ADAMS and The Cassini/Huygens Separation Event

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Abstract

The Jet Propulsion Laboratory is responsible for the management and execution of the U.S. unmanned space program. The Laboratory designs and builds robotic spacecraft and science instruments for the exploration of our solar system and beyond. The Spacecraft Structures and Dynamics group in the Applied Mechanics Technologies division supports that effort with analysis of the potential dynamic and structural behavior of spacecraft subjected to the launch and post-launch environments.

One such analysis effort has been concerned with the Cassini mission's Cassini Orbiter/Huygens Probe separation event. This separation event between a NASA orbiter and an atmospheric probe, designed and built by the European Space Agency (ESA), required the adoption of a new tool to make the analysis possible in a timely manner.

The analysis was nonlinear in nature and required handling elements such as intermittent contact, flexible body response and large angular deflections. ADAMS was selected as the tool of choice to handle such a problem . It allowed results to be obtained quickly which helped reduce design cycle time, essential for this international effort. The use of ADAMS software helped provide insight into the dynamics of a complex system that was difficult to understand without such a tool.

This presentation will discuss the nature of this analysis problem and benefits of using ADAMS as the analysis tool.

Summary

The Cassini mission to Saturn consist of an Orbiter and a Probe. The Orbiter contains all the communications and remote sensing science instruments. The Probe carries instruments for analyzing the atmosphere of Titan, a moon of Saturn. The Cassini Orbiter and the Huygens Probe separate from each other as they approach Titan and the Probe takes data as it falls through Titan's atmosphere. The data is relayed to the Orbiter for transmission to earth.

The Cassini Orbiter is a three axis stabilized spacecraft. The Huygens Probe is spin stabilized. This means that the separation event must provide the Probe with the correct velocity and spin rate for targeting and stability. The separation is therefore helical in nature. The Probe moves along helical tracks as the two bodies are pushed apart by separation springs.

Several elements of this separation make it difficult to analyze. The line of action of the primary separation forces does not go through the center of mass of the Orbiter. This causes geometric coupling of the Orbiter's inertias. Additionally the large mass of the Probe (1/5 the Orbiter mass) means that separation forces, accelerations and motions are high causing large angular deflections. Also the helical separation mechanism has "free play" or "slop" in it which allows intermittent contact between the constraint elements. Finally, the post-separation velocity state of the Probe is very critical for targeting and data relay purposes. Knowledge and control of the Probe velocity is required.

ADAMS was selected as the analysis tool of choice for this separation analysis. ADAMS allowed JPL to handle all the nonlinearities of this somewhat complex system with a fairly simple model. The analysis was able to provide insight into the sensitivity of the system response to various physical parameters. It was found that the initial gap or slop present in the helical separation mechanism was critical in the determination of the Probe velocity error. This result prompted a redesign of the separation hardware to eliminate this effect.

ADAMS proved an invaluable analysis tool that could obtain results at low computational and human costs. ADAMS has been chosen as a tool for future analyses.

JPL

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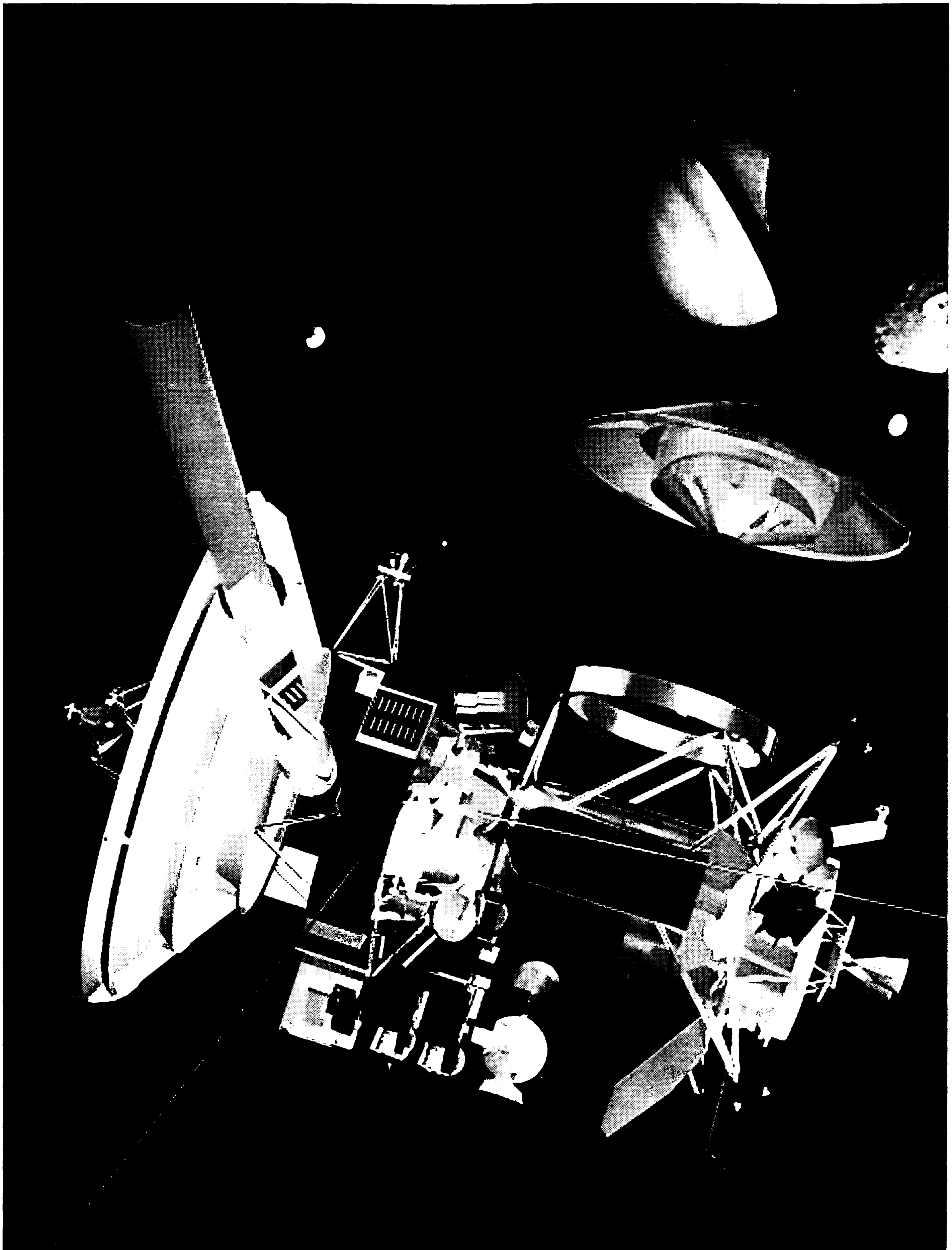


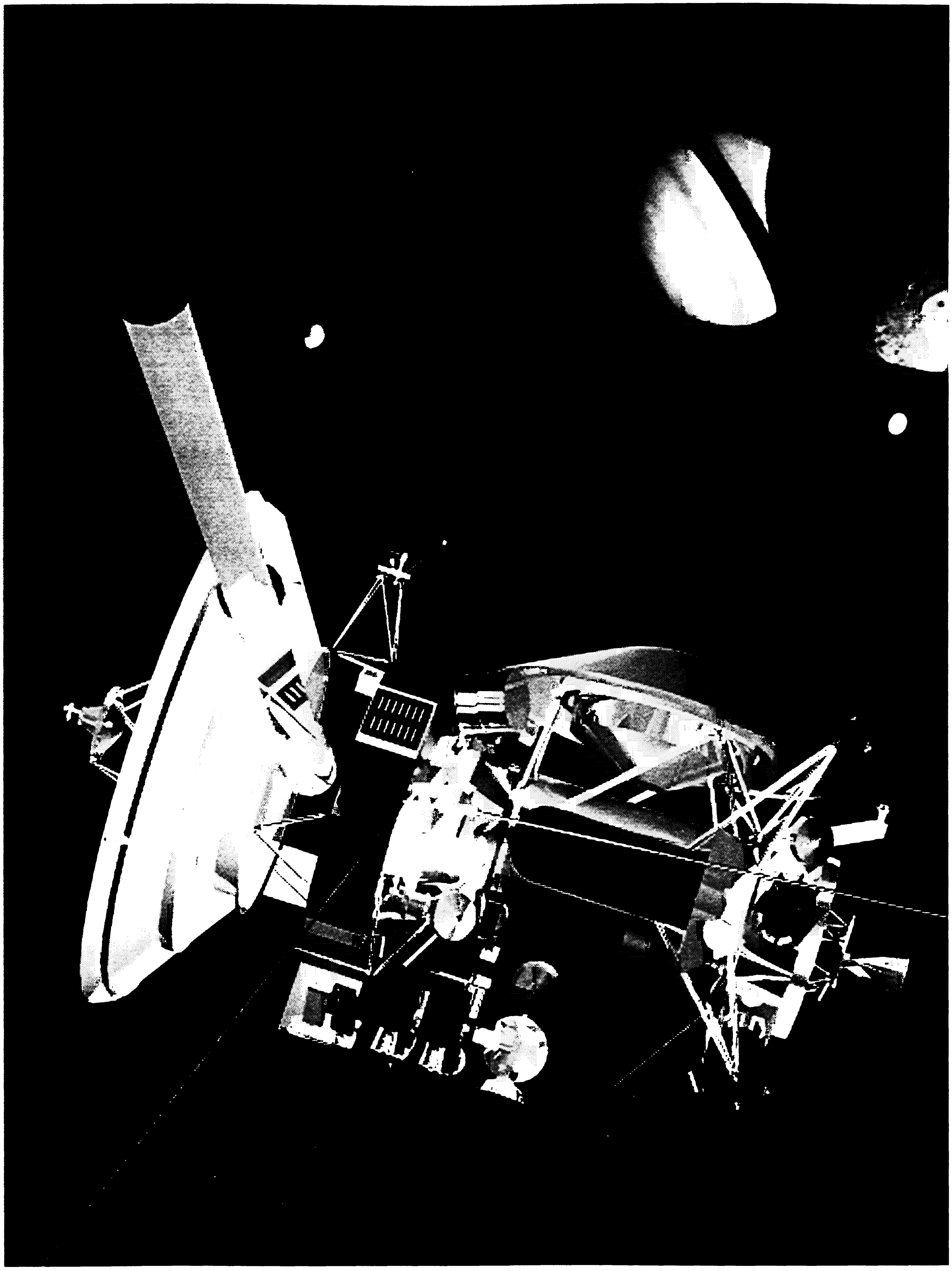
Outline

- What is the Cassini/Huygens separation event?
- What makes this separation so special?
- Why use ADAMS for the separation analysis?
- How was ADAMS used for the analysis?
- ADAMS Results
- Conclusions

What is the Cassini/Huygens Sep. Event?

- Separation between the Cassini Orbiter and the Huygens Titan Probe
  - Cassini Orbiter orbits Saturn taking remote data on the planet and its moons
  - The Huygens Probe takes data on the atmosphere of Titan (moon of Saturn) as it passes through the atmosphere on its way toward impact with the moons surface

- The separation occurs above Titan prior to the Orbiter's insertion into orbit around Saturn.



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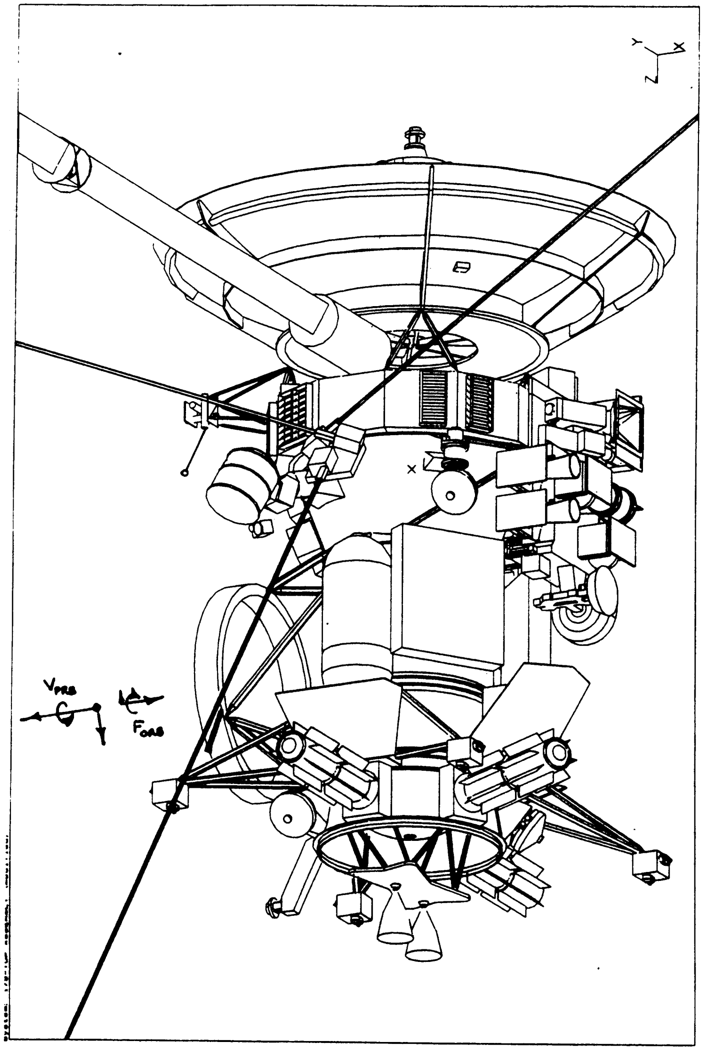
What makes this separation special?

- Off-axis separation
  - CG off-set
  - Inertial coupling
- Three axis stabilized Orbiter and spun stabilized Probe
  - Helical constraint separation
  - Large forces and torques applied to Orbiter
  - Structural integrity of Orbiter's appendages problematic
  - Propellant unporting a problem
- Effective mass properties of the Orbiter are time dependant
  - Flexible appendages
  - Fuel slosh
- Accuracy/knowledge of Probe post-separation velocity critical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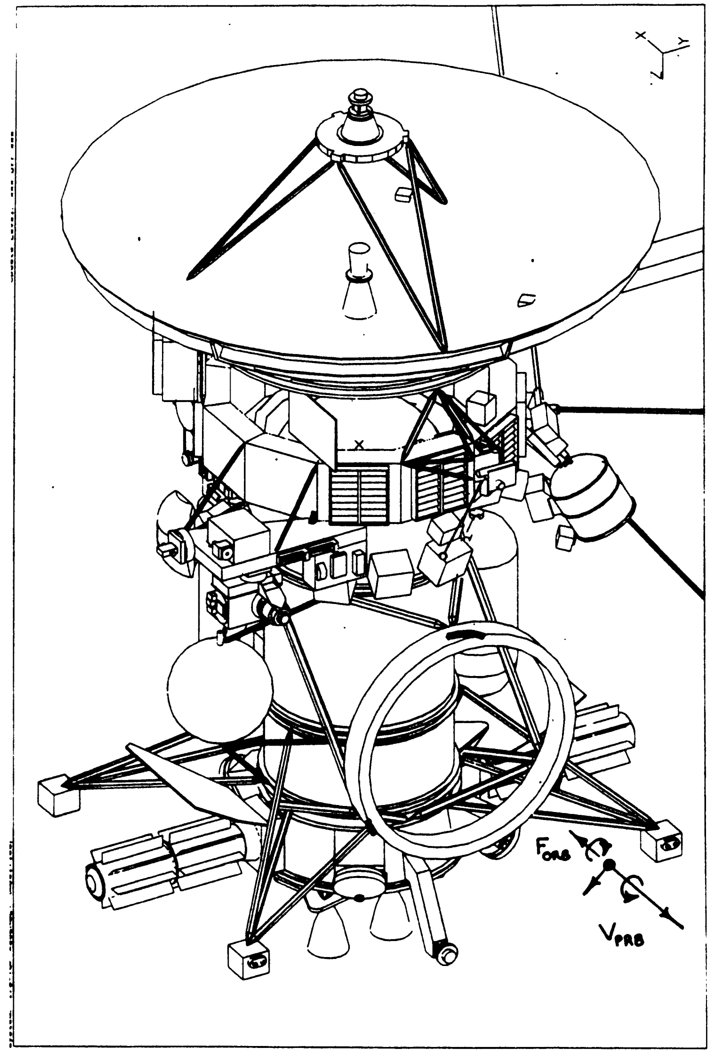
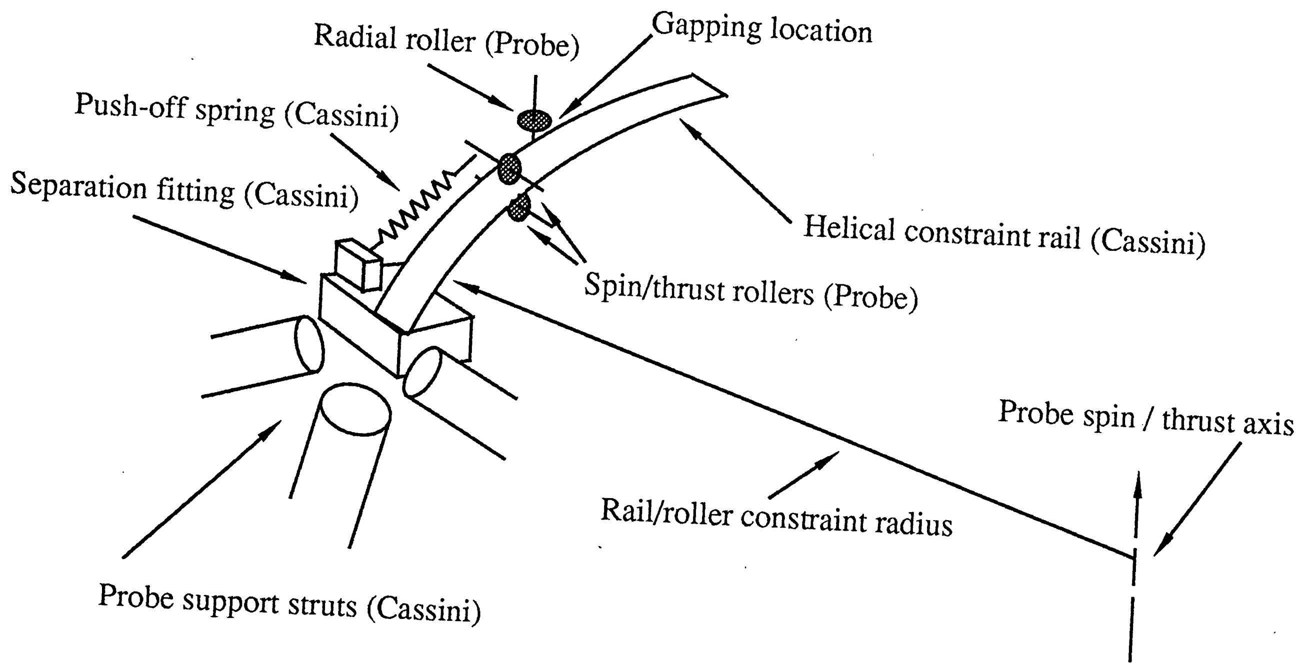
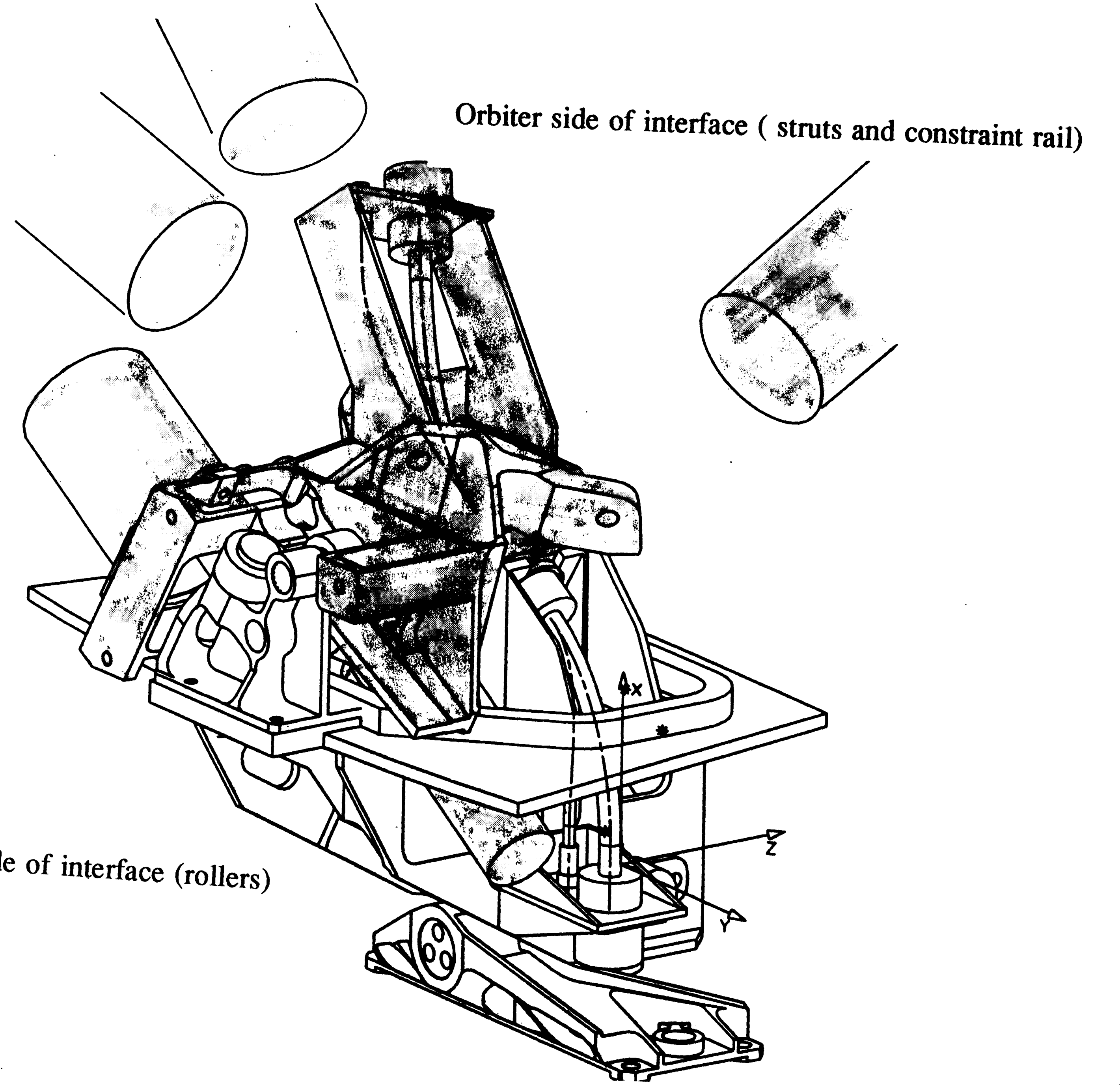
X
Z
VPRB
FORB

X
Y
Z
FORB
VPRB

What makes this separation special? (cont.)

- Hardware nonlinearities!!
  - Helical guide rails (Orbiter) and rollers (Probe) have initial gap
  - Flexible support truss can allow relative motion of the constraint rails
  - Intermittent contact occurs between helical guide rails and rollers
  - Hardware nonlinearities allow energy to move between structural modes of the system allowing increased velocity error



Orbiter side of interface (struts and constraint rail)



Probe side of interface (rollers)

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Why use ADAMS for this analysis?

ADAMS Provided:

- Ability to generate a simplified engineering model that captures all of the significant nonlinear behavior
- An easily modified model of this system
- Loads, clearance and velocity determination in a single model

ADAMS Facilitated:

- Hardware changes to be quickly incorporated
- Oversight and comparison with complex ESA finite element model

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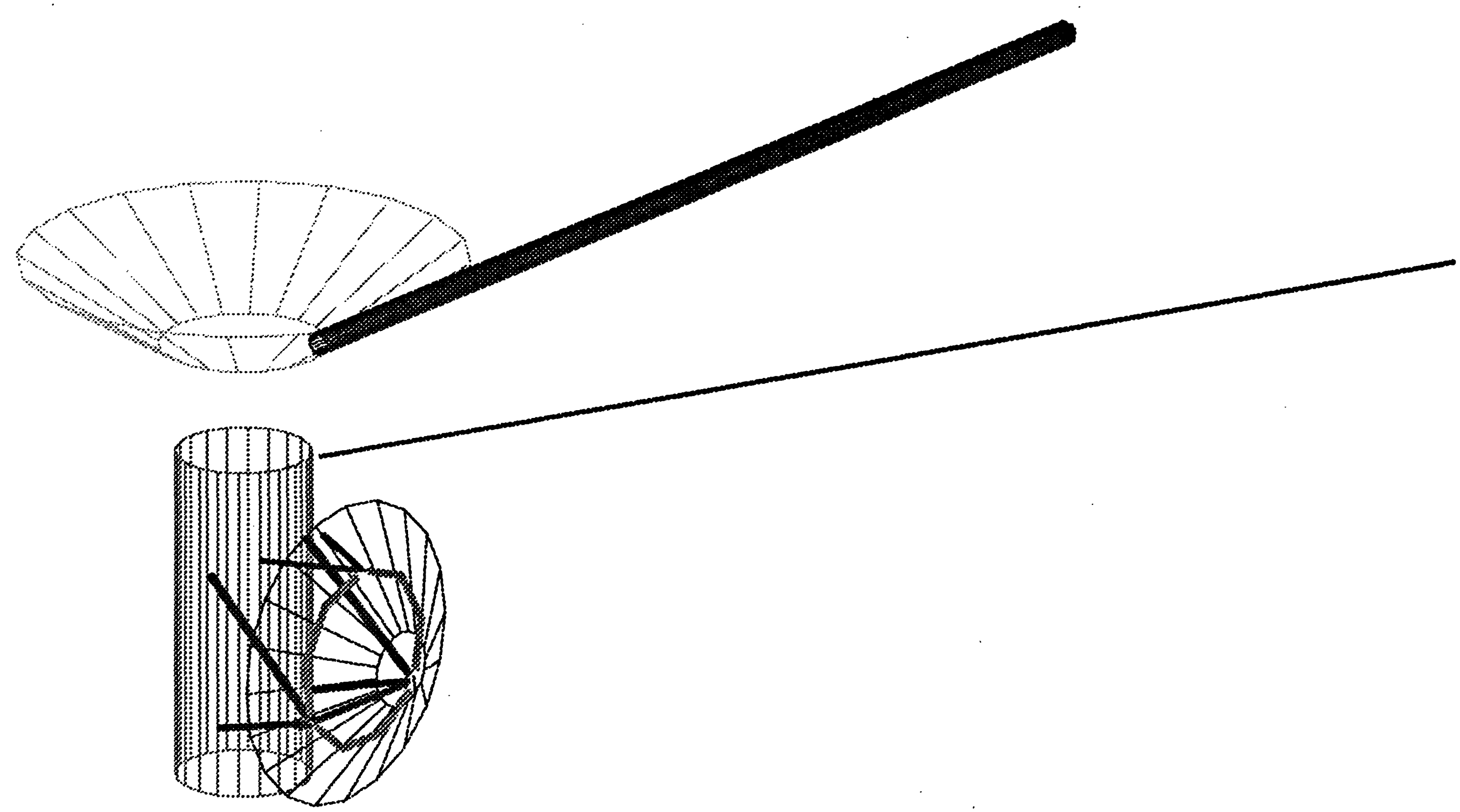

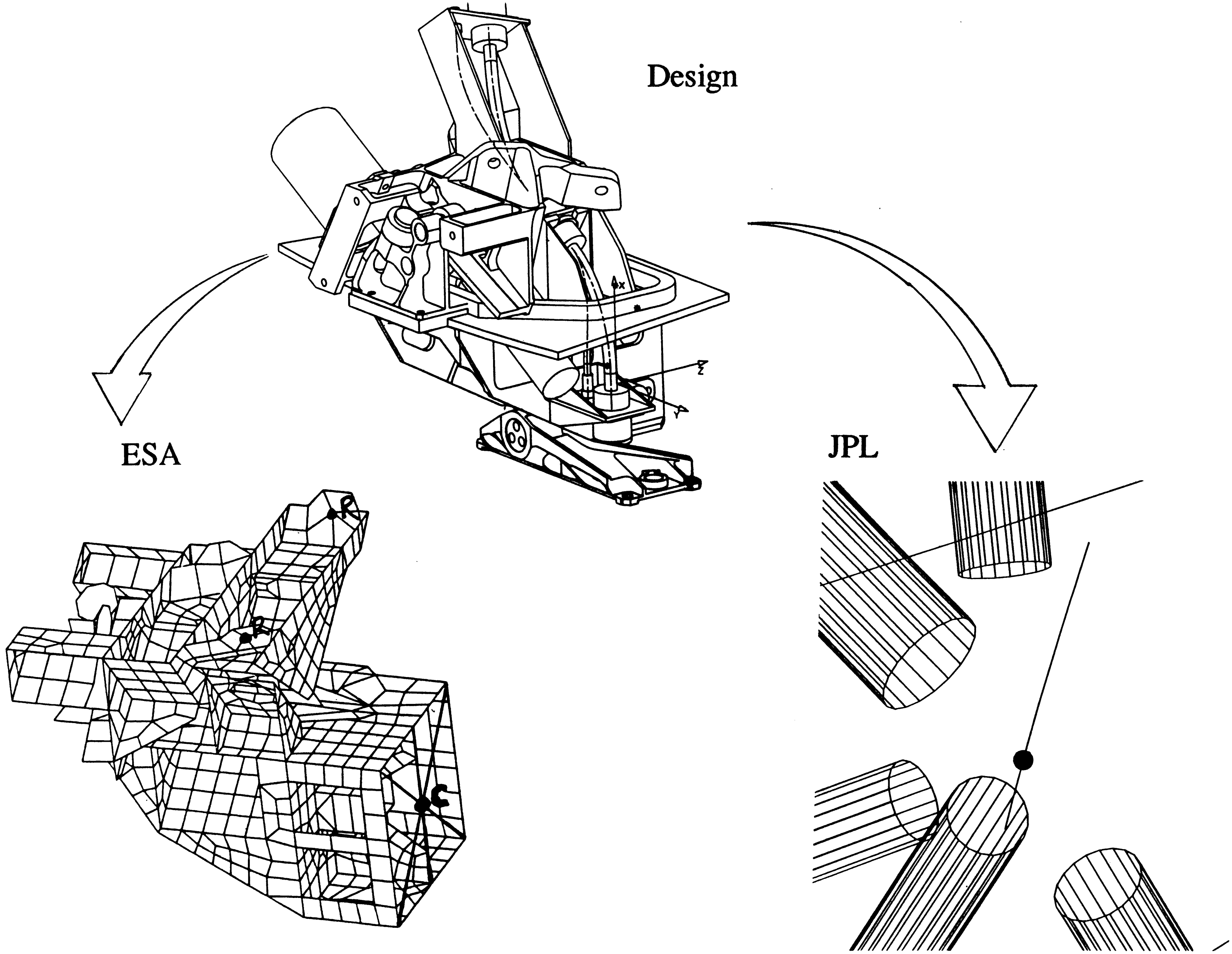
Design
ESA
JPL

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How was ADAMS used for this analysis?

Model:

- Two rigid bodies
- Flexible appendages modelled (*beams* and lumped mass parts) and forces recovered
- Flexible support truss (*beams* and lumped mass parts)
- Helical ramps modelled using *point curve constraints*
- Roller contact modelled using *impact* function *sforces*
- Push-off springs modelled as caged, compression only springs (*sforces*)
- Initial radial roller/rail gap varied to investigate parameter sensitivity

Output:

- Orbiter and Probe post separation velocity states
- Loads on flexible appendages
- Accelerations time histories at propellant management devices
- Clearances between Probe and Orbiter hardware including flexible appendages
- Constraint force time histories to evaluate constraint performance

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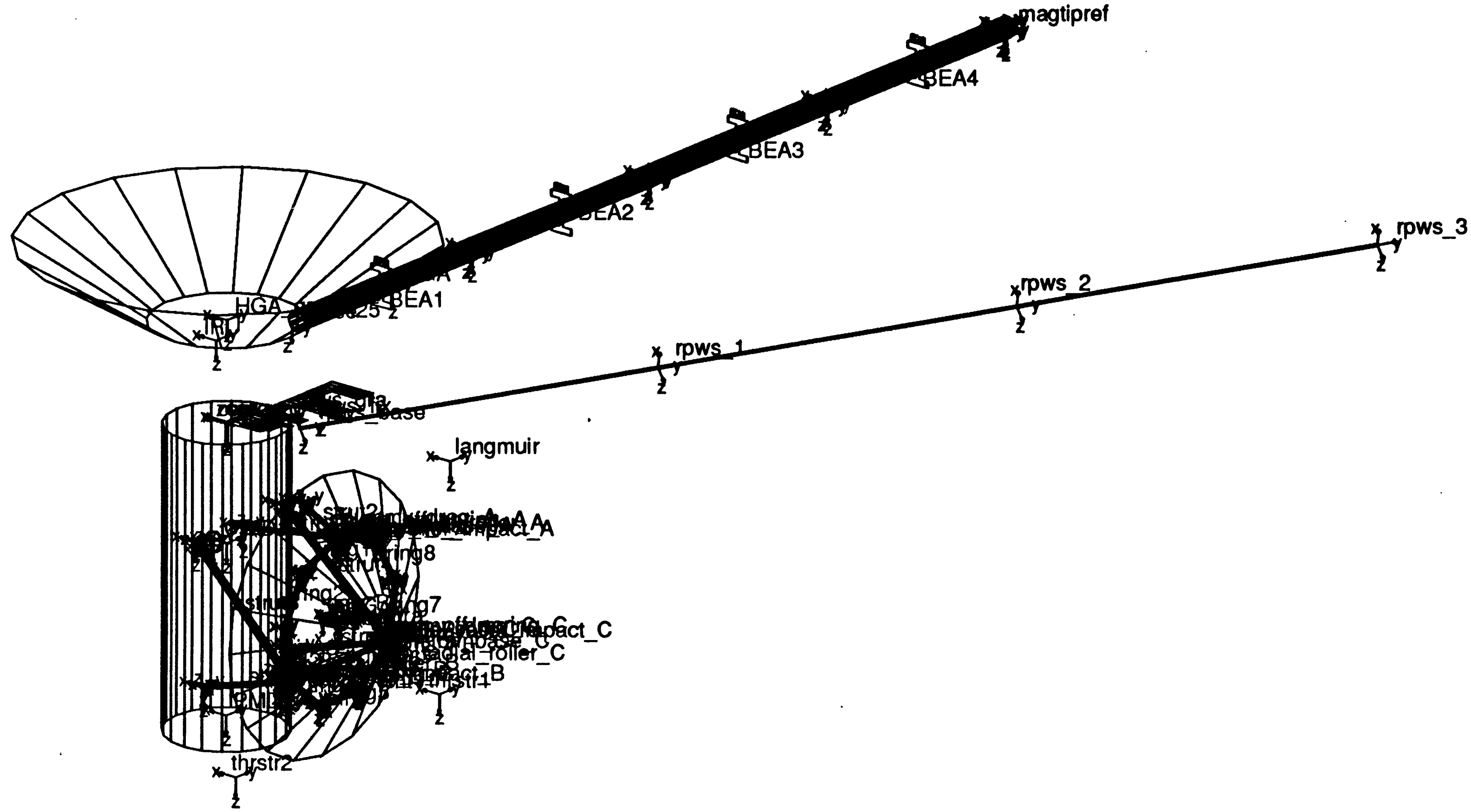

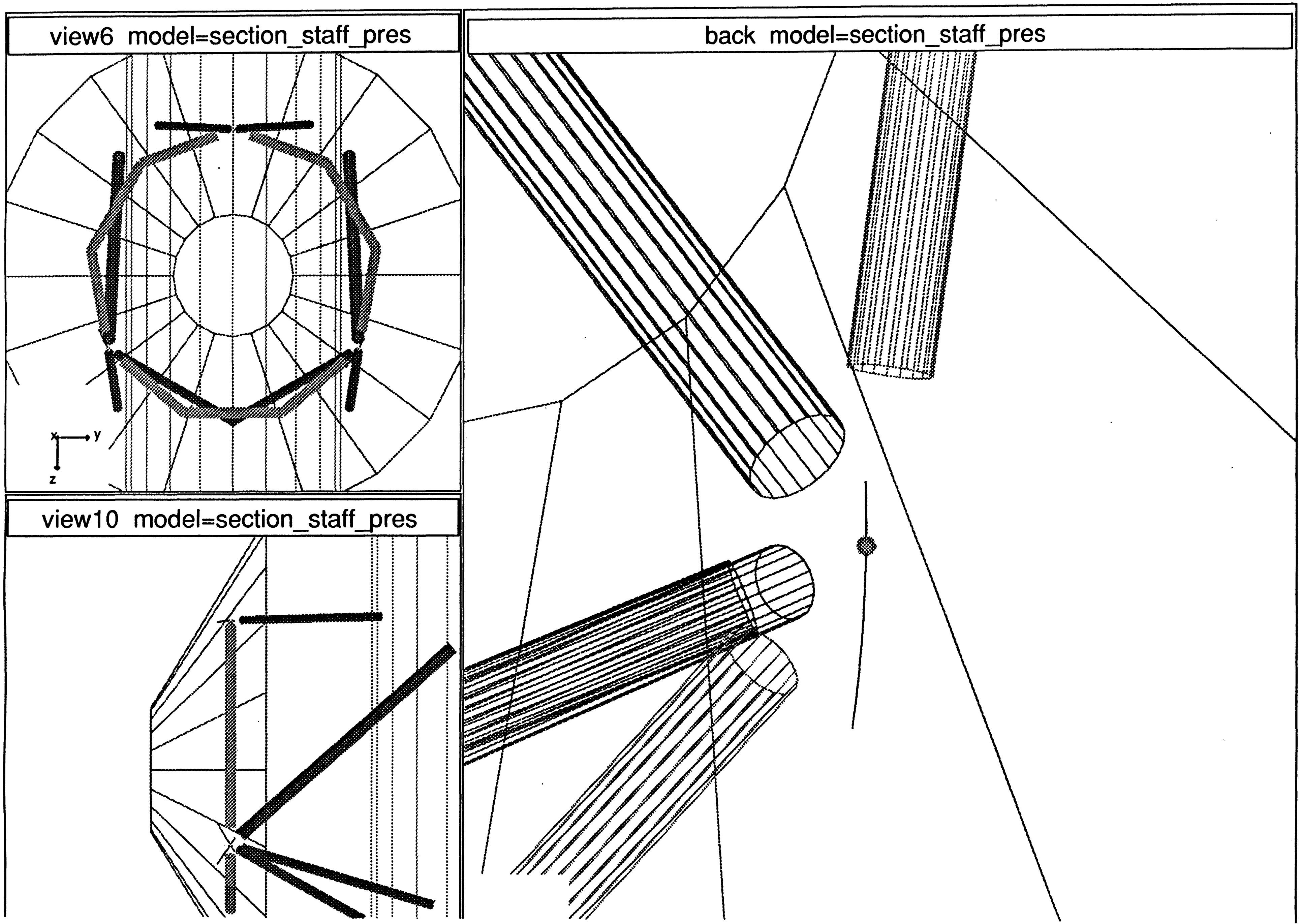
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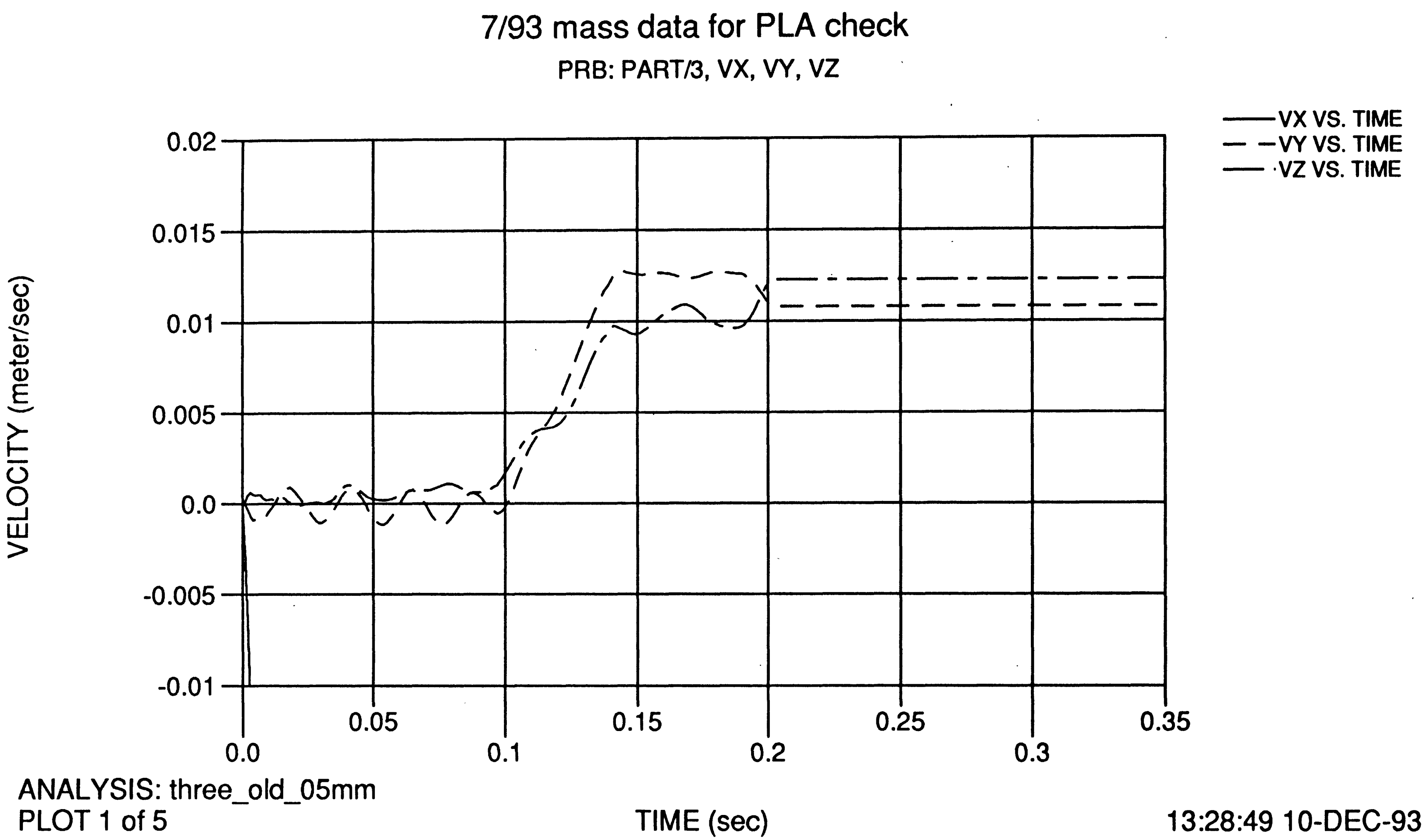
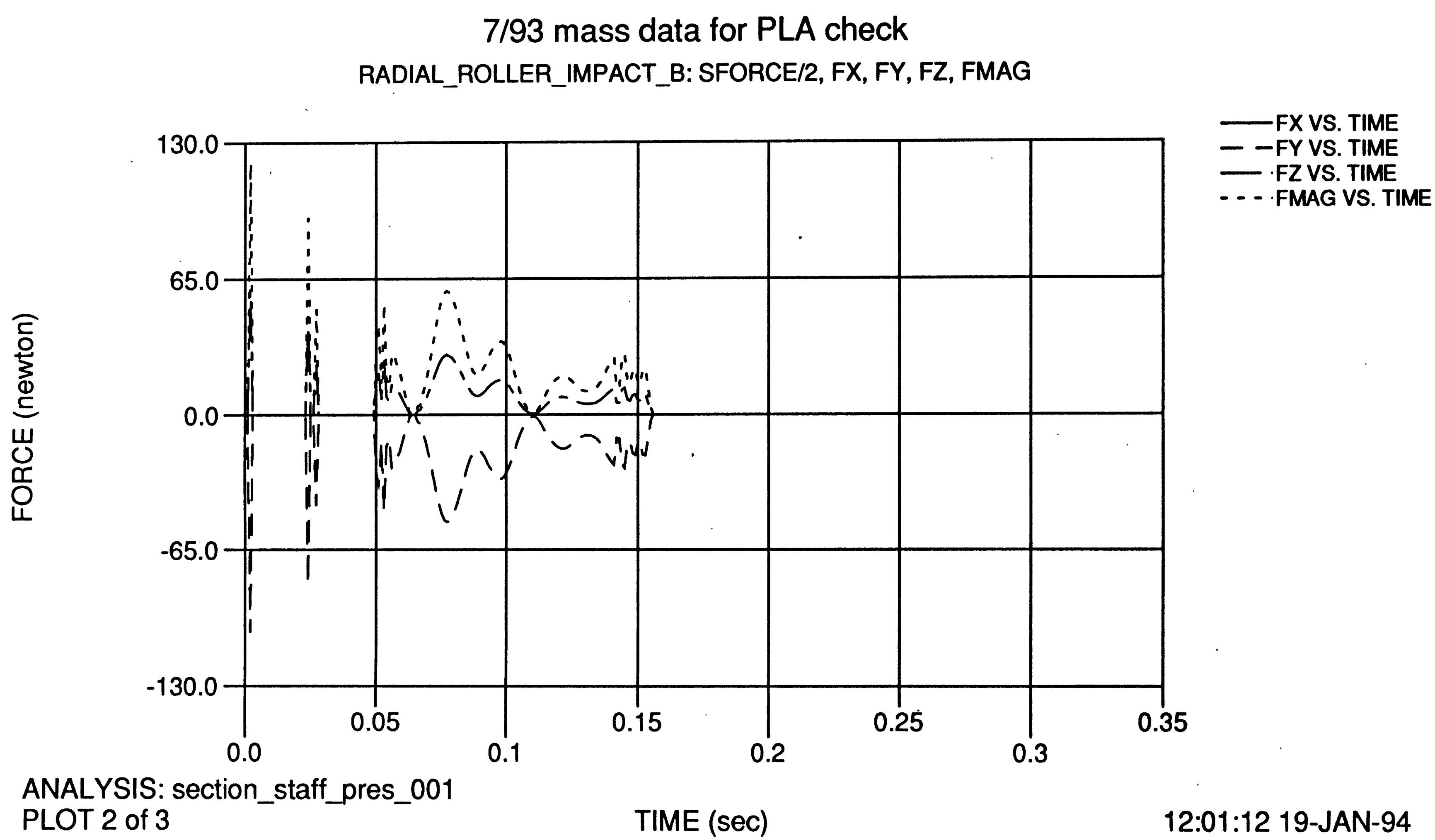
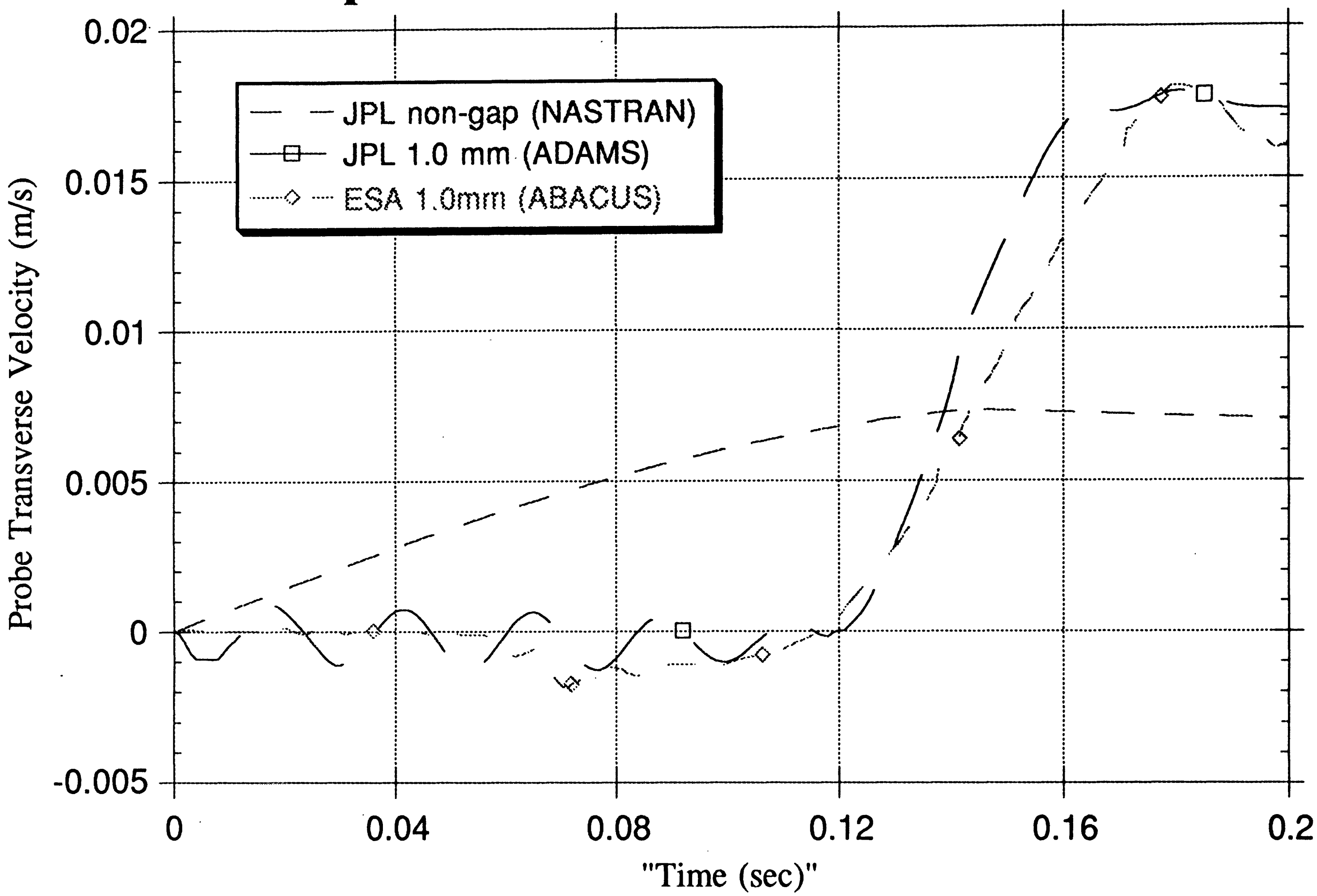
ADAMS Results



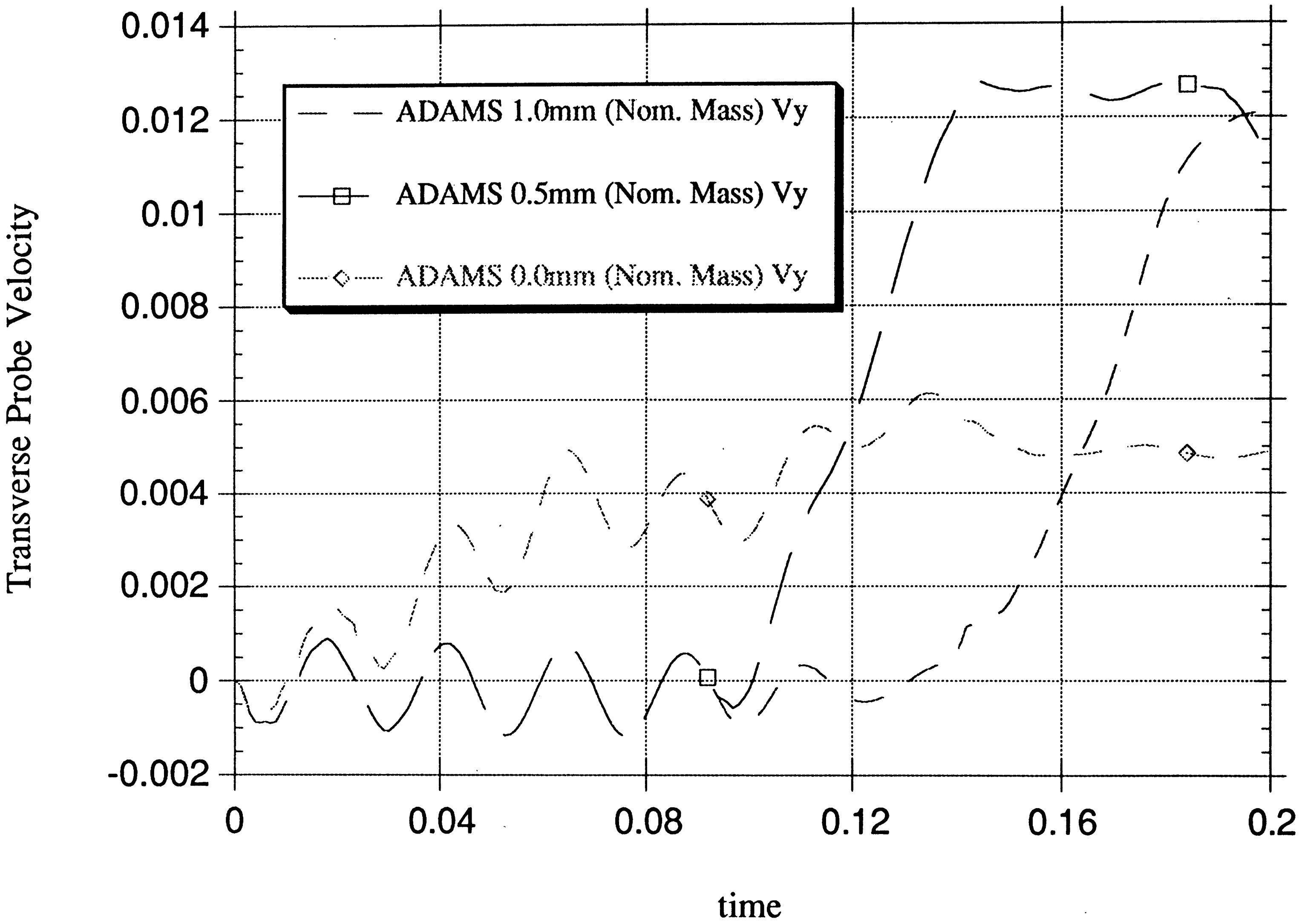
7/93 mass data for PLA check
PRB: PART/3, VX, VY, VZ
VX VS. TIME
VY VS. TIME
VZ VS. TIME
VELOCITY (meter/sec)
0.02
0.015
0.01
0.005
0.0
-0.005
-0.01
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
ANALYSIS: three_old_05mm
PLOT 1 of 5
TIME (sec)
13:28:49 10-DEC-93


7/93 mass data for PLA check
RADIAL_ROLLER_IMPACT_B: SFORCE/2, FX, FY, FZ, FMAG
FX VS. TIME
FY VS. TIME
FZ VS. TIME
FMAG VS. TIME
130.0
65.0
0.0
-65.0
-130.0
FORCE (newton)
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
TIME (sec)
ANALYSIS: section_staff_pres_001
PLOT 2 of 3
12:01:12 19-JAN-94

Comparison of JPL and ESA Results



Initial Radial Roller Gap Response



ADAMS Results (cont.)

- ADAMS analysis helped JPL gain insight into the sensitivity of the post-separation probe velocity to initial radial roller gap.
- ADAMS analysis allowed JPL to verify detailed (>10000 dof) ESA nonlinear finite element analysis.(JPL = 10 cpu min, ESA = 48 cpu hr)
- ADAMS analysis helped JPL ensure hardware clearances and the structural integrity of the Orbiter's propulsion and science boom subsystems during this somewhat violent separation event.

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Conclusion

- ADAMS is an excellent tool that can help provide insight into tough problems
  - Simple models can capture the response of systems with complex behavior
  - Simple models can be exercise to reveal parameter sensitivity
  - Results can be obtained with low computer and analyst cost

- Epilogue
  - ADAMS has been used on many projects from GLL/Jupiter to MESUR/Mars since this first application.
  - ADAMS usership in the Applied Technologies Section at JPL skyrocketing from one person a year ago to 10 current users.