Space Technology

Structure and Mechanisms

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Primary Structure

(Arianespace)

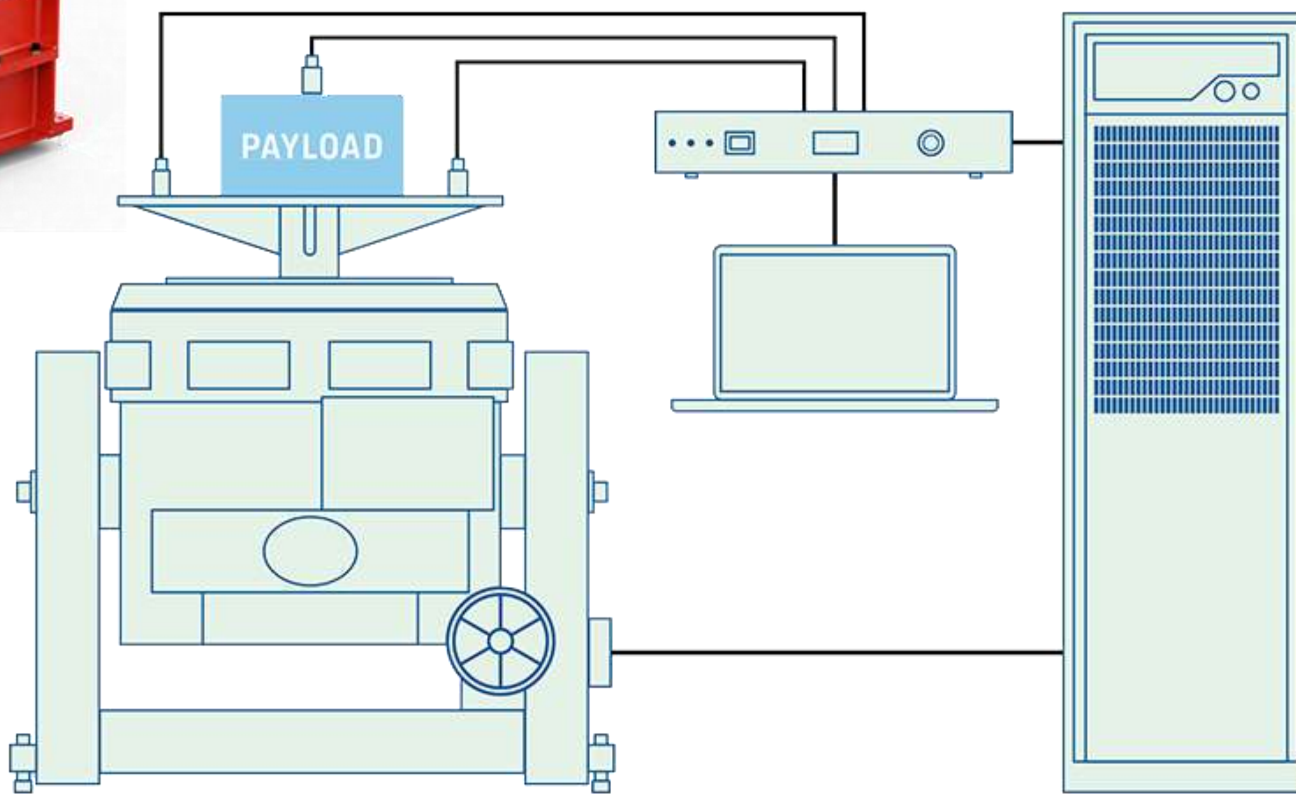
- ❑ The load-carrying cell of a spacecraft (S/C)
- ❑ All other units are fastened there

- ❑ Design phases:
  - ❑ Phase A: based on mission objective (geometry, launcher)
  - ❑ Phase B: feasibility studies, breadboard models
  - ❑ Phase C: final models and numerical analysis; building the flight model (FM)

Mechanical testing: BepiColombo vertical vibration test
(Mercury mission 2018-25)

Vibration testing

- Steady-state acceleration test
- Low-frequency (5-100Hz tests)
- Acoustic tests (20-2000Hz)
- Random vibration test



(Brüel & Kjær)

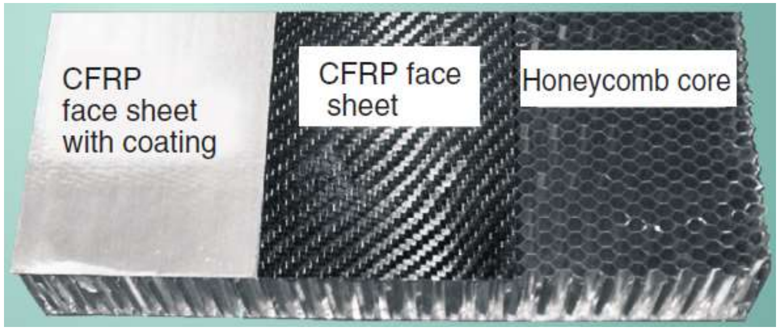
Load types

- Dynamic load during the launch
  - sinusoidal
  - random
  - acoustic
- Shock load
  - stage separation
  - firing pyros
- In-orbit: no critical load
  - opening solar panels
  - booms, servo motors
- Extraterrestrial missions
  - landing on a planet: more critical than the launch
  - extreme tharmal schock may arise

Material selection

- Metallic alloys for sheets, plates, profiles
  - aluminum (leading)
  - titanium-based alloys (hardness)
  - beryllium alloys (light but toxic)

- Fiber composites
  - carbon fiber
  - carbon fiber-reinforced plastic (CFRP)
  - glass fibers
  - aramid fibers; (synthetic fibers Kevlar)



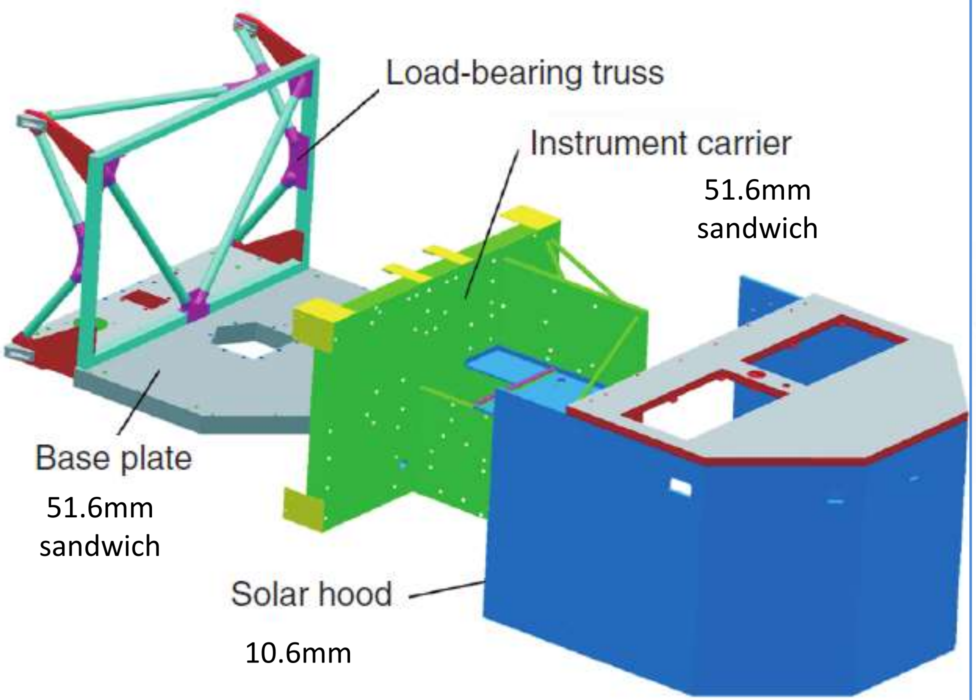
- Fiber–metal laminates (FML)

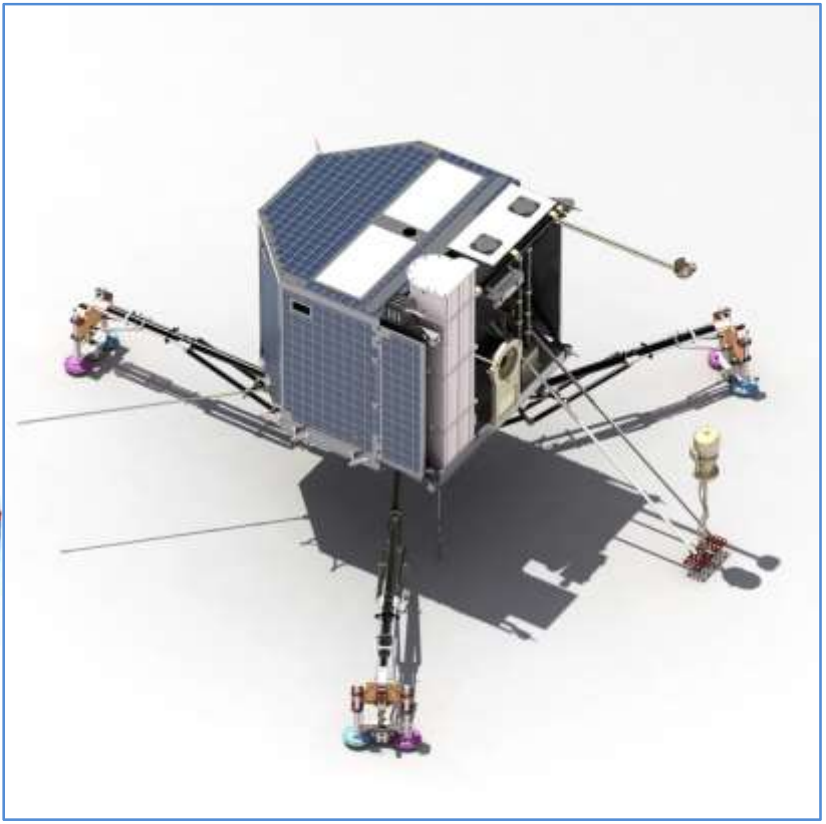
- For high temperature:
  - ceramic matrix composites (CMC)
  - carbon/carbon compounds (C/C)
  - silicon carbide compounds (C/SiC)

Construction 1.

- Structure with sandwich plates: two parallel face sheets on a (honeycomb) core with hexagonal cells
  - Appropriate for small satellites forming a cube or cuboid, no internal structure is needed
  - Larger satellites: a central structure also needed
  - [Cubesats]

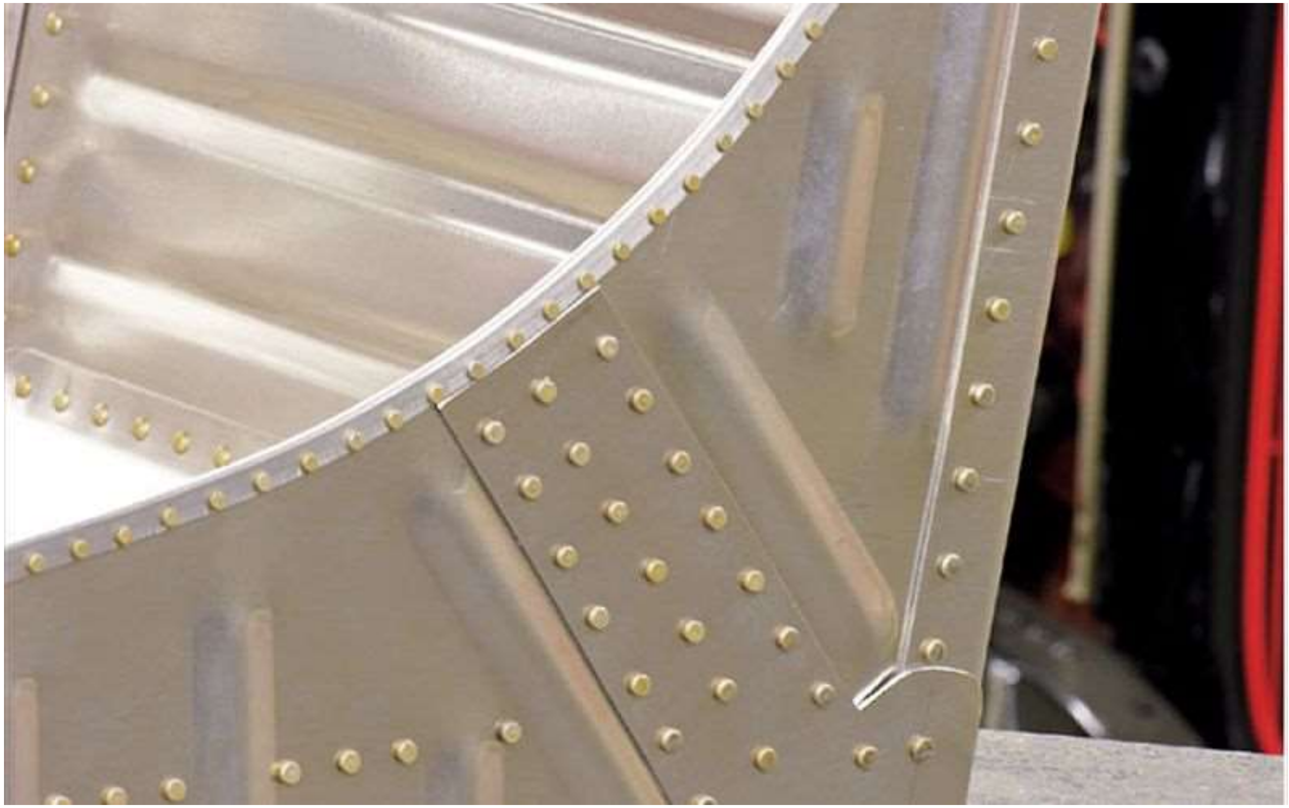
Example: the Rosetta Lander Philae)





Construction 2.

- Differential construction
  - combining preformed components connected by rivets or screws
  - cost effective but integration is time consuming
  - resistant to crack propagation



Construction 3.

- Monolithic construction
  - a single or only a few large parts
  - metallic structures manufactured using CNC technology (aluminum)
  - heavier than the sandwich technology

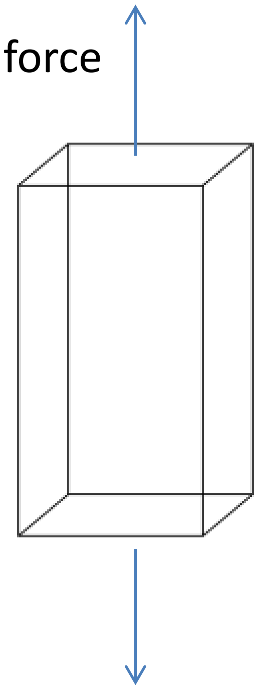
  - fiber composite structures: hand lamination of complex structural parts

Construction 4.

- Heat isolation with multi-layer structure
  - ESA-NASA's Solar Orbiter:
    - 41Mkm (closest)
    - Temperatures: - 180 … 520 °C
    - The front layer: thin sheets of titanium foil to reflect heat.
    - Heat shield is coated with a thin, black layer of calcium phosphate.
    - A honeycomb-patterned aluminum base, covered in more foil insulation, forms the inner slice.
    - 10 inch and 5 inch gaps without filling
    - Panels of radiators on the side of the spacecraft eject heat and ensure the instruments don't get too hot.

Structural analysis: physical concepts 1.

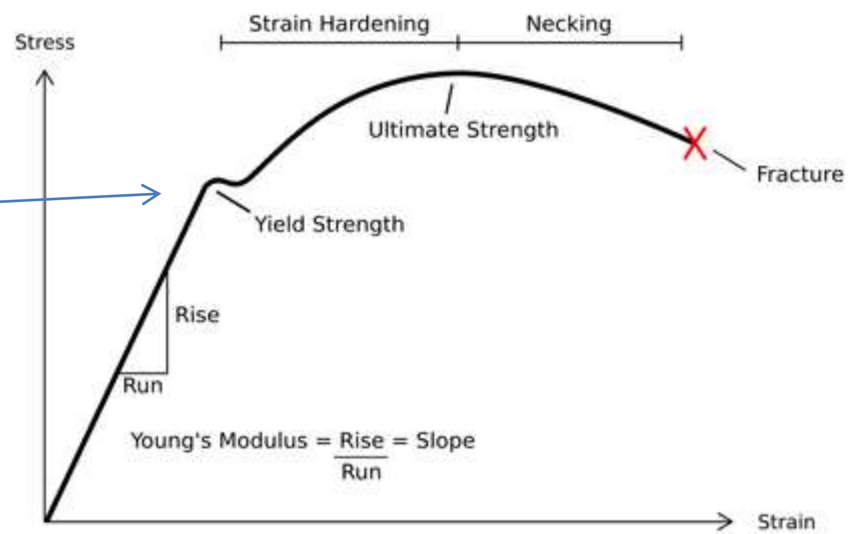
force



Yield

- ❑ Parameters:
  - ❑ L length
  - ❑ W width
  - ❑ A cross-section
- ❑ Apply axial force: the length changes
- ❑ Force/area=stress
- ❑ Deformation length/total length=strain

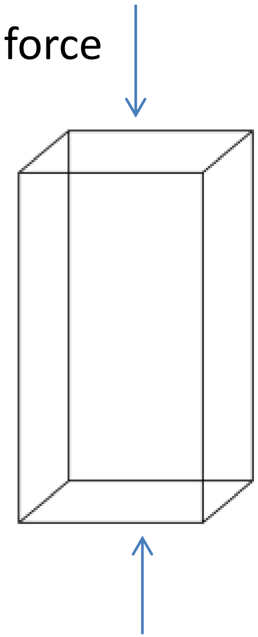
Safe structure:
stress below this point

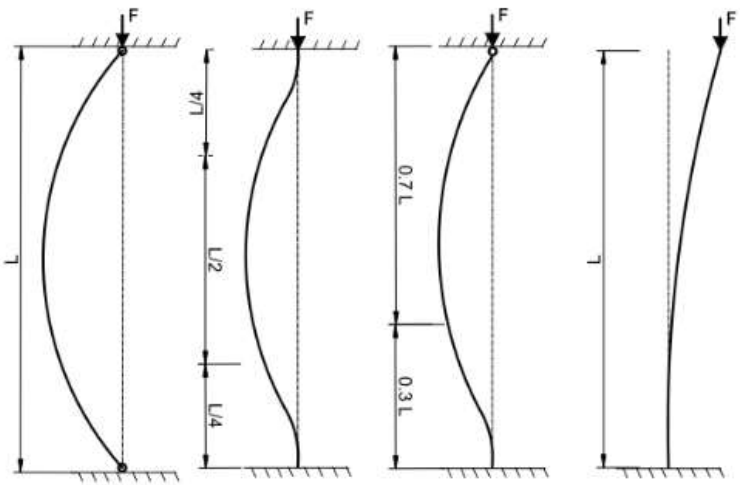


(elongation)

(Example 1.)

Structural analysis: physical concepts 2.





C=1 C=4 C=2 C=0.25

Compression->bending->break at much lower stress

<u>Strut types</u>

Euler's formula:

$$f_C = \frac{C\pi^2 E}{(L/\rho)^2}$$

Allowable stress under compression

L: length
E: elasticity modulus
ρ: gyration radius

(radial distance to a point which would have same moment of inertia as the body's actual mass distribution)

(Example 2.)

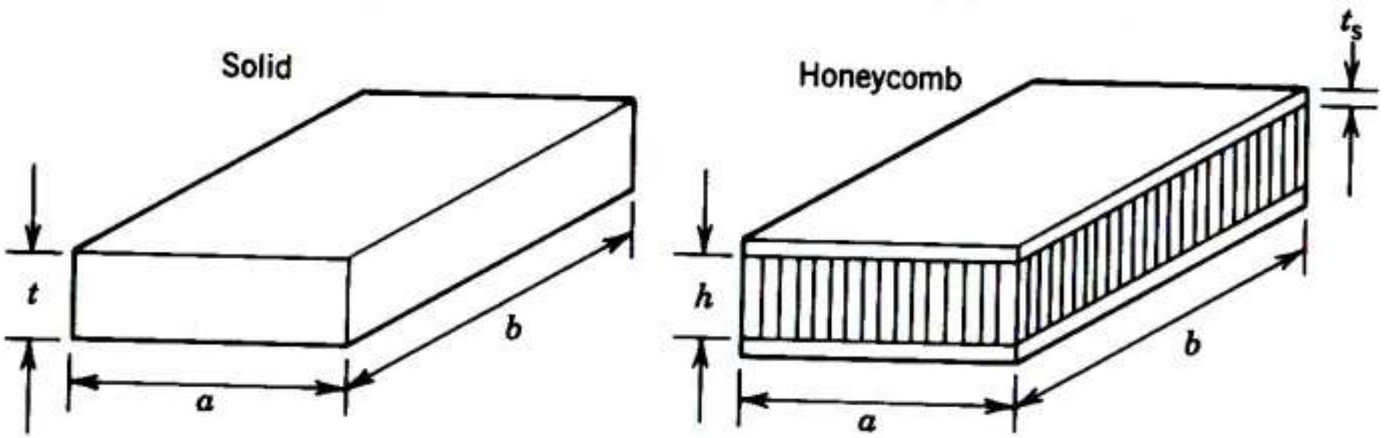
Structural analysis: physical concepts 3.

Flat panel maximum stress [N/m²]:

w: load/area (weight/area)
β: coefficient (0-1)

$$\sigma_{MAX} = \beta \frac{wa^2}{t^2}$$

$$\sigma_{MAX} = \beta \frac{wa^2}{6ht_S}$$



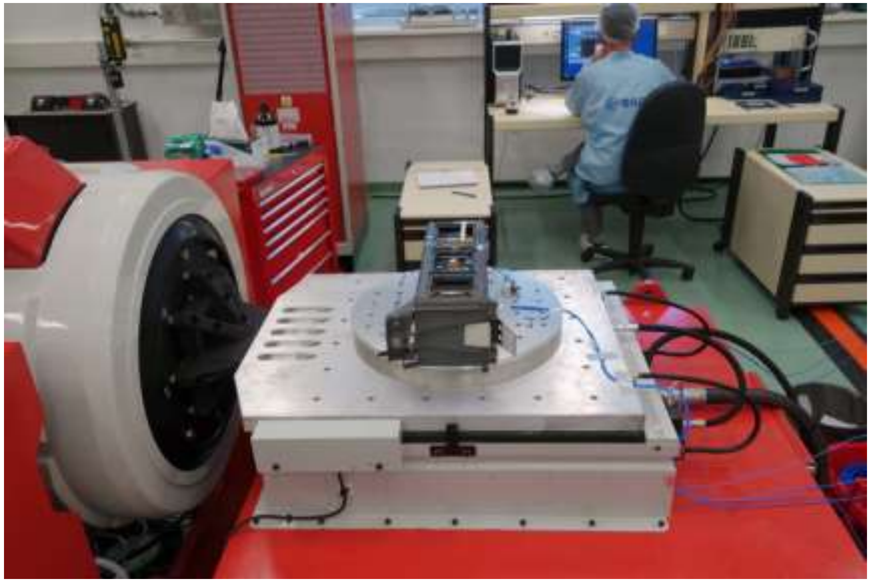
(Example 3a.)

Structural analysis: physical concepts 4.

Panel resonance:

β: aspect ratio dependent
D: rigidity
ρ: mass/area
a: smaller size dimension

$$\omega = \beta \sqrt{\frac{D}{\rho a^4}}$$



(Example 3b.)

Endurance under space conditions

- High vacuum: outgassing
  - material selection is critical
- High-energy radiation: UV, X-ray, gamma
  - destroys material bonds
  - kapton (polymide) and MLI foils
  - use of well-reflecting surface
  - use of conducting surfaces

Clean room

ESCC No 24900:
European Space Components Coordination

(ESA)

Applicable for:
manufacturing, testing and storage of electronic, electrical and electromechanical components
Goal:
minimize the effects of contamination from the environment
ISO cleanliness classes 4-8

- temperature
- humidity
- vibration
- light
- ESD
- EM field
- gases, chemicals, liquids
- contamination (chemical, human, machine)

‘Off the shelf’ products and useful links

https://www.ruag.com/en/products-services/space/spacecraft/satellite-structures

https://www.cubesatshop.com/product-category/cubesat-structures/

https://www.nasa.gov/smallsat-institute/sst-soa-2020/structures-materials-and-mechanisms

https://blog.satsearch.co/2020-09-25-satellite-structures-on-the-global-marketplace

Sources:

- Gary D. Gordon, Walter L. Morgan:
  Principles of Communications Satellites
  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- Metals that are often used in space technology
- Other materials (fiber and ceramic composites)
- Advantages of the honeycomb structure
- Main physical impacts (press, pull, vibration, flat panel stress)
- Space conditions that are affecting the material parameters