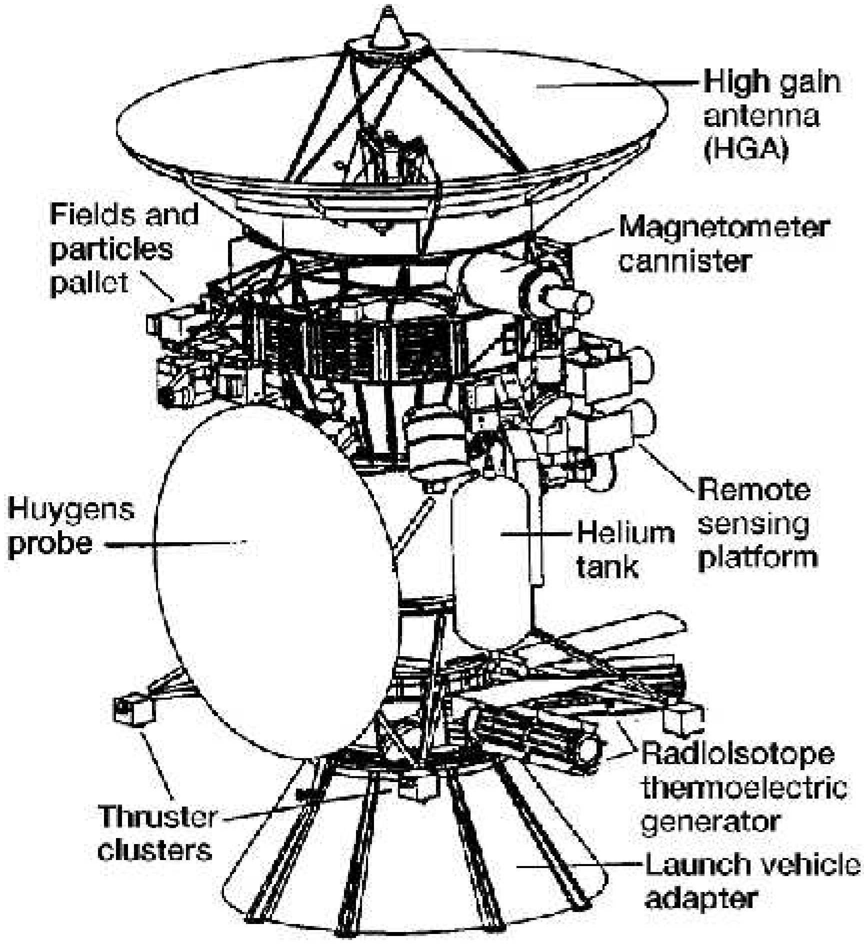
Nonlinear Dynamic Behavior in the Cassini Spacecraft Modal Survey



Cassini spacecraft.

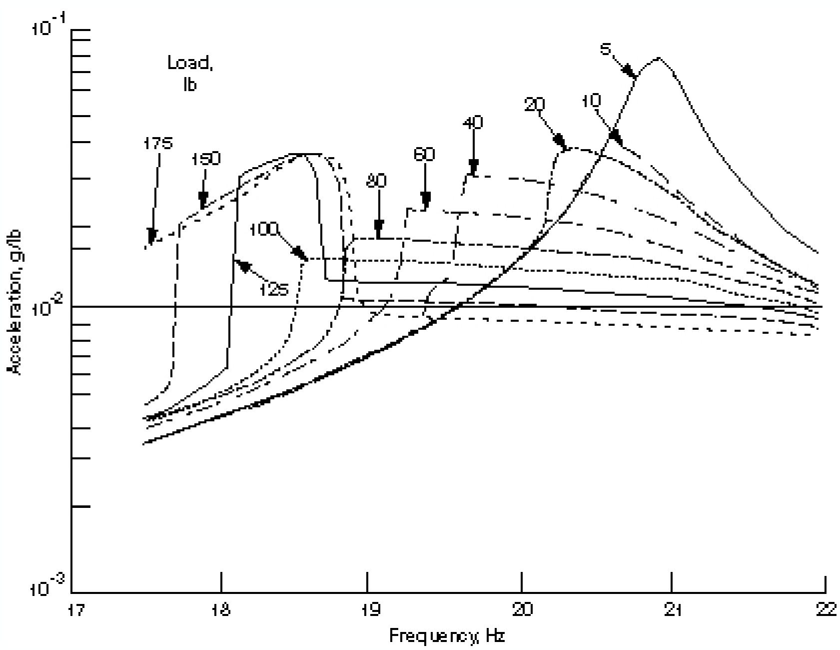
In October 1997, the 6 ½-ton robotic spacecraft, Cassini, will lift off from Cape Canaveral atop a Titan IV B rocket, beginning a 7-year journey to Saturn. Upon completion of that voyage, Cassini will send the Huygens probe into the atmosphere of Saturn's largest moon, Titan. Cassini will then spend years studying Saturn's vast realm of rings, icy moons, and magnetic fields.

The size and complexity of this endeavor mandates the involvement of many organizations. The Jet Propulsion Laboratory (JPL) manages the project for NASA and is responsible for the spacecraft design, development, and assembly. The NASA Lewis Research Center is the launch system integrator. As is typical for such a spacecraft, a test-verified finite element model is required for loads analysis. JPL had responsibility for the Cassini modal survey and the development of the spacecraft test-verified finite element model. Test verification is a complex and sometimes subjective process. Because of this, NASA Lewis independently verified and validated the Cassini spacecraft modal survey.

The Cassini modal survey was conducted in August 1995. Although the test was successful by standard measures, the Cassini spacecraft exhibited significant localized nonlinear behavior during testing. Loads predicted with worst-case assumptions would have necessitated a potentially unnecessary and expensive requalification of the Huygens probe, and perhaps even an unnecessary partial redesign.

The nonlinearities discovered during the Cassini modal survey manifested themselves primarily in the longitudinal mode of the Huygens probe. It had been previously known that a 15-percent reduction in the frequency of this mode would cause accelerations that exceeded the design specifications of the Huygens probe by almost 50 percent. This sensitivity occurs because the probe longitudinal mode tunes into the Titan IV B stage-two ignition-forcing event, which is primarily longitudinal.

Because of this extreme sensitivity to a potential drop in the frequency of the probe bounce mode, it was quite distressing to find that, as force levels increased in the August 1995 modal survey, the frequency for this mode decreased and kept decreasing until the load limits set for the modal survey were reached. At approximately 10 percent of the flight limit load, the frequency of this mode had decreased 5 percent, with no sign of the frequency drop leveling off. Planning began for retesting the Cassini test article, this time taking the probe to almost 50 percent of the load limit levels, determining behavior at high load levels. Nonlinear dynamic analysis had shown that offset gapping was the cause of the probe nonlinearity. At higher load levels, this type of nonlinearity moderates.



Nonlinear response of the probe. If this were a linear system, all of the curves would lie on the 5-lb line. The distortion of the curves is caused by the nonlinearity of the offset gapping.

In January of 1996, a high-force-level dynamic test of the Cassini spacecraft was performed. This test targeted the probe bounce mode exclusively. We discovered that, indeed, at higher load levels the probe longitudinal mode linearized somewhat (its frequency stopped decreasing) and that the nonlinear dynamic model with offset gapping matched the test data very well. A linearized representation of this mode was included in the JPL-test-verified dynamic model. Subsequently, Lewis certification of the dynamic model was completed successfully.

References

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3. Yunis; and Carney: Cassini: Spacecraft Independent Verification and Validation Final Modal Correlation Report. NASA Lewis Research Center, July 31, 1996.

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