Thermal and Structural Analysis of the GOES Scan Mirror's on Orbit Performance

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Abstract

This paper outlines the analysis techniques that were utilized to predict the on orbit performance of the GOES scan mirror. The design time is significantly influenced by the level of detail needed in the structural and thermal models. Thermal and structural modeling techniques are discussed, along with the level of modeling detail necessary to properly predict the resulting optical distortions. Selected parametric studies are presented with the resulting structural distortions.

Introduction

The primary mission of the Geostationary Operational Environmental Satellite (GOES) instruments being built by ITT Aerospace/Communications Division is to provide imagery of the earth. In addition to this mission, the instruments are also used as star trackers to improve the location (pointing) accuracy of the GOES system. For both missions the desired information is obtained by moving a scan mirror such that an image of the desired scene falls onto detectors housed inside the instrument.

To insure the quality of the imagery produced by the GOES instruments, specifications were set on the Modulation Transfer Function (MTF) and the Instantaneous Geometric Field of View (IGFOV). Very small deformations of the scan mirror will degrade the MTF and IGFOV . The level of degradation depends on the shape of the scan mirror deformation.

The task of estimating on orbit scan mirror deformations and the resulting impact on system MTF and IGFOV involves thermal, structural, and optical analyses. Thermal models provide temperature distributions to structural models which in turn provide distortions to optical models. Once a design is conceived and the various models are constructed the entire task of predicting MTF's and IGFOV's is reduced to transferring data between models. Unfortunately, creating the models and writing the software required to transfer data between models is a time consuming process much of which must be repeated for each different scan mirror design. A further delay is the fact that this process is serial in nature, the thermal model must be run before the structural model which must be run before the optical model. The time required for a designer to consider several designs can quickly run into months if some consideration in not paid to the level of detail used in the models. The following sections will detail the steps required for the thermal and structural analyses and will outline methods of transferring data between models.

Thermal Models

The time required to build and debug the thermal models is the pacing item in the task of estimating scan mirror distortions. The thermal models used for the scan mirror analysis were finite difference models. These models require that radiant interchange factors, solar loads, and linear conductors be calculated so that a finite difference solver can be used to predict temperatures.

The level of effort and amount of computer resources required to obtain the radiant interchange factors goes up sharply as model detail is increased. Initially a very detailed model (see Figure 1) of the scan mirror was created with the belief that the detail would simplify the task of mapping the temperatures to the structural model and because the sensitivity of scan mirror distortions to temperatures was unknown. This mirror model had a node for every cell wall and a node for the base of each cell. A geometric model of the scan mirror and the instrument that surrounds it was built (see Figure 2) and used with a software package called Thermal Model Generator (TMG) to calculate the solar loads and radiation interchange factors. The TMG package also calculated the linear conductors in the mirror. After the finite difference model was assembled a transient temperature solution was obtained and temperatures were mapped to the structural model.

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GOES Triangular Cell
Scan Mirror
Thermal Model

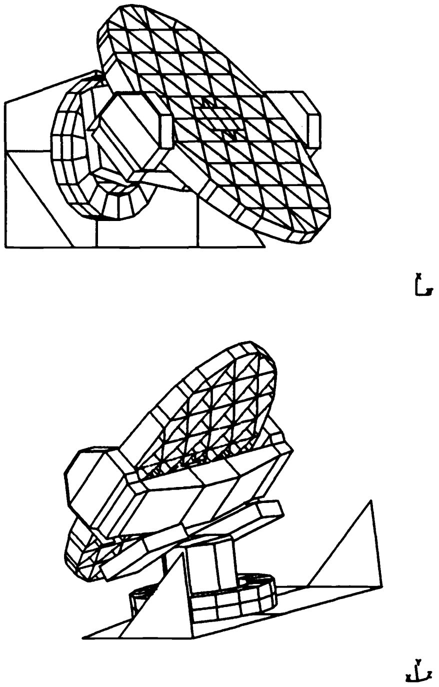

Figure 1

Cut Away View
of the
GOES System Thermal Model

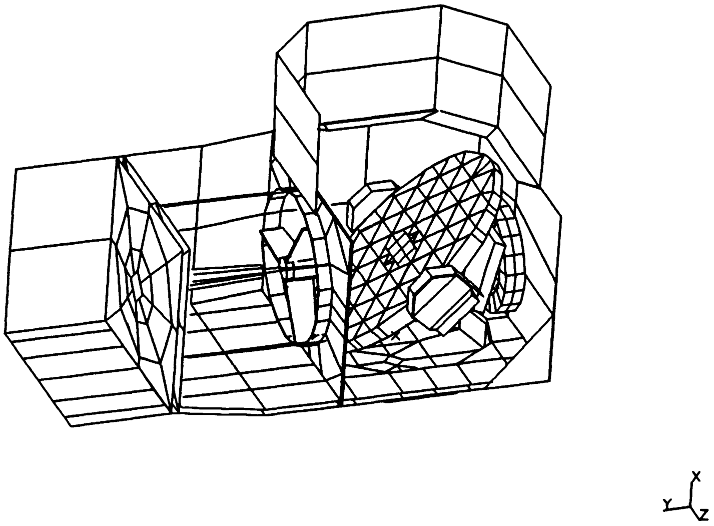

Figure 2

A much less detailed (simple) model of the scan mirror (see figure 3) was constructed by thermal analysts at Space Systems Loral (SSL). This model did not have individual cells modeled, instead it had nodes that represented the average of several cells and cell walls. An effective emissivity was calculated for the back of the mirror to account for the cell walls and this effective emissivity was used during calculation of radiant interchange factors.

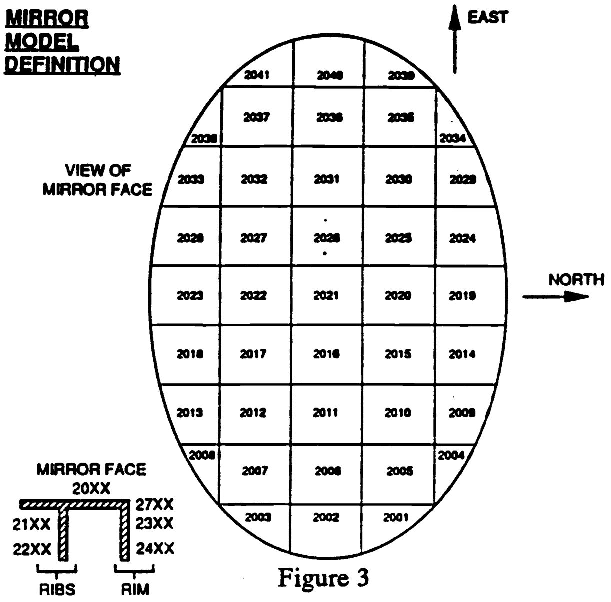

Figure 3

A comparison of the temperatures predictions of the detailed and simple models is shown figures 4 through 6. Figures 4 and 5 show comparisons of gradients along the major and minor axes and figure 6 shows a comparison of gradients through the thickness at a location along the rim of the mirror. The distortions resulting from these temperature predictions are shown in figure 7.

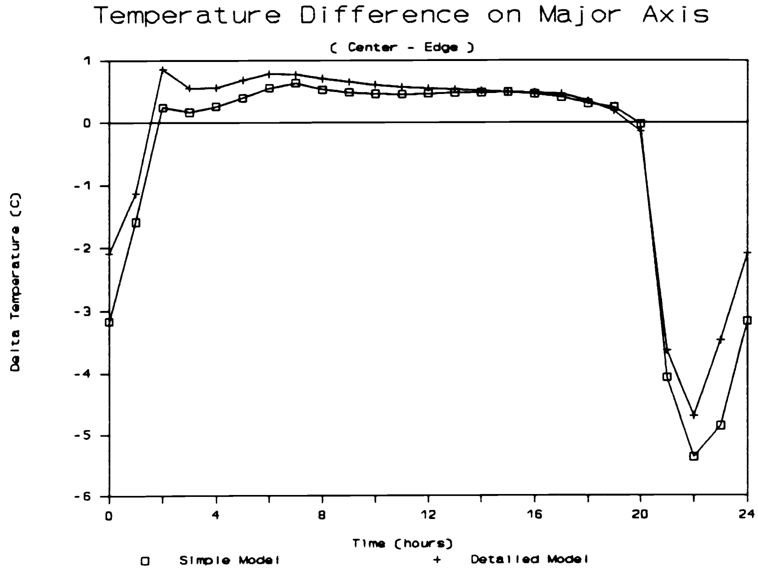

Figure 4

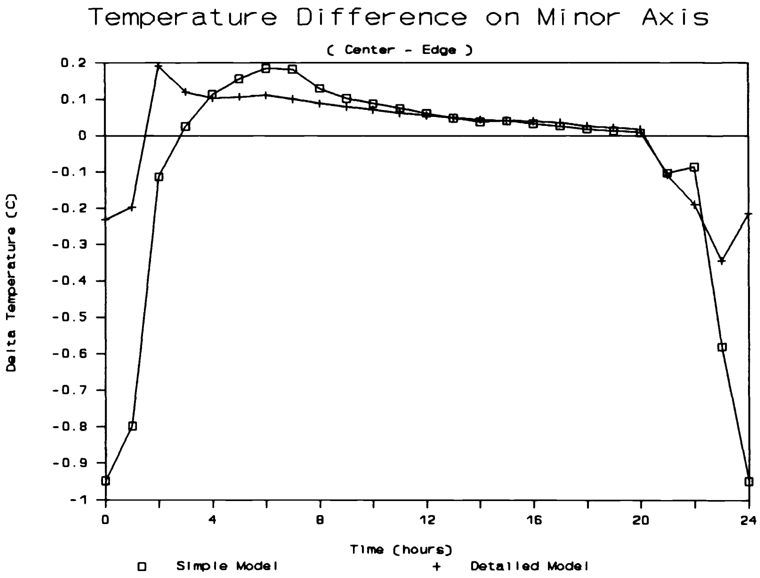

Figure 5

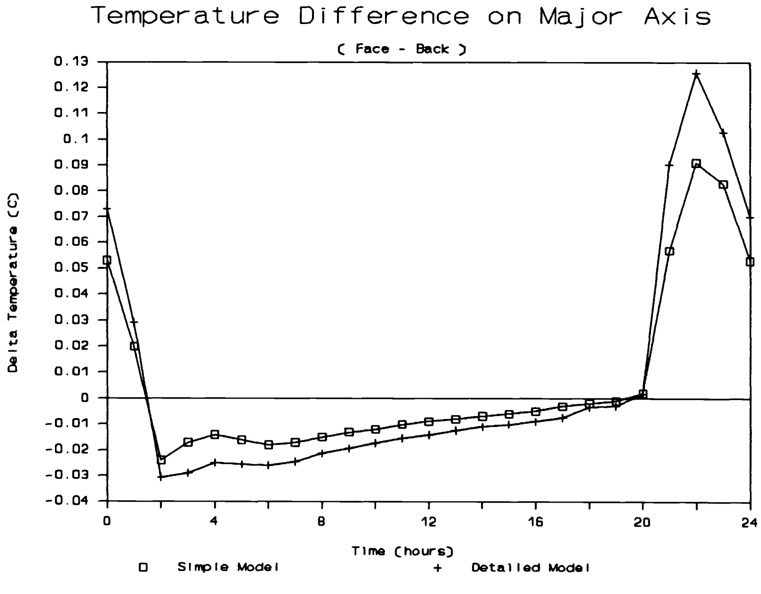

Figure 6

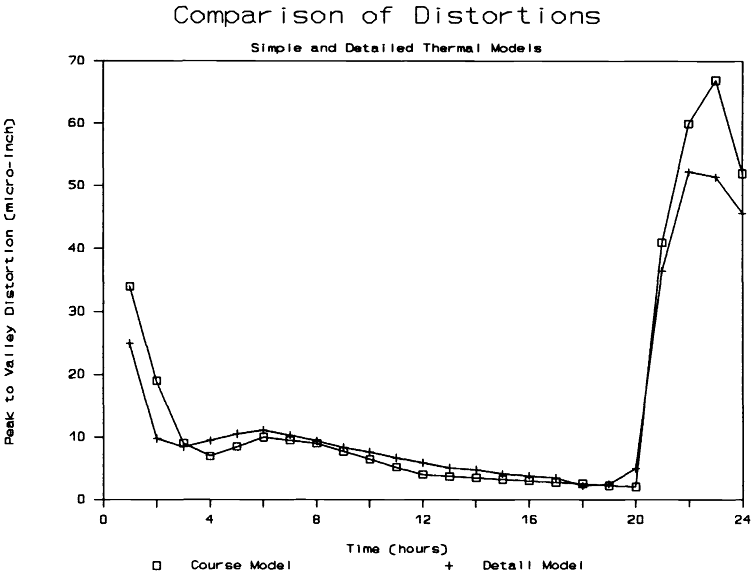

Figure 7

While the results from these two modeling techniques do not match exactly, they both indicate that the daytime distortions will be below 50 micro-inches (which is an acceptable level). The benefit of the less detailed model is that it can be built and solved much quicker than the detailed model.

Distortions of the scan mirror were found to be sensitive to temperature gradients in the plane of the optical surface (the face) of the mirror. The thermal properties of the mirror rim were varied to minimize temperature gradients in the face of the mirror. Figure 8 shows that changing the rim properties from silvered teflon to aluminum results in a marked decrease in mirror distortion.

Structural Models

The structural models were NASTRAN finite element models. When temperatures are defined for each of the grid points in the finite element model a solution for translations (and rotations) at the grid points can be obtained. The change in location of grid points representing the surface of the mirror approximates the distortions that the scan mirror would undergo due to the temperature distribution imposed on the grid points.

The structural model of the scan mirror was very similar to the detailed thermal model except it used four elements to represent each cell wall. The elements used to represent the face nodes had properties set by a PCOMP card so that coefficient of expansion differences between a nickel layer on the mirror face and the beryllium substrate could be represented.

Parametric studies were performed using structural models with a "benchmark" temperature distribution imposed on them. The benchmark distribution was a 2.5 degree circular distribution (along the minor axis). The use of this benchmark case allowed various design parameters such as CTE mismatch, cell geometries (hex, triangular, rectangular) and mirror type (open back or closed back) to be evaluated quickly.

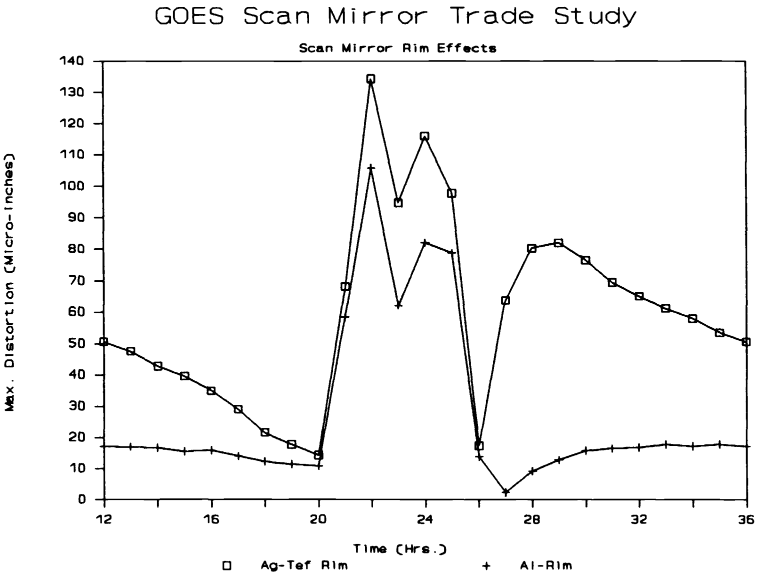

Figure 8

Data Transfer Between Models

The thermal model provides temperatures at the center of each node for as many times of the day as are requested. Grid point temperatures for the structural model are assigned by determining the closest thermal nodes to the grid location and interpolating on the temperatures in the thermal model to obtain a temperature for the grid point. A NASTRAN conduction solution was then run with all grid point temperatures assigned during the mapping process set as sinks. This automatically assigned temperatures to all grid points that did not get temperatures mapped from the thermal model.

After distortions were calculated by the structural model a set of Zernike polynomials were fit to the distortion data. These polynomials provided a means of representing the distorted surface in the optical models.

The most difficult step in the mapping process is mapping temperatures to the structural model. The problem is that the thermal model has no spacial information in the output of the thermal analyzer (a finite difference solution). The mapping for each model must be set up by hand or taken from the geometric models. The mapping of temperatures from the thermal model to the structural model can be automated for a given model but this work must be redone each time the nodal (or grid) layout of either model is changed. The conversion of displacements to Zernike polynomials can easily be automated because the NASTRAN displacement output is a list of grid numbers and XYZ coordinates. A program was written by analysts at Swales and Associates (under a NASA contract) to read the NASTRAN output and produce Zernike polynomials. This program was used to get data from the structural model to the optical model.

Conclusions

Thermal, structural and optical models were used to predict the on-orbit performance of the GOES scan mirror. The task of building, debugging and running the thermal model is the pacing item in the analysis chain. The time required to get orbital predictions can be significantly reduced by using simpler thermal models. A simpler thermal model can be used to provide temperatures to the structural model sooner, allowing the designers to consider many more design options. Detailed models of the final design can be built to get more exact predictions if they are needed.

The structural model is used to predict on-earth gravity sag and on-orbit distortions. A "benchmark" gradient can be imposed on structural models to allow designers to consider the sensitivity of designs to given temperature profiles. This technique was used at ITT to quickly evaluate hex, triangular and rectangular cell patterns.

Data transfer between models must be automated as much as possible. Transferring data from the thermal model to the structural model is not easily automated but it can be automated for a given set thermal nodes and structural grids. The step of transferring displacements from the structural model to the optical model was automated by using a program to take the NASTRAN displacement output and generate Zernike polynomials.

The analysis chain (thermal, structural, optical) is very long with many opportunities for mistakes to be made so a verification test should be performed. This test does not need to duplicate the on-orbit conditions but it must be flight like in that the heat transfer mechanisms that will be present on orbit are exercised in the test. Temperatures and distortions of the mirror can be measured during the test and used to correlate the thermal, structural and optical models.

Acknowledgments

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