Spacecraft Structures

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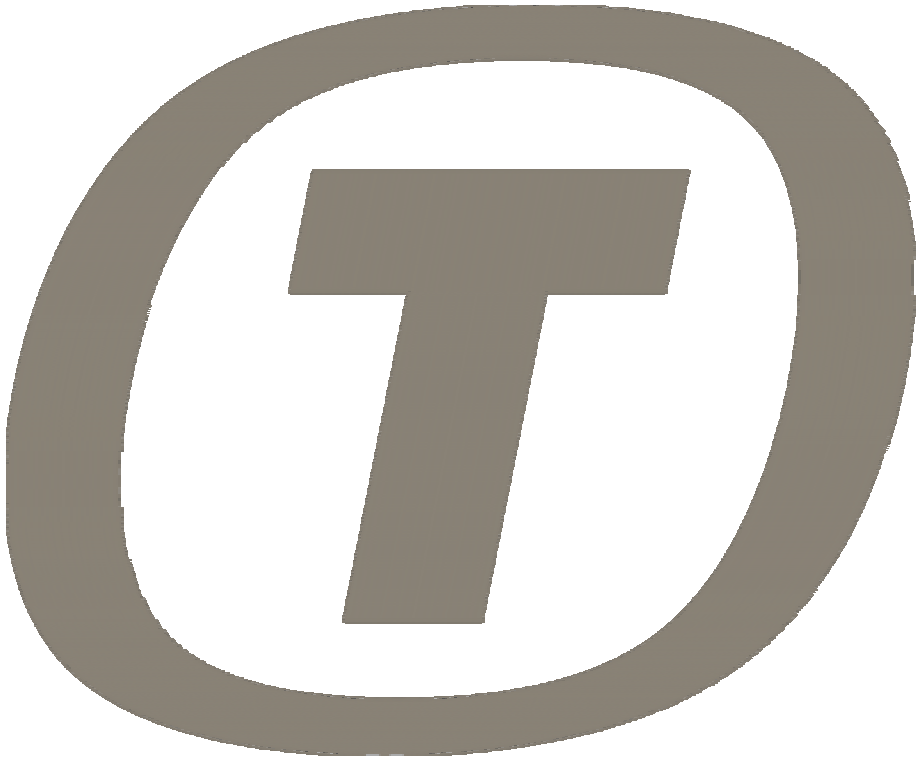

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Aalborg, 17 October 2001

Spacecraft Structures

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- **Agenda**

  - **Introduction**
  - **Ørsted**
  - **General**

Introduction

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- **TERMA A/S**
- **Terma Industries Grenaa**
    - **Ole Riis**
        - **VLT**
        - **XMM CFRP Mirror**
        - **Ørsted**
        - **Planck CFRP Mirror**
        - **SAC-C (Ørsted-2)**

Ørsted Satellite: Historical Background

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- Definition Phase ended 1991
- Design & Manufacture ended 1993
- Test campaign ended 1995
- Delayed due to P91 Argus
- Launch: 23 February 1999

Ørsted mission

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- **Ørsted Mission Profile**
  - **Carry science instruments into a polar, sun synchronous Low Earth Orbit.**
  - **Deploy the star imager and the magnetometer 6m and 8m away from satellite by means of a coilable boom.**
  - **During a life time of not less than 14 months measure the earth magnetic field, and solar high energy radiation**

System Design

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- **Satellite provide supporting structure for:**
  - **a coilable boom, 8 m**
  - **instruments**
  - **power (battery/solar panels)**
  - **data handling and storage**
  - **attitude control**
  - **communication**
  - **thermal control**

- **Dimensions: approx. 45 cm * 35 cm base; approx. 70 cm height**
- **Weight : approx. 60 kg**
- **Magnetic: clean**
- **Mechanisms: coilable boom, 8m; release mechanisms**

Launch Vehicle

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- **DELTA II**
  - **Main Data**
    - **Launcher:** Delta II 7920, Boeing
    - **Launch Site:** Space Launch Complex 2, Vandenberg AFB.
    - **First Flight:** November 1990, Flight No. 266.(Ørsted)
      - **Stage I and II:** First stage (LOX and kerosene) + 9 solid rocket boosters; Sec. stage (Aerozine and Nitrogen-tetraoxid)
    - **Weight at take-off:** approx. 228 ton
    - **Height:** 37,6 meter
    - **Diameter:** max 2,4 m, nose cap 3 meter
    - **Lift-off pressure:** 4904 kN
    - **Payload capacity:** approx. 5 ton

Launch Configuration

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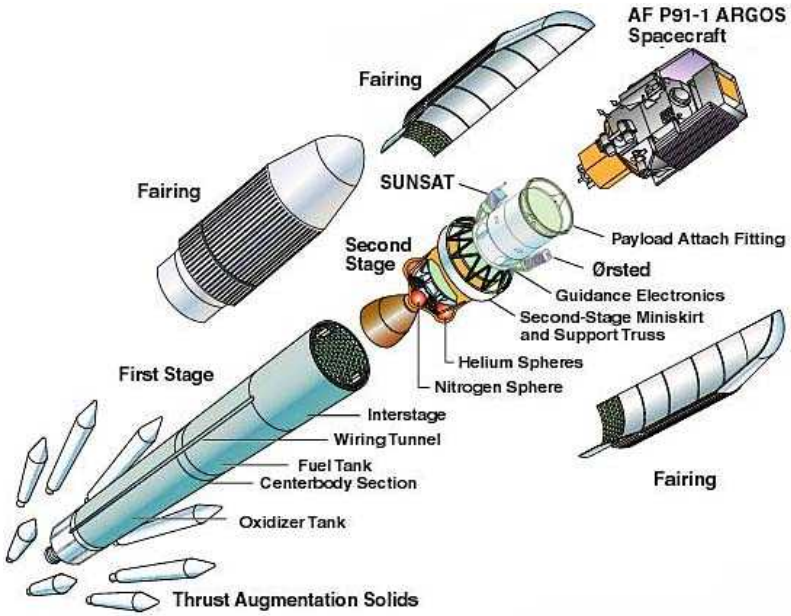

- **DELTA II Launch Configuration**

Launch Profile

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Event Time (h:mm:ss)

Lift-off 0:00:00.0
Mach 1 (738 mph) 0:00:32.5
Jettison last three solid motors 0:02:11.5
Main engine cut-off (MECO) 0:04:23.5

Second stage ignition 0:04:37.0
Jettison payload fairing 0:04:42.0
First cut-off - Second stage engine (SECO 1) 0:10:58.6
Second stage restart ignition 0:51:22.0
SECO 2 0:51:42.0

Begin manoeuvres for ARGOS separation 0:51:55.0
End manoeuvres for ARGOS separation 0:56:40.0
ARGOS spacecraft separation (release latches) 0:58:20.0

Begin manoeuvres for Ørsted/SUNSAT spacecraft separation 0:58:20.5
End manoeuvres for Ørsted/SUNSAT spacecraft separation 1:31:44.9

Reorient to Ørsted/SUNSAT spacecraft separation 1:35:00.0
Ørsted/SUNSAT spacecraft separation 1:40:00.0

Launch

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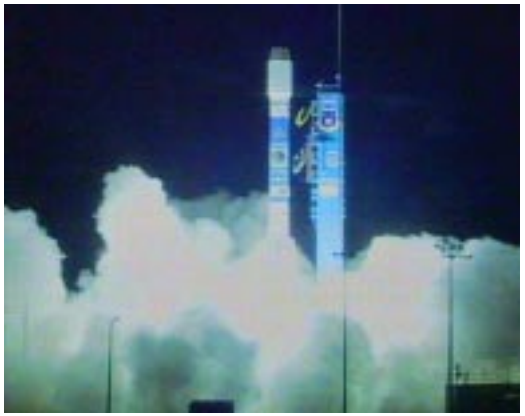

Structural Requirements

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- **“The structure shall support the payload and spacecraft subsystems with enough strength and stiffness to preclude any failure that may keep them from working successfully.”**

- **Provide:**
  - **a satellite primary structure which is the backbone, or major load path, between the satellite components and the launch vehicle.**
  - **satellite secondary structure which are beams, booms, trusses, and solar panels.**
  - **mechanisms which are moving assemblies, hinges, release mechanisms, drive, deployable solar panels.**
  - **a producible design which can be manufactured using affordable raw materials, established and simple processes, and available equipment.**
  - **a testable product which can be handled and tested on ground without complex equipment and procedures.**
  - **a maintainable product which is easy to access, remove, and replace.**
  - **a product which is operable with simple electronics and software**

Structural Requirements

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- **Secondary payload (SP):**
  - **“Secondary payload planners guide”**
    - **no hazard to primary payload**
    - **subject to approval of the primary payload project manager**
    - **primary mission orbit requirements shall not be affected by SP’s**
    - **not intrude on primary payload clearance envelope**
    - **support structure, clamp bands, and separation system provided by Boeing**

Ørsted Requirements

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- Parts, Materials and Processes	approved parts and material list
- Dissimilar materials	direct contact avoided / suitable surface protection
- Magnetic materials	avoided / minimised
- Venting	no closed cavities
- Mechanical interface	interface with DELTA II separation system
- Dimensions	
- Weight	< 65 kg
- Centre of Gravity	< 295 mm
- Weight and Balance	weight, CoG, MoI (Boom stowed / deployed)
- Operating life	> 14 months
- Storage life	> 24 months

Ørsted Requirements

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- **Magnetic Cleanliness**	**average less than 22 mA/m² per kg**
- **Normal modes (lateral)**	**> 50 Hz**
- **Normal modes (axial)**	**> 100 Hz**
- **Grounding**	**common ground**
- **Mechanisms:**	
- **Release mechanisms**	**provide safe stowage of boom**
- **Boom**	**deploy CSC Magnetometer/Star Imager 6m from satellite, and Overhauser magnetometer 8m from satellite**
- **Solar array**	**ventilated sandwich substrate / acoustic pressure**
- **Redundancy**	**incorporate piece part, subassembly and assembly level redundancy where necessary**
- **Functional redundancy**	**redundant component techniques**

Ørsted Requirements

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- Single point failure		eliminated or minimised (identify / analysis)
- FMECA		minimise effects
- Transportability		by road, rail or air (transport container)
- AIV		assembly, integration, verification
- Pre-Launch		
- RH		70 % max.
- Barometric pressure		109 to 89 kPa
- Temperature (integrated satellite)		-30 ºC to +45 ºC
- Launch		
- Thermal environment	launch:	fairing internal temperature
		after fairing jettison < 1135 W/m²
	orbit:	- 70 ºC to + 90 ºC

Ørsted Requirements

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- **Barometric pressure**	**- Sea level decreasing to 10^{-8} Pa, rate not less than 3.0 kPa/second**
- **Flight dynamic environment:**	**- Steady state acceleration (max at pre-MECO)** **- Sinusoidal vibration** **- Random vibration** **- Acoustic environment** **- Shock environment**
- **Electromagnetic radiation**	**-First stage/Second stage transmitter**
- **Post-Launch**	
- **Shock**	**- Separation mechanism operation**
- **Solar electromagnetic radiation**	**- 1353 W/m^2**
- **Atomic oxygen**	**- Materials / Surface finishes (oxidation of materials)**

Ørsted: Test and Analysis

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- **Test**
- **Boom:** **development tests**
  - **manufacturing**
  - **spacer: bending- / torsional stiffness**
  - **longeron: “coil test”**

  boom: deployment test
- **Satellite:** **modal test/survey**
  sinusoidal vibration
  random vibration
  shock
  acoustic noise
  boom release
  thermal vacuum
  thermal vacuum soak and cycling

Ørsted: Test and Analysis

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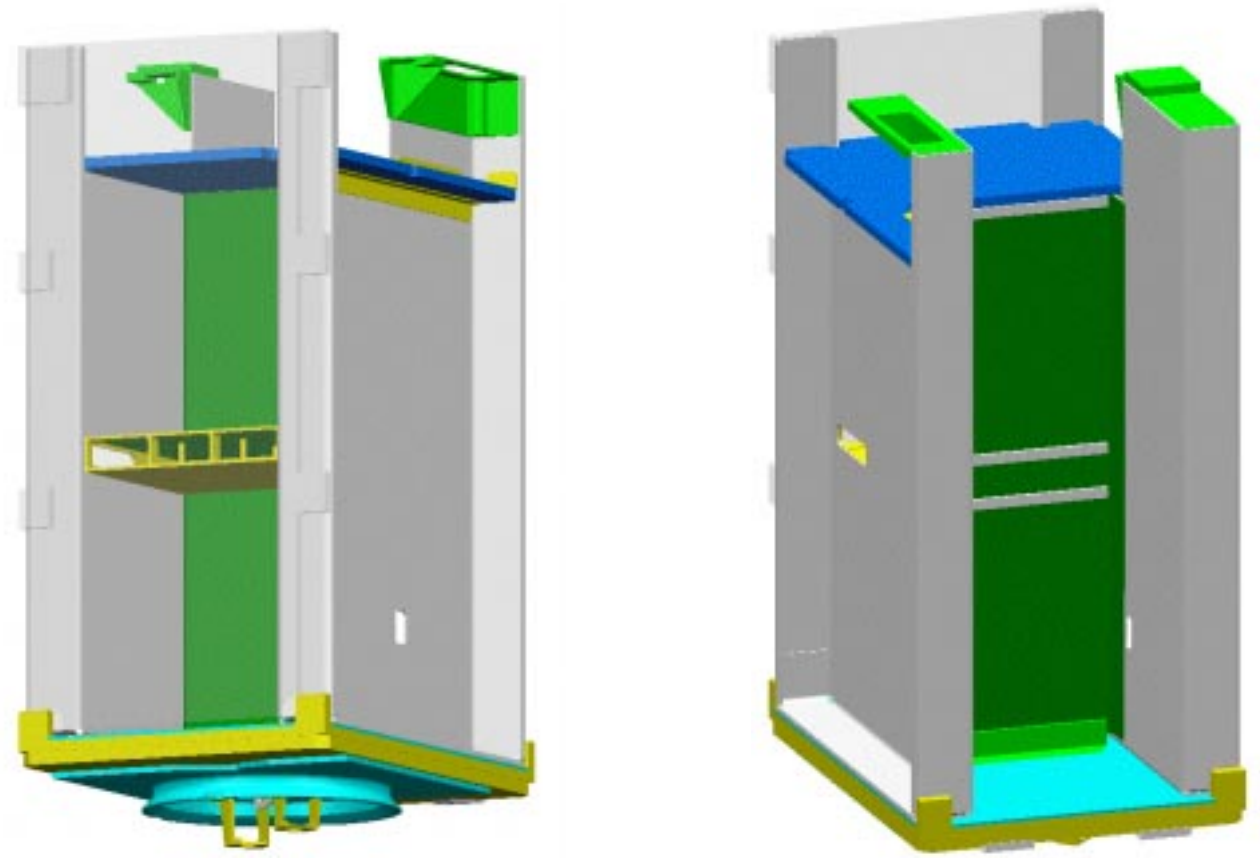
- **boom** — **thermal vacuum**
  thermal vacuum soak and cycling

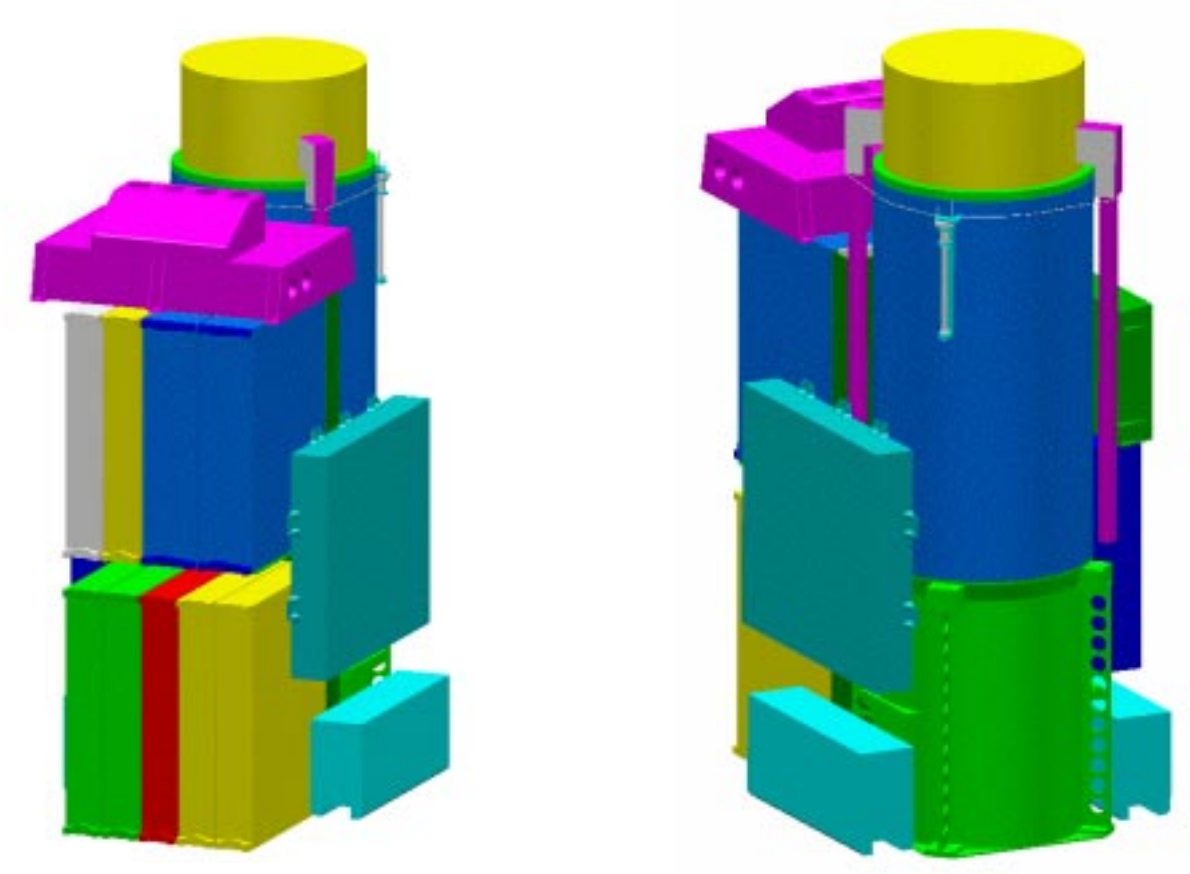
- **Analysis:** **Static ± 10 G, each axis simultaneously**
  (Based on prel. dynamic analysis (> 35 Hz))

  Dynamic: **Normal modes**
  Pre-test model
  Correlated Post-test model

Ørsted Primary Structure



Ørsted Payload



Ørsted Satellite and Boom

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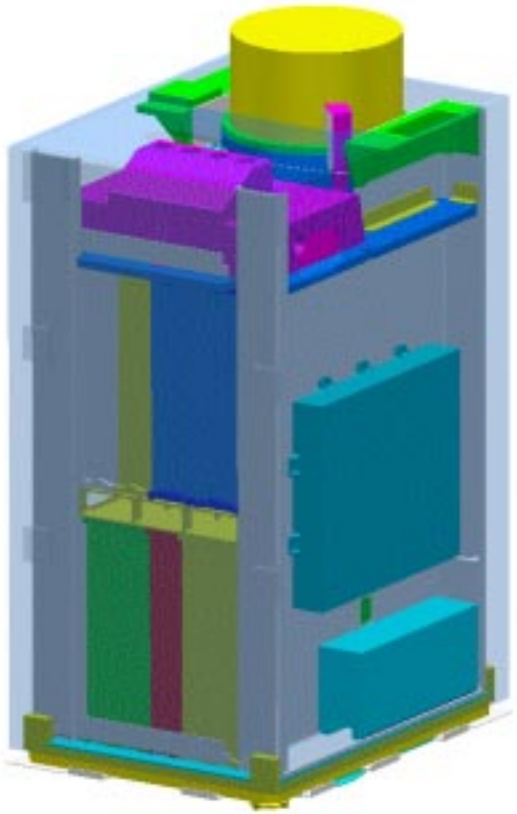

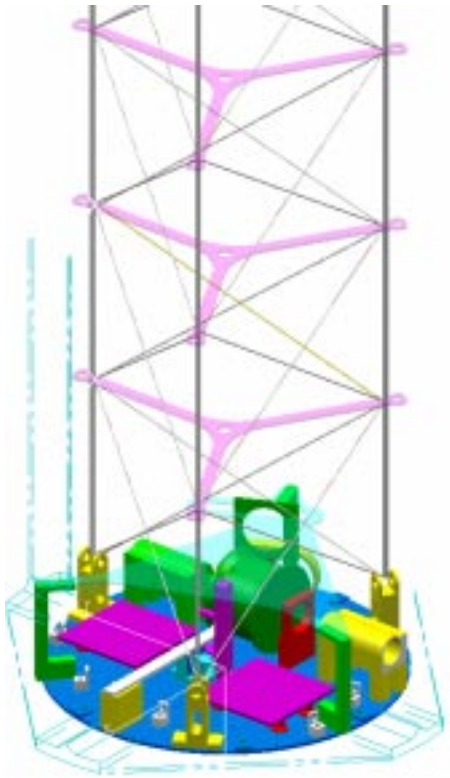

Key considerations for Spacecraft Structures and Mechanisms

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- **Dynamics and Loads**

  - **predict natural frequencies, modes of vibration, and damping**
  - **predict responses to time-varying forces and vibrations**

    - **identify design features that will reduce expected loads and vibrations**
    - **identify required structural characteristics and verify them prior to or instead of a test**
    - **predict loads and vibration environments for design and test**
    - **predict structural characteristics to help develop the attitude control system**
    - **plan modal test and interpret results**

Key considerations for Spacecraft Structures and Mechanisms

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- **Stress**

  - predict member loads and stresses to assess weather the structure can withstand
    - a single load application
    - cyclic or sustained loading

  - identify design features that will provide the required strength and life
  - verify strength and life requirements
  - develop conditions for strength tests and life tests, and interpret the results

Key considerations for Spacecraft Structures and Mechanisms

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- **Stiffness**

- **predict stiffness and displacement**

- **identify desirable design features**
- **verify stiffness requirements**

- **Mass Properties**

- **predict mass, centre of gravity, and mass moments of inertia**

- **verify mass-properties requirements**
- **provide inputs for stress, dynamics, propulsion, and attitude-control analysis**

Risk assessment

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- **Probability of failure / Consequence of failure**

  - **Relatively new launch vehicle**
  - **No development program**
  - **Long-lead items (schedule risk)**
  - **Materials uncharacterised / No flight heritage**
  - **New supplier (requirements definition)**
  - **Undeveloped manufacturing process**
  - **Complex designs**
  - **Complex manufacture (unproven)**
  - **Requirements hard to verify**

Environment

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- **Low-Earth Orbit (LEO); 200-700 km**

- **<u>Atomic oxygen</u>**
- **erodes exposed materials, degrade properties**
  - **surface protection**

- **<u>Radiation</u>**
- **solar, reflected, thermal: to hot / to cold**
  - **thermal protection**
- **particulate (solar wind/flares): penetrate structure, damage on electronics**
  - **shielding difficult**

- **<u>Vacuum</u>**
- **10E-8 Pa; rate 3.0 kPa/second: no closed cavities, out-gassing(TML and CVCM), de-absorb: degrade properties, condense, misalignment**
  - **venting, surface protection, bake-out, contamination budget, structural behaviour**

- **<u>Micro-meteorites / Debris</u>**
- **impact velocity, stiffness, mass: worst case - loss of satellite**

Mechanical verification

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- **Confidence in Mechanical Design and Product**
  - **Understand product requirement (SOW ….**
  - **Design to those requirements (PD …..**
  - **Manufacture to specifications (PO, DOL ….**
  - **Control product configuration (QA/QC …..**
    - **Verify requirements by combining:**
      - **analysis**
      - **process specification**
      - **inspection**
      - **test**

Verification: Test

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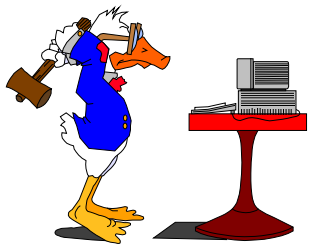
- Development test
  - demonstrate design concepts, information for design
  - manufacture of development article

- Qualification test
  - qualify design
  - QM, not used for flight
  - qualification test levels
  - low safety factor
  - lowest impact of test failure

- Acceptance test
  - only option to demonstrate workmanship / process control
  - FM, used for flight
  - acceptance test levels
  - test each member



Verification: Test

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- Proto-Flight test (CQAT), test one flight unit
  - combined qualification and acceptance test
  - FM used for flight
  - test level higher than acceptance levels, lower than qualification levels
  - only one of each member requires testing
  - cleanliness control
  - greater impact of test failure
  - increased requirements on analysis

- No structural test
  - saves cost and time
  - highest factors of safety
  - depends solely on analysis

Verification: Test types

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- **Static Loads**
  - constant level, verify stiffness, if random/acoustic test not adequate
  - structures with low natural frequencies, compact structures
  - combine limit load and temperature

- **Sinusoidal Vibration**
  - verify structural modes, low level to verify natural frequencies
  - structures with low natural frequencies, primarily sinusoidal loaded
  - not environmental test

- **Cyclic loads**
  - verify fatigue life, if random/acoustic test not adequate
  - no reliable fatigue data, uncharacterised materials

- **Pressure**
  - verify pressurised equipment
  - propellant tanks, pressurised equipment
  - qualification test (burst), acceptance test

Verification: Test types

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- **Random Vibration**
  - verify strength and life through mechanical interface
- **Acoustic Vibration**
  - verify strength and life through acoustic pressure
  - lightweight structures / large surface area
- **Pyrotechnic Shock**
  - high frequency shock waves
  - electrical components
- **Thermal Vacuum**
  - out-gassing levels
  - verify operational performance
  - electrical equipment; fully integrated spacecraft
- **Thermal Cycling**
  - verify life for cyclic thermal conditions
  - electrical equipment; fully integrated spacecraft

PMP control plan

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- **Parts, Materials and Processes**

  - **Purpose and Scope**
  - **Applicable Documents**
  - **PMP selection, responsibilities, and implementation**
  - **Technical requirements**

  - **Appendices**
    - **Materials**
    - **Mechanical parts**
    - **Mechanical process**
    - **Electronic parts**

AIV plan

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- **Assembly, Integration and Verification Plan**

  - **conceptual, preliminary and detail design, and test**
  - **assemble, wire and service equipment**
  - **MGSE, EGSE, OGSE**