

AFWAL-TR-80-3007

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**OPTIM III: A NASTRAN COMPATIBLE LARGE SCALE  
AUTOMATED MINIMUM WEIGHT DESIGN PROBLEM  
— USERS AND PROGRAMMERS MANUAL**

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TECHNICAL REPORT AFWAL-TR-80-3007  
Final Report for Period June 1977 — December 1979

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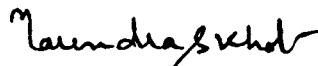
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|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| 1. REPORT NUMBER<br>(18) AFWAL-TR-80-3007                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 2. GOVT ACCESSION NO.<br>AD-A090334 | 3. RECIPIENT'S CATALOG NUMBER<br>(9)                                                                                        |
| 4. TITLE (and Subtitle)<br>OPTIM III: A NASTRAN COMPATIBLE LARGE<br>SCALE AUTOMATED MINIMUM WEIGHT DESIGN<br>PROBLEM.<br>USERS AND PROGRAMMERS MANUAL.                                                                                                                                                                                                                                                                                                                                                         |                                     | 5. TYPE OF REPORT & PERIOD COVERED<br>Final Report,<br>Jun 77 - Dec 1979                                                    |
| 7. AUTHOR(s)<br>(10) B. J. Dale, J. Padlog <del>and</del> Richard D. Thom                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                     | 6. PERFORMING ORG. REPORT NUMBER                                                                                            |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Bell Aerospace Textron, Inc.<br>Buffalo, New York 14240                                                                                                                                                                                                                                                                                                                                                                                                         |                                     | 8. CONTRACT OR GRANT NUMBER(s)<br>(15) F33615-77-C-3032                                                                     |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Flight Dynamics Laboratory (FIBRA)<br>AF Wright Aeronautical Laboratories<br>Wright-Patterson Air Force Base, Ohio 45433                                                                                                                                                                                                                                                                                                                                            |                                     | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS<br>Project 2307 (17)<br>Task 2307-N5<br>Work Unit 2307-N5-02 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)<br>(12) 182                                                                                                                                                                                                                                                                                                                                                                                                                        |                                     | 12. REPORT DATE<br>February 1980                                                                                            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                     | 13. NUMBER OF PAGES<br>182                                                                                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                     | 15. SECURITY CLASS. (of this report)<br>Unclassified                                                                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                     | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE                                                                               |
| 16. DISTRIBUTION STATEMENT (of this Report)<br>Approved for public release - distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                           |                                     |                                                                                                                             |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)                                                                                                                                                                                                                                                                                                                                                                                                                     |                                     |                                                                                                                             |
| 18. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                     |                                                                                                                             |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Structural Optimization<br>Force Method of Finite Element Analysis<br>Minimum Weight Design<br>Stress Constraints                                                                                                                                                                                                                                                                                                        |                                     |                                                                                                                             |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The weight optimization computer program OPTIM II was extended to a new version, OPTIM III, which is compatible with the input format of the NASTRAN finite element computer program. All features of the original program were retained including the use of optimality criteria to generate a highly efficient iterative optimization procedure with convergence characteristics independent of problem size.<br>(over) |                                     |                                                                                                                             |

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Membrane finite elements were extended to include the capability of handling layered, orthotropic material, composite membrane plate constructions. Various failure criteria for composite materials were included as required for strength constraints in the optimization process involving the composite plates.

New NASTRAN compatible input data instructions are provided and their use demonstrated by a sample problem.

An extended programmer's manual, designed to facilitate implementation, modification, and illustration of the OPTIM III program is included.

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## FOREWORD

This report describes the work performed by Bell Aerospace Textron, a Division of Textron, Inc., Buffalo, New York. The work was sponsored by the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Contract F33615-77-C-3032.

The work was initiated under Project 2307, "Research in Flight Vehicle Dynamics," Task 2307N502, "Basic Research in Structures and Dynamics." The work was administered by Dr. N. S. Khot, Project Engineer of the Structures and Dynamics Division (FIBR).

The contracted work was performed between June 1977 and October 1979.

The work was performed in the Advanced Mobility System Department, Bell Aerospace Textron. Mr. Richard D. Thom was the Technical Director of the study.

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## I. INTRODUCTION

The weight optimization computer program OPTIM II, Reference 1, was altered to make its input format compatible with the widely used NASTRAN program. The resulting new program is called OPTIM III. Accomplishment of this objective required the modification and addition of many subroutines.

Included in the new program, OPTIM III, is the capability of analyzing and optimizing structures which contain composite membrane plates. The method of approach adopted for analysis of composite membrane plates involves the stacking of triangle and quadrilateral orthotropic membrane plate elements and is discussed in Section II. Also included in Section II is a summary of the three types of failure criteria for composite materials in a state of plane stress which are available in OPTIM III for use in connection with the optimization process.

The theoretical bases for the triangle and quadrilateral orthotropic membrane plates inserted into OPTIM III is given in Section III which also includes a summary of all the eight finite elements available.

All NASTRAN compatible input data cards are described in Section IV and their utilization is illustrated by a sample problem in Section V.

A programmer's manual which describes the computer program OPTIM III in detail is presented in the appendix. The information presented in the appendix is geared specifically to the programmer and includes the general program logic, external file structure and detailed descriptions of the subroutines.

## II. OPTIMIZATION OF STRUCTURES CONTAINING COMPOSITE PLATES

### A. General

The membrane triangle and quadrilateral plate element originally included in OPTIMII were extended to handle composite plate constructions. The type of composite structures accepted by the optimization program is limited to flat composite plates composed of orthotropic layers of material. Each layer of the plate composite is idealized as a separate finite membrane plate element which is discussed later in this section.

When modeling a composite plate consisting of many layers, the gridpoints of all the membrane elements or layers of the plate are selected to be the same. This restriction ensures that each of the layers of the composite plate is subjected to the same deformation state and is in conformance with small displacement plate theory in which it is assumed that straight normals to the plate median surface before deformation remain straight after deformation. To ensure that this condition is satisfied, the layers of the plate composite must be oriented symmetrically with respect to the median surface of the composite plate.

Various failure criteria for composite materials were investigated and of these three types of criteria were included in OPTIMIII. These three types of criteria which are required in the optimization process for the layers in the composite plate are discussed in this section. (Reference 6, 7, 8).

## B. Analysis with Orthotropic Membrane Elements

Each layer in a composite membrane plate is assumed to be composed of fibers imbedded in a matrix material. The fibers are assumed to be oriented in such a way as to result in their characterization as an orthotropic material. A typical orthotropic layer of this type is illustrated in Figure 1. Coordinates  $X_m$ ,  $Y_m$  shown in the figure are the material axis of orthotropy in which the  $X_m$  axis is oriented parallel to the fibers.

Two types of orthotropic membrane plate finite elements are available in the optimization program and they are,

1. Triangle membrane element
2. Quadrilateral membrane element

These two finite elements are displayed in Figure 2. The angle  $\theta$  gives the orientation of the material axis with respect to the side connecting gridpoints 1 to 2. Note that for the triangle the material axis orientation angle  $\theta$  is measured from side 1-2 to the material axis  $X_m$  whereas for the quadrilateral it is measured from the material axis  $X_m$  to the side 1-2.

The relationship between the elastic stresses and strains for an orthotropic material in plane stress referenced to the material axis of orthotropy shown in Figure 1 is given by

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}_m = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{bmatrix} \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{xy} \end{Bmatrix}_m$$

where

$$\Delta = 1 - \mu_{xy} \mu_{yx}, \quad \frac{\mu_{xy}}{\mu_{yx}} = \frac{E_x}{E_y}$$

$$G_{11} = \frac{E_x}{\Delta}, \quad G_{12} = \frac{E_y \mu_{xy}}{\Delta}, \quad G_{13} = 0.0$$

$$G_{21} = G_{12}, \quad G_{22} = \frac{E_y}{\Delta}, \quad G_{23} = 0.0$$

$$G_{31} = G_{13}, \quad G_{32} = G_{23}, \quad G_{33} = G_{xy}$$

These stress-strain relations were used in the development of the membrane plate elements and reduced down to isotropic material properties. This situation makes it possible to construct a composite membrane plate composed of fiber-reinforced orthotropic materials and isotropic metallic-type materials.

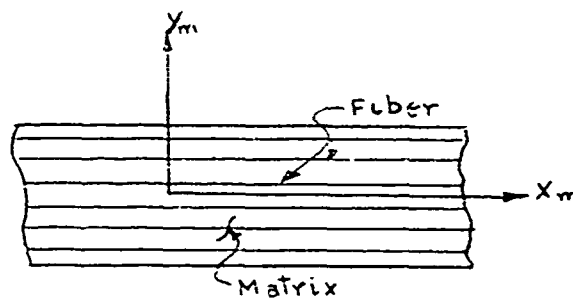
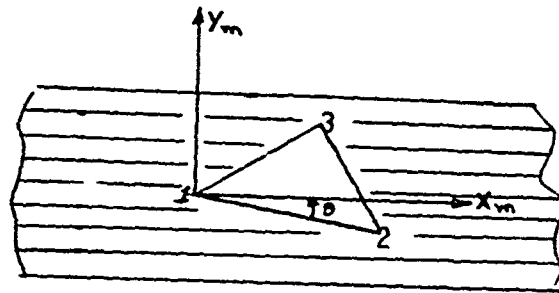
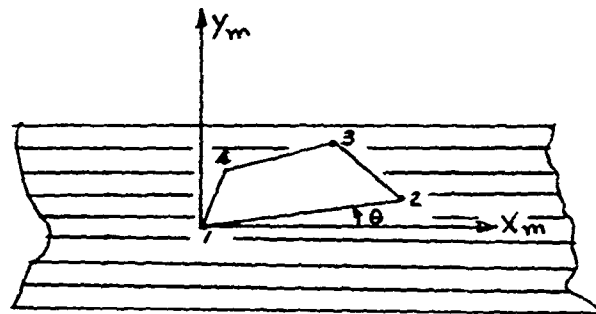


Figure 1. Typical fiber-reinforced layer in a composite membrane plate

The stresses are computed for both element types with respect to the material axis of orthotropy and are used in the failure criteria formulation discussed in the next section.



a. Triangle



b. Quadrilateral

Figure 2. Orientation of membrane elements in fiber-reinforced composite layer

### C. Criteria of Failure

Three types of criteria of failure have been inserted into the optimization program. They are

- a. Modified Von Mises or energy of distortion criterion of failure
- b. Maximum Stress Theory
- c. Maximum Strain Theory

In all of these theories, the applied stresses  $\sigma_x$ ,  $\sigma_y$  and  $\sigma_{xy}$  are referred to the material axes of orthotropy.

The modified distortion energy criterion of failure is given by

$$\left(\frac{\sigma_x}{F_x}\right)^2 + \left(\frac{\sigma_y}{F_y}\right)^2 - \frac{\sigma_x \sigma_y}{F_x F_y} + \left(\frac{\sigma_{xy}}{F_{xy}}\right)^2 = 1$$

where  $F_x$  and  $F_y$  are tensile (compression) failure stresses and  $F_{xy}$  is the shear failure stress. These failure stresses are determined for simple load test conditions with respect to the axis of orthotropy.

The maximum stress theory postulates that failure will occur when any one of the three applied stresses is equal to its corresponding failure stress. Thus failure occurs when any one of the following conditions is satisfied

$$\sigma_x = F_x$$

$$\sigma_y = F_y$$

$$\sigma_{xy} = F_{xy}$$

In the above two theories tension or compression failure stresses are selected in consistency with the sign of the applied stresses. Failure stresses  $F_x$ ,  $F_y$  and  $F_{xy}$  represent longitudinal, transverse, and shear modes of failure.

For the maximum strain theory it is assumed that failure is precipitated when any one of the applied strain components referred to the material axis attains its limiting failure strain. Thus for an orthotropic material the conditions of failure are

$$\begin{aligned}\epsilon_x &= \bar{\epsilon}_x \\ \epsilon_y &= \bar{\epsilon}_y \\ \gamma_{xy} &= \bar{\gamma}_{xy}\end{aligned}$$

where  $\bar{\epsilon}_x$ ,  $\bar{\epsilon}_y$  and  $\bar{\gamma}_{xy}$  are the failure strains. Note that a negative applied strain implies a compression failure strain. The condition of failure in terms of stresses are

$$\begin{aligned}\bar{\epsilon}_x E_{xx} &= \sigma_{xx} + M_{xy} \sigma_{yy} \\ \bar{\epsilon}_y E_{yy} &= \sigma_{yy} + M_{xy} \frac{E_{xx}}{E_{yy}} \sigma_{xx} \\ \bar{\gamma}_{xy} G_{12} &= \tau_{xy}\end{aligned}$$

Implementation of the above three failure criteria requires a knowledge of the following ten material failure properties:  $\pm F_x$ ,  $\pm F_y$ ,  $F_{xy}$ ,  $\pm \bar{\epsilon}_x$ ,  $\pm \bar{\epsilon}_y$ ,  $\bar{\gamma}_{xy}$ .

NOTE:  $M = \nu$  Poissons Ratio

### III. NEW ORTHOTROPIC PLATE ELEMENTS

#### A. General

As noted in Reference 1, the usefulness of an optimization program stems from the accuracy with which the real structure can be represented by the finite element model. In the OPTIM II program there are eight elements available for the analysis of a structure fabricated from isotropic materials. A major task of the present work was not only to put OPTIM II into a form compatible with NASTRAN but to extend its capability to include composite plate structures. In this latest version of OPTIM II there are eight elements as shown in Figure 3 with their program names and they are:

1. Axial Force Member
2. Pure Shear and Shear Web Elements
3. Triangular Plate in Plane Stress
4. Quadrilateral Plate in Plane Stress
5. Tubular Beam Element
6. Midpoint Axial Force Member
7. Midpoint Triangular Plate in Plane Stress
8. Midpoint Quadrilateral Plate in Plane Stress

The first three elements in the above list were in the pilot optimization program, OPTIM (Reference 2) and the remaining five added when OPTIM II was written. Explicit formulations for the element stiffness and other matrices are given in Reference 2 for the first five elements

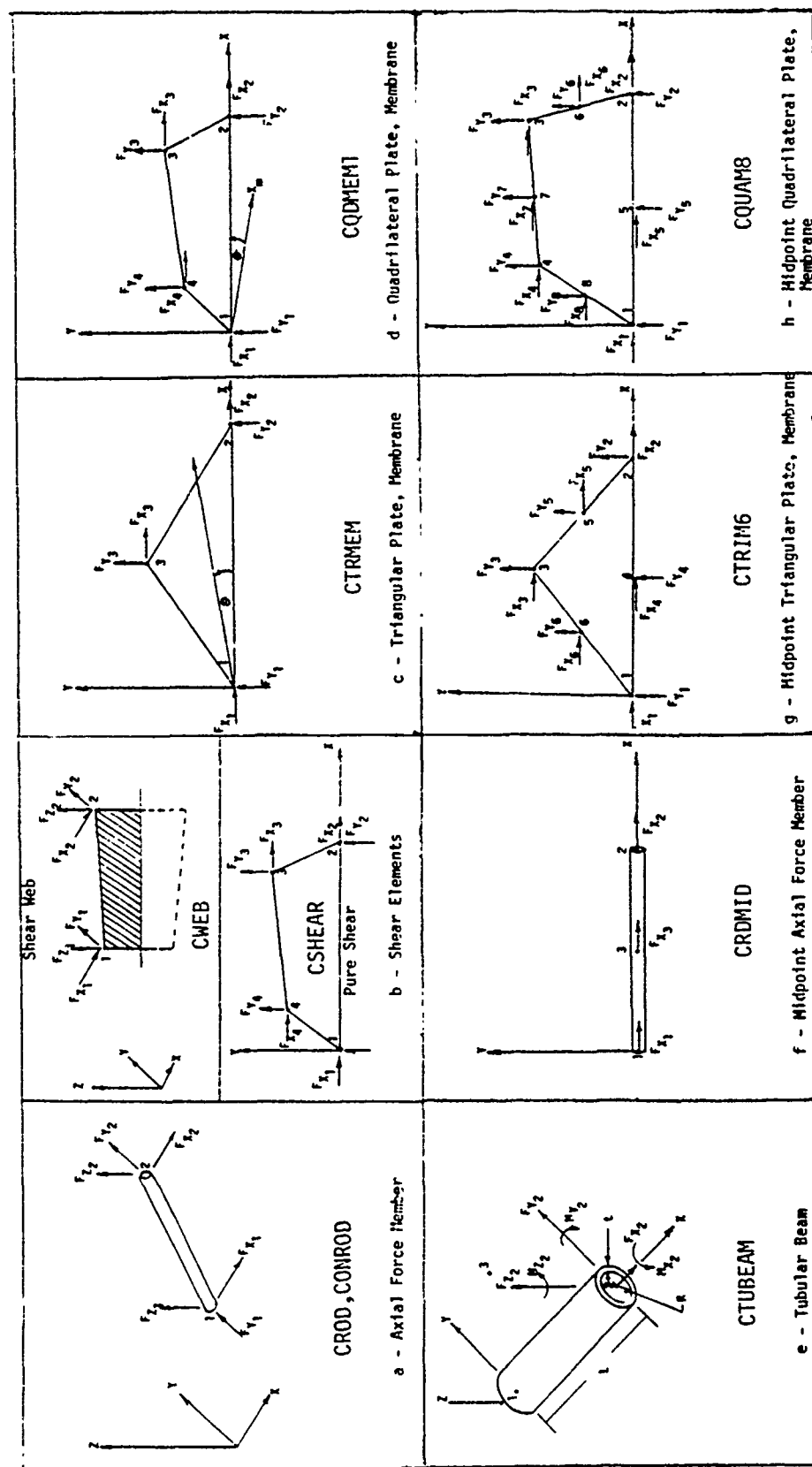


FIGURE 3. FINITE ELEMENT LIBRARY

in the above list. Formulations for the last three elements are given in Reference 1. The triangular and quadrilateral membrane plate elements, number 3 and 4, were extended to include orthotropic plate properties and the details of this extension are given in the next two sections.

#### B. Triangular Membrane Plate

The triangular plate in plane stress originally contained in the OPTIM II program was extended to include orthotropic material properties. The location of the material axis of orthotropy ( $X_m, Y_m$ ) is shown in Figure 3C, and is referred to the local reference axes ( $X, Y$ ) of the triangle by the angle  $\theta$ . A description of the procedure used to compute the stiffness and stress matrices is given below. Theoretical background for the procedure is given in References 2, 3 and 5.

As shown in Reference 2, the stiffness matrix referred to the local axis system is given by

$$[K] = t[B^{-1}]^T [A^*] [B^{-1}] \quad (3.1)$$

where

$$[B]^{-1} = \frac{1}{x_2 y_3 - x_3 y_2} \begin{bmatrix} (x_2 y_3 - x_3 y_2) & 0 & 0 & 0 & 0 & 0 \\ -y_{3-2} & y_3 & -y_2 & 0 & 0 & 0 \\ x_{3-2} & -x_3 & x_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & (x_2 y_3 - x_3 y_2) & 0 & 0 \\ 0 & 0 & 0 & -y_{3-2} & y_3 & -y_2 \\ 0 & 0 & 0 & x_{3-2} & -x_3 & x_2 \end{bmatrix} \quad (3.2)$$

The matrix  $[A^*]$  is given by

$$[A^*] = [T] [G_e] [T]^T \quad (3.4)$$

where the transformation matrix  $[T]$  is :

$$[T] = \begin{bmatrix} 0. & 0. & 0. \\ 1.0 & 0. & 0. \\ 0. & 0. & 1.0 \\ 0. & 0. & 0. \\ 0. & 0. & 0. \\ 0. & 1.0 & 0. \end{bmatrix} \quad (3.5)$$

For isotropic materials the material matrix  $[G_e]$  in Equation (3.4) is given by

$$[G_e] = \begin{bmatrix} \frac{E}{1-M^2} & \frac{ME}{1-M^2} & 0 \\ \frac{ME}{1-M^2} & \frac{E}{1-M^2} & 0 \\ 0. & 0. & G \end{bmatrix} \quad (3.6)$$

and for orthotropic material:

$$[G_e] = [U]^T [G_m] [U] \quad (3.7)$$

where the rotation transformation matrix  $[U]$  of strain components is given by

$$[U] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \cos\theta\sin\theta \\ \sin^2\theta & \cos^2\theta & -\cos\theta\sin\theta \\ -2\cos\theta\sin\theta & 2\cos\theta\sin\theta & \cos^2\theta - \sin^2\theta \end{bmatrix} \quad (3.8)$$

The elements of the material matrix  $[G_m]$  are defined in terms of orthotropic material properties as follows:

$$\begin{aligned}
 G_{11} &= \frac{E_x}{\Delta} & G_{12} &= \frac{E_y M_{xy}}{\Delta} & G_{13} &= 0.0 \\
 G_{21} &= G_{12} & G_{22} &= \frac{E_y}{\Delta} & G_{23} &= 0.0 \\
 G_{31} &= G_{13} & G_{32} &= G_{23} & G_{33} &= G_{xy}
 \end{aligned} \tag{3.9}$$

$$\Delta = 1 - M_{xy} M_{yx}, \quad \frac{M_{xy}}{M_{yx}} = \frac{E_x}{E_y}$$

The membrane stresses, assumed constant in the element, are given with reference to the material axis of orthotropy by

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = [S] \{u_e\} \tag{3.10}$$

where

$$[S] = [D] [B^{-1}] \tag{3.11}$$

$$[D] = [T_1] [T] [G_e] [T]^T [B^{-1}] \tag{3.12}$$

$$[T_1] = \begin{bmatrix} 0. & 1. & 0. & 0. & 0. & 0. \\ 0. & 0. & 1. & 0. & 0. & 0. \\ 0. & 0. & 0. & 0. & 0. & 1. \end{bmatrix} \tag{3.13}$$

### C. Quadrilateral Membrane Plate

The quadrilateral membrane plate, Figure 3d, is a linear stress variation element originally developed by Turner<sup>(4)</sup> for isotropic materials ( $\theta = 0$ ) and used subsequently in many analysis and optimization programs. For this element, the design variable is the plate thickness and the stress variations are given by

$$\sigma_x = a_1 + a_2 y$$

$$\sigma = a_3 + a_4 x$$

$$\gamma_{xy} = a_5$$

This element was extended to include orthotropic material properties, and theoretical details of the extension are given in Reference 3. However, the element matrices developed in Reference 3 were referred to the material axis and to make them compatible with the OPTIM II program, material to local axis transformation had to be introduced.

The stiffness matrix for the quadrilateral membrane plate referred to the local element axis is given by

$$[K] = t[T_2]^T [B^{-1}]^T [A^*] [B^{-1}] [T_2] \quad (3.14)$$

where:

$$[B] = \frac{1}{E_X} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ & x_2 y_2 & -\mu_{XY} x_2 & -\frac{\mu_{XY} x_2^2 - \frac{E_X}{E_Y} y_2^2}{2} & 0 & y_2 & 1 & 0 \\ x_3 & x_3 y_3 & -\mu_{XY} x_3 & -\frac{\mu_{XY} x_3^2 - \frac{E_X}{E_Y} y_3^2}{2} & 0 & y_3 & 1 & 0 \\ x_4 & x_4 y_4 & -\mu_{XY} x_4 & -\frac{\mu_{XY} x_4^2 - \frac{E_X}{E_Y} y_4^2}{2} & 0 & y_4 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_2 & -\frac{\mu_{XY} y_2^2 - x_2^2}{2} & \frac{E_X}{E_Y} y_2 & \frac{E_X}{E_Y} x_2 y_2 & \frac{E_X x_2}{G_{XY}} & -x_2 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_3 & -\frac{\mu_{XY} y_3^2 - x_3^2}{2} & \frac{E_X}{E_Y} y_3 & \frac{E_X}{E_Y} x_3 y_3 & \frac{E_X x_3}{G_{XY}} & -y_3 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_4 & -\frac{\mu_{XY} y_4^2 - x_4^2}{2} & \frac{E_X}{E_Y} y_4 & \frac{E_X}{E_Y} x_4 y_4 & \frac{E_X x_4}{G_{XY}} & -x_4 & 0 & \frac{E_X}{E_Y} \end{bmatrix} \quad (3.15)$$

$$[A^*] = \frac{t}{E_X} \begin{bmatrix} A & I_Y & -\mu_{XY} A & \mu_{XY} I_X & 0 & 0 & 0 & 0 \\ I_Y & I_Y^2 & -\mu_{XY} I_Y & -\mu_{XY} I_{XY} & 0 & 0 & 0 & 0 \\ -\mu_{XY} A & -\mu_{XY} I_Y & \frac{E_X}{E_Y} A & \frac{E_X}{E_Y} I_X & 0 & 0 & 0 & 0 \\ -\mu_{XY} I_X & -\mu_{XY} I_{XY} & \frac{E_X}{E_Y} I_X & \frac{E_X}{E_Y} I_X^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{E_X A}{G_{XY}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.16)$$

The matrix  $[T_2]$  transforms the element displacements from the material axis of orthotropy to the local element axis and is given by

$$[T_2] = \begin{matrix} & \begin{matrix} u_{1m} & u_{2m} & u_{3m} & u_{4m} & v_{1m} & v_{2m} & v_{3m} & v_{4m} \end{matrix} \\ \begin{matrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ v_1 \\ v_2 \\ v_3 \\ v_4 \end{matrix} & \begin{bmatrix} \cos\theta & 0 & 0 & 0 & -\sin\theta & 0 & 0 & 0 \\ 0 & \cos\theta & 0 & 0 & 0 & -\sin\theta & 0 & 0 \\ 0 & 0 & \cos\theta & 0 & 0 & 0 & 0 & 0 \\ \sin\theta & 0 & 0 & \cos\theta & 0 & 0 & -\sin\theta & 0 \\ 0 & \sin\theta & 0 & 0 & \cos\theta & 0 & 0 & -\sin\theta \\ 0 & 0 & \sin\theta & 0 & 0 & \cos\theta & 0 & 0 \\ 0 & 0 & 0 & \sin\theta & 0 & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 0 & \sin\theta & 0 & 0 & \cos\theta \end{bmatrix} \end{matrix} \quad (3.17)$$

Membrane stresses in the quadrilateral membrane plate element are given by Equation 3.10 with the stress matrix defined as

$$[S] = [D][B^{-1}][T_2] \quad (3.18)$$

where matrix  $[B]$  is given by Equation 3.15, transformation matrix  $[T_2]$  by Equation 3-17 and the  $[D]$  matrix by the following:

$$[D] = \begin{bmatrix} 1 & 0 & 0 & 0 & Y_m & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X_m & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.19)$$

where  $X_m$ ,  $Y_m$  are referred to the material axis.

Stresses used in the failure criteria for the quadrilateral membrane plate are located at its centroid which has the coordinates

$$\begin{aligned}\bar{X}_m &= \frac{X_{1m} + X_{2m} + X_{3m} + X_{4m}}{4} \\ \bar{Y}_m &= \frac{Y_{1m} + Y_{2m} + Y_{3m} + Y_{4m}}{4}\end{aligned}\tag{3.20}$$

## IV. PROGRAM INPUT DESCRIPTION

### A. Input Overview

This section describes the input data required to execute the NASTRAN compatible optimization program OPTIM III.

OPTIM III was developed such that most of the input data cards are in NASTRAN format. This input consists of a deck beginning with "BEGIN BULK" and ending with "ENDDATA". All data cards are optional except those defining controls, loads, grid, and boundary conditions. Elements must also be defined.

The NASTRAN input feature of submitting data in any order, either left or right adjusted, is preserved. The GRID cards, SPC cards, FORCE, MOMENT, and MAT1, MAT2 cards are similar to NASTRAN input. Figure 3 shows the OPTIM III element library and the appropriate C\*TIM input code for each element. The following is a summary of OPTIM III Input Cards:

### B. Definitions of Input Cards

|            |                                                        |
|------------|--------------------------------------------------------|
| BEGIN Bulk | First Card of Input                                    |
| *Buck      | Define elements which require buckling                 |
| *Buck1     | Define set of elements which require buckling          |
| CONROD     | AXIAL FORCE MEMBER Property and Connection             |
| CQUAM8     | 8 Noded Midpoint Quadrilateral Connection              |
| CQDMEM1    | Quadrilateral Membrane Connection Card                 |
| CRDMID     | Midpoint AXIAL Force Member Connection                 |
| CROD       | Axial Force Element Connection                         |
| CSHEAR     | Shear Panel Element Connection                         |
| CTRIM6     | Triangular 6 node midpoint membrane element connection |
| CTRMEM     | Triangular membrane element connection                 |
| CTUBEAM    | Tubular beam element connection                        |
| CWEB       | Shear Web element connection                           |
| FORCE      | Static load at grid point                              |
| *GCON      | Generalized Constraint Components                      |
| *GPCEQN    | Grid Point Constraint Equations                        |
| GRID       | Grid Point Coordinates                                 |
| *ICON      | Individual Constraints                                 |
| *LINKS     | Linked group element members                           |
| MAT1       | Isotropic material properties                          |
| MAT2       | Anisotropic material properties                        |
| MOMENT     | Static moment at a gridpoint                           |
| *OPDVIR    | Selected element design variables                      |
| OPLOADS    | Loads for optimization                                 |
| OPTIM      | Optim control parameters                               |
| PQUAM8     | Property card for 8 node midpoint quadrilateral        |
| PQDMEM1    | Property card for quadrilateral membrane               |
| PRDMID     | Property card for midpoint axial force membrane        |

\*These cards are optional and need to be input only if necessary

|           |                                              |
|-----------|----------------------------------------------|
| PROP      | Property card for axial force member         |
| PSHEAR    | Property card for shear panel                |
| PTRIM6    | Property card for triangular 6 node midpoint |
| PTMEM     | Property card for triangular membrane        |
| PTUBEAM   | Property card for tubular beam               |
| PWEB      | Property card for shear web                  |
| SPC       | Single point constraint                      |
| SPC1      | Sets of single point constraints             |
| SPC1 THRU | Sets of single point constraints             |
| TITLE     | Title card information                       |
| ENDDATA   | End of Data Deck                             |

### C. Input Format

In this section detail OPTIM III input card descriptions are presented in a manner similar to the NASTRAN User's Manual. That is, each data card is described individually in alphabetical order.

Input Data Card BEGIN Bulk

Description: First Card of Input

| 1          | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------------|---|---|---|---|---|---|---|---|----|
| BEGIN Bulk |   |   |   |   |   |   |   |   |    |

This card is identical to the format of the first card used in a NASTRAN bulk data deck.

Input Data Card BUCK Buckling Elements

Description: Defines elements which require buckling calculations

Format and Example:

| 1    | 2   | 3               | 4               | 5               | 6               | 7               | 8               | 9               | 10 |
|------|-----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----|
| BUCK | SID | EL <sub>1</sub> | EL <sub>2</sub> | EL <sub>3</sub> | EL <sub>4</sub> | EL <sub>5</sub> | EL <sub>6</sub> | EL <sub>7</sub> |    |
| BUCK | 1   | 2               | 3               | 7               | 8               | 9               | 10              | 12              |    |

Field

SID Identification number of the buckling set

EL<sub>1</sub>, etc. Element number

Input Data Card BUCK1      Buckling Elements

Description:      Defines sets of element which require buckling calculations

Format and Example:

| 1     | 2   | 3               | 4      | 5               |
|-------|-----|-----------------|--------|-----------------|
| BUCK1 | SID | EL <sub>1</sub> | "THRU" | EL <sub>n</sub> |
| BUCK1 | 1   | 1               | THRU   | 17              |

Field

|                 |                                    |
|-----------------|------------------------------------|
| SID             | Identification of the buckling set |
| EL <sub>1</sub> | Element number                     |
| EL <sub>n</sub> | Element number                     |

# BULK DATA DECK

Input Data Card CØNRØD AXIAL FORCE MEMBER Property and Connection

Description: Defines a rod element of the structural model without reference to a property card.

## Format and Example:

| 1      | 2   | 3  | 4  | 5   | 6    | 7 | 8 | 9 | 10 |
|--------|-----|----|----|-----|------|---|---|---|----|
| CØNRØD | EID | G1 | G2 | MID | A    |   |   |   |    |
| CØNRØD | 2   | 16 | 17 | 23  | 2.69 |   |   |   |    |

| <u>Field</u> | <u>Contents</u>                                                               |
|--------------|-------------------------------------------------------------------------------|
| EID          | Unique element identification number (Integer > 0)                            |
| G1, G2       | Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2) |
| MID          | Material identification number (Integer > 0)                                  |
| A            | Area of rod (Real)                                                            |

Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. For structural problems, CØNRØD cards may only reference MAT1 material cards.

Input Data Card CQUAM8 Midpoint Quadrilateral Element Connection

Description: Defines a midpoint quadrilateral membrane element (QUAM8) of the structure.

Format and Example:

|        |     |     |    |    |    |    |    |    |      |
|--------|-----|-----|----|----|----|----|----|----|------|
| 1      | 2   | 3   | 4  | 5  | 6  | 7  | 8  | 9  | 10   |
| CQUAM8 | EID | PID | G1 | G2 | G3 | G4 | G5 | G6 | +abc |
| CQUAM8 | 10  | 3   | 1  | 10 | 11 | 8  | 9  | 20 | SST  |

|      |    |    |   |   |   |
|------|----|----|---|---|---|
| 1    | 2  | 3  | 4 | 5 | 6 |
| +abc | G7 | G8 |   |   |   |
| +ST  | 13 | 16 |   |   |   |

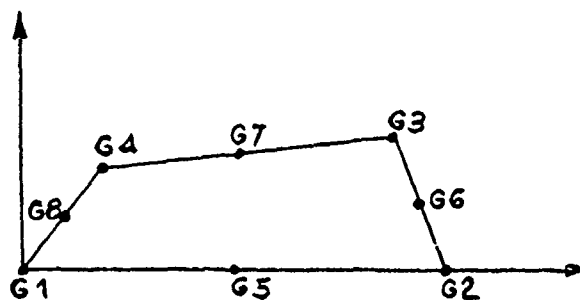
Field

Contents

EID            Element identification number (Integer >0)

PID            Identification number of a PQUAM8 property card

G1 through G8    Gridpoint identification numbers of connection points (Integer >0)



Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Gridpoints G1 through G8 must be ordered as shown in the sketch of the element.
3. All interior angles must be less than 180 degrees.

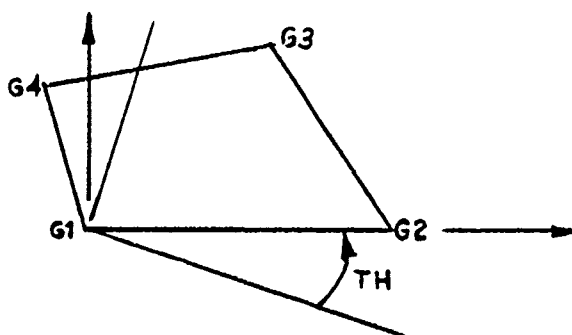
Input Data Card CQDMEM1 Quadrilateral Element Connection

Description: Defines a quadrilateral membrane element (QDMEM1) of the structural model.

Format and Example:

| 1       | 2   | 3   | 4  | 5  | 6  | 7  | 8    | 9 | 10 |
|---------|-----|-----|----|----|----|----|------|---|----|
| CQDMEM1 | EID | PID | G1 | G2 | G3 | G4 | TH   |   |    |
| CQDMEM1 | 72  | 13  | 13 | 14 | 15 | 16 | 29.2 |   |    |

| <u>Field</u>    | <u>Contents</u>                                                                                              |
|-----------------|--------------------------------------------------------------------------------------------------------------|
| EID             | Element identification number (Integer > 0)                                                                  |
| PID             | Identification number of a PQDMEM1 property card (Integer > 0)                                               |
| G1,G2,<br>G3,G4 | Grid point identification numbers of connection points (Integer > 0); $G1 \neq G2 \neq G3 \neq G4$           |
| TH              | Material property orientation angle in degrees (Real).<br>The sketch below gives the sign convention for TH. |



- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
  2. Gridpoints G1 through G4 must be ordered consecutively around the perimeter of the element.
  3. All interior angles must be less than 180 degrees.

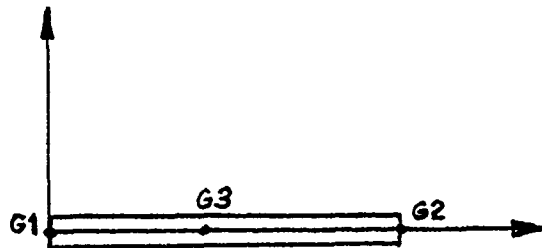
Input Data Card CRDMID Midpoint Axial Force Element Connection

Description: Defines a midpoint axial force element RDMID of the structural model.

Format and Example:

|        |     |     |    |    |    |   |   |   |    |
|--------|-----|-----|----|----|----|---|---|---|----|
| 1      | 2   | 3   | 4  | 5  | 6  | 7 | 8 | 9 | 10 |
| CRDMID | EID | PID | G1 | G2 | G3 |   |   |   |    |
| CRDMID | 72  | 13  | 13 | 14 | 15 |   |   |   |    |

| <u>Field</u> | <u>Contents</u>                                                                           |
|--------------|-------------------------------------------------------------------------------------------|
| EID          | Element identification number (Integer > 0)                                               |
| PID          | Identification number of a PRDMID property card (Integer > 0)                             |
| G1,G2,G3     | Gridpoint identification numbers of connection points (Integer > 0); $G1 \neq G2 \neq G3$ |



- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
  2. Gridpoints G1 through G3 must be ordered as shown.

Input Data Card CRØD Axial Force Element Connection

Description: Defines a tension-compression element (RØD) of the structural model

Format and Example:

|      |     |     |    |    |     |     |    |    |    |
|------|-----|-----|----|----|-----|-----|----|----|----|
| 1    | 2   | 3   | 4  | 5  | 6   | 7   | 8  | 9  | 10 |
| CRØD | EID | PID | G1 | G2 | EID | PID | G1 | G2 |    |
| CRØD | 12  | 13  | 21 | 23 | 3   | 12  | 24 | 5  |    |

| <u>Field</u> | <u>Contents</u>                                                               |
|--------------|-------------------------------------------------------------------------------|
| EID          | Element identification number (Integer > 0)                                   |
| PID          | Identification number of a PRØD property card                                 |
| G1, G2       | Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2) |

- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
  2. See CØNRØD for alternative method of rod definition.
  3. One or two RØD elements may be defined on a single card.

Input Data Card CSHEAR Shear Panel Element Connection

Description: Defines a shear panel element (SHEAR) of the structural model.

Format and Example:

| 1      | 2   | 3   | 4  | 5  | 6  | 7  | 8 | 9 | 10 |
|--------|-----|-----|----|----|----|----|---|---|----|
| CSHEAR | EID | PID | G1 | G2 | G3 | G4 |   |   |    |
| CSHEAR | 3   | 6   | 1  | 5  | 3  | 7  |   |   |    |

| <u>Field</u>      | <u>Contents</u>                                                                            |
|-------------------|--------------------------------------------------------------------------------------------|
| EID               | Element identification number (Integer > 0)                                                |
| PID               | Identification number of a PSHEAR property card                                            |
| G1, G2,<br>G3, G4 | Grid point identification numbers of connection points<br>(Integer > 0; G1 ≠ G2 ≠ G3 ≠ G4) |

- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
  2. Grid points G1 thru G4 must be ordered consecutively around the perimeter of the element.

Input Data Card CTRIM6 Midpoint Triangular Membrane Plate  
Element Connection

Description: Defines a triangular membrane element (TRIM6) of the structural model.

Format and Example:

| 1      | 2    | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10   |
|--------|------|-----|-----|-----|-----|-----|-----|-----|------|
| CTRIM6 | EID  | PID | G1  | G2  | G3  | G4  | G5  | G6  | +abc |
| CTRIM6 | 220  | 666 | 100 | 110 | 120 | 210 | 220 | 320 | BSS  |
| +abc   |      |     |     |     |     |     |     |     |      |
| +BS    | 90.0 |     |     |     |     |     |     |     |      |

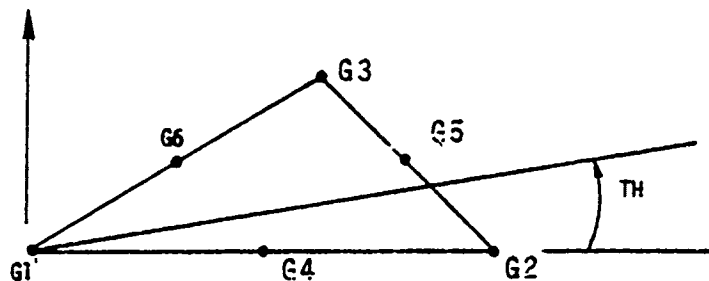
Field

Contents

EID Element identification number (Integer > 0)

PID Identification number of PTRIM6 property card.

G1,G2,G3,  
G4,G5,G6 Gridpoint identification numbers of connection points (Integers > 0);  $G1 \neq G2 \neq G3 \neq G4 \neq G5 \neq G6$ ).



- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
  2. Interior angles must be less than  $180^\circ$ .
  3. The gridpoints must be ordered consecutively around the perimeter in a counter clockwise direction and starting at a vertex.
  4. The continuation card must be present.
  5. Gridpoints G2, G4 and G6 are assumed to lie at the midpoints of the sides.

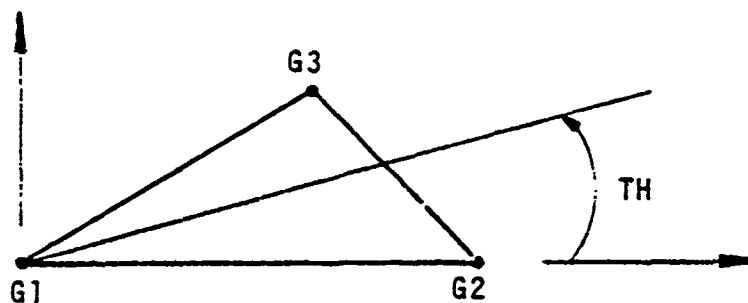
Input Data Card CTRMEM Triangular Element Connection

Description: Defines a triangular membrane element (TRMEM) of the structural model.

Format and Example:

| 1      | 2   | 3   | 4  | 5  | 6  | 7    | 8 | 9 | 10 |
|--------|-----|-----|----|----|----|------|---|---|----|
| CTRMEM | EID | PID | G1 | G2 | G3 | TH   |   |   |    |
| CTRMEM | 16  | 2   | 12 | 1  | 3  | 16.3 |   |   |    |

| <u>Field</u> | <u>Contents</u>                                                                                            |
|--------------|------------------------------------------------------------------------------------------------------------|
| EID          | Element identification number (Integer > 0)                                                                |
| PID          | Identification number of a PTRMEM property card                                                            |
| G1,G2,G3     | Gridpoint identification numbers of connection points (Integer > 0; $G1 \neq G2 \neq G3$ )                 |
| TH           | Material property orientation angle in degrees (Real) - The sketch below gives the sign convention for TH. |



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

Input Data Card CTUBEAM

## Tubular Beam Element Connection

Description: Defines a tension-compression-torsion element (TUBE) of the structural model.

Format and Example:

| 1       | 2   | 3   | 4  | 5  | 6  |
|---------|-----|-----|----|----|----|
| CTUBEAM | EID | PID | G1 | G2 | G3 |
| CTUBEAM | 12  | 13  | 21 | 23 | 3  |

FieldContents

|            |                                                                                   |
|------------|-----------------------------------------------------------------------------------|
| EID        | Element identification number (Integer > 0)                                       |
| PID        | Identification number of a PTUBEAM property card (Default is EID) (Integer > 0)   |
| G1, G2, G3 | Gridpoint identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3) |

Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. See Figure 3e.

Input Data Card CWEB

Shear Web Element Connection

Description: Defines a 2 node symmetric Web element (Web) of the structural model

Format and Example:

| 1    | 2   | 3   | 4  | 5  | 6 | 7 | 8 | 9 | 10 |
|------|-----|-----|----|----|---|---|---|---|----|
| CWEB | EID | PID | G1 | G2 |   |   |   |   |    |
| CWEB | 4   | 2   | 1  | 3  |   |   |   |   |    |

Field

EID Element identification number

PID Identification of PWEB property card

G1, G2 Gridpoint identification numbers

Remarks: 1. See Figure 3b.

Input Data Card FORCE Static Load

Description: Defines a static load at a grid point by specifying a vector.

Format and Example:

|       |     |   |   |     |     |     |     |   |    |
|-------|-----|---|---|-----|-----|-----|-----|---|----|
| 1     | 2   | 3 | 4 | 5   | 6   | 7   | 8   | 9 | 10 |
| FORCE | SID | G |   | F   | N1  | N2  | N3  |   |    |
| FORCE | 2   | 5 |   | 2.9 | 0.0 | 1.0 | 0.0 |   |    |

| <u>Field</u> | <u>Contents</u>                               |
|--------------|-----------------------------------------------|
| SID          | Load set identification number (Integer > 0)  |
| G            | Gridpoint identification number (Integer > 0) |
| F            | Scale factor (Real)                           |
| N1,N2,N3     | Components of Vector                          |

Remarks: 1. The static load applied to gridpoint G is given by

$$\vec{f} = F \vec{N}$$

where  $\vec{N}$  is the vector defined in fields 6, 7 and 8.

2. Load set is selected on the OPLOADS card.

Input Data Card GCON Generalized Constraint Components

Description: Defines the translation and rotation components of each gridpoint which are active degrees of freedom in a generalized constraint equation defined by GPCEQN cards

Format and Example:

| 1    | 2   | 3  | 4                   | 5                                        | 6 | 7 | 8 | 9 | 10 |
|------|-----|----|---------------------|------------------------------------------|---|---|---|---|----|
| GCON | SID | GP | $\pm U \pm V \pm W$ | $\pm \theta_x \pm \theta_y \pm \theta_z$ |   |   |   |   |    |
| GCON | 14  | 1  | +X $\Delta$ -X      | $\Delta$ +X $\Delta$                     |   |   |   |   |    |

Field

SID Equation identification

GP Gridpoint number

+, - Algebraic sign of component coefficient

x The x mark indicates that the component exists.

$\Delta$  A triangle indicates that the component does not exist.

Remarks: The SID numbers on these cards appear in the GPCEQN cards which set up the constraint equation. See remarks under GPCEQN for further explanation.

# Input Data Card GPCEQN Generalized Constraint Equation

Description: Defines the upper and lower limits of a generalized constraint equation. The existence of each GPCEQN card is necessary for each constraint equation.

## Format and Example:

| 1      | 2   | 3   | 4                            | 5                            | 6 | 7 | 8 | 9 | 10 |
|--------|-----|-----|------------------------------|------------------------------|---|---|---|---|----|
| GPCEQN | SID | GCS | Upper<br>Limit <sub>UL</sub> | Lower<br>Limit <sub>LL</sub> |   |   |   |   |    |
| GPCEQN | 1   | 14  | 4.0                          | 1.0                          |   |   |   |   |    |

## Field

|     |                                                                               |
|-----|-------------------------------------------------------------------------------|
| SID | Equation identification                                                       |
| GCS | Set identification of GCON cards which define the components in the equation. |
| UL  | Upper limit of constraint equation                                            |
| LL  | Lower limit of constraint equation                                            |

Remarks: 1. Suppose the user wants to define the following generalized constraint equations:

$$1.0 \leq -U_1 + V_2 + 0_{x1} \leq 4.0$$

$$1.0 \leq W_2 - 0_{x4} \leq 6.0$$

The input cards would be as follows:

| 1      | 2  | 3  | 4   | 5   |
|--------|----|----|-----|-----|
| GPCEQN | 1  | 14 | 4.0 | 1.0 |
| GPCEQN | 2  | 12 | 6.0 | 1.0 |
| GCON   | 14 | 1  | -X  | +X  |
| GCON   | 14 | 2  | +X  |     |
| GCON   | 12 | 2  | +X  |     |
| GCON   | 12 | 4  |     | -X  |

Equation #1  
Equation #2  
-U<sub>1</sub>, 0<sub>x1</sub>  
V<sub>2</sub>  
W<sub>2</sub>  
-0<sub>x4</sub>

2. A generalized constraint consists of the algebraic combination of the selected degrees of freedom of all participating gridpoints and is maintained within the upper and lower limits defined for the particular group.

Input Data Card GRID      Grid Point

Description:      Defines the location of a geometric gridpoint of the structural model and its permanent single-point constraints.

Format and Example:

| 1    | 2  | 3 | 4   | 5   | 6   | 7 | 8   | 9 | 10 |
|------|----|---|-----|-----|-----|---|-----|---|----|
| GRID | ID |   | X1  | X2  | X3  |   | PS  |   |    |
| GRID | 2  |   | 1.0 | 2.0 | 3.0 |   | 316 |   |    |

| <u>Field</u> | <u>Contents</u>                                                                                                                      |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------|
| ID           | Gridpoint identification number (0<Integer<999999)                                                                                   |
| X1,X2,X3     | Location of the grid point.                                                                                                          |
| PS           | Permanent single-point constraints associated with grid-point (any of the digits 1-6 with no imbedded blanks) (Integer ≥ 0 or blank) |

Remarks:    1.    The coordinate system defined on all GRID cards is called the Global Coordinate System. All degrees-of-freedom, constraints, and solution vectors are expressed in the Global Coordinate System.

Input Data Card ICON

## Individual Constraints

Description: Defines the constraint limits (both lower and upper) and gridpoint components which require individual constraints.

Format and Example:

| 1    | 2          | 3     | 4     | 5              | 6              | 7              | 8              | 9              | 10 |
|------|------------|-------|-------|----------------|----------------|----------------|----------------|----------------|----|
| ICON | Components | Lower | Upper | G <sub>1</sub> | G <sub>2</sub> | G <sub>3</sub> | G <sub>4</sub> | G <sub>5</sub> |    |
| ICON | 146        | 1.0   | 3.0   | 1              | 2              | 3              | 6              |                |    |

Field

Components            1-6 signifies component numbers

Lower                    Lower limit

Upper                    Upper limit

G<sub>1</sub>, G<sub>2</sub>, G<sub>3</sub>, etc.        Gridpoint numbers. Upto 5 gridpoint numbers may appear on one ICON card.

Remarks:

- Each ICON card contains up to 5 gridpoints. When more than 5 are desired, list them on separate ICON cards.
- For example, let there be the following individual constraints:  
 U<sub>1</sub>, U<sub>2</sub>, W<sub>1</sub>, W<sub>2</sub> greater than 1.0 and less than 4.0.  
 V<sub>1</sub>, V<sub>2</sub>, V<sub>3</sub> greater than 1.0 and less than 8.0.

The required ICON cards would be:

| 1    | 2  | 3   | 4   | 5 | 6 | 7 |
|------|----|-----|-----|---|---|---|
| ICON | 13 | 1.0 | 4.0 | 1 | 2 |   |
| ICON | 2  | 1.0 | 8.0 | 1 | 2 | 3 |

- Rotational limits are indicated only when the beam (tube) element is used.

Input Data Card LINKS

Description: Defines element numbers which are in a "linked" group either for purposes of specifying area ratios or for buckling definitions.

Format and Example:

|       |   |       |    |      |                |                |                |   |    |
|-------|---|-------|----|------|----------------|----------------|----------------|---|----|
| 1     | 2 | 3     | 4  | 5    | 6              | 7              | 8              | 9 | 10 |
| LINKS |   | BELEM | NG | BUCK | N <sub>1</sub> | N <sub>2</sub> | N <sub>3</sub> |   |    |
| LINKS |   | 5     | 3  | YES  | 1              | 2              | 3              |   |    |

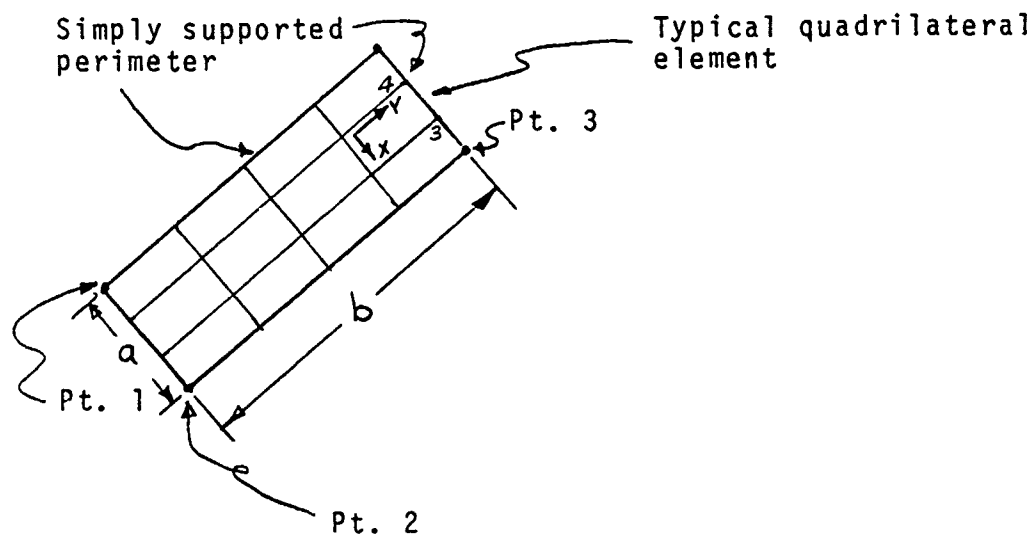
| <u>Field</u>                                   | <u>Contents</u>                                                                                                                                                 |
|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BELEM                                          | Base element number entered in integer format                                                                                                                   |
| NG                                             | Number of elements in the group. The total number of elements including the base element is entered.                                                            |
| BUCK                                           | Buckling control. When "yes" is in this field, then the grouping defined is to be considered for buckling and <u>no</u> linking between design variables exist. |
| N <sub>1</sub> ,N <sub>2</sub> ,N <sub>3</sub> | Node points defining rectangular area.                                                                                                                          |

Remarks:

1. This data is optimal.
2. The base element is the lowest numbered element in the group and it must also be the element with the smallest minimum allowable element design variable. All elements within a group are directly related to the base element through the area ratios specified on the element property cards. In other words the minimum allowable area is entered for the base element. For other members in the group the ratio ( $\geq 1$ ) of member area to base element area is entered instead of an allowable. This ratio is maintained during the solution.
3. The example above indicates that elements 5, 6 and 7 belong to a linked group in which element 5 is the base element.
4. The buckling option has been included in order that a User might specify a simply supported area that is comprised of more than one element.

Remarks: (continued)

The three node point numbers are entered as fixed point numbers in order to define the rectangular simply supported region. The sketch illustrates the three points and their relationship to the contained groups of elements.



Input Data Card MØMENT Static Moment

Description: Defines a static moment at a grid point by specifying a vector.

Format and Example:

|        |     |   |   |     |     |     |     |   |    |
|--------|-----|---|---|-----|-----|-----|-----|---|----|
| 1      | 2   | 2 | 4 | 5   | 6   | 7   | 8   | 9 | 10 |
| MØMENT | SID | G |   | M   | N1  | N2  | N3  |   |    |
| MØMENT | 2   | 5 |   | 2.9 | 0.0 | 1.0 | 0.0 |   |    |

| <u>Field</u> | <u>Contents</u>                               |
|--------------|-----------------------------------------------|
| SID          | Load set identification number (Integer > 0)  |
| G            | Gridpoint identification number (Integer > 0) |
| M            | Scale factor (Real)                           |
| N1,N2,N3     | Components of Vector                          |

Remarks: 1. The static moment applied to gridpoint G is given by

$$\vec{m} = M \cdot (N1, N2, N3)$$

2. Load set is selected on the OPLOADS card.

# Input Data Card MAT1 Material Property Definition

Description: Defines the material properties for linear, temperature-independent, isotropic materials.

## Format and Example:

|      |       |       |       |    |      |   |   |   |      |
|------|-------|-------|-------|----|------|---|---|---|------|
| 1    | 2     | 3     | 4     | 5  | 6    | 7 | 8 | 9 | 10   |
| MAT1 | MID   | E     | G     | NU | RH0  |   |   |   | +abc |
| MAT1 | 17    | 3.+7  | 1.9+7 |    | 4.28 |   |   |   | ABC  |
| +abc | SL    | SU    |       |    |      |   |   |   |      |
| +BC  | 20.+4 | 15.+4 |       |    |      |   |   |   |      |

## Field

## Contents

|         |                                                           |
|---------|-----------------------------------------------------------|
| MID     | Material identification number (Integer > 0)              |
| E       | Young's modulus (Real $\geq$ 0.0 or blank)                |
| G       | Shear modulus (Real $\geq$ 0.0 or blank)                  |
| NU      | Poisson's ratio ( $-1.0 < \text{Real} \leq 0.5$ or blank) |
| RH0     | Mass density (Real)                                       |
| SL, SU, | Lower stress limit, upper stress limit                    |

- Remarks:
1. One of E or G must be positive (i.e., either  $E > 0.0$  or  $G > 0.0$  or both E and G may be  $> 0.0$ ).
  2. If any one of E, G or NU is blank, it will be computed to satisfy the identity  $E = 2(1+NU)G$ ; otherwise, values supplied by the user will be used.
  3. The material identification number must be unique for all MAT1 and MAT2 cards.

# Input Data Card MAT2 Material Property Definition

Description: Defines the material properties for linear, anisotropic materials.

Format and Example: (consists of 2 cards)

|      |     |       |     |     |       |       |       |       |    |
|------|-----|-------|-----|-----|-------|-------|-------|-------|----|
| 1    | 2   | 3     | 4   | 5   | 6     | 7     | 8     | 9     | 10 |
| MAT2 | MID | G11   | G12 | G13 | G22   | G23   | G33   | RHO   |    |
| MAT2 | 13  | 6.2+3 |     |     | 6.2+3 |       | 5.1+3 | 0.056 |    |
| +abc |     |       |     |     |       | SL    | SU    |       |    |
| +BC  |     |       |     |     |       | 20.+5 |       |       |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| MID          | Material identification number (Integer > 0) |
| Gij          | The material property matrix (Real)          |
| RHO          | Mass density (Real)                          |
| SL, SU       | Lower stress limit, upper stress limit       |

- Remarks:
1. The material identification numbers must be unique for all MAT1, MAT2 cards.
  2. The convention for the Gij in fields 3 through 8 is represented by the matrix relationship.

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{12} & G_{22} & G_{23} \\ G_{13} & G_{23} & G_{33} \end{bmatrix} \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

3. Only TRMEM and CQDMM elements may use MAT2 cards.

## Input Data Card OPDVIR

Description: Defines design variables for selected elements. These design variables are used as starting guesses in an optimization run or else as specified values in a status run.

### Format and Example:

| 1      | 2  | 3                 | 4  | 5                 | 6  | 7                 | 8  | 9                 | 10 |
|--------|----|-------------------|----|-------------------|----|-------------------|----|-------------------|----|
| OPDVIR | E1 | DVAR <sub>1</sub> | E2 | DVAR <sub>2</sub> | E3 | DVAR <sub>3</sub> | E4 | DVAR <sub>4</sub> |    |
| OPDVIR | 1  | .1                | 3  | .6                | 4  | .50               | 7  | .23               |    |

### Field

E1,E2...etc. Element numbers for which design variables are input.

DVAR<sub>1</sub>, DVAR<sub>2</sub>, etc. Design variable starting guesses for elements 1, 2, etc.

- Remarks:
1. Up to 4 elements may be defined on one OPDVIR card. More elements may be defined by successive OPDVIR cards.
  2. The use of these values is dependent on the calculation control on the OPTIM input card - field #9, OPT.
    - a. If OPT = GOPT the program will optimize using the design variable minimums input in this section as a starting guess.
    - b. If OPT = GSTA, the program will perform a statics solution using the design variables input in this section.

Input Data Card OPLOADS

Description: Defines the character of the loads for optimization, i.e., symmetric, nonsymmetric, antisymmetric.

Format and Example:

|         |      |      |      |                |                |                |                |
|---------|------|------|------|----------------|----------------|----------------|----------------|
| OPLOADS | LOAD | NSYM | SYA  | F <sub>i</sub> | M <sub>i</sub> | F <sub>2</sub> | M <sub>2</sub> |
| OPLOADS | 1    |      | ANTI | 5              | 7              |                |                |

| <u>Field</u>   | <u>Contents</u>                                                                  |
|----------------|----------------------------------------------------------------------------------|
| LOAD           | LOAD number identification (any number)                                          |
| NSYM           | Number of nodes on symmetric plane                                               |
| SYA            | SYMM - Symmetric loads<br>ANTI - Antisymmetric loads<br>NON - Nonsymmetric loads |
| F <sub>i</sub> | SID number of FORCE cards                                                        |
| M <sub>i</sub> | SID number of MOMENT cards                                                       |
| F <sub>2</sub> | required only      SID number of FORCE cards                                     |
| M <sub>2</sub> | for nonsymmetric      SID number of MOMENT cards                                 |

- Remarks:
1. If F<sub>i</sub> is present, i force cards are required.  
If M<sub>i</sub> is present, i moment cards are required.
  2. Each external load requires an OPLOADS entry.

Remarks: (contd)

3. Number of Nodes on the Symmetry Plane. When a geometrically symmetric half structure is subject to antisymmetric and/or nonsymmetric loading this capability is provided wherein boundary conditions are internally defined and results are output for the entire structure. The nodes on the symmetry plane must be numbered from 1 to N and it is N that is entered here. The BOUND section must specify these nodes as free.

# Input Data Card OPTIM

Description: Defines various control parameters for the OPTIM program.

## Format and Example:

| 1     | 2   | 3   | 4   | 5    | 6   | 7     | 8     | 9   | 10 |
|-------|-----|-----|-----|------|-----|-------|-------|-----|----|
| OPTIM | PRI | PRS | PRE | BU   | MAX | CONVD | CONVW | OPT |    |
| OPTIM | NO  | YES | YES | NONE | 10  | .01   | 100.0 | OPT |    |

## Field

## Contents

PRI NO/YES Print displacements every iteration

PRS NO/YES Print stresses every iteration

PRE NO/YES Print element design variables every iteration

BU NONE/ALL/SEL Buckling Anaysis SEL=SID of BUCK

MAX Maximum number iterations

CONVD Convergence criteria for design number

CONVW Convergence criteria for weight perturbations

OPT OPT Optimize using design variable on property card

GOPT Optimize using OPDVIR starting guess

GSTA Statics run using OPDVIR

STA Statics run using property card

Remarks: 1. CONVD - Convergence Criteria (Design Variable). If two successive iterations of element design variables i.e., thickness or area, meet the criteria  $\left| \frac{A_n - A_{n+1}}{A_n} \right| \leq C_1$  then the iteration is stopped.  $C_1$  is entered here.

2. CONVW - Convergence Criteria (Weight Perturbation). If two successive perturbations of the structural weight meet this criteria, then the iteration is stopped.

$$\frac{W_n - W_{n+1}}{W_n} > C_2$$

$C_2$  is entered here.

Input Data Card PQUAM8 MIDPOINT QUADRILATERAL MEMBRANE PROPERTY

Description: Used to define the properties of a midpoint quadrilateral membrane element. Referenced by the COUAM8 card. No bending properties are included.

Format and Example:

|        |     |     |      |   |     |     |   |   |    |
|--------|-----|-----|------|---|-----|-----|---|---|----|
| 1      | 2   | 3   | 4    | 5 | 6   | 7   | 8 | 9 | 10 |
| PQUAM8 | PID | MID | T    |   | PID | MID | T |   |    |
| PQUAM8 | 17  | 23  | 4.25 |   |     |     |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| T            | Membrane thickness (Real > 0.0)              |

- Remarks:
1. All PQUAM8 cards must have unique property identification numbers.
  2. One or two quadrilateral membrane properties may be defined on a single card.

Input Data Card PQDMEM1      Quadrilateral Membrane Property

Description:    Used to define the properties of quadrilateral membrane. Referenced by <sup>14</sup> CQDMEM1 card. No bending properties are included.

Format and Example:

|         |     |     |     |   |     |     |   |   |    |
|---------|-----|-----|-----|---|-----|-----|---|---|----|
| 1       | 2   | 3   | 4   | 5 | 6   | 7   | 8 | 9 | 10 |
| PQDMEM1 | PID | MID | T   |   | PID | MID | T |   |    |
| PQDMEM1 | 235 | 2   | 0.5 |   |     |     |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| T            | Minimum thickness of membrane (Real > 0.0)   |

- Remarks:
1. All PQDMEM1 cards must have unique property identification numbers.
  2. One or two quadrilateral membrane properties may be defined on a single card.

Input Data Card PRDMID

Description: Used to define the properties of a midpoint axial force member. Referenced by the CRDMID card.

Format and Example:

| 1      | 2   | 3   | 4   | 5 | 6   | 7   | 8   | 9 | 10 |
|--------|-----|-----|-----|---|-----|-----|-----|---|----|
| PRDMID | PID | MID | A   |   | PID | MID | A   |   |    |
| PRDMID | 24  | 2   | .49 |   | 25  | 3   | .60 |   |    |

Field

PID      Property identification number (integer > 0)  
MID      Material identification number (integer > 0)  
A        Cross sectional area (minimum)

Remarks:

1. All PRDMID must have unique property identification numbers.
2. One or two midpoint axial force member properties may be defined on a single card.

Inout Data Card PRØD Rod Property

Description: Defines the properties of a rod which is referenced by the CRØD card

Format and Example:

|      |     |     |      |   |   |   |   |   |    |
|------|-----|-----|------|---|---|---|---|---|----|
| 1    | 2   | 3   | 4    | 5 | 6 | 7 | 8 | 9 | 10 |
| PRØD | PID | MID | A    |   |   |   |   |   |    |
| PRØD | 17  | 23  | 42.6 |   |   |   |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| A            | Area of rod (Real)                           |

Remarks:

- 1 PRØD cards must all have unique property identification numbers.
2. For structural problems, PRØD cards may only reference MAT1 material cards.

Input Data Card PSHEAR Shear Panel Property

Description: Defines the elastic properties of a shear panel.  
Referenced by the CSHEAR card.

Format and Example:

|        |     |     |     |   |     |     |     |   |    |
|--------|-----|-----|-----|---|-----|-----|-----|---|----|
| 1      | 2   | 3   | 4   | 5 | 6   | 7   | 8   | 9 | 10 |
| PSHEAR | PID | MID | T   |   | PID | MID | T   |   |    |
| PSHEAR | 13  | 2   | 4.9 |   | 14  | 6   | 4.9 |   |    |

| <u>Field</u> | <u>Contents</u>                               |
|--------------|-----------------------------------------------|
| PID          | Property identification number (Integer > 0)  |
| MID          | Material identification number (Integer > 0)  |
| T            | Minimum thickness of shear panel (Real ≠ 0.0) |

- Remarks:
1. All PSHEAR cards must have unique identification numbers.
  2. PSHEAR cards may only reference MAT1 material cards.
  3. One or two shear panel properties may be defined on a single card.

Input Data Card PTRIM6 Linear Strain Midpoint Triangular  
Membrane Property

Description: Defines the properties of a midpoint triangular membrane element. Referenced by the CTRIM6 card. No bending properties are included.

Format and Example:

|        |     |     |      |   |   |   |   |   |    |
|--------|-----|-----|------|---|---|---|---|---|----|
| 1      | 2   | 3   | 4    | 5 | 6 | 7 | 8 | 9 | 10 |
| PTRIM6 | PID | MID | T1   |   |   |   |   |   |    |
| PTRIM6 | 666 | 999 | 1.17 |   |   |   |   |   |    |

Field

PID            Property identification number (Integer> 0)

MID            Material identification number (Integer> 0)

|    |                                          |
|----|------------------------------------------|
| T1 | Membrane thickness of the element (Real) |
|----|------------------------------------------|

Remarks: 1. All PTRIM6 cards must have unique property identification numbers.

2. PTRIM6 cards may only reference MAT1.

Input Data Card PTRMEM Triangular Membrane Property

Description: Used to define the properties of a triangular membrane element. Referenced by the CTRMEM card. No bending properties are included.

Format and Example:

| 1      | 2   | 3   | 4    | 5 | 6   | 7   | 8 | 9 | 10 |
|--------|-----|-----|------|---|-----|-----|---|---|----|
| PTRMEM | PID | MID | T    |   | PID | MID | T |   |    |
| PTRMEM | 17  | 23  | 4.25 |   |     |     |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| T            | Membrane thickness (Real > 0.0)              |

- Remarks:
1. All PTRMEM cards must have unique property identification numbers.
  2. One or two triangular membrane properties may be defined on a single card.

Input Data Card PTUBEAM Tubular Beam Property

Description: Defines the properties of tubular beam element.  
Referenced by the CTUBE card.

Format and Example:

| 1       | 2   | 3   | 4    | 5    | 6 | 7 | 8 | 9 | 10 |
|---------|-----|-----|------|------|---|---|---|---|----|
| PTUBEAM | PID | MID | TT   | RAD  |   |   |   |   |    |
| PTUBEAM | 2   | 6   | 6.29 | 0.25 |   |   |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| TT           | Minimum tube thickness                       |
| RAD          | Radius of tube element                       |

- Remarks:
1. PTUBE cards must all have unique property identification numbers.
  2. PTUBE cards may only reference MAT1 material cards.

Input Data Card PWEB WEB Property

Description: Used to define the properties of 2 node WEB.  
Referenced by the CWEB.

Format and Example:

|      |     |     |     |   |     |     |   |   |    |
|------|-----|-----|-----|---|-----|-----|---|---|----|
| 1    | 2   | 3   | 4   | 5 | 6   | 7   | 8 | 9 | 10 |
| PWEB | PID | MID | T   |   | PID | MID | T |   |    |
| PWEB | 235 | 2   | 0.5 |   |     |     |   |   |    |

| <u>Field</u> | <u>Contents</u>                              |
|--------------|----------------------------------------------|
| PID          | Property identification number (Integer > 0) |
| MID          | Material identification number (Integer > 0) |
| T            | Thickness of the shear web (Real > 0.0)      |

- Remarks:
1. All PWEB cards must have unique property identification numbers.
  2. One or two WEB properties may be defined on a single card.

# Input Data Card SPC Single-Point Constraint

Description: Defines sets of single-point constraints

Format and Example:

| 1   | 2   | 3  | 4   | 5 | 6 | 7 | 8 | 9 | 10 |
|-----|-----|----|-----|---|---|---|---|---|----|
| SPC | SID | G  | C   |   | G | C |   |   |    |
| SPC | 2   | 32 | 436 |   | 5 | 1 |   |   |    |

| <u>Field</u> | <u>Contents</u>                                                                                                                         |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| SID          | Identification number of single-point constraint set (Integer > 0)                                                                      |
| G            | Grid point identification number (Integer > 0)                                                                                          |
| C            | Component number (Any unique combination of the digits 1-6 (with no imbedded blanks) when point identification numbers are gridpoints). |

Remarks:

1. Single-point constraint sets must be present in the input.
2. From one to twelve single-point constraints may be defined on a single card.
3. SPC degrees of freedom may be redundantly specified as permanent constraints on the GRID card.
4. The SID number should be the same on all SPC cards.

Input Data Card SPC1 Single-Point Constraint

Description: Defines sets of single-point constraints.

Format and Example:

|      |     |   |    |    |    |    |    |    |    |
|------|-----|---|----|----|----|----|----|----|----|
| 1    | 2   | 3 | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| SPC1 | SID | C | G1 | G2 | G3 | G4 | G5 | G6 |    |
| SPC1 | 3   | 2 | 1  | 3  | 10 | 9  | 6  | 5  |    |

Alternate Form

|      |     |       |      |        |      |
|------|-----|-------|------|--------|------|
| SPC1 | SID | C     | GID1 | "THRU" | GID2 |
| SPC1 | 313 | 12456 | 6    | THRU   | 32   |

Field

Contents

SID Identification number of single-point constraint set  
(Integer > 0)

C Component number (Any unique combination of the digits  
1-6 (with no imbedded blanks) when point identification  
numbers are gridpoints.

G1,GID1 Grid point identification numbers (Integer > 0)

Remarks:

1. Single-point constraint sets must be present in the input.
2. SPC degrees of freedom may be redundantly specified as permanent constraints on the GRID card.
3. All gridpoints referenced by G1D1 thru G1D2 must exist.
4. No NASTRAN "continuation" cards are allowed.

Input Data Card TITLE

Title Card

Description: Information to be printed at the beginning of the computer listing.

Format and Example:

| 1                          | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----------------------------|---|---|---|---|---|---|---|---|----|
| TITLE                      |   |   |   |   |   |   |   |   |    |
| Plate Membrane Prob. No. 2 |   |   |   |   |   |   |   |   |    |

Input Data Card ENDDATA

Description: Defines the end of the Data Deck

Format and Example:

| 1       | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------|---|---|---|---|---|---|---|---|----|
| ENDDATA |   |   |   |   |   |   |   |   |    |
| ENDDATA |   |   |   |   |   |   |   |   |    |

- Remarks:
1. This card required even if no physical data cards exist in the deck.
  2. ENDDATA must begin in columns 1 or 2.
  3. Failure to include this card will result in an operating system termination caused by input end of file error.

## V. SAMPLE PROBLEM

This sample demonstration problem, taken from Reference 1 is presented primarily to illustrate the new NASTRAN compatible data input procedure and format included in OPTIM III.

The structure selected is a symmetric wing box as shown in Figure 4. One half of the symmetric wing box is idealized and consists of 7 grid points and 16 finite elements of the following types:

- 4 axial force members
- 8 shear web elements
- 2 quadrilateral membrane elements
- 1 triangular membrane element

Gridpoints 1 and 2 are completely constrained in the x and y coordinate directions. Two load conditions are considered and they are:

1. 5,000 Lb. force at gridpoint 7 in the Z coordinate direction.
2. 10,000 Lb. force at gridpoint 7 in the x coordinate direction.

A summary of the NASTRAN compatible input data (BULK DATA) is given in Figure 5. Results of the computations performed are given in Figure 6.

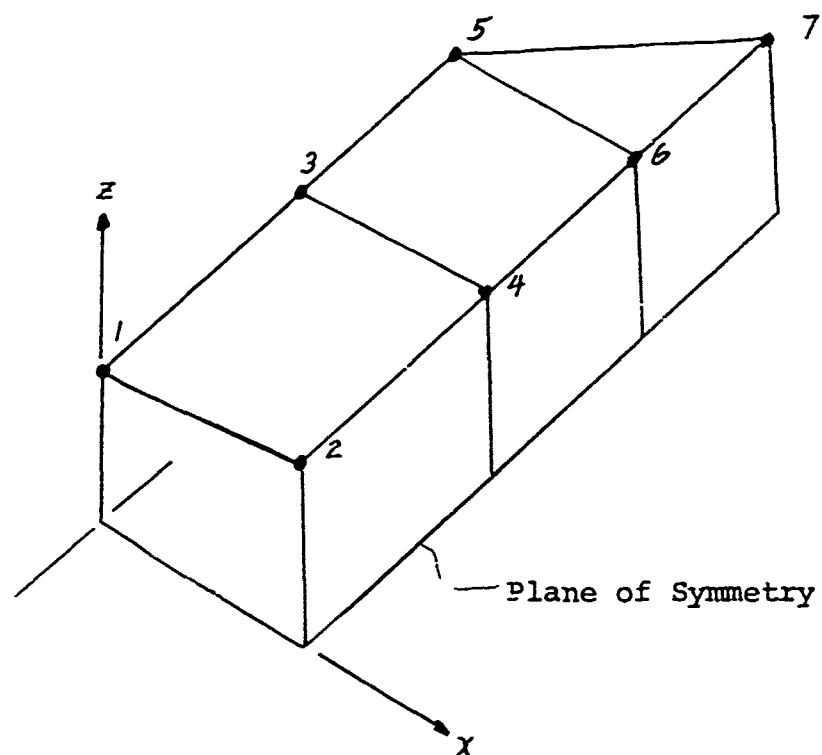


Figure 4 Wing Box

| BEGIN BU | LR     | SIXTEEN ELEMENT WING BOX FOR REPORT FORM INPUT AND DYNAMIC STORAGE |                     |        |       |         |         |         |         |         |         |         |         |         |         |         |         |
|----------|--------|--------------------------------------------------------------------|---------------------|--------|-------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| TITLE    |        | 1                                                                  | 2                   | 3      | 4     | 5       | 6       | 7       | 8       | 9       | 10      | 11      | 12      | 13      | 14      | 15      | 16      |
| GRID     | 1      | 0.0                                                                | 0.0                 | 10.000 | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 2      | 100.000                                                            | 0.0                 | 8.000  | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 3      | 0.0                                                                | 70.000              | 10.000 | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 4      | 100.000                                                            | 70.000              | 8.000  | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 5      | C.C                                                                | 140.000             | 10.000 | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 6      | 100.000                                                            | 140.000             | 8.000  | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| GRID     | 7      | 100.000                                                            | 190.000             | 8.000  | 0     |         |         |         |         |         |         |         |         |         |         |         |         |
| ICCN     | 2      | -2.0000                                                            | 2.0000              | 7      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| SPCL     | 1      | 123                                                                | 1                   | THRU   | 2     |         |         |         |         |         |         |         |         |         |         |         |         |
| OPTIM    | NO     | NO                                                                 | YES                 | NCNE   | 2     | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 | 0.01000 |
| OPLGADS  | 1      | 0                                                                  | SYMM                | 10     | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| OPLGADS  | 2      | 0                                                                  | SYMM                | 20     | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| FORCE    | 10     | 7                                                                  | 0.500E 04.0         | 0.0    |       |         |         |         |         |         |         |         |         |         |         |         |         |
| FORCE    | 20     | 7                                                                  | 0.100E 05.100E 01.0 | 0.0    |       |         |         |         |         |         |         |         |         |         |         |         |         |
| CONROD   | 1      | 1                                                                  | 3                   | 28     | 0.100 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CONROD   | 2      | 3                                                                  | 5                   | 28     | 0.100 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CGNRD    | 3      | 2                                                                  | 4                   | 28     | 0.100 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CONROD   | 4      | 4                                                                  | 6                   | 28     | 0.100 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CONROD   | 5      | 6                                                                  | 7                   | 28     | 0.100 | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 6      | 50                                                                 | 3                   | 4      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 7      | 50                                                                 | 5                   | 6      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 8      | 50                                                                 | 5                   | 7      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 9      | 50                                                                 | 2                   | 4      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 10     | 50                                                                 | 4                   | 6      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 11     | 50                                                                 | 6                   | 7      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 12     | 50                                                                 | 1                   | 3      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CWEB     | 13     | 50                                                                 | 3                   | 5      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CTRMEN   | 14     | 43                                                                 | 5                   | 6      | 7.0   | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CDMEM1   | 15     | 23                                                                 | 1                   | 2      | 4     | 3       | 5       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| CDMEM1   | 16     | 33                                                                 | 3                   | 4      | 6     | 5       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| PATI     | 28     | 1.0E7                                                              | 3                   | .30    | .1    | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| PCD      | -1.0E4 | 1.0E4                                                              |                     |        |       |         |         |         |         |         |         |         |         |         |         |         |         |
| PWEB     | 50     | 28                                                                 | 0.0200              | 0      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| PTRMEN   | 43     | 28                                                                 | 0.0200              | 0      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| PQMEM1   | 33     | 28                                                                 | 0.0200              | 0      | 0     | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| ENCCATA  |        |                                                                    |                     |        |       |         |         |         |         |         |         |         |         |         |         |         |         |

Figure 5 Input Data, Sample Problem

| CARD COUNT OF INPUT DATA |           |        |
|--------------------------|-----------|--------|
|                          | CARD TYPE | NUMBER |
|                          | BEGIN BU  | 1      |
| 1                        | TITLE     | 1      |
| 2                        | BUCK      | 0      |
| 3                        | CCNSOC    | 5      |
| 4                        | CTUEEAM   | 0      |
| 5                        | CCCMEM1   | 2      |
| 6                        | BUCK1     | 0      |
| 7                        | CQUAMB    | 0      |
| 8                        | CREMIC    | 0      |
| 9                        | CRCD      | 0      |
| 10                       | CSFEAR    | 0      |
| 11                       | CTRIM6    | 0      |
| 12                       | CTRMEM    | 1      |
| 13                       | GCCN      | 0      |
| 14                       | CWEB      | 8      |
| 15                       | EGRCE     | 2      |
| 16                       | GRIC      | 7      |
| 17                       | ICGN      | 1      |
| 18                       | LIAXS     | 0      |
| 19                       | MAT1      | 1      |
| 20                       | HGMENT    | 0      |
| 21                       | ORLOACS   | 2      |
| 22                       | GPCECN    | 0      |
| 23                       | GPCVIR    | 0      |
| 24                       | CPTIM     | 1      |
| 25                       | PGCMEM1   | 1      |
| 26                       | PRDMID    | 0      |
| 27                       | PRCC      | 0      |
| 28                       | PSFEAR    | 0      |
| 29                       | PTRMEM    | 1      |
| 30                       | PTUEEAM   | 0      |
| 31                       | SPC       | 0      |
| 32                       | SPC1      | 0      |
| 33                       | SPC1      | 1      |
| 34                       | PWEB      | 1      |
| 35                       | PTRIM6    | 0      |
| 36                       | PCUAMB    | 0      |
| 37                       | ENCCATA   | 1      |
| 38                       | PTUEEAM   | 0      |
| 39                       | MAT2      | 0      |

Figure 6

Output, Sample Problem

| LINE | BEGIN BU | LK | TITLE   | SIXTEEN ELEMENT WING BOX FOR REPORTS FORM INPUT AND DYNAMIC STORAGE |
|------|----------|----|---------|---------------------------------------------------------------------|
| 41   | GRID     | 1  | C.C     | 0.0 10.000 0                                                        |
| 42   | GRID     | 2  | 100.000 | 0.0 8.000 0                                                         |
| 43   | GRID     | 3  | 0.0     | 70.000 10.000 0                                                     |
| 44   | GRID     | 4  | 100.000 | 70.000 8.000 0                                                      |
| 45   | GRID     | 5  | 0.0     | 140.000 10.000 0                                                    |
| 46   | GRID     | 6  | 100.000 | 140.000 8.000 0                                                     |
| 47   | GRID     | 7  | 100.000 | 190.000 8.000 0                                                     |
| 48   | ICCN     | 2  | -2.0000 | 2.0000 7 0 0 0                                                      |
| 49   | SPEC     | 1  | 123     | 1 1 THRU 2                                                          |
| 50   | OPTIM    | NO | NO      | YES NCNE 2 0.01000 0.01000 OPT                                      |
| 51   | CPLDACS  | 1  | 0       | SYMM 10 0 0 0                                                       |
| 52   | CPLCACS  | 2  | 0       | SYMM 20 0 0 0                                                       |
| 53   | FORCE    | 10 | 7       | 0.500E 04.0 .0                                                      |
| 54   | FORCE    | 20 | 7       | 0.100E 05.100E 01.0 .0                                              |
| 55   | CCNR00   | 1  | 1       | 3 28 0.100 0 0 0                                                    |
| 56   | CCNR00   | 2  | 3       | 5 28 0.100 0 0 0                                                    |
| 57   | CCNR00   | 3  | 2       | 4 28 0.100 0 0 0                                                    |

|    |         |        |       |        |     |       |   |     |   |    |
|----|---------|--------|-------|--------|-----|-------|---|-----|---|----|
| 1  | CCNR00  | 4      | 4     | 6      | 28  | 0.100 | 0 | 0   | 0 | 0  |
| 2  | CONG00  | 5      | 6     | 7      | 28  | 0.100 | 0 | 0   | 0 | 0  |
| 3  | CWEB    | 6      | 50    | 3      | 6   | 0     | 0 | 0   | 0 | 0  |
| 4  | CWEB    | 7      | 50    | 5      | 6   | 0     | 0 | 0   | 0 | 0  |
| 5  | CWEB    | 8      | 50    | 5      | 7   | 0     | 0 | 0   | 0 | 0  |
| 6  | CWEB    | 9      | 50    | 2      | 6   | 0     | 0 | 0   | 0 | 0  |
| 7  | CWEB    | 10     | 50    | 4      | 6   | 0     | 0 | 0   | 0 | 0  |
| 8  | CWEB    | 11     | 50    | 6      | 7   | 0     | 0 | 0   | 0 | 0  |
| 9  | CWEB    | 12     | 50    | 3      | 3   | 0     | 0 | 0   | 0 | 0  |
| 10 | CWEB    | 13     | 50    | 3      | 5   | 0     | 0 | 0   | 0 | 0  |
| 11 | CTRMEM  | 14     | 43    | 5      | 6   | 7.0   | 0 | 0   | 0 | 0  |
| 12 | CCQMEM1 | 15     | 33    | 3      | 2   | 6     | 3 | 0   | 0 | 0  |
| 13 | CCQMEM1 | 16     | 33    | 3      | 4   | 6     | 5 | 0   | 0 | 0  |
| 14 | MAT1    | 28     | 1.0E7 |        | .30 | .1    |   |     |   | CD |
| 15 | CCQ     | -1.0E4 | 1.0E4 |        |     |       |   |     |   |    |
| 16 | PWEB    | 50     | 28    | 0.0200 |     | 0     | 0 | 0.0 |   |    |
| 17 | PTRMEM  | 43     | 28    | 0.0200 |     | 0     | 0 | 0.0 |   |    |
| 18 | PCQMEM1 | 33     | 28    | 0.0200 |     | 0     | 0 | 0.0 |   |    |
| 19 | ENCCATA |        |       |        |     |       |   |     |   |    |

Figure 6 (Continued)

# INPLT PROCESSOR DIAGNOSTICS

|    | SECTION | MESSAGE TEST        |
|----|---------|---------------------|
| 1  |         |                     |
| 2  |         |                     |
| 3  |         |                     |
| 4  | COORD   | NO ERRORS DETECTED. |
| 5  |         |                     |
| 6  | ELEM    | NO ERRORS DETECTED. |
| 7  |         |                     |
| 8  | TEXT    | NO ERRORS DETECTED. |
| 9  |         |                     |
| 10 | BOUN    | NO ERRORS DETECTED. |
| 11 |         |                     |
| 12 | OLOA    | NO ERRORS DETECTED. |
| 13 |         |                     |
| 14 | ICON    | NO ERRORS DETECTED. |
| 15 |         |                     |
| 16 | END     | NO ERRORS DETECTED. |
| 17 |         |                     |
| 18 |         |                     |
| 19 |         |                     |
| 20 |         |                     |
| 21 |         |                     |

| THE COORDINATES OF THE NODE POINTS |          |          |         |
|------------------------------------|----------|----------|---------|
| PT                                 | X        | Y        | Z       |
| 1                                  | 0.0      | 0.0      | 10.0000 |
| 2                                  | 100.0000 | 0.0      | 8.0000  |
| 3                                  | 0.0      | 70.0000  | 10.0000 |
| 4                                  | 100.0000 | 70.0000  | 8.0000  |
| 5                                  | 0.0      | 140.0000 | 10.0000 |
| 6                                  | 100.0000 | 140.0000 | 8.0000  |
| 7                                  | 100.0000 | 190.0000 | 8.0000  |

Figure 6 (Continued)

THE INPUT FOR EACH ELEMENT OF THE STRUCTURE  
---NODES---

| EL TYPES | 1          | 2          | 3          | 4          | 5          | 6          | 7          | 8          | 9          | 10         | 11         | 12         | 13         | 14         | 15         | 16         |
|----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 1        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 2        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 3        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 4        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 5        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 6        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 7        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 8        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 9        | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 10       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 11       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 12       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 13       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 14       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 15       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| 16       | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          | 1          |
| SIGU     | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    | 10000.0    |
| SIGL     | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   | -10000.0   |
| E        | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 | 10000000.0 |
| MU       | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      | 0.300      |
| PHO      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      |
| MIN SIZE | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      | 0.100      |

Figure 6 (Continued)

```

33 THE FOLLOWING NODES ARE RESTRAINED
34
35 IN THE X-DIRECTION
36 1 2
37
38 IN THE Y-DIRECTION
39 1 2
40
41 IN THE Z-DIRECTION
42 1 2
43 *** WARNING *** SYMMETRIC LOAD CONDITION 1
44 DEGREE OF FREEDOM 1 IS CONSTRAINED
45 THE C.O. LOAD IS SUPPRESSED
46 *** WARNING *** SYMMETRIC LOAD CONDITION 1
47 DEGREE OF FREEDOM 2 IS CONSTRAINED
48 THE C.O. LOAD IS SUPPRESSED
49 *** WARNING *** SYMMETRIC LOAD CONDITION 2
50 DEGREE OF FREEDOM 1 IS CONSTRAINED
51 THE C.O. LOAD IS SUPPRESSED
52 *** WARNING *** SYMMETRIC LOAD CONDITION 2
53 DEGREE OF FREEDOM 2 IS CONSTRAINED
54 THE C.O. LOAD IS SUPPRESSED
55 INCIV.DISPL.CONSTRAIN RED.DIR NOS,SYM THEN ANTISYM
56 10
57 0

```

UPPER AND LOWER DISP.CONSTRAINT LIMITS  
0.200E 01

0.200E 01

```

1 THE APPLIED LOAD MATRIX
2 0.0 0.0
3 0.0 0.0
4 0.0 0.0
5 0.0 0.0
6 0.0 10000.0000
7 0.0 0.0
8 0.0 0.0
9 0.0 0.0
10 0.0 0.0
11 0.0 0.0
12 0.0 0.0
13 0.0 0.0
14 0.0 0.0
15 5000.0000 0.0

```

Figure 6 (Continued)

|                                  |        |        |        |        |        |        |        |
|----------------------------------|--------|--------|--------|--------|--------|--------|--------|
| ITERATION 1                      | 0.4897 | 0.4897 | 0.4897 | 0.4897 | 0.4897 | 0.4897 | 0.4897 |
|                                  | 0.0979 | 0.0979 | 0.0979 | 0.0979 | 0.0979 | 0.0979 | 0.0979 |
| THE STRUCTURE WEIGHT IS 233.8619 |        |        |        |        |        |        |        |
| ITERATION 2                      | 0.3950 | 0.1625 | 0.4228 | 0.4202 | 0.1465 | 0.0370 | 0.0243 |
|                                  | 0.0504 | 0.0304 | 0.0374 | 0.0216 | 0.0237 | 0.0033 | 0.1056 |
| THE STRUCTURE WEIGHT IS 174.7180 |        |        |        |        |        |        |        |

## DISPLACEMENTS BY LOAD CONDITION

| DISPLACEMENTS BY LOAD CONDITION |                 |                 |                 |                                 |      |                 |                 |                                |             |      |                 |                                 |                 |             |  |
|---------------------------------|-----------------|-----------------|-----------------|---------------------------------|------|-----------------|-----------------|--------------------------------|-------------|------|-----------------|---------------------------------|-----------------|-------------|--|
| SYMMETRIC -- LOAD CONDITION A1  |                 |                 |                 | ASYMMETRIC -- LOAD CONDITION A2 |      |                 |                 | SYMMETRIC -- LOAD CONDITION A3 |             |      |                 | ASYMMETRIC -- LOAD CONDITION A4 |                 |             |  |
| NODE                            |                 | X-COMPONENT     | Y-COMPONENT     | Z-COMPONENT                     | NODE |                 | X-COMPONENT     | Y-COMPONENT                    | Z-COMPONENT | NODE |                 | X-COMPONENT                     | Y-COMPONENT     | Z-COMPONENT |  |
| 1                               | 0.0             | 0.0             | 0.0             | 0.0                             | 1    | 0.0             | 0.0             | 0.0                            | 0.0         | 1    | 0.0             | 0.0                             | 0.0             | 0.0         |  |
| 2                               | 0.0             | 0.0             | 0.0             | 0.0                             | 2    | 0.0             | 0.0             | 0.0                            | 0.0         | 2    | 0.0             | 0.0                             | 0.0             | 0.0         |  |
| 3                               | -0.31387211E-01 | -0.5006677E-01  | -0.30002379E 00 | 0.0                             | 3    | -0.11255510E-01 | -0.36790813E-C2 | -0.40478740E-01                | 0.0         | 3    | -0.11255510E-01 | -0.36790813E-C2                 | -0.40478740E-01 | 0.0         |  |
| 4                               | -0.13678531E-02 | -0.55420891E-01 | 0.41383725E 00  | 0.0                             | 4    | 0.51333383E-02  | -0.3212732E-02  | -0.27189689E-01                | 0.0         | 4    | 0.51333383E-02  | -0.3212732E-02                  | -0.27189689E-01 | 0.0         |  |
| 5                               | -0.38250279E-01 | -0.5586242E-01  | 0.8596087E 00   | 0.0                             | 5    | -0.29176656E-02 | -0.3311478E-01  | 0.11346346E 00                 | 0.0         | 5    | -0.29176656E-02 | -0.3311478E-01                  | 0.11346346E 00  | 0.0         |  |
| 6                               | -0.21545753E-01 | -0.11656994E 00 | 0.13675670E 01  | 0.0                             | 6    | 0.15481196E-01  | 0.12022015E-01  | -0.10295248E 00                | 0.0         | 6    | 0.15481196E-01  | 0.12022015E-01                  | -0.10295248E 00 | 0.0         |  |
| 7                               | -0.1047580E 00  | -0.16321755E C0 | 0.23638496E 01  | 0.0                             | 7    | -0.1047580E 00  | -0.16321755E C0 | 0.23638496E 01                 | 0.0         | 7    | -0.1047580E 00  | -0.16321755E C0                 | 0.23638496E 01  | 0.0         |  |

# THE STRESS MATRIX

## SYMMETRIC - LOAD CONDITION NO. 1

|    |              |              |              |              |              |
|----|--------------|--------------|--------------|--------------|--------------|
| 1  | -0.78581E 04 |              |              |              |              |
| 2  | -0.25419E 03 |              |              |              |              |
| 3  | -0.64667E 04 |              |              |              |              |
| 4  | -0.82132E 04 |              |              |              |              |
| 5  | -0.32611E 04 |              |              |              |              |
| 6  | -0.56567E 04 |              |              |              |              |
| 7  | 0.66740E 04  |              |              |              |              |
| 8  | 0.0          |              |              |              |              |
| 9  | 0.84544E 04  |              |              |              |              |
| 10 | 0.10000E 05  |              |              |              |              |
| 11 | 0.52219E 04  |              |              |              |              |
| 12 | 0.55066E 04  |              |              |              |              |
| 13 | 0.66737E 04  |              |              |              |              |
| 14 | -0.23355E 04 | 0.0          |              |              |              |
| 15 | -0.25574E 04 | -0.41694E 04 | -0.88399E 04 | -0.11708E 04 | -0.85246E 04 |
| 16 | -0.14756E 04 | -0.64055E 03 | -0.80954E 04 | -0.41954E 03 | -0.43119E 04 |
| 17 |              |              |              |              | -0.26323E 04 |

## SYMMETRIC - LOAD CONDITION NO. 2

|    |              |              |             |              |             |
|----|--------------|--------------|-------------|--------------|-------------|
| 1  | -0.29710E 03 |              |             |              |             |
| 2  | -0.15764E 04 |              |             |              |             |
| 3  | 0.45745E 03  |              |             |              |             |
| 4  | 0.12600E 04  |              |             |              |             |
| 5  | -0.46343E 03 |              |             |              |             |
| 6  | 6.58256E 03  |              |             |              |             |
| 7  | -0.45891E 04 |              |             |              |             |
| 8  | 0.92718E 04  |              |             |              |             |
| 9  | -0.72417E 03 |              |             |              |             |
| 10 | -0.50314E 03 |              |             |              |             |
| 11 | -0.25670E 04 |              |             |              |             |
| 12 | 0.18242E 04  |              |             |              |             |
| 13 | 0.10821E 04  |              |             |              |             |
| 14 | 0.17027E 04  | 0.0          |             |              |             |
| 15 | 0.28600E 01  | -0.24774E 03 | 0.38681E 03 | -0.23548E 03 | 0.95324E 01 |
| 16 | -0.46893E 03 | -0.13523E 04 | 0.16963E 04 | 0.61367E 03  | 0.54441E 03 |
| 17 |              |              |             |              | 0.25867E 02 |
| 18 |              |              |             |              | 0.64159E 03 |

Figure 6 (Continued)

|    |                                  |                 |                 |                 |
|----|----------------------------------|-----------------|-----------------|-----------------|
| 45 | THE STRUCTURE WEIGHT IS 174.7180 |                 |                 |                 |
| 46 | REACTIONS BY LOAD CONDITION      |                 |                 |                 |
| 47 | SYMMETRIC - LOAD CONDITION NO. 1 |                 |                 |                 |
| 48 | NODE                             | X-COMPONENT     | Y-COMPONENT     | Z-COMPONENT     |
| 49 | 1                                | 0.13256477E 05  | 0.52437484E 05  | -0.15400227E 04 |
| 50 | 2                                | 0.26254907E 04  | 0.53213336E 05  | -0.34600156E 04 |
| 51 | 3                                | 0.50781250E-01  | 0.42961750E-01  | -0.14801025E-01 |
| 52 | 4                                | 0.11718750E-01  | 0.50781250E-01  | -0.61035156E-02 |
| 53 | 5                                | -0.23437500E-01 | 0.50781250E-01  | 0.28076172E-01  |
| 54 | 6                                | -0.31250000E-01 | 0.31640625E 00  | -0.99868774E-01 |
| 55 | 7                                | 0.53791612E-01  | 0.51953125E 00  | 0.12917835E 00  |
| 56 | SYMMETRIC - LOAD CONDITION NO. 2 |                 |                 |                 |
| 57 | NODE                             | X-COMPONENT     | Y-COMPONENT     | Z-COMPONENT     |
|    | 1                                | -0.20305934E 04 | 0.25862354E 03  | -0.35286646E 03 |
|    | 2                                | -0.30502546E 04 | -0.32337964E 03 | 0.35287183E 03  |
|    | 3                                | -0.78125000E-02 | -0.52185059E-02 | -0.53405762E-03 |
|    | 4                                | -0.46366719E-02 | 0.35062500E-02  | 0.27665820E-03  |
| 1  | 5                                | -0.62011719E-01 | -0.78125000E-02 | 0.58841705E-03  |
| 2  | 6                                | -0.31250000E-01 | 0.00            | 0.71716309E-03  |
| 3  | 7                                | -0.42927314E-01 | -0.36987305E-01 | -0.61048083E-02 |
| 4  |                                  |                 |                 |                 |

Figure 6 (Continued)

VI. PROGRAMMER'S MANUAL

The programmer's manual for the OPTIM III Program is designed to facilitate its implementation, operation, modification, and extension. This manual is presented in the appendix.

## VII. CONCLUSIONS

This report documents the revision and extension of the weight optimization program OPTIM II to a new program OPTIM III. The new program utilizes a NASTRAN input type format (BULK DATA DARDS) and is applicable to the analyses and optimization of complex large scale structures which contain composite membrane plate types of elements.

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APPENDIX

PROGRAMMER'S MANUAL FOR OPTIM III

Beverly J. Dale

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## SECTION I

### INTRODUCTION

The large scale automated minimum weight design program OPTIM II has been altered to make its input format compatible with the NASTRAN program. The resulting new program is called OPTIM III and the programming aspects are described in this Appendix.

The information presented here is geared to the Programmer. It is sufficient to fully describe the program logic and the required peripheral storage. All element generated data is stored externally to reduce core storage. A separate section is devoted to the development of these files so that I/O time may be optimized through efficient buffer description. Individual subroutine write-ups are presented along with the complete Fortran source listing.

A short description of each routine is included to aid in getting an overall familiarity with the program components. The manner of allocating storage for the stress and displacement matrices is described in diagram form.

## SECTION 2

### GENERAL PROGRAM LOGIC

The general organization of the "OPTIM" program is illustrated in Figures 1, 2 and 3.

The program consists of 3 principal phases:

1. Control and Data Interpretation Phase
2. Initialization Phase
3. Calculation Phase

#### 1. Control and Data Interpretation Phase (Figure 1)

The principal purpose of this phase is to read the NASTRAN form input and prepare the information for the next two phases. Five subroutines, MAIN, SORT, ZZ, OPTIM2 and OPIMPT perform this function. The "MAIN" routine controls the program flow. The "SORT" and "ZZ" routines sort and count the data cards and then form the dynamic storage constants. Each NASTRAN label card is processed and stopped in core by "ZZ". An input file data tape based on OPTIM related input is then written. This data file is then used by "OPINPT" which writes on unit NTAPE all the data needed for initialization.

#### 2. Initialization Phase (Figure 2)

This phase produces a variety of information for the Final Calculation Phase. Upon being activated by the "MAIN" routine, the "NEWS" routine determines the dynamic storage allocation for the Initialization Phase. The "AONE" routine is then activated and performs the following tasks:

A load matrix is generated in reduced form and written on tape NSS1.

Stiffness and stress matrices are defined by the called element routines (ELEM1 to ELEM8) and are written on tapes NSS1 and NSS2, respectively. The element routines write the number of stresses in the element and the weight of the element with a unit design variable on the tape NSS3.

A final tape, NSS4, is written with information on linked groups, stress and constraint limits and various other key control data.

#### 3. Calculation Phase (Figure 3)

The Calculation Phase is begun by the "SIZE" routine. Upon being called by the "MAIN" routine, "SIZE" determines the dynamic storage allocation for the Incore Calculation Phase.

For the case where there is enough storage available for an incore solution then the routine "ATWO" controls the calculations. If enough storage is not available then control is passed to the "SIZE1" routine which attempts to allocate storage for an out-of-core solution. If the storage for out-of-core is adequate then the routine "ATWO1" controls the calculation. A brief description of both in-core logic and out-of-core logic follows:

#### In Core Logic

The routine "ATWO" controls the following functions:

A. Tapes NSS3 and NSS4 are read. These tapes are read once and the information is used to initiate the program.

B. For each iteration tapes NSS1 and NSS2 are read. The stiffness matrices are assembled in-core and then displacements are computed by the banded in-core equation solver "BANCHO". All the element stresses are computed in core and are used with the displacements by the "SCALE" routine. Scaling of the structure is done within the stress and displacement constraint limits. If buckling is specified then during the scaling process the "BUCKTB" and "IGEN2" routines are called by the "SCALE" routine. The "MODIFY" routine then adjusts element design variables by a recursive relationship using element displacements and stiffness matrices.

C. The print out of displacements, element stresses and element design variables is done by the "ATWO" routine. "ATWO" also calculates and prints the reactions after the last iteration.

#### Out-of-Core Logic

The routine "ATWO1" controls the following functions:

A. Tapes NSS3 and NSS4 are read and used to initialize the program. Later during execution, tape NSS3 will contain the stress matrix, one column/record. The NSS4 tape will contain the assembled stiffness matrix.

B. For each iteration tapes NSS1 and NSS2 are read. The stiffness matrices are assembled out-of-core on tape NSS4 by the "BASS" routine. Tapes NSS3 and NSS5 are used as scratch data sets for this step. The assembled stiffness matrix (which is also banded) is triangularized by routine "TCONTX" and placed on tape NSS5. Routine "EEQSX" performs the final equation solving using tape NSS5 as input. The stress matrix is computed and stored on NSS3 one column/record. The stresses and the in-core displacements are used by the "SCALE1" routine to scale the structure within stress and displacement constraint limits. If buckling is specified, the "SCALE1" routine calls

the "BUCKETB" and "IGEN2" to perform this function. As with the in-core solution, the "MODIFY" routine adjusts element design variables by a recursive relationship using element displacements and element stiffness matrices on tape NSS1.

C. The print out of displacements, element stresses and element design variables is done by the "ATW01" routine. "ATW01" also calculates and prints the reactions after the last iteration.

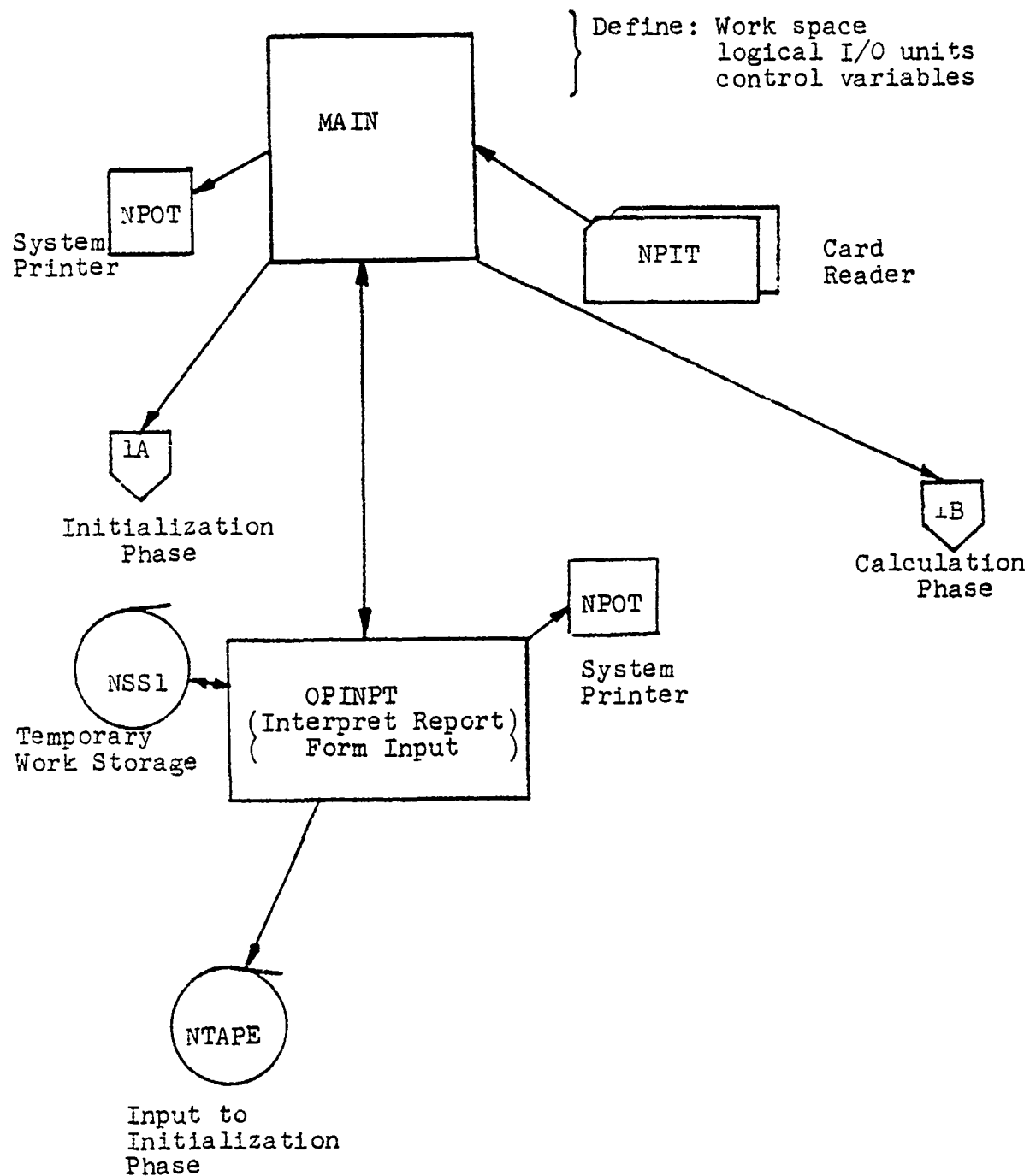


Figure 1 (Control and Data Interpretation Phase)

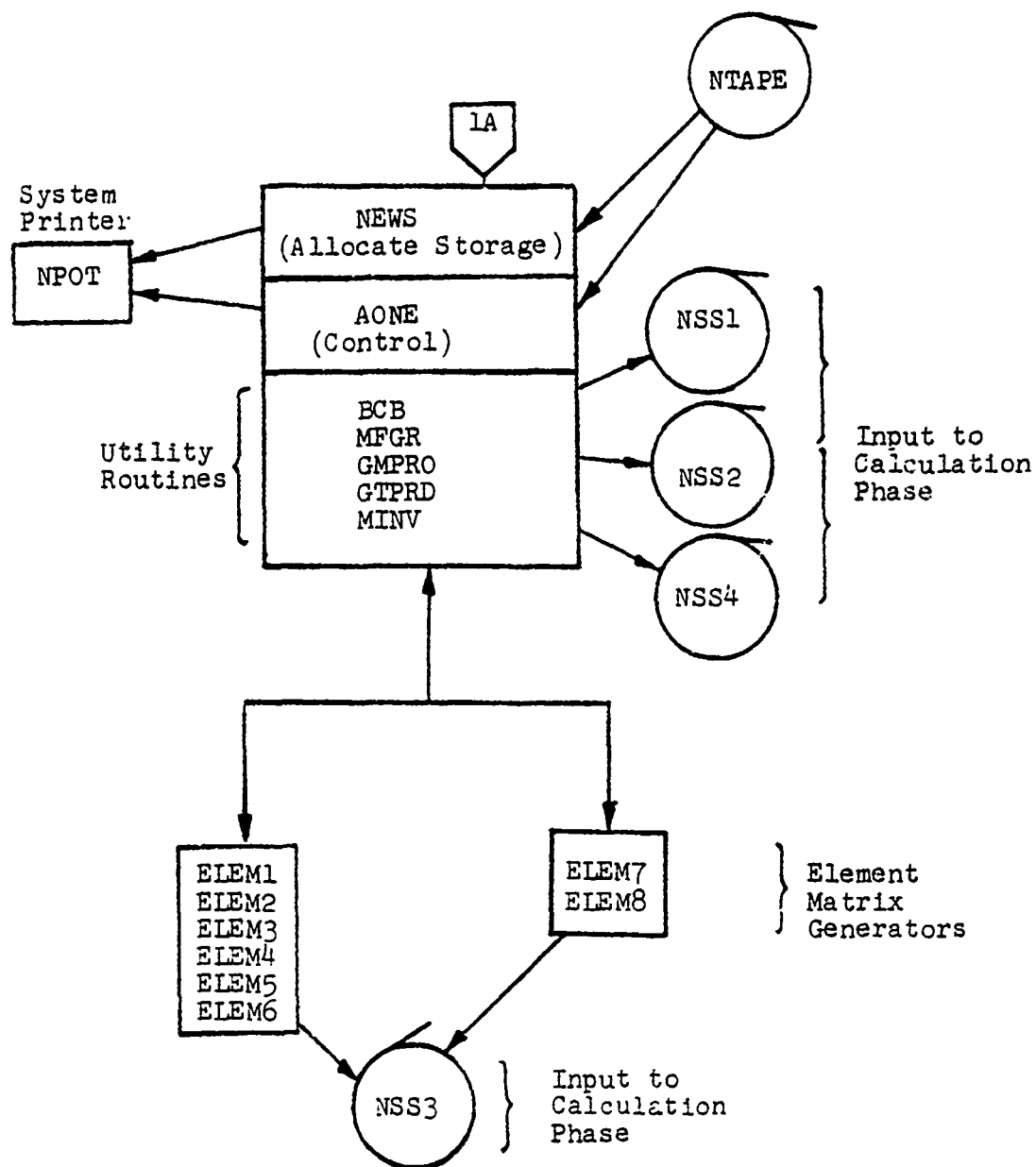


FIGURE 2 (INITIALIZATION PHASE)

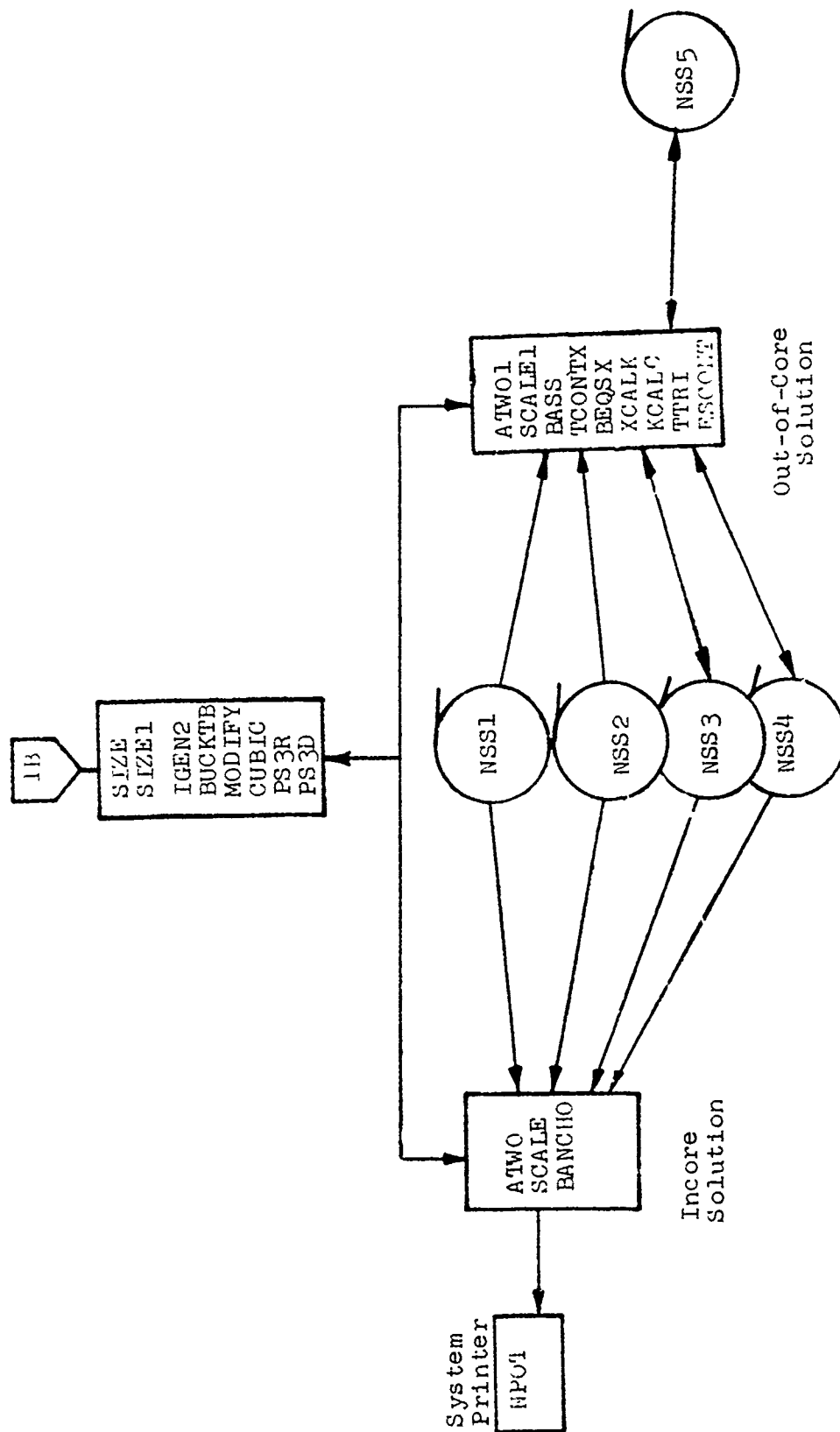


Figure 3 (Calculation Phase)

## SECTION 3

### EXTERNAL DATA SET STRUCTURE

This program uses seven data sets during execution. The delivery version of the OPTIM program comes with the following variable names and real unit designations. These unit numbers may be redefined in the "MAIN" routine.

| <u>Unit Name</u> | <u>Unit Id</u> | <u>Usage</u>                                                                                                                                                                                                                                                                                                        |
|------------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NTAPE/NSS5       | 8<br>(BINARY)  | Output from "MAIN" and "OPINPT" routines and input to "AONE" routine.<br><br>For out-of-core solution (Calculation Phase) this data set is called NSS5. It is next used as a scratch data set then it is used to store the triangularized stiffness matrix.                                                         |
| NSS1             | 1<br>(BINARY)  | Contains load matrix and element stiffness matrices with assembly information                                                                                                                                                                                                                                       |
| NSS2             | 2<br>(BINARY)  | Contains element stress matrices.                                                                                                                                                                                                                                                                                   |
| NSS3             | 3<br>(BINARY)  | ITOT (no. of elements) pairs of information from element matrix generation routines used to initialize the calculation phase.<br><br>For out-of-core solution (Calculation Phase) this data set is next used as a scratch data set during stiffness matrix assembly. Finally it is used to store the stress matrix. |
| NSS4             | 4<br>(BINARY)  | Contains initialization information for ATWO routine or ATWO1 Routine.<br><br>For out-of-core solution (Calculation Phase) this data set is next used to store the banded assembled stiffness matrix.                                                                                                               |

| <u>UNIT NAME</u> | <u>UNIT ID</u>   | <u>USAGE</u>                                                                                       |
|------------------|------------------|----------------------------------------------------------------------------------------------------|
| L4               | 9<br>(FORMATTED) | Output from "SORT" and input to "ZZ". Contains identification record and NASTRAN input card image. |
| L7               | 7<br>(FORMATTED) | Output from "ZZ" and input to "OPTIM2". Contains card images in OPTIM MAGIC format.                |
| NPIT/J5/L5       | 5                | Standard card input (80 column card)                                                               |
| NPOT/JE6/J6/L6   | 6                | Standard Line Printer (132 characters/line).                                                       |

NOTE: Since units 5 and 6 are standard input and output, they will not be considered in this discussion.

# NTAPE CONTENTS

## OPDIVIR Section Input

For the Out-of-Core Calculation Phase. This data set is called NSS5. The triangularized stiffness matrix is stored on NSS5.

|                                    |                                                    |                                               |
|------------------------------------|----------------------------------------------------|-----------------------------------------------|
| NTCDS                              | 20A4                                               |                                               |
| RECORDS                            |                                                    |                                               |
| Title Cards                        |                                                    |                                               |
| One                                |                                                    |                                               |
| Record                             | ((Grid (I,J), J=1, 3), I=1, N2)                    |                                               |
| (Coordinates)                      |                                                    |                                               |
| One                                |                                                    |                                               |
| Record                             |                                                    |                                               |
| Per Element                        | NEL, NID, IBUCK, (NODES(J), J=1, 8), (EM(J)J=1, 7) |                                               |
| ITOT                               |                                                    |                                               |
| Records                            |                                                    |                                               |
| One Record                         |                                                    |                                               |
| Linked Group                       | IBGP, (ILINK(LL),LL=1,IBGP)                        |                                               |
| Bucking Info                       |                                                    |                                               |
| ONE RECORD                         |                                                    |                                               |
| Linking                            | (ILINK(LL),LL=1, NSG)                              |                                               |
| Info                               |                                                    |                                               |
| One Record                         | (NBOUND(I), I=1,NAM)                               | NREACT Array number of each component bounded |
| Boundary Condition Info            |                                                    |                                               |
| NNZL                               |                                                    |                                               |
| Records                            | IR,IC,C1,C2                                        |                                               |
| Load Components                    |                                                    |                                               |
| IF                                 | One                                                | (NBDF(I), I=1, NDL)                           |
| NDL.NE.0                           | Record                                             |                                               |
| Individual Constraint Info (ICON)  |                                                    |                                               |
| IF                                 | NAA                                                | KNL, (NBDF(JK),JK=1,KNL)                      |
| NAA.NE.0                           | Records                                            |                                               |
| Generalized Constraint Info (GCON) |                                                    |                                               |
| If                                 | One                                                | (DISPU(I),DISPL(I),I=1,NDLL)                  |
| NAA+NDL.NE.0                       | Record                                             |                                               |
| IF                                 | One                                                | (DVJR(J),J=1,ITOT)                            |
| IRST.EQ.1                          | Record                                             |                                               |
| or 2                               |                                                    |                                               |

# NSSI Contents

1st Record

(DELTA(I), I=1, J1)

Load Matrix

3 Records  
Per Element

J, K

(X(L), L=1, J)

Stiffness Matrix

(M(L), L=1, K), (M2(L), L=1, K), NNO, (NODES(L), L=1, NNC)

Symmetric Antisymmetric

Nodes used in  
Element  
Definition

Assembly info vectors

# NSS2 CONTENTS

3 Records  
Per Element

J, K, JK

((STR(KK, JJ), KK=1, K), JJ=1, J)

Element  
Stress  
Matrices

(M(L), L=1, J), (M2(L), L=1, J)

### NSS3 Contents

2 Records  
Per Element

LIST(I)

Number of Stresses

(PAR(L), L=KK, KK2)

Weight Info and  
 $X_2 X_3$  info for element  $u$

Purpose: Initialization of ATWO routine

For Out-Of-Core Calculation Phase

The stress matrix is stored on this data set. There is one record for each column of the stress matrix.

# NSS4 Contents

|                                                                                                 |  |                                                          |
|-------------------------------------------------------------------------------------------------|--|----------------------------------------------------------|
| NRDF, NLOAD, ITOT, NALD, NDL, NSG, NAA                                                          |  | Stress and Design Parameters<br>Limits Buckling Controls |
| (SIGL(I), SIGU(I), ALL(I), I=1, ITOT),<br>IBS, (IBK(I), I=1, IBS)                               |  |                                                          |
| (N7(I), I=1, NSG)                                                                               |  | Linked Group Information                                 |
| NRDF                                                                                            |  | No. of Reduced Deg.<br>of Freedom                        |
| (NBDF(I), I=1, K), (NBDF2(I), I=1, K)                                                           |  | Individual Constraint Info                               |
| NEAA, (NE(I), I=1, NEAA), NEA2, (NE2(I), I=1, NEA2)                                             |  | Generalized<br>Constraint Info                           |
| (DISPU(I), DISPL(I), I=1, NDL)                                                                  |  | Limits for Constraints                                   |
| C1, C2, ITERN                                                                                   |  |                                                          |
| (AREA(I), I=1, ITOT)                                                                            |  |                                                          |
| LOAD1, LOAD2, NSYM, NASYM, NONSYM, NRDF,<br>(LNOD(I), I=1, NRDF), NRDF2, (LNOD2(I), I=1, NRDF2) |  |                                                          |
| NREF, NDOF, KKTROL, NBOU, (NPI(I), I=1, NBOU),<br>NBOUN2, (NP2(I), I=1, NBOUN2)                 |  |                                                          |

## For Out-Of-Core Calculation Phase

The banded and assembled stiffness matrix is stored in this data set.

These records can be in any order on the file. It represents data in "pairs" of records. Each pair represents one specific type of data items determined by the value "NKIND" and "NCOUNT" which are written on the first record of the pair. R

Record one of the pair: NKIND, NCOUNT

Record two is determined by NKIND as shown in the following table:

| NKIND | Second Record |      |
|-------|---------------|------|
| 1     | BULK          | data |
| 2     | TITLE         | "    |
| 3     | BUCK          | "    |
| 4     | CONROD        | "    |
| 5     | CQDMEM        | "    |
| 6     | CQDMEM1       | "    |
| 7     | CQDMEM2       | "    |
| 8     | CQDMID        | "    |
| 9     | CQUAD1        | "    |
| 10    | CQUAD2        | "    |
| 11    | CRDMID        | "    |
| 12    | CROD          | "    |
| 13    | CSHEAR        | "    |
| 14    | CTRIA1        | "    |
| 15    | CTRIA2        | "    |
| 16    | CTRMEM        | "    |
| 17    | CTRMID        | "    |
| 18    | CTUBE         | "    |
| 19    | END*          | "    |
| 20    | ENDDATA       | "    |
| 21    | FORCE         | "    |
| 22    | GCON          | "    |
| 23    | GRID          | "    |
| 24    | ICON          | "    |

|    |            |      |
|----|------------|------|
| 25 | LINKS      | data |
| 26 | MOMENT     | "    |
| 27 | MAT1       | "    |
| 28 | OPLOAD     | "    |
| 30 | OPDVIR     | "    |
| 31 | OPTIM      | "    |
| 32 | PQDMEM     | "    |
| 33 | PQDMEM1    | "    |
| 34 | PQDMEM2    | "    |
| 35 | PQDMID     | "    |
| 36 | PQUAD1     | "    |
| 37 | PQUAD2     | "    |
| 38 | PRDMID     | "    |
| 39 | PROD       | "    |
| 40 | PSHEAR     | "    |
| 41 | PTRIA1     | "    |
| 42 | PTRIA2     | "    |
| 43 | PTRMEM     | "    |
| 44 | PTRMID     | "    |
| 45 | PTUBE      | "    |
| 46 | SPC        | "    |
| 47 | SPC1       | "    |
| 48 | SPC1 THRU  | "    |
| 49 | CWEB       | "    |
| 50 | PWEB       | "    |
| 51 | BEGIN BULK | "    |
| 52 | CTRM6      | "    |
| 53 | CTRSHL     | "    |
| 54 | CQUAM8     | "    |
| 55 | CQUSHL     | "    |
| 56 | PTRIM6     | "    |
| 57 | PTRSHL     | "    |
| 58 | PQUAM8     | "    |
| 59 | PQUSHL     | "    |

## L7 Contents

(80 character  
card images)

|                   |                                                                              |
|-------------------|------------------------------------------------------------------------------|
| Record #1         | REPORT (2A4)                                                                 |
| " #2              | TITLE (2A4)                                                                  |
| " #3              | NTIT (6X, 113)                                                               |
| " #4              | (IEDINC(I), I=1, 20)                                                         |
| " #5              | SYSTEM, (BLANK, I=1, 18)                                                     |
| " #6              | NGR1, NGR2, NS4S, ILOAD, NECARD, MNN                                         |
| " #7              | OPTIM (OPT(I), I=1, 16)                                                      |
| " #8              | COORD, (BLANK, I=1, 18)                                                      |
| NGRI<br>records   | { M, C1, C2, C3                                                              |
| NEL<br>records    | ELEM, (BLANK, I=1, 18)<br>{ I, NOPT(I), X, NNODES(I), (NODENO(I, J), J=1, 8) |
|                   | OEXTERN, (BLANK, I=1, 18)                                                    |
| NECARD<br>records | { I, BUCK(I), A, B, C, D, E, F, G, H, P, Q, R,<br>J, ANGLE(I)                |
|                   | LINK, (BLANK, I=1, 18)<br>LLINK                                              |
|                   | BOUND, (BLANK, I=1, 18)<br>(BLANK, I=1, 20)<br>MODAL (1, I=1, NSIS)          |
| NOCARD records    | I, (LBOUND (I, J), J=1, NSYS)                                                |
| NLOADS<br>TIMES   | OLOADS, (BLANK, I=1, 18)<br>LCOND, IL                                        |
|                   | MODAL, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0                                          |
|                   | { IGR, C1, C2, C3, C4                                                        |
|                   |                                                                              |
| NICON<br>records  | ICON, (BLANK, I=1, 19)<br>{ EYEC (J, I), J=1, 13)                            |

|        |         |                                       |
|--------|---------|---------------------------------------|
| NGROUP | {       | GCON, (BLANK, I=1, 19)                |
| TIMES  |         | { GGROUP, I                           |
|        | records | { GROUP(5, I), GROUP(6, I)            |
|        | {       | { GCOND (2, J), (GCOND(K, J) K=3, 14) |
|        |         | NGC1                                  |
|        | record  |                                       |
|        |         | . OPDVIR, (BLANK, I=1, 18)            |
| NLL    |         | { OPD, (BLANK, I=1, 18)               |
| TIMES  |         | { OPDV                                |
| last   |         | FEND = "END"                          |
| record |         |                                       |

## Section 4

### Subroutine Write-Ups

The OPTIM program contains 37 subprograms, each with a unique sequence number. Columns 73, 74, 75 and 76 contain the "DECK" name and columns 77 through 80 contain the card sequence number for that subprogram. The first is always ----0000 with successive increments of 10.

Included with each description is a statement declaring the size of the subprogram. This number is intended as a guide only, as it reflects the storage requirement on an IBM/360/65, FORTRAN G level 19 compiler.

In this manual the subroutine writeups are presented in alphabetical order.

## Brief Routine Descriptions

| <u>Routine Name</u> | <u>Purpose</u>                                                                               |                    |
|---------------------|----------------------------------------------------------------------------------------------|--------------------|
| ADJUST              | Adjust each NASTRAN form field so that it is either left or right adjusted.                  |                    |
| AONE                | Control initialization                                                                       |                    |
| ATWO                | Control calculation and print out (in-core solution)                                         |                    |
| ATWO1               | Control calculation and print out (out-of-core solution)                                     |                    |
| BANCHO              | Banded in-core equation solver                                                               |                    |
| BASS                | Assemble banded stiffness matrix (out-of-core solution)                                      |                    |
| BCB                 | Matrix triple product                                                                        |                    |
| BEQSX               | Equation solver (out-of-core solution)                                                       |                    |
| BMAT                | Generates A matrix for triangular plate, also area                                           |                    |
| EUCKTB              | Interfaces with SCALE and IGEN2. Determines minimum plate thickness for stability.           |                    |
| CMAT3               | Generates C <sub>3</sub> matrix for triangular plate                                         |                    |
| CUBIC               | Solve for principle beam stresses                                                            |                    |
| EGMAT               | Generates EG matrix for triangular plate                                                     |                    |
| EMAT                | Generate elasticity matrix for either orthotropic or isotropic properties, membrane triangle |                    |
| ELEM1               | <div><div></div><div>Element<br/>Matrix<br/>Generators</div><div></div></div>                | Axial              |
| ELEM2               |                                                                                              | Shear web          |
| ELEM3               |                                                                                              | Triangle           |
| ELEM4               |                                                                                              | Quad               |
| ELEM5               |                                                                                              | Beam (tube)        |
| ELEM6               |                                                                                              | Mid-point axial    |
| ELEM7               |                                                                                              | Mid-point triangle |
| ELEM8               |                                                                                              | Mid-point quad     |

# Brief Routine Descriptions (Cont'd.)

| <u>Routine<br/>Name</u> | <u>Purpose</u>                                                                                        |
|-------------------------|-------------------------------------------------------------------------------------------------------|
| ESCONT                  | Solve matrix equation $A^* A \text{ Transpose} * X = F$ , for X (out-of-core solution)                |
| FOMO                    | Process Force Cards                                                                                   |
| GMPRD                   | Matrix product                                                                                        |
| GTPRD                   | Matrix product with transpose of first matrix                                                         |
| IGEN2                   | Solves Eigenvalue for buckling coefficient of plate                                                   |
| INSPC                   | Stores data obtained from input card into working storage                                             |
| INSRTI                  | Stores element properties and material numbers into working storage                                   |
| KCALC                   | Solve for XK where $A * XF = F$ and A is banded <u>lower</u> triangular matrix (out-of-core solution) |
| KMAT                    | Generates stiffness matrix for triangular membrane                                                    |
| MAIN                    | Control program flow                                                                                  |
| MFGR                    | Matrix Ranking                                                                                        |
| MINV                    | Matrix Inverse                                                                                        |
| MODIFY                  | Next element design parameter guess after scaling                                                     |
| NEWS                    | Allocate storage for initialization                                                                   |
| OPTIM2                  | Interprets input and initializes data.                                                                |
| OPINPT                  | Interpret report from input and place results on NTAPE                                                |
| PS3D                    | Define cubic equation from beam stress components                                                     |
| PS3R                    | Normalize stresses                                                                                    |
| READI                   | Reads and modifies input data                                                                         |
| SCALE                   | Scale structure using stress, displacement and buckling constraints (in-core solution)                |
| SCALE1                  | Scale structure using stress, displacement and buckling constraints (out-of-core solution)            |
| SIZE                    | Allocate storage for calculation phase (in-core solution)                                             |

# Brief Routine Descriptions (Cont'd)

| <u>Routine Name</u> | <u>Purpose</u>                                                                           |
|---------------------|------------------------------------------------------------------------------------------|
| SIZEL               | Allocate storage for calculation phase (out-of-core solution)                            |
| SMAT                | Generate stress element matrix for membrane triangular plate with orthotropic properties |
| SORT                | Sort and count data based on LABEL information                                           |
| SPCSUB              | Process SPC (single point constraint) cards                                              |
| TCONTX              | Control tape flow to triangularize stiffness matrix (out-of-core solution)               |
| TMAT                | Generate transformation matrix for triangular plate orthotropic angle                    |
| TTRI                | Triangularize rows of a banded matrix A (out-of-core solution)                           |
| WRITEL              | Tests character of element connection card and writes element information on to file     |
| XCALK               | Solve for X where $A * X = XK$ and A is an <u>upper</u> triangular matrix                |
| XTRAK               | Interpret degree of freedom informations                                                 |
| XTRAK2              | Interpret degree of freedom informations for generalized constraint information          |
| ZZ                  | Generates OPTIM data which is input by NASTRAN form input cards                          |

- |                     |                                                                                                                                                                                                       |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine Name  | ADJUST                                                                                                                                                                                                |
| 2. Purpose          | Adjust each NASTRAN form field so that it is either left or right adjusted.                                                                                                                           |
| 3. Procedures       | Each character of the word is tested to see if it is blank. When a non-blank is met, it is shifted to the end of the word.                                                                            |
| 4. Input Arguments  | <p>WORD - Input word to be either right or left adjusted</p> <p>Icode Icode = 8 specifies that the word should be right adjusted</p> <p>Icode = 1 specifies that the word should be left adjusted</p> |
| 5. Output Arguments | Word right adjusted, word is stored back into WORD                                                                                                                                                    |
| 6. Error Returns    | None                                                                                                                                                                                                  |
| 7. Calling Sequence | CALL ADJUST (Word, ICODE)                                                                                                                                                                             |
| 8. Subroutine User  | NEWS                                                                                                                                                                                                  |

1. Subroutine Name: AONE
2. Purpose: Assemble all initialization information for the calculation phase of the program.
3. Equations and Procedures:
  - a) Print out title cards.
  - b) Retrieve (I5) coordinate+element data. If requested print this data out.
  - c) Recalculate boundary conditions if symmetry plane nodes are specified.
  - d) Create load matrix from input loads.
  - e) Define virtual loads for individual constraints and generalized constraints.
  - f) Call element routines.
  - g) Four tapes of data are written with information for the calculation program (ATWO).

4. Input Arguments:

|           |                                      |
|-----------|--------------------------------------|
| I5        | (Unit 8) tape                        |
| NPOT      | (Unit 6) printer                     |
| NSS1-NSS4 | (Units 1-4) tapes                    |
| N2        | No. of nodes                         |
| NAA       | No. of generalized constraints       |
| NDL       | No. of Individual Constraints        |
| NSG       | No. of Linked Groups                 |
| NNZL      | No. of input loads                   |
| KLN2      | No. of symmetry plane nodes          |
| NSYM      | No. of symmetric load conditions     |
| NASYM     | No. of antisymmetric load conditions |
| NONSYM    | No. of non-symmetric load conditions |
| ITERN     | Max. no. of iterations               |
| NTCDS     | No. of title cards                   |

5. Output Arguments:

|        |                                                         |
|--------|---------------------------------------------------------|
| C1INP) | Convergence limits                                      |
| C2INP) |                                                         |
| NRDF   | No. of reduced DOF (symmetric load condition)           |
| NEAA   | No. of generalized displacement constraints             |
| NBOU   | Total no. of constrained DOF (symmetric load condition) |
| IRST   | Calculation control                                     |

6. Error Returns: IER

7. Calling Sequence:

CALL AONE(X,Y,Z,N5,N6,N7,E,AMU,N8,N17,ALL,RHO,SIGU,  
SIGL,R,N11,N13,N15,NOAL,NOAL2,KL,KL2,LNOD,LNOD2,  
DISPU,DISPL,NBDF,NBDF2,NSE,DELTA,I5,NPOT,NSS1,NSS2,  
NSS3,NSS4,IBUKL,IELT,IBK,N1,N2,NAA,NDL,NSG,NNZL,

NALD, KLN2, NSYM, NASYM, NONSYM, ITERN, NTCDS, IREST, ITOT,  
IELI, NREACT, C1INP, C2INP, NRDF, NRDF2, NEAA, NEA2, NDL1,  
NDL2, NBOU, NBOUN2, IRST, KNCAL, IER)

8. Input Tapes: NTAPE (unit 8)

9. Output Tapes:

NSS1 (unit 1)  
NSS2 (unit 2)  
NSS3 (unit 3)  
NSS4 (unit 4)

10. Scratch Tapes: None

11. Storage Required: (20160 bytes) 5040 words

12. Subroutine User: NEWS

13. Subroutine Required:

ELEM1  
ELEM2  
ELEM3  
ELEM4  
ELEM5  
ELEM6  
ELEM7  
ELEM8

14. Remarks: None

1. Subroutine Name:      ATWO
2. Purpose:      Control execution of the in-core calculation phase of the program.
3. Equations and Procedures:
  - a. Read in all data from NSS4 tape.
  - b. Generate information vectors for BANCHO (in-core equation solver).
  - c. Read in data from NSS3. Element information consisting of number of stresses and weight factor.
  - d. Assemble stiffness matrices and solve for stresses and displacements in two passes. The first pass computes symmetric load conditions and the second pass computes anti-symmetric load conditions.
  - e. If this is a statics problem go to g) otherwise continue.
  - f. Call SCALE routine to scale stresses, displacements and design variables.
  - g. Print design parameters, displacements and stresses if requested for every iteration or if this is last iteration. If statics run go to j).
  - h. Check convergence.
  - i. Call MODIFY routine and return to d).
  - j. If last iteration compute and print reactions by load and node.

4. Input Arguments:

|           |                                              |
|-----------|----------------------------------------------|
| LLK       | Total number of stresses                     |
| NPOT      | (Unit 6) printer                             |
| NSS1-NSS4 | (Units 1-4) tapes                            |
| NGV       | Calculation control                          |
| NTERN     | Maximum number of iterations                 |
| IP1       | Print control for displacements              |
| IP2       | Print control for stresses                   |
| IPRINT    | Print control for element design variables   |
| IBUKL     | Buckling control from OPTIM section of input |

5. Output Arguments:      None

6. Error Returns:      IER

7. Calling Sequence:

CALL ATWO(N7,SIGL,SIGU,ALL,LIST,AREA,AQEA,BIGS,PAR,DELTA,  
STRESS,NE,NE2,DISPU,DISPL,NEDF,NEDF2,LNOD,LA,LR,AUX,  
N2,LA2,LNOD2,ST,NP1,NP2,ADFA,N5,N6,AREAD,LLK,NPOT,NSS1,  
NSS2,NSS3,NSS4,IP1,IP2,NGV,NTERN,IPRINT,IBUKL,IBK,IER)

8. Input Tapes:

|      |          |
|------|----------|
| NSS1 | (Unit 1) |
| NSS2 | (Unit 2) |
| NSS3 | (unit 3) |
| NSS4 | (Unit 4) |

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(14032 Bytes) 3508 words

12. Subroutine User: Size

13. Subroutine Required:

BANCHO  
SCALE  
MODIFY

14. Remarks: None

1. Subroutine Name:     ATW01
2. Purpose:         Control execution of the out-of-core calculation phase of the program.
3. Equations and Procedures:

The difference between the ATW0 and ATW01 routines is that the stress matrix is stored on tape and the assembled stiffness matrix is also on tape for the ATW01 routine.

- a) Read in all data from NSS4 tape.
- b) Read data from NSS3 tape.
- c) Assemble stiffness matrices and solve for displacements and stresses in two passes. The first pass solves for symmetric load conditions and the second pass solves for anti-symmetric load conditions. Call routines BASS, BEQSX AND TCONTX to assemble and solve for displacements.
- d) Go to f) for statics problem.
- e) Call SCALE1 routine to scale stresses, displacements and design variables.
- f) Print design variables, displacements and stresses if requested for every iteration or if this is the last iteration. If statics run go to i).
- g) Check convergence.
- h) Call MODIFY routine and return to c).
- i) If last iteration compute and print reactions by load and node.

4. Input Arguments:

|           |                                              |
|-----------|----------------------------------------------|
| LLK       | Total number of stresses                     |
| NPOT      | Printer                                      |
| NSS1-NSS5 | Tape Units                                   |
| NGV       | Calculation control                          |
| NTERN     | Maximum number of iterations                 |
| IP1,IP2,} | Print controls for displacement stress+      |
| IPRINT }  | element design variables, respectively       |
| IBUKL     | Buckling control from OPTIM section of input |

5. Output Arguments:     None
6. Error Returns:       None
7. Calling Sequence:

CALL ATW01 (N7,SIGL,SIGU,ALL,LIST,AREA,AQEA,BIGS,PAR,DELTA,STRESS,NE,NE2,DISPU,DISPL,NBDF,NBDF2,LA,NZ,INOD2,ST,NP1,NP2,ADEA,N5,N6,AREAD,LLK,NPOT,NSS1,NSS2,NSS3,NSS4,NSS5,IP1,IP2,NGV,NTERN,IPRINT,IBUKL,IBK,NTOTAL,IER).

8. Input Tapes:

NSS1  
NSS2  
NSS3  
NSS4  
NSS5

9. Output Tapes:           None

10. Scratch Tapes:        NS

11. Storage Required:

(14978 Bytes) 3745 words

12. Subroutine User:       SIZE1

13. Subroutine Required:

BASS  
SCALE1  
MODIFY  
BEQX  
TCONTX

1. Subroutine Name: BANCHO
2. Purpose:  
In core banded matrix equation solver.
3. Equations and Procedures:  
When given an NbyN positive definite matrix [A] a general Cholesky triangularization is effected.
4. Input Arguments:  
A Matrix of coefficients  
R Independent variable (vectors)  
N Number of equations  
M Number of dependent variables for solution  
IR Row numbers  
IC Column number of first non-zero term in A (for each row).  
IA Diagonal locations in A  
AUX Dummy array (N long)
5. Output Arguments:  
R Solution vectors  
A Is destroyed
6. Error Returns:  
Writes matrix can not be inverted, ROW, I4, STOP
7. Calling Sequence:  
CALL BANCHO (A,R,N,M,IR,IC,IA,AUX)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required:  
(4358 Bytes) 1089 words
12. Subroutine User: ATWO
13. Subroutine Required: None

1. Subroutine Name: BASS
2. Purpose:  
Assembly of banded symmetric matrix from symmetric element arrays.
3. Equations and Procedures:
  - a) The total assembled matrix is initially set = zero.
  - b) A "core full" section of the assembled matrix is handled at one time. Each element matrix is read into STA from tape I4. Each LISTEL is read from tape I4. This LISTEL is an element matrix array which contains the row numbers of the assembled matrix into which the element matrix must be added.
  - c) Each fixed point number in LISTEL is examined. If it is = 0 no addition into the system matrix is made. If it is greater than the maximum row number considered in the current computation pass, the particular element information is put on Tape I8 for later use in a subsequent computation pass.
  - d) If more than one computation pass is necessary, the section of the element matrix which has not been used is placed on tape I3.
  - e) Steps 2, 3, 4, are repeated for each element.
  - f) The assembled matrix portion for each computation pass is placed on tape I3 in banded form. Each row of the matrix constitutes a record.

4. Input Arguments:

|        |                                                                               |
|--------|-------------------------------------------------------------------------------|
| STA    | Storage array for assembled matrix                                            |
| NELEM  | Number of elements                                                            |
| NMDB   | Order of system                                                               |
| LISTEL | Element of assembly vector                                                    |
| NZEL   | Cumulative total of non zero elements in rows 1 through i-1 or reduced matrix |
| IZR    | Number of zero elements in row of reduced matrix                              |
| IRA    | Work storage array                                                            |
| IMAX   | Number of work storages available                                             |
| ST     | Storage array for element stiffness matrix                                    |
| AREA   | Element design parameter array                                                |
| KASEM  | Symmetric/anti-symmetric indicator                                            |

5. Output Arguments:

|      |                                        |
|------|----------------------------------------|
| N5   | Output element array read from tape I4 |
| N6   | Output element array read from tape I4 |
| BIGS | Output element array read from tape I4 |

6. Error Returns: None

7. Calling Sequence:

CALL BASS (STA, NELEM, NMDB, LISTEL, NZEL, IZR, IRA, IMAX,  
ST, I4, I8, I3, I7, AREA, KASEM, N5, N6, BIGS).

8. Input Tapes:

Tape I4 - Element matrices and element controls

9. Output Tapes:

Tape I3 - Assembled matrix in banded symmetric form.  
Each row equals a record.

10. Scratch Tapes:

I7 - Temporary storage for element matrices  
I8 - First temporary storage for element matrices  
for later computation pass

11. Storage Required:

(3456 Bytes) 864 words

12. Subroutine User: ATWO1

13. Subroutine Required: None

1. Subroutine Name:     BCB
2. Purpose: To evaluate the triple product: the transpose of a matrix A, a symmetric matrix S and the A matrix
3. Equations and Procedures:  

$$AN_{MM} = \sum_N \sum_N^T A_{MN} * S_{NN} * A_{NM}$$
4. Input Arguments:
 

|       |                                                      |
|-------|------------------------------------------------------|
| A     | The elements of the A matrix                         |
| SYM   | The elements of the S matrix (symmetric-bottom half) |
| ND,MD | Dimension of A matrix                                |
| N, M  | Order of A matrix                                    |
| N1    | Number of rows to be deleted in multiplication = 0   |
| SCAL  | Scalar quantity                                      |
| IASSY | See remark                                           |
5. Output Arguments:
 

|     |                                                      |
|-----|------------------------------------------------------|
| AN: | Elements of the matrix AN which is the final product |
|-----|------------------------------------------------------|
6. Error Returns:     None
7. Calling Sequence:  
 CALL BCB(A,SYM,AN,ND,MD,N,M,N1,SCAL,IASSY)
8. Input Tapes:       None
9. Output Tapes:      None
10. Scratch Tapes:    None
11. Storage Required:  
 (1040 bytes) 260 words
12. Subroutine User:  
 ELEM7, ELEM4, ELEM5
13. Subroutine Required: None
14. Remarks:  
 IASSY controls the summation procedure.  
 If = 1, AN will be the sum of the calculated AN and all previous elements of AN.  
 =0, AN will be the triple product.

1. Subroutine Name: BEQSX

2. Purpose:

To perform simultaneous equation solution for banded symmetric matrix input using Cholesky procedure.

3. Equations and Procedures:

1. The program is designed so that a "core-filled" piece is considered at one time. The procedure to handle this is set up.
2. All loads are stored in pcol from the input argument list.
3. A call to ESCONT is made. This is the routine which actually does the computation.
4. Displacements are stored in the DISPL array output from ESCONT.

4. Input Arguments:

|        |                                                                               |
|--------|-------------------------------------------------------------------------------|
| AK     | Storage array for input matrix                                                |
| NZEL   | Cumulative total of non-zero elements in rows 1 through i-1 of reduced matrix |
| IZR    | Number of zero elements in row of reduced matrix                              |
| XK     | Working storage array                                                         |
| PCOL   | Load vector                                                                   |
| NMDB   | Order of system                                                               |
| NTOTAL | No. of work storages available                                                |
| NL     | No. of load conditions                                                        |

5. Output Arguments:

DISPL - Displacements

6. Error Returns: None

7. Calling Sequence:

CALL BEQSX (AK,NZEL,IZR,XK,DISPL,PCOL,I7,NMDB, NTOTAL,NL)

8. Input Tapes:

I7 - Input triangularized banded matrix array

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(1864 Bytes) 466 words

12. Subroutine User:    ATW01

13. Subroutine Required: ESCONT

1. Subroutine NAME: BMAT
2. Purpose Generates A matrix for triangular plate. Also generates AREA of triangle.

3. Equation and Procedures

$$\text{BINV} = \frac{\begin{vmatrix} x_2y_3 - x_3y_2 & 0 & 0 \\ y_2 - y_3 & y_3 & -y_2 \\ x_3 - x_2 & -x_3 & x_2 \end{vmatrix}}{x_2y_3 - x_3y_2}$$

$$\text{Area} = \frac{1}{2} (x_1y_2 + x_2y_3 + x_3y_1 - y_3x_1 - x_3y_2 - x_2y_1)$$

4. Input Arguments
 

|        |                     |   |               |
|--------|---------------------|---|---------------|
| $x(i)$ | x coordinate values | } | $i = 1, 2, 3$ |
| $y(i)$ | y coordinate values |   |               |
5. Output Arguments
 

|      |                      |
|------|----------------------|
| BINV | output matrix        |
| AREA | output value of area |
6. Error Returns None
7. Calling Sequence CALL BMAT (BINV, X, Y, AREA)
8. Subroutine User ORTHO3
9. Subroutine Required None

1. Subroutine Name: BUCKTB

2. Purpose:

This subroutine will determine the minimum plate thickness for the stability of a flat rectangular simply supported plate subjected to biaxial stresses and shear.

3. Equations and Procedures:

The Shear Buckling Coefficient,  $K_s$ , is determined for symmetric and antisymmetric buckling modes wherein the eigenvalue subroutine IGEN2 is employed. A one dimensional Newton Raphson iterative procedure is used to converge the  $K_s$  calculated and the  $K_s$  determined from the element geometry and state of Stress. The solution is based on the Raleigh-Ritz method and the general form assumed for the deflected surface is

$$W = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{b}$$

$K_s$  is calculated from the homogeneous linear set of equations represented as

$$\sum_p \sum_q \frac{mnpq}{(m^2-p^2)(n^2-q^2)} a_{pq} = \frac{-\pi^2}{32K_s\beta^3} \left[ (m^2+n^2\beta^2)^2 - K_x m^2\beta^2 - K_y n^2\beta^4 \right] a_m$$

where  $\beta = a/b$ ;  $m=1, 2, 3 \dots$ ;  $n = 1, 2, 3 \dots$ ; and  $(m \neq p, n \neq q)$  are odd numbers.

4. Input Arguments:

|        |                                     |
|--------|-------------------------------------|
| SIGX   | Stress in the x direction           |
| SIGY   | Stress in the y direction           |
| TAU    | Shear stress in x-y plane           |
| T0     | Given thickness                     |
| AL, BL | Lengths of sides of rectangle AL BL |
| DC     | Input material constant             |
| IELE   | Element number                      |

5. Output Arguments:

TB - Output material thickness

6. Calling Sequence:

CALL BUCKTB(SIGX,SIGY,TAU,TO,AL,BL,DC,IELE,IOP,TB)

7. Input Tapes: None

8. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(9880 Bytes) 2470 words

12. Subroutine User: SCALE

13. Subroutine Required: IGEN2

1. Subroutine NAME           CMAT3
2. Purpose                   Generates  $C_3$  matrix for triangular plate
3. Equations and  
    Procedures                $C_3 = T * E_g * T^T$   
  
 $T = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$
4. Input Arguments          EG       3 x 3 material elasticity matrix
5. Output Arguments          $C_3$        Matrix defined by equation above
6. Error Return:           None
7. Calling Sequence         CALL CMAT3 ( $C_{3_1}$  EG)
8. Subroutine User          ORTHO3

1. Subroutine Name: CUBIC
2. Purpose:  
To determine principle stresses for the tube (beam) element.
3. Equations and Procedures:  
Where X is the stress given  
$$x^3 + Ax^2 + Bx + C = 0$$
  
Solve the cubic equation and return the three roots.
4. Input Arguments:  
A, B, C - Coefficients of cubic equation  
XX - Proportionality factor
5. Output Arguments:  
A,B,C - Three unequal real roots
6. Error Returns: None
7. Calling Sequence: CALL CUBIC (A,B,C,XX)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required:  
(1748 Bytes) 437 words
12. Subroutine User: PS3D
13. Subroutine Required: None
14. Remarks: None

- |                            |                                                                   |
|----------------------------|-------------------------------------------------------------------|
| 1. Subroutine Name         | EGMAT                                                             |
| 2. Purpose                 | Generate Eg matrix for triangular plate                           |
| 3. Equation and Procedures | $Eg = TET^T$                                                      |
| 4. Input Argument          | $E = 3 \times 3$ matrix<br>$T = 3 \times 3$ transformation matrix |
| 5. Out Arguments           | $Eg =$ matrix defined by equations above                          |
| 6. Error Returns           | None                                                              |
| 7. Calling Sequence        | Call EGMAT (EG, E, T)                                             |
| 8. Subroutine User         | ORTH03                                                            |

1. Subroutine Name            EMAT
2. Purpose                    To generate elasticity matrix for either orthotropic or isotropic properties
3. Equations and Procedures    Orthotropic             $E = \begin{vmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{vmatrix}$   
                                   (IMAT = 2)
- Isotropic                 $E = \begin{vmatrix} E_x & \mu_{xy} & 0 \\ \mu_{xy} E_y & E_y & 0 \\ 0 & 0 & G_{xy} \end{vmatrix}$   
                                   (IMAT = 1)
4. Input Arguments             $E_x, E_y, \mu_{xy}, G_{xy}$  - material properties  
  
                                   EM - contains  $G_{ij}$  values  
                                   IMAT - Orthotropy code = 2 orthotropic  
                                               Orthotropy code = 1 isotropic
5. Output Arguments          E        - output 3 x 3 matrix defined by equations above
6. Error Returns               None
7. Calling Sequence           Call EMAT ( $E_x, E_y, \mu_{xy}, G_{xy}, E, EM, IMAT$ )
8. Subroutine User

1. Subroutine Name: ELEM1

2. Purpose:

To compute the elemental stress and stiffness matrices for an axial element.

3. Input Arguments:

|         |                         |
|---------|-------------------------|
| X, Y, Z | Node point coordinates  |
| E       | Modulus of elasticity   |
| AMU     | Poisson's ratio         |
| RHO     | Density                 |
| N5, N6  | Element nodes           |
| NEL     | Element number          |
| N1      | Degrees of freedom/node |
| N2      | Total number of nodes   |

4. Output Arguments:

|         |                                                               |
|---------|---------------------------------------------------------------|
| M       | Unreduced direction numbers for degrees of freedom of element |
| M(25)   | Order of stiffness matrix                                     |
| M(26)=1 | Number of stress components (tape NSS3)                       |
| ST(1)   | Start of stiffness matrix                                     |
| ST(301) | Start of stress matrix                                        |
| AK(1)   | (on tape NSS3) weight of element with unit design variable    |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM1 (X, Y, Z, E, AMU, RHO, N7, N5, N6, N8, N9, N10, N11, N12, R, M, NEL, N1, N2)

7. Input Tapes: None

8. Output Tapes: NSS3

9. Scratch Tapes: None

10. Storage Required:

(1789 Bytes) 445 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

The stress matrix provides one stress component,  $\sigma_x$ .

1. Subroutine Name: ELEM2

2. Purpose:

To compute the element stress and stiffness matrices for a shear web element.

3. Input Arguments:

|             |                         |
|-------------|-------------------------|
| X,Y,Z       | Node point coordinates  |
| E           | Modulus of Elasticity   |
| AMU         | Poisson's Ratio         |
| RHO         | Element Density         |
| N5,N6,N7,N8 | Element nodes           |
| NEL         | Element number          |
| N1          | Degrees of freedom/node |
| N2          | Total number of nodes   |

4. Output Arguments:

|          |                                                            |
|----------|------------------------------------------------------------|
| MM       | Unreduced direction numbers for degrees of freedom element |
| MM(25)   | Order of stiffness matrix                                  |
| MM(26)=1 | Number of stress components (on tape NSS3)                 |
| ST(1)    | Start of stiffness matrix                                  |
| ST(301)  | Start of stress matrix                                     |
| ARG1     | (On tape NSS3) weight of element with unit design variable |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM2 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,N12,  
R,MM,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required:

(7246 Bytes) 1811 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

- A. This element can be defined by 2 or 4 nodes.
- B. The stress matrix provides one stress component,  $\gamma_{xy}$ .

1. Subroutine Name: ELEM3

2. Purpose:

To compute the element stress and stiffness orthotropic matrices for a triangular plate element, with properties and material angle variation.

3. Input Arguments:

|            |                         |
|------------|-------------------------|
| X, Y, Z    | Node point coordinates  |
| E          | Modulus of elasticity   |
| AMU        | Poisson's ratio         |
| RHO        | Density                 |
| N5, N6, N7 | Element nodes           |
| NEL        | Element number          |
| N1         | Degrees of freedom/node |
| N2         | Total number of nodes   |
| EM         | Material properties     |
| IMAT       | Orthotropic code        |
| ANGLE      | Material angle          |

4. Output Arguments:

|         |                                                            |
|---------|------------------------------------------------------------|
| M       | Reduced direction number for degrees of freedom of element |
| M(25)   | Order of stiffness matrix                                  |
| M(26)=3 | Number of stress components (on tape NSS3)                 |
| ST(1)   | Start of stiffness matrix                                  |
| ST(301) | Start of stress matrix                                     |
| AREA    | (On tape NSS3) weight of element with unit design variable |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM3 (X, Y, X, E, AMU, RHO, N7, N5, N6, N8, N9, N10, N11, N12, R, M, NEL, N1, N2, GM, IMAT, ANGLE)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

- 10. Storage Required: (4876 Bytes) 1219 words
- 11. Subroutine User: AONE
- 12. Subroutine Required: ORTH03
- 13. Remarks:

Three components of stress at the midpoint are provided.  
These stresses are  $\sigma_x$ ,  $\sigma_y$ ,  $\tau_{xy}$ .

1. Subroutine Name: ELEM4

2. Purpose:

This routine computes the element stress and stiffness matrices for a quadrilateral plate element.

3. Input Arguments:

|                       |                         |
|-----------------------|-------------------------|
| X,Y,Z                 | Node point coordinates  |
| E                     | Modulus of elasticity   |
| AMU                   | Poisson's ratio         |
| RHO                   | Density                 |
| N5, N6, )<br>N7, N8 ) | Element nodes           |
| NEL                   | Element number          |
| N1                    | Degrees of Freedom/node |
| N2                    | Total number of nodes   |

4. Output Arguments:

|           |                                                               |
|-----------|---------------------------------------------------------------|
| M         | Unreduced direction numbers for degrees of freedom of element |
| M(25)     | Order of stiffness matrix                                     |
| M(26)=7   | Number of stress components (on tape NSS3)                    |
| ST(1)     | Start of stiffness matrix                                     |
| ST(301)   | Start of stress matrix                                        |
| ARG1      | (On tape NSS3) weight of element with unit design variable    |
| $X_2/X_3$ | Ratio (on tape NSS3) used in SCALE routine                    |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM4 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,  
N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (6544 Bytes) 1636 words

11. Subroutine User: AONE

12. Subroutine Required: MINV  
BCB

13. Remarks: Seven components of stress are defined. These stresses are:

$\sigma_{x1}, \sigma_y, \sigma_{x3}, \sigma_{y3}, \sigma_{xm}, \sigma_{ym}, \tau_{xy_m}$  (M-indicates midpoint)

1. Subroutine Name: ELEM5

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a beam (tube) element.

3. Input Arguments:

|          |                         |
|----------|-------------------------|
| X,Y,Z    | Node point coordinates  |
| E        | Modulus of elasticity   |
| AMU      | Poisson's ratio         |
| RHO      | Density                 |
| N5,N6,N7 | Element nodes           |
| NEL      | Element number          |
| N1       | Degrees of freedom/node |
| N2       | Total number of nodes   |

4. Output Arguments:

|         |                                                               |
|---------|---------------------------------------------------------------|
| M       | Unreduced direction numbers for degrees of freedom of element |
| M(25)   | Order of stiffness matrix                                     |
| M(26)=6 | No. of stress components (on tape NSS3)                       |
| ST(1)   | Start of stiffness matrix                                     |
| ST(301) | Start of stress matrix                                        |
| ARG1    | (On tape NSS3) weight of element with unit design variable    |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM5 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (4466 Bytes) 1116 words

11. Subroutine User: AONE  $\sqrt{6}$

12. Subroutine Required: BCB

13. Remarks:

Six stresses are available from the stress matrix.  
These stresses are  
 $\sigma_x, \tau_{yz}, \sigma_{my_1}, \sigma_{my_2}, \sigma_{mz_1}, \sigma_{mz_2}$ .

1. Subroutine Name: ELEM6

2. Purpose:

This subroutine computes the element stress and stiffness matrices for an axial element with a mid-point node.

3. Input Arguments:

|          |                                             |
|----------|---------------------------------------------|
| X,Y,Z    | Node point coordinates                      |
| E        | Modulus of elasticity                       |
| AMU      | Poisson's ratio                             |
| RHO      | Density                                     |
| N5,N6,N7 | Element nodes N7 (NEL) is the midpoint node |
| NEL      | Element number                              |
| N1       | Degrees of freedom/node                     |
| N2       | Total number of nodes                       |

4. Output Arguments:

|         |                                                               |
|---------|---------------------------------------------------------------|
| M       | Unreduced direction numbers for degrees of freedom of element |
| M(25)   | Order of stiffness matrix                                     |
| M(26)=2 | No. of stress components (on tape NSS3)                       |
| ST(1)   | Start of stiffness matrix                                     |
| ST(301) | Start of stress matrix                                        |
| WT      | (On tape NSS3) weight of element with unit design variable    |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM6 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,  
N12,R,M,NEL, N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (267<sup>4</sup> Bytes) 669 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

A. Two stress components are provided by the stress matrix. These stresses are:  $\sigma_{x_1}$  and  $\sigma_{x_2}$ .

B. The coordinates for the mid-point node are computed in the routine.

1. Subroutine Name: ELEM7

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a triangular plate element with midpoint nodes.

3. Input Arguments:

|                       |                         |
|-----------------------|-------------------------|
| X,Y,Z                 | Node point coordinates  |
| E                     | Modulus of elasticity   |
| AMU                   | Poisson's ratio         |
| RHO                   | Density                 |
| N5,N6,N7<br>N8,N9,N10 | Element nodes           |
| NEL                   | Element no.             |
| N1                    | Degrees of freedom/node |
| N2                    | Total no. of nodes      |

4. Output Arguments:

|          |                                                               |
|----------|---------------------------------------------------------------|
| M        | Unreduced direction numbers for degrees of freedom of element |
| M(25)    | Order of stiffness matrix                                     |
| M(26)=12 | No. of stress components (on Tape NSS3)                       |
| ST(1)    | Start of stiffness matrix                                     |
| ST(301)  | Start of stress matrix                                        |
| WT       | (On tape NSS3) weight of element with unit design variable    |

5. Error Returns: None

6. Calling Sequence:

CALL ELEM7 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,  
N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (8022 Bytes) 2006 words

11. Subroutine User: AONE

12. Subroutine Required: MINV  
BCB

13. Remarks:

- A. Twelve components of stress are provided by the stress matrix. These stresses are:

$$\sigma_{x_1}, \sigma_{y_1}, \tau_{xy_1}, \sigma_{x_2}, \sigma_{y_2}, \tau_{xy_2}, \sigma_{x_3}, \sigma_{y_3}, \tau_{xy_3},$$

$$\sigma_{x_m}, \sigma_{y_m}, \tau_{xy_m}$$

where  $m$  - denotes the centroid of the element.

- B. Coordinates of the midpoint nodes are computed in the routine.

1. Subroutine Name: ELEM8

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a quadrilateral plate element with midpoint nodes.

3. Input Arguments:

|                                  |                         |
|----------------------------------|-------------------------|
| XC,YC,ZC                         | Node point coordinates  |
| E                                | Modulus of elasticity   |
| AMU                              | Poisson's ratio         |
| RHO                              | Density                 |
| N5,N6,N7<br>N8,N9,N10<br>N11,N12 | } Element nodes         |
| NEL                              |                         |
| N1                               |                         |
| N2                               | Element no.             |
|                                  | Degrees of freedom/node |
|                                  | Total no. of nodes      |

4. Output Arguments:

|          |                                                               |
|----------|---------------------------------------------------------------|
| M        | Unreduced direction numbers for degrees of                    |
| M(25)    | Order of stiffness matrix                                     |
| M(26)=15 | No. of stress components (on tape NSS3)                       |
| ST(1)    | Start of stiffness matrix                                     |
| ST(301)  | Start of stress matrix                                        |
| WT       | (On tape NSS3) weight of element with<br>unit design variable |

5. Error Returns:

If the ranking routine MFGR outputs a rank not equal to 16, there will be a print out (B matrix error). This will usually be due to a program input error.

6. Calling Sequence:

CALL ELEM8 (XC,YC,ZC,E,AMU,RHO,N7,N5,N6,N8,N9,N10,  
N11,N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (31162 Bytes) 7791 words

11. Subroutine User: AONE

12. Subroutine Required:

MFGR  
MINV  
GMFRD  
GTPRD  
ECB

13. Remarks:

- A. Fifteen stress components are provided by the stress matrix. These are:

$\sigma_{x_1}, \sigma_{y_1}, \tau_{xy_1}, \sigma_{x_2}, \sigma_{y_2}, \tau_{xy_2}, \sigma_{x_3}, \sigma_{y_3}, \tau_{xy_3}, \sigma_{x_4}, \sigma_{y_4},$

$\tau_{xy_4}, \sigma_{x_m}, \sigma_{y_m}, \tau_{xy_m}.$

where m - denotes the element centroid.

- B. Coordinates of the midpoints are computed by the subroutine.

1. Subroutine Name:    ESCONT
2. Purpose:  
Solves matrix equation  $A * A \text{ transpose} * X = F$  for  $X$ .
3. Equations and Procedures:  
The matrix equation  $A * A \text{ transpose} X = F$  is solved for  $X$  by solving the matrix equations  $A * X K = F$   
 $A \text{ transpose} * X = X K$   
where  $A$  is a banded lower triangular matrix and  $X$  and  $F$  are column vectors.  
  
Procedure:  
  - (1) Rows ISTRT to ICALC of  $A$  are read from tape I7.
  - (2) A call to KCALC routine computes  $XK$ .
  - (3) A call to XCALK routine computes  $X$ .
  - (4) Steps 1, 2 and 3 are repeated for each pass.
4. Input Arguments:  

|       |                                         |
|-------|-----------------------------------------|
| N     | Order of system                         |
| NPASS | Number of computation passes necessary  |
| NROW  | Array for control of computation passes |
| IZR   | Banding information array               |
| NZEL  | Banding information array               |
| A     | Storage array for input matrix          |
| F     | Storage array for input column          |
| NTAPE | Input tape logical number               |
| XK    | Working storage array                   |
| NL    | No. of load conditions                  |
5. Output Arguments:  $X$ =Output answer column array
6. Error Returns:       None
7. Calling Sequence:  
CALL ESCONT (N, NPASS, NROW, IZR, NZEL, A, F, X, XK, NTAPE, NL)
8. Input Tapes:  
Tape I7 contains input triangular matrix  $A$ .  $A$  is in banded form. Each row is a separate record.
9. Output Tapes:       None
10. Scratch Tapes:     None
11. Storage Required: (2000 Bytes) 500 words

12. Subroutine User: BEQ SX

13. Subroutines Required:

KCALC

XCALK

- |                             |                                                                                                                                                                                                                               |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine Name          | FOMO                                                                                                                                                                                                                          |
| 2. Purpose                  | Process force cards                                                                                                                                                                                                           |
| 3. Equations and Procedures | The cards are read from file L5 and counted by a counter KFORCE. The input values are (Force 1(i), i = 1, 2), F, and (F <sub>2</sub> (i), i = 1, 2, 3); (Force 2(i) = F - F <sub>n</sub> (i), i = 1, 2, 3).                   |
| 4. Input Arguments          | <p>OUT = storage for reading data</p> <p>FORCE 1 = set id number, grid point number</p> <p>FN (i), i = 1, 2, 3 = components of force</p> <p>L5 = input file number</p> <p>L6 = output file number</p> <p>F = scale factor</p> |
| 5. Output Arguments         | Force 2(i) for each component                                                                                                                                                                                                 |
| 6. Error Returns            | None                                                                                                                                                                                                                          |
| 7. Calling Sequence         | Call FOMO (FORCE 1, FORCE 2, L5, NFO, K FORCE, OUT, L6)                                                                                                                                                                       |
| 8. Subroutine User          | ZZ                                                                                                                                                                                                                            |

1. Subroutine Name: GMPRD
2. Purpose:  
Multiply two general matrices to form a resultant general matrix
3. Equations and Procedures:  
The M by L matrix 'B' is premultiplied by the N by M matrix 'A' and the result is stored in the N by L matrix 'R'.
4. Input Arguments:
 

|   |                                      |
|---|--------------------------------------|
| A | Name of first input matrix           |
| B | Name of second input matrix          |
| N | Number of rows in A                  |
| M | Number of columns in A and rows in B |
| L | Number of columns in B               |
5. Output Arguments:
 

|   |               |
|---|---------------|
| R | Output matrix |
|---|---------------|
6. Error Returns: None
7. Calling Sequence:  
CALL GMPRD (A,B,R,N,M,L)
8. Input tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (656 Bytes) 164 words
12. Subroutine User: ELEM8
13. Subroutine Required: None
14. Remarks:
  1. All matrices must be stored as general matrices.
  2. Matrix R cannot be in same location as matrix A.
  3. Matrix R cannot be in same location as matrix B.
  4. Number of columns of matrix A must be equal to number of rows in matrix B.

1. Subroutine Name: GTPRD

2. Purpose:

Premultiply a general matrix by the transpose of another general matrix.

3. Equations and Procedures:

Matrix transpose of A is not actually calculated. Instead elements of matrix A are taken columnwise rather than row-wise for post-multiplication by matrix B.

4. Input Arguments:

|   |                                      |
|---|--------------------------------------|
| A | Name of first input matrix           |
| B | Name of second input matrix          |
| N | Number of rows in A and B            |
| M | Number of columns in A and rows in R |
| L | Number of columns in B and R         |

5. Output Arguments:

|   |                       |
|---|-----------------------|
| R | Name of output matrix |
|---|-----------------------|

6. Error Returns: None

7. Calling Sequence:

CALL GTPRD (A,B,R,N,M,L)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (656 Bytes) 164 words

12. Subroutine User: ELEM8

13. Subroutine Required: None

14. Remarks:

1. Matrix R cannot be in the same location as matrix A.
2. Matrix R cannot be in the same location as matrix B.
3. All matrices must be stored as general matrices.

1. Subroutine Name: IGEN2
2. Purpose:  
Compute eigenvalues used in buckling analysis.
3. Equations and Procedures:  
Eberleins method is used. This consists of a sequence of similarity transporations which are intended to reduce the Euclidean norm of the matrix under study (A), so that it can practically speaking, be made arbitrarily normal.
4. Input Arguments:  
A Matrix whose eigenvalues are desired  
N Order of A-matrix  
YR Used to control convergence (min. 1E-7 smallest element of A)  
ISW=0 Do not form eigenvectors (control)  
ID=6 Dimension of 'A' in calling routine
5. Output Arguments:  
A Overlayed with matrix of eigenvalues along diagonal  
IT Iteration counter (maximum of 50)
6. Error Returns:  
IIT If off diagonal elements of 'diagonalized'
7. Calling Sequence:  
CALL IGEN2 (N, YR, ISW, IT, IIT, ID, A, AA, T, TI, RES)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (5700 Bytes) 1425 words
12. Subroutine User: BUCKTB
13. Subroutine Required: None
14. Remarks: None

- |                                |                                                                       |
|--------------------------------|-----------------------------------------------------------------------|
| 1. Subroutine Name             | INSPC                                                                 |
| 2. Purpose                     | Stores data obtained from input card<br>into working storage          |
| 3. Equations and<br>Procedures | SPCINF = Out storage, SPCTYP                                          |
| 4. Input Argument              | SPCTYP = Special code for type of card<br>OUT = Storage for card data |
| 5. Output Argument             | SPCINF<br>NSCARD = Counter for no. special input<br>cards             |
| 6. Error Returns               |                                                                       |
| 7. Calling Sequence            | Call INSPC (NSCARD, OUT, NSPCS, SPCTYP,<br>SPCINF)                    |
| 8. Subroutine User             |                                                                       |

- |                             |                                                                                                                                                                                                                                                     |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine Name          | INSRT1                                                                                                                                                                                                                                              |
| 2. Purpose                  | Stores element properties and material numbers into working storage                                                                                                                                                                                 |
| 3. Equations and Procedures | $\left. \begin{array}{l} F(I) = FA \\ G(I) = GA \\ MATNO(I) = NM \end{array} \right\} \begin{array}{l} \text{If } NA = NAST(I) \text{ and} \\ \text{If } NP = NPROP(I) \end{array}$                                                                 |
| 4. Input Argument           | <p>FA = Element property</p> <p>GA = Element property</p> <p>NM = Material property SID</p> <p>NUM = Number elements</p> <p>NAST = Element id number</p> <p>NPROP = Property SID</p> <p>NA = Work value of NAST</p> <p>NP = Work value of NPROP</p> |
| 5. Output Argument          |                                                                                                                                                                                                                                                     |
| 6. Error Return             | None                                                                                                                                                                                                                                                |
| 7. Calling Sequence         | Call INSRTI (NAST, NA, NPROP, NP MATNO, NM, F, FA, G, GA, NUM)                                                                                                                                                                                      |
| 8. Subroutine User          |                                                                                                                                                                                                                                                     |

1. Subroutine Name: KCALC

2. Purpose:

Solve for XK where  $A \cdot XK = F$  and A is a banded lower triangular matrix.

3. Equations and Procedures:

Determine elements ISTRT to ICALC of each load vector XK in the matrix equation  $A \cdot XK = F$ .

$$XK(1) = \frac{F_1}{A_{11}} \quad XK(I) = F(I) - \sum_{L=1}^{I-1} A_{LI} XK(L) \quad I > 1$$

This constitutes the first step in equation solution by Cholesky or "square root" method.  
Repeat above procedure for all load conditions.

4. Input Arguments:

|       |                                                                                   |
|-------|-----------------------------------------------------------------------------------|
| ISTRT | Beginning row number of computation pass                                          |
| ICALC | End row number of computation pass                                                |
| IZR   | Number zero elements in row of reduced matrix                                     |
| NZEL  | Cumulative total of nonzero elements in rows<br>1 through i - 1 of reduced matrix |
| A     | Storage array for input matrix                                                    |
| F     | Column vector array                                                               |
| N     | Order of System                                                                   |
| NL    | Number of load conditions                                                         |

5. Output Arguments: XK = output vector array

6. Error Returns: None

7. Calling Sequence:

CALL KCALC (ISTRT, ICALC, IZR, NZEL, A, F, XK, N, NL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (810 Bytes) 203 words

12. Subroutine User: ESCONT

13. Subroutines Required: None

- |                             |                                                                                                                                                                        |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine Name          | KMAT                                                                                                                                                                   |
| 2. Purpose                  | Generate stiffness matrix for membrane triangle                                                                                                                        |
| 3. Equations and Procedures | $SYMM = BINV^* C BINV * H * AREA$                                                                                                                                      |
| 4. Input Argument           | <p>S = Intermediate work storage</p> <p>BIUV = BINV matrix (transformation)</p> <p>C = Elaso C matrix</p> <p>AREA = Area of triangle</p> <p>H = Thickness of plate</p> |
| 5. Output Arguments         | KSymm = output symmetric stiffness matrix                                                                                                                              |
| 6. Error Returns            | None                                                                                                                                                                   |
| 7. Calling Sequence         | CALL KMAT (S, BINV, C, KSymm, AREA, H)                                                                                                                                 |
| 8. Subroutine User          | ORTHO3                                                                                                                                                                 |

1. Subroutine Name: MFGR

2. Purpose:

Determine rank and linearly independent rows and columns of a given matrix

3. Equations and Procedures:

The standard Gaussian elimination technique with complete pivoting is used. This implies that the rows and columns of the given M by N matrix A are interchanged at each elimination step if necessary. The interchange information is recorded in two integer permutation vectors IROW and ICOL.

The  $I^{\text{th}}$   $\left\{ \begin{array}{l} \text{Row} \\ \text{Column} \end{array} \right\}$  of the interchanged matrix corresponds

to the  $\left\{ \begin{array}{ll} \text{IROW}(I)^{\text{th}} & \text{Row} \\ \text{ICOL}(I)^{\text{th}} & \text{Column} \end{array} \right\}$  in the original matrix A

Initially  $\text{IROW}(J) = J$  and  $\text{ICOL}(J) = J$

4. Input Arguments:

|     |                                                |
|-----|------------------------------------------------|
| A   | Given matrix with M rows and N columns         |
| M   | Number of rows of matrix A                     |
| N   | Number of cols of matrix A                     |
| EPS | Test value for zero affected by roundoff noise |

5. Output Arguments:

|       |                                                                                                      |
|-------|------------------------------------------------------------------------------------------------------|
| IRANK | Resultant rank of given matrix                                                                       |
| IROW  | Integer vector of dimension M containing the subscripts of basic rows in IROW(1)...IROW(RANK)        |
| ICOL  | Integer vector of dimension N containing the subscripts of basic columns in ICOL(1) UP TO ICOL(RANK) |

6. Error Returns: None

7. Calling Sequence:

CALL MFGR (A,M,N,EPS,IRANK,IROW,ICOL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

- 11. Storage Required:  
(2092 Bytes) 523 words
- 12. Subroutine User: ELEM8
- 13. Subroutine Required: None
- 14. Remarks: None

1. Subroutine Name: MINV
2. Purpose: Invert a matrix
3. Equations and Procedures:  
Uses the standard Gauss-Jordan method in which the inverted matrix is stored back on itself.
4. Input Arguments:  
A Matrix to be inverted  
N Order of matrix  
D Determinant value  
L Work vector of length N  
M Work vector of length N
5. Output Arguments:  
A Contains the inverted matrix
6. Error Returns:  
If  $D=0$ , matrix is singular
7. Calling Sequence:  
CALL MINV (A,N,D,L,M)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (2068 Bytes) 517 words
12. Subroutine User:  
ELEM4, ELEM7, ELEM8
13. Subroutine Required: None
14. Remarks: None

1. Subroutine Name: MODIFY

2. Purpose:

Evaluate the recursion relationships for the iterative determination of an elements design variable when a displacement constraint is violated.

3. Equations and Procedures:

The general recursion relationship is

$$A_j^{n+1} = \frac{A_j^n}{(\Delta^* - \Delta_0)} \left( \frac{\sum_k \frac{|\delta^P|^T [K_{EL}] |\delta^Q|}{C_{kj}}}{\sum_k C_{kj} L_{kj} \rho_{kj}} \right)^{\frac{1}{2}} \times \sum_i A_i \left( \frac{\sum_l C_{li} L_{li} \rho_{li} \sum_1 \frac{|\delta^P|^T [K_{EL}] |\delta^Q|}{C_{li}}}{C_{li}} \right)^{\frac{1}{2}}$$

which allows for all members of a linked group to participate in the redesign. Members are considered passive in the above equation if the size of that member is defined by other than a displacement constraint. The largest area generated in the above equation is taken from the combined set resulting from all loads and displacement constraints. These areas are then compared with those based upon stresses or minimum sizes and the larger values selected for each member.

4. Input Arguments:

SIGL, SIGU Lower and upper stress bounds for each element  
ALL Minimum design variable  
DISPU, DISPL Upper and lower limits for displacement constraints  
DELTA Displacement matrix  
BIGS Residual strength ratio output by scale routine  
LIST Array containing number of stress components for each element  
PAR Element information array originally on NSS3

5. Output Arguments:

AREA New design variable for each element

6. Error Returns: None

7. Calling Sequence:

CALL MODIFY (SIGL,SIGU,ALL,N7,DISPU,DISPL,NBDF,NE,  
DELTA,BIGS,AREA,STRESS,LLST,PAR,NBDF2,NE2,AQEA,N5,  
N6,X,AREAD,NSTRES,NSS1)

8. Input Tapes:

NSS1 (Unit 1) Element stiffness matrices

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (7516 Bytes) 1879 words

12. Subroutine User: ATWO

13. Subroutine Required: None

14. Remarks: None

1. Subroutine Name: NEWS

2. Purpose:

To determine max core available vs problem size and set up dynamic storage subscripts for the initialization phase of the program.

3. Equations and Procedures:

Storage requirements for the arrays used by the AONE (utilization routine) are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then IER is set to one, a message is written describing the additional storage required and the routine returns to the main routine.

If the storage available is adequate, locations in the W array are computed for the required arrays and routine AONE is called.

4. Calling Arguments: (\* Input)

|         |                                                                                       |
|---------|---------------------------------------------------------------------------------------|
| *N1     | Control for degrees of freedom of a node set to 3 internally.                         |
| *N2     | No. of nodes in problem.                                                              |
| *ITOT   | Number of elements in problem                                                         |
| *NSG    | Number of components in integer array indicating linked groups                        |
| *NAAALL | Number of generalized constraint groups (NAA) + cumulative length of all groups       |
| *NBCU   | Total number of constrained degrees of freedom for a symmetric load condition         |
| *NSYM   | Number of symmetric load conditions                                                   |
| *NONSYM | Number of nonsymmetric load conditions                                                |
| *NASYM  | Number of anti-symmetric load conditions                                              |
| *NDL    | Number of individual constraints                                                      |
| *NAA    | Number of generalized constraints                                                     |
| *NTAPE  | Input tape for AONE routine (Unit 8)                                                  |
| *NPOT   | Print-out data set (Unit 6)                                                           |
| *NSS1)  | Unit 1                                                                                |
| *NSS2)  | Unit 2                                                                                |
| *NSS3)  | Unit 3                                                                                |
| *NSS4)  | Unit 4                                                                                |
| *IBUCL  | Buckling control                                                                      |
| *NNZL   | Number of loads input                                                                 |
| *NALD   | Total number of load conditions (NSYM+NASYM+NONSYM)                                   |
| *KLN2   | Number of nodes on symmetry plane                                                     |
| *ITERN  | Maximum number of iterations                                                          |
| *NTODS  | Number of title cards                                                                 |
| *IREST  | Print control for printing input                                                      |
| IELI    | Integer array indicating number of each type element, e.g., IELI(5)=N type 5 elements |

|         |                                                                                                                           |
|---------|---------------------------------------------------------------------------------------------------------------------------|
| NREACT  | Integer array six elements long indicating total number of constraints e.g. NREACT(1)= number of constrained U components |
| *C1INP  | Convergence control                                                                                                       |
| *C2INP  | Convergence control                                                                                                       |
| NRDF    | Number of reduced degrees of freedom for symmetric load condition                                                         |
| NRDF2   | Number of reduced degrees of freedom for antisymmetric load condition                                                     |
| NEAA    | Number of generalized constraint groups (NAA) + cumulative length of all groups                                           |
| NEA2    | Same as above                                                                                                             |
| NDLI    | Sum of individual constraints minus bounded constraints for symmetric load condition                                      |
| NDL2    | Same as above except for antisymmetric load condition                                                                     |
| NBOUN2  | Total number of constrained degrees of freedom for antisymmetric load condition                                           |
| *KNLMAX | Max. length of a generalized constraint group                                                                             |
| *IRST   | Calculation control which determines use of OPDVIR section                                                                |
| *MAXCOR | Size of 'W' array available for dynamic storage                                                                           |
| *W      | Array used for dynamic storage                                                                                            |
| IER     | Error control                                                                                                             |

5. Error Returns:

IER $\neq$ 0 not enough core available to complete initialization

6. Calling Sequence:

CALL NEWS(N1,N2,ITOT, NSG,NAAALL, NBOU,NSYM,NONSYM,NASYM  
NDL,NAA,NTAPE,NPOT,NSS1,NSS2,NSS3,NSS4,IBUKL,NNZL,NAID,  
KLN2,ITERN,NTODS,IREST,IELI,NREACT,C1INP,C2INP,NRDF,NRDF2,  
NEAA,NEA2,NDL1,NDL2,NBOUN2,KNLMAX,IRST,IBGP,MAXCOR,W,IER)

7. Input Tapes: None

8. Output Tapes: None

9. Scratch Tapes: None

10. Storage Required: (3436 Bytes) 859 words

11. Subroutine User: MAIN

12. Subroutine Required: AONE

13. Remarks: None

1. Subroutine Name: OPINPT

2. Purpose:

To complete NTAPE (Unit 8); input to the AONE routine.

3. Equations and Procedures:

Process input needed by the AONE routine in this order.

COORD  
ELEM  
OEXTERN  
LINKS  
BOUND  
OLOADS  
ICON  
GCON  
OPDVIR

Place all information on NTAPE (Unit 8).  
Print diagnostic messages if necessary.

4. Input Arguments:

|        |                                   |
|--------|-----------------------------------|
| NPIT   | Unit 5 (card reader)              |
| NPOT   | Unit 6 (printer)                  |
| NTAPE  | Unit 8 (tape)                     |
| N2     | Number of nodes                   |
| NDL    | Number of individual constraints  |
| NAA    | Number of generalized constraints |
| NNZL   | Number of input cards for loads   |
| NSS1   | Unit 1 (tape)                     |
| NREF   | Info from System section input    |
| NGRD   |                                   |
| NDOFPN |                                   |
| NALD   |                                   |
| ITOT   |                                   |
| NIBCP  |                                   |

5. Output Arguments:

|        |                                        |
|--------|----------------------------------------|
| NREACT | Array indicating number of bounded DOF |
| IER    | Error indicator                        |

6. Error Returns: IER=0

7. Calling Sequence:

CALL OPINPT(NPIT, NPOT, NTAPE, NREF, NGRD, NDOFPN, NALD, ITOT,  
NIBCP, N1, N2, NSGIN, NDL, NAA, NDLA, NREACT, NNZL, IELI, IRST,  
NAANUM, NSG, NSS1, KNLMAX, IER, GRID, IBOUND, NBOUND, INODE,  
NBDF, DISPU, DISPL, LINKB, LINKN, ILINK, DVIR, IBUCKL, NAM, IBO,  
IG1, IG2, IG3, IBGP)

- 8. Input Tapes: None
- 9. Output Tapes: NTAPE
- 10. Scratch Tapes:  
NSSL (Unit 1) used to merge ELEM and OEXTRN sections
- 11. Storage Required: (15844 Bytes) 3961 words
- 12. Subroutine User: MAIN
- 13. Subroutine Required: None
- 14. Remarks: None

1. Subroutine Name    OPTIM2
2. Purpose:  
    To control the program execution.
3. Equations and Procedures:  
    Identify all external files and rewind them.  
    Read REPORT, TITLE, SYSTEM and OPTIM sections to define  
      variables needed for dynamic storage.  
    If there are any title cards read them and put them on  
      NTAPE (Unit 8).  
    Print message if any sections are out of order.  
    Call OPINPT routine to read rest of input sections.  
    If there is any error (IER#0) call exit.  
    Call NEWS routine to perform dynamic storage allocation  
      and call routines to perform initialization.  
    If there is any error (IER#0) call exit.  
    Call SIZE routine to perform dynamic storage allocation  
      and call routines to perform problem calculation.  
    If there is any error (IER#0) call exit.
4. Input Arguments:    None
5. Output Arguments:   None
6. Error Returns:      (IER#0) call exit
7. Calling Sequence:   Call OPTIM2 (WORK, NPIT)
8. Input Tapes:        WORK = Work storage  
                         NPIT = Input file number
9. Output Tapes:        NTAPE (Unit 8)
10. Scratch Tapes:  
    NSS1 (Unit 1)  
    NSS2 (Unit 2)        These tapes are defined and rewound  
    NSS3 (Unit 3)        only.  
    NSS4 (Unit 4)
11. Storage Required:  
    (35630 Bytes) 8907 words  
    This size includes 'W' work array of 8000.  
    This array is used to dynamically locate arrays.
12. Subroutine User:    Not applicable
13. Subroutine Required: OPINPT  
                         NEWS  
                         SIZE
14. Remarks:    None

1. Subroutine Name: PS3D

2. Purpose:

Create cubic equation coefficients from stress components for beam (tube) element

3. Equations and Procedures:

$$\tau^3 - (\tau_{xx} + \tau_{yy} + \tau_{zz})\tau^2 + (\tau_{xx}\tau_{yy} + \tau_{yy}\tau_{zz} + \tau_{zz}\tau_{xx}$$

$$- \tau_{xz}^2 - \tau_{xy}^2 - \tau_{yz}^2)\tau - (\tau_{xx}\tau_{yy}\tau_{zz} - \tau_{xx}\tau_{yz}^2 - \tau_{yy}\tau_{xz}^2$$

$$- \tau_{zz}\tau_{xy}^2 + 2\tau_{xy}\tau_{yz}\tau_{xz}) = 0$$

or

$$\tau^3 - A\tau^2 + B\tau - C = 0$$

4. Input Arguments:

S1 - S6. Stress components (xx,yy,zz,xy,yz,zx)  
XX Proportioning factor

5. Output Arguments:

A }  
B } Roots returned from cubic  
C }

6. Error Returns: None

7. Calling Sequence:

CALL PS3D(S1,S2,S3,S4,S5,S6,XX,A,B,C,)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (696 Bytes) 176 words

12. Subroutine User: PS3R

13. Subroutine Required: CUBIC

14. Remarks: None

1. Subroutine Name: PS3R
2. Purpose: Normalize Stresses
3. Equations and Procedures:  
 $X = 1/\text{average stress}$   
Multiply all stresses by average stress
4. Input Arguments: B1  $\rightarrow$  B6
5. Output Arguments:  
A, B, C Principal stresses of Beam (tube) element
6. Error Returns: None
7. Calling Sequence:  
CALL PS3R (B1, B2, B3, B4, B5, B6, A, B, C)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (664 Bytes) 166 words
12. Subroutine User: SCALE
13. Subroutine Required: PS3D
14. Remarks: None

|                             |                                                                                                                                                                                                                                 |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine Name          | READI                                                                                                                                                                                                                           |
| 2. Purpose                  | Reads and modifies input data                                                                                                                                                                                                   |
| 3. Equations and Procedures | Reads the card data from file J5, right adjust the data fields, counts each data type, prints the data and finally stores the modified data on file J6                                                                          |
| 4. Input Argument           | LABEL     = array of BCD label codes<br>ILAB      = array of label integers<br>ISPECL    = array of special labels<br>NILAB     = total no. of labels<br>J6        = output file number<br>NSPECL    = total no. special labels |
| 5. Output Arguments         | NCARDS     = array of card counters<br>L7CASE    = code to indicate that file<br>is = 7                                                                                                                                         |
| 6. Error Returns            | None                                                                                                                                                                                                                            |
| 7. Calling Sequence         | CALL READI (LABEL, ILAB, ISPECL, NCARDS, NILAB, NSPECL, J6, L7CASE)                                                                                                                                                             |
| 8. Subroutine User          | SORT                                                                                                                                                                                                                            |
| 9. Subroutines Used         | ADJUST                                                                                                                                                                                                                          |

1. Subroutine Name: SCALE

2. Purpose:

To scale the stresses, displacements and design variables of the structure. For the in-core solution

3. Equations and Procedures:

- A. Determine maximum ratio BIG = actual stress/allowable for all elements and all load conditions.  
For the beam (tube) element use maximum principle stress from both ends as allowable.  
For all other elements use Von Mises reference stress

$$\sigma_{REF} = (\sigma_x^2 - \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2)^{\frac{1}{2}}$$

- B. Determine max. ratio (BIG) using individual and generalized displacement constraints

- C. Scale element design variables (use minimum if larger).  
If buckling is specified use this criteria for quadrilateral selected.

- D. Scale all actual element stresses

$$\hat{\sigma} = \hat{\sigma}_{act} / BIG$$

- E. Determine residual ratio (BIGS) for each element after scaling stresses. First use

$$BIGS(I) = \frac{\text{minimum design var.}}{\text{actual design var.}}$$

Then compare against ratio obtained as in step B).  
Use maximum for each element.

4. Input Arguments:

|       |                                                                                       |
|-------|---------------------------------------------------------------------------------------|
| LK    | No. of stresses                                                                       |
| SIGL  | Lower stress limit for each element                                                   |
| SIGU  | Upper stress limit for each element                                                   |
| ALL   | Minimum design variable for each element                                              |
| N7    | Not used                                                                              |
| DISPU | Upper displacement limits                                                             |
| DISPL | Lower displacement limits reduced deg. of free.                                       |
| NBDF  | Integer array locating RDOF of individual constraints symmetric load conditions       |
| NE    | Integer array locating RDOF of generalized constraints anti-symmetric load conditions |
| DELTA | Displacement matrix                                                                   |

|         |                                                                                                   |
|---------|---------------------------------------------------------------------------------------------------|
| BIGS    | Residual ratio for each element after scaling                                                     |
| STRESS  | Stress matrix                                                                                     |
| LIST    | Integer array giving no. of stress components for each element                                    |
| PAR     | Array containing element weight factors and the parameter $x_2/x_3$ for element 4 (quadrilateral) |
| NBDF2   | Integer array locating RDOF of individual constraints for anti-symmetric load conditions          |
| NE2     | Same as NE except for anti-symmetric load condition                                               |
| AREA    | Not used                                                                                          |
| AL }    | Lengths of sides of quadrilaterals                                                                |
| BL }    |                                                                                                   |
| IBUKL } | Constant Array - used to control buckling analysis                                                |
| IBK }   |                                                                                                   |

5. Output Arguments:

AQEA            Element design parameters

6. Error Returns:            None

7. Calling Sequence:

CALL SCALE (LK, SIGL, SIGU, ALL, N7, DISPU, DISPL, NBDF, NE, DELTA, BIGS, AREA, STRESS, LIST, PAR, NBDF2, NE2, AQEA, AL, BL, IBUKL, IBK)

8. Input Tapes:            None

9. Output Tapes:            None

10. Scratch Tapes:            None

11. Storage Required:        (9110 Bytes) 2277 words

12. Subroutine User:        ATWO

13. Subroutine Required:

PS3R  
BUCKTB

1. Subroutine Name: SCALE1

2. Purpose:

To scale the stresses, displacements and design variables of the structure for an "out-of-core-solution".

3. Procedure:

The procedure followed here is identical to the SCALE routine except the stress matrix is on data set NSS3 (one column/record).

A. Determine max. ratio (BIG)= actual stresses/allowable stress for all elements and all load conditions.  
For the beam (tube) element use matrix principle stress from both ends as allowable  
For all other elements use Von Misses Reference stress.

B. Determine max. ratio (BIG) using individual and generalized displacement constraints.

C. Scale element design variables (use specified minimum (if larger)).  
If buckling is specified use this criteria for quadrilaterals selected.

D. Scale all actual element stresses.

$$\bar{S} = S_{act}/BIG$$

E. Determine residual ratio (BIGS) for each element after scaling stresses

4. Input Arguments:

See SCALE write-up for more complete listing of Arguments.

|       |                                          |
|-------|------------------------------------------|
| LK    | No. of stresses                          |
| SIGL  | Lower stress limit for each element      |
| SIGU  | Upper stress limit for each element      |
| ALL   | Minimum design variable for each element |
| DISPU | Upper displacements limits               |
| DISPL | Lower displacement limits                |
| DELTA | Displacement matrix                      |
| NSS3  | Data set containing stress matrix        |

5. Output Arguments:

AREA Element design parameters

6. Error Returns: None

7. Calling Sequence:

CALL SCALE1 (LK,SIGL,SIGU,ALL, N7,DISPU,DISPL,NBDF,NE,  
DELTA,BIGS,AREA,STRESS,LIST,PAR,NBDF2,NE2,AQEA,AL,BL,  
IBUKL,IBK,NSS3,BIG)

8. Input Tapes:

NSS3                      Stress matrix (1 column/record)

9. Output Tapes:                      None

10. Scratch Tapes:                      None

11. Storage Required:                      (8836 Bytes) 2209 words

12. Subroutine User:                      ATW01

13. Subroutine Required:

PS3R  
BUCKTB

1. Subroutine Name: SIZE

2. Purpose:

To determine max. core available vs problem size and set up dynamic storage subscripts for the calculation phase of the program in-core solution.

3. Equations and Procedures:

Storage requirements for the arrays used by the ATWO (calculation routine) are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then a message is written describing the additional storage required and the program calls the SIZE1 routine for an attempt at an out-of-core solution.

If the storage available is adequate, locations in the 'W' array are computed for the required arrays and routine ATWO is called.

4. Input Arguments:

|           |                                                                 |
|-----------|-----------------------------------------------------------------|
| NELEM     | Total number of elements                                        |
| NRDF      | No. of reduced degrees of freedom for symmetric load conditions |
| NSYM      | No. of symmetric load conditions                                |
| NASYM     | No. of antisymmetric load conditions                            |
| NCNSYM    | No. of nonsymmetric load conditions                             |
| NPOT      | Printer data set                                                |
| NSS1-NSS5 | Data sets                                                       |
| IP1, IP2  | Print controls                                                  |
| IPRINT    |                                                                 |
| MAXCOR    | Size of 'W' array                                               |
| W-WORK    | Array for dynamic storage                                       |

5. Output Arguments:

IER=0 indicates error (problem exceeds storage reserved)

6. Error Returns:

If MAXCOR is exceeded then the ATWO routine is not called and the program writes storage required. Then a call is made to the SIZE1 routine.

7. Calling Sequence:

CALL SIZE (NELEM, NRDF, NDL1, NAA, NRDF2, NDL2, NSYM, NASYM, NCNSYM, IEL1, NSG, NEAA, NEA2, NDL, NBOU, NBOUN2, NPOT, NSS1, NSS2, NSS3, NSS4, NSS5, IP1, IP2, IRST, ITERN, IPRINT, IBUKL, MAXCOR, W, IER)

8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (2780 Bytes) 695 words
12. Subroutine User: MAIN
13. Subroutine Required:
- A TWO  
SIZEL
14. Remarks: None

1. Subroutine Name: SIZE1

2. Purpose:

To determine max. core available vs problem size and set up dynamic storage subscripts for the calculation phase of the program out-of-core solution.

3. Equations and Procedures:

Storage requirements for the arrays used by the ATW01 (out-of-core) calculation routine are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then a message is written describing the additional storage required and the program halts after a return to the MAIN routine.

If the storage available is adequate, locations in the 'W' array are computed for the required arrays and routine ATW01 is called.

4. Input Arguments:

|                         |                                                                 |
|-------------------------|-----------------------------------------------------------------|
| NELEM                   | Total number of elements                                        |
| NRDF                    | No. of reduced degrees of freedom for symmetric load conditions |
| NSYM                    | No. of symmetric load conditions                                |
| NASYM                   | No. of antisymmetric load conditions                            |
| NONSYM                  | No. of nonsymmetric load conditions                             |
| NPOT                    | Printer data set                                                |
| NSS1-NSS5               | Data sets                                                       |
| IP1, IP2, }<br>IPRINT } | Print controls                                                  |
| MAXCOR                  | Size of 'W' array                                               |
| W                       | Work array for dynamic storage                                  |

5. Output Arguments:

IER=0 indicates error (problem exceeds storage reserved)

6. Error Returns:

If MAXCOR is exceeded then the ATW0 routine is not called and the program writes storage required. A return to the 'MAIN' routine then halts the program.

7. Calling Sequence:

CALL SIZE1 (NELEM, NRDF, NDL1, NAA, NRDF2, NDL2, NSYM, NASYM, NONSYM, IEL1, NSG, NEAA, NEA2, NDL, NBOU, NBOUN2, NPOT, NSS1, NSS2, NSS3, NSS4, NSS5, IP1, IP2, IRST, ITERN, IPRINT, IBUKL, MAXCOR, W, IER)

8. Input Tapes: None

- 9. Output Tapes: None
- 10. Scratch Tapes: None
- 11. Storage Required: (2728 Bytes) 682 words
- 12. Subroutine User: SIZE
- 13. Subroutine Required: ATW01

- |                                |                                                                                               |
|--------------------------------|-----------------------------------------------------------------------------------------------|
| 1. Subroutine Name             | SMAT                                                                                          |
| 2. Purpose                     | Generate stress element matrix for<br>membrane triangular plate with ortotropic<br>properties |
| 3. Equations and<br>Procedures | $SMAK = T * C * BINV$ where T is generated in<br>SMAT, C and BINV are input                   |
| 4. Input Arguments             | C = 6 x 6 matrix<br>BINV = 6 x 6 matrix                                                       |
| 5. Output Arguments            | SMAK = 3 x 6 stress matrix                                                                    |
| 6. Error Returns               | None                                                                                          |
| 7. Calling Sequence            | CALL SMAT (C, SMAK, BINV)                                                                     |
| 8. Subroutine User             | ORTH03                                                                                        |

|                             |                                                                                                                                                                                                                                                                                                            |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | Sort                                                                                                                                                                                                                                                                                                       |
| 2. Purpose                  | Sort and count data based on LABEL information.                                                                                                                                                                                                                                                            |
| 3. Equations and Procedures | Using READI, the data is read and counted. The final counters are then modified.                                                                                                                                                                                                                           |
| 4. Input Arguments          | L4 = file number for storage of sorted input deck                                                                                                                                                                                                                                                          |
| 5. Output Arguments         | <div> <div>{</div> <div> MEL = total no. elements<br/> MGR = total no. grid points<br/> MMT = " " materials<br/> MOGCON = " " generalized constraints<br/> MICON8 = " " INdividual Constraints<br/> MILINKS = " " Links<br/> MFO = " " Forces<br/> MMO = " " Moments<br/> MLOADS = " " Loads </div> </div> |
| 6. Error Returns            | None                                                                                                                                                                                                                                                                                                       |
| 7. Calling Sequence         | Call Sort (MEL, MGR, MMT, MOGCON, MICON8, MILINKS, MFO, MMO, MLOADS, MGROUF, MSPCS, L4, L7CASE)                                                                                                                                                                                                            |
| 8. Subroutine User          | Main Program                                                                                                                                                                                                                                                                                               |
| 9. Subroutines Used         | READ I                                                                                                                                                                                                                                                                                                     |

- |                             |                                                                                                                                                                                                              |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | SPCSUB                                                                                                                                                                                                       |
| 2. Purpose                  | Process SPC (single point constraint) Cards                                                                                                                                                                  |
| 3. Equations and Procedures | Boundary information is processed as read in OUT (I) and NOUT (I). This information is interpreted and stored in LBOUND.                                                                                     |
| 4. Input Arguments          | NOUT = input data storage<br>OUT = input data storage<br>NSPC = no. SPC cards<br>KWORD = work storage<br>NUM = work storage<br>NKIND = type of boundary information available<br>NGR = total no. grid points |
| 5. Output Arguments         | LBOUND = boundary array information<br>NBCARD = counter of boundary information                                                                                                                              |
| 6. Error Returns            | None                                                                                                                                                                                                         |
| 7. Calling Sequence         | Call SPCSUB (NOUT, OUT, NSPC, KWORD, NUM, LBOUND, NBCARD, NKIND, NGR)                                                                                                                                        |
| 8. Subroutine User          | ZZ                                                                                                                                                                                                           |
| 9. Subroutines Used         | XTRAK                                                                                                                                                                                                        |

1. Subroutine Name: TCONTX
2. Purpose:  
This routine controls tape flow for the triangularization routine.
3. Equations and Procedures:
  1. Controls for setting up computation passes are computed in ICALC and ISTRT.
  2. A portion of the input matrix A is read in from Tape I3=MTAPE.
  3. This information is given to the routine TTRI which actually performs the triangularization for row numbers ISTRT to ICALC.
  4. This triangularized output portion in A is stored on tape NTAPE = I7.
  5. Computation is repeated for each portion of the matrix until all rows are completed.
4. Input Arguments:
 

|        |                                                                       |
|--------|-----------------------------------------------------------------------|
| N      | order of system to be handled                                         |
| IZR    | banding information array                                             |
| NZEL   | banding information array                                             |
| A      | storage array for input row of banded matrix which is read by routine |
| NTOTAL | total number of words which can be considered as a "full-core"        |
| ATRI   | intermediate storage array equals length of maximum order             |
| MTAPE  | input tape logical number                                             |
| NTAPE  | output tape logical number                                            |
5. Output Arguments:

|        |                          |
|--------|--------------------------|
| IERROR | error indication value   |
| WS     | accumulative determinant |
6. Error Returns:  
IERROR not = 0 if WS is returned from TTRI as less than zero
7. Calling Sequence:  
CALL TCONTX (N, IZR, NZEL, A, NTOTAL, ATRI, MTAPE, NTAPE, IERROR, WS)

8. Input Tapes:

MTAPE = I3 = input matrix A in banded row form.  
Each row equals 1 record.

9. Output Tapes:

NTAPE = I7 = triangularized matrix T in banded row  
form. Each row equals 1 record.

10. Scratch Tapes: None

11. Storage Required: (1592 Bytes) 398 words

12. Subroutine User: ATW01

13. Subroutines Required: TTRI

- |                             |                                                                                                                                                                                                                                                   |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | TMAT                                                                                                                                                                                                                                              |
| 2. Purpose                  | Generate transformation matrix for triangular plate orthotropic material angle.                                                                                                                                                                   |
| 3. Equations and Procedures | $T = \begin{bmatrix} \cos^2 \theta & \sin^2 \theta & \sin \theta \cos \theta \\ \sin^2 \theta & \cos^2 \theta & -\sin \theta \cos \theta \\ -2 \sin \theta \cos \theta & 2 \sin \theta \cos \theta & \cos^2 \theta - \sin^2 \theta \end{bmatrix}$ |
| 4. Input Arguments          | THETA = material angle                                                                                                                                                                                                                            |
| 5. Output Arguments         | T = 3 x 3 matrix                                                                                                                                                                                                                                  |
| 6. Error Returns            | None                                                                                                                                                                                                                                              |
| 7. Calling Sequence         | CALL TMAT (THETA, T)                                                                                                                                                                                                                              |
| 8. Subroutine User          | ORTHO3                                                                                                                                                                                                                                            |
| 9. Subroutines Used         | None                                                                                                                                                                                                                                              |

1. Subroutine Name: TTTRI

2. Purpose:

To triangularize rows ISTRT to ICALC of a banded matrix A.

3. Equations and Procedures:

1. This routine triangularizes rows ISTRT to ICALC of a banded matrix A where rows 1 to ISTRT-1 of the A matrix (already triangularized) are on tape NTAPE.

2. If ISTRT = 1, then NTAPE and work storage ATRI are not used since A is assumed to be in core.

3. Procedure:

Using Cholesky technique, the off diagonal terms of the portion in core are triangularized. Off diagonals are then computed. Output is stored in array A.

4. Cholesky equations:

$$(1) \quad s_{11} = (a_{11})^{\frac{1}{2}} \quad (3) \quad s_{1i} = (a_{1i} - \sum_{q=1}^{i-1} s_{1q}^2)^{\frac{1}{2}} \quad i > 1$$

$$(2) \quad s_{ij} = \frac{a_{ij}}{s_{11}} \quad (4) \quad s_{ij} = \frac{a_{ij} - \sum_{q=1}^{i-1} s_{1q} s_{qj}}{s_{11}} \quad j > i$$

4. Input Arguments:

|       |                                                 |
|-------|-------------------------------------------------|
| ISTRT | Beginning row of triangularized portion         |
| ICALC | End row of triangularized portion               |
| IZR   | Banding information array                       |
| NZEL  | Banding information array                       |
| NTAPE | logical tape number of input tape. NTAPE=I7     |
| A     | Storage array for input A and also output array |
| ATRI  | Working storage array                           |

5. Output Arguments: A=output array

6. Error Returns:

IERROR = I = row numbers such that  $WS = s_{11}$  is not greater than zero.

7. Calling Sequence:

CALL TTRI (ISTRT,ICALC,IZR,NZEL,NTAPE,A,ATRI,IERROR,WS)

8. Input Tapes:

NTAPE = tape which contains already triangularized rows of matrix.

9. Output Tapes:           None

10. Scratch Tapes:         None

11. Storage Required:     (1844 Bytes) 461 words

12. Subroutine User:     TCONTX

13. Subroutines Required: None

|                             |                                                                                                                                         |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | WRITEL                                                                                                                                  |
| 2. Purpose                  | Tests character of element connection card and writes element information into file.                                                    |
| 3. Equations and Procedures | If $C_1$ and $C_3$ are 0, $C_2$ and $C_4$ are stored.<br>If $C_2$ & $C_4$ are 0, $C_1$ & $C_3$ are stored.                              |
| 4. Input Arguments          | $L_7$ = Output file number<br>IGR = Grid point number<br>$M$ = Position of A array to be restored<br>$C_1, C_2, C_3, C_4$ = Input codes |
| 5. Output Arguments         | IGR and A array are stored on file $L_7$                                                                                                |
| 6. Error Returns            | None                                                                                                                                    |
| 7. Calling Sequence         | CALL WRITEL ( $C_1, C_2, C_3, C_4, M, IGR, L$ )                                                                                         |
| 8. Subroutine User          | ZZ                                                                                                                                      |
| 9. Subroutines Used         | None                                                                                                                                    |

1. Subroutine Name: XCALK

2. Purpose:

Solves for X where  $A \cdot X = XK$  and A is upper triangular matrix.

3. Equations and Procedures:

Determine ISTRT to ICALC of each load vector X in the matrix equation  $A \cdot X = XK$  where A is upper triangular matrix and X and XK are column vectors.

$$X(N) = \frac{XK(N)}{A_{nn}} \quad X(I) = XK(I) - \sum_{L=I+1}^N A_{IL} X_L \quad I < N$$

This constitutes the second part in calculating an equation solution by Cholesky or "square root" method. Repeat above procedure for all load conditions.

4. Input Arguments:

|       |                                                                                 |
|-------|---------------------------------------------------------------------------------|
| N     | Order of system                                                                 |
| ISTRT | Beginning row number of computation pass                                        |
| ICALC | End row number of computation pass                                              |
| IZR   | Number zero elements in row of reduced matrix.                                  |
| NZEL  | Cumulative total of nonzero elements from row 1 through 1 - i of reduced matrix |
| A     | Storage array for matrix                                                        |
| XK    | Column vector array                                                             |
| NL    | No. of load conditions                                                          |

5. Output Arguments:

|   |                     |
|---|---------------------|
| X | Output vector array |
|---|---------------------|

6. Error Returns: None

7. Calling Sequence:

CALL XCALK (N, ISTRT, ICALC, IZR, NZEL, A, XK, X, NL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (1116 Bytes) 279 words

12. Subroutine User: ESCONT

13. Subroutines Required: None

- |                             |                                                                                                                      |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | XTRAK                                                                                                                |
| 2. Purpose                  | Interpret degree of freedom information                                                                              |
| 3. Equations and Procedures | Interprets NWORD and breaks this down into 6 individual components. These components are then stored in KWORD array. |
| 4. Input Arguments          | NWORD = No. components input word<br>NP = Control word                                                               |
| 5. Output Arguments         | KWORD = Output data array<br>NUM = Total no. DOF recognized                                                          |
| 6. Error Returns            | None                                                                                                                 |
| 7. Calling Sequence         | CALL XTRAK (NWORD, KWORD, NUM, NP)                                                                                   |
| 8. Subroutine User          | SPCSUB                                                                                                               |
| 9. Subroutines Used         | None                                                                                                                 |

- |                                |                                                                                                         |
|--------------------------------|---------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME             | XTRAK 2                                                                                                 |
| 2. Purpose                     | Interpret degree of freedom<br>information for generalized constraint<br>data.                          |
| 3. Equations and<br>Procedures | Checks on information supplied in<br>NP and stores codes into LGCON array.                              |
| 4. Input Arguments             | NP = Input word to be interpreted<br>NM = 2nd input word to be interpreted.<br>NODE = Node point number |
| 5. Output Arguments            | LGCON = Generalized constraint array                                                                    |
| 6. Error Returns               | None                                                                                                    |
| 7. Calling Sequence            | CALL XTRAK 2 (LGCON, NODE, NP, NM)                                                                      |
| 8. Subroutine User             |                                                                                                         |
| 9. Subroutines Used            | XTRAK                                                                                                   |

|                             |                                                                                                                                                                                                                                                                                          |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Subroutine NAME          | ZZ                                                                                                                                                                                                                                                                                       |
| 2. Purpose                  | Generates OPTIM data which is input by NASTRAN format input cards.                                                                                                                                                                                                                       |
| 3. Equations and Procedures | Each card is read and interpreted based on content and use in the OPTIM program.                                                                                                                                                                                                         |
| 4. Input Arguments          | L5 = Input file tape number<br>L7 = Output file tape number                                                                                                                                                                                                                              |
| 5. Output Arguments         | All of the grid point, boundary condition, element, material property, load, constraint and buckling information arrays needed by OPTIM.                                                                                                                                                 |
| 6. Error Returns            |                                                                                                                                                                                                                                                                                          |
| 7. Calling Sequence         | CALL ZZ (NAST, NOPT, MATNO, NPROP, NBUCK, NNODES, NOID, REF, OPDVIR, LBOUND, COOR, AMAT, MID, EYEC, LINKS, NEL, NGR, NMT, NICON8, NLINKS, NOGCON, NP, PA, NAP, GA, NFO, NMC, NLOADS, NSPCS, IGRID, SPCINF, GCOND, FORCE3, ANGLE, FORCE1, FORCE2, MOMNT1, MOMNT2, OPLOAD, GROUP, L5, L7). |
| 8. Subroutine User          | Main program                                                                                                                                                                                                                                                                             |
| 9. Subroutines Used         | None                                                                                                                                                                                                                                                                                     |

## SECTION 5

### PROBLEM SIZE LIMITATIONS

The key limitations are brought about by the total number of elements, number of load conditions and the number of degrees of freedom in the problem.

Due to dynamic storage allocation techniques the problem size can be controlled by changing two cards in the 'MAIN' routine. Both the dimension of the 'WORK' array (card MAIN0050) and the size of the variable 'NWORK' (card MAIN 0290) must be equal. The delivered size is 20,000 words, but may be adjusted to your system.

If there is insufficient storage space defined for a problem the program will print a message indicating the amount of storage required for the problem and the amount of storage reserved by the above mentioned cards in the 'MAIN' routine. To execute the problem modify the dimension and 'NWORK' variable to be what the problem needs or reduce the number of elements, number of load conditions and/or number of degrees of freedom indicated on the input sheet.

## SECTION 6

### STORAGE ALLOCATIONS

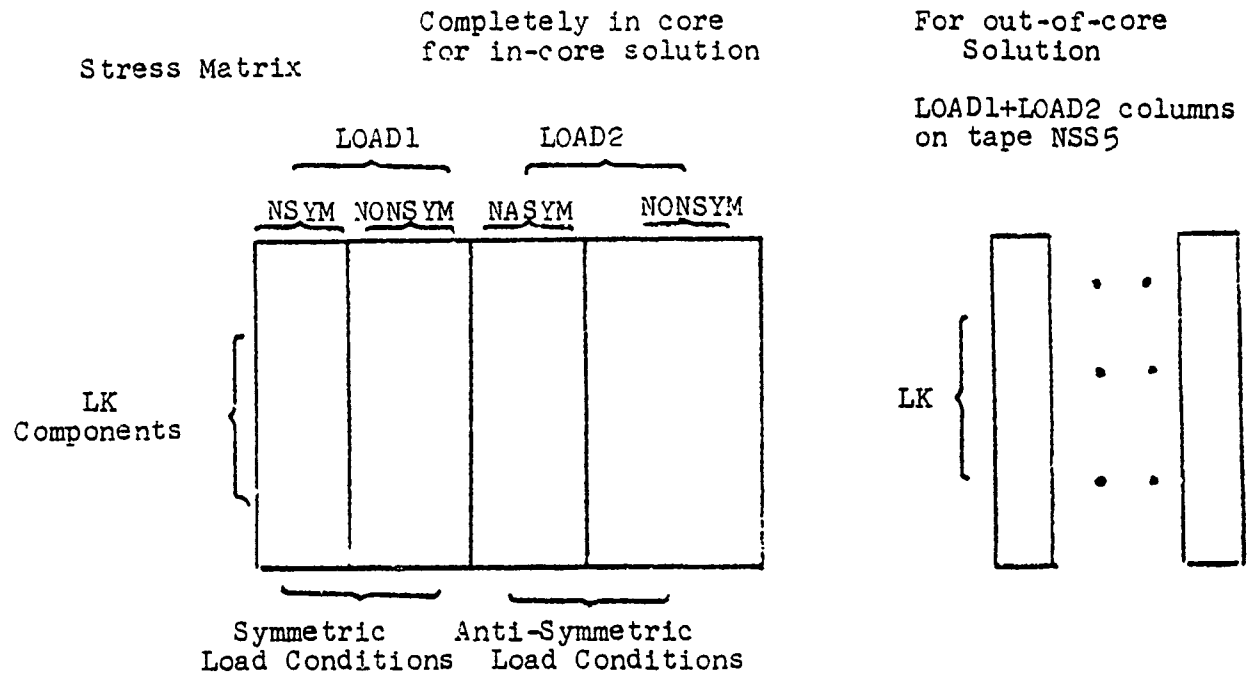
This section includes two diagrams indicating the manner of arranging the stress and displacement matrices to handle all load conditions.

The key to handling non-symmetric loads and displacements is in defining the nonsymmetric load as a symmetric and an anti-symmetric load.

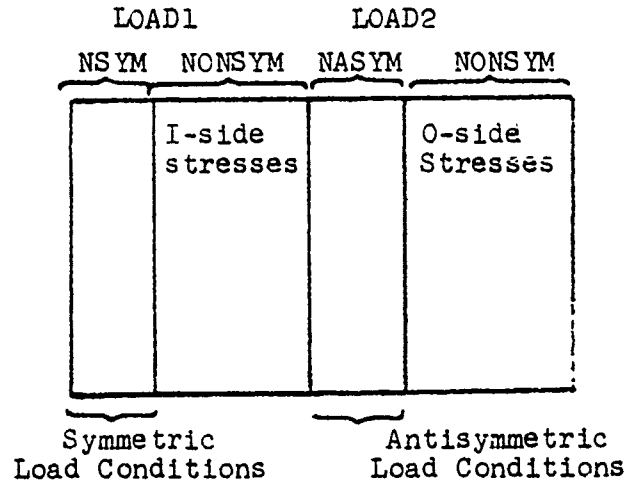
The definition of a number of key parameters used in the diagrams follows:

- NDL1 - Total no. of individual constraints minus any constraints that may be bounded during execution of the problem. For symmetric load conditions.
- NDL2 - Same as above except for anti-symmetric load conditions.
- NAA - No. of generalized constraints, all are assumed unbounded.
- NRDF - No. of reduced degrees of freedom (i.e., all bounded degrees of freedom removed) for symmetric load condition.
- NRDF2 - Same as above except for anti-symmetric load condition.

See Figures 4 and 5.



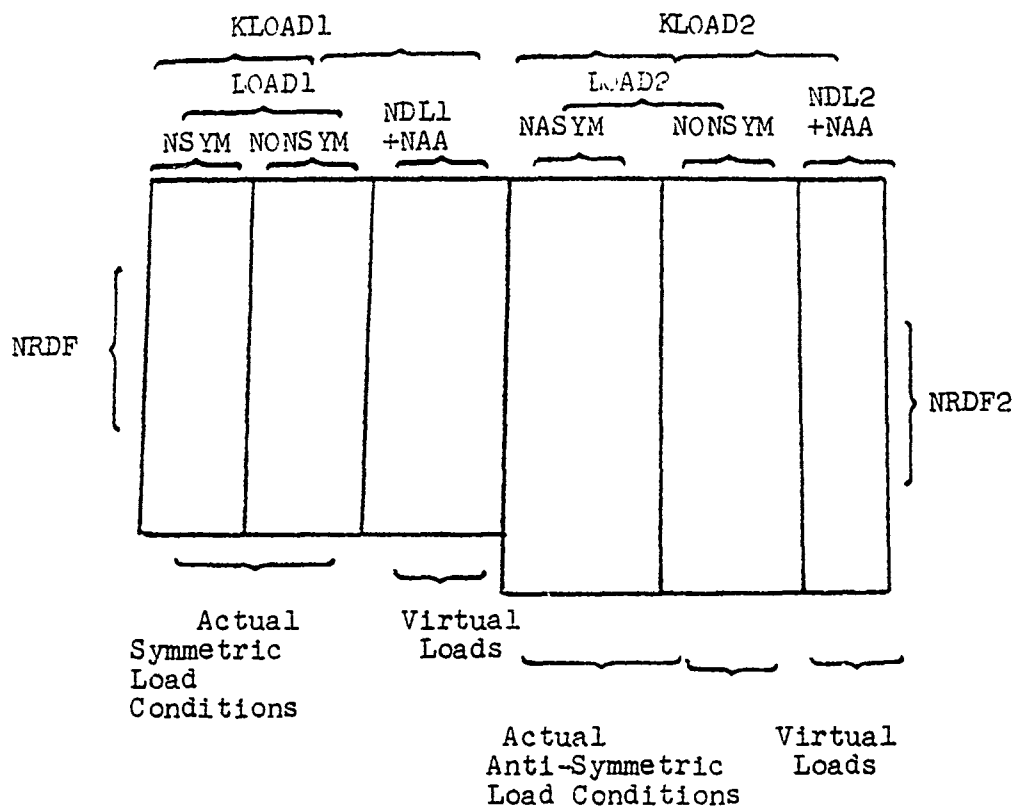
AFTER CALCULATION OF STRESSES



BEFORE ENTRY INTO SCALE ROUTINE

Figure 4: STRESS MATRIX STORAGE ALLOCATION

# DISPLACEMENT MATRIX



## Singly Subscripted

In-core for both in-core and out-of-core solutions.

FIGURE 5. DISPLACEMENT AND LOAD MATRIX STORAGE ALLOCATION