



Global Forum on Longevity of Structures
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Orlando, Florida

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Spacecraft Structures and Dynamics
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Spacecraft Structures

What is the work of the Jet Propulsion Laboratory?

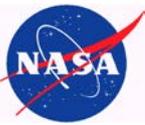
JPL's charter is to conduct robotic space missions for NASA, to explore planetary systems, understand the origin and evolution of the universe and make critical measurements to understand the earth, which leads to its protection.

How are mission objectives achieved with respect to longevity of the structural mechanical element?

- Ensure design margin by accounting for uncertainties of loading events, thermal environment, and structural analyses → model uncertainties, loads uncertainties, thermal margins, factors of safety
- Consider all significant affects which contribute to the stress state → residual stresses, pressure, thermal, static and transient accelerations, stress concentrations/discontinuities
- Account for any material degradation due to radiation affects, thermal cycling, operating temperature, creep. Add protection against micrometeroid impact
- Implement a test verification program to develop mechanical properties, test assemblies, and verify the end to end design at the Spacecraft assembly level to shock, acoustics, and random vibration environments

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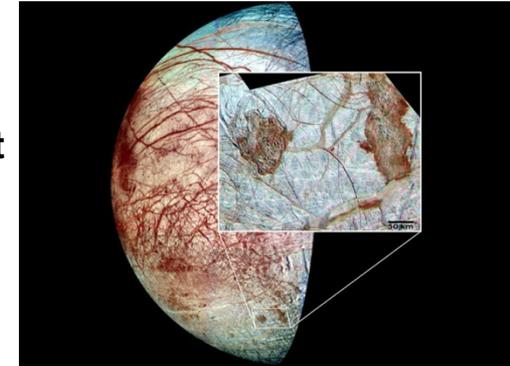


JPL Past Missions

**Volcanic
Plumes of
Io Nov '97**



**Evidence of Wet
& Wild Europa
April '97**



Galileo mission to Jupiter (launched on Shuttle Oct 18, 1989)

- Prime mission objectives completed Dec 7, 1997 (two years in Jovian system)
 - Note the High Gain Antenna failed to fully deploy affecting data transfer rates
- Extended Galileo Europa Mission for 14 additional orbits and study of moons Europa and Io
- Extended Galileo Millennium Mission for study of moons Europa and Io and radiation affects on Spacecraft – mission ended 2001
- Spacecraft destroyed Sept 21, 2003 when it entered and was crushed by Jupiter's atmosphere

→ Total science mission duration was ~6 years vs 2 years prime, cameras destroyed by the high radiation environment and were deactivated in Jan '02

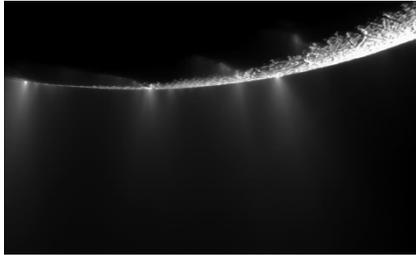
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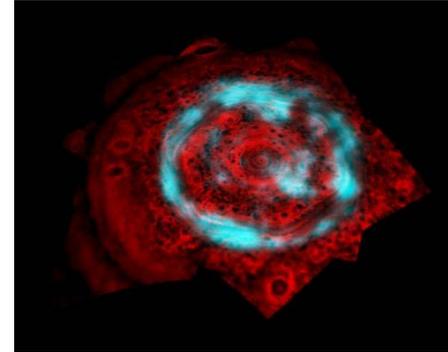


JPL Past Missions

**Plumes of Enceladus
Nov '09**



**Saturn Polar
Aurora June '08**



Cassini mission to Saturn (launched on Titan IV Oct 15, 1997)

- Prime mission objectives completed June 2008 (four years in Saturnian system)
- Extended Cassini Equinox mission, 2 years
- Extended Cassini Solstice to study a complete seasonal period to Sept 2017

→ Total science mission duration expected
~13 years vs 4 years prime





JPL Past Missions

Spirit's arm
on
Adirondack



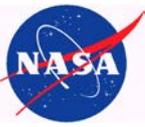
Opportunity Landing
at Eagle Crater

Mars Exploration Rovers mission to Mars (launched on Delta II June/July 2003)

- Prime mission objectives completed Jan 2004 (90 sols/Mars days on the surface, 1 km travel)
- Spirit Rover stopped communicating on March 22, 2010
 - First evidence of mechanical issues: failure of right front wheel drive May 2009
- Opportunity Rover continues to operate

→ Total science mission duration to date

- Spirit Rover: traveled 7.7 km, 2210 sols
- Opportunity Rover: traveled 30 km, 2640 sols



Design and Verification of Spacecraft

Loads Definition (Launch and Entry, Descent, and Landing)

- Launch loads typical use three loads cycles with Loads Uncertainty Factors (LUF) of 1.50, 1.25, 1.10 (Modal characterization of primary spacecraft required)
- EDL loads can follow various approaches with use of LUF of 1.25 or Monte Carlo 99%tile loads

Computation of Structural Margins of Safety

- For structures which will be test verified at 1.20 x Limit Loads: standard Factors of Safety of 1.40 ultimate and 1.25 yield (1.50 ultimate for composite structures)
- Material strengths for margins of safety calculations use A-basis for metals and B-basis for composites
- Development program implemented to establish bonded joint allowables and composite layup allowables
- Fatigue critical structures: able to sustain 1 life plus 3 extra (total of 4 lives)

System Level Environmental Testing: Random, Acoustic, 2 firings of each pyro device

Mechanisms (Moving Mechanical Assemblies)

- Mission-critical Mechanisms require Fault Tree Analyses, No single point failures, and functional redundancy or graceful degradation
- Test Verification: exposure to all dynamic environments, functional tests at Allowable Flight Temp -15/+20 C, life cycle tests (≥ 2 lives), demonstrate 100% functional margin under worst case conditions by test (or test and analysis)

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Longevity of Spacecraft Structures

What is the source of excess capacity in spacecraft structures?

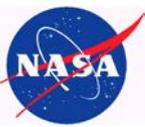
- Primary structures are designed for the most stressing loads environment
 - For flyby missions, the critical stressing environment is launch. During the science acquisition phase, the acceleration loading is extremely low at the time when thermal cycling and radiation exposure degrade materials
 - For EDL missions, the critical stressing environment occurs with high acceleration loading, degraded material strengths, and surface phase thermal cycling
 - The critical acceleration loading events are low cycle, not fatigue critical
 - Structural margins are based on factored loads, factored stress, and statistical material allowables
- Moving Mechanical Assemblies are required to demonstrate ≥ 2 lives

When do missions end

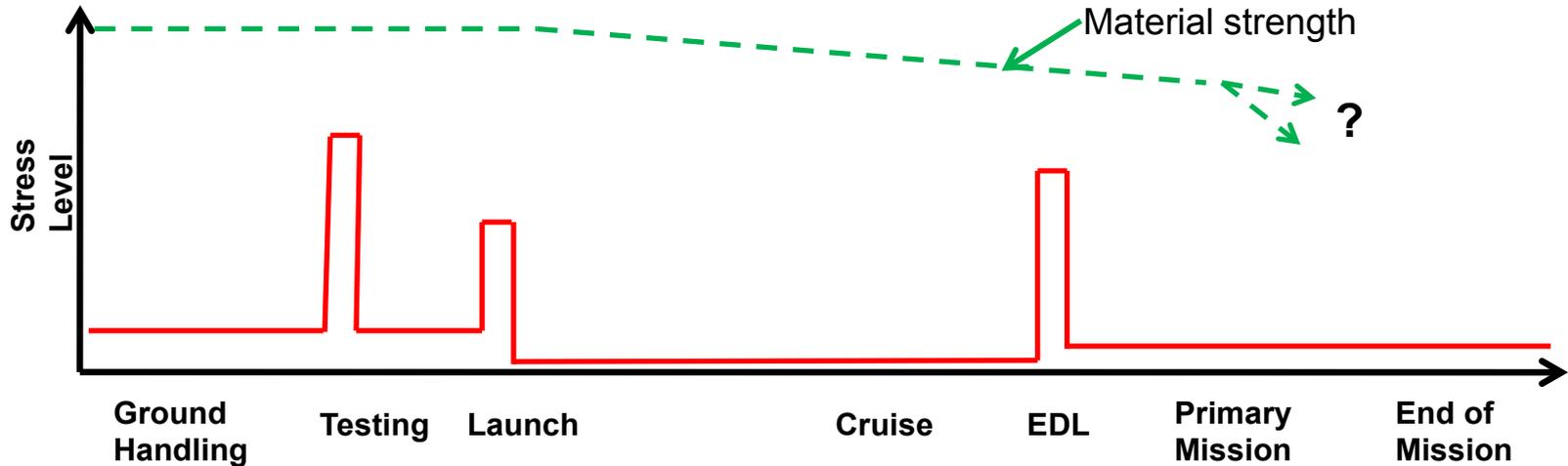
- Material and electronic parts degradation due to thermal cycling or radiation exposure
- Wear of moving parts due to thermal cycling and debris
- Limited resources: fuel for propulsion, solar power, and battery life
- Intentional de-orbits and probe releases (crushed by high pressure environment and high temperature)

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Longevity of Spacecraft Structures



Spacecraft Structures through the design and verification process are robust with respect to primary mission objectives

- In general, key material properties (strength or performance) should be protected to limit degradation to no more than 25% for the primary mission
- Aerospace practices are contained in the following references:
 - NASA STD 5001 “Structural Design and Test Factors of Safety for Spaceflight Hardware”
 - NASA STD 7002A “Payload Test Requirements”
 - NASA STD 5019 “Fracture Control Requirements for Spaceflight Hardware”