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STRUCTURAL MODELING OF THE NEXT GENERATION SPACE TELESCOPE'S PRIMARY MIRROR

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STRUCTURAL MODELING OF THE NGST

Introduction

In recent years, astronomical observations made with space telescopes have dramatically increased our understanding of the history of the universe. In particular, the cosmic Background Explorer (COBE) and the Hubble Space Telescope (HST) have yielded observations that cannot be achieved at ground-based observatories. We now have views of the universe before galaxies existed (from COBE) and views of young galaxies (from HST). But none of the existing observatories can provide views of the period in which the galaxies were born, about 100 million to one billion years after the "big bang." NASA expects the Next Generation Space Telescope (NGST) to fill this gap.

Although several preliminary designs have been proposed for the NGST, the current focus of NASA's effort is the design proposed in 1996 by a NASA team with members at Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and Marshall Space Flight Center (MSFC). This design is depicted in Figure 1. The salient features of the design are the inflatable sunshade (to keep the mirror's temperature at about 40 K), the large segmented primary mirror, the central mast supporting the secondary mirror, and the remaining optics and other instruments placed between the primary mirror and the sunshade. The primary and secondary mirrors, together with their supporting structures, are referred to as the optical telescope assembly (OTA).

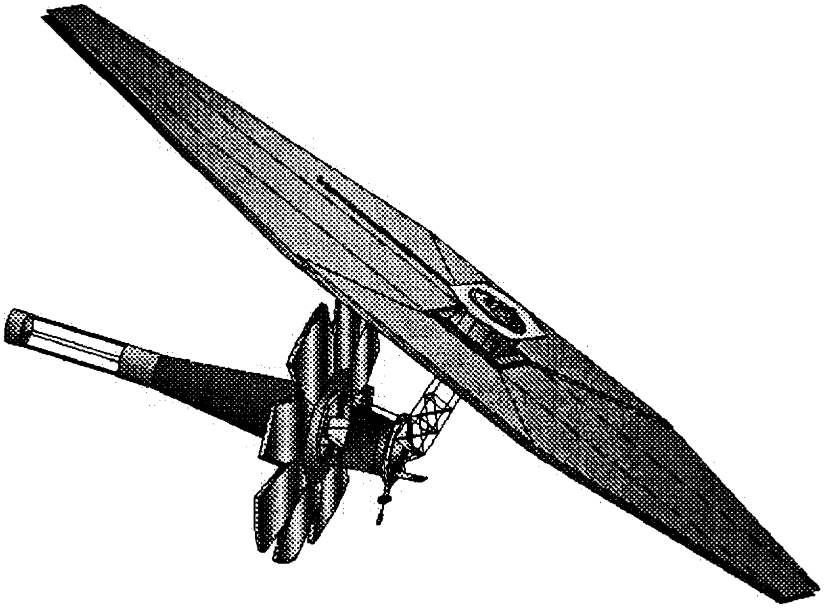

Figure 1. NASA (GSFC, JPL, MSFC) Preliminary design for the NGST.

Because the primary mirror, which is eight meters in diameter, is to be launched by an existing vehicle, the mirror cannot be made in one piece. In the current design, the mirror is made of nine segments. These include a central octagon, itself containing a central circular hole, and eight movable petals. For launch, four of the petals fold toward the front of the mirror and the other four fold toward the back, as shown in Figure 2. On orbit, the petals are opened and the mast holding the secondary mirror is extended, as seen in Figure 3. Each petal is supported by its own reaction structure, depicted in Figures 2 and 3 as a second layer of material in each petal.

Various materials have been proposed for the primary mirror, including beryllium, nickel, silicon carbide, and glass. The first three of these are sufficiently stiff so that the mirror portion of each petal need be supported only at three points. But a glass mirror would be so flexible as to require support at about 150 points per petal. In what follows, we discuss the ability of current modeling techniques to predict the behavior of a glass primary mirror.

Current structural models of the NGST primary mirror are based on the finite element method (FEM) and incorporate triangular, flat-plate elements. Models are analyzed with standard computer codes such as NASTRAN and EAL. The discussion below is focused on two specific aspects of what could be called, in general, validation of the models used in these codes. Are the models sufficiently accurate for the current design of the glass primary mirror? For what aspects of the glass design have the codes been validated? If the codes converge to some "best" analysis as the finite element mesh is refined, how accurate are the results of that "best" analysis?

The launch of any space telescope would be preceded by a program of testing, which would be used to validate (or invalidate) modeling. But successful validation through testing requires that the tests include measurements that can be used to assess the accuracy of all aspects of the modeling that have not been otherwise validated. Answers to the questions posed above are needed to insure that testing programs measure only that which needs to be measured.

Structural models of the NGST's primary mirror should accurately predict both stress and deformation. Accurate stress prediction is needed to prevent the loss of structural integrity. Accurate deformation prediction is needed to insure acceptable optical performance, which is characterized by waveform error. Optical modeling techniques predict this error using detailed predictions of the mirror's deformation. If the structural models do not accurately predict the deformation, the optical models may not accurately predict the optical performance. In that case, despite maintaining its structural integrity, a space telescope could be a failure. It follows that validation of the modeling, through testing or otherwise, should include validation of both stress and deformation predictions.

Two assumptions currently used in structural modeling of the NGST's primary mirror are (a) that shear deformation is negligible and (b) that deformation

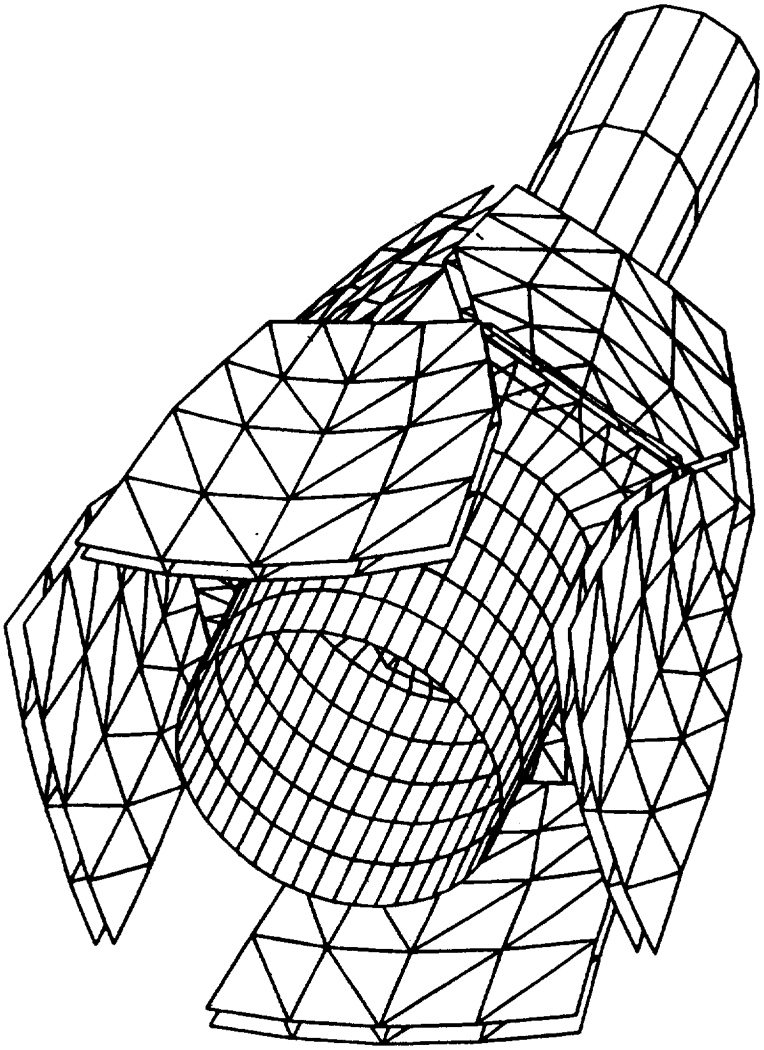

Figure 2. Launch configuration for the NGST's optical telescope assembly.

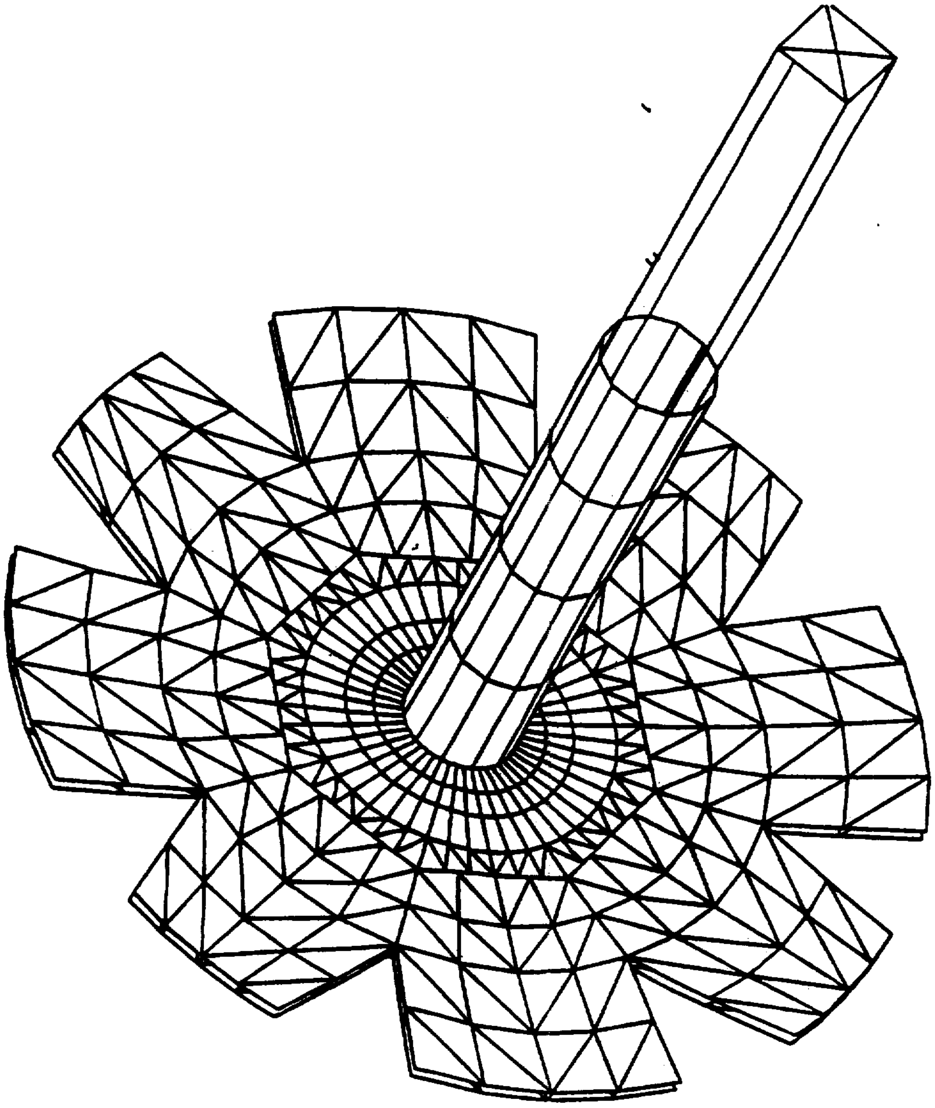

Figure 3. Deployed (on-orbit) configuration for the NGST's optical telescope assembly.

varies slowly with position over the surface of any petal. The validity of both these assumptions was investigated during the period covered by this report. The investigation began with a brief literature search, which revealed little documented work that would apply to these issues as manifested in the NGST mirror. This literature search continues.

Methodology

Lacking applicable previous work, we conducted a preliminary investigation of the two assumptions listed above by analyzing the simple models depicted in Figures 4 through 7. Each model is an infinite beam with equally spaced support loads. The support loads represent those that a mirror petal would experience on orbit.

In Figures 4 and 5, the support loads are developed in reaction to a uniformly distributed load applied to the beam. On orbit, such a load would not be present. Rather, the predominant loading experienced by the supports would be created by the mirror's tendency to deform in response to temperature gradients. If such gradients were small, the support loads would vary slowly over the surface of the petal. In that case, the deformation between the supports would be approximately the same as that for the model shown in Figures 4 and 5.

In Figures 6 and 7, the support loads are assumed to be developed in response to rapidly varying deformation of the mirror. For convenience, the support loads are taken to be equal in magnitude and alternating in direction. This could only occur in response to large temperature gradients.

Results

Elementary beam theory (no shear deformation) leads to deformation patterns illustrated in Figure 8. From the figure it is apparent that the peak-to-peak deformation expected for the model depicted in Figure 6 is about fifteen times larger than that expected for the model depicted in Figure 4. This indicates that the assumption of small temperature gradients is critical. If it is significantly in error, performance of the mirror may not be as expected.

When elementary beam theory is combined with well-known analysis of shear deformation, the deformation patterns for the two beam models are as shown in Figures 9 and 10. These figures indicate that shear deformation will not be significant provided the mirror thickness remains less than about one-tenth the spacing of the support loads. For the current glass design, this ratio is about 0.025. Hence, it is unlikely that shear deformation will be significant in the NGST's primary mirror.

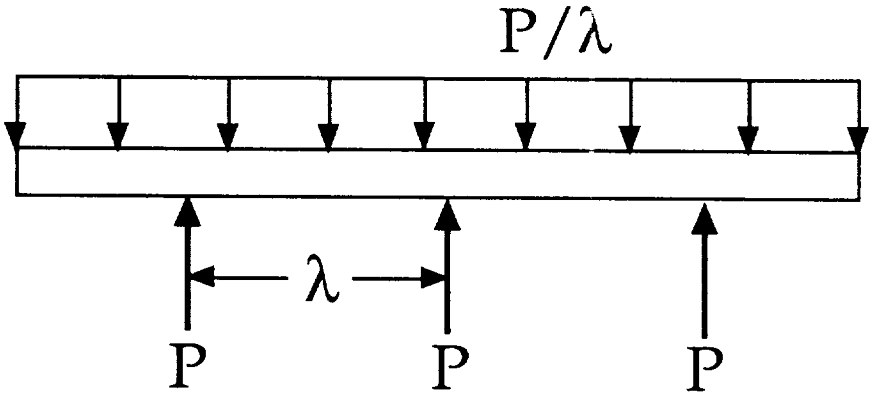

Figure 4. Infinite beam with uniformly distributed applied load and equally spaced supports.

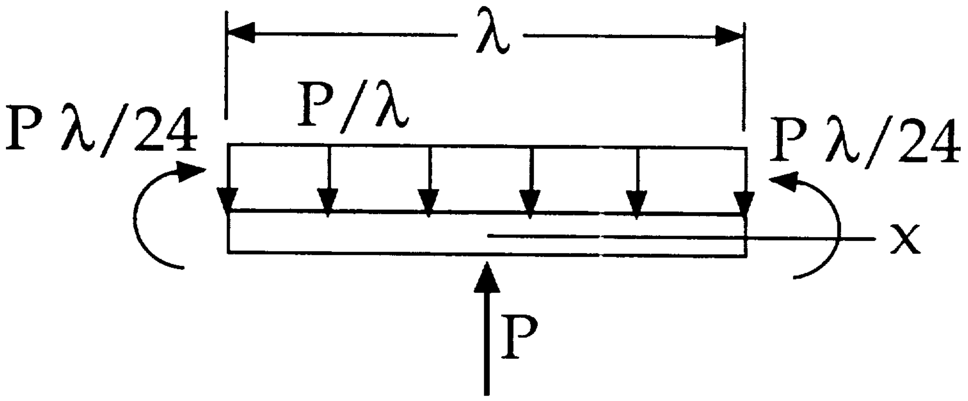

Figure 5. Free-body diagram of one wavelength of the beam depicted in Figure 4.

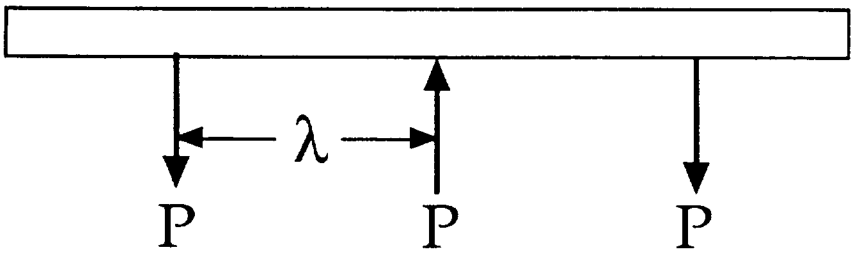

Figure 6. Infinite beam with no applied load and equally spaced, self-equilibrating support loads.

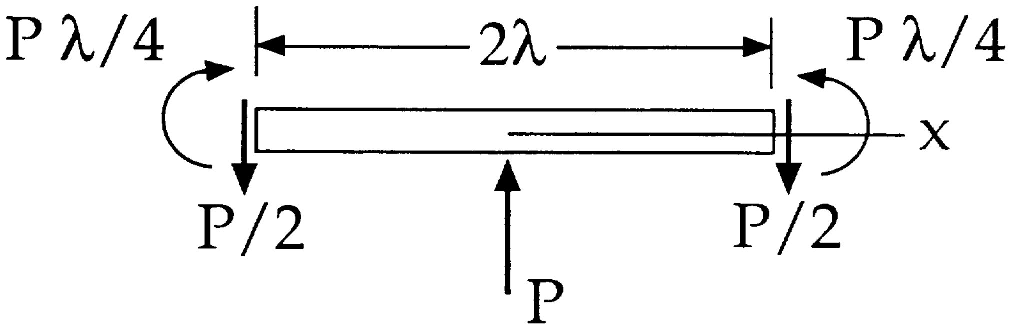

Figure 7. Free-body diagram of one wavelength of the beam depicted in Figure 6.

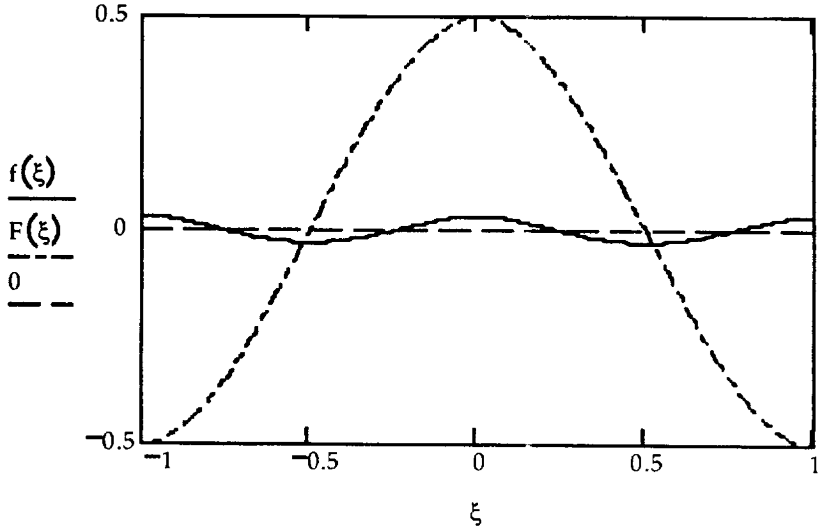

Figure 8. Normalized deflections of beams depicted in Figure 4 (solid line) and Figure 5 (nonuniformly dashed line), without shear deformation.

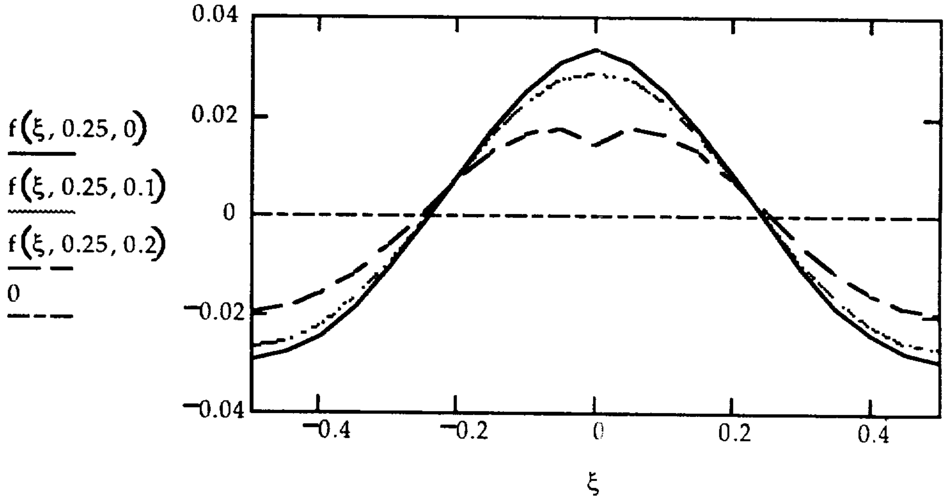

Figure 9. Effect of shear deformation on beam depicted in Figure 4. Poisson's ratio is 0.25. The ratio of the beam thickness to the spacing between the supports varies from zero (no shear deformation) to 0.2

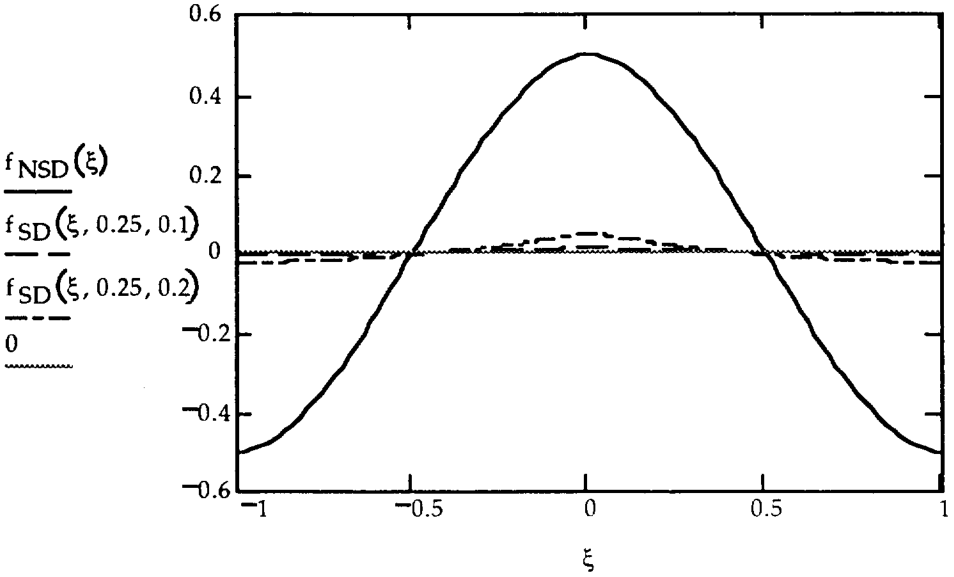

Figure 10. Effect of shear deformation on beam depicted in Figure 6. Poisson's ratio is 0.25. When the beam thickness is zero (solid line), there is no shear deformation. The dashed lines show the deformation that would be added to the solid line due to shear deformation when the beam thickness is 0.1 or 0.2 times the spacing of the support loads.

Conclusions

Although shear deformations is not likely to be significant in the NGST's primary mirror, the assumption of small temperature gradients is critical. If its validity cannot be verified, the current design should be pursued under the assumption that large temperature gradients may exist.

Acknowledgement

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