Space engineering

Mechanisms – Training Course Level 2

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ECSS-E-ST-33-01C

1. Scope

Specifies the requirements applicable to the

- concept definition
- development
- design
- production
- verification
- in-orbit operation

of space mechanisms on spacecraft and payloads in order to ***meet the mission performance requirements***.

1. Scope

Remark:

New issue of ECSS-E-ST-33-01 coming!

Current issue 01C:
Does not cover requirements for

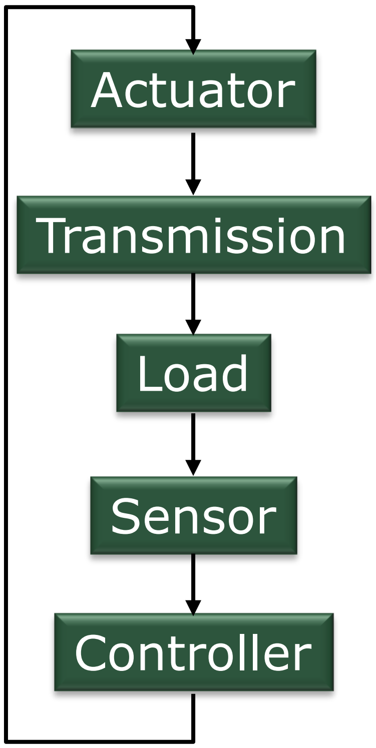
- mechanisms on launchers,
- safety critical mechanisms,
- Planetary exploration missions.

2. Normative References

Standard	Title
ECSS-E-ST-10-02	Space engineering – Verification
ECSS-E-ST-20C	Electrical and electronic
ECSS-E-ST-32	Space engineering – Structural
ECSS-E-ST-32-10	Space engineering – Structural factors of safety for spaceflight hardware
ECSS-Q-ST-70	Space product assurance – material, mechanical part and process
ISO 76, Edition 2, Amendment 1	Rolling bearings – Static load rating

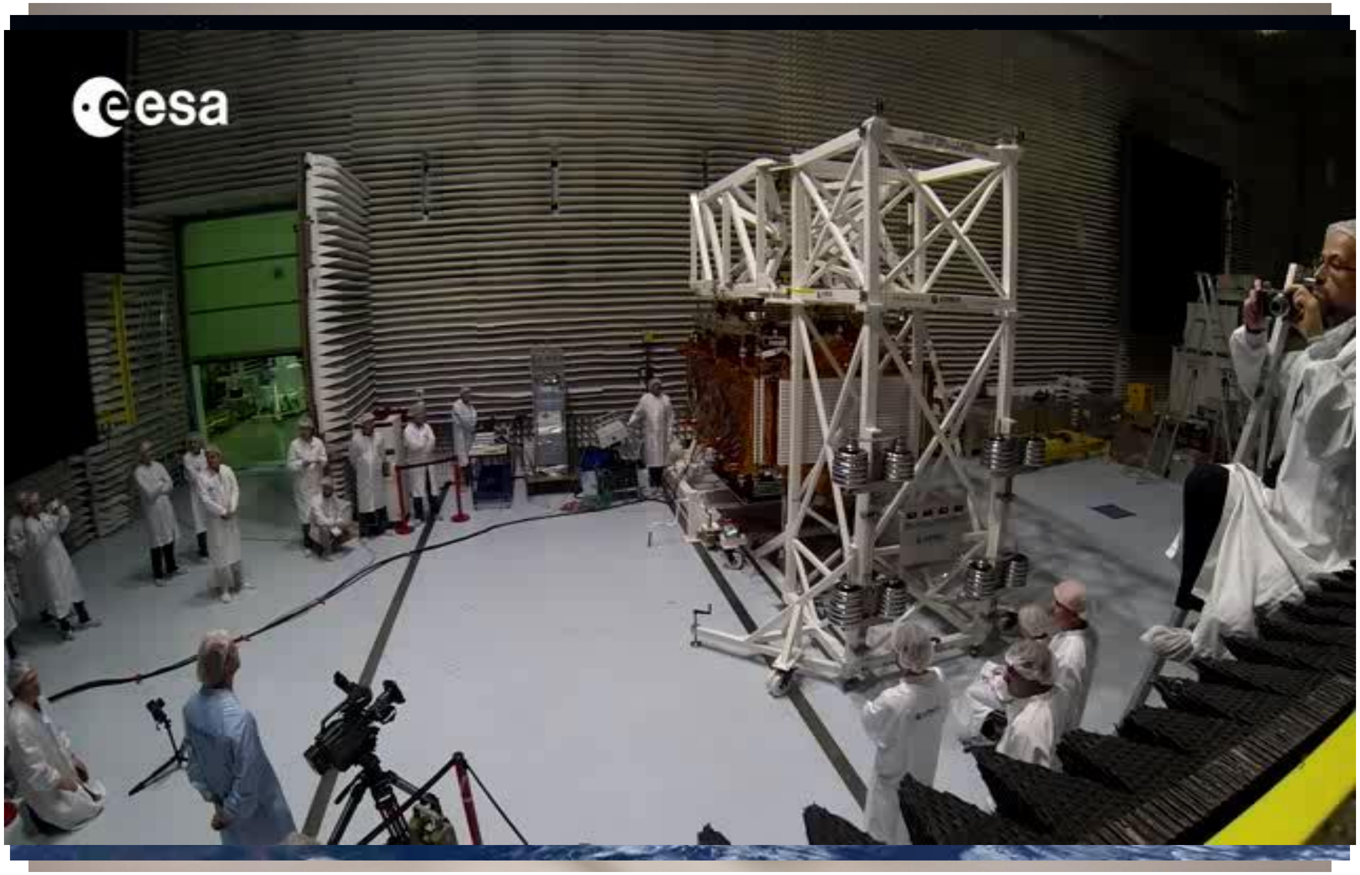
Mechanism

Assembly of components that are linked together to ***enable a relative motion***.



3.2 Terms & Definition

Mechanism



3.2 Terms & Definition

actuator

component that performs the moving function of a mechanism

component

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

lubrication

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

tribology

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

4. Requirements

1. Overview
2. General requirements
3. Mission and environments
4. Functional
5. Constraints
6. Interfaces
7. **Design requirements**
8. **Verification**
9. Production and manufacturing
10. Deliverables

2. Mission Specific Requirements

A dedicated **specific mechanism specification (SMS)** shall be established in conformance with Annex A for each individual mechanism in a project, and agreed by the customer.

4.2. General Requirements

3. Units

All units to be used: **SI**

4.1.2 Marking and Labelling

- All delivered items shall be identified (***labelled***)

- Marking shall not be done on functional or otherwise ***sensitive surfaces***

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

4.2. General Requirements

4.2. Parts and Components

a. Existing parts and components used in mechanisms should have been ***previously qualified***

- for the intended application
- at part or component level.

b. ***Flight proven*** parts and components should be used.

ECSS-Q-ST-60: EEE Parts

ECSS-Q-ST-70: Parts & Materials

4.2. General Requirements

4.2. General Requirements

4.4. Maintainability

a. […] **maintenance free** during storage and ground life.

4.2. General Requirements

4.4. Maintainability

b. […] the maintenance requirements shall be ***documented*** in the SMS.

c. Maintenance ***procedures*** shall be provided.

5.1. Reliability

4.2. General Requirements

a. […] conformance to the specified ***reliability figure*** shall be demonstrated:

1. electronic components: e.g. ***parts count***

   → **ECSS-Q-ST-30C Dependability**

2. mechanical parts: e.g. ***stress analysis***

   → **ECSS-E-ST-32 Structural Design**

3. mechanical limited life by ***life test***.

5.2. Redundancy

a. […] ***Single point failure modes*** shall be identified.

b. Single points of failure eliminated by ***redundant components***.

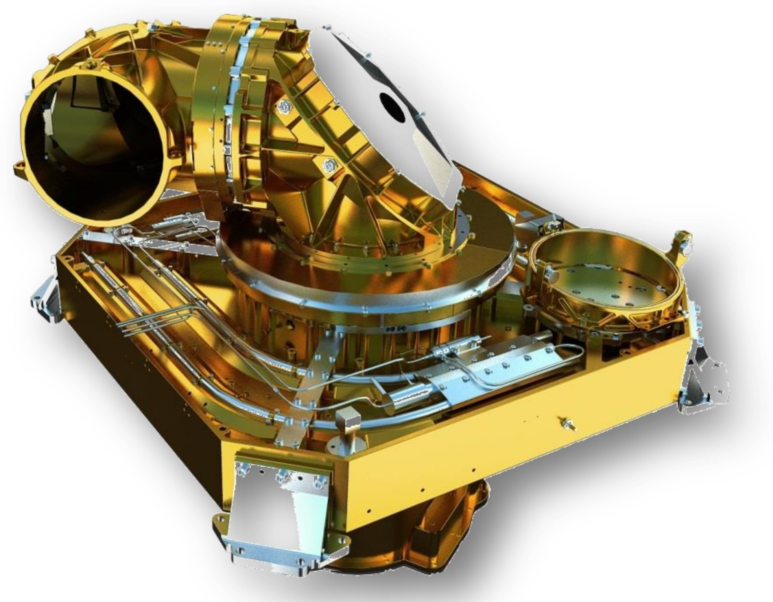
d. Unless redundancy is achieved by the provision of a complete redundant mechanism, ***active elements*** of mechanisms shall be redundant, such as sensors, motor windings, brushes, actuators, switches and electronics.

4.2. General Requirements

6. Flushing and Purging

a. […] ***means for flushing the critical parts*** with an inert clean dry gas shall be provided.

b. Only lubricants qualified in respect to the ***residual humidity*** of the dry gas shall be used.



4.3 Mission Environment

The mechanism engineering shall consider ***<u>every mission phase</u>*** identified for the specific space programme and conform to the related mission requirements and environmental constraints.

4.4 Functional

1. System Performance

   a. […] shall conform to the **system performance requirements**.

2. Mechanism function

   b. Mechanical interface, position accuracy or velocity **tolerances** shall be specified and verified that they conform to the functional needs.

   c. The **envelope of movement** for each moving part shall be defined.

   d. […] no **mechanical interference** with any other part of the mechanism, spacecraft, payload or launcher.

2. Materials

For

- Material selection
- Corrosion
- Dissimilar metals
- Stress corrosion cracking
- Fungus protection
- Flammable, toxic and unstable materials
- Induced emissions (stray light protection)
- Radiation
- Atomic oxygen
- Fluid compatibility

→ **ECSS-Q-ST-70 – Materials**

4.5 Constraints

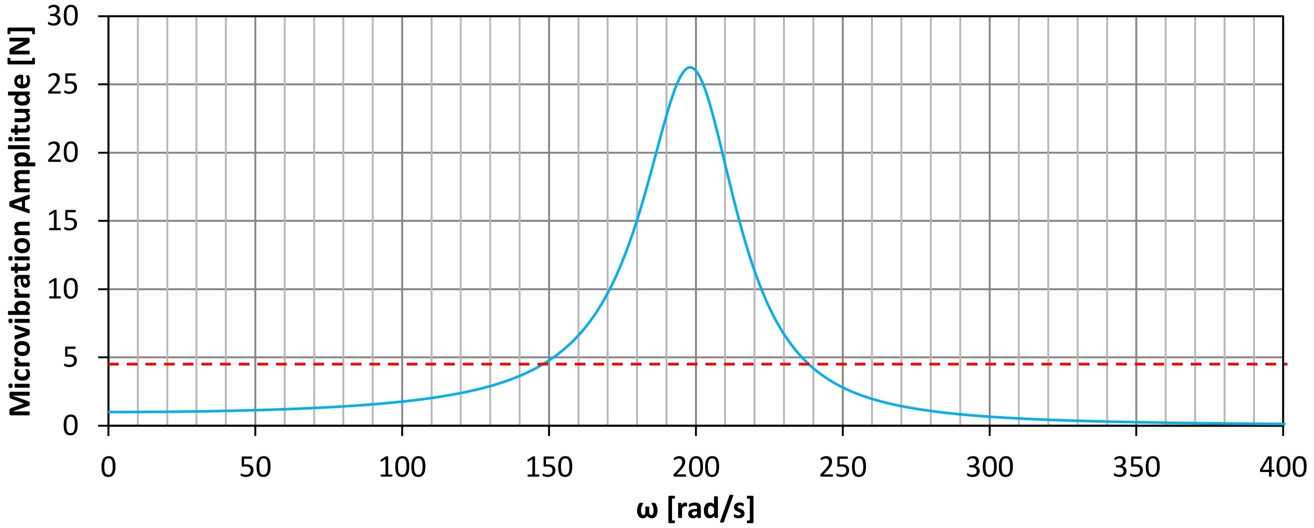
4.5 Constraints

3. Operational

a. [...] should not impose any **operational constraints** on the spacecraft and mission.

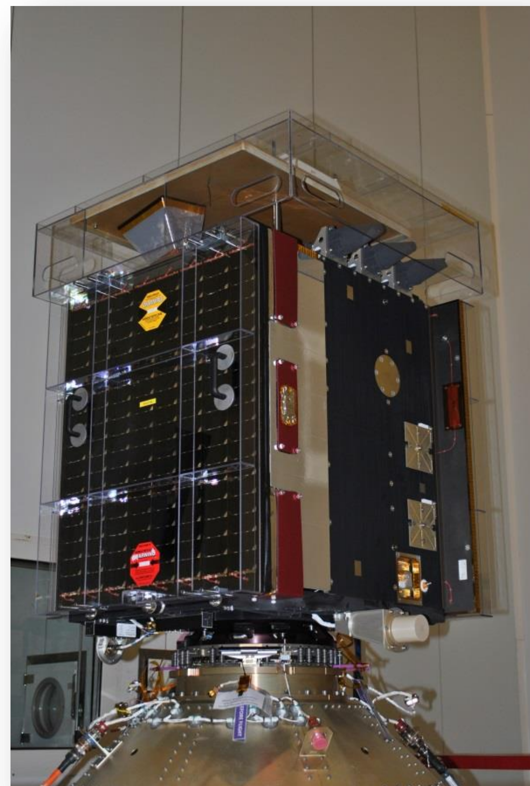
b. [...] operational constraints [...] shall be identified, justified and **approved by the customer**.

c. [...] shall be documented in the mechanism **user manual**.



2. Thermo-mechanical interfaces

a. […] designed to take into account the **stresses induced** by the structure between the mechanism and its I/F attachment points.



4.6 Interfaces

4.7. Design

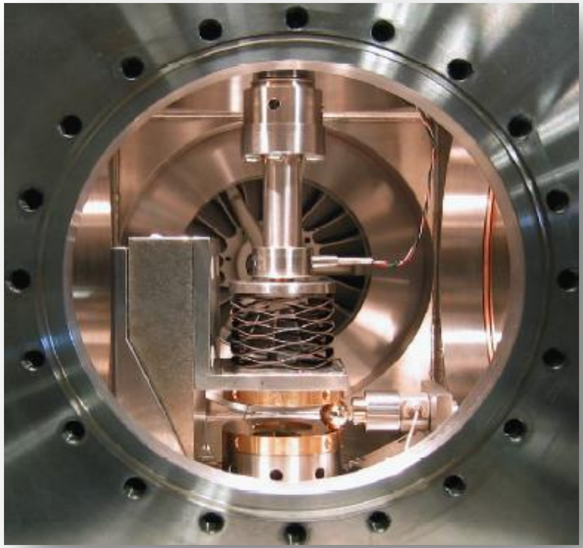
2. General

a. The design of mechanism shall be compatible with operation on ground **<u>in ambient and thermal vacuum</u>** conditions.

4.7. Design

3. Tribology

1. General



[1]

Mechanisms shall

a. be designed with a ***lubrication function*** between surfaces

→ Wear

→ Lifetime

b. use only lubricants ***qualified for the mission*** (e.g. environment, lifetime, contact pressure, temperature, number of cycles)

→ **ECSS-E-ST-10-04 Space Environment**

c. Lubricant shall be **verified** for entire mechanisms life.

3. Tribology

1. General

d. ***Sliding*** surfaces shall be avoided.

e. If sliding surfaces are used 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).

4.7. Design

4.7. Design

3. Tribology

1. General

f. Metal to metal tribological contacts should be composed of **dissimilar materials**

g. Metal to metal tribological sliding contacts shall be composed of **dissimilar materials**

h. Prior to the application of lubricant, **clean surfaces**

i. Cleaning shall **not degrade** the lubricating action.

j. The lubricant shall conform to the **contamination** requirements.

3.2 Dry Lubrication

4.7. Design

a. During the lubrication of mechanism tribological surfaces, samples of representative material, surface roughness, surface cleanliness and surface orientation shall be **co-deposited in each process** with the flight components so that verification checks can be performed.

b. The **thickness and adhesion** of the lubricant on samples shall be verified.

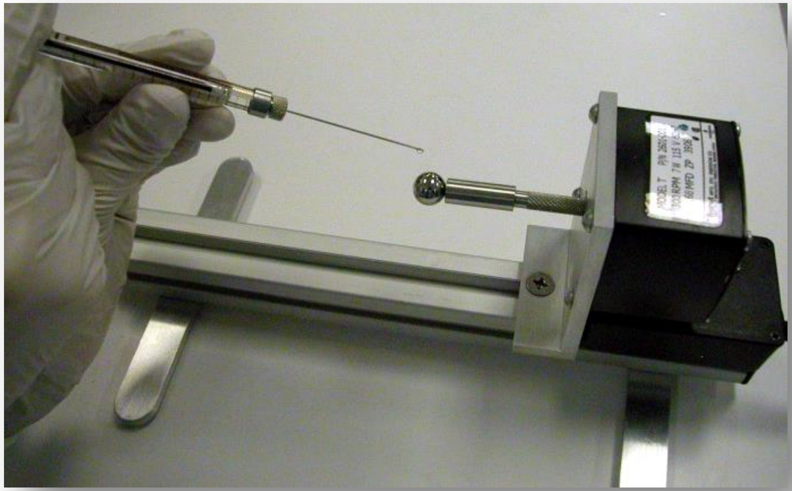
c. The dry lubricant application process shall be verified with respect to lubricant **performance and repeatability**.

3.3.1 Amount of Fluid Lubrication

a. The quantity of lubricant used shall be **<u>determined</u>**.

b. The quantity of lubricant shall take into account **<u>outgassing, creep</u>** and other sources of absorption or degradation.

c. The effect of exposure to on-ground storage and related **<u>gravity effects</u>**, and other ground or in-orbit accelerations on lubricant distribution shall be validated.



[2]

4.7. Design

3.2 Outgassing

a. The outgassing rate of fluid lubricants shall be ***measured*** […]

b. Limits of ***acceptance*** for material outgassing:

Application	TML [%]	RML [%]	CVCM [%]
General	< 1	n.a.	<0.1
Optical devices	n.a.	<0.1	<0.01

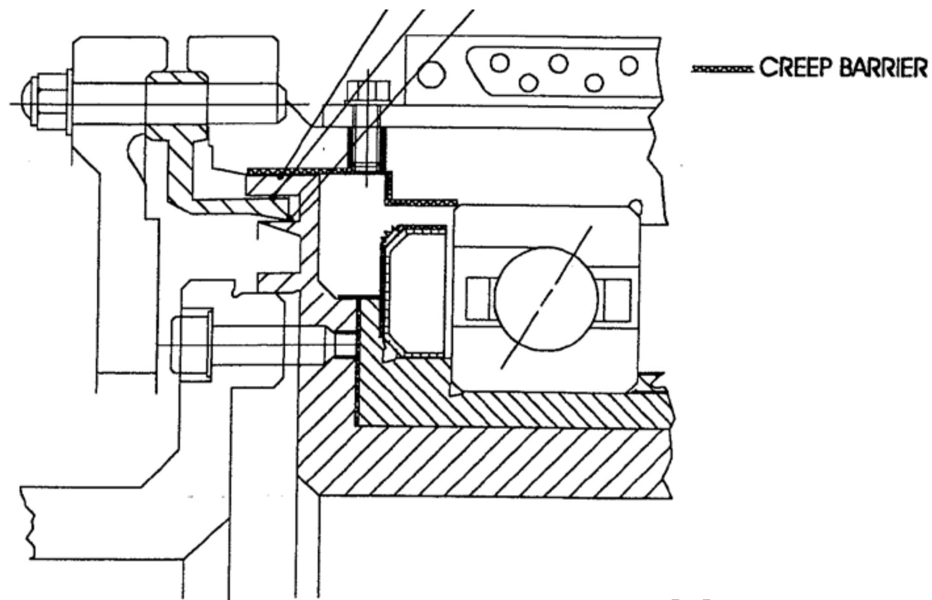
→ **ECSS-Q-ST-70-02C**

3.3 Anti-Creep Barriers

a. […] avoid migration of fluid lubricants to the internal/external **sensitive equipment**

b. […] causes a **change of the lubricant amount** on the parts to be lubricated […]

c. The integrity of the anti-creep barrier shall be verifiable by **indicators**.

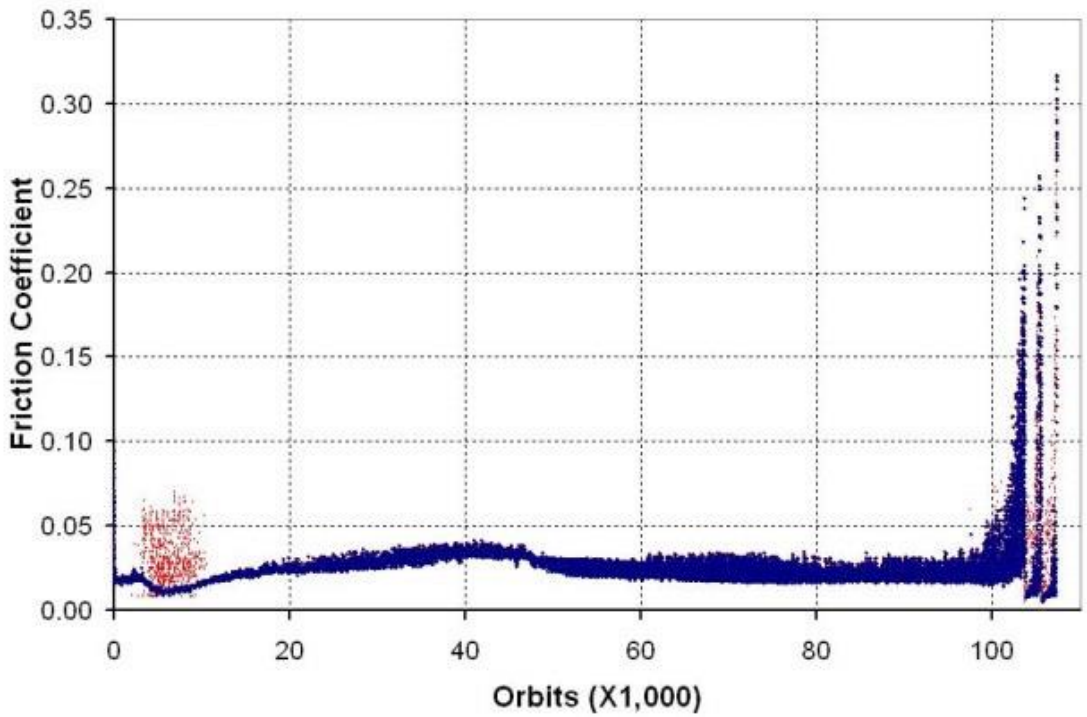


[2]

4.7. Design

3.4.1 Life

The life of tribological components **shall be verified** under worst case ground and flight conditions.



[2]

4.7. Design

3.4.2 Bearing Preload (1/2)

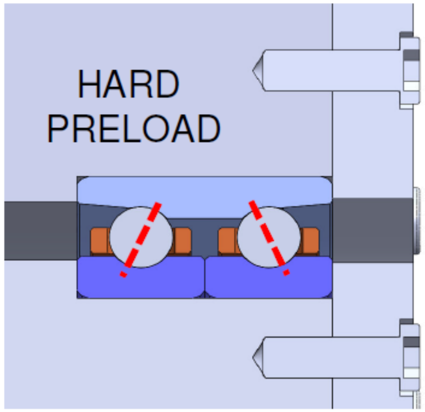
4.7 Design

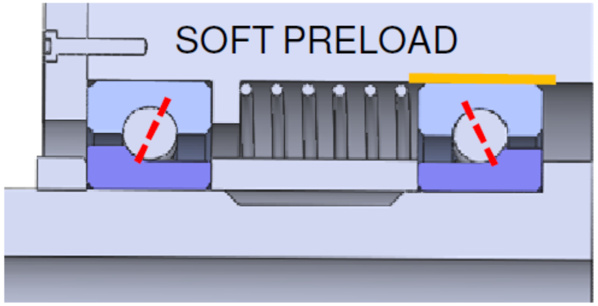
a. Ball bearings shall be **pre-loaded**.

b. The calculation shall be **documented**.

c. Pre-loading should be applied by **solid** pre-load or **flexible** pre-load (no sliding at the bearing mounting interfaces.

d. If pre-loading is not applied by (c) , sliding shall be facilitated by a **lubricated sliding** sleeve, bush or dedicated tribological coating.





[2]

3.4.2 Bearing Preload (2/2)

a. Avoid bearing **gapping** by appropriate bearing pre-load

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

c. Bearing preload should be measured **after final mechanism assembly**, or

d. Assessed in any appropriate way

e. Perform **run – in** tests.

[3]

4.7 Design

4.7 Design

3.4.3 Mechanical Cables

Mechanical cables under friction used on moving parts or assemblies shall be **lubricated**.

4.1 Thermal Engineering

The mechanism engineering shall conform to the **thermal engineering requirements** specified by the customer.

→ **ECSS-E-ST-31 Thermal Control**

4.2 Mechanisms thermal design and sizing

4.7 Design

a. The thermal design of the mechanism shall ensure that all components are maintained within their **qualification temperature** range

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

c. Minimum temperature margins :

1. **Acceptance**: 5 K above specification
2. **Qualification**: 10 K above specification

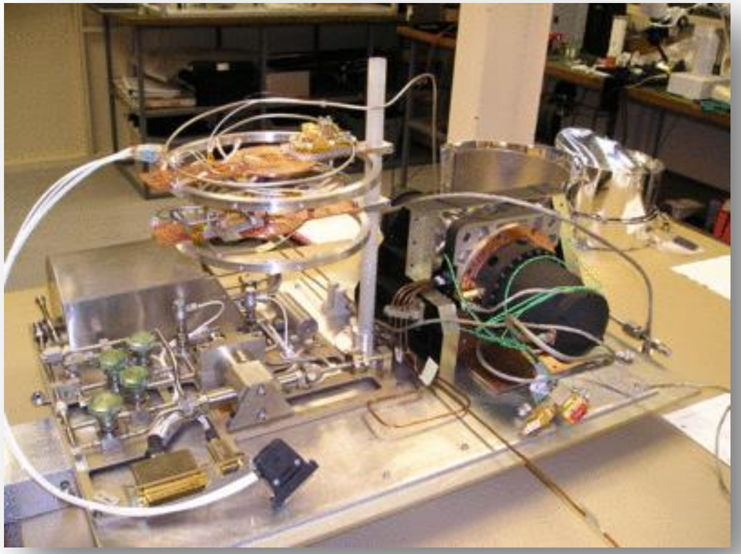
4.7 Design

4.2 Mechanisms thermal design and sizing

d. Thermal control shall **be passive**

e. The mechanism design shall take into account the worst-case combinations (including uncertainties) of:

1. **extremes** (op & non-op)
2. **transient** temperatures,
3. mechanism **heat dissipation**, and
4. the **temperature gradients** across the mechanism.



4.3 Multi-layer insulation (MLI)

a. Supported at **discrete positions** at the distance of not more than 100 mm

b. Clearances with **margins** maintained throughout the mission.

c. **Dynamic envelopes** of the MLI during vibration exposure and venting or purging or in orbit environment taken into account.

4.7 Design

5. Mechanical Sizing and Dimensioning
5.2 Structural Dimensioning

f. The margin of safety (MOS) shall be the smallest of the following values:

$$MOS = \frac{allowable\ stress\ limit}{actual\ stress\ \cdot FOS} - 1 > 0$$

$$MOS = \frac{allowable\ load\ limit}{actual\ load\ \cdot FOS} - 1 > 0$$

→ ECSS-E-ST-32 Structures

5.3 Functional Dimensioning (Motorization)

1. a. Actuators shall be sized to provide […] ***torques*** / ***forces*** in conformance with:

$$T_{min} = 2 \cdot (1.1 \cdot I + 1.2 \cdot S + 1.5 \cdot H_M + 3 \cdot F_R + 3 \cdot H_Y + 3 \cdot H_A + 3 \cdot H_D) + 1.25 \cdot T_D + T_L$$

$$F_{min} = 2 \cdot (1.1 \cdot I + 1.2 \cdot S + 1.5 \cdot H_M + 3 \cdot F_R + 3 \cdot H_Y + 3 \cdot H_A + 3 \cdot H_D) + 1.25 \cdot F_D + F_L$$

4.7 Design

$$T_{min} \geq 2 \cdot \sum_i k_i \cdot T_{loss,i} + T_L + 1.25 \cdot T_D$$

- throughout the operational lifetime
- over the full range of travel
- worst case environmental and operational conditions

5.3 Functional Dimensioning (Motorization)

4.7 Design

ECSS Uncertainty factors:

Component of resistance	Symbol	Theoretical Factor	Measured Factor
Inertia	I	1,1	1,1
Spring	S	1,2	1,2
Motor mag. losses	H_M	1,5	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	3

c. […] measurement according to a test procedure **approved by the customer** […]

4.7 Design

Exercise: Determination of the motorization margin of a Reaction Wheel

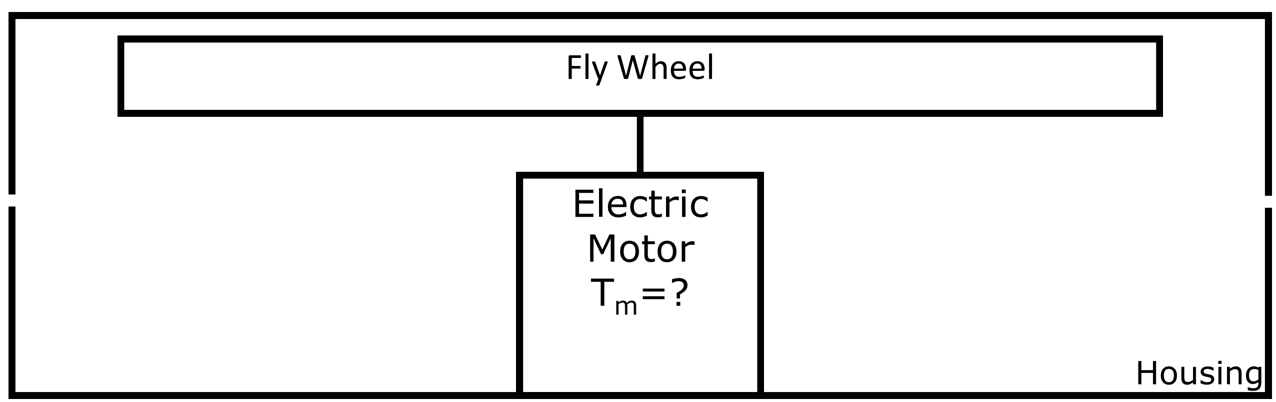
$T_{reaction}$ = 0.10 Nm

$T_{friction}$ = 0.01 Nm

$T_{magnetic}$ = 0.01 Nm

$T_{Windage}$ = 0.02 Nm

$$T_m = 2 \cdot \left(3 \cdot T_{friction} + 1.5 \cdot T_{magnetic} + 3 \cdot T_{windage}\right) + T_{output} = 0.31Nm$$



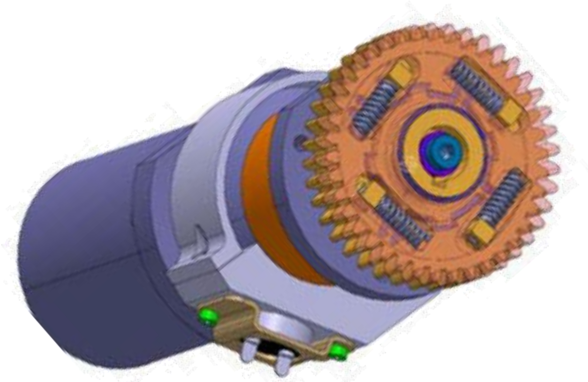
4.3.2 Actuation Torque / Force Dimensioning

4.7 Design

e. […] the actuation torque supplied by the spring shall be […] multiplied by the maximum uncertainty ***factor of 0.8***

…***factor of 0.5***

f. […] spring actuators shall be redundant […]



[4]

4.7 Design

4. Other Mechanical Design and Sizing Requirements

4.1. Replaceable Elements

a. […] they shall be designed to ensure they can only be **<u>installed in the correct orientation</u>** and position

4.2 Status Monitoring

a. […] mechanisms shall include means to **<u>monitor the execution</u>**

5.4.3 Latching or Locking

a. […] designed to avoid inadvertent opening by **vibration or shock**

b. […] **indication** of whether the latch or lock is open or closed

g. Latches shall be **resettable** […]

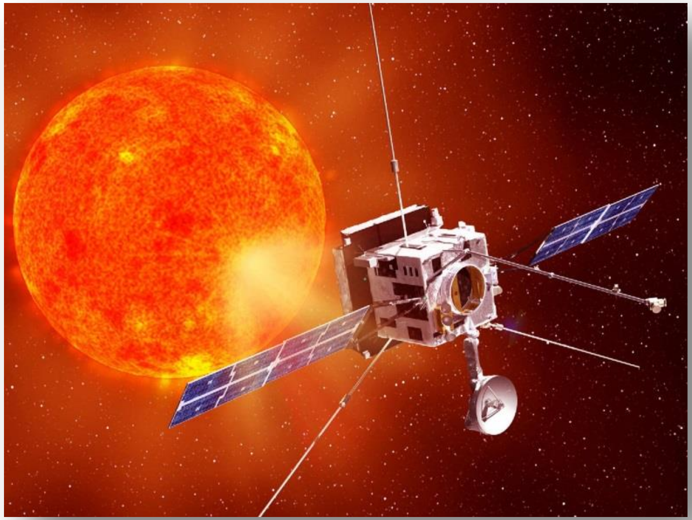
4.7 Design

5.4.4 End Stops

a. Mechanisms with **restricted travel or rotation** shall be provided with regular or emergency mechanical end stops to limit their motion and travel extremes to the maximum position.

f. […] take into account the ***worst case loads***, including shock

h. […] **deployment indicators** shall not be used as mechanical end stops



4.7 Design

4.7 Design

5.4.5 Separable Surfaces

(other than gears, balls and journal bearings)

a. […] maintain **adhesion forces** below the specified limits

b. The contact between the mating surfaces shall **be characterized**
   - i.e. surfaces roughness, hardness, material properties, and contact geometry

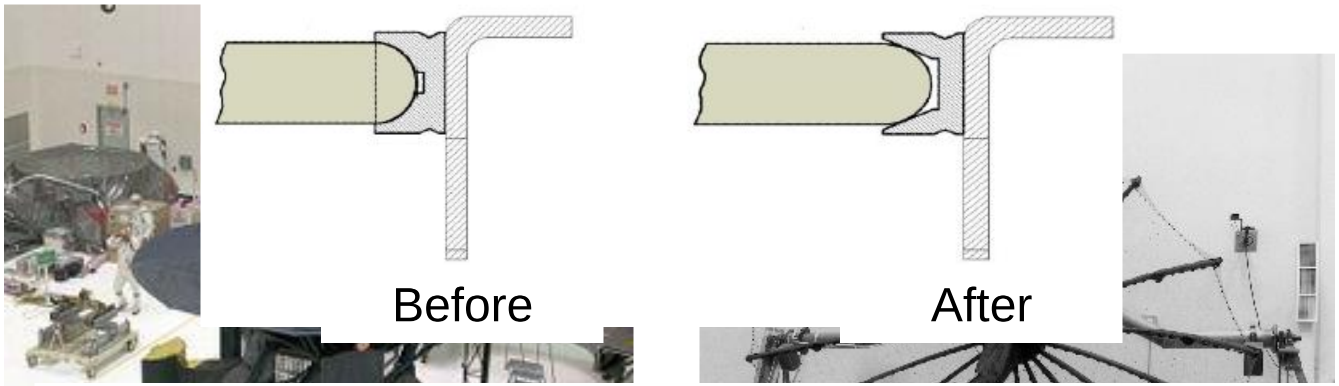
c. […] **repeatability** of the contact between the mating surfaces shall be verified […]

d. **peak hertzian contact stress** shall be verified to be below 93 % of the yield limit

e. **Sliding** at the separable contact surfaces before separation shall be prevented […]
   - e.g. fretting, cold welding!

Example: Galileo High Gain Antenna

[5]



4.7 Design

- → “Minor” design change introduced
- → Significant increase in hertzian contact pressure
- → Lubrication breakdown
- → Relative motion in vacuum lead to seizure / cold welding between pin and socket
- → HGA failed to deploy
- → Significantly decreased down link rate

4.7 Design

5.4.6 Ball Bearings

a. […] shall be sized concerning the static load rating in conformance with **ISO 76** with respect to the maximum allowable hertzian contact stress.

b. The sizing of ball bearings made of materials other than **hardened steel** shall be agreed by the customer.

c. Ball bearings should be **shielded**.

[2]

Exercise: Static Load Capacity of a Ball Bearing

4.7 Design

Supplier X specifies the following ***Static Load Capacities*** for their ball bearings. What's the allowable load (force) per bearing in axial and radial direction according to ECSS-E-ST-33-01C?

Radial Static Rating = 7000 N

Axial Static Rating = 4000 N

$F_{radial} = ?$

ECSS Safety Factor against ***yield stress***: 1.25

$$\sigma \propto F^{\frac{1}{3}}$$

LOAD capacity ***~ 51%*** of catalogue value

Axial Static = 2048 N

Radial Static = 3584 N

5.4.8 Mechanical Clearances

4.7 Design

a. […] clearance shall be provided to prevent movable and actuating elements from:

1. ***interfering*** (collision) with the structure,
2. ***contacting*** with electrical wiring and components, thermal insulation, or other subsystem components,
3. ***puncturing*** of fluid lines, valves and tanks, and
4. ***blocking*** optical paths.

b. Clearances shall be verified by analysis using worst-case ***tolerance budgets*** including thermoelastic effects and operational loads.

c. Clearances shall be verified by ***inspection***.

d. Clearances should be ***at least 3 times*** its associated tolerance.

5.4.10 Threaded Parts or locating devices

a. […] shall use ***secondary, positive locking***.

b. […] shall be made from materials, which are not susceptible to ***stress corrosion cracking***.

→ ECSS-Q-ST-70-36 preferred list
→ ECSS-Q-ST-70-37 material validation
→ ECSS-Q-ST-70-46 manufacturing

c. […] shall be designed to ***be failsafe***.

4.7 Design

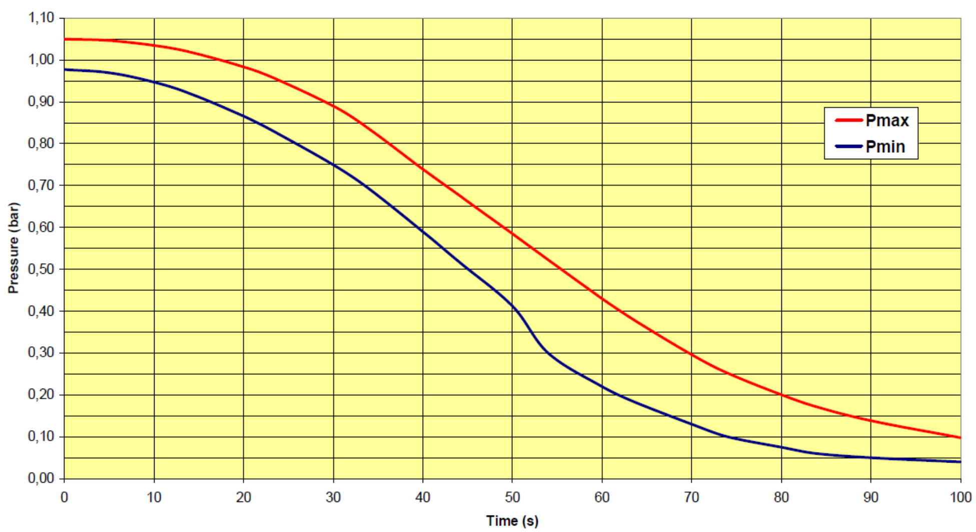
4.7 Design

5.4.11 Venting

a. [...] all closed cavities shall be provided with a ***venting hole*** [...]

b. [...] prevent ***particles contamination*** of bearings, optics and external sensitive components [...] → e.g. by means of filters

c. [...] ***compatibility*** of the lubricant with the other spacecraft materials [...]



[6]

5.4.12 Release and locking devices with pyrotechnics or other actuators

a. […] should be ***redundant***.

d. The operation of release devices shall be compatible with the ***cleanliness requirements***.

e. All ***debris*** shall be contained.

f. If critical, contamination shall be ***measured***.

4.7 Design

→ ECSS-E-ST-33-11 Explosive systems and devices

7.1 Electrical and electronic

7.1.1 General

a. [...] requirements regarding ***electrical interfaces*** and performances.

b. [...] stable ***electrical characteristics*** and electromechanical transfer functions [...].

c. Electrical power consumption, generation and thermal dissipation ***shall be quantified*** by design.

d. ***Fault propagation*** shall be prevented.

e. Generated electrical disturbances shall conform to the project specific ***EMC requirements***.

4.7 Design

4.7 Design

7.2 Insulation

a. Electrical ***wires shall be insulated*** from the structure […]

b. Electric ***motor windings shall be insulated*** from the structure […]

7.3 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***.

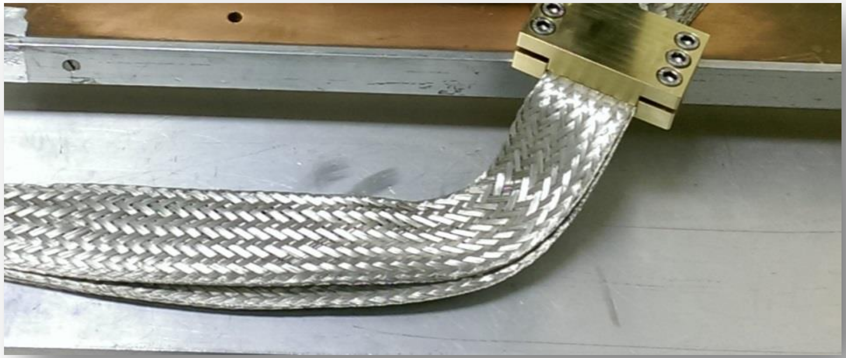
7.4 Grounding

a. Each mechanism shall be ***electrically bonded*** to the spacecraft structure […]

b. […] a ground ***bonding strap*** shall be used between the mechanism housing and the mounting ground plane.

c. […] the ***length-to-width ratio*** of the bonding strap should be smaller than four.

d. […] ***DC resistance*** […] shall be less than 10 mΩ.



4.7 Design

7.5 Electrical Connector

a. […] shall be made through electrical connectors of a type ***qualified*** for the intended application.

b. Flying leads should be avoided.

c. […] preclude damage or inadvertent operation resulting from ***mis-mating***.

d. Electrical connectors shall be ***redundant***

4.7 Design

7.6 Over current protection

a. […] protected against ***overcurrent*** due to abnormal applied voltage or internal conditions

→ **ECSS-E-ST-20 Electrical and electronic**

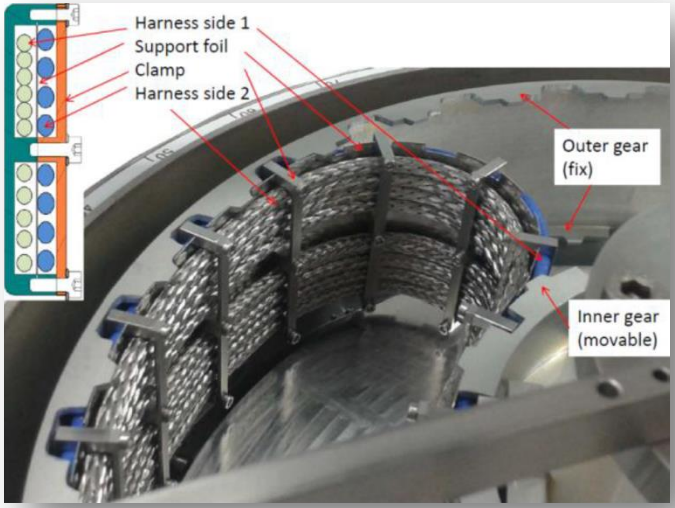
7.7 Strain on wires

a. Routing shall be designed to be ***reproducible***.

c. Resistive torques or forces shall be ***measured*** under worst-case conditions.

d. The ***relative position*** of cables within the harness shall not change during motion.

e. Connections shall be protected from harness ***induced loads***



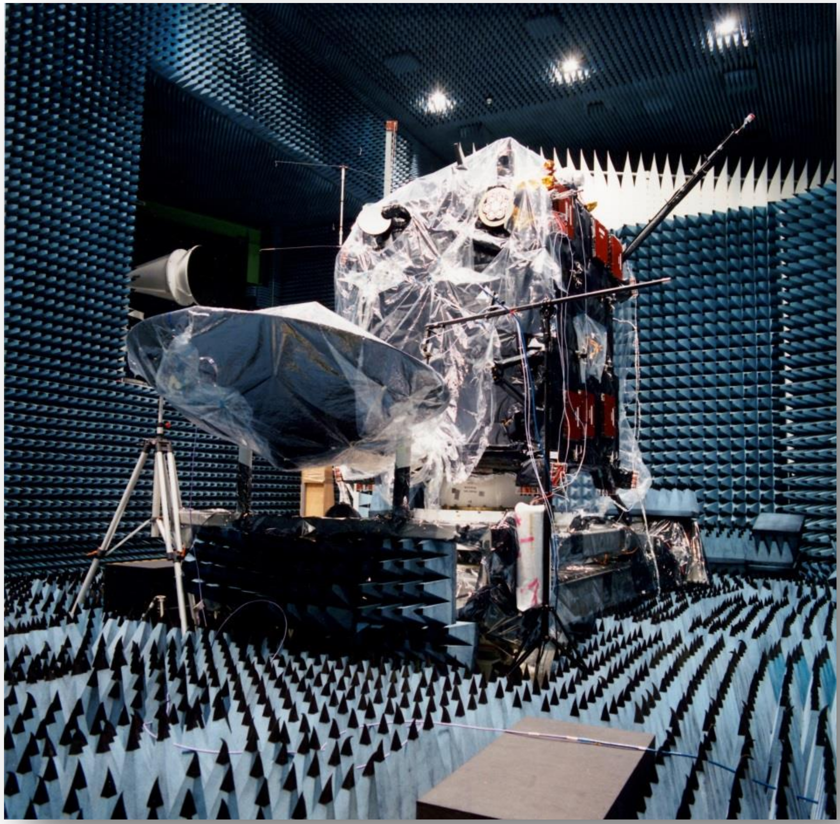
[7]

4.7 Design

7.8 Magnetic cleanliness and ESD or EMC protection

ECSS-E-ST-20-06 Spacecraft charging
ECSS-E-ST-20-07 Electromagnetic compatibility

4.7 Design



8. Open loop and closed loop control system for mechanisms

4.7 Design

- Gain margin
- Phase margin
- Frequency gain
- Bandwidth
- Damping ratio
- Sample rates
- Sensor resolution

→ Aliasing
→ Amplification
→ Excitation of natural frequencies
→ Ageing

4.8 Verification

1. General

a. […] verification process in conformance with ***ECSS-E-ST-10-02*** ***(Verification)***

→ See also **ECSS-E-ST-10-03C Testing**

b. […] ***verification matrix*** shall be established

2. Verification by analysis

2.1 General

a. The analyses shall cover

1. [...] ***extreme conditions***
2. the effect of ***on-ground environmental*** conditions.

2.2 Worst-cases identification

a. [...] characteristics for the ***particular spacecraft*** and mechanism

2.5 Preload and tolerance budget analysis

a. [...] worst case loads [...] and ***manufacturing tolerances***.

4.8 Verification

2.6 Functional performance analysis

2.6.1 General

a. Functional performance analysis shall be performed in ***all specified environments*** under ***all operational conditions*** […]

2.6.2 Functional model requirements

a. […] ***represents the flight hardware*** […] with respect to: mass, inertia, location of center of mass, structural stiffness, actuation forces / torques etc.

b. […] ***parametric study*** / update of input parameters

2.6.3 Analysis requirements

4.8 Verification

a. It shall be ***demonstrated by analysis*** that the mechanism conforms to

   1. the specific mechanism ***requirement specification***

   2. the mechanical ***design and sizing requirements*** under worst-case parameter combinations.

b. Failure cases shall be analyzed […]

c. An ***integrity check*** of the results of the analysis shall be performed […]

d. […] ***sensitivity analysis*** (parameter variation) […]

e. If test results do not match predictions, the reason of the ***disagreement*** shall be found […]

2.7 Hertzian contact and contact stress

a. An analysis shall be provided of the predicted hertzian contact […] to verify the compliance with the ***material allowables*** […]

b. An analysis shall be provided to verify ***sizing of ball bearings*** in conformance with ISO 76

4.8 Verification

[8]

4.8 Verification

2.8 Functional Dimensioning

→ Force, Torque, Kinematics

2.9 Reliability Analysis, FMECA

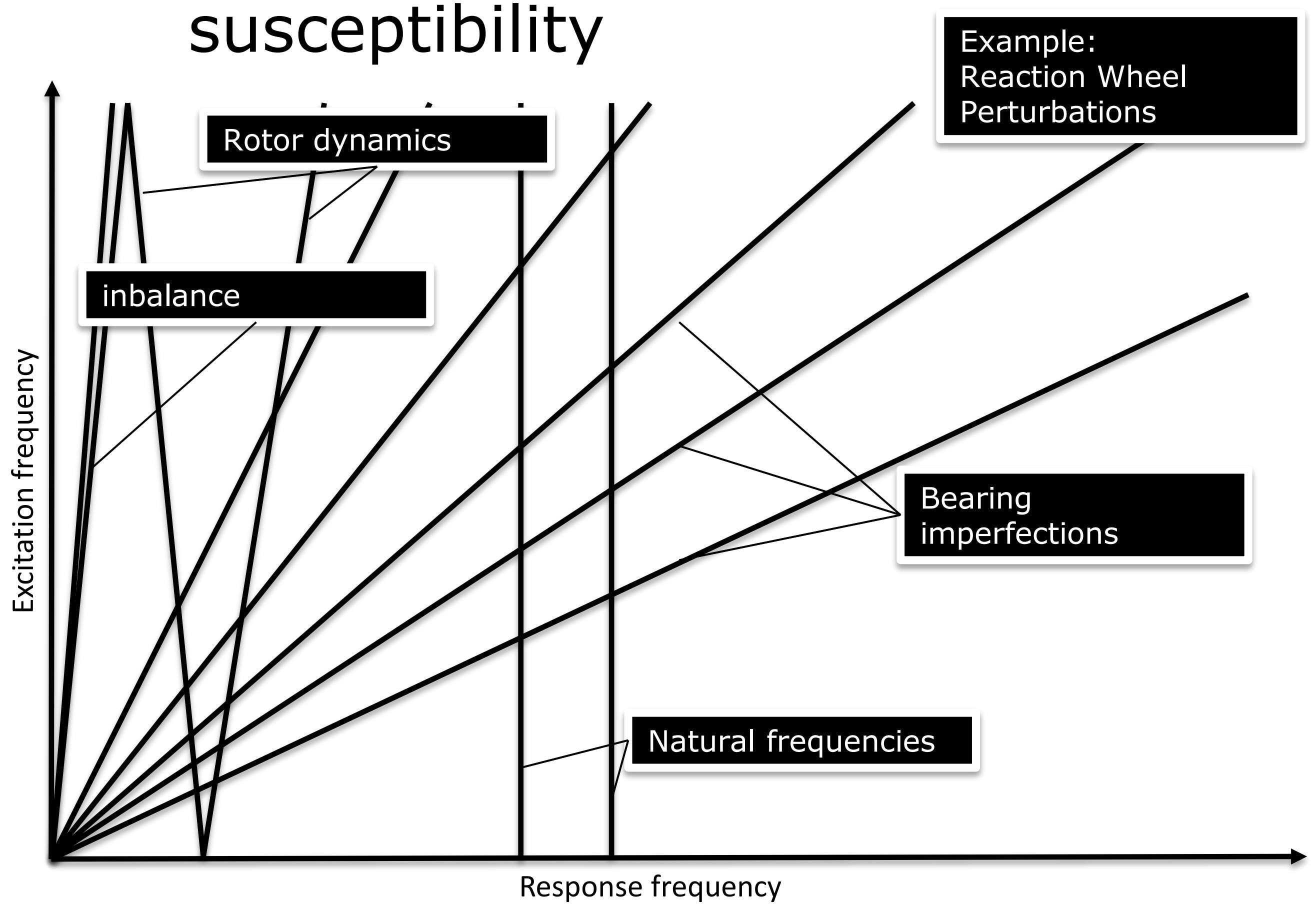
→ **ECSS-Q-ST-30 Dependability**

2.10 Gear Analysis

→ **ISO 6336**

2.11 Shock Generation and Susceptibility

2.12 Disturbance generation and susceptibility



Examples:

- → FEM base structural analysis (natural frequencies)
- → Rotor dynamics (gyroscopic effect)
- → Bearing geometry (disturbance frequencies)
- → Simple physics (unbalance)

2.14 Lubrication Analysis

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

b. The analysis shall be based on ***similarity*** to a qualified application [...]

c. For fluid lubrication systems, the analysis shall verify the compatibility of the lubricant with the ***specified lifetime*** increased by a factor of 1,5 [...]

4.8 Verification

Potential Oil Loss Mechanisms:

Creep, centrifugal forces, evaporation, absorption by porous materials

4.8 Verification

2.15 Lifetime Analysis

→ Tribological Systems, Springs, Structures, etc.

2.16 Hygroscopic Effect Analysis

→ humid environments on-ground

2.17 Magnetic and Electromagnetic Analysis

→ relevant for science missions

→ electric motors

2.18 Radiation Analysis

→ electronic parts

2.19 Electrical

→ **ECSS-Q-ST-30-11 Derating**

3. Verification by Test

3.1 General

a. The tests to be performed […] shall be

1. ***Defined*** in a test plan
2. ***Agreed*** by the customer
   → TRR: **ECSS-E-ST-10-03C Testing**

b. […] permissible operations […]

c. […] conformance to ECSS and SMS

d. […] conformance to functional dimensioning

e. […] performance in launch and operation configuration

f. […] thermal verification

g. […] structural verification

h. […] characterize the dynamic behavior

4.8 Verification

3.2 Characterization or Development Testing

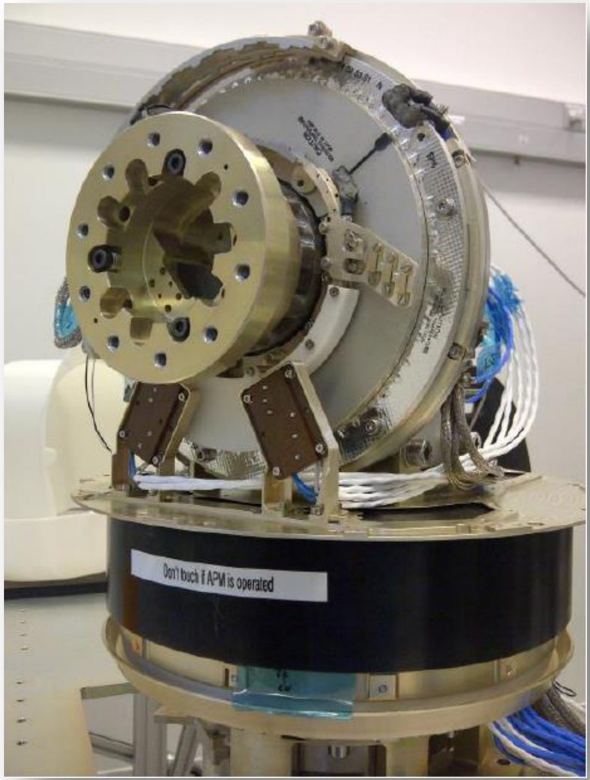
3.2.1 Model Requirements

a. […] bread-board model

3.2.2 Test

a. […] shall be performed during ***<u>phase A or B</u>***

1. Functional performance tests […]
2. Vibration and thermal test
3. Tribological lifetime tests



[7]

→ **ECSS-E-ST-10 C System engineering general requirements**

→ **ECSS-M-ST-10 C Project planning and implementation**

4.8 Verification

3.3 Qualification Testing

3.3.1 General

a. […] all mechanisms shall be qualified ***for the application***

b. […] ***representative*** sequence and ***representative*** environment

3.3.2 Structural qualification testing

3.3.3 Thermal Vacuum Qualification Testing

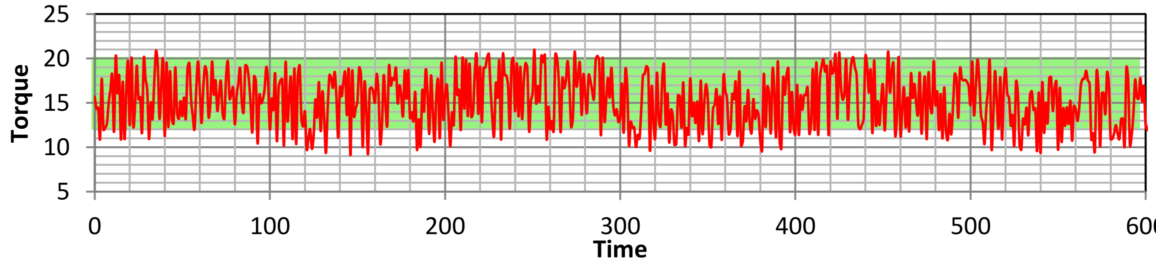
- Suitability of lubrication (outgassing, ***viscosity***)
- Stresses due to ***thermal expansion***
- Geometric

3.3.4 Functional Qualification Testing

a. ***Settling*** and thermal stabilization […]

→ i.e. run-in, thermal settling

b. […] ***following the exposure*** to environmental conditions



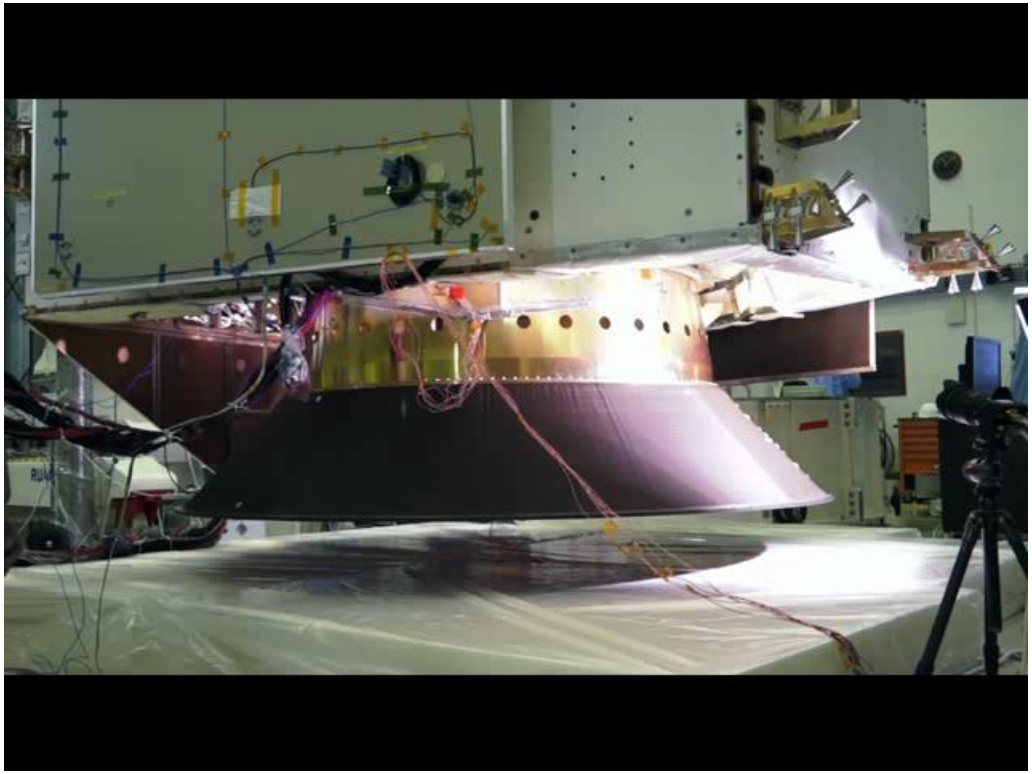
4.8 Verification

4.8 Verification

3.3.5 Energy and Shock

a. […] ***to withstand*** release and end shocks […]

b. […] shock emissions shall ***be measured***



4.8 Verification

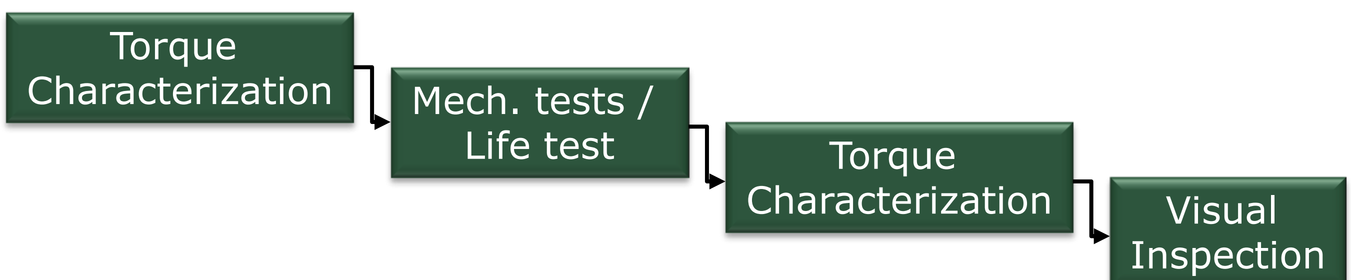
3.3.6 Solid Lubricated Ball Bearing Verification

3.3.7 Fluid Lubricated Ball Bearing Verification

a. […] cage ***material***, ***design***, ***impregnation*** procedures […]

b. Lubricant ***quantity***

c. […] ***compatibility*** of the fluid lubricant with the mechanism materials



4.8 Verification

3.3.8 EMC or ECD qualification testing

a. […] susceptibility and ***emissivity***

3.3.9 Electrical Qualification Testing

a. […] ***insulation***

b. […] ***disruptive discharges***

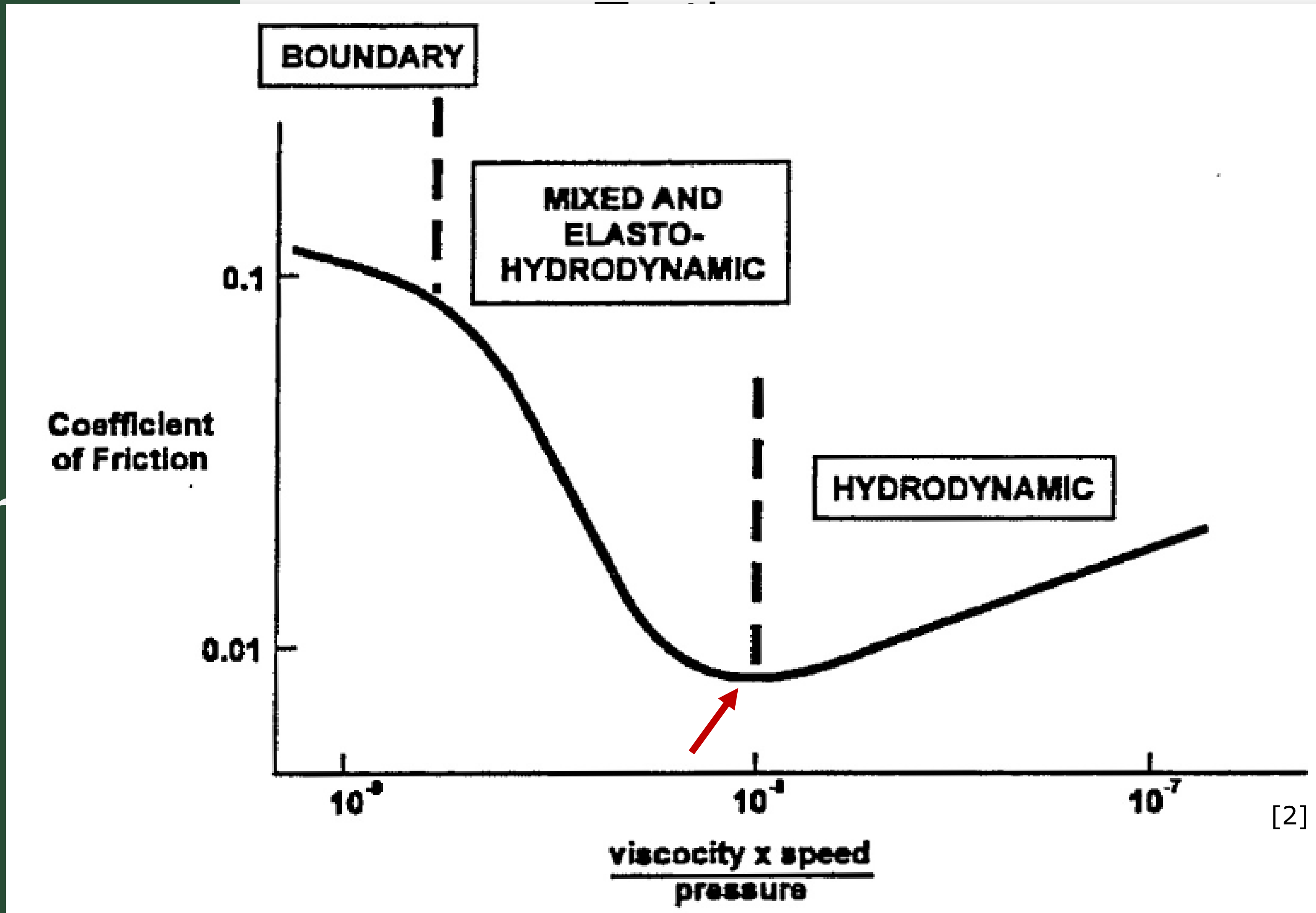
3.3.10 Control Systems Qualification

a. […] ***model correlation***

b. […] ***independent*** measurement devices

3.3.11 Lifetime Qualification

4.8 Ver



2. ***Lubrication*** regime

3.3.14 Life Test Duration

a. […] the ***factored sum*** of the predicted nominal ground cycles and in-orbit cycles.

b. […] multiplied by ***the factors***

Type	Number of expected cycles	Factor
Ground testing (minimum is 10!)	1 to 1 000 cycles	4
	1 001 to 100 000 cycles	2
	> 100 000 cycles	1,25
In orbit	1 to 10 cycles	10
	11 to 1 000 cycles	4
	1 001 to 100 000 cycles	2
	> 100 000 cycles	1,25

Exercise: Determination of Life Test Cycles

Example 1: Solar Array Deployment Mechanism

- Expected in-orbit operations: **1**
- Expected ground test cycles: **2**

$$1 \times 10 + 10 = 20$$

4.8 Verification

Exercise: Determination of Life Test Cycles

Example 1: Solar Array Drive Mechanism for LEO

- Expected orbit life: 5 years
- Required on-ground operation: 20 days

4.8 Verification

LEO orbital period: 90h

Number of in-orbit cycles: $5 \times 365.24 \times \frac{24}{1.5} = 29219.2$

Number of on-ground cycles: $20 \times \frac{24}{1.5} = 320$

Number of life test cycles: $29219 \times 2 + 320 \times 4 \approx 60{,}000$

4.8 Verification

3.3.15 Accelerated Lifetime Testing

a. […] shall ***be representative*** of the worst-case environmental conditions

3.3.14 Post Test Inspection

a. […] ***disassembled*** into its tribological components

3.3.17 Qualification Testing Success Criteria

- No direct contact between metal parts
- Surface properties unchanged
- No chemical deterioration
- Acceptable size and amount of wear
- Acceptable performance
- …

4.8 Verification

3.4 Acceptance testing

[…] actual manufactured hardware is free from ***manufacturing defects***

[…] levels which are ***higher than expected*** in flight but less than qualification

[…] ***wires*** shall be tested […]

3.3.4 Acceptance Test Criteria

[…] peak torque / force ***variations*** less than measured in qualification tests (incl. life test)

[…] peak ***torque*** / ***force*** less than measured in-flight

[…] less ***deterioration*** than measured in qualification

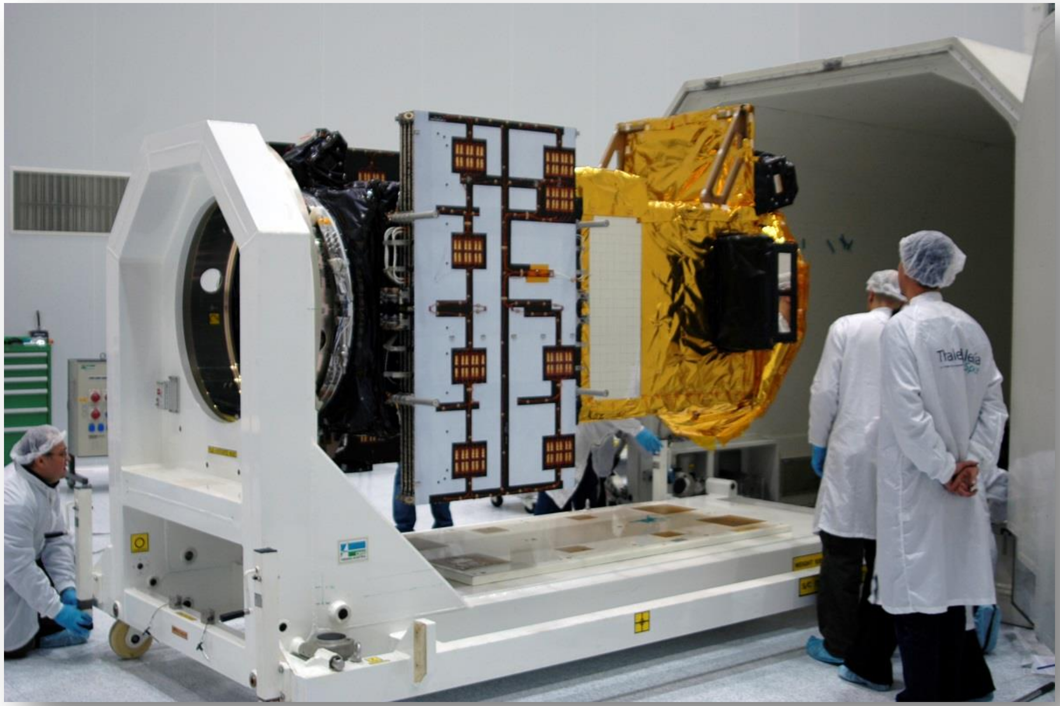
[…] conformance to requirement ***specification***

4.9.3 Assembly

[…] shall be performed in a ***clean room*** environment

→ **ECSS-E-ST-70-01C Cleanliness and contamination control**

→ **ISO 14644 Cleanrooms and associated controlled environments**



4.9 Production and Manufacturing

4.10 Deliverables

a. […] design description

b. […] Mechanisms analytical verification

→ Structural analysis report

→ Thermal analysis report

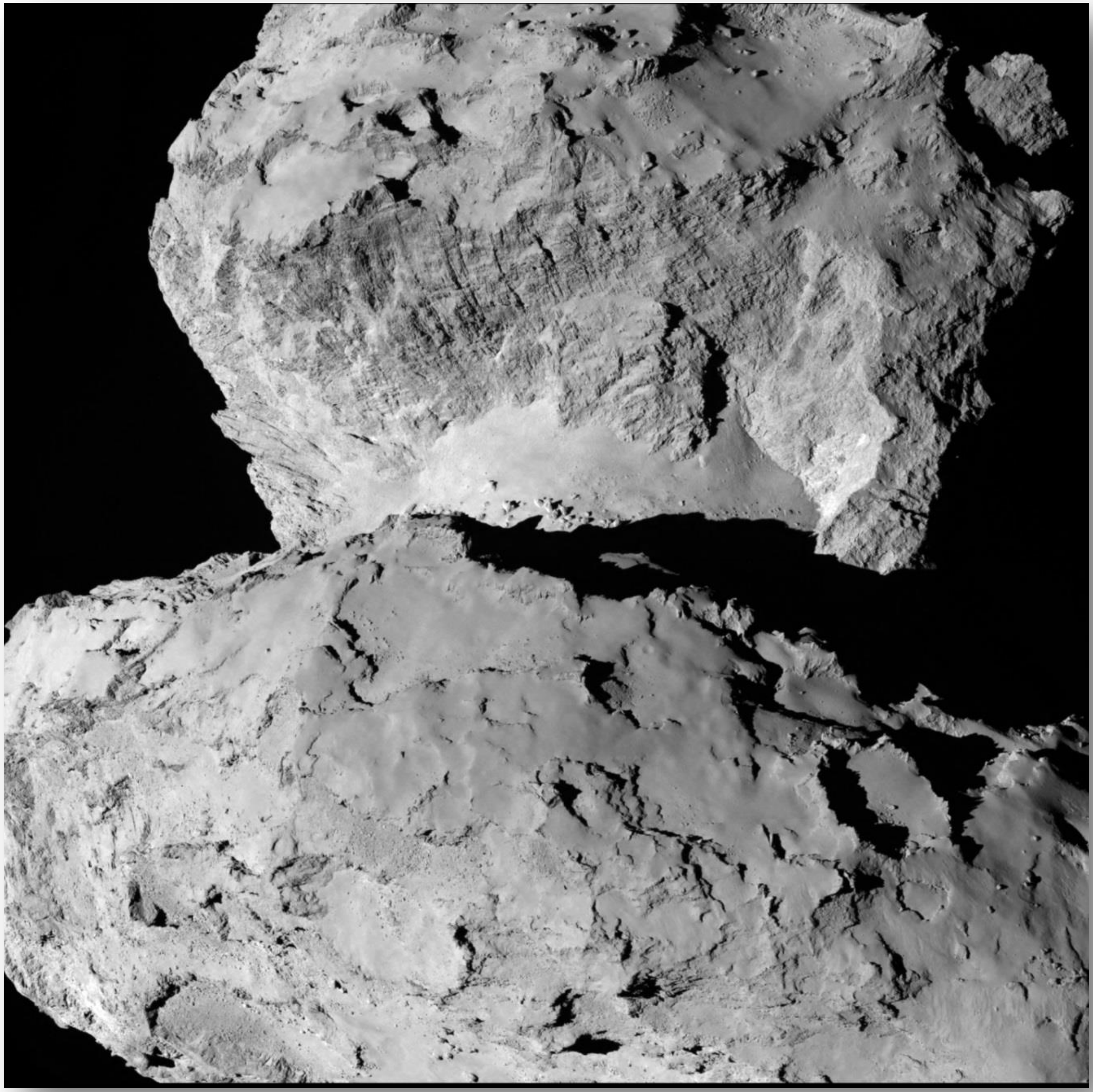
→ Bearing load analysis

→ FEM model description

→ Etc.

c. […] Mechanical user manual

Thank You and Good Bye!



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