ECSS-E-30 Part 3A
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EUROPEAN COOPERATION
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FOR SPACE STANDARDIZATION

Space engineering

Mechanical — Part 3: Mechanisms

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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.

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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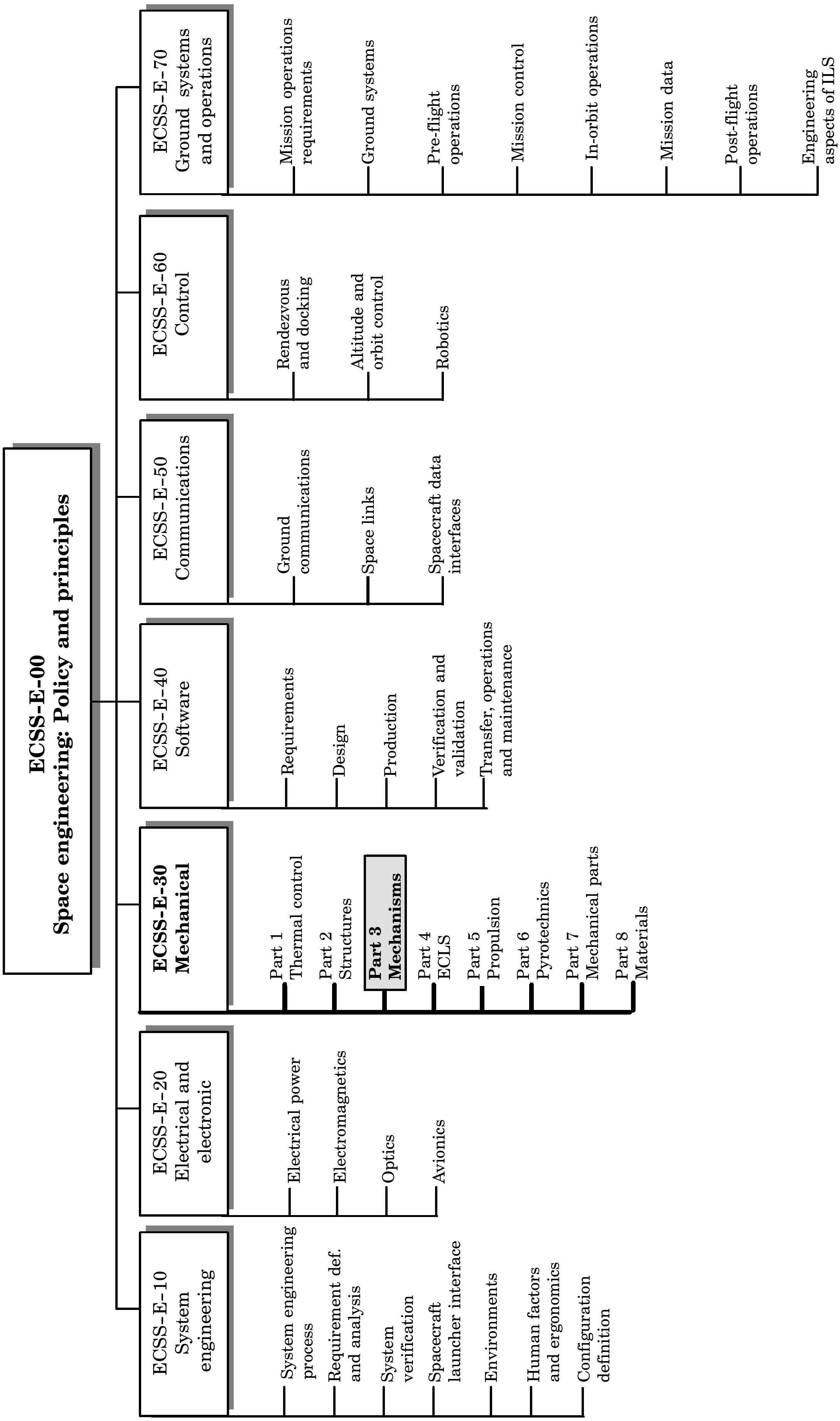

Structure of the ECSS-Engineering standards system

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Scope

Part 3 of ECSS‐E‐30 in the engineering branch of the ECSS Standards defines mechanical engineering requirements for mechanisms.

This Standard defines the requirements and statements applicable to the concept definition, design, analysis, development, production, test verification and in-orbit operation of space mechanisms on spacecraft, payloads and launcher elements in order to meet the mission performance requirements.

This Standard contains the list of mandatory requirements to achieve reliable operation of space mechanisms in orbit. It should also prevent anomalies during the development phase influencing schedule and cost efficiency of space programmes.

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 publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-E-10	Space engineering — System engineering
ECSS-E-20	Space engineering — Electrical and electronic
ECSS-E-30 Part 1	Space engineering — Mechanical — Part 1: Thermal control
ECSS-E-30 Part 2	Space engineering — Mechanical — Part 2: Structural
ECSS-E-30 Part 6	Space engineering — Mechanical — Part 6: Pyrotechnics
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-60	Space product assurance — EEE Components
ECSS-Q-70	Space product assurance — Materials, mechanical parts and processes
ISO 76:1987	Rolling bearings — Static load ratings
ISO 128	Technical drawings
ISO 6336-1	Calculation of the load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors
ISO 6336-2	Calculation of the load capacity of spur and helical gears — Part 2: Calculation of surface durability (pitting)
ISO 6336-3	Calculation of the load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength

ISO 677:1976	Straight bevel gears for general engineering and for heavy engineering — Basic rack
ISO 678:1976	Straight bevel gears for general engineering and for heavy engineering — Modules and diametral pitches
ISO 1341:1976	Straight bevel gears – Information to be given to the manufacturer by the purchaser in order to obtain the gear required

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Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purpose of this ECSS-E-30 Part 3 Standard, the definitions as given in ECSS-P-001, together with the following terms and definitions specific to this Standard shall apply.

3.1.1
acceptance test

test to determine that a system, sub-system, component, or functional part is capable of meeting performance requirements prescribed in purchase specifications or other documents specifying what constitutes the adequate performance capability for the item and to demonstrate the item is free from manufacturing defects

3.1.2
actuator

component that performs the moving function of a mechanism

NOTE An actuator can be either an electric motor, or any other mechanical (e.g. spring) or electric component or part providing the torque or force for the motion of the mechanism.

3.1.3
cleanliness

level in both particulate contamination and molecular contamination that contaminates the part or assembly

3.1.4
component

assembly or any combination of parts, sub-assemblies and assemblies, and assemblies mounted together and normally capable of independent operation in a variety of situations

3.1.5
control system

system (open or closed loop) which controls the relative motion of the mechanism

3.1.6
deliverable output torque (T_L)or force(F_L)
torque or force at the mechanism or actuator output required by the customer for an unspecified purpose and not affecting the actual performance of the mechanism except in applying the external torque or force

EXAMPLE A theoretical torque or force of a robotic mechanism (service tool) for which no specific function except torque or force provision can be specified at an early stage in the project development.

3.1.7
drawings
graphic data, including drawings as defined in the ISO/DIS 128 series.

3.1.8
dynamic output force (F_D)
force required to accelerate a mass

3.1.9
dynamic output torque (T_D)
torque required to accelerate an inertia

3.1.10
electronics
current carrying or voltage operated devices

3.1.11
fasteners
part utilized to provide attachment of two or more separate parts, components or assemblies

EXAMPLE Fasteners have the function of locking the parts together and thus providing the structural load path between the parts or, if used as securing part, to ensure proper locating of the parts to be secured (e.g. bolt, nut, joint axis shaft securing).

3.1.12
flushing or purging
control of the mechanism environment by enclosing the mechanism in specific gaseous or fluid media which are either surrounding the mechanism or passing over or through the mechanism

3.1.13
integration
combination of activities and processes to assemble payload or spacecraft components, subsystems, and systems elements into a desired configuration ensuring compatibility

3.1.14
interface
mechanical, thermal, electrical, and operational common boundary between two elements of a system

3.1.15
item
any level of hardware assembly (system, subsystem, equipment, component, or part)

3.1.16
latching or locking
intentional constraining of one or more previously unconstrained degrees of freedom of a mechanism which then requires action to release

3.1.17
lubrication
use of specific material surface properties or of applied material between two surfaces in contact in order to reduce friction, wear or adhesion between contacting or moving surfaces

3.1.18
mechanism
assembly of components that are linked together allowing relative motion

3.1.19
mission
performance of coherent investigations or operations in space to achieve program goals

NOTE A single mission might require more than one flight, or more than one mission might be accomplished on a single flight.

3.1.20
off-loading
complete or partial unloading of a part or assembly from an initial pre-load typically employed not to expose a mechanisms part or assembly to launch loads or other induced loads

3.1.21
payload
total complement of specific instruments, space equipment, support hardware, and consumables carried in the spacecraft to accomplish a discrete activity in space

3.1.22
phase margin
indicator for the stability of dynamic control systems

3.1.23
programme
activity involving manpower, material, funding, and scheduling which is necessary to achieve desired goals (e.g. space mission)

3.1.24
positively locked
form-locking of a part or assembly into a defined position from which release can only be obtained by application of a specific actuation force

3.1.25
qualification tests
tests to determine that the design of a system, subsystem, component or functional part is capable of meeting it’s specified performance requirements in it’s operational environment with the margins specified

3.1.26
screw
fastener without a shank, being threaded over the full length of the shaft

3.1.27
shank
unthreaded portion of the bolt or fastener shaft between the underside of the head and start of the thread

3.1.28
stowing
process of placing a payload or spacecraft component, subsystem, and systems element in a retained position

3.1.29
stud
externally threaded headless fastener with shank separating the threaded portions

3.1.30
threaded fastener
fastener with a head at one end and threaded portion at the other

NOTE The threaded portion is intended to mate with a matching internally threaded part, usually a nut.
A fastener is not threaded over the full length having a shank.
A threaded fasteners is often referred to as a bolt.

3.1.31
tribology
study that deals with the design, friction, wear and lubrication of interacting surfaces in relative motion to each other

3.1.32
venting
compensation of the internal mechanism pressure environment with its surrounding pressure environment (e.g. by use of dedicated venting holes or passages)

3.1.33
wire
definition of wire covers both electrical and mechanical wires, when electrical issues are addressed, the wire definition covers both flat harness wires and single or bundle harness wires

3.2 Symbols and abbreviated terms

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

Abbreviation	Meaning
AC	alternating current
CVCM	collected volatile contaminant material
DC	direct current
EMC	electromagnetic compatibility
ESD	electrostatic discharge
F_D	dynamic force
F_L	deliverable output force
FMECA	failure mode effects and criticality analysis
F_{min}	minimum actuator force required
F_R	friction torque/force
H_A	harness and other torque/force resistances
H_D	adhesion torque/force

H_Y	hysteresis torque/force
HV	hardness Vickers
I_F	inertia resistance (linear)
I_T	inertia resistance (angular)
LEO	low Earth orbit
M	mass
MLI	multi-layer insulation
MS	strength safety margin
n.a.	not applicable
RML	recovered mass loss
S	spring force
S/C	spacecraft
TBD	to be determined
TBS	to be specified
T_D	dynamic torque
T_L	deliverable output torque
T_{min}	minimum actuator torque required
TML	total mass loss
V	volt

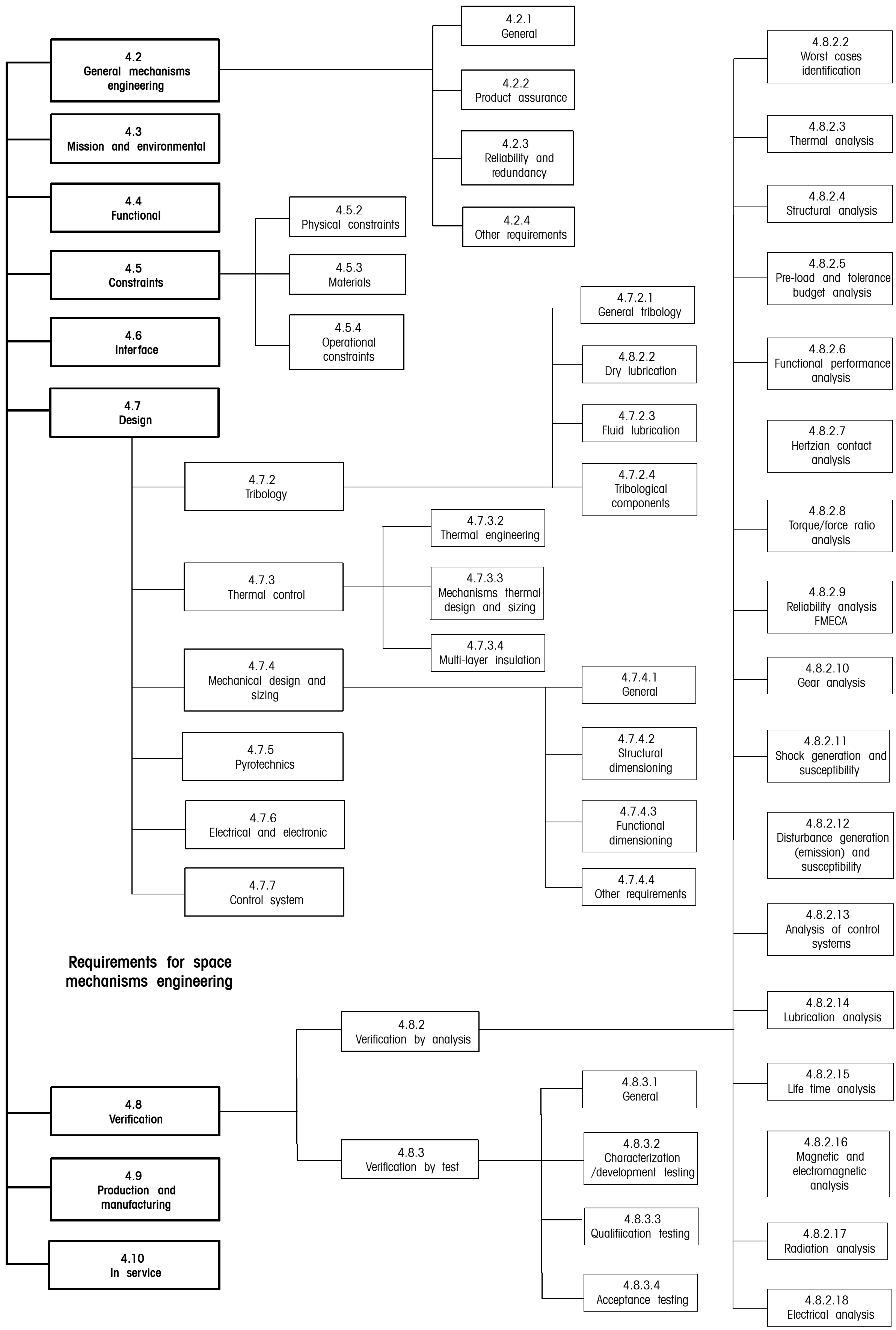

Figure 1: Requirements for space mechanisms engineering

4

Space mechanisms

4.1 Overview

This Standard addresses the detailed aspects of the mechanical engineering steps for the various engineering disciplines involved in the achievement of the required space mechanisms performance. The disciplines cover where applicable thermal control, structures, pyrotechnics, mechanical parts, materials, processes, electrical/electronic engineering, and control systems engineering.

The following requirements are identified considering the typical interfaces and interactions of mechanisms with thermal control, structures, functional operations, materials and parts, pyrotechnics, electrical and electronics, and servo-control interactions. Where interactions with other ECSS Engineering Standards are identified, reference is made to the corresponding documentation of the related standards.

4.2 General mechanism

4.2.1 General

This group of requirements covers the interaction of mechanisms engineering with project management, processes, parts and components, product assurance, and the related requirements affecting the conceptual definition, design, sizing, analysis, development, and hardware production of mechanisms. Figure 1 provides an overview of the subjects covered by this Standard.

4.2.2 Product assurance

4.2.2.1 Marking and labelling

a. Marking and labelling of mechanisms components, sub-assemblies, assemblies of the mechanism shall carry an identification.

b. The marking and labelling related requirements in subclause 4.2.2.2 are specific to mechanisms and shall be applied taking precedence over other standards.

4.2.2.2 Specific identification

Any delivered piece of hardware, part, component, sub-assembly, assembly shall carry identification (removable if appropriate) on non functional surfaces consisting of at least the following information:

1. identification number;
2. equipment title;
3. serial number (where appropriate).

Items 1. and 2. may be defined by the contracting authority.

4.2.2.3 Parts and components

a. Existing (commercially available or off-the-shelf) parts and components used in mechanisms shall be fully qualified for the intended application according to a qualification procedure approved by the customer.

b. The use of flight proven parts and components shall be preferred, or shall be selected according to the procedures defined in ECSS-E-30 Part 7.

4.2.2.4 Marking of bearings

Bearings shall not be marked by the use of vibro-etch marks on the lateral faces of the bearing races.

NOTE Etched marks on the lateral faces of the bearing races affect the mounting tolerances of the bearing in the housing and the bearing's tribological performance characteristics.

4.2.2.5 Interchangeability

All components, sub-assemblies and assemblies having the same identification number shall be functionally and dimensionally interchangeable.

4.2.2.6 Maintainability

a. The mechanism shall be designed to require no maintenance during storage and ground life.

b. If ground maintenance during storage or ground operation cannot be avoided, the maintenance requirements including
   1. number of operations,
   2. frequency of operations,
   3. special tooling and test equipment,
   4. calibration and adjustments, and
   5. fault identification and repair,

shall be documented, justified and agreed with the customer.

4.2.3 Reliability and redundancy

4.2.3.1 General

In view of the criticality of space mechanisms which are often potential mission critical single point failures, the reliability and redundancy of mechanisms engineering shall require particular attention.

4.2.3.2 Reliability

a. All mechanisms which are critical to mission success shall demonstrate conformance to the required reliability figure according to the following methods:
   1. electronic components: by parts count as a minimum or other methods to be agreed by the customer;
   2. mechanical parts: by stress analysis or other methods to be agreed by the customer;
   3. mechanical limited-life parts: reliability and confidence to be demonstrated by life test to be agreed by the customer.

b. Other (non-critical) mechanisms shall identify conformance to the reliability figure by simplified methods (parts count or other methods accepted by the customer).

c. The method to achieve by design, derive by analysis, and demonstrate the required reliability figure can be found in ECSS-Q-30.

d. Failure of one part or element shall not result in consequential damage to the equipment or other spacecraft components.

4.2.3.3 Structural reliability

a. Structural reliability, subclause 4.2.13 of ECSS-E-30 Part 2A shall apply.

b. Where structural failure of a mechanisms can cause a catastrophic or critical hazardous event (see ECSS-Q-40), fasteners and load bearing paths within mechanisms shall be designed in accordance with fracture control principles.

4.2.3.4 Redundancy

a. High-reliability of a mechanism may be incorporated in a design by including component redundancy or high design margins. The aim shall be to deliver a design which is single failure tolerant.

b. During the design of the mechanism all single point failure modes shall be identified.

c. All single points of failure shall be eliminated by redundant components where practicable.

d. Redundancy concepts shall be selected to minimize the number of single points of failure and to satisfy the reliability requirements.

e. Where a single point failure mode is identified and redundancy cannot be provided, the required reliability shall be demonstrated.

f. Unless redundancy is achieved by the provision of a complete redundant mechanism, active elements of mechanisms such as sensors, motor windings (and brushes where applicable), actuators, switches and electronics shall be redundant.

g. Failure of one element or part shall not prevent the other redundant element or part from performing its intended function, nor the equipment from meeting its performance requirements.

4.2.4 Flushing and purging

a. Parts of mechanisms that are sensitive to operation in air due to the presence of moisture or other deleterious contamination shall be provided with a means for flushing with an inert clean dry gas.

b. The cleanliness of the gas shall conform to the mechanism specification.

c. The residual humidity of the dry gas shall be compatible with the specific lubricant performance concerned.

4.3 Mission and environments

4.3.1 General

This group of requirements covers the interaction of mechanisms engineering with mission requirements and environments.

4.3.2 Mission

a. The mission phase shall commence with on-ground life of the mechanisms until end of operational life of the spacecraft.

b. The mechanism engineering shall consider every mission phase identified for the specific space programme and conform to the related mission requirements and environmental constraints.

c. Based on the mission phases, a mechanism specification shall be established.

d. The mechanism specification shall define the functional requirements and environments applicable to each phase of the mission.

e. The mechanism specification shall conform to the spacecraft system specification.

4.3.3 Environment

The mechanism shall conform to its environmental specification.

4.4 Functional requirements

4.4.1 General

This group of requirements covers the overall function of mechanisms on spacecraft and payload.

4.4.2 System performance

The mechanism functional performance shall conform to the system performance requirements.

4.4.3 Mechanism function

a. The mechanism shall provide structural support to an equipment or payload unit of the spacecraft and shall change its relative position with respect to the spacecraft.

b. The kinematic requirements applicable to each position change shall be substantiated; mechanical interface, position accuracy or velocity tolerances shall be specified and demonstrated to conform to the functional needs.

c. The envelopes within which each moving part is allowed to move shall be defined. The movement shall be without risk of mechanical interference with any other part of the mechanism, the spacecraft or the payload.

4.5 Constraints

4.5.1 General

This group of requirements covers the constraints to which mechanisms shall conform and to which the mechanisms have to be designed, manufactured and operated.

4.5.2 Physical constraints

4.5.2.1 Climatic protection and specific environment constraints

Specific climatic protection requirements shall be defined. Parts, components, sub-assemblies and assembly shall conform to the specific climatic protection requirements.

4.5.2.2 Sterilization

Sterilization requirements and sterilization test procedure requirements shall be defined. The mechanism shall conform to its sterilization requirements and sterilization test procedures requirements.

4.5.3 Materials

4.5.3.1 Mechanical and physical properties of materials

The materials used for space mechanisms shall conform to the materials requirements defined in the ECSS-E-30 Part 8.

The following material requirements are however specific to this Standard and shall be applied taking precedence over ECSS-E-30 Part 8.

4.5.3.2 Material selection

Materials shall be selected from the preferred materials list or shall be demonstrated to conform to approved requirements. (See ECSS-Q-70-71, ECSS-Q-70-04, and where applicable ECSS-Q-70-36 and ECSS-Q-70-37).

For additional requirements relating to tribology, see 4.7.2

4.5.3.3 Corrosion

All metals shall be either corrosion resistant, or shall be suitably treated using a process, approved by the customer which resists corrosion caused by conditions arising during storage, test and all phases of the mission. This shall include stress corrosion where applicable

NOTE Corrosion resistance is demonstrated when no corrosion is identified on the surface after exposure to the worst case conditions and mission phases durations, and if the material is a Class 1 material (see ECSS-Q-70-37) and has demonstrated not to show surface corrosion after exposure to the related test environment.

4.5.3.4 Dissimilar metals

Where possible, dissimilar metals shall not be used in contact with each other unless they have been treated by a customer approved process which resists galvanic and electrolytic corrosion.

4.5.3.5 Stress corrosion cracking

Metals used and not demonstrated to conform to approved selection criteria, shall be tested according to approved methods and shall demonstrate conformance to respect to stress corrosion cracking (see ECSS-Q-70-36 and ECSS-Q-70-37).

4.5.3.6 Material allowables

The requirements identified in subclause 4.7.4.2 are applicable.

4.5.3.7 Fungus protection

Materials that are nutrients for fungi shall not be used where their use can be avoided. Where they are used and not hermetically sealed, they shall be treated with an approved fungicidal agent.

4.5.3.8 Flammable, toxic and unstable materials

The use of flammable, toxic and unstable materials shall be avoided as far as possible. In manned space systems, the use of flammable, toxic and unstable materials is not allowed.

4.5.3.9 Induced emissions (stray-light protection)

Stray light protection and emission requirements shall be determined. Materials and their coatings shall be selected such that their surface properties reduce their induced emissions (stray light and others) below the permitted levels of stray light.

4.5.3.10 Radiation

The degradation of material properties due to the effects of exposure to radiation shall not degrade the functional performance of the mechanism below requirement over the complete mission.

4.5.3.11 Atomic oxygen

The material properties due to exposure to atomic oxygen present in LEO shall not degrade below the functional performance requirements of the mechanism throughout the mission

4.5.4 Operational constraints

a. The mechanism shall not impose additional operational constraints on the mission.

b. If operational constraints cannot be avoided, they shall be identified, justified and approved by the customer.

4.6 Interfaces

4.6.1 General

This group of requirements covers the interfaces of mechanisms on spacecraft and payload.

4.6.2 Structural interfaces

The mechanism shall conform to the structural interface definitions and requirements identified in the mechanism specification.

4.6.3 Thermal interfaces

The mechanism shall conform to the thermal interface definitions and requirements identified in the mechanism specification.

4.6.4 Thermo-mechanical interfaces

Thermo-mechanical interfaces shall be designed to account for the induced stress.

4.6.5 Electrical interfaces

The mechanism shall conform to the electrical interface definitions and requirements identified in the mechanism specification.

4.6.6 Data interfaces

The mechanism shall conform to the data interface definitions and requirements identified in the spacecraft mechanism specification.

4.6.7 Physical interfaces

The mass of the mechanism shall conform to the requirements specified by the customer.

4.6.8 Other interfaces

The mechanism shall conform to optical, alignment, access, stay-out zones and GSE interfaces identified in the mechanism specification.

4.7 Design requirements

4.7.1 General

The design requirements have been further split into tribology, thermal control, mechanical design and sizing, pyrotechnic, electrical and electronic, and control system requirements.

4.7.2 Tribology

4.7.2.1 General tribology requirements

a. This group of requirements covers the requirements related to tribological issues of mechanisms on spacecraft and payload. The tribology of surfaces that separates or moves relative to one another play a key function in the conceptual definition, design, analysis, test verification, launch, and in-orbit non-operational or operational performance of the mechanisms. The following requirements shall be applied.

b. Mechanisms shall be designed to provide adequate lubrication function between surfaces in relative motion in order to ensure it conforms to the mechanism performance requirements throughout the required lifetime and to minimize wear.

c. Mechanisms shall employ lubricants or lubricating surfaces that are space approved (see ECSS-Q-70).
If non-approved lubricants are used, they shall be validated in advance to ensure space compatibility of the lubricant material (see ECSS-Q-70)

NOTE The lubrication function is not covered in ECSS-Q-70.

d. Degradation of the lubricant in the on-ground and in-orbit environments shall be verified not to occur or shall be verified not to lead to unacceptable mechanism performance degradation (adhesion friction, wear, lubricant performance variability).

e. The use of sliding surfaces shall be avoided as far as possible, but where such use cannot be avoided, one of the surfaces shall be hard and the other shall be lubricated or shall be composed of a self-lubricating material (e.g. polyimide resins). Metal to metal contacts shall be composed of dissimilar materials.

f. The cleaning of surfaces prior to the application of lubricant shall facilitate adequate adhesion or wetting of lubricant on the substrate surface. The cleaning of the surfaces prior to lubricant application shall not degrade the lubricating action.

g. The lubricant shall conform to the molecular and particulate contamination requirements specified for the entire mission.

4.7.2.2 Dry lubrication

a. Dry lubricants shall be selected in accordance with space tribology requirements (see ECSS-E-30-09).

b. At the same time as the mechanism tribological surfaces are being lubricated, samples of representative material, surface roughness, surface cleanliness and surface orientation shall be co-deposited in each process run with the flight components. The thickness and adhesion of the lubricant on the samples shall be verified.

c. The process validation of the dry lubricant application shall be demonstrated with respect to achieved lubricant performance and repeatability.

d. Handling, storage and all operational requirements of all dry lubricated components shall be defined and documented.

4.7.2.3 Fluid lubrication

a. Amount of fluid lubricant

The quantity of lubricant provided shall be determined to leave an adequate surplus of lubricant at the end of the total lifetime of the mechanism and shall take into account outgassing, creep and other sources of absorption or degradation. The exposure to on-ground storage and related gravity effects, and other ground or in-orbit accelerations on lubricant distribution shall be validated.

b. Containment or sealing requirements

Liquid lubricated systems shall be appropriately designed to prevent outgassing, creeping and possible sources of contamination and shall demonstrate conformance to the contamination requirements.

c. Outgassing rate

The outgassing rate of liquid lubricants shall be measured by an approved screening test (see ECSS-Q-70-02). The limits of acceptance for material outgassing shall be according to Table 1.

Table 1: Outgassing limits

Application	TML [%]	RML [%]	CVCM [%]
General applications	< 0,1	n.a.	< 0,1
Optical device applications	n.a.	< 0,1	< 0,01

These limits can be more stringent if the materials concerned are later used in critical areas. The use of materials that are deemed acceptable according to the limits stated above does not necessarily ensure that the spacecraft system or component remains uncontaminated.

d. Sensitive applications

For sensitive applications, specific outgassing requirements shall be defined.

e. Anti-creep barriers

Anti-creep barriers shall be used to avoid migration of liquid lubricants to sensitive equipment within the mechanism or when migration of liquid lubricants causes a change of the lubricant amount on the essential parts to be lubricated.

f. Integrity of the anti-creep barrier

The integrity of the anti-creep barrier shall be verifiable by using suitable indicators (e.g. UV-detectable).

4.7.2.4 Tribological components requirements

4.7.2.4.1 Materials for tribological surfaces

a. The mating surfaces used in end stops shall be < Ra 0,4 μm.

b. When metallic material mating or separating surfaces subject to relative motion are used, they shall have a minimum hardness of 500 HV (unless one surface is a self-lubricating material e.g. bronze) and shall be composed of dissimilar material or at least one of the two surfaces shall have a dissimilar coating (e.g. nitride, carbide or oxide). The use of bonded or sputtered MoS_2 or polymeric materials is not excluded.

c. The life of tribological components shall be demonstrated to suit the application under representative conditions.

4.7.2.4.2 Bearing pre-loading

a. Ball bearings shall be pre-loaded. Pre-loading should be applied by solid pre-load or produced by compliant loading techniques which do not require sliding at the bearing mounting interfaces.

b. If sliding at the bearing mounting interfaces cannot be prevented, sliding shall be facilitated by a dedicated lubricated sliding sleeve/bush or dedicated tribological coating.

c. If bearing gapping occurs during vibration, adequacy of lubricant and potential consequential mechanisms damage or degradation due to bearing components or shaft motion shall be demonstrated to conform with the required functional performance and lifetime.

d. Any set pre-load at component level shall be measured.

e. Where the functional performance of the mechanism or spacecraft is sensitive to the pre-load, the pre-load shall be measured after assembly.

f. Where the pre-load can be affected by the running-in process, the pre-load shall be confirmed after running-in. If possible, the pre-load shall be checked without dismantling the mechanism.

4.7.2.4.3 Mechanical cables

Mechanical cables used on moving parts or assemblies shall be adequately lubricated.

4.7.3 Thermal control requirements

4.7.3.1 General

This group of requirements covers the interaction of mechanisms engineering with thermal control and its related requirements affecting mechanisms engineering.

4.7.3.2 Thermal engineering

a. The mechanism engineering shall conform to the thermal engineering requirements identified in the ECSS-E-30 Part 1.

b. If no specific thermal control provisions are applied on the mechanism, the applicability of ECSS-E-30 Part 1 shall be limited to the overall thermal sizing, analysis and verification requirements.

c. The following requirements of subclause 4.7.3.3 are specific to this Standard and shall be applied taking precedence over ECSS-E-30 Part 1.

4.7.3.3 Mechanisms thermal design and sizing requirements

a. The thermal design of the mechanism shall ensure that all components are maintained within their qualification temperature range under all specified ground, test, launch and in-orbit conditions throughout the lifetime of the mechanism.

b. The mechanism shall be compatible with on-ground thermal vacuum testing which is representative of in-orbit thermal conditions.

c. Temperature control shall be passive to the maximum extent practicable.

d. The mechanism design shall consider the extremes of operational and survival steady-state and transient temperatures that can be encountered and also the temperature gradients across the mechanism.

   NOTE Failure to consider the effects of differential expansion can lead to a catastrophic failure. Further details of the thermal analysis required and margins to be used on predicted temperatures are given under the Verification requirements group 4.8.

4.7.3.4 Multi-layer insulation (MLI) requirements

a. When using MLI, supported at discrete positions (supports: maximum of 100 mm apart), on moving parts of mechanisms or on spacecraft structure close to its moving paths, the following clearances shall be provided:

   1. between structural components and MLI hardware a minimum clearance of 20 mm (in out-of-plane direction to the MLI)

   2. between MLI protected moving parts and other MLI hardware a minimum clearance of 35 mm (in out-of-plane direction to the MLI).

b. Other specific design solutions (e.g. MLI not supported at discrete positions) shall demonstrate that clearances with adequate margin, agreed by the customer, are maintained throughout the mission.

c. The MLI design shall be such that the dynamic envelopes of the MLI during vibration exposure and venting or purging do not exceed the required clearances.

4.7.4 Mechanical design and sizing

4.7.4.1 General

a. This group of requirements covers the overall conceptual design, the mechanical sizing of parts, components and assemblies, and the detailed design definition of mechanisms.

b. Mechanisms shall be designed to meet the mechanical performance requirements and to withstand the specified environment during handling, transportation, testing, storage, launch and operation in orbit for the specified lifetime without damage or degradation.

4.7.4.2 Structural dimensioning

4.7.4.2.1 Structural engineering requirements

The structural dimensioning of mechanisms shall conform to the Structural Engineering requirements identified in the ECSS-E-30 Part 2.

The following requirements of subclause 4.7.4.2 are specific to this Standard and shall be applied taking precedence over ECSS-E-30 Part 2.

4.7.4.2.2 General

Mechanisms shall conform to the specified stiffness, strength and safety requirements derived from the launcher and the spacecraft structural requirements.

4.7.4.2.3 Loads

The requirements of subclause 4.2.10 of ECSS-E-30 Part 2A shall apply with the following additions for in-orbit loads:

a. The operational loads shall be added to the in-orbit loads.

b. The operational loads of the mechanisms shall be derived according to the functional dimensioning requirements based on dynamic performance analyses or test measurements in worst case conditions.

c. For the derivation of the operational loads, the related induced reaction of the spacecraft shall be considered.

4.7.4.2.4 Limit loads

The requirements of subclause 4.2.11 of ECSS-E-30 Part 2A shall apply with the following modifications for the worst case condition:

For cases where a statistical distribution of the loads cannot be demonstrated (typically for mechanisms operating loads), the limit loads shall be defined based on the worst case conditions.

4.7.4.2.5 Design loads

The requirements of subclause 4.2.12 of ECSS-E-30 Part 2A shall apply.

4.7.4.2.6 Material allowables

The requirements of subclauses 4.6.9 through 4.6.13 inclusive of ECSS-E-30 Part 2A shall apply to structural sizing, with the following addition for the "A" values:

Metallic material "A" allowable value as specified in ref. MIL-HDBK-5F or equivalent definition shall be used for structural sizing.

4.7.4.2.7 Margin of safety (MOS)

The requirements of subclause 4.6.14 of ECSS-E-30 Part 2A on structural margin of safety shall apply with the following modifications:

a. Mechanisms shall be designed with a positive margin of safety against yielding and against ultimate under all environmental and operational load conditions.

b. The margin of safety (MOS) shall be derived from stresses and shall employ the factors of safety (FOS) identified below. It is defined as follows and shall be demonstrated to be positive:

   MOS = (allowable stress limit / (actual stress x factor of safety)) - 1 > 0.

4.7.4.2.8 Factors of safety (FOS)

The requirements of subclause 4.6.15 of ECSS-E-30 Part 2A on structural factors of safety definition shall apply with the following modifications:

a. In the computation of safety margins the following minimum factors of safety shall be used for standard metallic materials:

   - yield stress factor of safety 1,25
   - ultimate stress factor of safety 1,5
   - minimum fatigue factor (cycles) 4

b. Other materials shall require customer approval of required factors of safety on a case by case basis.

c. The following specific factors of safety shall apply on the components identified below:

   - cables, stress factor of safety against rupture 3
   - stops, shaft shoulders and recesses, against yield 2

4.7.4.3 Functional dimensioning (motorization)

4.7.4.3.1 General

The mechanisms engineering shall conform to the motorization factor requirements on quasi-static torque (or force) ratio and where applicable on dynamic torque (or force) ratio as defined in the following subclauses.

4.7.4.3.2 Quasi-static torque applicability

The quasi-static torque (or force) ratio is applicable to mechanisms where the moving function is performed without imposing design driving requirements on the functional performance due to time constraints. (e.g. deployment systems, unfolding devices).

NOTE The quasi-static torque (or force) ratio is defined as the actuation torque (or force) divided by the sum of the factored worst case resistive components opposing the movement of the mechanism plus any required deliverable output torque or force.

4.7.4.3.3 Dynamic torque applicability

The dynamic torque (or force) ratio requirement is applicable to mechanisms which have to fulfil a specified acceleration requirement or for which an indirect acceleration requirement can be deduced from speed/time or other (dynamic) requirements.

NOTE The ratio is defined as the dynamic actuation torques (or forces) divided by the sum of the factored dynamic worst case resistive components and the additional factored inertial torque (or force) induced by the acceleration of the mechanism moving assembly plus any required deliverable output torque or force.

4.7.4.3.4 Motorization factor - "quasi-static" torque (or force) ratio

a. Actuators (electrical, mechanical, thermal and others) shall be sized to provide throughout the operational lifetime and over the full range of travel actuation torques (or forces) which exceed at least two times the combined factored worst case resistive torque or forces in addition to any required deliverable output torque or force. The following minimum uncertainty factors shall be applied to the resistance components when deriving the worst case resistive torques (or forces):

In order to derive the factored worst case quasi-static resistive torques (or forces), the components of resistance, considering worst case conditions, shall be multiplied by the following minimum uncertainty factors (see Table 2).

Table 2: Minimum uncertainty factors

Component of resistance	Symbol	Factor
Inertia	I_T (or I_F)	1,1
Spring	S	1,2
Friction	F_R	3 # (1,5)
Hysteresis	H_Y	3 # (1,5)
Others (harness)	H_A	3 # (1,5)
Adhesion	H_D	3

b. The minimum required actuation torque (or force) is defined by the equations:

Minimum required actuation torque (T_{min})

$$T_{min} = 2,0 \times (1,1\, I_T + 1,2\, S + 3\, F_R + 3\, H_Y + 3\, H_A + 3\, H_D) + T_L$$

c. Minimum required actuation force (F_{min})

$$F_{min} = 2,0 \times (1,1\, I_F + 1,2\, S + 3\, F_R + 3\, H_Y + 3\, H_A + 3\, H_D) + F_L$$

The deliverable output torque or force is only applicable if specified by the customer.

d. When a function of the mechanism is to deliver an output torques or forces T_L / F_L, for further actuation, the output torque or force shall be derived according to the above torque or force requirements considering the specified uncertainty factors on the individual components of resistance as appropriate and the motorization factor of two shall also be applied to T_L / F_L .

e. The inertia resistance term (I_T or I_F) in the required minimum actuation torque (or force) equation is applicable to mechanisms being mounted in an accelerating frame of reference (e.g. spinning spacecraft, payload or other) and shall be derived considering the imposed inertial resistance load.

f. The specified uncertainty factors marked by # in Table 2 may be reduced to 1,5 providing that the worst case measured torque or force resistive components to which they refer are determined by measurement according to a test procedure approved by the customer and demonstrate the adequacy of the uncertainty factor with respect to the dispersions of the resistive component functional performances.

g. The kinetic energy of the moving components shall not be considered in the provision of actuation torques (or forces).

h. Environmental effects shall be accounted for separately in addition to the use of the above uncertainty factors when deriving the worst case resistive torques (or forces).

4.7.4.3.5 Motorization factor - dynamic torque (or force) ratio

a. Actuators (electrical, mechanical, thermal and others) shall be sized to provide throughout the operational lifetime and over the full range of travel actuation torques (or forces) which exceed the sum of at least two times the combined worst case dynamic resistive torque (or forces) and 1,25 times the inertial resistance torque (or force) caused by the required worst case acceleration function. The minimum uncertainty factors (see Table 2) shall be applied to the resistance components when deriving the worst case resistive dynamic torques (or forces).

In order to derive the worst case dynamic resistive torques (or forces), the components of resistance considering the worst case conditions shall be multiplied by the minimum uncertainty factors (see Table 2).

b. The minimum required actuation torque (T_{min}) to meet the dynamic torque ratio requirements is given by the formula:

$$T_{min} = 2{,}0 \times (1{,}1\, I_T + 1{,}2\, S + 3\, F_R + 3\, H_Y + 3\, H_A + 3\, H_D) + 1{,}25\, T_D$$

where

T_D is the dynamic torque.

c. The minimum required actuation force (F_{min}) to meet the dynamic force ratio requirements is given by the formula:

$$F_{min} = 2{,}0 \times (1{,}1\, I_F + 1{,}2\, S + 3\, F_R + 3\, H_Y + 3\, H_A + 3\, H_D) + 1{,}25\, F_D$$

where

F_D is the dynamic force.

d. The inertia resistance term (I_T or I_F) in the required minimum actuation torque (or force) equation is applicable to mechanisms being mounted in an accelerating frame of reference (e.g. spinning spacecraft, payload or other) and shall be derived considering the imposed inertial resistance load.

e. The specified uncertainty factors marked by # in table 2 may be reduced to 1,5 providing that the worst case measured torque or force resistive components to which they refer are determined by measurement according to a test procedure approved by the customer and demonstrating adequacy of the uncertainty factor with respect to the dispersions of the resistive component functional performances.

f. The kinetic energy of the moving components shall not be considered in the provision of actuation torques (or forces).

g. Environmental effects shall be accounted for separately in addition to the use of the above uncertainty factors when deriving the worst case resistive torques (or forces).

4.7.4.3.6 Actuation torque (or force) dimensioning

a. When the actuation torque (or force) is supplied by a spring actuator, the worst case actuation torque required in the equations in subclause 4.7.4.3, shall be derived considering worst case conditions and shall be multiplied by the maximum uncertainty factor of 0,8.

b. Spring actuators shall be redundant unless agreed by the customer, and unless it is demonstrated by analysis and test that appropriately conservative spring sizing and functional performance characteristics guarantee the required reliability of the mission. The appropriate spring sizing shall demonstrate that a spring failure can be excluded as potential failure mode.

c. Actuating torques or forces based on hysteresis, harness generated, or any item whose primary function is not to provide torques or forces, shall not be used as a motorization source.

d. If torques (or forces) from harness or other above excluded actuator sources are relied upon to meet the motorization requirements in subclause 4.8.3.3. their use shall be justified, agreed with the customer and the adequacy of the uncertainly factor with respect to the dispersion of the component actuation functional performances shall be demonstrated.

4.7.4.4 Other requirements

4.7.4.4.1 Replaceable elements

a. All parts or components which are intended to be replaced or re-installed shall be designed to ensure they can only be installed in the correct orientation.

b. Designs of mechanisms using deformable elements (e.g. crush dampers.) shall only allow correct assembly orientation or orientations.

c. The design of replaceable items shall inhibit the reuse in the mechanism or spacecraft in the un-refurbished state.

4.7.4.4.2 Status monitoring

Unless monitored at spacecraft system level, the design of mechanisms shall include appropriate means to monitor the execution of its main functions. Mission critical mechanisms shall be designed in such way that monitoring information of its critical function(s) is accessible to the spacecraft telemetry.

4.7.4.4.3 Latching or locking

a. Latching mechanisms used to assure positive locking shall be designed to avoid inadvertent opening by vibration or shock occurring during the mission.

b. Locking or latching mechanisms shall provide a clear indication of whether the latch or lock is open or closed.

c. Electrically actuated deployable items require positive latching or locking.

d. The latch capture range shall be sufficient to ensure capture of the mechanism over the complete range of temperatures or temperature gradients and manufacturing and assembly tolerances.

e. Where latching is not achieved on initial completion of motion, the design shall not prevent subsequent successful latching.

f. Latches shall be self-locking and shall be easily resettable for ground testing.

g. Off-load mechanisms shall be capable of being operated manually.

h. Latches and locks shall conform to the shock load requirements.

4.7.4.4.4 End stops

a. Mechanisms with restricted travel or rotation shall be provided with regular or emergency mechanical end stops which limit their motion and travel extremes to the maximum position for proper functioning of the actuated item and to prevent interference with interfacing equipment.

b. The mechanical end stops and arresting mechanisms shall be designed to withstand without damage the maximum shock loads possible.

c. The shock loads shall conform to the sizing requirements on adhesion forces for end stops stated in subclause 4.7.4.4.5a.

d. Contact with a stop shall not result in a non-recoverable situation.

e. Electrical deployment indicators (e.g. micro switches) shall not be used as mechanical end stops.

4.7.4.4.5 Separable contact surfaces (not applicable to gears and ball or journal bearings)

a. Separable contact surfaces shall be designed to minimize the adhesion forces. The contact between the mating surfaces shall be well-characterized and reproducible, including for the area of contact, alignment and load conditions.

b. The peak Hertzian contact pressure shall be demonstrated to be below 93% of the yield limit of the weakest material.

c. Sliding at the separable contact surfaces shall be prevented to avoid potential contact surface property changes.

d. The torque or force ratio of the actuator which separates the contact surfaces shall be sized according to subclause 4.7.4.3.4 and shall be demonstrated to overcome two times the worst possible adhesion force in representative environmental condition.

e. The minimum hardness of metal to metal couples in contact shall be 500 HV.

4.7.4.4.6 Ball bearings - sizing for static loads

Ball bearings "manufactured from good quality hardened steel" (ISO 76) shall be sized concerning the static load rating in accordance with ISO 76 with respect to the maximum allowable Hertz contact stress.

4.7.4.4.7 Gears

The dimensioning and sizing of gears shall be performed according to the ISO 6336 standard and its reference documents.

4.7.4.4.8 Mechanical clearances

When designing and locating movable, actuating, or similar mechanisms, adequate clearance shall be provided to prevent:

- interference (collision) with the structure;
- contact with electrical wiring and components, thermal insulation, or other subsystem components;
- puncture of fluid lines, valves and tanks if applicable;
- blocking of optical paths if applicable.

4.7.4.4.9 MLI clearance

For clearance requirements to MLI see subclause 4.7.3.4.

4.7.4.4.10 Threaded parts or locating devices

a. All threaded parts (e.g. fasteners and others) and locating devices require secondary, redundant locking, i.e. shall be positively locked.

b. All threaded fasteners, screws and studs shall be manufactured in accordance with general requirements for threaded fasteners (see ECSS-Q-70-46).

c. All threaded fasteners, screws and studs shall be made from materials which are not susceptible to stress corrosion cracking, (see ECSS-Q-70-37).

d. All threaded fasteners, screws and studs shall be designed to be fail-safe.

4.7.4.4.11 Venting

a. Unless the mechanism is hermetically sealed or sized in all its functions and performances for internal pressure build-up, adequate means of venting during launch and in-orbit shall be provided.

b. The method and design of venting shall minimize the contamination of bearings, optics and other sensitive components.

c. If venting to the outside of a lubricated enclosure is implemented, compatibility of the lubricant with the other spacecraft materials used and with contamination requirements shall be demonstrated.

4.7.4.4.12 Release and locking devices with pyrotechnics or other actuators

a. All pyrotechnic and other release and locking devices actuators (e.g. thermal knives, memory metal and paraffin actuators) shall be redundant unless agreed by the customer. Redundancy shall be provided by duplication up to and including the level of the initiators, heating element or equivalent for non-pyrotechnic devices and its power supply.

b. The design, material and manufacture of bolts, rods and cables (and other elements to be cut) used in release and locking devices shall be demonstrated to conform to the reliability requirements to be fulfilled in the cutting function.

c. The operation of release devices shall be compatible with the cleanliness requirements. Suitable means of debris containment shall be included. If critical, contamination shall be measured.

d. Release and locking devices shall conform to the shock load requirements.

4.7.5 Pyrotechnics

For pyrotechnic actuators see ECSS-E-30 Part 6.

4.7.6 Electrical and electronic requirements

4.7.6.1 General

a. This group of requirements covers the interaction of mechanisms engineering with electrical and electronic engineering and its related requirements affecting mechanisms engineering.

b. For electrical and electronic engineering requirements see ECSS-E-20. If no electrical or electronic provisions are applied on the mechanism, the applicability of the Standard shall be limited to the potential compatibility requirements of mechanical systems with electrical and electronic systems.

c. The following electrical and electronic requirements are specific to this Standard and shall be applied taking precedence over ECSS-E-20.

4.7.6.2 Electrical design

a. Mechanisms shall be designed to meet all the requirements regarding electrical interfaces and performances, and shall exhibit stable electrical characteristics and electromechanical transfer functions throughout their specified period of life.

b. Electrical power consumption, generated electrical disturbances and propensity for fault propagation shall be minimized by design.

c. The design of electric motors shall conform with the design requirement for space electric motors.

4.7.6.3 Insulation

a. Electrical wires shall be insulated from the structure and from each other by not less than 10 MΩ measured with a DC voltage of 500 V applied.

b. Electric motor windings shall be insulated from the structure and from each other by not less than 100 MΩ measured with a DC voltage of either 100, 250 or 500 V DC applied. The voltage applied shall be about five times the worst case flight operating voltage.

4.7.6.4 Dielectric

a. Electrical wires shall be designed to withstand a high voltage of 500 V AC (50 Hz) applied between each other or between wires and the structure without causing disruptive discharges.

b. Electric motor windings shall be designed to withstand a high voltage of:

- 250 V AC (worst flight operating motor current up to 50 V)
- 500 V AC (worst flight operating motor current up to 100 V)

applied between each other or between windings and the structure without causing disruptive discharge.

4.7.6.5 Grounding

a. Each mechanism shall be electrically bonded to the satellite structure or its carrying equipment.

b. If electronic or electrical components are mounted internally to or externally on the mechanism, an earth bonding strap shall be used.

c. The length-to-width ratio of the bonding strap shall be smaller than four (4).

d. The DC resistance, between the mechanism and the spacecraft ground plane or carrying equipment ground plane in both polarities, shall be less than 10 mΩ if an earth bonding strap is used.

e. The DC resistance, between any point on a metallic external surface of the mechanism and the bonding point reference of the mechanism, shall be less than 5 mΩ if an earth bonding strap is used.

f. Where the grounding is to provide protection against electrostatic discharge only and the mechanism contains no electronics, the DC resistance shall be less than 1 Ω .

4.7.6.6 Electrical connectors

a. With the exception of the bonding strap for grounding, all electrical connections to the mechanism shall be made through electrical connectors of an approved type mounted on the mechanism where practicable.

b. Flying leads shall be avoided where practicable.

c. Connector types and configurations (e.g. number of pins) shall be selected to preclude damage or inadvertent operation resulting from mis-mating.

d. Electrical connectors shall be redundant.

4.7.6.7 Over current protection

a. Mechanisms containing electrical parts and circuitry shall incorporate adequate means of protection against excessive currents due to abnormal impressed voltages or internal conditions (e.g. faults). The current protection can be provided externally.

b. The mechanism shall provide adequate means to protect against the generation of over voltages.

4.7.6.8 Strain on wires

Moving cable harness shall have reproducible resistive torques or forces. The lay up of cables shall not change during motion.

4.7.6.9 Magnetic cleanliness and ESD or EMC protection

Mechanisms shall conform to the spacecraft system requirements on magnetic cleanliness, and conductivity of external surfaces for electrostatic discharge (ESD) protection.

4.7.7 Control system

4.7.7.1

The following requirements are mandatory where applicable for mechanisms that utilize a control system (open or closed loop) to achieve the specified performance.

4.7.7.2

The gain margin shall not be less than a factor of four (4) throughout the operational lifetime for linear or quasi-linear control systems. Non-linear control systems may use a lower gain margin that shall be agreed with the customer.

4.7.7.3

The phase margin shall not be less than 30 degrees throughout the operational lifetime of the equipment and under worst case combination of parameters (drift, temperature effects).

4.7.7.4

The bandwidth of the control system shall be designed to achieve the commanded action within the required response time.

4.7.7.5

The damping ratio of the control system shall be greater than 0,05 (equivalent Q value (amplification factor) of 10).

4.7.7.6

The control system shall not excite mechanism and where applicable shall not excite structural resonances of the spacecraft as agreed by with the customer.

4.7.7.7

The control system shall, as far as practical, be decoupled between different directions of movement.

4.7.7.8

The control system shall be compatible with the maximum angular rates and accelerations of the spacecraft.

4.7.7.9

The control system shall respect the torque or force ratio requirements identified in subclause 4.7.4.3.

4.7.7.10

Transfer functions of the controller shall not contain pure derivative terms (to prevent excessive amplification of the noise). The ratio between the derivative time constant and the time constant limiting the high frequency gain shall not exceed 20.

4.7.7.11

Harnesses and cables to moving parts shall be characterized in terms of hysteresis and stiffness, and shall be taken into account in the control system design. The characterization shall take place in representative configuration over the full range of displacement and over the specified qualification temperature range and shall also include lifetime, speed effects.

4.7.7.12

If the sampling frequency is not sufficiently high to prevent aliasing of the sampled data, an anti-aliasing filter to reduce the bandwidth of the analogue signal (to be sampled) shall be used.

4.7.7.13

The resolution of sensors used in the control system to feedback information shall be at least a factor of five (5) better than the required resolution of the complete system.

4.8 Verification

4.8.1 General

a. The verification process shall be a mandatory step in the development of a space mechanism and shall comprise verification of both analytical and test. Accordingly, the mechanisms verification requirements are subdivided into analytical and test verification requirements.

b. A verification matrix shall be established and agreed with the customer.

4.8.2 Verification by analysis

4.8.2.1 General

a. The mechanisms parts, components and assembly analytical verification shall include, where applicable:

   1. Worst operational and non-operational sizing cases identification thermal analysis;
   2. Structural analysis (stiffness, stress or strength, thermo-elastic effects, fatigue, fracture control (if relevant) to demonstrate adequate sizing of the components and the overall assembly for all sizing cases. For the structural analyses, the requirements of subclause 4.9 of ECSS-E-30A Part 2 Structural are applicable;
   3. Pre-load and tolerance budgets considering manufacturing tolerances, thermo-elastic effects, external or induced loads;
   4. Functional performance analyses in all applicable environments under all operational conditions (based on worst case identification) to derive sizing loads, time, shocks, speed, dimensional stability and positional accuracy;
   5. Hertzian contact analysis for separable contacts, sliding contacts or for bearings;
   6. Torque or force ratio;
   7. Reliability (parts count reliability as a minimum), FMECA;
   8. Gear analysis;
   9. Shock generation and susceptibility;
   10. Disturbance generation and susceptibility (micro-vibration);
   11. Analysis of control systems (performance, stability margin);
   12. Lubrication analysis;
   13. Lifetime analysis;
   14. Hygroscopic effects analysis;
   15. Magnetic or electromagnetic analysis;
   16. Radiation analysis;
   17. Electrical analysis.

b. If any of the analysis above is considered not relevant, adequate justification shall be provided.

c. The analyses shall cover the combinations of range of extreme conditions applicable to the flight system and which do not necessarily all occur during qualification testing (e.g. worst case friction levels). Analysis shall always cover the worst or extreme case conditions.

4.8.2.2 Worst cases identification

The worst case operational and non-operational sizing of a mechanism shall be identified according to the environmental, load and functional performance characteristics applicable to the particular spacecraft and mechanism concerned.

4.8.2.3 Thermal analysis

Thermal analysis of a mechanism shall conform to the requirements identified in ECSS-E-30 Part 1.

4.8.2.4 Structural analysis

Mechanisms structural analysis shall conform to the requirements identified in ECSS-E-30 Part 2, however, for the derivation of margins of safety subclause 4.7.4.2 of this Standard shall apply.

4.8.2.5 Pre-load and tolerance budget analysis

Mechanisms pre-load and tolerance budget analysis shall consider the relevant combination of the worst cases environmental, functional, residual loads, manufacturing tolerances and demonstrate adequacy of the moving joint play for incorporation of worst case conditions in the functional analysis.

4.8.2.6 Functional performance analysis

a. Functional model requirements

   1. The analysis shall be based on an analytical or numerical model, which shall represent the flight hardware mechanisms and its components, including interface conditions and overall spacecraft characteristics, with respect to mass, inertia, location of the centre of mass, structural stiffness, actuation forces or torques, resistances for conditions specified in subclause 4.7.4.3.
   2. The model shall be sufficiently accurate to allow an adequate assessment of the behaviour of the mechanism to be made.
   3. The model shall allow a parametric study of all the mechanical variables to be made and allow an update of input parameters during the design and test phase.

b. Analysis requirements

   1. The analysis shall demonstrate that the mechanism conforms to the mechanism requirement specification and the mechanical design and sizing requirements (subclause 4.7.4) under worst case parameter combinations.
   2. Failure cases shall be analysed and, where identified, contingency scenarios shall be validated by analysis.
   3. An integrity check of the results shall be performed (e.g. energy or momentum balance).
   4. A sensitivity analysis (parameter variation) covering the uncertainty of parameters shall be carried out.
   5. The results of the analysis shall be verified by comparison with relevant test results.

4.8.2.7 Hertzian contact and contact stress

a. An analysis shall be provided of the predicted Hertzian contact or yield or bending stresses of moving surfaces in contact under worst case conditions. The analysis shall demonstrate adequacy with the material allowables of the chosen material couple, lubricant and other coating used.

b. An analysis shall be provided demonstrating appropriate sizing of ball bearings in accordance with ISO 76 or equivalent norm.

4.8.2.8 Torque or force ratio analysis

Conformance of mechanisms to specified requirements on torque or force ratio shall be demonstrated by analysis.

4.8.2.9 Reliability analysis, FMECA

The reliability of a mechanism shall be determined (see ECSS-Q-30).

4.8.2.10 Gear analysis

An analytical verification of the adequacy of dimensioning and sizing of gears shall be performed according to ISO 6336.

4.8.2.11 Shock generation and susceptibility

The conformance of the mechanism with the requirements identified in the mechanism requirement specification concerning shock generation and susceptibility shall be verified by analysis. Adequate dimensioning and sizing shall be demonstrated.

4.8.2.12 Disturbance generation (emission) and susceptibility

a. The conformance of the mechanism operation with the requirements identified in the mechanism requirement specification concerning vibration (microvibration) shall be characterized by analysis. Adequate dimensioning and sizing shall be demonstrated.

b. The moving parts of the mechanism shall be balanced to meet the specified requirements on disturbances.

4.8.2.13 Analysis of control systems

a. A mathematical model or computer simulation describing the dynamic behaviour of the mechanism and its associated control system shall be established to perform verification by analysis.

b. the functional performance of the control system shall be analysed for

   1. stability,
   2. bandwidth,
   3. dynamic and static accuracy,
   4. resolution, and
   5. generation of and susceptibility to disturbances at the interfaces of the mechanism,

   and shall demonstrate conformance to the mechanism requirement specification.

c. Non-linearities such as backlash, dead-zones, friction, saturation of drive electronics shall be characterized and taken into account in the control system analysis. Characterization shall take place over the full range of displacements and over the full specified qualification temperature range. The worst case combinations of parameters occurring during the operational lifetime of the equipment shall be considered.

d. Non-linearities, if any, shall be analysed

e. The robustness of the control against variations in the environment and over the operational lifetime shall be demonstrated by analysis.

4.8.2.14 Lubrication analysis

a. An assessment of the choice of lubrication system and its adequate dimensioning for the proposed application and lifetime shall be provided.

b. The adequacy of the quantity of lubricant shall be assessed by analysis.

4.8.2.15 Lifetime analysis

a. Limited-life components shall be identified.

b. Conformance of limited-life components to the lifetime requirements shall be demonstrated by analysis, using as a minimum the lifetime factors specified in subclause 4.8.3.3.9 in addition to the fatigue factor specified in subclause 4.7.4.2

4.8.2.16 Magnetic and electromagnetic

The sizing of magnetic or electromagnetic components shall be substantiated by analysis.

4.8.2.17 Radiation analysis

Components susceptible to radiation shall be analysed with respect to the accumulated radiation dose and to demonstrate the (lifetime) performance requirements are met.

4.8.2.18 Electrical analysis

Electrical parts stress analysis shall be performed to demonstrate the electrical parts conform to the derating requirements (see ECSS-Q-30-06).

4.8.3 Verification by test

4.8.3.1 General

a. Verification by test shall be a mandatory step in the demonstration that the mechanisms fulfil the requirements for use as space hardware. The aim of testing can be either characterization, development, qualification or acceptance.

b. The mechanism design shall be compatible with operation on ground in ambient and thermal vacuum conditions. The permissible operations and the constraints for the operations in ambient shall be defined.

c. The mechanisms verification test programme shall ensure that the hardware conforms to the design, construction and performance requirements.

d. The test verification shall demonstrate that the mechanism conforms to the torque (or force) ratio requirements specified in subclause 4.7.4.3.

e. Tests shall be performed to check mechanism performance in both launch and operational configurations.

f. Mechanisms shall be considered as structures as far as strength and stiffness tests are concerned, and their design shall be verified against the same requirements as other structural components as defined in subclause 4.7 ECSS-E-30 Part 2A.

g. When relevant, fracture control shall be verified according to subclause 4.7.29 of ECSS-E-30 Part 2A.

h. Hysteresis, backlash and other non-linearities shall be measured in order to characterize the dynamic behaviour of the mechanism.

4.8.3.2 Characterization or development testing

4.8.3.2.1 Model requirements

Developments tests shall be carried out on bread-board models of varying levels of sophistication to test specific aspects or assumptions of a design on which the outcome of the design depends.

4.8.3.2.2 Test

Unless the heritage is clearly demonstrated by test data from previous space applications the following verification tests on development model mechanisms shall be performed at an early stage of the project:

1. functional performance tests in ground ambient environment;
2. vibration tests;
3. tribological lifetime test on life critical components.

4.8.3.3 Qualification testing

4.8.3.3.1 General

a. All mechanisms shall be qualified by test for the application concerned.

b. The qualification tests shall be performed in a representative sequence and in a representative environment, agreed with the customer.

4.8.3.3.2 Structural qualification testing

The mechanisms structure shall be qualified according to the requirements for structural qualification identified in ECSS‐E‐30 Part 2.

4.8.3.3.3 Thermal vacuum qualification testing

a. The thermal qualification of the mechanism shall be performed according to the requirements identified in ECSS‐E‐30 Part 1.

b. Adequate operation in representative environment of the mechanism under worst case temperature gradients shall be demonstrated by test at a level agreed with the customer.

4.8.3.3.4 Functional qualification testing

a. When relevant, micro-setting and thermal stabilization shall be performed prior to functional performance testing.

b. The conformance of the mechanism to the performance requirements following exposure to environmental conditions (loads, thermal) at qualification level and mechanism qualification duration shall be demonstrated by test.

4.8.3.3.5 Energy or shock

a. Adequacy of mechanisms to withstand release and end shocks caused by the motion of the mechanism shall be demonstrated by test.

b. Latching shock emissions shall be measured.

4.8.3.3.6 Solid lubricated ball bearing verification

a. The adequacy of solid lubricated ball bearing material, design and performance (including the cage) shall be demonstrated by testing.

b. The appropriate environment for the lubricant life test demonstration shall be agreed with the customer.

4.8.3.3.7 Liquid lubricated ball bearing verification

a. The adequacy of ball bearing cage material, design, impregnation procedures for cages and reservoirs, and performance shall be demonstrated by testing.

b. The adequacy of the lubricant quantity shall be demonstrated by confidence tests.

c. The compatibility of the liquid lubricant with the mechanism materials and if applicable other lubricants used within the mechanism, shall be demonstrated.

4.8.3.3.8 Lifetime qualification

The adequacy of the mechanism design, lubricant lifetime and performance shall be demonstrated by test on a flight representative life test model in the appropriate environment after exposure to flight representative environmental tests (worst case loads and accumulated vibration durations). Exposure of lifetime model to vibrations prior to life test shall include:

1. One time exposure to qualification load level and duration of vibration;
2. Exposure to accumulated durations of acceptance tests at acceptance load level and accumulated durations corresponding to the number of vibrations tests to be seen by the flight hardware.

The environment in which the lifetime of a lubricant is to be demonstrated shall be agreed with the customer.

4.8.3.3.9 Life test model requirements

The model and lifetime testing shall be valid with respect to the representation of the following lifetime influencing parameters:

1. Thermal conditions, loading conditions, contact stress, motion profile and speed during testing appropriately representative of the operational conditions;
2. Lubrication regime representative of worst cases anticipated operational conditions, and for durations factored as a minimum according to subclause 4.8.3.3.6. Where relevant, extended life durations to be agreed by the customer shall be implemented to satisfy the simulation of realistic conditions during accelerated tests.

4.8.3.3.10 Life test profile

The profile and sequence of a life test shall be justified.

4.8.3.3.11 Life test duration

The lifetime qualification shall be demonstrated using the factored sum of the predicted nominal ground test cycles and the in-orbit operation cycles. For the test demonstration, the number of predicted cycles shall be multiplied by the following factors in Table 3:

Table 3: Life test duration factors

Type	Number of predicted cycles	Factor
Ground testing	Number of on-ground test cycles (minimum 10)	4
In-orbit	1 to 10 cycles	10
	11 to 1000 cycles	4
	1001 to 100000 cycles	2
	> 100000 cycles	1,25

The cycle definition is subject to agreement with the customer and shall consider as a minimum, the number of motions over the same location, motion amplitude and number of reversals. In order to determine the lifetime to be demonstrated by test, an accumulation of cycles multiplied by their individual factors shall be used.

EXAMPLE	Predicted ground test cycles:	15	15 × 4	= 60
	Predicted in-orbit cycles:	100		
	10 cycles (first 10 cycles)		10 × 10	= 100
	90 cycles (remaining 90 cycles)		90 × 4	= 360
	Total life test number			= 520

Any element in a chain of actuation (e.g. motor, bearing, gear) shall conform with the maximum number of cycles applicable to any of the remaining elements in the chain.

4.8.3.3.12 Lifetime testing success criteria

Lifetime testing of critical mechanisms components or assemblies shall be considered successful when the following criteria are demonstrated at the end of the test:

a. No metal to metal contact identified in the interface of solid lubricated contact surfaces;

b. Surface properties of contact surfaces unmodified in its essential performance properties;

c. No detrimental chemical deterioration of liquid lubricants is found;

d. The amount and size of wear products conforms to contamination requirements and overall mechanism performance requirements;

e. Worst case variation or degradation peak torque or force overall throughout life testing is compatible with the required torque (or force) ratio requirements (subclause 4.7.4.3) and deterioration torque or force performance is less than or equal 50%. Other degradation factors shall be agreed, case by case, with the customer.

4.8.3.3.13 Accelarated lifetime testing

If accelerated lifetime testing is employed to verify the lifetime performance of the mechanism, the model used for accelerated lifetime testing shall be representative of the worst case environmental conditions with respect to degradation.

4.8.3.3.14 Post-test inspection

After completion of the life test, the mechanisms shall be disassembled into its tribological components. The status of the components shall be verified with respect to the life test success criteria identified in subclause 4.8.3.3.12.

4.8.3.3.15 EMC or ESD qualification testing

a. EMC tests

The EMC performance (susceptibility and emissivity) of mechanisms shall be verified by testing when components are used on the mechanism which are sensitive to EMC or when spacecraft specific EMC requirements are imposed on the mechanism.

b. ESD tests

Testing shall be performed on a complete mechanism including all electrical components and thermal hardware.

4.8.3.3.16 Electrical qualification testing

a. Electrical wire – insulation test

Electrical wires shall be demonstrated to provide insulation from the structure and from each other by not less than 10 MΩ with a DC voltage of 500 V applied for a duration of 2 minutes or until a steady state resistance value is measured.

b. Electric motors – insulation test

Motor windings shall be demonstrated to provide insulation from the structure and from each other by not less than 100 MΩ with a DC voltage of at least five times the worst case flight operating voltage applied for a duration of 2 minutes or until a steady state resistance value is measured.

c. Electrical wires – dielectric test

Electrical wires shall be demonstrated to withstand a voltage of 500 V AC (50 Hz) applied between each other or between wires and the structure for a duration of 1 minute without causing disruptive discharges (flash-over, spark-over, breakdown).

d. Electric motors – dielectric test

Motor windings shall be demonstrated to withstand a voltage of:

- 250 V AC (worst flight operating motor voltage up to 50 V);
- 500 V AC (worst flight operating motor voltage up to 100 V).

(50 Hz) applied between each other or between windings and the structure for a duration of 1 minute without causing disruptive discharges (flash-over, spark-over, breakdown).

4.8.3.3.17 Control system qualification testing

a. The mathematical model used to analyse the dynamic behaviour of the control system shall be correlated with measurements performed on representative hardware.

b. The verification of control system performance by test shall preferably be demonstrated using independent measurement devices of sufficient bandwidth and resolution. Use of the control system transducer as a reference during the tests shall only be admissible if the transducer has been calibrated previously in a representative environment.

4.8.3.4 Acceptance testing

4.8.3.4.1 Mechanical micro-setting and thermal stabilization

If relevant, mechanical micro-setting and thermal stabilization shall be performed prior to acceptance testing.

4.8.3.4.2 Acceptance tests

New builds of qualified designs shall be acceptance tested to verify that the actual manufactured hardware is free from manufacturing defects. The acceptance level testing shall be carried out at levels which are higher than expected in flight but less than the qualification levels. After acceptance testing, refurbishment should not be required as the test levels experienced should be at a level which is not detrimental to the health of the hardware.

4.8.3.4.3 Dielectric test

Electrical wires shall be demonstrated to withstand a voltage of:

- 250 V AC (worst flight operating motor voltage up to 50 V);
- 500 V AC (worst flight operating motor voltage up to 100 V).

(50 Hz) applied between each other or between windings and the structure for a duration of 10 seconds without causing disruptive discharges (flash-over, spark-over, breakdown).

4.9 Production and manufacturing requirements

4.9.1 Manufacturing process

a. In order to achieve the required levels of safety and reliability, proven and repeatable procedures shall be used to manufacture mechanisms hardware.

b. All processes used in the manufacture of space mechanisms hardware require customer approval and shall be part of the overall product assurance system.

4.9.2 Manufacturing drawings

Manufacturing drawings shall conform to ISO 128.

4.9.3 Marking and labelling

The requirements of subclauses 4.2.2.1, 4.2.2.2 and 4.2.2.4 are applicable.

4.9.4 Assembly

The assembly of mechanisms shall be performed in an appropriate clean environment.

4.10 In-service

a. The design of a mechanism shall not impose operational constraints on the spacecraft.

b. If the above requirement (4.10 a.) cannot be met, all the operational constraints shall be identified, agreed with the customer and documented in the mechanism operational manual.

c. When the in-service operation of a mechanism results in limited oscillatory motion of a ball (rolling element) bearing, the bearing shall be exercised over a complete revolution where possible at regular intervals.

d. An operations (user) manual for the mechanism shall be established, by the supplier of the mechanism.

4.11 Deliverables

a. To demonstrate the viability of the design of a space mechanism, the following technical subjects (Table 4) shall, as a minimum, be included in documents to be provided by the supplier.

b. Where the subject is not specified as part of the content of an existing document requirement definition (DRD), the customer and supplier shall agree the most suitable document or format in which to report the subject.

Table 4: Document requirements for mechanisms

Document title	Controlling DRD reference
AIT plan	ECSS-E-10-02
Assembly fault analysis	ECSS-Q-40-12
Assembly safety analysis	ECSS-Q-40
Calibration data	–
CFL (critical functions list)	–
Critical items list	ECSS-Q-20-04
Configuration item data list	ECSS-M-40
Declared components list	ECSS-Q-60
Design description	ECSS-E-10
Design verification	ECSS-E-10-02
Design load summary	–
Design, development and verification plan	–
Declared materials list	ECSS-Q-70
Declared parts list	ECSS-Q-70
FEM description and condensed FEM model – in a format to be agreed	
FMECA	ECSS-Q-30
Fracture control plan and where necessary analysis	–
Hazard analysis	ECSS-Q-40
Interface control documentation	ECSS-E-10
Manufacturing plan	ECSS-E-10
Manufacturing file or drawings	–
Mechanism end item data package	ECSS-Q-20
Mechanisms user manual	ECSS-E-10
Mechanisms specification	ECSS-E-10
Parts procurement plan	–
Qualification status list	–

Table 4: Document requirements for mechanisms (continued)

Document title	Controlling DRD reference
Resource budget, including pointing alignment budget	–
Structural analysis	–
Test procedures	ECSS-E-10-02
Test prediction analysis	–
Test results and correlation analysis	–

4.12 Use of this Standard to define project requirements

The mechanism requirements in this document may be tailored to suit specific programs subject to the tailoring implementation described in annex A.

Annex A (normative)

Tailoring

A.1 General

This section of the standard for space mechanisms defines the rules, principles, methods, approach and process to be followed in applying tailoring to the requirements for the use in specific space projects.

A.2 Applicability

Tailoring is the process by which the relevant requirements for a particular application are selected from the "complete" set given. The higher level customer or contractor is primarily responsible for tailoring the requirements and passing on a specific subset to the contractor or supplier.

A.3 Objectives

The requirements of the mechanisms engineering standard are generically applicable considering the full range of space mechanism designs for all projects. However, some of these requirements may not be applicable to every type of mechanism or mission. As a result, the total number of requirements identified in this Standard may be reduced for particular projects.

The objective of this section is to provide guidelines to the customer to consciously select the applicable requirements for the particular mission application. As a result of the tailoring process, the requirements shall be classified as mandatory requirements and other requirements of a lesser importance. The latter can enable the use of more cost efficient company proprietary approaches and processes for the benefit of achieving substantial cost savings within the project. The relaxation of the requirements, however, can lead to a related risk increase with respect to the mechanisms function, the overall spacecraft development costs and total mission success.

A.4 How to use the tailoring table

The columns are used to indicate if a requirement is not suitable for tailoring (i.e. mandatory), type applicable, customer related or specified and finally whether waiving the requirements can result in a cost saving but with some associated increase in risk of experiencing anomalies in flight or during development. Anomalies in flight can only be worked around while anomalies discovered in the development of a mechanism have inherent rectification costs.

In each column against each requirement a 'X' has been entered depending on the requirement category. It is reasonable for there to be more than one 'X' against an individual requirement. This most commonly occurs where mandatory requirements are not applicable to all types of mechanism. For example, the mandatory electric motor requirements are obviously not applicable if the mechanism does not include an electric motor.

A.5 No tailoring allowed (mandatory)

Where an 'X' has been placed against a requirement in this column, the requirement shall not be subject to tailoring and the requirement shall be considered mandatory. Most of the requirements are listed as mandatory . However, some are related to specific types of mechanism or design, development or qualification phases. Where this is the case, an 'X' has also been added to the type applicable column.

A.6 Type applicable

The "Type applicable" column has been used to highlight if the requirement is applicable only to a specific type of mechanism. In addition this column has also been used to indicate if the requirement is only applicable during certain phases of the mechanisms development. This identifies for the user (in this case customer or supplier) which mandatory requirements can be tailored out.

A.7 Customer related

Many of the requirements are subject to an agreement between the customer and the supplier which is explicitly stated in the requirement. In some cases, customer involvement is implicit. In both cases, this has been indicated by using the "Customer-related" column. This shall enable the person responsible to identify the requirements in which the level of detail shall be agreed between the customer and supplier.

A.8 Cost reduction and risk increase:

Not all of requirements are mandatory and can with the agreement of the customer be waived. In which case, the supplier and customer should ensure alternative in-house requirements are in place which are known to be satisfactory. The customer shall be made aware of the risk or cost benefit that waiving the requirement entails.

A.9 Tailoring table

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.2 General mechanisms				
4.2.2 Product assurance				
4.2.2.1	X			
4.2.2.2	X			
4.2.2.3	X			
4.2.2.4	X			
4.2.2.5			X	X
4.2.2.6.a			X	X
4.2.2.6.b	X			
4.2.3 Reliability and redundancy				
Reliability				
4.2.3.2.a	X	X	X	
4.2.3.2.b	X		X	
4.2.3.2.c	X			
4.2.3.2.d	X			
Structural reliability				
4.2.3.3.a	X			
4.2.3.3.b	X			
Redundancy				
4.2.3.4.a	X			
4.2.3.4.b			X	X
4.2.3.4.c	X		X	
4.2.3.4.d	X		X	
4.2.3.4.e	X			X
4.2.3.4.f	X			
Flushing or purging				
4.2.4.a	X	X		
4.2.4.b	X			
4.2.4.c	X			
4.3 Mission and environments				
Mission				
4.3.2.b	X			
4.3.2.c	X			
4.3.2.d	X			
4.3.2.e	X			
Environment				
4.3.3	X			
4.4 Functional requirements				

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
System performance				
4.4.2	X			
Mechanism function				
4.4.3.a	X			
4.4.3.b	X			
4.4.3.c	X			
4.5 Constraints				
Physical constraints				
4.5.2.1	X	X		
4.5.2.2	X		X	
Materials				
4.5.3.1	X	X		
4.5.3.2	X		X	
4.5.3.3	X		X	
4.5.3.4	X			
4.5.3.5	X			
4.5.3.6	X			
4.5.3.7	X			
4.5.3.8	X			
4.5.3.9	X	X		
4.5.3.10	X	X		
4.5.3.11	X	X		
Operational constraints				
4.5.4.a	X			
4.5.4.b	X		X	
4.6 Interfaces				
4.6.2	X			
4.6.3	X			
4.6.4	X			
4.6.5	X			
4.6.6	X			
4.6.7	X			X
4.6.8	X			
4.7 Design requirements				
Tribology				
Tribology requirements				
4.7.2.1.b	X	X		
4.7.2.1.c	X	X		
4.7.2.1.d	X	X		
4.7.2.1.e	X	X		

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.7.2.1.f	X			
4.7.2.1.g	X			
Dry lubrication				
4.7.2.2.a	X	X		
4.7.2.2.b	X	X		
4.7.2.2.c	X	X		
4.7.2.2.d	X	X		
Fluid lubrication				
4.7.2.3.a	X	X		
4.7.2.3.b	X	X		
4.7.2.3.c	X	X		
4.7.2.3.d	X	X		
4.7.2.3.e	X	X		
4.7.2.3.f	X	X		
4.7.2.4 Tribological components requirements				
4.7.2.4.1.a		X		
4.7.2.4.1.b	X	X	X	
4.7.2.4.1.c	X	X		
4.7.2.4.2.a	X			
4.7.2.4.2.b	X	X		
4.7.2.4.2.c	X	X		
4.7.2.4.2.d	X	X		
4.7.2.4.2.e	X	X		
4.7.2.4.2.f	X	X		
4.7.2.4.3	X	X		
4.7.3 Thermal control requirements				
Thermal engineering				
4.7.3.2.a	X	X		
4.7.3.2.b	X	X		
4.7.3.2.c	X	X		
Mechanisms thermal design and sizing requirements				
4.7.3.3.a	X			
4.7.3.3.b	X			
4.7.3.3.c	X			
4.7.3.3.d	X			
Multi-layer insulation requirements				
4.7.3.4.a	X	X		
4.7.3.4.b	X	X	X	
4.7.3.4.c	X	X		
-				

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.7.4 Mechanical design and sizing				
General				
4.7.4.1	X			
Structural dimensioning				
4.7.4.2.1	X			
4.7.4.2.2	X			
4.7.4.2.3	X			
4.7.4.2.4	X			
4.7.4.2.5	X			
4.7.4.2.6	X			
4.7.4.2.7	X			
4.7.4.2.8	X			
4.7.4.2.8.a	X			
4.7.4.2.8.b	X	X	X	
4.7.4.2.8.c	X	X		
Functional dimensioning (motorization)				
4.7.4.3.1	X			
4.7.4.3.2	X			
4.7.4.3.3	X			
4.7.4.3.4.a	X			
4.7.4.3.4.b	X			
4.7.4.3.4.c	X			
4.7.4.3.4.d	X			
4.7.4.3.4.e	X			
4.7.4.3.4.f	X	X		
4.7.4.3.4.g		X	X	
4.7.4.3.4.h	X			
4.7.4.3.5.a	X	X		
4.7.4.3.5.b	X	X		
4.7.4.3.5.c	X	X		
4.7.4.3.5.d	X	X		
4.7.4.3.5.e	X	X		
4.7.4.3.5.f		X		
4.7.4.3.5.g	X	X		
4.7.4.3.6.a	X	X		
4.7.4.3.6.b	X	X		
4.7.4.3.6.c	X	X		
4.7.4.3.6.d	X	X		
Other requirements				
4.7.4.4.1.a	X	X		

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.7.4.4.1.b	X	X		
4.7.4.4.1.c	X	X	X	
4.7.4.4.2	X			
4.7.4.4.3.a	X	X		
4.7.4.4.3.b	X	X		
4.7.4.4.3.c		X	X	
4.7.4.4.3.d	X	X		
4.7.4.4.3.e	X	X		
4.7.4.4.3.f	X	X		
4.7.4.4.3.g	X	X		
4.7.4.4.3.h	X	X		
4.7.4.4.4.a	X	X		
4.7.4.4.4.b	X	X		
4.7.4.4.4.c	X	X		
4.7.4.4.4.d	X	X		
4.7.4.4.4.e	X	X		
4.7.4.4.5.a	X	X		
4.7.4.4.5.b	X	X		
4.7.4.4.5.c	X	X		
4.7.4.4.5.d	X	X		
4.7.4.4.5.e	X	X		
4.7.4.4.6	X	X		
4.7.4.4.7	X	X		
4.7.4.4.8	X			
4.7.4.4.10.a	X			
4.7.4.4.10.b	X			
4.7.4.4.10.c	X			
4.7.4.4.10.e	X			
4.7.4.4.11.a	X	X		
4.7.4.4.11.b	X	X		
4.7.4.4.11.c	X	X		
4.7.4.4.12.a	X	X		
4.7.4.4.12.b	X	X		
4.7.4.4.12.c	X	X		
4.7.4.4.12.d	X	X		
4.7.5 Pyrotechnics				
4.7.5	X	X		
4.7.6 Electrical and electronic requirements				
General				
4.7.6.1	X	X		

Subclause	**No tailoring allowed (mandatory)**	**Type applicable**	**Customer related**	**Cost reduction and risk increase**
Electrical design				
4.7.6.2.a	X	X		
4.7.6.2.b	X	X		
4.7.6.2.c	X	X		
Insulation				
4.7.6.3.a	X			
4.7.6.3.b	X	X		
Dielectric				
4.7.6.4.a	X	X		
4.7.6.4.b	X	X		
Grounding				
4.7.6.5.a	X			
4.7.6.5.b	X	X		
4.7.6.5.c	X	X		
4.7.6.5.d	X	X		
4.7.6.5.e	X	X		
4.7.6.5.f	X			
Electrical connectors				
4.7.6.6.a	X		X	
4.7.6.6.b	X	X		
4.7.6.6.c	X	X	X	
4.7.6.6.d	X	X		
Over current protection				
4.7.6.7.a	X	X	X	X
4.7.6.7.b	X	X	X	
Strain on wire				
4.7.6.8	X			X
Magnetic cleanliness and ESD or EMC protection				
4.7.6.9	X	X		
4.7.7 Control system				
4.7.7.2	X	X	X	
4.7.7.3	X	X	X	
4.7.7.4	X	X		
4.7.7.5	X	X		
4.7.7.6	X	X	X	
4.7.7.7	X	X		
4.7.7.8	X	X		
4.7.7.9	X	X		
4.7.7.10	X	X		
4.7.7.11	X	X		

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.7.7.12	X	X		
4.7.7.13	X	X		
4.8 Verification				
General				
4.8.1	X			
Verification by analysis				
4.8.2.1.a	X			
4.8.2.1.b	X			
4.8.2.1.c	X			
Worst cases identification				
4.8.2.2	X			
Thermal analysis				
4.8.2.3	X			
Structural analysis				
4.8.2.4	X			
Pre-load and tolerance budget analysis				
4.8.2.5	X	X		
Functional performance analysis				
4.8.2.6.a.1	X	X	X	X
4.8.2.6.a.2	X	X	X	X
4.8.2.6.a.3	X	X	X	X
4.8.2.6.b.1	X			
4.8.2.6.b.2	X	X	X	
4.8.2.6.b.3	X	X	X	
4.8.2.6.b.4	X	X	X	
4.8.2.6.b.5	X	X	X	
Hertzian contact analysis				
4.8.2.7.a	X	X		
4.8.2.7.b	X	X		
Torque or force ratio analysis				
4.8.2.8	X			
Reliability analysis FMECA				
4.8.2.9	X		X	
Gear analysis				
4.8.2.10	X	X		
Shock generation and susceptibility				
4.8.2.11	X	X	X	
Disturbance generation (emission) and susceptibility				
4.8.2.12.a	X	X		
4.8.2.12.b	X			

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
Analysis of control systems				
4.8.2.13.a	X	X		
4.8.2.13.b	X	X		
4.8.2.13.c	X	X		
4.8.2.13.d	X	X		
4.8.2.13.e	X	X		
Lubrication analysis				
4.8.2.14.a	X			
4.8.2.14.b	X		X	X
Life time analysis				
4.8.2.15.a	X			
4.8.2.15.b	X	X		
Magnetic and electromagnetic				
4.8.2.16	X	X		
Radiation analysis				
4.8.2.17	X	X		
Electrical analysis				
4.8.2.18	X	X		
4.8.3 Verification by test				
General				
4.8.3.1.b	X			
4.8.3.1.c	X			
4.8.3.1.d	X			
4.8.3.1.e	X			
4.8.3.1.f	X			
4.8.3.1.g	X	X	X	
4.8.3.1.h	X	X		X
Characterization or development testing				
4.8.3.2.1	X	X	X	X
4.8.3.2.2	X	X		X
Qualification testing				
General				
4.8.3.3.1.a	X			
4.8.3.3.1.b	X		X	
Structural qualification testing				
4.8.3.3.2	X			
Thermal vacuum qualification testing				
4.8.3.3.3.a	X			
4.8.3.3.3.b	X		X	
Functional qualification testing				

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.8.3.3.4.a	X	X		
4.8.3.3.4.b	X			
Energy or shock				
4.8.3.3.5.a	X			
4.8.3.3.5.b	X	X	X	
Solid lubricated ball bearing verification				
4.8.3.3.6.a	X		X	X
4.8.3.3.6.b	X	X		
Liquid lubricated ball bearing verification				
4.8.3.3.7.a	X	X		
4.8.3.3.7.b	X	X		
4.8.3.3.7.c	X	X		
Lifetime qualification				
4.8.3.3.8	X		X	
Life test model				
4.8.3.3.9	X		X	
4.8.3.3.10	X			
4.8.3.3.11	X			
4.8.3.3.12	X		X	
4.8.3.3.13	X	X		
4.8.3.3.14	X			X
EMC or ESD qualification testing				
4.8.3.3.15.a	X	X		
4.8.3.3.15.b	X	X		
Electrical qualification testing				
4.8.3.3.16.a	X	X		
4.8.3.3.16.b	X	X		
4.8.3.3.16.c	X	X		
4.8.3.3.16.d	X	X		
Control system qualification testing				
4.8.3.3.17.a	X	X		
4.8.3.3.17.b	X	X		
Acceptance testing				
4.8.3.4.1	X	X		
4.8.3.4.2	X			
4.8.3.4.3	X	X		
4.9 Production and manufacturing requirements				
4.9.1.a	X			
4.9.1.b				
4.9.1.c	X		X	X

Subclause	No tailoring allowed (mandatory)	Type applicable	Customer related	Cost reduction and risk increase
4.9.2	X		X	X
4.9.3	X			
4.9.4	X			
4.10 In service				
4.10.a	X		X	
4.10.b	X	X	X	
4.10.c	X	X	X	
4.10.d	X			

Annex B (informative)

Summary of normative documents contents

B.1 ISO 6336 Calculation of the load capacity of spur and helical gears

ISO 6336 provide the principles for a coherent system of procedures for the calculation of the cylindrical involute gears with external and internal teeth. It addresses the gear principles and general influence factors and demonstrates how to calculate the surface durability and tooth strength and hence leads to a correctly sized design.

B.2 ISO 677, 678 Calculation of the load capacity of straight cut bevel gears

The information in these standards aids the engineer with the design of straight cut bevel gears and allows the correct information to be given to the manufacturer in order to obtain the required gear.

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Annex C (informative)

Model definition

C.1 Bread board model

Bread board models are used to demonstrate key aspects of a design are feasible and understood. They should be manufactured during the early stages of a project such that maximum benefit can be derived. They need not be flight representative in respect of the materials used but are functionally representative of the key aspects to be proven.

C.2 Engineering (development) model

The engineering model is representative of the intended flight design in all functional aspects and materials. Some relaxation in the level of redundancy implemented or the quality of the electronic components is permissible. Tests on this model give confidence that the qualification programme using the QM is ready to proceed.

C.3 Qualification models (QM)

The intention of the qualification model is that it should be identical to the proposed flight design and be subjected to testing at levels in excess of those that the flight unit will experience. In this manner any incipient flaws in the design or any aspects of the design for which there is insufficient margin should be identified. A unit which has been subjected to qualification testing is not fit for flight.

C.4 Life test model

The purpose of the life test model is to prove by testing that the mechanism can perform the required quantity of cycles under extreme conditions, taking into account the applicable margins. For development schedule or development risk reduction, this model can be a specific model.

C.5 Flight models

The flight model is the realized design delivered for flight. The flight model is subjected to acceptance testing to demonstrate the actual build performs as required and is free from manufacturing defects.

C.6 Protoflight model

As yet there is no accepted or satisfactory route by which a mechanism can be tested to reach a qualified status and be accepted for flight. The duration or levels of vibration seen during qualification by a purpose built qualification model are required to exceed the duration or levels that the flight unit will accumulate during acceptance testing and flight. Clearly this is not possible with a protoflight unit. Each protoflight approach shall be justified on a case by case basis.

Bibliography

Informative references to the extent specified in the text are cited at appropriate places and listed hereafter. They contain non-mandatory mechanisms design practices and validation information, however, which is strongly recommended for use in order to achieve anomaly-free operation of space mechanisms. Summary information on the listed documents is attached as Annex C.

ECSS-Q-20-07 [1)]	Space product assurance — Quality assurance of test facilities
ECSS-Q-30-06 [1)]	Space product assurance — Derating
ECSS-Q-70-04	Space product assurance — Thermal cycling test for the screening of space materials and processes
ECSS-Q-70-36	Space product assurance — Material selection for controlling stress-corrosion cracking
ECSS-Q-70-37	Space product assurance — Determination of susceptibility of metals to stress-corrosion cracking
ECSS-Q-70-46 [1)]	Space product assurance — General requirements for threaded fasteners
ECSS-Q-70-71 [1)]	Space product assurance — Data for the selection of space materials
ECSS-E-30-01	Space engineering — Fracture control
ECSS-E-30-09 [1)]	Space engineering — Space tribology handbook
MIL-HDBK-5F	Military handbook, metallic materials and elements for aerospace vehicle structures
MIL-A-83577B(USAF)	Assemblies, moving mechanical, for space and launch vehicles, general specification for.
MSFC-STD-1299	Design criteria for flight experiment latches

1) To be published.

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ECSS Document Improvement Proposal

1. Document I.D.	**2. Document date**	**3. Document title**
ECSS-E-30 Part 3A	25 April 2000	Mechanical — Part 3: Mechanisms
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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