STRUCTURAL-THERMAL-OPTICAL PROGRAM (STOP)

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The Structural-Thermal-Optical Program (STOP) is intended to coordinate technical disciplines and develop methods which exist in various areas and in their interfaces, as shown in Figure 1. This program primarily concerns the optical performance or alignment problem because of the structural deformation due to changing thermal conditions in the space environment. Applications exist in areas such as the OAO, LST, SAS, and any complex system where alignments are critical. It must be emphasized, however, that the methods developed in various areas can be used independently for many engineering applications.

When NASTRAN is used for structural analysis in computing thermally induced deflections or stresses, accurate input data of temperature distribution in the structural members are required. Unfortunately, the existing thermal computer programs using the lumped-node method are limited in size and are incompatible with the basic format of the structural model; the locations of the thermal nodes and the grid points of the NASTRAN structure program generally do not conform.

For this reason, and in order to have a unified computer program, we attempted to develop methods in four areas, which are represented by four tasks in Figure 1. They are all centered around the finite-element method NASTRAN structure program. With respect to task 1, the feasibility of using NASTRAN to solve heat transfer problems is attributed to the mathematical analogy existing between the two systems. This analogy is made clear when both systems are cast in the matrix form via the variational principle (by introducing finite elements and applying the Ritz method).

When variables or terms are properly interpreted, heat transfer problems can be solved by using the familiar vibration equation or the structural dynamics equation shown in Figure 2. The two diagrams in Figure 3 show the basic difference between the lumped-node method and the finite-element method. Average temperature of each area (volume) is

represented by the lumped node at the center in the case of the lumped-node method, but temperatures are represented at the vertices of each element in the case of the finite-element method.

An important advantage of the finite-element approach is that the output of one segment of the program is compatible with the input to the next. Another advantage is the ability to expand the size of the thermal analysis. Example problems solved by the finite-element method have been successfully demonstrated either by direct formulation or by the NASTRAN solution. A few selected examples are illustrated in Figure 4.

The convective and radiating fins of regular and tapered shape are shown in Figures 4(a) and 4(b). Figure 4(c) shows a radiating disk which has internal heat generation $\dot{q}$ (J/s-m^2) and circumferential heat input q (J/s-m). Figure 4(d) shows an L-shaped configuration that was adopted because it was suitable for the application of a number of different sets of boundary conditions. All solutions of the example problems by the finite-element method are in close agreement with the results obtained by the conventional methods of either exact or numerical solutions.

Task 2 is to develop a method of interpolating, through NASTRAN grid points, the displacements which yield deformations at any point on the surface. In Figure 5, the incoming ray hits the deformed surface at i', which must be related to the undeformed position i through the grid point displacements. The problem is then reduced to determining the direction cosines and coordinates at i. Consequently, the available ray-trace program can be used to obtain information about optical performance.

The method developed allows consideration of the case of an asymmetrically deformed optical surface. The uncertainties in input data in either the case of thermal or structural analysis naturally lead us to doubt the reliability of the computed results.

Task 3 is the thermal variance analysis, and the details of this analysis will be presented in the paper by J. S. Heuser. Task 4 is the structural variance analysis. In summary, STOP has been employed in four areas of investigation. The feasibility of using the finite-element method or of using NASTRAN directly in solving heat transfer problems has been demonstrated successfully. The resulting equations for the interface problem existing

between the structural deformation program and the ray-trace program (which indicates optical performance) are currently being coded into a computer program.

Both the thermal and structural variance problems have been explored and tackled, and work is still continuing. Since the successful results demonstrate the feasibility of this approach, pilot programs are to be implemented that will lead to a group of bona fide general purpose, large-capacity, working, and unified computer programs—the objectives of STOP.
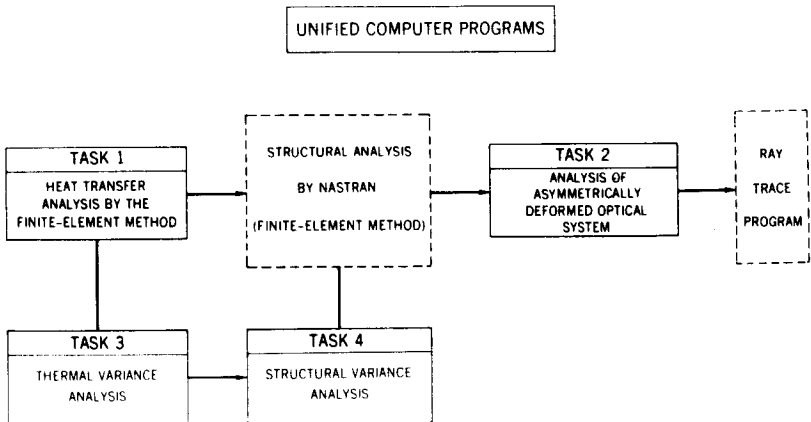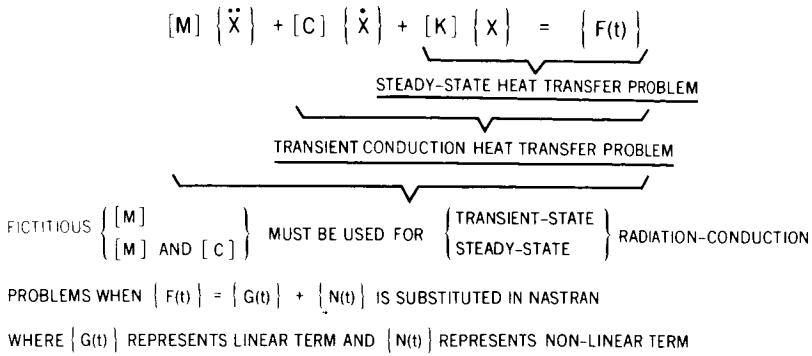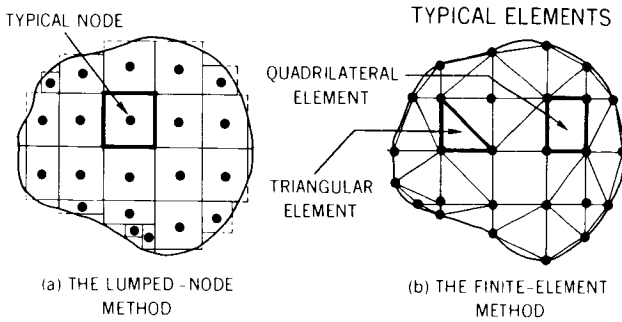

Figure 1—Structural-Thermal-Optical Program (STOP).

$$[M] \left\{ \ddot{X} \right\} + [C] \left\{ \dot{X} \right\} + [K] \left\{ X \right\} = \left\{ F(t) \right\}$$

STEADY-STATE HEAT TRANSFER PROBLEM

TRANSIENT CONDUCTION HEAT TRANSFER PROBLEM

FICTITIOUS $\left\{ \begin{array}{l} [M] \\ [M] \text{ AND } [C] \end{array} \right\}$ MUST BE USED FOR $\left\{ \begin{array}{l} \text{TRANSIENT-STATE} \\ \text{STEADY-STATE} \end{array} \right\}$ RADIATION-CONDUCTION

PROBLEMS WHEN $\left\{ F(t) \right\} = \left\{ G(t) \right\} + \left\{ N(t) \right\}$ IS SUBSTITUTED IN NASTRAN

WHERE $\left\{ G(t) \right\}$ REPRESENTS LINEAR TERM AND $\left\{ N(t) \right\}$ REPRESENTS NON-LINEAR TERM

STRUCTURAL SYSTEM		THERMAL SYSTEM
$\left\{ X \right\}$ DISPLACEMENT		TEMPERATURE
$\left\{ F \right\}$ APPLIED LOAD		HEAT SOURCE
$[K]$ STIFFNESS	(EQUIVALENCE)	CONDUCTIVITY
$[C]$ DAMPING		THERMAL CAPACITY
$[M]$ MASS		NO EQUIVALENCE

Figure 2—Similarity between structural and thermal systems.

TYPICAL NODE   TYPICAL ELEMENTS

QUADRILATERAL ELEMENT

TRIANGULAR ELEMENT

(a) THE LUMPED-NODE METHOD

(b) THE FINITE-ELEMENT METHOD

ADVANTAGES OF USING THE FINITE-ELEMENT METHOD

- COMPATIBILITY
- CAPACITY

Figure 3—Distinction between the lumped-node method and the finite-element method.
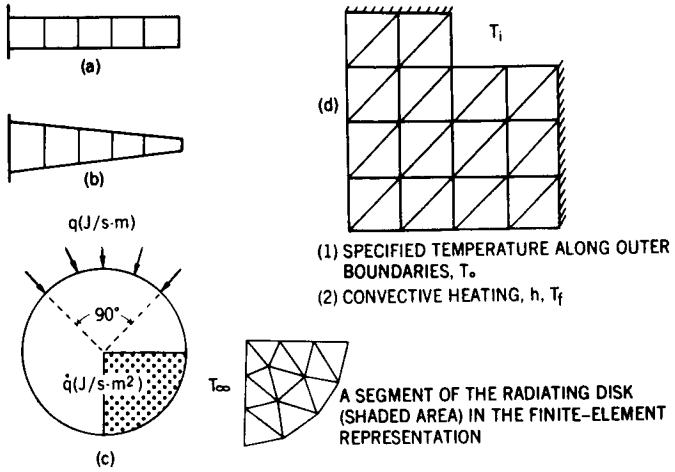
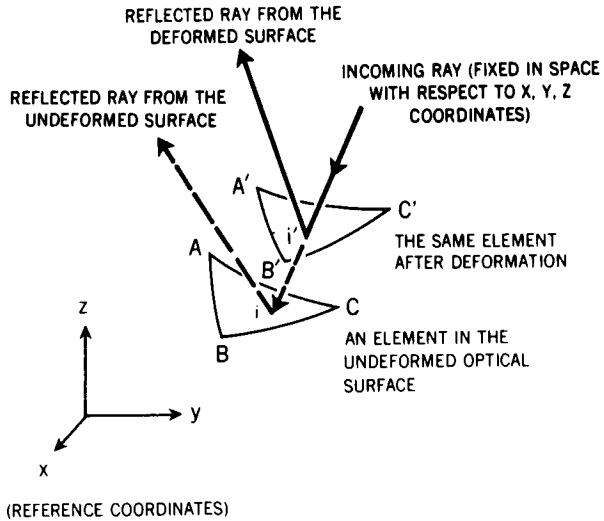Figure 4—Typical heat transfer problems being solved by the finite-element method.

Figure 5—Deviation of reflected rays from an undeformed optical surface and from a deformed optical surface.