Introduction to *Spacecraft Mechanisms via:*
ECSS-E-ST-33-01C Rev. 1

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1. **Terms and Definitions**
   → What is a mechanism? Which disciplines are involved?

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   → Design (dimensioning, material selection, etc.)
   → Verification (analysis and test)

Spacecraft Mechanisms

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

Spacecraft Mechanisms

Actuators	e.g. electric motor, spring, SME, voice coil, piezo-electric, etc.
Transmission	e.g. shafts, couplings, gears, etc.
Bearings	e.g. ball bearings, journal bearings, etc.
Sensors	e.g. optical, magnetic, mechanical, etc.
Controller	open / closed loop, uncontrolled

tribology

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

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

ECSS-E-ST-33-01C Rev.1

...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**.

ECSS-E-ST-33-01C Rev.1

1. Scope
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ECSS-E-ST-33-01C Rev.1

New revision of ECSS-E-ST-33-01 released in Feb 2017

Changes w.r.t. previous revision:

- Requirements for safety critical mechanisms (i.e. human space flight)
- Alignment with other standards (structures, thermal, PA, etc.)
- New rules on ball bearings

Normative references

ECSS-S-ST-00-01	ECSS system — Glossary of terms
ECSS-E-ST-10-02	Space engineering – Verification
ECSS-E-ST-20	Space engineering – Electrical and electronic
ECSS-E-ST-20-06	Space engineering – Spacecraft charging
ECSS-E-ST-20-07	Space engineering – Electromagnetic compatibility
ECSS-E-ST-31	Space engineering – Thermal control general requirements
ECSS-E-ST-32	Space engineering – Structural
ECSS-E-ST-32-01	Space engineering – Fracture control
ECSS-E-ST-32-10	Space engineering – Structural factors of safety for spaceflight hardware
ECSS-E-ST-33-11	Space engineering – Explosive systems and devices
ECSS-Q-ST-30	Space product assurance - Dependability
ECSS-Q-ST-40	Space product assurance – Safety
ECSS-Q-ST-70	Space product assurance – material, mechanical part and process
ECSS-Q-ST-70-36	Space product assurance – Material selection for controlling stress corrosion cracking
ECSS-Q-ST-70-37	Space product assurance – Determination of the susceptibility of metals to stress corrosion cracking
ECSS-Q-ST-70-71	Space product assurance – Data for selection of space materials and processes
ISO 76 (2006)	Rolling bearings – Static load rating
ISO 128 (1996)	Technical drawings
ISO 677 (1976)	Straight bevel gears for general engineering and for

General Requirements: Units

All units to be used: SI

E.g. kinematic viscosity

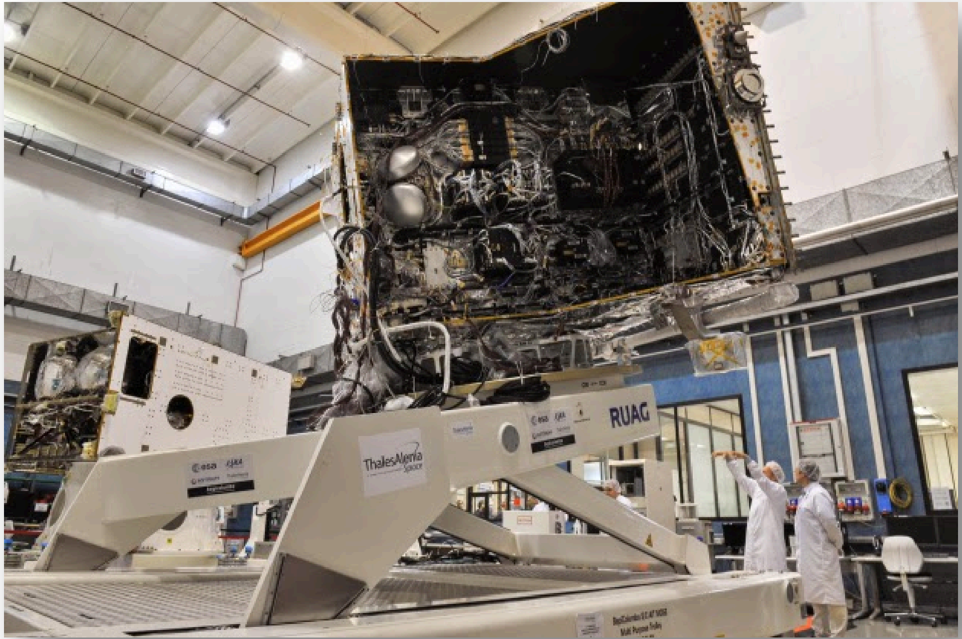
$= [St]$ Stokes

$= 10^{-4}\ m^2 \cdot s^{-1}$

General Requirements: Maintainability

→ Mechanisms shall be designed to be **maintenance free**

→ If maintenance is required, it shall be **approved** by the customer and **procedures** shall be provided

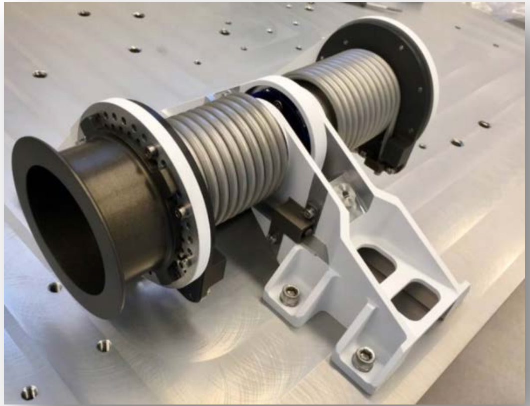


General Requirements: Redundancy

- single point failure modes shall be identified;

- single points of failure should be eliminated by **redundant components**;

- **active elements** of mechanisms shall be redundant, such as sensors, motor windings, brushes, actuators, switches and electronics;



Courtesy of Sener (PL)

http://www.componeticsinc.com/

Mission Environment

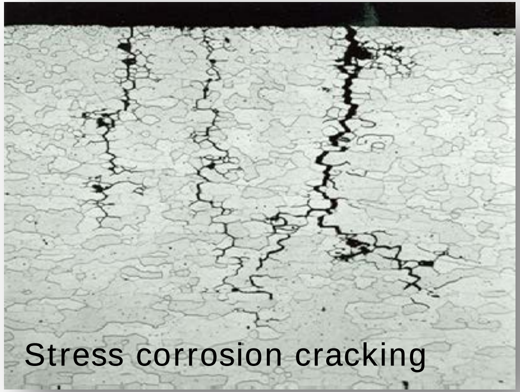
The mechanism engineering shall consider **every mission phase** identified for the specific space programme, i.e.:

- → Assembly and integration (humidity, oxygen)
- → Testing (1 g environment, additional resistive loads)
- → Storage (long term effects)
- → Handling and shipment (loads, accessibility)
- → Launch (mechanical loads)
- → In-orbit operation / hibernation (operational loads, thermal, radiation, EMC, life, etc.)

Material selection

... shall be performed in conformance with **ECSS-Q-ST-70 (Materials)**:

- → Corrosion
- → **Galvanic corrosion (→ dissimilar metals)**
- → **Stress corrosion cracking (e.g. 440C, Cronidur X30)**
- → Fungus protection
- → Flammable, toxic and unstable materials
- → Induced emissions (stray light protection)
- → Radiation
- → Atomic oxygen
- → Fluid compatibility

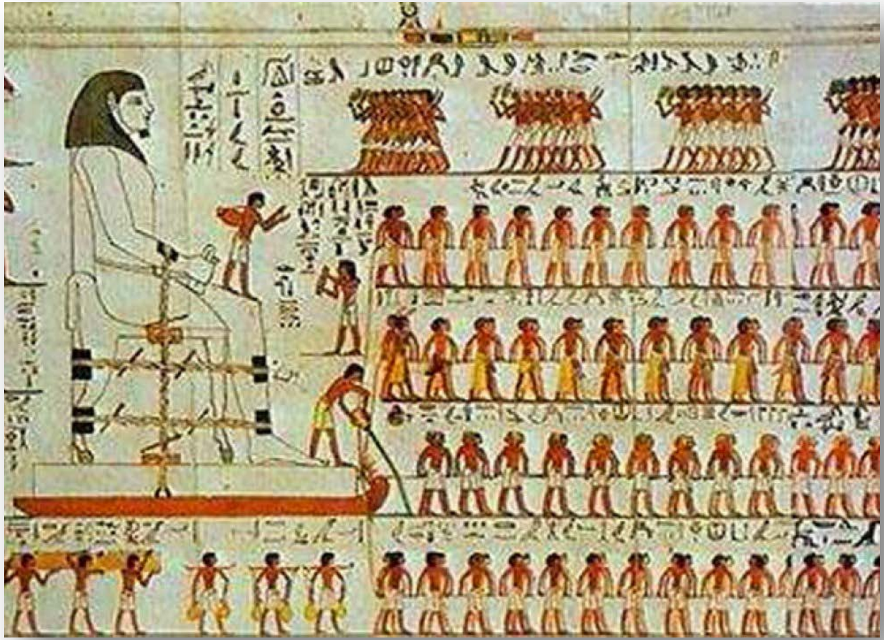


Design Requirements: Tribology

Mechanisms shall:

- be designed with a **lubrication function** between surfaces
  - Reduce friction and wear
  - Increase lifetime

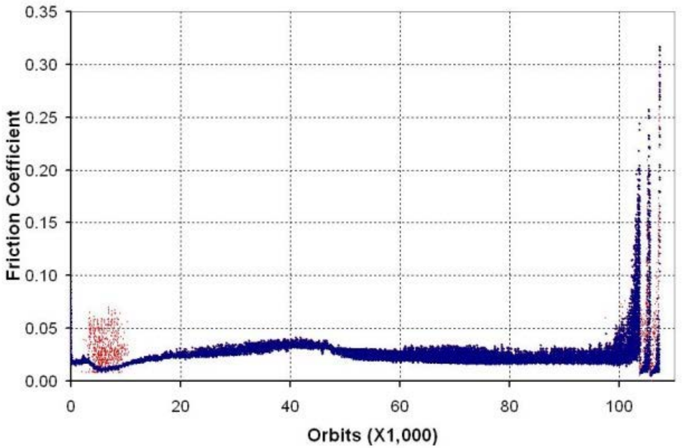
- use only lubricants **qualified for the mission**
  - Temperatures, ambient pressure, contact pressure, number of cycles, lifetime, relative velocity etc.

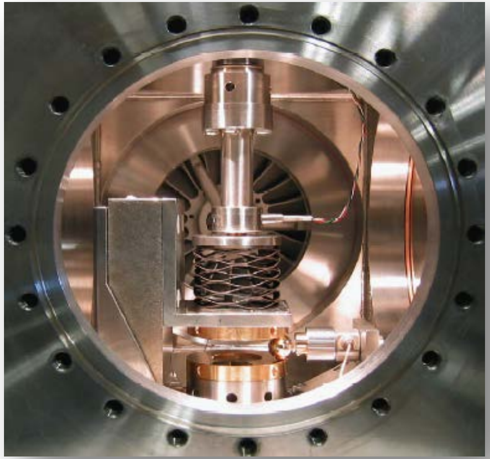


Design Requirements: Tribology (cont'd)

Qualification of lubricant via:

- → Lifetest (see slides 51 ff.)
- → Component level: bearing / gear test rigs, Pin on disc (POD), Spiral orbit tribometer (SOT)





SOT device by ESTL

European Space Tribology Laboratory (ESTL):

- → operates test facilities
- → has data base on qualified lubricants
- → provides consultancy

www.esrtechnology.com

Design Requirements: Dry Lubrication

... preferred for operation in **high temperature**, at **low speeds**, **low number of operational cycles**, when **cleanliness** is an issue (low outgassing rate)

... applied through processes such as sputtering, vapor deposition etc.

... e.g. MoS2, WS2, graphite, PTFE, lead

→ Samples of representative material [...] shall be co-deposited in each process with the flight components so that verification checks can be performed;

→ The thickness and adhesion of the lubricant on samples shall be verified;

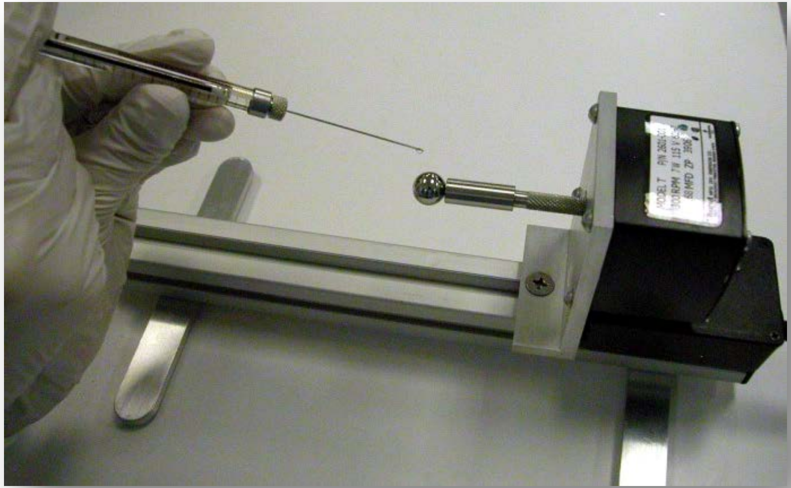
Design Requirements: Fluid Lubrication

... for **high speed**, **low friction** and **high number of operational cycles**

... wide range of space qualified hydrocarbon and synthetic oils

- → The **quantity** of lubricant used shall be determined.
- → **Outgassing**, **creep** and absorption shall be taken into account (including **ground effects**, i.e. gravity)
- → For rules on outgassing (total / relative mass loss, collected volatile condensable materials):

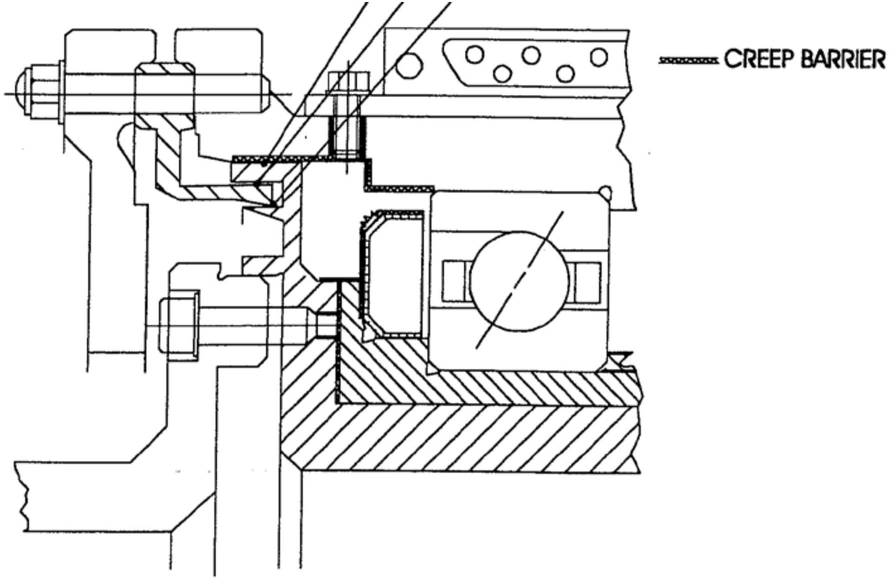
  → **ECSS-Q-ST-70-02**



Courtesy of ESTL

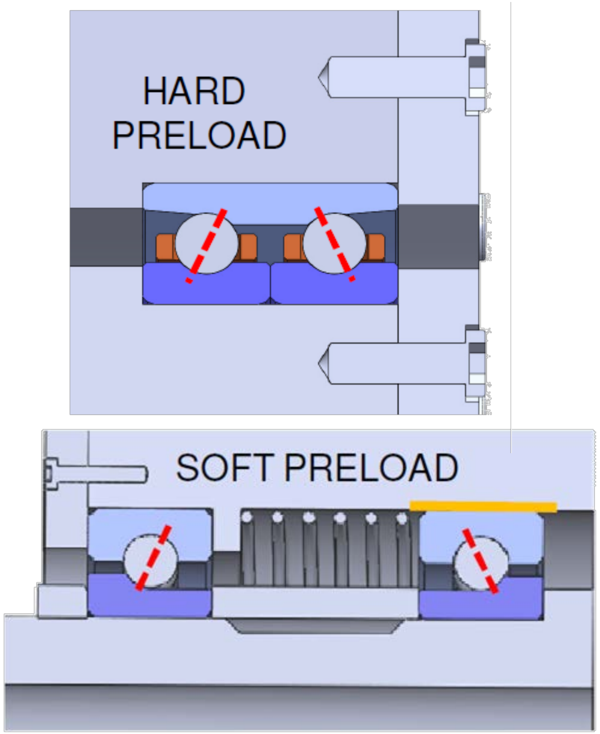
Design Requirements: Anti-creep barriers

- **avoid migration** of fluid lubricants to the internal/external sensitive equipment;
- causes a **change of the lubricant amount** on the parts to be lubricated;
- **integrity** of the anti-creep barrier shall be verifiable by indicators.



Design Requirements: bearing preload

- → Ball bearings shall be preloaded to **withstand mechanical environment**;
- → Preload **calculation** shall be made available
- → Preloading should be applied by **solid or flexible** preload;
- → Preload **<u>should</u> be measured** after assembly;
- → preload should be confirmed **after running-in**;



Design Requirements: structural dimensioning

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

- **ECSS-E-ST-32** (structures):

> **4.5.16 Margin of safety (MOS)**
>
> a. Margins of safety (MOS) shall be calculated by the following formula:
>
> $$MOS = \frac{design\ allowable\ load}{design\ limit\ load \times FOS} - 1$$
>
> NOTE Loads can be replaced by stresses if the load- stress relationship is linear.

- **ECSS-E-ST-32-10** (factors of safety):

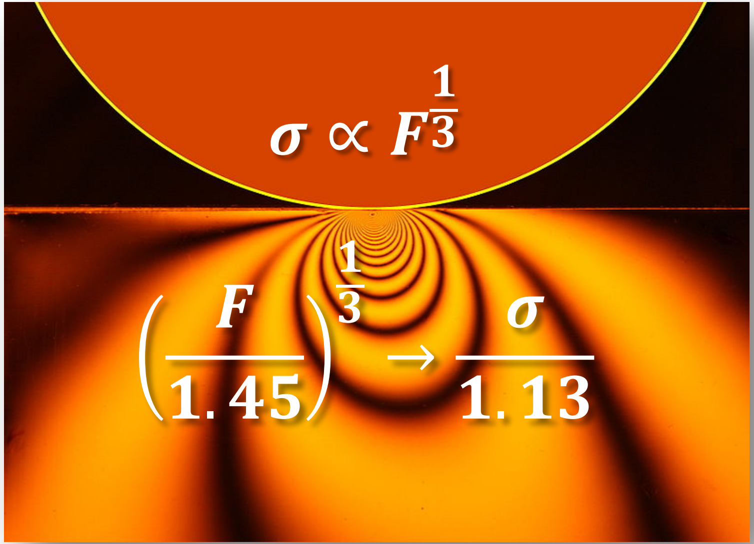
$$FOS_Y = 1.1$$

$$FOS_U = 1.25$$

(typical values)

Design Requirements: ball bearings

- → shall be sized with respect to the maximum allowable **peak hertzian contact stress**;
- → For the evaluation of the peak hertzian contact stress, a minimum **factor of 1.45** shall be applied to the design limit load;



According to **ISO76** (static load rating):

→ axial / radial static load capacity ≙ load producing a maximum contact stress of

3700 MPa ← 4200 MPa (for hardened steels, e.g. SAE 52100)

3500 MPa ← 4000 MPa (for stainless steels, e.g. 440C)

Design Requirements: motorisation

Actuators shall be sized to provide ***torques*** / ***forces*** in conformance with:

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

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

- throughout the operational **lifetime** (ageing, lubricant degradation, creep, etc.)
- over the full **range of travel**
- worst case **environmental and operational conditions** (temperatures, mechanical loads)

Design Requirements: motorisation (cont'd)

Actuators shall be sized to provide ***torques*** / ***forces*** in conformance with:

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

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

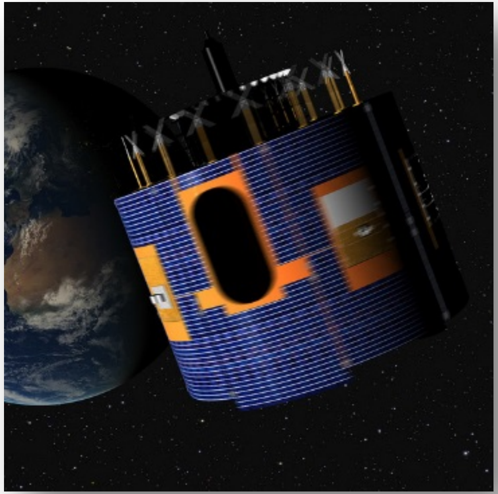
T_L: Deliverable **output torque of the mechanism** when specified by customer

T_D: **inertial resistance torque** caused by the worst-case acceleration function specified by the customer (i.e. customer specifies a motion rather than a torque)

Design Requirements: motorisation (cont'd)

Minimum uncertainty factors for **loss terms:**

Resistive force or torque contributor	Symbol	Theoretical Factor	Measured Factor
Inertia	I	1,1	1,1
Spring	S	1,2	1,1
Magnetic effects	H_M	1,5	1,1
Friction	F_R	3	1,5
Hysteresis	H_Y	3	1,5
Others (e.g. Harness)	H_A	3	1,5
Adhesion	H_D	3	3



→ **$I \neq T_D$**, but resistive inertia load due to acceleration of mechanism itself (e.g. spinning spacecraft!)

→ **S ≠ actuation torque**, but resistive spring load (e.g. latch)

Design Requirements: motorisation (cont'd)

If actuation force / torque is supplied by a spring:

- → springs shall be redundant (e.g. 1:2 or 2:3 redumdancy)
- → actuation torque / force shall be multiplied by an uncertainty **factor of 0.8** (→ only if ageing measurements are not available)

If actuation force / torque is supplied by an electric motor:

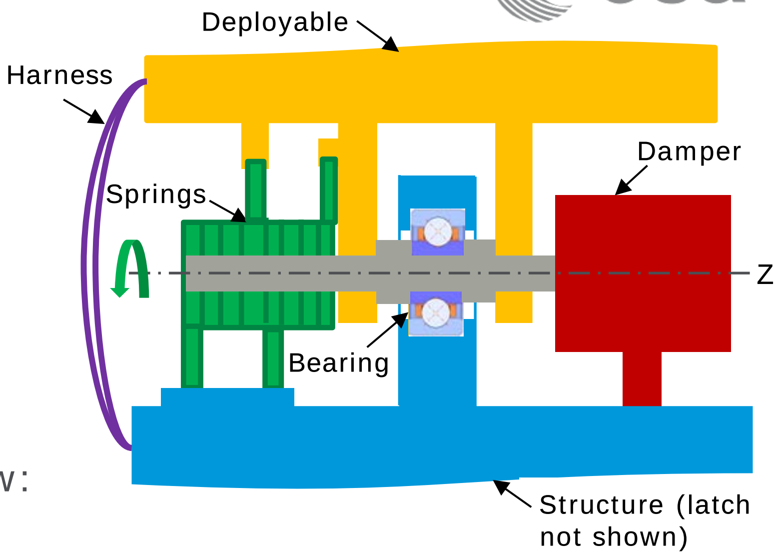
- → Worst case actuation torque / force shall be **measured at operating conditions** (i.e. at representative temperatures, pressures, speeds, loads etc.)

Actuation forces / torques supplied by **devices whose primary function is not to provide actuation** (e.g. harness) shall not be taken into account

Spring motorisation example

Example mechanism

- Consider the example simple spring deployment hinge illustration, requirements and characterised resistive contributors shown here:
- This is a rotating mechanism without a specific load requirement at customer level. Thus, the minimum actuation torque is derived using the equation from section 4.7.5.3.1.d of ECSS-E-ST-33-01C, shown below:



The minimum actuation torque (T_{min}) shall be derived by the equation:

$$T_{\min} = 2 \times (1{,}1\, I + 1{,}2\, S + 1{,}5\, H_M + 3\, F_R + 3\, H_Y + 3\, H_A + 3\, H_D) + 1{,}25\, T_D + \cancel{T_L}$$

<u>Relevant Requirements:</u>

R1. Deployment angle = 60 °

R2. Deployable CoG distance from Z = 1.5 m

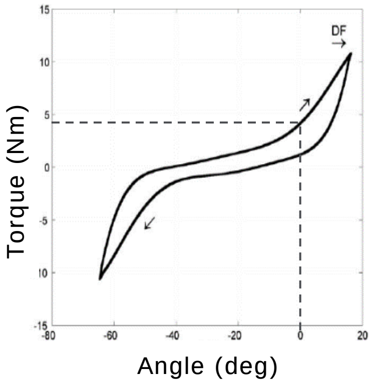
R3. Deployable mass = 10 kg

R4. Max global acc = 0.1 m/s^2 (any axis)
(note: also be aware of any rotational accelerations)

Spring motorisation example

Example Budget:

Contributor Description	Contributor Origin	Values	Units	ECSS Factor	Factored Contribution	Reference
Deployable inertia	Inertia (I)	1.50	Nm	1.10	1.65	*Derived from requirements R2, R3 & R4.*
Bearing Friction	Friction (FR)	0.10	Nm	1.50	0.15	*Tested at bearing level. Report xxx.*
Damper	Friction (FR)	0.20	Nm	1.50	0.30	*Tested at damper level. Report xxx.*
Latch	Friction (FR)	0.10	Nm	3.00	0.30	*Predicted by analysis. Report xxx*
Harness	Other (HA)	4.00	Nm	1.50	6.00	*Tested on Harness EM. Report xxx.*
	Magnetic effects	n/a	n/a	n/a	n/a	n/a
	Hysteresis	n/a	n/a	n/a	n/a	n/a
	Adhesion	n/a	n/a	n/a	n/a	n/a
	Dynamic Acceleration	n/a	n/a	n/a	n/a	n/a
Total Resistance		**5.90**	**Nm**		**8.40**	
Torque including motorisation factor				2.00	16.80	
Min required torque per spring	Spring		**Nm**	0.80	**21.0**	



e.g. Harness resistance data

Active motorisation example

Example active mechanism

- Consider the example of a powered actuator using a DC motor and planetary gearbox to provide motion for the requirements defined hereunder
- This is a rotating mechanism with a specific load requirement at customer level. Thus, the minimum actuation torque is derived using the equation from section 4.7.5.3.1.e of ECSS-E-ST-33-01C, shown below:

$$T_{\min} = 2 \times (1{,}1\,I + 1{,}2\,S + 1{,}5\,H_M + 3\,F_R + 3\,H_Y + 3\,H_A + 3\,H_D) + 1{,}25\,T_D + T_L$$

Example Relevant Requirements:

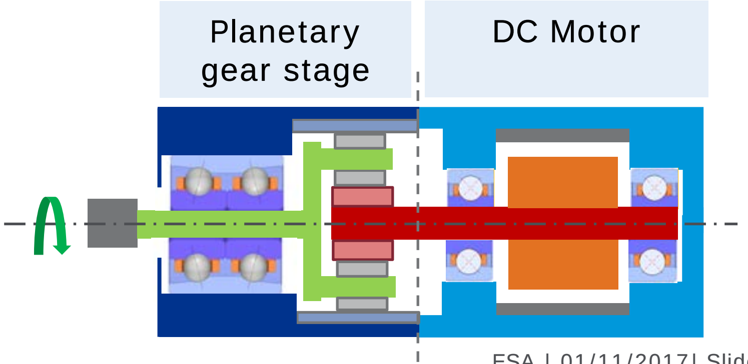
R1. Output Torque = 0.2 Nm

R2. Max commanded speed = 1.5 rads/s

R3. Max command current = 2 A

R4. Max command voltage = 24 V

R5. Temperature range = -20 °C to 30 °C



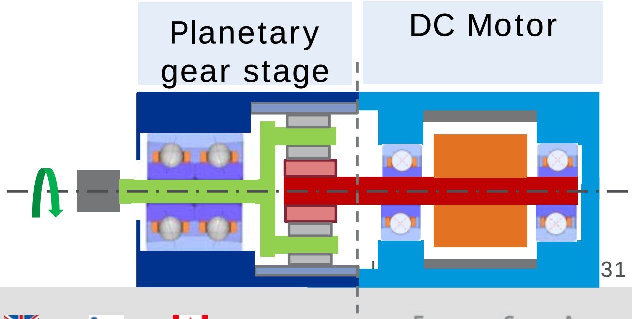
Active motorisation example

Example actuation budget

Budget for cold case @ -20 °C   Gear ratio from output to motor: 8

Contributor Description	Contributor Origin	Units	Unfactored value at output	ECSS Uncertainty Factors	Factored Contribution @ Output	Factored Contribution @ Motor	Reference
Deliverable Output Torque	(T_L)	Nm	0.20	1.00	0.200	0.02500	*Derived from requirement R1*
Gearbox output bearings	Friction (FR)	Nm	0.080	1.5	0.120	0.01500	*Tested at bearing level. Report xxx.*
Planetary gear stage 1 (based on efficiency)	Friction (FR)	Nm	0.040	1.5	0.060	0.00750	*Tested at gear level. Report xxx.*
Motor Bearings Uncertainty	Friction (FR)	Nm	-	1.5-1=0.5	0.040	0.005	*Tested at bearing level. Report xxx.*
Total Resistance		Nm	0.200		0.220	0.028	
Motorisation factor			2		2	2	
Total inc Motorisation factor		Nm	0.400		0.440	0.055	
Gearbox inertia	Inertial resistance (Td)	Nm	2.458E-04	1.25	3.07E-04	3.84E-05	*Actuator design report xxx.*

Min required torque	**0.055**	**Nm**

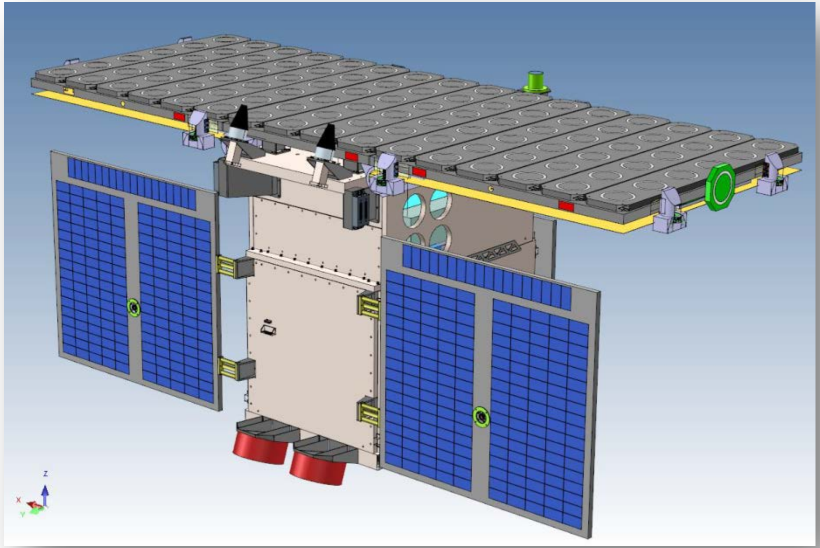


- This is a “black box” motor case needing caution
- The budget is calculated from output to input to ensure the consequence of output uncertainty is reflected on gears

Design Requirements: end stops

For mechanisms with restricted travel or rotation:

- Use of regular or emergency mechanical end stops (i.e. don't rely on actuator function, e.g. by electric motor)
- deployment indicators shall not be used as mechanical end stops
- Requirements on separable contact surfaces do apply (see next slide)

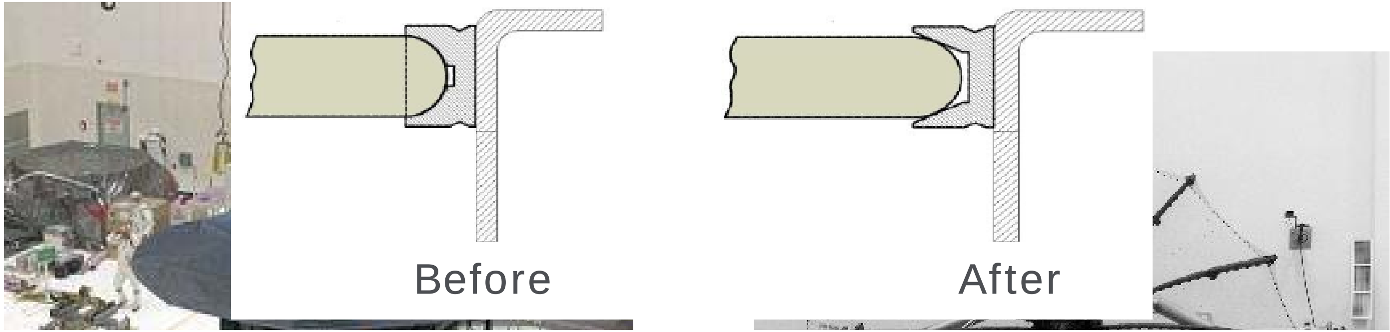


Courtesy of Qinetiq Space N.V.

Design Requirements: separable contact surfaces
(other than gears, balls and journal bearings)

- maintain **adhesion forces** below the specified limits
- contact between the mating surfaces **shall be characterized**
  - → surface roughness, hardness, contact geometry
- the **peak hertzian contact stress** shall be verified to be below 93 % of the yield limit of the weakest material
- avoid potential contact surface **property changes**
- for metallic surfaces (→ risk of **cold welding**!):
  - → minimum **hardness** of 500HV
  - → use of **dissimilar metal** (conflict with galvanic corrosion constraints)
  - → use of lubricant / dissimilar coatings

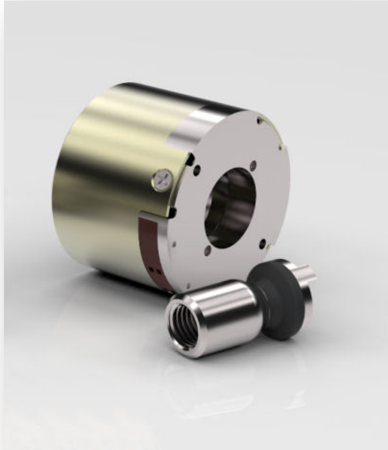
Example: NASA's Galileo High Gain Antenna



- Introduction of a "minor" design change
- Significant increase in hertzian contact pressure (in particular during launch vibrations)
- Lubrication breakdown
- Relative motion in vacuum leading to cold welding between pin and socket
- Partial deployment failure
- Significantly reduced down-link rate

Design Requirements: Threaded parts

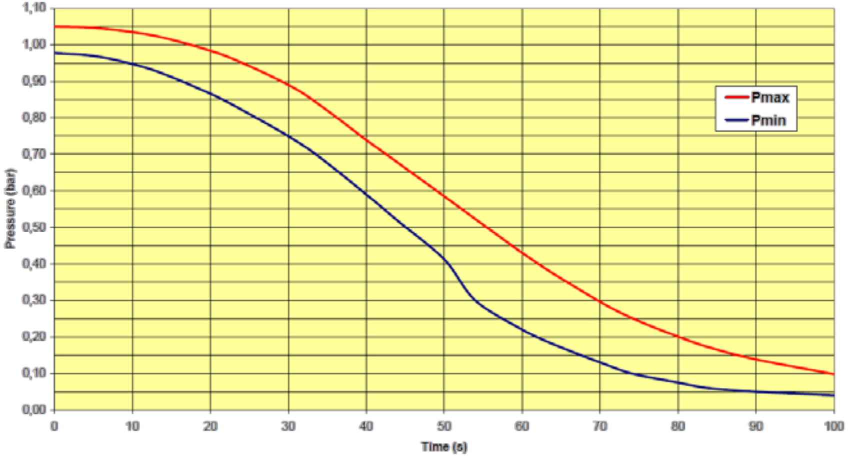
- Use of materials not susceptible to **stress corrosion cracking**
  - → Material selection according to ECSS-Q-ST-70-36C
- shall be designed to be **fail-safe** ≠ **safe life**
  - → **Fracture control** requirements in ECSS-E-ST-32-01C Rev.1
- **preload** shall be justified taking into account **scattering** of all parameters
  - → e.g. manufacturing, lubrication and tightening tolerances



http://www.neaelectronics.com/

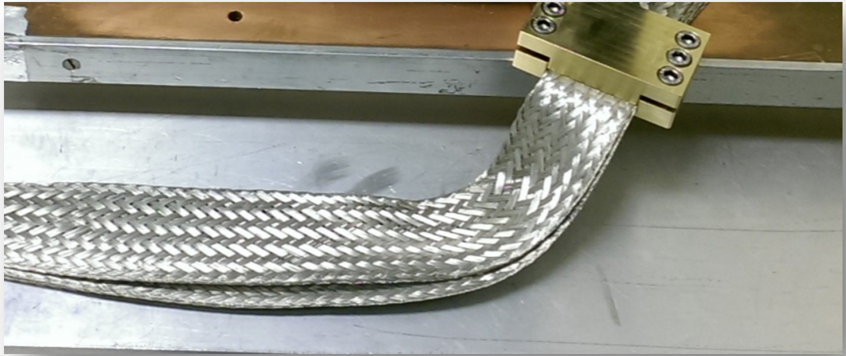
Design Requirements: Venting

- all closed cavities shall be provided with a **venting hole**
- **prevent particles contamination** of bearings, optics and external sensitive components
  - → e.g. by means of filters
- **compatibility of the lubricant** with the other spacecraft materials



Design Requirements: Grounding

- Each mechanism shall be **electrically bonded** to the spacecraft structure
- a ground **bonding strap** shall be used between the mechanism housing and the mounting ground plane
- the **length-to-width ratio** of the bonding strap should be smaller than four
- **DC resistance** shall be less than 10 mΩ.



Design Requirements: Others

Other design requirements, regarding:

- Open and closed loop **control systems** (e.g. gain and phase margins)
- Electrical **insulation**
- **Strain** on wires
- Mechanical **clearances** (e.g. MLI support locations)
- Marking and **labelling**
- Flushing and **purging**
- Thermal control (shall be **passive**!)
- **Magnetic cleanliness / EMC**

Verification Requirements: General

- Verification process in conformance with **ECSS-E-ST-10-02 (Verification)**

Review of design, Inspection, Measurement, **Analysis**, **Test**

- Verification matrix shall be established

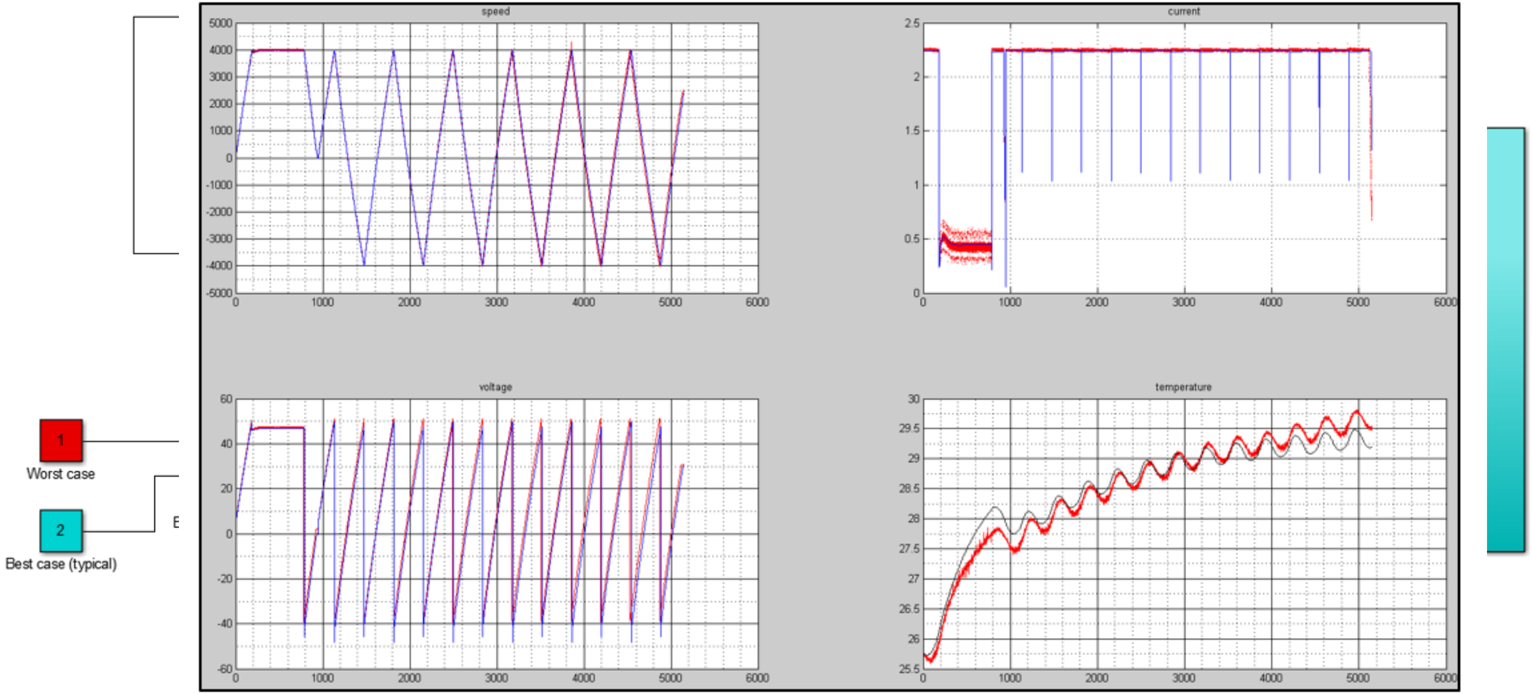
Verification by analysis

... shall cover extreme conditions

- In flight
- On ground

- ❑ Thermal analysis
- ❑ Structural analysis
- ❑ Preload budget
- ❑ Functional performance analysis
- ❑ Hertzian contact analysis
- ❑ Functional dimensioning analysis
- ❑ Reliability analysis, FMECA
- ❑ Gear analysis
- ❑ Shock generation and susceptibility
- ❑ Disturbance generation and susceptibility
- ❑ Analysis of control systems
- ❑ Lubrication analysis
- ❑ Lifetime analysis
- ❑ Hygroscopic effect analysis
- ❑ Magnetic and electromagnetic analysis
- ❑ Radiation analysis
- ❑ Electrical analysis

Functional performance analysis



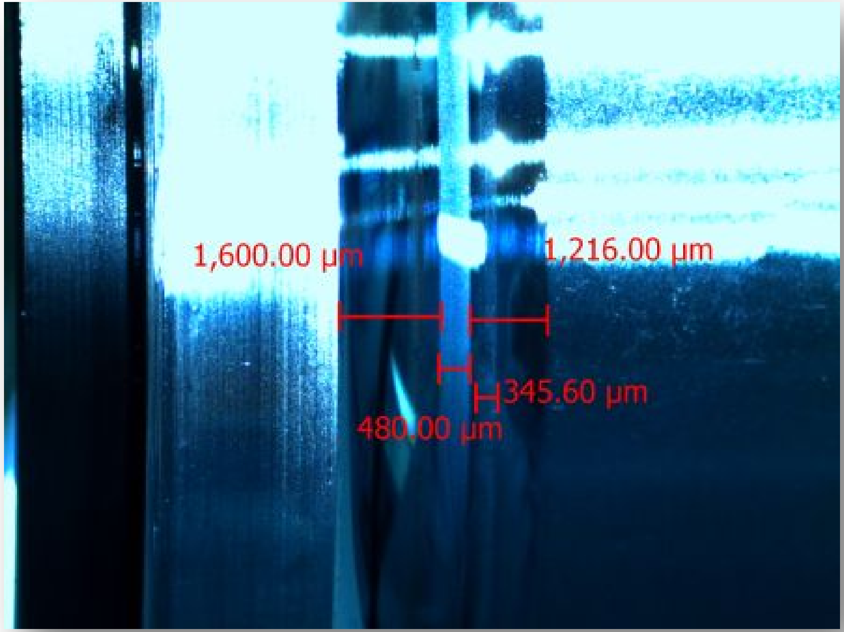
Hertzian contact stress analysis

- Analysis of the **predicted hertzian contact stress** to verify the compliance with the material allowables

- Analysis to verify **sizing of ball bearings** in conformance with the allowable peak hertzian contact stress

  - → Ball bearing analysis tools: CABARET, RBSDyn, KISSsoft, ORBIN

  - → Also for separable contact surfaces, gears, end stops



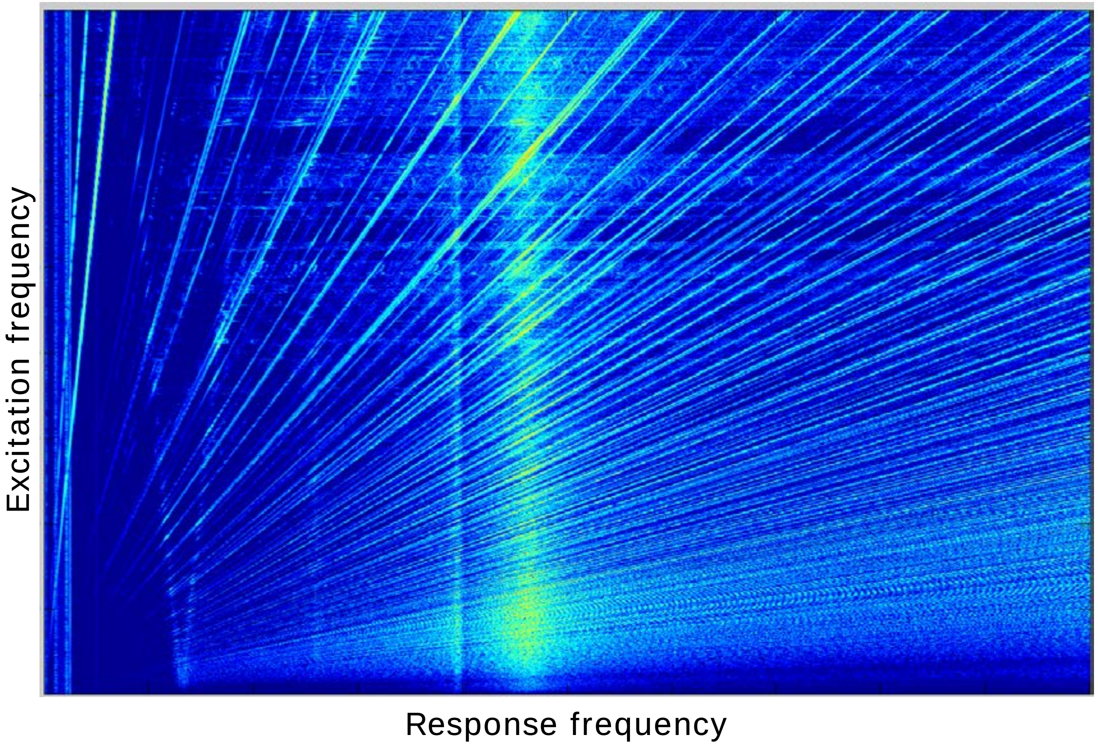
Disturbance generation and susceptibility

Example: Microvibration generation

- Bearing geometry
- Unbalance
- Structural resonances (e.g. FEM model)
- Control frequencies
- Rotor dynamics

$$FTF = \frac{f_r}{2} \cdot \left(1 - \frac{d}{D} \cdot \cos\alpha\right)$$

e.g. Fundamental train frequency



Lubrication analysis

Analysis of the choice of lubrication system and its dimensioning for the proposed application and lifetime shall be provided:

- contact stress
- number of cycles
- environmental conditions

$$\frac{dm}{dt} = (p_v - p_p)\sqrt{\frac{M}{2 \cdot \pi \cdot R \cdot T}}$$

e.g. Langmuir equation to analyse oil loss by evaporation

Potential Oil Loss Mechanisms:

Creep, centrifugal forces, evaporation, absorption by porous materials

Magnetic and electromagnetic analysis

Example: Polarised Solenoid (Pin Puller)

Verification by test

- The tests to be performed shall be
  - Defined in a test plan
  - Agreed by the customer
- conformance to ECSS and mechanisms specification
- conformance to functional dimensioning
- performance in launch and operation configuration
- thermal verification
- structural verification
- characterize the dynamic behavior

> - Characterisation testing
> - Qualification testing
> - Acceptance testing

Characterisation testing

- Breadboard model testing during **Phase A or B**
- Gain confidence in technology (no flight representative hardware)
  - Functional performance test
  - Vibration and thermal tests
  - Tribological lifetime test on critical items

    (Example: usage of certain lubricant in bearing / gear test rig)

→ **No formal qualification!**

Table 5-1: Space segment equipment - Qualification test baseline

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment												Application notes
			a	b	c	d	e	f	g	h	i	j	k	l	
General															
Functional and performance (FFT/RFT)	5.5.1.1		R	R	R	R	R	R	R	R	R	R	R	R	For k (solar array), the deployment test is mandatory before and after the environmental tests (manual deployment before the environmental tests).
Humidity	5.5.1.2		X	X	X	X	X	X	X	X	X	X	-	X	For k (solar array) and l (solar panel), see ECSS-E-ST-20-08.
Life	5.5.1.3	See Table 5-2 No 1	X	X	R	R	X	X	R	X	X	R	-	-	To be performed on dedicated model. For l (solar panels), the life tests are covered by the ECSS-E-ST-20-08.
Burn-in	5.5.1.4		X	-	-	X	-	-	X	-	-	-	-	-	The test is performed in parallel with other funct. & environm. tests.
Mechanical															
Physical properties	5.5.2.1		R	R	R	R	R	R	R	R	R	R	R	R	Upon agreement with customer the CoG and MoI is not measured by test but calculated.
Static load	5.5.2.2	See Table 5-2 No 2	X	X	X	X	X	X	X	X	X	X	X	-	One of the three types of test is performed if not covered by the sinusoidal vibration test.
Spin	5.5.2.2	See Table 5-2 No 3	X	X	X	X	X	X	X	X	X	X	X	-	
Transient	5.5.2.2	See Table 5-2 No 4	X	X	X	X	X	X	X	X	X	X	X	-	
Random vibration	5.5.2.3	See Table 5-2 No 5	R	X	R	R	R	R	R	R	X	X	X	-	For k (solar array), the random vibration test should be added to acoustic test for fixed solar array mounted directly to the spacecraft side wall (without offset bracket).
Acoustic	5.5.2.4	See Table 5-2 No 6	-	X	-	-	-	-	-	-	X	X	R	-	For b (antennas), i (optical), j (mechanism), random vibration or, acoustic or both tests are selected depending on the type, size and location of the space segment equipment.
Sinusoidal vibration	5.5.2.5	See Table 5-2 No 7	R	R	R	R	R	R	R	R	R	R	R	-	
Shock	5.5.2.6	See Table 5-2 No 8	R	X	R	R	R	X	R	X	R	R	-	-	If it is demonstrated that the susceptibility to shock of the space segment equipment is above the shock environment, the test needs not to be performed. For k (solar array) shock qualification is performed at components level and confirmed during the deployment test.
Micro-vibration generated environment	5.5.2.7		X	X	-	X	X	-	X	-	-	X	-	-	Test to be performed only if need is identified by analysis.
Micro-vibration susceptibility	5.5.2.8	See Table 5-2 No 9	X	-	-	-	-	-	-	-	X	X	-	-	Test to be performed only if need is identified by analysis.
Structural integrity															
Leak	5.5.3.1	See Table 5-2 No 10	X	-	R	R	R	R	X	X	-	-	-	-	Leak and pressure tests may be combined.

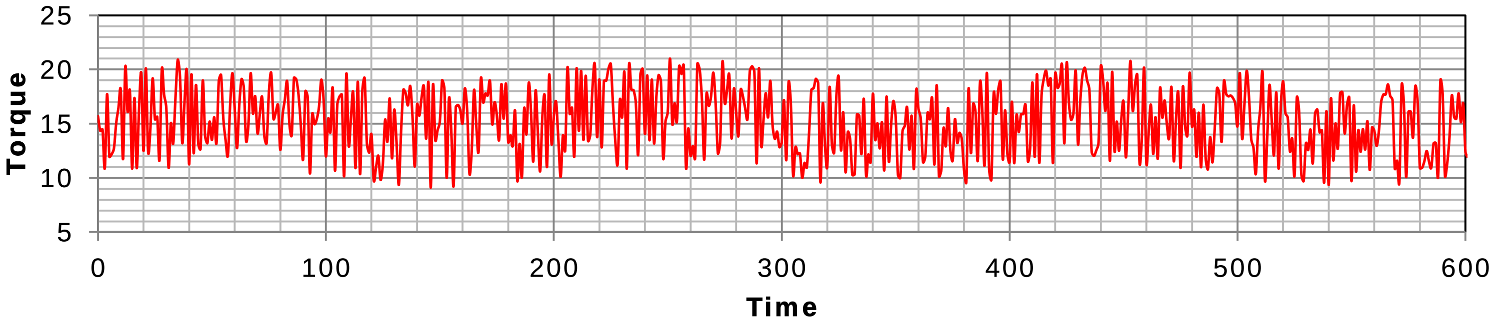
Thermal qualification

- Qualify mechanism performance for operational and non-operational temperature limits (usually **predicted limits ±10K**)
- Operation of the mechanism in a representative environment under worst-case **temperature gradients** shall be verified
- Pressure for TVAC < 10^{-5} mbar

Functional qualification testing

- Functional performance testing after **mechanical and thermal settling**
  - → i.e. run-in, thermal settling

- **Following the exposure** to environmental conditions



Energy and shock

- to withstand **release and end shocks**
- **shock emissions** shall be measured
- Micro-**vibration emissions** to be tested in representative configuration

Lifetime qualification testing

... shall be performed:

1. on a flight representative life test model
2. after exposure to flight representative environmental loads

Total vibration test duration:

acceptance duration at acceptance load × Number of acceptance tests + Qual. duration at qual. load

Including sub-system and system level tests!

Lifetime qualification testing (cont'd)

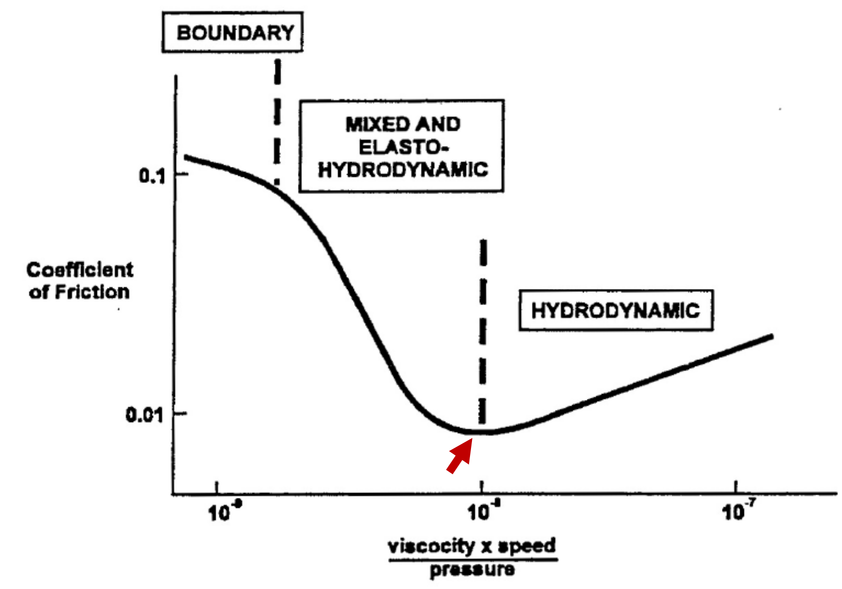
lifetime testing shall be representative with respect to:

1. Thermal conditions, loading conditions, contact stress, motion profile and speed

2. **<u>Lubrication regime</u>** (see Stribeck curve)

→ Very careful with acceleration of life test

→ Changes in ambient / operating conditions change lubrication regime



Lifetime qualification testing (cont'd)

Life test duration shall be no less than

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

→ [...] 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

Example I: Solar array deployment mechanism

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

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

Example II: Solar array drive mechanism for LEO

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

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: $29219 \times 2 + 320 \times 4 \approx \mathbf{60,000}$

Qualification testing success criteria

Disassembly and visual inspection of tribological parts:

- No direct contact between metallic parts
- Surface properties of contact surfaces not modified beyond specified limits
- No chemical deterioration beyond the specified limits of fluid lubricants
- Amount and size of wear acceptable (performance, contamination)
- Resistive torques according to 4.7.5.3. (motorization)
- Less than 50% degradation of resistive torques / forces
- Performance according to spec

Acceptance testing

- Tests to confirm that flight hardware free from manufacturing defects;
- Test content according to ECSS-E-ST-10-03C, table 5-3;
- Vibration levels and thermal loads which are higher than expected in flight but less than qualification
- Refurbishment should not be performed after successful acceptance testing

Thank you for your attention!