 The mathematical models enable preparation of experimental testing and verification of requirements not demonstrable by tests, e.g. through coupled analysis.
 - NOTE 4 The mathematical models help in defining load cases or combination of load cases.
 - NOTE 5 The mathematical models can also give designers insight on sensitivity of the design with respect to uncertainties.
- b. Mathematical models shall be validated by correlation with test results for specific needs.

4.6.2.3 Static analysis

- a. Static analysis shall be performed to verify that the structural responses (e.g. displacements, forces, stresses and internal loads) to (quasi) static loads conform to the structural requirements.
- b. The static analysis shall use representative load introduction, load distribution and boundary conditions.
- c. Provisions shall be made to include the effects of residual stresses due to the manufacturing process (e.g. welding).
- d. Static analysis shall take into account stress concentrations.

NOTE Stress concentrations essentially take place in areas with steeply varying shape or section and with notches (macro and micro stress raisers). For metals stress concentrations are known to have a detrimental effect on fatigue lifetime. For fibre reinforced plastics stress concentrations have a detrimental effect on static strength.

4.6.2.4 Modal analysis

- a. Modal analysis shall be performed to
 1. verify that the structure conforms to the natural frequency requirements, and
 2. determine associated modal characteristics (e.g. natural frequencies, mode shapes, generalized and effective masses).
- b. Pretension and spin effects shall be included.
- c. For large lightweight structures (e.g. solar arrays, antenna reflectors), the effect of the surrounding air shall be included in the analysis.

4.6.2.5 Dynamic response analysis

- a. Dynamic response analysis shall be used to verify the structural response due to excitations (e.g. force or motion inputs via mechanical interfaces, thermal input such as eclipse transitions, spinner centrifugal forces, and possible combination thereof) either in the frequency domain (e.g. sine and random) or time domain (transient) according to the definition of loads.
- b. Coupled loads analyses are performed to verify the loads resulting from dynamic behaviour of structural assemblies as follows:
 1. The mathematical models applied in coupled analyses shall represent the structural assemblies by characterization of the dynamic parameters, namely natural frequencies, mode shapes, associated generalized and effective masses, and damping.
 2. The characterization of natural frequencies with small effective masses (e.g. multilayer insulation) need not be performed if it can be shown that these modes do not participate to the overall dynamic behaviour.

4.6.2.6 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.

4.6.2.7 Fluid structure interaction (FSI)

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

4.6.2.8 Fatigue analysis

- a. Fatigue analysis shall be performed to verify that fatigue defect (crack or delamination) initiation or propagation resulting in structural failure or functional degradation cannot occur throughout the service life of the structure.
- b. Effects of stress concentrations shall be included in the analysis.
- c. The life of the structure shall be verified for the specified service life multiplied by the specified scatter factor considering the most unfavourable load sequence within each event.
- d. Design limit loads (multiplied by factors of safety specified by the customer for fatigue) shall be used for fatigue analysis.
- e. Alternate, permanent, and acoustic loads and their combination and sequence shall be used to perform the fatigue analysis.

NOTE 1 Fatigue analysis normally uses a cumulative damage approach which estimates fatigue life from stress spectra and fatigue material allowables (S-N or Wöhler curves).

NOTE 2 The following safety factors are usually applied for fatigue analysis: 1,0 for metallic materials, and 1,15 for composite materials.

4.6.2.9 Fracture control analysis

For fracture control analysis requirements, see ECSS-E-ST-32-01.

4.6.2.10 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. Effects on stability of boundary conditions, defects and geometrical imperfections in the structure shall be included in the buckling analysis.

NOTE Geometrical imperfections refer to any deviation from the nominal shape including effect due to assembly tolerances.

- d. Minimum gauge shall be used for buckling analysis.

4.6.2.11 Thermo-elastic and Hygro-thermal analysis

- a. Thermo-elastic analysis shall be performed to compute stresses and deformations due to occurring temperatures.

NOTE To perform thermo-elastic analysis temperature distributions defined by thermal analysis are usually mapped on the structural model.

- b. Hygro-thermal analysis shall be performed to compute deformations due to occurring moisture release or absorption.

4.6.2.12 Bonded joints

- a. The analysis of bonded joints shall be performed in accordance with standards or procedures agreed with the customer.

NOTE 1 For the mechanical characteristics of the bonded joints the following is usually taken into account:

- the influence of the characteristics of the adhesive,
- the material of the adherents
- any surface treatments,
- the dimensions of the bonded areas, and
- the relative stiffness of the parts.

NOTE 2 For bonded joints, see ECSS-E-HB-32-21.

4.6.2.13 Bolted joints

- a. Bolted joints shall be analysed according to standards or procedures agreed with the customer.

NOTE For bolted joints, see ECSS-E-HB-32-23.

4.6.2.14 Welded joints

- a. Welded joints shall be analysed according to standards or procedures agreed with the customer.

NOTE The analytical verification of welded joints usually takes into account the following:

- stress concentrations,
- type and quality of the weld,
- local maximum allowable geometrical defects (e.g. mismatch and peaking), and
- residual stresses and material characteristics changes due to local heating and cooling.

4.6.2.15 Riveted joints

- a. Riveted joints shall be analysed according to standards or procedures agreed with the customer.

4.6.2.16 Inserts

- a. Inserts shall be analysed according to standards or procedures agreed with the customer.

NOTE 1 Inserts are generally used in sandwich constructions with cores of low strength.

NOTE 2 For inserts, see ECSS-E-HB-32-22.

4.6.2.17 Aeroelastic analysis

- a. Aeroelastic analysis shall be used to assess the interaction between the aerodynamic flow and the structure.

4.6.2.18 Mass and inertia properties

- a. The inertia properties shall be computed according to the specified accuracy using the inertia matrix of individual components.
- b. The inertia properties shall be monitored and presented in a mass budget report issued on a regular basis agreed with the customer.
- c. A breakdown of mass to component level shall be given together with mass contingency estimates based on the design maturity.
- d. The mass and inertia data shall include the following:
 - 1. mass,
 - 2. co-ordinates of the centre of mass with respect to specified co-ordinate system,
 - 3. moments of inertia with respect to specified co-ordinate system, and
 - 4. the principal moments of inertia and their orientation with respect to specified coordinate system.

4.6.2.19 Alignments

- a. It shall be demonstrated by analysis that alignment requirements can be met with the chosen design tolerances.

4.6.2.20 Dimensional stability

- a. Short, medium and long term effects shall be included in the analysis to determine the dimensional stability of the structure.
- b. A stability budget shall be established and the contributors shall be identified, analysed and allocated.

NOTE Examples of contributors affecting dimensional stability are: thermo-elastic effects, moisture