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INTEGRATED MODELING OF ADVANCED OPTICAL SYSTEMS

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
Hugh C. Briggs
Laura Needels
B. Martin Levine

This poster session paper describes an integrated modeling and analysis capability being developed at JPL under funding provided by the JPL Director's Discretionary Fund and the JPL Control/Structure Interaction Program (CSI). The posters briefly summarize the program capabilities and illustrate them with an example problem.

The computer programs developed under this effort will provide an unprecedented capability for integrated modeling and design of high performance optical spacecraft. The engineering disciplines supported include structural dynamics, controls, optics and thermodynamics. Such tools are needed in order to evaluate the end-to-end system performance of spacecraft such as OSI, POINTS, and SMMM.

This paper illustrates the proof-of-concept tools that have been developed to establish the technology requirements and demonstrate the new features of integrated modeling and design. The current program also includes implementation of a prototype tool based upon the CAESY environment being developed under the NASA Guidance and Control Research and Technology Computational Controls Program. This prototype will be available late in FY'92. The development plan proposes a major software production effort to fabricate, deliver, support and maintain a national-class tool from FY'93 through FY'95.

The proof-of-concept tools shown in the posters consist of the Controlled Optics Modeling Package (COMP) and the Integrated Modeling of Optical Systems (IMOS) Integration Workbench.

COMP is a stand-alone FORTRAN program for the analysis of optical systems. In COMP, a collection of optical elements are modeled as conical surfaces, fragments of conical surfaces, and surfaces tiled with hexagonal segments or refractive lenses. A mesh of rays, described by the user in the system input plane, is then propagated through the train of optical elements. Both geometric propagation and diffraction propagation are supported. Since COMP is intended to be used with structural dynamics modeling systems, methods are provided to compute the sensitivities of the optical system to perturbations in the element positions and orientations.

The IMOS Integration Workbench is a collection of Pro-Matlab functions to model structural dynamics by the finite element method and to integrate these models with COMP optical models. The discipline models are assembled in Pro-Matlab where the spacecraft end-to-end performance can be analyzed and trade studies conducted to design the system.

Application Examples

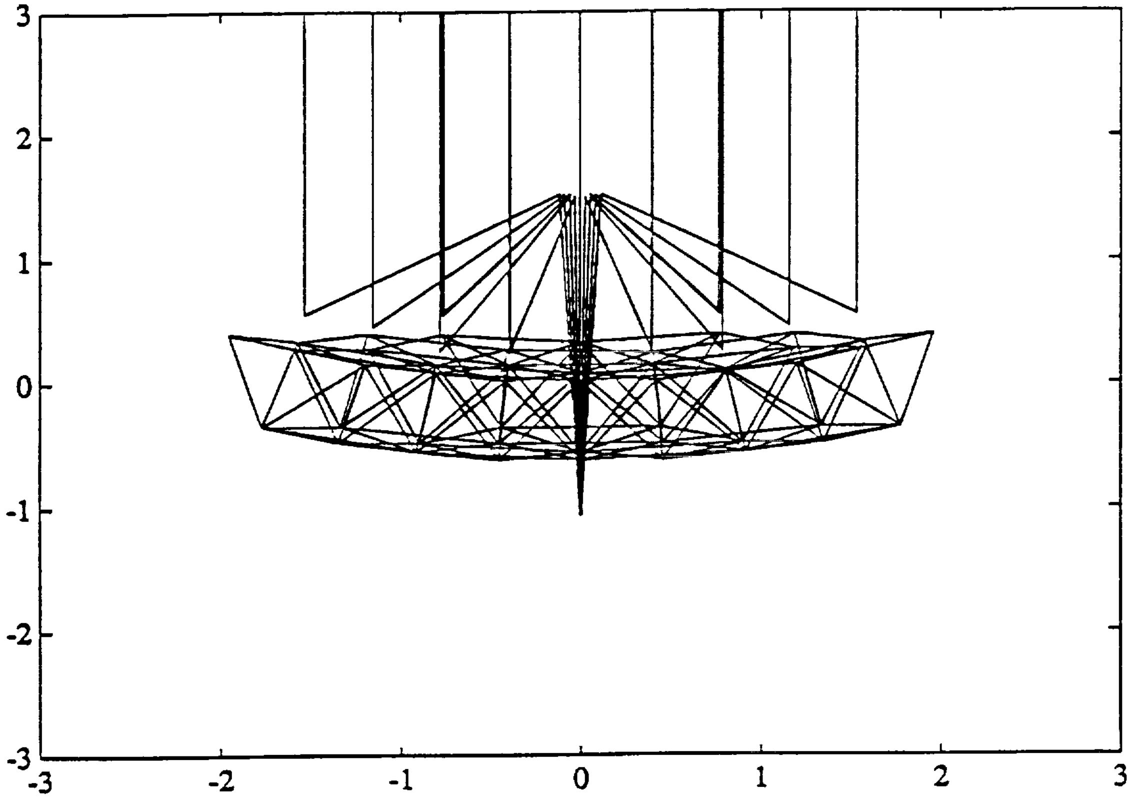
The capabilities of the proof-of-concept tools will be illustrated through two examples. A space telescope with a segmented primary reflector is the basis for the system model. The first case will show the impact of a typical vibration mode on the end-to-end performance of the telescope, and the second will consider a typical on-orbit temperature distribution. The point spread function and the spot diagram will, in both cases, be the measure of system performance. Other perturbations, not reported here, have included enforced base acceleration as might be expected in a laboratory test environment for the telescope.

The point spread function is considered the telescope optical impulse response function and is the image in the detector of a point source at infinity. The light from such a distant source enters the telescope as a plane wave and, in an unperturbed system, results in the delta-like function shown in the chart. Any perturbations to the telescope result in a reduction of the amplitude of the central spike and the introduction of significant off-axis or secondary lobes.

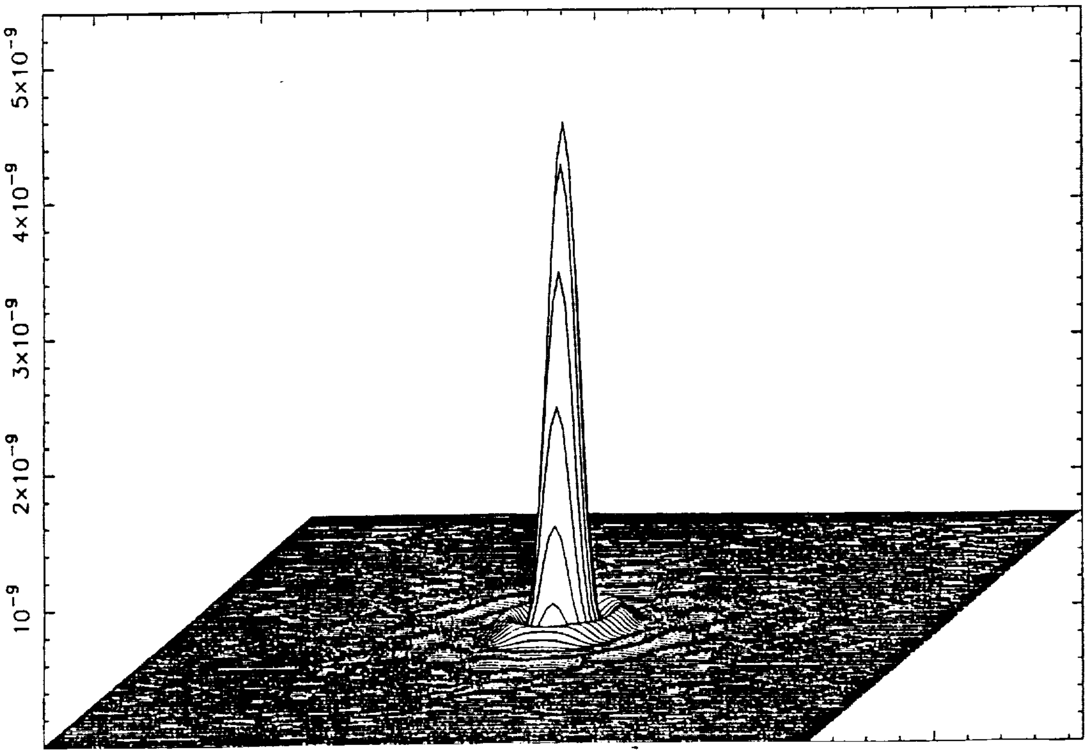
The spot diagrams represent the locations where rays pierce the plane of the detector. In an unperturbed focused system, all rays go through the focal point. When the system is perturbed, the rays no longer focus and hit the detector at other points. A system performance metric might be any function that measures the distance of these points from the focus.

The system model has structural dynamics elements to represent a primary-backup truss, a secondary with metering tower, and primary segments with three linear actuators for each panel. In the examples, the actuators are not commanded, as they might be to remove the distortion in the optical system, and maintain their nominal length. The optical system was modeled with COMP and included the primary segments and the secondary mirror. Surface-to-surface diffraction was utilized in computing the point spread functions while geometric optics was used to compute the spot diagrams.

Optical and Structural Model



The Unperturbed System Point Spread Function



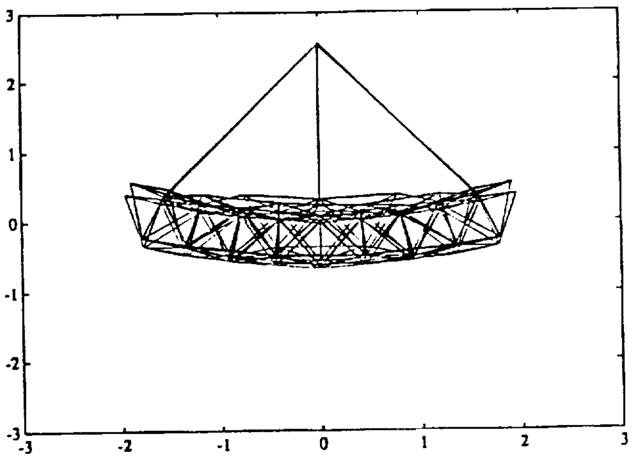
Impact of Modal Vibration

The integrated tools can be used to evaluate the performance impact of any system perturbation, where it is static or dynamic. This chart shows the 8th system mode of vibration, and the spot diagram and point spread function corresponding to this perturbation. The 8th mode is one of the lower frequency truss bending modes that, if uncorrected, alters the radius of curvature of the primary. The upper figure shows the deformed shape, greatly amplified for clarity, superimposed on the nominal structural model.

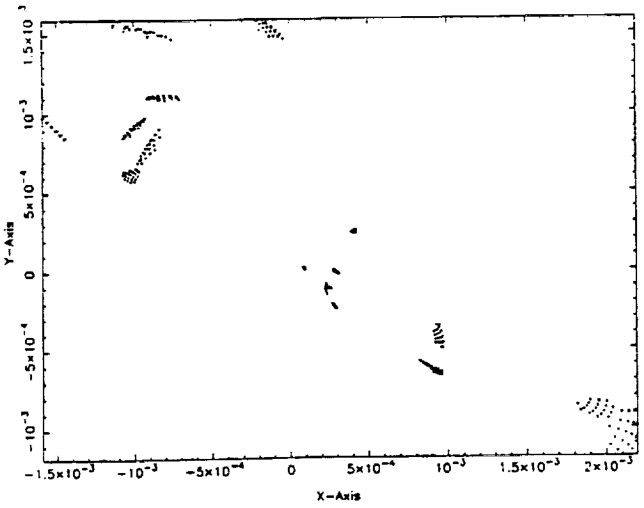
The middle figure shows the location of the rays in the plane of the detector and the lower figure shows the point spread function when the system is deformed into this shape. These figures were created in COMP by applying the 8th mode shape as a perturbation to the optical elements. Notice the reduction in the height of the central peak and the presence of side lobes.

Similar figures have been obtained to show the results of time domain simulations of response to base accelerations. Other measures of the performance might be time series of motions of the rays in the detector or animations of the point spread function. See, for example, "Integrated Control/ Structures/Optics Dynamic Performance Modeling of a Segmented Reflector Telescope" by H. C. Briggs, D. C. Redding, and C. C. Ih in the Proceedings of the Twenty-First Annual Pittsburgh Conference on Modeling and Simulation, 3-4 May, 1990.

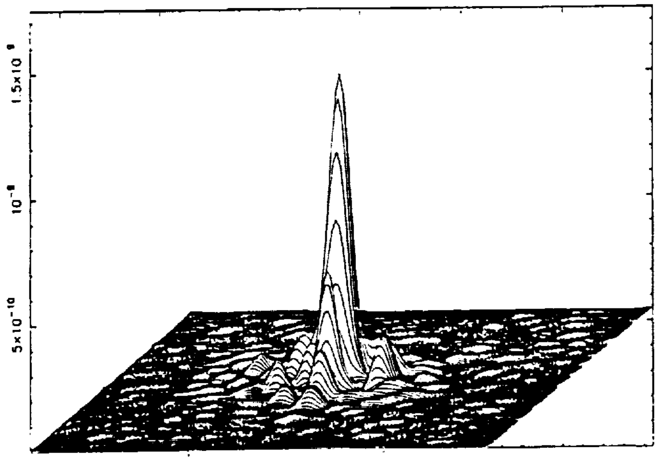
8th Structural Mode of Vibration



Spot Diagram for the 8th Mode



Point Spread Function for the 8th Mode



Impact of Temperature Variations

The second example illustrates the optical performance impact of a non-uniform temperature variation across the telescope. The upper figure shows the temperature distribution imposed upon the primary mirror support truss. The structural deformations resulting from thermal expansion were computed and applied to the optical model to compute the performance metrics below. The temperatures were taken from a study of an IR telescope in earth orbit and represent a single case that contained significant thermal variation. See "The Precision Segmented Reflector Program: On-Orbit Thermal Behavior of the Submillimeter Imager and Line Survey Telescope" by G. Tsuyuki and M. Mahoney, AIAA Paper 91-1304, for information concerning the independent thermal analysis.

Again, the middle figure shows the spot diagram and the lower figure shows the point spread function.

Acknowledgment

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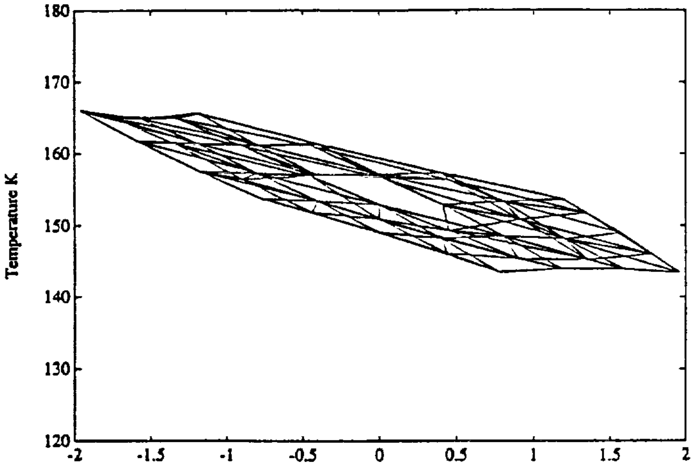
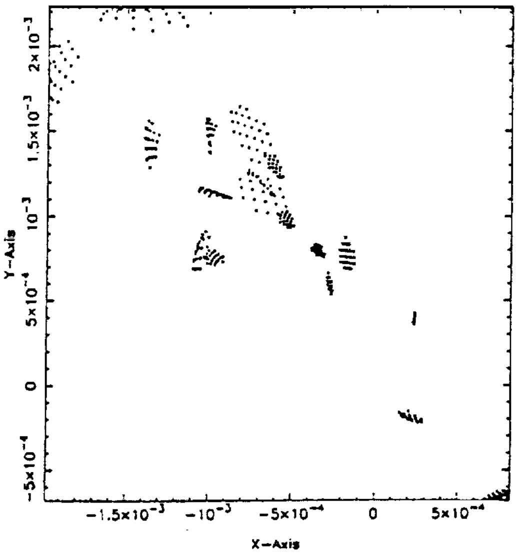
Temperature Variation Across the Truss



Spot Diagram for the Temperature Variation



Point Spread Function for the Temperature Variation