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ACCESS-2
APPROXIMATION CONCEPTS CODE FOR EFFICIENT STRUCTURAL SYNTHESIS - USER'S GUIDE

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SUMMARY

The ACCESS-2 computer program was developed, based on successful experience with ACCESS-1, to study the performance of approximation concepts when they are applied to problems of practical size and complexity. Each modular process, such as equation solution, eigen-analysis or numerical optimization, is carried out in-core. As a consequence problem size is still limited by main memory capacity, even though solvable problem size has been increased significantly, relative to ACCESS-1. Data transfer among various modules is carried out through sequential data files. Dynamic array allocation techniques are employed extensively to make the best use of available main memory in each module. The introduction of dynamic array allocation leads to a more complicated program structure, however, the benefit of data compaction is an essential ingredient of the quest for efficiency in the context of structural synthesis problems of practical size.

A thermal load analysis capability is added with particular emphasis on the importance of thermal stress/strain considerations in design with fiber composite materials. This provides test cases for problems involving load vectors which depend on design variables. Frequency constraints are installed since they are important in their own right. In addition to being a good measure of overall structural stiffness, natural frequencies represent fundamental information that is essential to the formation of more advanced dynamic constraints (e.g. flutter). Since direct application of ACCESS 1 type approximation (first order Taylor

series expansion with respect to the reciprocals of linked design variables) did not exhibit as good a performance as it did for static constraints, additional features for representing natural frequency constraints as first or second order Taylor series expansions with respect to regular linked variables were implemented.

A constant strain triangular element with arbitrary orthotropic material properties was included in the element library to model laminated fiber composite material membrane structures. Membrane laminates are modeled by stacking elements of this type, with different material axis orientations, together. A thermal shear panel (TSP) element was introduced to take uniform soak temperature effects into account. A special shear panel element is needed because the symmetric shear panel (SSP) element formulation does not permit the neutral surface to change length, hence it cannot represent the thermal expansion associated with a uniform temperature change in the panel. The TSP element was especially devised for representing midplane symmetric wings subject to thermal soak temperature conditions in combination with aerodynamic and inertia loads. The temperature change effect is midplane symmetric and it is treated using the TSP element representation of the wing shear webs. On the other hand the mechanical loads on the wing induces midplane antisymmetric response (bending and twisting) and it is treated using regular SSP elements. The two results are then superimposed. Gradient information for the critical and near critical response quantities is also computed by superposing independently computed symmetric and antisymmetric contributions.

Optimization algorithms are completely independent of the other parts of the program and the current version includes the NEWSUMT optimizer. Only a few interface program statements would be required to add other optimizer options in parallel with NEWSUMT.

ACCESS - 2

Approximation Concepts Code for Efficient Structural Synthesis

User's Guide

1. Introduction

The development of the ACCESS-2 computer program was motivated by the successful demonstration, via the ACCESS-1 program, of the effectiveness of the approximation concepts in automated structural synthesis. The ACCESS-1 program was developed to test the performance of the coordinated use of approximation concepts on problems of relatively small scale, subject to simple static constraints. Furthermore, ACCESS-1 was designed as a base program that would lend itself to experimentation aimed at testing the effectiveness of new ideas and techniques for efficient structural synthesis. Therefore, the program and the data structures of ACCESS-1 were kept simple enough so that anyone with fundamental experience in computer programming would be able to understand the codes and modify them. As reported in Ref. 1 efficiency, in terms of the number of finite element structural analyses needed to obtain near optimal designs, was improved significantly over previously reported capabilities having comparable generality. Furthermore, during the past two years at least four distinct research projects were carried out using ACCESS-1 as a base program and modifying it to test new ideas. Experience has shown that ACCESS-1 has been useful both in its own right and as a research tool designed to promote the use of approximation concepts in automated structural design.

However, many practical design problems are beyond the capacity of ACCESS-1 and consideration of more complicated constraints than those treated in ACCESS-1 is often necessary and desirable. For example, in aeronautical applications, composite materials and thermal loads as well as stability and dynamic response constraints are extremely important. Indeed, there is frequently an even more compelling need for automated design capabilities when these rather complex materials and constraints are involved. The ACCESS-2 computer program has been developed in response to these needs and to build a body of experience that can be used to set effective guidelines for future development of large scale industrial application programs.

The key ideas central to creation of the ACCESS-2 program are similar to those on which ACCESS-1 was built. Finite element analysis techniques and mathematical programming algorithms have been combined using a collection of innovative approximation concepts. Structures with prescribed configuration and given material properties are optimized so that their structural weight is minimized by modifying the sizing of finite elements; i.e. cross-sectional areas or thicknesses. (Optimum variation of configuratio and/or topological design features are still the subject of basic research investigations and no conclusive demonstrations of efficient design algorithms are available as yet).

The fundamental structure of the ACCESS-2 program is outlined in Fig. 1. Upon activation, the preprocessor reads and prints out the input data in a readable format. The preprocessor then computes all the ancillary data that is independent of changes in the design variables and it stores the results in appropriate arrays as well as in temporary external files (see Table 1). When preprocessing is completed successfully, the design process control (DPC) block is activated and it initializes the design iteration process. At the outset the design given in the input data is transferred to the approximate problem generator (APG), and this design is analyzed by the finite element method. Constraint functions are evaluated using the response quantities obtained from the finite element analysis and then the initial set of critical and potentially critical constraints is identified and tagged. Explicit approximate expressions for these tagged constraints are computed using the Taylor series expansion with respect to appropriate intermediate design variables. Reciprocals of independent design variables are used as intermediate variables throughout the program, except for an optional use of the independent design variables themselves when expanding frequency constraints. In ACCESS-2, the objective function is structural weight and it may be expressed exactly and explicitly in terms of the independent design variables or their reciprocals. Thus, the APG block can generate an approximate problem statement of the form:

$$\text{Minimize} \quad W(\vec{X})$$

$$\vec{X} = (x_1, x_2 \ldots x_n)$$

$$\text{Subject to}$$

$$\tilde{H}_q(\vec{X}) \geqq 0 \qquad q = 1,2,\ldots Q$$

where $W(\vec{X})$ and all $\tilde{H}_q(X)$ are explicit analytic functions of $\vec{X}$. Note that the number of constraints Q for this approximate problem is much smaller than that of the original structural design problem, because only the tagged constraints are included and all other constraints are temporarily ignored during a particular design stage.

The data which define the approximate problem are sent back to DPC and subsequently given to the optimization algorithm block (OA). The primary function of OA is to carry out numerical search process which will improve the design by operating on the current approximate problem statement. Since OA deals with problems that are stated in algebraically explicit form, it is not even aware that these problems are related to structural design. Therefore, any established algorithm for inequality constrained minimization of a function of many variables may be used. Ideally it would be desirable to select an OA from a collection of available options, taking into account the size and special functional characteristics of the current explicit approximate problem statement. However, in the current version of ACCESS-2 only the NEWSUMT optimization algorithm is available. This OA implements a sequence of unconstrained minimizations technique using a modified Newton's method and a quadratic extended penalty function feature to facilitate the unconstrained minimizations. One virtue of this interior penalty function type of OA (i.e. NEWSUMT) is that it can usually be controlled so as to provide an improved design that is also feasible with respect to all of the constraint at each stage in the design process.

After carrying out a numerical search with the approximate problem, the optimization algorithm (OA) block proposes an improved design $\vec{X}'$ to DPC. This step completes one stage of the design iteration procedure.

In summary, one stage of iteration includes one finite element structural analysis, one constraint deletion process, one sensitivity evaluation for retained constraints, and one optimization of an approximate problem. Since the final design is subject to a detailed finite element analysis, the total number of finite element analyses equals the number of iteration stages plus one, which will be typically 10. The iterative design process is terminated when one of the specified convergence criteria is satisfied.

Strictly speaking each new design $\vec{X}'$ proposed by the OA block to DPC is a better design than the original design $\vec{X}$ only with respect to the approximate problem statement. When the structural design corresponding to $\vec{X}'$ is analyzed by means of the finite element method, it may turn out that some constraints are violated. This situation may occur when the design changes in one stage exceed the applicable range of the approximate problem statement. It should be noted that the NEWSUMT optimizer is capable of locating feasible designs starting from an infeasible design. However, violation of constraints in the intermediate stages usually has a deleterious effect on the convergence characteristics and it is also inconvenient if constraint violations are found at the final design. Constraint violation can usually be controlled or eliminated by appropriate use of the maximum step size parameter STEPMX and its dynamic modification feature via parameters STEPMX-multiplier and STEPMX-lower limit (see Appendix B).

All routines are written in standard FORTRAN IV language and they have been tested on: (a) the IBM 360/91 using the FORTRAN-H compiler at UCLA; and (b) the CDC 6600 at the NASA Langley Research Center. Implementation on other types of computers will be straightforward provided those computers have the required main memory capacity. Except for the blank COMMON arrays, 380_{10}K and 280_{10}K bytes are required on IBM 360/91 without and with program overlay, respectively. On a CDC 6600, the corresponding basic memory requirement is 100_8K words with overlay.

2. Program Implementation

ACCESS-2 computer program may be executed as a stand alone program. It consists of approximately 8500 FORTRAN statements. The program supplied upon request is a version operational either on IBM 360/370 or CDC 6600/7600 systems. Since it contains no machine dependent statements, it can be made operational on various computers, provided enough main memory capacity and auxiliary data storage support are available.

Auxiliary storage files are required as shown in Table 1. Files 10, 11, 12, 13, 14 and 15 are required for all problems. File 16 is required only when type 4 elements (TSP) are used in the structural model. Files 18, 19, 20, 21 and 22 are required only when second order expansions of frequency constraints are specified.

The required size of blank common is very problem dependent: i.e. it depends on the structural analysis model (number of nodes, elements and load conditions), the number of independent design variables, and the constraint types included. For certain problems, it also depends on the initial design. Hence, it is rather difficult to give explicit formulas which estimate the size of blank common requirements. Table 2 gives actual blank common array size requirements for several example problems.

Overlay or segmentation of the program can be designed easily by referring to Fig. 2. The simple 3 level overlay is adequate to solve most of the meaningful problems. If an operating system allows more flexible overlay structure, it is possible to decrease the core requirement further. However, the net gain acquired by the elaborate overlay may not be significant, since most of the core is used for data and not for instructions.

3. Structural Model and Input Data Preparation

It is assumed that the reader is familiar with elastic structural analysis via the finite element displacement method, as well as with associated structural modelling techniques and typical data preparation procedures. Sufficient information for preparing the input data card images is given in Appendix B, therefore the explanations given in this section are limited to topics which require somewhat detailed technical discussion in order to avoid possible misunderstandings.

3.1 System of Units

Input data of the ACCESS-2 computer program may be prepared in any system of units as long as they are consistent. For example, if it is decided that the units for length and force are to be centimeters and Newtons, respectively, then the corresponding units for pressure load or allowable stress must be N/cm^2. Note that the material constant specification calls for the specific weight of the material, not its mass density. To be consistent lumped nodal mass should be given using weight rather than mass units. Example problems given in Appendix C are presented both in the International System (IS) of Units and in the U.S. Customary (U.S.) units. Computer input data for examples are shown using numerical values associated with the U.S. units, simply because all the examples were originally presented in the literature using U.S. units.

3.2 Node Numbering Scheme for the Effective Use of Memory

The system stiffness and the mass matrices are stored in a vector form within the skyline of the non-zero elements, i.e. there are no operations or no storage allocations with elements that remain zero during the solution. This scheme allows somewhat more flexible node numbering arrangement than the ordinary band equation solver. It is better, however, to follow the same guidelines in preparing data as for a banded matrix solution scheme; i.e., differences among node numbers associated with an element must be kept as small as possible for all elements.

3.3 Symmetric Wing Model

If the webs of a midplane symmetric wing are modelled with SSP elements, only the upper (or lower) half of the wing is modelled. Assuming that the X-Y reference plane is the plane of symmetry, the X and Y displacement components and loading components are then anti-symmetric. Displacements and loadings in the Z direction are identical for both sides of the X-Y plane. For example, if a cantilever beam such as that shown in Fig. 3(a) is to be modelled using two SSP elements, then the simplified model should be that shown in Fig. 3(b). Note that only half of the load P need be applied to the node 3, since the other half is implicitly applied to the conjugate node 3' (which does not exist explicitly in the model). The SSP elements are always vertical to the X-Y plane of symmetry.

The assumed displacement function for SSP elements cannot accommodate uniform thermal expansion of each SSP element. If specified midplane symmetric temperature changes are specified for a midplane symmetric structural model, in which the vertical webs are represented by SSP elements, ACCESS 2 branches and makes a separate calculation which adds in the midplane symmetric temperature change effects. This is accomplished by assembling equilibrium equations for the midplane symmetric structure with all of the SSP elements replaced by TSP elements while only considering midplane symmetric temperature change loading. These equilibrium equations are solved for displacements $\vec{u}_{th}$ due only to midplane symmetric temperature changes. These thermally induced midplane symmetric displacements are superimposed on the previously computed midplane antisymmetric displacement state due to mechanical loads only. Treating the symmetric and antisymmetric contributions separately reduces the number of displacement degrees of freedom that need to be considered in each of the two analyses and for thin wings it also tends to improve the accuracy of the analysis by avoiding the poor conditioning often associated with simultaneous treatment of bending and membrane response. The strain state is computed based on the total displacement, and the stress state is computed by transforming the strain state using the stress-strain relationships.

3.4 Design Variable Linking

The general concept of design variable linking is discussed in Sec. 2.3.1 of Ref. 1. In the ACCESS-2 computer program, if the sizes of some group of finite elements of the same type are controlled by a single design variable, these elements are said to belong to the same design variable linking group. The sizes of elements in a design variable linking group are modified in proportion to the initial sizes given in the input data.

Design variable linking groups are also used to define "regions" for the regionalization of stress constraints. The general idea of regionalization is described in Sec. 2.4.1 of Ref. 1. Elements which belong to the same design variable linking group form a region and only one stress constraint per load condition (the most critical) is considered for each group in any stage of the iterative design procedure. Selection of the critical stress constraints within a region is not rigidly fixed, but dynamically updated at the beginning of each stage. If the location of the critical stress constraints shifts frequently within a region from stage to stage the iteration process may be unstable, although this type of instability was not observed in solving any of the problems given in Ref. 1. However, if the user desires to remove the regionalization of stress constraints, it is only necessary to specify IGLINK = -200.

3.5 Failure Criteria for CSTOR elements

The CSTOR element is implemented to model structures made with orthotropic materials including multi-layered fiber composite laminates. While strength failure criteria for isotropic metal alloy materials are imposed using the von Mises combined effective stress, strength failure criteria for CSTOR elements are selected from 3 available options.

They are:

A. Maximum strain criteria

$$\bar{\varepsilon}_L^c \le \varepsilon_L - \alpha_L \Delta T \le \bar{\varepsilon}_L^t$$

$$\bar{\varepsilon}_T^c \le \varepsilon_T - \alpha_T \Delta T \le \bar{\varepsilon}_T^t$$

$$|\gamma_{LT}| \le \bar{\gamma}_{LT}$$

B. Stress interaction formulas

$$\left(\frac{\sigma_L}{F_L}\right)^2 \le 1$$

$$\left(\frac{\sigma_T}{F_T}\right)^2 + \left(\frac{\tau_{LT}}{F_{LT}}\right)^2 \le 1$$

C. Tsai-Azzi Criterion

$$\left(\frac{\sigma_L}{F_L}\right)^2 - \left(\frac{\sigma_L \sigma_T}{F_L^2}\right) + \left(\frac{\sigma_T}{F_T}\right)^2 + \left(\frac{\sigma_{LT}}{F_{LT}}\right)^2 \le 1$$

where

ε_L : longitudinal strain

ε_T : transverse strain

γ_{LT} : shear strain

σ_L : longitudinal stress

σ_T : transverse stress

τ_{LT} : shear stress

$\bar{\varepsilon}_L^c$: allowable longitudinal compressive strain

$\bar{\varepsilon}_L^t$: allowable longitudinal tensile strain

$\bar{\gamma}_{LT}$: allowable shear strain

F_L, F_T : allowable longitudinal and transverse stresses

F_{LT} : allowable shear stress

ν_{TL} : Poisson's ratio relating to contraction in the longitudinal direction due to extension in the in-plane transverse direction

ν_{LT} : Poisson's ratio relating to contraction in the in-plane transverse direction due to extension in the longitudinal direction

Among the three alternative strength criteria, the maximum strain criterion is the most conservative while the stress interaction formulas are usually the least conservative.

3.6 Computation of Constraints

All constraints, except the side constraints, are normalized so that potentially critical constraint functions in the feasible region assume values between 0.0 and 1.0. Constraint functions are defined as follows:

Side Constraints

$$D^{(U)}/D - 1.0 \geq 0$$

$$1.0 - D^{(L)}/D \geq 0$$

Displacement Constraints

$$(\delta^{(U)} - \delta)/\delta^{(U)} \geq 0$$

$$(\delta - \delta^{(L)})/\delta^{(L)} \geq 0$$

Slope (Relative Displacement) Constraints

Slope

$$\frac{s^{(U)} - (\delta_2 - \delta_1)/d_p}{s^{(U)}} \geq 0$$

Relative Displacement

$$\frac{r^{(U)} - (\delta_2 - \delta_1)}{r^{(U)}} \geq 0$$

where d_p is the projection of the distance between the two points on a plane normal to the displacement components δ_1 and δ_2.

Stress (Strain) Constraints

$$\frac{\sigma^{(U)} - \sigma}{\sigma^{(U)}} \geq 0$$

$$\frac{\sigma - \sigma^{(L)}}{\sigma^{(L)}} \geq 0$$

For strain constraints, see 3.5.

Frequency Constraints

$$\frac{{\omega^{(U)}}^2 - \omega^2}{{\omega^{(U)}}^2} \geq 0$$

$$\frac{\omega^2 - {\omega^{(L)}}^2}{{\omega^{(L)}}^2} \geq 0$$

4. Restrictions and Limitations

The amount of main memory storage required for solution of a particular problem depends upon many factors, including the number of nodes, the number of elements, the number of design variables, the element types used, the kinds of constraints imposed, and even the initial design employed etc. For static problems, it is necessary to retain two system stiffness matrices and the load vectors in core. For dynamic problems, three system matrices must be retained in core. If a problem involves dynamic constraints and thermal shear panel elements, four system matrices must be in core simultaneously. Also a complete approximate problem statement (all retained constraint values and all the corresponding derivative components) must be in core for the OA block. It is difficult to estimate the array size required for a system stiffness matrix in advance. Only the nonzero skyline of an upper half matrix is stored, hence the memory requirement depends on the node numbering scheme. For medium size problems (300 -600 DOF), the density of nonzero elements in the matrix is usually 20-50% and a first approximation can be made by estimating the density based on observation of the finite element model. The main memory storage required for the integer portion of the blank COMMON is usually less than 10,000 words, but the real variable portion is very dependent on the nature of the problem. For problems in which the number of constraints retained tends to be larger and in which there are many independent design variables (e.g. structures involving laminated fiber composite skins) the constraint derivative array size [i.e. (Number of Design Variables) x (Number of Constraints Retained)] may limit the problem size, since this large array must be in core in addition to the instructions and local variables.

When first order approximations are used frequency constraints can be imposed on any subset of frequencies within the lowest NFREQ frequencies. If second order approximations are employed all frequencies in the lowest NFREQ frequencies must be bounded.

Capabilities for aeroelastic constraints are not available in this version, therefore NMODE must be zero and the flight condition specification flags must all be zero.

All input data are read in with fixed format, hence column positions of the punched data are of critical importance. Especially note that all blank columns are regarded as zeroes for numerical inputs.

REFERENCES

1. Schmit, L.A. and H. Miura, "Approximation Concepts for Efficient Structural Synthesis," NASA CR-2552, March 1976.
2. Miura, H. and Schmit, L.A., "ACCESS 1 Program Documentation and User's Guide," NASA CR-144905, 1976.
3. Przemieniecki, J.S., "Theory of Matrix Structural Analysis," McGraw Hill, New York, 1968.

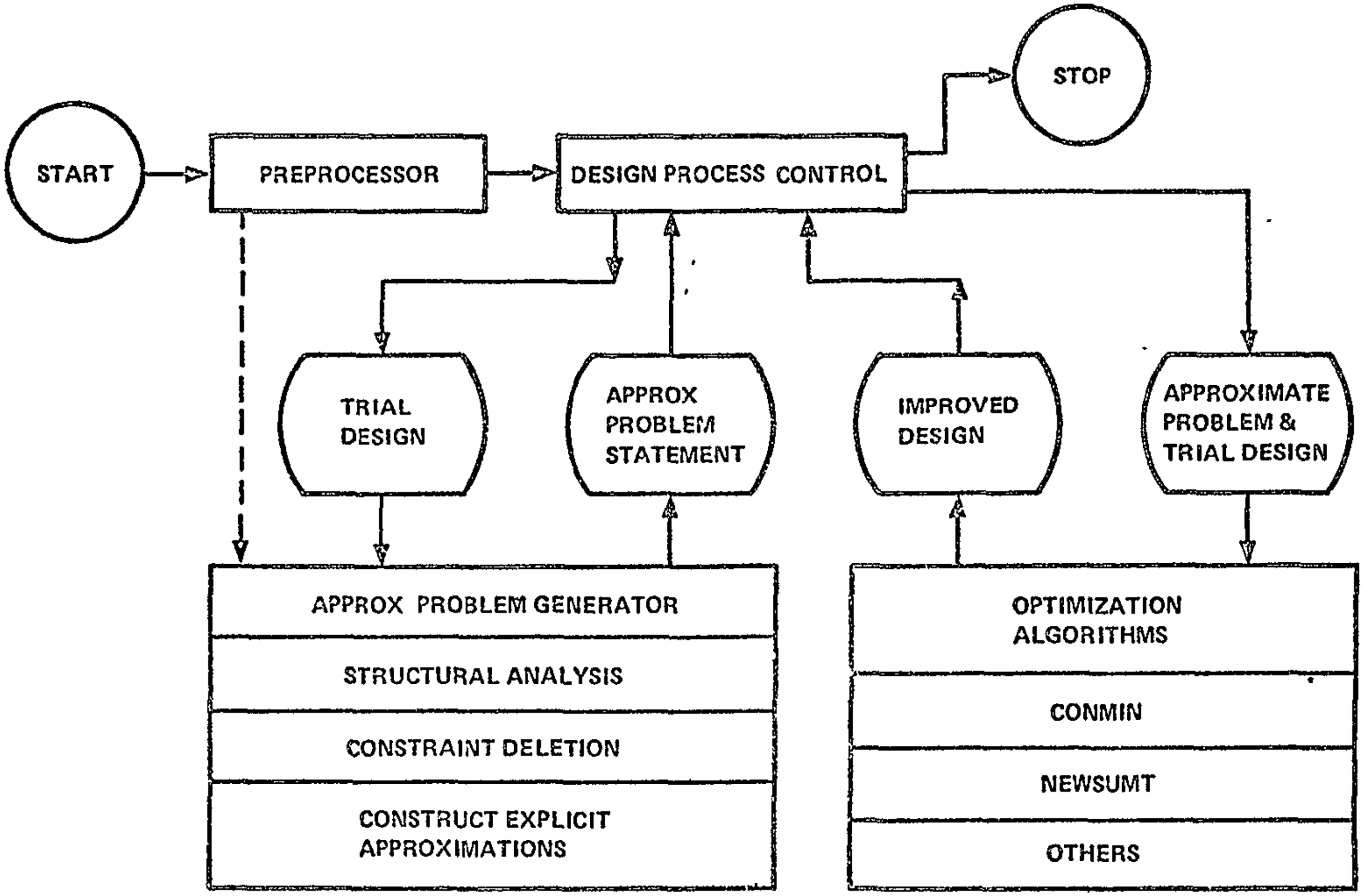


Figure 1. ACCESS 2 Basic Organization.

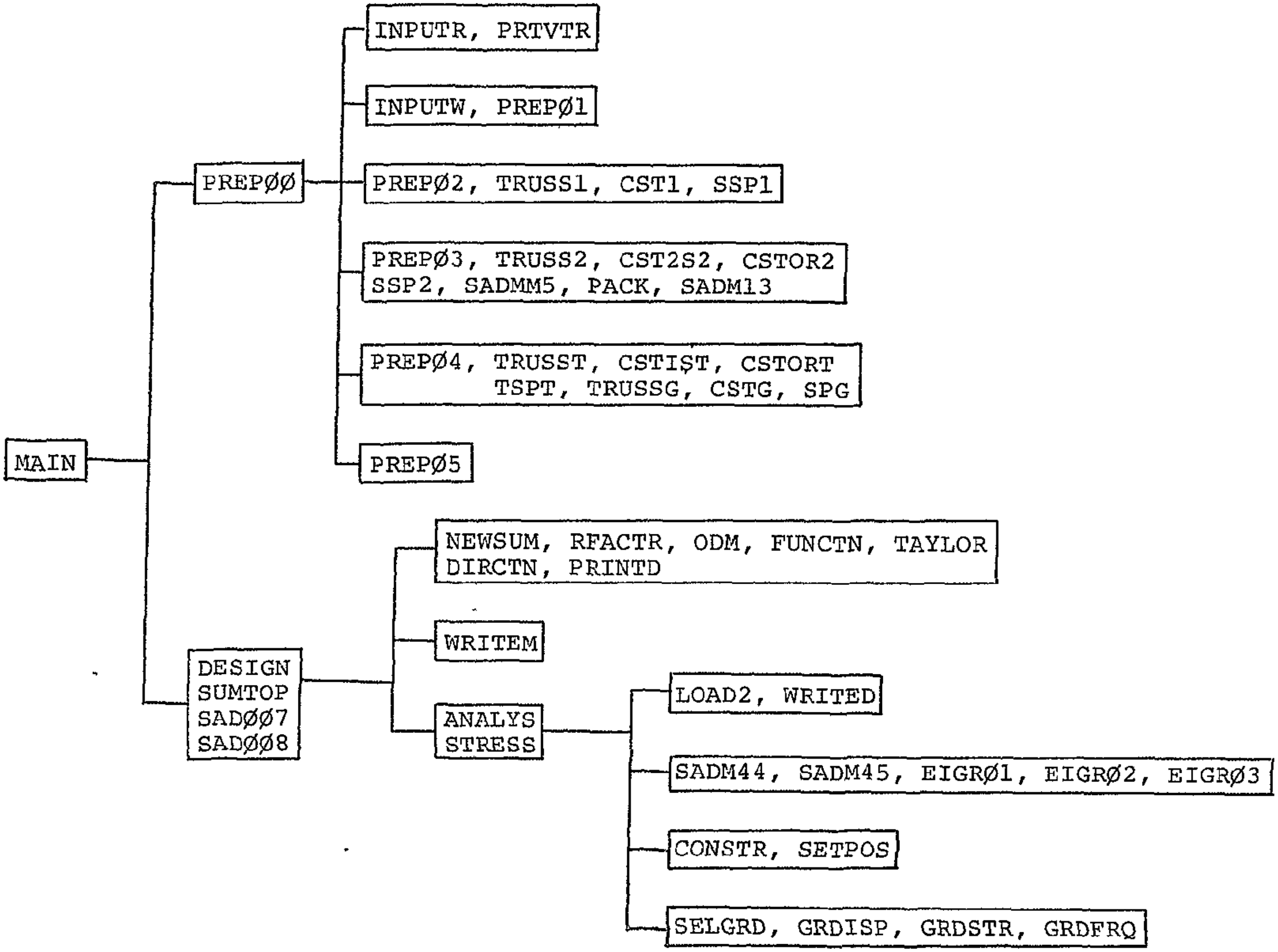
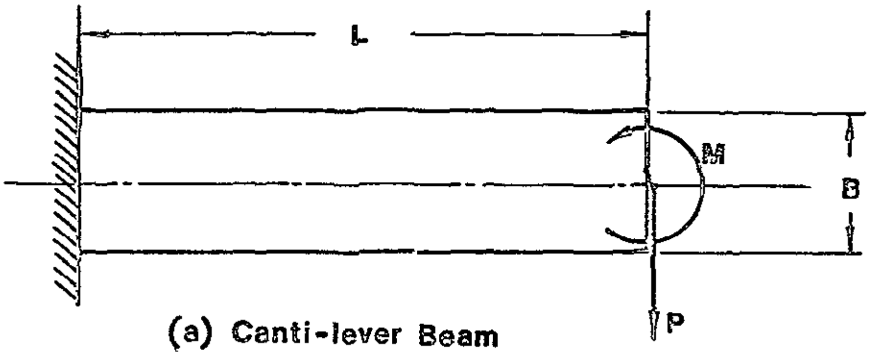
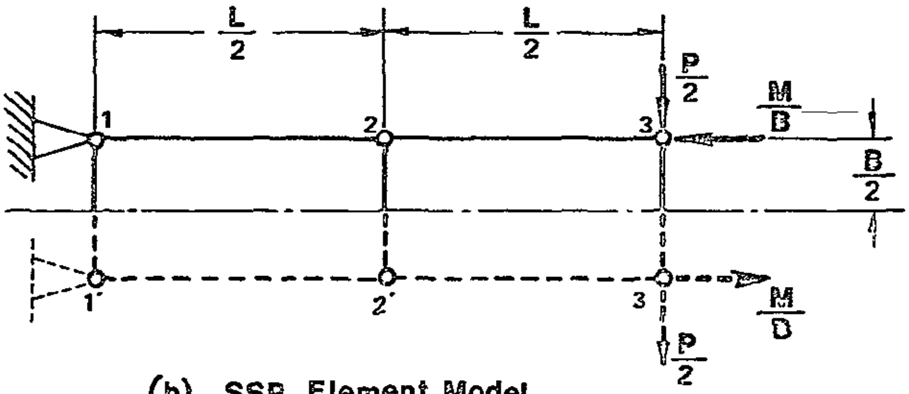


Fig. 2. Overlay Structure of ACCESS-2



(a) Canti-lever Beam



(b) SSP Element Model

Fig.3 SSP Element Model Example

Table 1. Temporary Files

File Name	Contents
10	Stiffness matrix components associated with unit values of independent design variables and load vector components which are independen of design variables
11	Mass matrix components associated with unit values of independent design variables
12	Load vector components due to thermal loads and dependent on independent design variables
13	Load vector components due to inertia loads and dependent on independent design variables
14	Constraint gradients
15	Input data and a part of preprocessor output
16	Thermal shear panel stiffness matrix components Used only when IETP(6)$\neq$0
17	Not used
18	Eigenvector sensitivity vectors, if computed
19	Mass matrix post-multiplied by eigenvectors. Required only when second order expansion of frequency constraints is used.
20	Original system stiffness and mass matrices. Required only when second order expansion of frequency constraints is used.
21	Modified $[K-\lambda_1 M]$ in the eigenvector sensitivity computation. Stored in decomposed form.
22	$\frac{\partial K}{\partial \alpha_b} - \lambda_i \frac{\partial M}{\partial \alpha_b} \bar{X}_i$, ((i=1, NEIG), b=1, B) Required only when second order expansion of frequency constraints is used

Table 2. Required Blank Common Size

Problems	Elements	Total No. of Elements	Free Displ. d.o.f.s	No. of Design Variables	Total No. of Constraints	Required Real Array	Required Integer Array
Wing Carry-Through Truss Model (static)	TRUSS	63	42	63	319	11415	1896
Delta Wing (Metal) (Static & Dynamic)	CST SSP	63 70	105	28	164	7400	2033
Delta Wing-Composite (Static & Dynamic)	CSTOR SSP	252 70	105	60	2725	12750	6747
Delta Wing-Composite (Static, thermal and Dynamic)	CSTOR SSP TSP	252 70 70	105	60	2725	16960	8264
Elevon-Composite (Static, thermal and Dynamic)	TRUSS CSTOR SSP TSP	45 192 45 45	109	68	3354	47334	10680

APPENDIX A

ELEMENT LIBRARY

Currently, 6 element types are available: they are TRUSS, CSTIS, CSTOR, SSP, PSP and TSP. Basic characteristics of these elements are given in the sequel.

1. Type 1 - TRUSS : Pin jointed bar element of uniform cross section

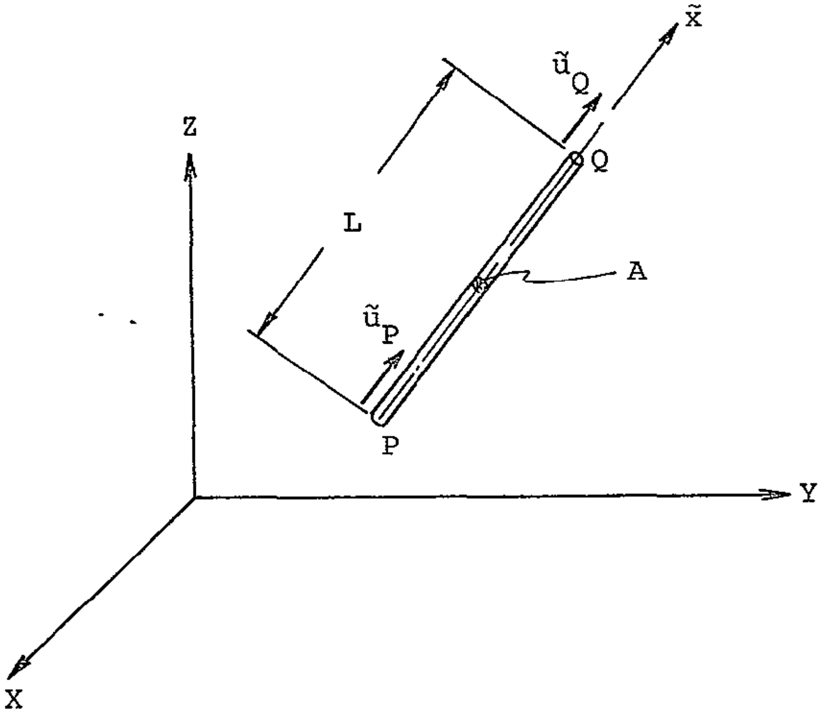


Fig. A-1 Space Truss Element

Strain-Displacement Relation (local coordinate)

$$\varepsilon = \frac{1}{L} [-1 \quad 1] \begin{Bmatrix} \tilde{u}_P \\ \tilde{u}_Q \end{Bmatrix} \tag{A-1}$$

Stress Strain Relation (local coordinate)

$$\sigma \; = \; E \, \varepsilon - E\alpha\Delta T \tag{A-2}$$

where α : thermal expansion coefficient

ΔT : average temperature change

Force Displacement Relation (local coordinate)

$$\frac{EA}{L} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{u}_Q \end{Bmatrix} - E\alpha\Delta TA \begin{Bmatrix} -1 \\ 1 \end{Bmatrix} - \begin{Bmatrix} \tilde{f}_P \\ \tilde{f}_Q \end{Bmatrix} = 0 \tag{A-3}$$

where F_p, F_q are externally applied force at P and Q nodes, respectively.

Force Displacement Relation (reference coordinates)

$$\frac{EA}{L} \begin{bmatrix} \ell^2 & \ell m & \ell n & -\ell^2 & -\ell m & -\ell n \\ & m^2 & mn & -\ell m & -m^2 & -mn \\ & & n^2 & -\ell n & -mn & -n^2 \\ & & & \ell^2 & \ell m & \ell n \\ & \text{Symm} & & & m^2 & mn \\ & & & & & n^2 \end{bmatrix} \begin{Bmatrix} U_P \\ V_P \\ W_P \\ U_Q \\ V_Q \\ W_Q \end{Bmatrix}$$

$$= -E\alpha\Delta TA \begin{Bmatrix} \ell \\ m \\ n \\ -\ell \\ -m \\ -m \end{Bmatrix} + \begin{Bmatrix} X_P \\ Y_P \\ Z_P \\ X_Q \\ Y_Q \\ Z_Q \end{Bmatrix} \tag{A.4}$$

Consistent Mass Matrix (reference coordinates)

$$[M] = \frac{\rho AL}{6} \begin{bmatrix} 2 & 0 & 0 & 1 & 0 & 0 \\ & 2 & 0 & 0 & 1 & 0 \\ & & 2 & 0 & 0 & 1 \\ & & & 2 & 0 & 0 \\ & \text{Sym} & & & 2 & 0 \\ & & & & & 2 \end{bmatrix} \qquad \text{(A-5)}$$

where ρ : density

2. Type 2 - CSTIS: Constant strain triangular membrane element with uniform thickness and isotropic material

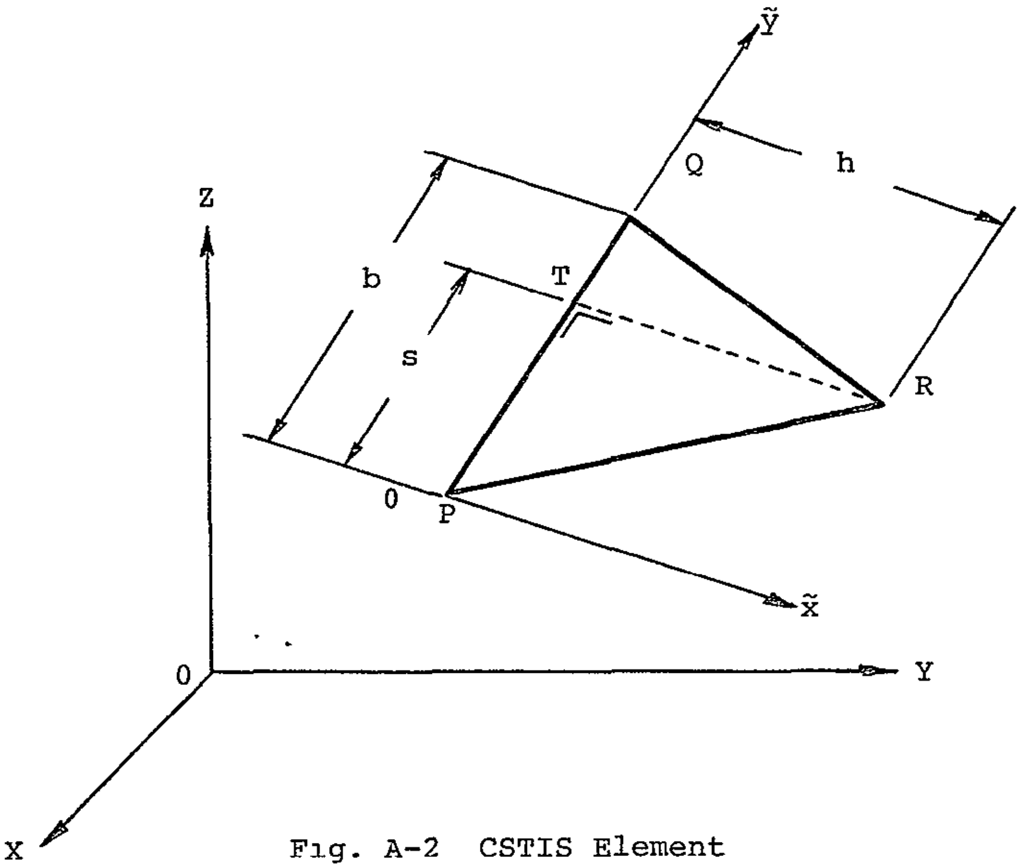


Fig. A-2 CSTIS Element

<u>Strain-Displacement Relation</u> (local coordinate)

$$\left\{\begin{matrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{matrix}\right\} = \frac{1}{bh} \begin{bmatrix} (s-b) & 0 & -s & 0 & b & 0 \\ 0 & -h & 0 & h & 0 & 0 \\ -h & (s-b) & h & -s & 0 & b \end{bmatrix} \left\{\begin{matrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{w}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \\ \tilde{w}_Q \end{matrix}\right\} \qquad \text{(A-6)}$$

Stress-Strain Relation (local coordinate)

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \gamma_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} - \frac{E\alpha\Delta T}{1-\nu} \begin{Bmatrix} 1 \\ 1 \\ 1 \end{Bmatrix} \qquad \text{(A-7)}$$

Stress-Displacement Relation (local coordinate)

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{bh(1-\nu^2)} \begin{bmatrix} (s-b) & -\nu h & -s & \nu h & b & 0 \\ \nu(s-b) & -h & -\nu s & h & \nu b & 0 \\ \frac{-(1-\nu)h}{2} & \frac{(1-\nu)(s-b)}{2} & \frac{(1-\nu)h}{2} & \frac{-(1-\nu)s}{2} & 0 & \frac{(1-\nu)b}{2} \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{w}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \\ \tilde{w}_Q \end{Bmatrix}$$

$$- \frac{E\alpha\Delta T}{1-\nu} \begin{Bmatrix} 1 \\ 1 \\ 0 \end{Bmatrix} \qquad \text{(A-8)}$$

Local-Reference Displacement Relation

$$\begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \\ \tilde{u}_R \\ \tilde{v}_R \end{Bmatrix} = \begin{Bmatrix} \vec{\lambda}_x^{\,T} \cdot \vec{U}_P \\ \vec{\lambda}_y^{\,T} \cdot \vec{U}_P \\ \vec{\lambda}_x^{\,T} \cdot \vec{U}_Q \\ \vec{\lambda}_y^{\,T} \cdot \vec{U}_Q \\ \vec{\lambda}_x^{\,T} \cdot \vec{U}_R \\ \vec{\lambda}_y^{\,T} \cdot \vec{U}_R \end{Bmatrix} \qquad \text{or } \tilde{u} = [T]\vec{U} \qquad \text{(A-9)}$$

where $\vec{\lambda}_x$: unit vector parallel to the x-axis

$\vec{\lambda}_y$: unit vector parallel to the y-axis

U_P, U_Q, U_R : displacement vectors of P,Q,R nodes.

$$[T] = \begin{bmatrix} \ell_x & m_x & n_x & & 0 & & & 0 & \\ \ell_y & m_y & n_y & & & & & & \\ & & & \ell_x & m_x & n_x & & & \\ & 0 & & & & & & 0 & \\ & & & \ell_y & m_y & n_y & & & \\ & & & & & & \ell_x & m_x & n_x \\ & 0 & & & 0 & & & & \\ & & & & & & \ell_y & m_y & n_y \end{bmatrix} \qquad \text{(A-10)}$$

Stiffness Matrix. (local coordinate system)

$$K = K_n + K_s \qquad \text{(A-11)}$$

where

$$K_n = \frac{Et}{4A(1-\nu^2)} \begin{bmatrix} (s-b)^2 & -\nu(s-b)h & -(s-b)s & \nu(s-b)h & (s-b)b & 0 \\ & h^2 & \nu hs & -h^2 & -\nu hb & 0 \\ & & s^2 & -\nu hs & -bs & 0 \\ & \text{Symm.} & & h^2 & \nu bh & 0 \\ & & & & b^2 & 0 \\ & & & & & 0 \end{bmatrix}$$

$$K_s = \frac{Et}{8A(1+\nu)} \begin{bmatrix} h^2 & -(s-b)h & -h^2 & hs & 0 & -bh \\ & (s-b)^2 & (s-b)h & -(s-b)s & 0 & (s-b)b \\ & & h^2 & -hs & 0 & bh \\ & & & s^2 & 0 & -bs \\ & & & & 0 & 0 \\ & \text{Symm.} & & & & b^2 \end{bmatrix}$$

<u>Force-Displacement Relation</u> (local coordinates)

$$K\,\tilde{u} + \frac{E\alpha\Delta Tt}{2(1-\nu)} \begin{Bmatrix} b-s \\ h \\ s \\ -h \\ -b \\ 0 \end{Bmatrix} = \tilde{f} \qquad \text{(A-12)}$$

<u>Consistent Mass Matrix</u>

$$[M] = \frac{\rho At}{12} \begin{bmatrix} 2 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ & 2 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ & & 2 & 0 & 0 & 1 & 0 & 0 & 1 \\ & & & 2 & 0 & 0 & 1 & 0 & 0 \\ \text{Symm.} & & & & 2 & 0 & 0 & 1 & 0 \\ & & & & & 2 & 0 & 0 & 1 \\ & & & & & & 2 & 0 & 0 \\ & & & & & & & 2 & 0 \\ & & & & & & & & 2 \end{bmatrix} \qquad \text{(A-13)}$$

where ρ : density

3. Type 3 - CSTOR: Constant strain triangular membrane element with uniform thickness of an orthotropic material

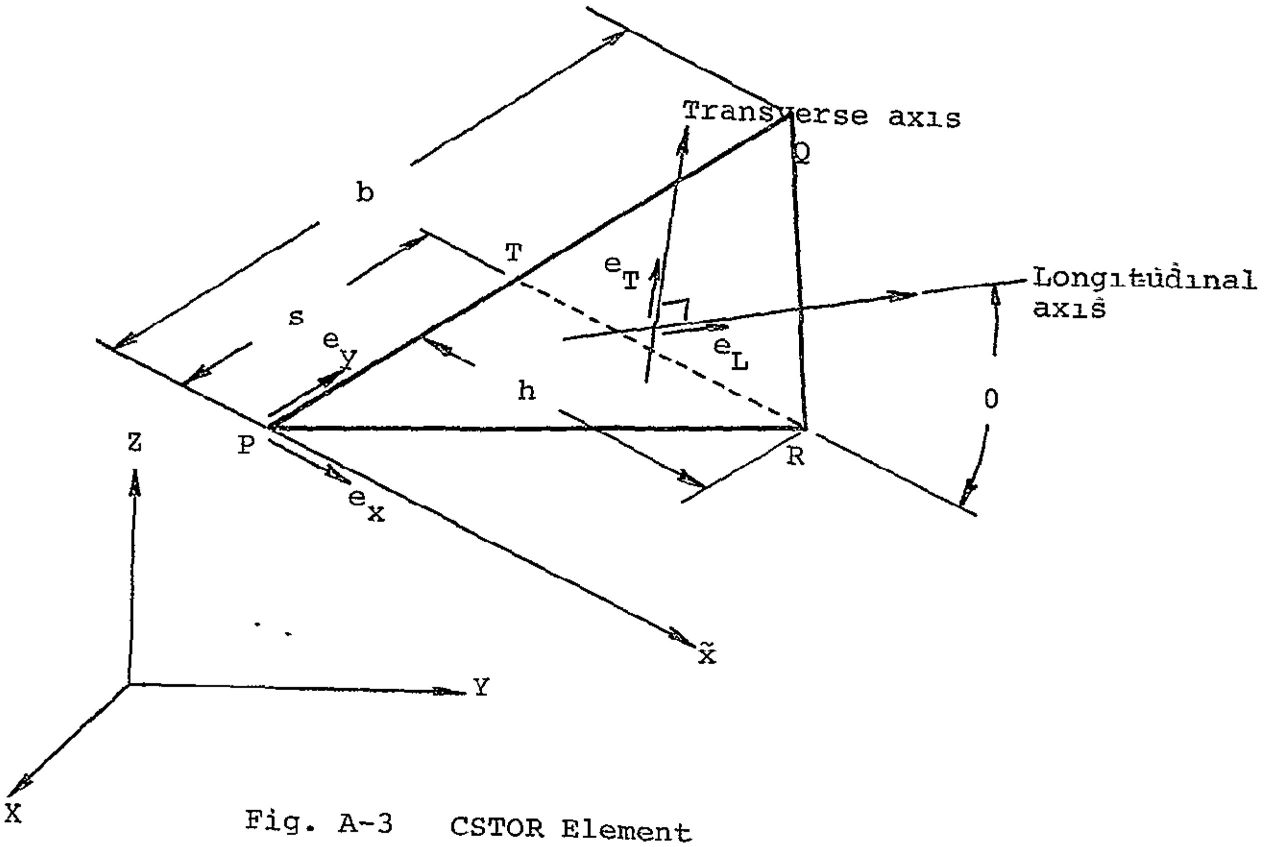


Fig. A-3 CSTOR Element

Strain-Displacement Relation (local coordinate)

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = \frac{1}{bh} \begin{bmatrix} (s-b) & 0 & -s & 0 & b & 0 \\ 0 & -h & 0 & h & 0 & 0 \\ -h & (s-b) & h & -s & 0 & b \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \\ \tilde{u}_R \\ \tilde{v}_R \end{Bmatrix} \qquad \text{(A-14)}$$

$$= [B]\ \tilde{u}$$

Stress-Strain Relation (material axis)

$$\begin{Bmatrix}\sigma_{LL}\\ \sigma_{TT}\\ \gamma_{LT}\end{Bmatrix}=\underbrace{\begin{bmatrix}\frac{E_L}{1-\nu_{LT}\nu_{TL}} & \frac{\nu_{TL}E_L}{1-\nu_{LT}\nu_{TL}} & 0\\ \frac{\nu_{LT}E_T}{1-\nu_{LT}\nu_{TL}} & \frac{E_T}{1-\nu_{LT}\nu_{TL}} & 0\\ 0 & 0 & G_{LT}\end{bmatrix}}_{[D]}\begin{Bmatrix}\varepsilon_{LL}\\ \varepsilon_{TT}\\ \gamma_{LT}\end{Bmatrix}-\Delta T\underbrace{\begin{Bmatrix}\frac{E_L(\alpha_L+\nu_{TL}\alpha_T)}{1-\nu_{LT}\nu_{TL}}\\ \frac{E_T(\alpha_T+\nu_{LT}\alpha_L)}{1-\nu_{LT}\nu_{TL}}\\ 0\end{Bmatrix}}_{\vec{h}} \qquad (A-15)$$

Strain Transformation Law (material-local)

$$\begin{Bmatrix}\varepsilon_{LL}\\ \varepsilon_{TT}\\ \gamma_{LT}\end{Bmatrix}=\underset{[T]}{\begin{bmatrix}\ell_{Lx}^2 & \ell_{Ly}^2 & \ell_{Lx}\ell_{Ly}\\ \ell_{Tx}^2 & \ell_{Ty}^2 & \ell_{Tx}\ell_{Ty}\\ 2\ell_{Lx}\ell_{Tx} & 2\ell_{Ly}\ell_{Tx} & \ell_{Ly}\ell_{Tx}+\ell_{Ty}\ell_{Lx}\end{bmatrix}}\begin{Bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \gamma_{xy}\end{Bmatrix} \qquad (A-16)$$

where $\ell_{Lx} = \vec{e}_L^T \cdot \vec{e}_x = \cos\theta$, $\ell_{Tx} = \vec{e}_T^T \cdot \vec{e}_x = -\sin$

$\ell_{Ly} = \vec{e}_L^T \cdot \vec{e}_y = \sin\theta$, $\ell_{Ty} = \vec{e}_T^T \cdot \vec{e}_y = \cos\theta$

Note: the direction of $\vec{e}_2$ is chosen so that

$(\vec{e}_1 \times \vec{e}_2) \cdot (\vec{e}_x \times \vec{e}_y) > 0.$

Stress-Displacement Relation

$$\begin{Bmatrix}\sigma_{LL}\\ \sigma_{TT}\\ \gamma_{LT}\end{Bmatrix} = [D][T][B]\,\tilde{u} - \Delta T \cdot \vec{h} \qquad (A-17)$$

Local-Reference Displacement Relation

same as type 2

Stiffness Matrix (local coordinate)

$$K = K_n + K_s \tag{A-18}$$

$$K_n = \frac{t}{2bh(1-\nu_{LT}\nu_{TL})}\begin{bmatrix} C_1(s-b)^2 & -C_2(s-b)h & -C_1(s-b)s & C_2(s-b)h & C_1(s-b)b & 0 \\ & C_2h^2 & C_2hs & -C_3h^2 & -C_2bh & 0 \\ & & C_1s^2 & -C_2hs & -C_1bs & 0 \\ & \text{Symm} & & C_2h^2 & C_2bh & 0 \\ & & & & C_1b^2 & 0 \\ & & & & & 0 \end{bmatrix} \tag{A-19}$$

where

$$C_1 = \rho^4 E_L + 2\rho^2\mu^2\nu_{LT}E_T + \mu^4E_T$$

$$C_2 = \rho^2\mu^2E_L + (\rho^4 + \mu^4)\nu_{LT}E_T + \rho^2\mu^2E_T$$

$$C_3 = \mu^4E_L + 2\rho^2\mu^2\nu_{LT}E_T + \rho^4E_T$$

$$\nu_{LT}E_T = \nu_{TL}E_L$$

$$\rho = \sin\theta$$

$$\mu = \cos\theta$$

$K_s =$

$$\left[\begin{array}{c|c|c|c|c|c}
(s-b)^2 D_1 + 2h(s-b)D_2 + h^2 D_3 & & & \text{Symm.} & & \\
\hline
h(s-b)D_1 + [h^2-(s-b)^2]D_2 - h(s-b)D_3 & h^2 D_1 - 2h(s-b)D_2 + (s-b)^2 D_3 & & & & \\
\hline
-s(s-b)D_1 - (2s-b)hD_2 - h^2 D_3 & -hsD_1 [(s-b)s-h^2]D_2 + (s-b)h\,D_3 & s^2 D_1 + 2hsD_2 + h^2 D_3 & & & \\
\hline
-h(s-b)D_1 + [(s-b)s-h^2]D_2 + sh\,D_3 & -h^2 D_1 + h(2s-b)D_2 - s(s-b)D_3 & hsD_1 + (h^2-s^2)D^2 - hs\,D_3 & h^2 D_1 - 2hs\,D_2 + s^2 D_3 & & \\
\hline
b(s-b)D_1 + bh\,D_2 & bhD_1 - b(s-b)D_2 & -bsD_1 - bh\,D_2 & -bhD_1 + bs\,D_2 & b^2 D_1 & \\
\hline
-b(s-b)D_2 - bh\,D_3 & -bhD_2 + b(s-b)D_3 & bs\,D_2 + bh\,D_3 & bh\,D_2 - bs\,D_3 & -b^2 D_2 & b^2 D_3
\end{array}\right] \qquad (A-20)$$

where $D_1 = 4\rho^2\mu^2$

$D_2 = 2\rho\mu(\rho^2-\mu^2)$

$D_3 = (\rho^2-\mu^2)^2$

Equilibrium Equation (local coordinate)

$$K\,\tilde{u} + \vec{h} = \vec{f}$$

$$\vec{h} = t\,\Delta T \begin{Bmatrix} -(b-s)(\rho^2 h_1 + \mu^2 h_2) + 2h\rho\mu(h_1 - h_2) \\ -h(\mu^2 h_1 + \rho^2 h_2) + 2(b-s)\rho\mu(h_1 - h_2) \\ -s(\rho^2 h_1 + \mu^2 h_2) - 2h\rho\mu(h_1 - h_2) \\ h(\mu^2 h_1 + \rho^2 h_2) + 2s\rho\mu(h_1 - h_2) \\ b(\rho^2 h_1 + \mu^2 h_2) \\ -2b\rho\mu(h_1 - h_2) \end{Bmatrix} \qquad \text{(A-21)}$$

where

$$h_1 = -\frac{E_L(\alpha_L + \nu_{TL}\alpha_T)}{1-\nu_{LT}\nu_{TL}}$$

$$h_2 = -\frac{E_T(\alpha_T + \nu_{LT}\alpha_L)}{1-\nu_{LT}\nu_{TL}}$$

Consistent Mass Matrix (reference coordinate)

same as type 2

4. Type 4 - SSP: Symmetric shear panel element with uniform thickness and isotropic material

This is a special element used to model relatively thin symmetric structures such as idealized supersonic lifting surfaces. Theoretical discussion is given in Ref. 1. It is assumed that this element models the upper (or lower but not both) half of the symmetric structure and the element plane of symmetry coincides with the X-Y plane. It is further assumed that all SSP elements are placed vertically with respect to the X-Y reference coordinate plane.

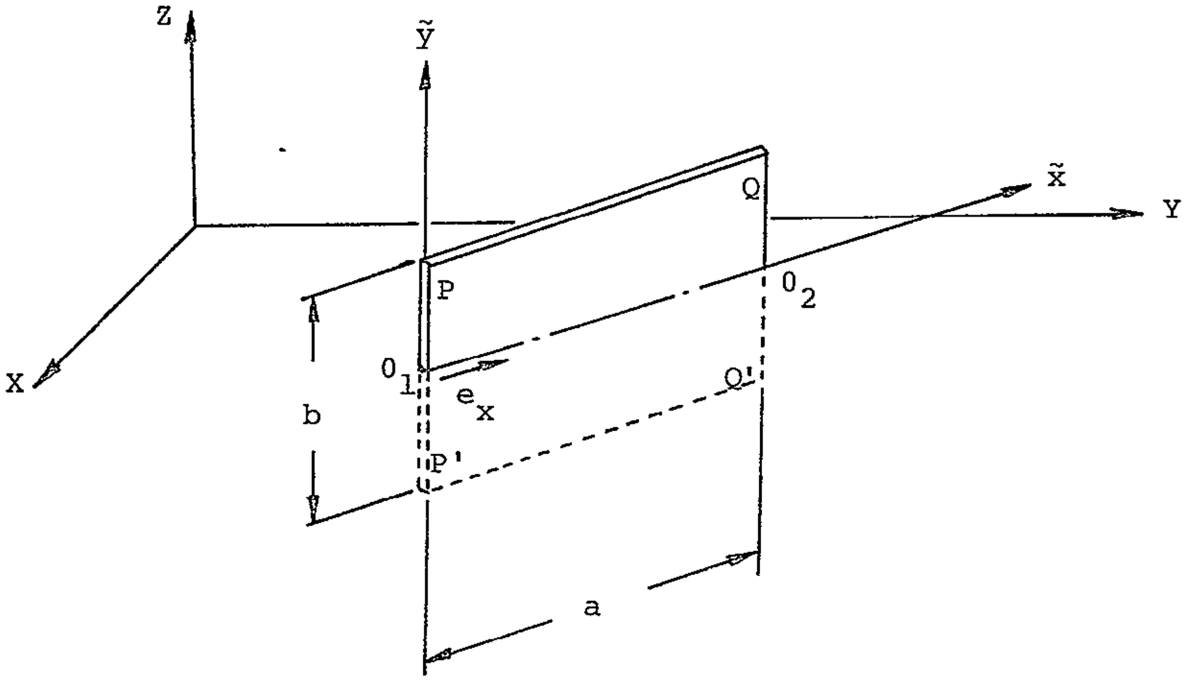


Fig. A-4 SSP Element

Note:

1. There are only two nodes per element.
2. The line of intersection with the XY plane does not move in the XY plane. It can only move vertically.

3. If the heights PP' and QQ' are different, the average (PP' + QQ')/2 is considered as the height of the element, i.e. b.

4. No thermal load can be considered in this element

Strain Displacement Relation (local coordinate)

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} -\frac{2\eta}{a} & 0 & \frac{2\eta}{a} & 0 \\ \frac{2\nu\eta}{a} & 0 & \frac{2\nu\eta}{a} & 0 \\ \frac{1}{b} & -\frac{1}{a} & \frac{1}{b} & \frac{1}{a} \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} \qquad \text{(A-22)}$$

$\tilde{\varepsilon} = [B]u$

wherein $\eta \doteq \tilde{Y}/b$

Stress-Strain Relation (local coordinate)

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \qquad \text{(A-23)}$$

Stress Displacement Relation (local coordinate)

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = E \begin{bmatrix} -\frac{2\eta}{a} & 0 & \frac{2\eta}{a} & 0 \\ 0 & 0 & 0 & 0 \\ \frac{1}{2(1+\nu)b} & \frac{1}{2(1+\nu)a} & \frac{1}{2(1+\nu)b} & \frac{1}{2(1+\nu)a} \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} \qquad \text{(A-24)}$$

Local to Reference Displacement Transformation

$$\begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} = \begin{bmatrix} \ell_x & m_x & 0 & & & \\ & & & & 0 & \\ 0 & 0 & \pm 1^* & & & \\ & & & \ell_x & m_x & 0 \\ & 0 & & & & \\ & & & 0 & 0 & \pm 1^* \end{bmatrix} \begin{Bmatrix} U_P \\ V_P \\ W_P \\ U_Q \\ V_Q \\ W_Q \end{Bmatrix} \qquad \text{(A-25)}$$

*(-) sign if $Z_P < 0$ and $Z_Q < 0$

where ℓ_x and m_x are components of a unit vector $\vec{e}_x$ along the local $\tilde{x}$ axis.

Stiffness Matrix (local coordinate)

$$K = \frac{Et}{12(1+\nu)} \begin{bmatrix} F+3\alpha & -3 & -F+3\alpha & 3 \\ & 3/\alpha & -3 & -3/\alpha \\ \text{Symm.} & & F+3\alpha & 3 \\ & & & 3/\alpha \end{bmatrix} \qquad \text{(A-26)}$$

where $\alpha = \frac{a}{b}$

$F = \frac{2(1+\nu)}{\alpha}$

Consistent Mass Matrix (local coordinate)

$$M = \frac{\rho abt}{2} \begin{bmatrix} \frac{1}{9} + G & -\frac{1}{12} H & 0 & \frac{1}{18} - G & -\frac{1}{12} H & 0 \\ & \frac{1}{3} & 0 & \frac{1}{12} H & \frac{1}{6} & 0 \\ & & \frac{1}{9} & 0 & 0 & \frac{1}{18} \\ & & & \frac{1}{9} + G & \frac{1}{12} H & \frac{1}{3} \\ & \text{Symm.} & & & \frac{1}{3} & 0 \\ & & & & & \frac{1}{9} \end{bmatrix} \qquad \text{(A-27)}$$

where ρ = density

$$G = \frac{\alpha^2}{30} + \frac{\nu}{18} + \frac{\nu^2}{30\alpha^2}$$

$$H = \alpha + \frac{1}{\alpha}$$

It may look strange that the mass matrix depends upon Poisson's ratio ν through G. This is due to the fact that the assumed displacement field is derived based on assumed stress field. (see Refs. 1 and 3)

5. Type 5 - PSP: Pure symmetric shear panel element with uniform thickness and isotropic material

This element is identical to a type 4 (SSP) element, except for a minor change in the assumed displacement state so that the stress state of the element is pure shear: i.e. $\sigma_x = \sigma_y \equiv 0$. This implies that $\varepsilon_x = \varepsilon_y \equiv 0$.

Strain Displacement Relation (local coordinate)

$$\gamma_{xy} = \left[\frac{1}{b}, - \frac{1}{a}, \frac{1}{b}, \frac{1}{a} \right] \left\{ \tilde{u}_P, \tilde{v}_P, \tilde{u}_Q, \tilde{v}_Q \right\}^T \tag{A-28}$$

Stress-Strain Relation (local coordinate)

$$\tau_{xy} = \frac{E}{2(1+\nu)} \gamma_{xy} \tag{A-29}$$

Stress-Displacement Relation

$$\tau_{xy} = \frac{E}{2(1+\nu)} \left[\frac{1}{b}, - \frac{1}{a}, \frac{1}{b}, \frac{1}{a} \right] \left\{ \tilde{u}_P, \tilde{v}_P, \tilde{u}_Q, \tilde{v}_Q \right\}^T. \tag{A-30}$$

Local to Reference Displacement Transformation

same as type 4.

Stiffness Matrix (local coordinate)

same as type 4 except $F \equiv 0$.

Mass Matrix

Assumed to be the same as type 4.

6. Type 6 - TSP: Thermal symmetric shear panel element with uniform thickness and isotropic material

Since SSP and PSP cannot be used for problems involving thermal loads, this special element is added to the ACCESS-2 element library. The TSP element is designed to be used under steady thermal soak load conditions such that the temperature change in each TSP element is uniform and therefore symmetric with respect to the X-Y plane.

If the structure is subject to both mechanical and thermal loads, two structural models must be created and analyzed separately. One model is to use SSP elements to model shear panels and it is subject to only mechanical loads. The other model uses TSP elements to model the shear panels and it is subject to only thermal soak loads. These two models are created automatically, if the user specifies both SSP and TSP elements. Displacement and stress states of the structure subject to both thermal and mechanical loads are generated by superimposing the results obtained from the two separate models.

Theoretically, it is also possible to consider the PSP - TSP element combination, but this is not implemented in the current version of ACCESS-2.

Note that the TSP option requires a significant amount of core memory and CPU time, since two system stiffness matrices are stored and decomposed. Sensitivity analyses of the responses must be carried out separately and superimposed afterwards. Therefore, analysis effort is nearly doubled when thermal effects need to be considered.

Strain-Displacement Relation (local coordinates)

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} -\frac{1}{a} & -\frac{\nu}{b}(1-\frac{2x}{a}) & \frac{1}{a} & \frac{\nu}{b}(1-\frac{2x}{a}) \\ 0 & \frac{2}{b}(1-\frac{x}{a}) & 0 & \frac{2x}{ab} \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} \qquad \text{(A-31)}$$

Stress-Strain Relation

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1+\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} - \frac{E\alpha\Delta T}{1-\nu} \begin{Bmatrix} 1 \\ 1 \\ 0 \end{Bmatrix} \qquad \text{(A-32)}$$

Stress-Displacement Relation

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \gamma_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \left[\begin{array}{c|c|c|c} -\frac{1}{a} & \frac{\nu}{b} & \frac{1}{a} & \frac{\nu}{b} \\ \hline -\frac{\nu}{a} & \frac{1}{b}[2-\nu^2-\frac{2(1-\nu^2)}{a}x] & \frac{\nu}{a} & \frac{1}{b}[\nu^2+\frac{2(1-\nu^2)}{a}x] \\ \hline 0 & 0 & 0 & 0 \end{array} \right] \begin{Bmatrix} u_P \\ v_P \\ u_Q \\ v_Q \end{Bmatrix}$$

$$- \frac{E\alpha\Delta T}{1-\nu} \begin{Bmatrix} 1 \\ 1 \\ 0 \end{Bmatrix} \qquad \text{(A-33)}$$

Local to reference displacement transformation

same as type 4

Stiffness Matrix (local coordinate

$$K = \frac{Et}{2(1-\nu^2)} \begin{bmatrix} \frac{1}{\alpha} & -\nu & -\frac{1}{\alpha} & -\nu \\ & \frac{4-\nu^2}{3}\alpha & \nu & \frac{2+\nu^2}{3}\alpha \\ & & \frac{1}{\alpha} & \nu \\ \text{Symm.} & & & \frac{4-\nu^2}{3}\alpha \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} \tag{A-34}$$

where $\alpha = \frac{a}{b}$

Force Displacement Relation (local coordinate)

$$K\,\tilde{u} - \frac{E\alpha\Delta T\ t}{2(1-\nu)} \begin{Bmatrix} -b \\ a \\ b \\ a \end{Bmatrix} = \tilde{f} \tag{A-35}$$

Consistent Mass Matrix

Assumed to be the same as type 4

Note: As shown in the stress-displacement relation, stress distribution is linear with respect to x. In order to simplify the problem, an approximate stress displacement relation is used in computing stress and stress sensitivity.

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \end{Bmatrix}_{\text{approx.}} = \frac{E}{1-\nu^2} \begin{bmatrix} -\frac{1}{a} & \frac{\nu}{b} & \frac{1}{a} & \frac{\nu}{b} \\ -\frac{\nu}{a} & \frac{1}{b} & \frac{\nu}{a} & \frac{1}{b} \end{bmatrix} \begin{Bmatrix} \tilde{u}_P \\ \tilde{v}_P \\ \tilde{u}_Q \\ \tilde{v}_Q \end{Bmatrix} - \frac{E\alpha\Delta T}{1-\nu} \begin{Bmatrix} 1 \\ 1 \end{Bmatrix} \qquad \text{(A-36)}$$

APPENDIX B

INPUT DATA DESCRIPTION

I. Job description and heading cards (I1, 79A1)

The first column is used as follows

0 or blank: ordinary heading cards, whose contents in columns 2-80 will be printed on the first page of the output.

1 : indicates that this is the last heading card and input data cards follow.

2 : request for immediate normal termination of this job.

Any number of cards may be used to describe or to comment the job. Note that the last heading card must have "1" punched in the first column. Without this, all of the data may be regarded as heading cards.

II. Primary control cards

Card 1 (7I5)

IOPT : 1 = Input data check only
2 = Structural analysis only
3 = Structural analysis and constraint function evaluation
4 = optimization by the NEWSUMT optimizer
5
: } Not used yet

IPRINT : Printout control parameter except for output from each optimizer.
2 = Standard output

IGLINK : 0 = standard execution

-200 = removal of stress constraint regionalization

-300 = removal of stress constraint regionalization for fixed size elements only

IANALY(1)-IANALY(4)

: Not required to specify (leave as blanks) if IOPT $\geq$ 4. Must specify if IOPT $\leq$ 3.

IANALY(1) : 1 = Compute displacement

0 = Skip displacement calculation

IANALY(2) : 1 = Compute stress/strain for all elements

0 = Skip stress/strain calculation

IANALY(3) : 1 = Compute eigenanalysis

0 = Skip eigenanalysis

IANALY(4) : 0 always

Card 2 (10I5)

IN : Total number of nodes

IBN : Number of boundary nodes

INL : Number of load conditions

IMATIS : Number of isotropic materials

IMATOR : Number of orthotropic materials

INITVG : Number of initial value groups for design varia

ILOWBG : Number of minimum size groups for design variab

IUPPBG : Number of maximum size groups for design variab

ITHLDG : Number of thermal load groups

IPRLDG : Number of pressure load groups

Card 3 (10I5)

IETP(i), i = 1,2,...10

Number of elements in the i-th element type

i = 1	TRUSS	
2	CSTIS	CST isotropic
3	CSTOR	CST orthotropic
4	SSP	symmetric shear panel
5	PSP	pure shear panel
6	TSP	thermal shear panel

III. Node Coordinates (I5, 5X, 3E10.4)

IN cards are required to specify the node coordinates of node numbers 1 through IN. The order of the cards may be random.

n_i : Number of the i-th node
Xn_i : X coordinate of the node n_i
Yn_i : Y coordinate of the node n_i
Zn_i : Z coordinate of the node n_i

IV. Boundary Conditions (4I5, 3E10.4)

If all 3 degrees of freedom associated with a node are free, the node is not a boundary node. Otherwise it is a boundary node and for each boundary node, a card is required.

bn_i : i-th boundary node number

$$\left.\begin{array}{l} IBX_{bn_i} : \\ IBY_{bn_i} : \\ IBZ_{bn_i} : \end{array}\right\} \text{constraint code: } \begin{array}{l} 0 = \text{free} \\ 1 = \text{fixed} \\ 2^* = \text{prescribed nonzero displacement} \end{array}$$

---

* not available in the current version

$$\left.\begin{array}{ll} PDX_{bn_i} & : \\ PDY_{bn_i} & : \\ PDZ_{bn_i} & : \end{array}\right\}$$ prescribed nonzero displacements required only for constrain code = 2

V. Element Data

If IETP(i) = 0 for the i-th element type, no data is required. For each element type with IEPT(i)≠ 0, IETP(i)+1 cards are required.

Card 1 : element type number (I5)

Card 2-IETP(i)+1 : element information (11I5)

M_i : element number

NP : node number corresponding to the internal node number P

NQ : node number Q

NR : node number R

NS : node number S

LGN : linking group number, = 0 for the fixed size elements

IGN : initial value group number

LBGN : lower bound group number

UBGN : upper bound group member

MTLGN : material group number

> 0 for isotropic materials : 1,2,...

< 0 for orthotropic materials: -1,-2,...

SCC : side constraint code

-1 : element size restricted by the lower bound only

0 : non negativity constrain only

1 : element size restricted by the upper bound only

2 : element size restricted both by lower and upper bounds

Comments

1. Elements must be numbered starting from 1 through IETP(i) for each element type. For example, if a structure is modeled using 100 TRUSS elements and 300 CST elements, TRUSS element numbers are 1,2,3,...100 and CST element numbers are 1,2,3...300. Within an element type, order of element data cards may be random.
2. NR and/or NS are not required for element types with only 2 or 3 nodes per element.
3. LGN, linked group number starts from 1 for each element type. For example, if a structure is modeled with 100 TRUSS and 300 CST elements, with 10 and 30 design variables allocated to TRUSS and CST, respectively, then the linked group number for TRUSS runs from 1 through 10 and that for CST ranges from 1 through 30.

VI. Initial Values (7E10.4)

INITVG real numbers must be given. If INITVG > 7, two or more cards are required. The first value of the first card indicates the initial value for the group number 1, and so on.

VII. Lower Bound Values (7E10.4)

Minimum gauge values. ILOWBG real numbers must be given.

If ILOWBG > 7, two or more cards are required. If ILOWBG = 0, no card is required.

VIII. Upper Bound Values (7E10.4)

Maximum gauge values. IUPPBG real numbers must be given. If IUPPBG > 7, two or more cards are required. If IUPPBG = 0, no card is required.

IX. Isotropic Material Data (6E10.4)

IMATIS cards are required and on each card the following 6 real numbers must be given.

E : Elastic modulus
ν : Poisson's ratio
γ : Specific weight
α : Thermal expansion coefficient
σ_{LB} : Allowable compression stress
σ_{UB} : Allowable tensile stress

X. Orthotropic Material Data (7E10.4/7E10.4/6E10.4)

IMATOR X 3 cards are required, i.e. for each material group 3 cards are required, containing the following data.

<u>Card 1</u>

E_L : Longitudinal elastic modulus
E_T : Transverse elastic modulus
G_{LT} : Shear modulus
ν_{LT} : Longitudinal Poisson's ratio
γ : Specific weight
α_L : Longitudinal thermal expansion coefficient
α_T : Transverse thermal expansion coefficient

Card 2

ℓ_L : Direction cosines of the longitudinal
m_L : axis with respect to system reference
n_L : coordinates
ε_L^t : Tensile allowable longitudinal strain
ε_L^c : Compressive allowable longitudinal strain
ε_T^t : Tensile allowable transverse strain
ε_T^c : Compressive allowable transverse strain
γ_{LT} : Allowable shear strain
F_L^t : Tensile allowable longitudinal stress
F_L^c : Compressive allowable longitudinal stress
F_T^t : Tensile allowable transverse stress
F_T^c : Compressive allowable transverse stress
F_{LT} : Shear allowable stress

Comments

1. The transverse Poisson's ratio ν_{TL} is internally computed using the relation $\nu_{TL}E_L = \nu_{LT}E_T$
2. Depending upon the failure criteria applied to the specific material, either strain allowables or stress allowables are left unspecified. Failure criteria options will be specified later in the category XX.

XI. Lumped Nodal Loads

Two card groups are required to specify lumped nodal loads applied to the structure.

Card Group 1 (14I5)

Number of nodes subject to lumped nodal loads for each load conditions. INL integer numbers must be given.

Card Group 2 (I5, 5X, 3E10.4)

For each load condition, the specified number (by the group 1 cards) of cards must be given to identify the node numbers and associated load components in the reference coordinate system.

XII. Pressure Load Data

No card is required if IPRLDG = 0. If IPRLDG > 0, the following 5 groups of cards must be given.

Card Group 1 (10I5)

Number of elements subject to pressure load for each element type. (Presently, only CSTIS and CSTOR elements can be subject to pressure loads).

Card Group 2 (14I5)

Pressure load ON-OFF flag for each load condition.

$ONOFF^k$ = 0 No pressure load for load condition k

- 1 Pressure load should be considered for the k-th load condition.

Card Group 3 (14I5)

Element numbers subject to pressure loads for all member types corresponding to $NEPL^{MTYP} \neq 0$. For each element type, the first element number subject to pressure load must be punched in columns 1-5; namely the group 3 cards should be subgrouped for different element types.

Card Group 4 (14I5)

For each load condition corresponding to a load condition with $\mathrm{ONOFF}^k = 1$, an identical amount of data similar to that specified in the card group 3 must be given. Those numbers designate the pressure magnitude group numbers, which are the pointers to the pressure magnitude applied to the corresponding element type and element number. This set of cards should be given for all load conditions with $\mathrm{ONOFF}^k = 1$.

Card Group 5 (7E10.4)

Pressure load magnitude for each pressure load group must be given. IPRLDG real numbers are required.

Comments:

1. The direction of the pressure force is determined by the node numbering scheme of the triangular element and also by the sign of the pressure load magnitude specified in the card group 5. When the P, Q and R nodes of the triangle are in counter clockwise order and the corresponding pressure magnitude has a positive sign, positive pressure is applied to the surface of the triangular region.

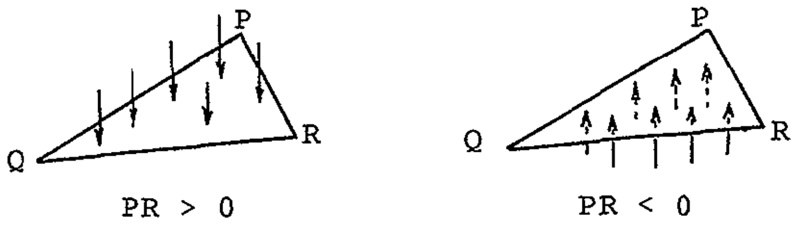


Fig. B-1 Pressure Load Sign Convention

2. Pressure applied on a single triangular surface must be uniform; no variation of pressure over an elements surface can be represented.

XIII. Inertia Load Data

Self-weight in a gravitational field or uniform translational acceleration will be accounted for by specifying this set of data. Note that rotational inertia loads cannot be considere Two groups of cards are required.

Card Group 1 (14I5)

INERTL^k : k = 1,2,...INL

Interia load ON-OFF for each load condition.

1 : Inertia load exists

2 : No inertia load for the load condition

Card Group 2 (4E10.4)

For each load condition with $\text{INERTL}^k \neq 0$, one card will be required.

ACC^k : Magnitude of acceleration in units of the standard earth gravitational field (i.e. 4g)

$$\left.\begin{array}{l}X :\\ Y :\\ Z :\end{array}\right\}$$ Direction cosine components of the acceleratio vector in the reference coordinate system.

XIV. Thermal Load Data

No card is required if ITHLDG = 0. If ITHLDG > 0, the following 5 groups of cards must be given.

Card Group 1 (10I5)

Number of elements subject to thermal load for each element type.

Card Group 2 (14I5)

Thermal load ON-OFF flag for each load condition.

$\text{ON-OFF}^k = 0$ No thermal load for load condition k

1 Thermal load should be considered for the k-th load condition.

Card Group 3 (14I5)

Element numbers subject to thermal loads for all member types corresponding to $\text{NETH}^{\text{MTYP}} \neq 0$. For each element type, the first element number subject to thermal load must be punched in columns 1-5; namely the group 3 cards should be subgrouped for different element types.

Card Group 4 (14I5)

For each load condition corresponding to the load condition with $\text{ON-OFF}^k = 1$, an identical amount of data similar to that specified in the card group 3 must be given. Those numbers designate the temperature magnitude applied to the corresponding element type and element number. This set of cards should be given for all load conditions with $\text{ONOFF}^k = 1$.

Card Group 5 (7E10.4)

Temperature change for each thermal load group must be given. ITHLDG real numbers are required.

Comments:

1. Each element is considered to have uniform temperature.
2. Temperature change should be computed with respect to an appropriate uniform reference temperature. Note

that if all elements are made of the same material and assume the same temperature, then thermal stress are not induced.

XV. Flight Condition Data

This block of data will be reserved for future development of ACCESS-2 program which may include flutter constrains. Specify 0 for all $IFLIGH^k$, $k = 1,2,\ldots INL$.

No additional cards are required.

XVI. Lumped Nodal Mass Data

Card 1 (I5)

NMASS : Number of lumped nodal masses

Card 2-(NMASS+1) (I5, 5X, E10.4)

: Node number to which the mass is attached.

: Weight of the mass

Comment:

Note that the magnitude must be given in weight units, not in mass units.

XVII-XXII Constraint Control Data

There are 5 types of constrains which can be specified. Each constraint type may have different truncation control, although the method used is identical for all types of constraints. The truncation strategy is similar to the one used in ACCESS-1, but the sign of feasible region is reversed. If a g^{th} constraint function at a design $\vec{\alpha}$ is evaluated as $h_q(\vec{\alpha})$, $h_q(\vec{\alpha})$ is compared with a truncation boundary value (TBV) which is determined by

$$\mathrm{TBV} = + \{\underset{q}{\mathrm{Min}}[h_q(\vec{\alpha}) - C]\} \times \mathrm{TRF} + C,$$

where $\underset{q}{\mathrm{Min}}$ is applied to all q's in the constraint type. Initially, TRF is set to be TRF-initial and at the end of each design state, TRF is updated by

$$\mathrm{TRF} = \mathrm{TRF} \times (\mathrm{TRF\ multiplier})$$

Since TRF-multiplier is chosen to be less than 1, TBV is decreased stage by stage, which means more and more constraints are truncated as the design proceeds.

XVII. Side Constraint Control Data

Since side constraint codes are specified in the element data, only truncation control parameters are specified:

TRF-initial : Initial truncation factor
TRF-max : Upper limit of TRF
C-cutoff : Cutoff base value
TRF-multiplier : TRF modification multiplier

XVIII. Displacement Constraint Control Data

Card 1 (I5)

NDPC : Number of constrained displacement degrees of freedom

Card 2 (E10.4)

TRF-initial : Initial truncation factor
TRF-max : Upper limit of TRF
C-cutoff : Cutoff base value
TRF-multiplier : TRF modification multiplier

Min. Norm Ftr. : Minimum constraint normalization factor. Constraints are usually normalized by the absolute values of the limiting values.

Card 3 - (NDPC+2) (3I5, 5X, 2E10.4)

Node $_i$: Node number associated with the i-th displacement constraint

Ixyz : Direction identifier

0 = not used
1 = X direction
2 = Y direction
3 = Z direction

Code : -1 = Lower bound only
0 = No constraint
1 = Upper bound only
2 = Both

Lower Bound : Lower bound of the displacement component

Upper Bound : Upper bound of the displacement component

XIX. Slope/Relative Displacement Constraint Control Data

This constraint type is restricted to place bounds on relative displacement components of two arbitrary nodes. In other words, the difference between Y-displacement components of the L^{th} and U^{th} nodes may be bounded. But the difference between the Z-displacement of L^{th} and X-displacement component of U^{th} node cannot be bounded.

Card 1 (I5)

NSLC : Number of slope/rel-displacement constraints

Card 2 (5E10.4)

TRF-initial : Initial truncation factor

TRF-Max : Upper limit of TRF

C-cutoff : Cutoff base value

TRF-multiplier : TRF modification multiplier

Min. Norm. Ftr : Minimum constraint normalization factor

Card 3-(NSLC+2) (3I5, E10.4)

Node$_i^{(L)}$: Node number of the Lth node associated with the ith slope constraint

Node$_i^{(U)}$: Node number of the Uth node associated with the ith slope constraint

I_{xyz} : Direction and code

0	:	not used	
1	:	X direction	relative displacement
2	:	Y direction	
3	:	Z direction	
4	:	X direction	slope
5	:	Y direction	
6	:	Z direction	

Upper Bound : Upper bound of the slope/rel. displ.

Note:

1. If $I_{xyz} = 1$, for example, the constraint function is

$$1 - (U_x^{Node^{(U)}} - U_x^{Node^{(L)}})/\text{Upper Bound} \geq 0$$

2. If $I_{XYZ} = 4$, for example, constraint function is

$$1 - \frac{U_X^{\text{Node}^{(U)}} - U_X^{\text{Node}^{(L)}}}{\bar{D}_{YZ}} \text{/Upper-bound} \geq 0$$

where $\bar{D}_{YZ}$ is the projection of the distance between node $^{(U)}$ and node $^{(L)}$ to the Y-Z plane.

3. If lower bound is to be specified, node$^{(L)}$ and node$^{(U)}$ should be exchanged to transform it to an upper bound constraint.

XX. Stress/Strain Constraint Data

Card 1 (10I5)

Code $^{\text{MTYP}}$: Stress/Strain constraint code

Except for element type 3

-1 = read stress constrain code element by element

0 = no stress constraint

1 = all elements in this element type are constraine by lower bounds on compression stress

2 = all elements in this element type are constraine by upper bounds on tensile stress or Von Mises combined stress (Element Type 1 or Types 2,4,5,6

3 = effectively this implies that both codes 1 and 2 are applied simultaneously

For element type 3

-1 = read strain constraint code element by element

0 = no strain constraint imposed

1 = maximum strain envelope criteria imposed on all elements

2 = stress interaction criteria imposed on all eleme

3 = Tsai-Azzi criteria imposed on all elements

Card 2 (7E10.4)

TRF-initial : Initial truncation factor

TRF-max : Upper limit of TRF

C-cutoff : Cutoff base value

TRF-multiplier : TRF modification multiplier

Min.Stress Norm Ftr. : Minimum stress constraint normalization factor

Min.Strain Norm Ftr. : Minimum strain constraint normalization factor

TEBCF : Truss Euler buckling control factor

If TEBCF < 0, TEBCF stands for the specified mean radius r of the truss element assuming tubular cross section. Stress constraint is

$$\sigma \geq \mathrm{Max}\{\sigma^{c}_{\mathrm{allowable}} \quad -\pi^{2}Er/2\ell^{2}\}$$

If TEBCF > 0, it stands for the thickness to mean radius ratio of the truss element (r) assuming cylindrical cross section stress constraints

$$\sigma \geq \mathrm{Max}\{\sigma^{c}_{\mathrm{allowable}} \quad -\pi^{2}EA/[4\ell^{2}\cdot(\frac{t}{r})]\}$$

If TEBCF = 0, no Euler buckling constraints are considered.

Card 3 - (14I5)

Stress/strain constraint specification for element type code, Code $^{MTYP} < 0$. If all Code ^{MTYP} are positive, no cards are required.

For each element type with Code $^{MTYP} = -1$, stress/strain code must be given to all elements sequentially starting from element number 1.

Element stress/strain constraint code.

Stress code

-1 : only compression side is bounded

0 : no constraint

+1 : only tensile (truss only) or Von Mises combined stress is bounded

+2 : both compressive and tensile stress are bounded.

Strain code

same as Code^{MTYP} specification

XXI. Natural Frequency Constraint Data

Card 1 (2I5)

NFREQ : number of lowest frequencies to be bounded

NSPACE : frequency constraint approximation scheme

0 = first order Taylor series expansion with respect to linked reciprocal variables (linear in the optimization design space).

1 = first order Taylor series expansion with respect to linked direct variables (nonlinear constrain in the optimization design space)

2 = second order Taylor series expansion with respect to linked direct variables

Card 2 (7E15.6)

TRF-initial : Initial truncation factor
TRF-max : Upper limit of TRF
C-cutoff : Cutoff base value
TRF-multiplier : TRF modification multiplier
Min.Norm.Ftr. : Minimum constraint normalization factor
Eig. Conv. : Eigenvalue analysis convergence criteria (see note below)
Acc. Gravity : Acceleration of gravity If 0.0, American standard unit is assumed and replaced by 386.0 in/sec^2.

Note: Subspace iteration algorithm is used to obtain eigenvalues and eigenvectors. Iteration is judged to be converged if the relative differences of all eigenvalues are less than Eig. Conv.

Card 3 (I5, 2E10.4)

Code$^{f=1}$: constraint code

-1 = lower bound only
0 = not bounded
1 = upper bound only
2 = lower and upper bounds

Lower Bound : lower bound on the i^{th} frequency
Upper Bound : upper bound on the i^{th} frequency

XXII. Not used

Card 1 : supply one blank card.

XXIII. NEWSUMT Optimizer Control Card

Card 1 :

JPRINT : Optimizer printout control
standard output = 0

MAXSTG : Maximum allowable number of stages

MAXRSF : Maximum number of response surfaces per stage; i.e. response factor is reduced MAXRSF times before the approximate problem is updated.

MAXODM : Maximum allowable number of one dimensional minimization per response surface

JSIGNG : sign of feasible region
1 : feasible region is $q_q(\vec{\alpha}) \geq 0$
-1 : feasible region is $q_q(\vec{\alpha}) \leq 0$

Card 2 and 3 :

EPSSTG : Stage convergence criterion.
Overall iteration is judged to be converged if both of the following conditions are satisfied at the end of the P^{th} stage.

$$|W_P - W_{P-1}|/W_P \leq \text{EPSSTG}$$

$$|W_{P-1} - W_{P-2}|/W_{P-1} \leq \text{EPSSTG}$$

EPSODM : Unconstrained minimization convergence criterion. Convergence is obtained if the relative values of total function at the ends of 3 successive one dimensional minimzations are not different by EPSODM.

RACUT : Response factor decrease ratio

STEPMX : Maximum step size at each stage. All design variable components are constrained by

$$\frac{1}{\text{STEPMX}} \le \beta_i \le \text{STEPMX}. \quad i = 1,\dots B.$$

ITP : Initial transition point for the extended penalty function

Power Fr : specify = 0.5

Coefficient : specify = 1.0

STEPMX-mul : Maximum step size modification multiplier

STEPMX-L.L. : Lower limit on the STEPMX

ACCESS-2 CARD IMAGE FORMAT (1)

column number

5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
	Heading Cards (any number of cards)													
1	Last Heading Card ("1" in column 1)													
IOPT	IPRINT	IGLINK	IANALY(1) ~ IANALY(4)				MFLAG			Master Control Cards				
IN	IBN	INL	IMATIS	IMATOR	INITVG	ILOWBG	IUPPBG	ITHLDG	IPRLDG					
IEPT(1)			~					IETP(10)						
Node No n_i	not-used	X_{n_i}		Y_{n_i}		Z_{n_i}			Node Coordinates "IN" Cards					
Boundary Node No				Prescribed Nonzero Displacements (not yet available)						Boundary Conditions "IBN" Cards				
bn_i	IBX_{bn_i}	IBY_{bn_i}	IBZ_{bn_i}	DX_{bn_i}		DY_{bn_i}		DZ_{bn_i}						
MTYP														
Element -No	P-Node -No-	Q-Node -No	R-Node No	S-Node No	Linking Group No	Initial Value Group No	Lower Bound Group No	Upper Bound Group No	Material Group No	Side Constraint Code	IETP(MTYP) Cards		Repeat for All Element Types with IETP(MTYP)≠0	
M_i														

ACCESS-2 CARD IMAGE FORMAT (2)

column number 5 10	15 20	25 30	35 40	45 50	55 60	65 70	75
$D^{Initial}_{Group=1}$	$D^{Initial}_{Group=2}$					$D^{Initial}_{Group=7}$	
$D^{Initial}_{Group=8}$							
Initial Design Variables (7E10.4)							
$D^{Lower\ Bound}_{Group=1}$	$D^{Lower\ Bound}_{Group=2}$						
Lower Bounds on Design Variables (7E10.4)							
$D^{Upper\ Bound}_{Group=1}$	$D^{Upper\ Bound}_{Group=2}$					$D^{Upper\ Bound}_{Group=7}$	
Upper Bounds on Design Variables (7E10.4)							
Elastic Modulus	Poisson's Ratio	Specific Weight	Thermal Expansion Coefficient	Compressive Allowable Stress	Tensile Allowable Stress		
Material Constants for Isotropic Materials							
E_L	E_T	G_{LT}	ν_{LT}	γ	α_L	α_T	
l_L	m_L	n_L	ε^t_{aL}	ε^c_{aL}	ε^t_{aT}	ε^c_{aT}	
γ_{aLT}	F^t_L	F^c_L	F^t_T	F^c_T	F_{LT}		
Material Constants for Orthotropic Materials (3(7E10.4)) 3 cards per material - not required if IMATOR = 0							

ACCESS-2 CARD IMAGE FORMAT (3)

column number 5	10	15 – 20	25 – 30	35 – 40	45 – 75
$NN^{k=1}$	$NN^{k=2}$	Number of Nodes Subject to Lumped Nodal Loads for Load Condition k (14I5)			
Node No	Not Used	P_x X-component	P_y Y-component	P_z Z-component	
		Lumped Loads for Load Condition = 1 (I5, 5X, 3E10.4)			
Node No	Not Used	P_x	P_y	P_z	
		Lumped Loads for Load Condition = 2			
		⋮			

ACCESS-2 CARD IMAGE FORMAT (4)

column number 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

$NEPL^1$ $NEPL^2$ $NEPL^3$ . . . $NEPL^{10}$

Number of Elements subject to Pressure Load for Each Element Type

$ONOFF^1$ $ONOFF^2$

Pressure Load ON-OFF Flag for Each Load Condition 1=ON 0=OFF

M_1^1 M_2^1 M_3^1

Element Number subject to Pressure Load for Element TYPE = 1 (Not required if $NEPL^1=0$)

M_1^2 M_2^2 M_3^2 M_4^2 . .

Element Number subject to Pressure Load for Element Type = 2 (Not required if $NEPL^2=0$)

M_1^{10} M_2^{10} M_3^{10} M_4^{10} . . . . . .

$NPG_{M_1^1}$ $NPG_{M_2^1}$ $NPG_{M_3^1}$ - - - -

Pressure Load Group No applied to the corresponding Elements in MTYP=1, Load Condition=1

$NPG_{M_1^2}$ $NPG_{M_2^2}$ $NPG_{M_3^2}$ - - - - -

$NPG_{M_1^{10}}$ $NPG_{M_2^{10}}$

Repeat INL times

PG_1 PG_2 PG_3 PG_4 . . . .

Pressure Magnitude for Each Pressure Group (7E10-4)

('IPRLDG' numbers must be given)

ACCESS-2 CARD IMAGE FORMAT (5)

column number 5 10	15 20	25 30	35 40	45 50 55 60 65 70 75
ON-OFF^1 ONDFF^2	ONOFF^3 ...			
Inertia Load ON-OFF Flag for EACH Load Condition (1=ON, 0=OFF)				
$ACC_{K=1}$	$COSX_{K=1}$	$COSY_{K=1}$	$COSZ_{K=1}$	Not required for load conditions whose ON-OFF flags are 0
$ACC_{K=2}$	$COSX_{K=2}$	$COSY_{K=2}$	$COSZ_{K=2}$	
⋮				
Magnitude of Acceleration in the unit gravitational Constant 'g'	Direction Cosines of Acceleration Vector			
$ACC_{K=INL}$	$COSX_{K=INL}$	$COSY_{K=INL}$	$COSZ_{K=INL}$	

ACCESS-2 CARD IMAGE FORMAT (6)

column number 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
$NETH^1$	$NETH^2$	$NETH^3$	.	.					$NETH^{10}$					
Number of Elements Subject to Thermal Load for Each Element Type														
$ONOFF^1$	$ONOFF^2$	$ONOFF^3$	. .	. .										
Thermal Load ON-OFF Flag for Each Load Condition 1 = ON, ϕ = OFF														
M_1^1	M_2^1	M_3^1	M_4^1	M_5^1	.									
Element Numbers Subject to Thermal Loads for Element Type 1 (Not Required if $NETH^1 = \phi$)														
M_1^2	M_2^2	M_3^2												
Element Numbers Subject to Thermal Loads for Element Type 2 (Not Required, if $NETH^2 = \phi$)														
M_1^{10}	M_2^{10}	M_3^{10}			.	.								
$NTG_{M_1^1}$	$NTG_{M_2^1}$	$NTG_{M_3^1}$												Repeat INL Times
Thermal Load Group Numbers Corresponding to the Element Numbers in MTYP = 1														
$NTG_{M_1^2}$	$NTG_{M_2^2}$	$NTG_{M_3^2}$	$NTG_{M_4^2}$		. . . . .									
Thermal Load Group Numbers Corresponding to the Element Numbers in MTYP = 2														
$NTG_{M_1^{10}}$	$NTG_{M_2^{10}}$	$NTG_{M_3^{10}}$												
PG_1		PG_2		PG_3		PG_4		. . . . .						
Thermal Load (Temperature deviation from the reference temperature) Magnitude for Each Thermal Load Group ('ITHLDG' numbers must be given)														

ACCESS-2 CARD IMAGE FORMAT (7)

column number 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

ONOFF^1	ONOFF^2	ONOFF^3	• • • • •

Flutter Analysis ON-OFF Flag for EACH Load Condition (1 = ON, 0 = OFF)
(Capability not available in the present version, specify 0)

U^1 Free Stream Velocity	RHO^1 Air Density	A^1 Speed of Sound	H^1 Altitude	$ALPHA^1$ Root Angle of Attack	W^1 Payload	T^1 Air Temperature
U^{INC}	RHO^{INC}	A^{INC}	H^{INC}	$ALPHA^{INC}$	W^{INC}	T^{INC}

NMASS	(Number of Nodal Lumped Masses)

Node Number n_i	Not Used	W_{n_i}

NMASS Cards are required

ACCESS-2 CARD IMAGE FORMAT (8)

column number 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
$TRF^{Initial}$		TRF^{Max}		$C^{Cutoff Base}$		$TRF^{Multiplier}$		Side Constraint Control Parameters						
NDPC	(Number of Displacement Constraints)													
$TRF^{Initial}$		TRF^{Max}		$C^{Cutoff Base}$		$TRF^{Multiplier}$		Min Normalization Factor		Displacement Constraint Data				
$Node_1$	$IXYZ_1$	$ICODE_1$		$LowerBound_1$		$UpperBound_1$								
$Node_2$	$IXYZ_2$	$ICODE_2$		$LowerBound_2$		$UpperBound_2$								
	(Direction)		Not Used											
		⋮												
$Node_{NDPC}$	$IXYZ_{NDPC}$	$ICODE_{NDPC}$		$LowerBound_{NDPC}$		$UpperBound_{NDPC}$								
NSLC	(Number of Slope/Relative Displacement Constraints)													
$TRF^{Initial}$		TRF^{Max}		$C^{Cutoff Base}$		$TRF^{Multiplier}$		Min Normalization Factor		Slope/Relative Displacement Constraint Data				
$Node^L_1$	$Node^U_1$	$IXYZ_1$	$UpperBound_1$											
$Node^L_2$	$Node^U_2$	$IXYZ_2$	$UpperBound_2$											
$Node^L_{NSLC}$	$Node^U_{NSLC}$	$IXYZ_{NSLC}$	$UpperBound_{NSLC}$											

ACCESS-2 CARD IMAGE FORMAT (9)

column number 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
CODE^1	CODE^2	CODE^3							CODE^{10}						Stress/Strain Constraint Data
TRF^{Initial}		TRF^{Max}		C$^{Cutoff\ Factor}$		TRF^{Multiplier}		Min Stress Normalization Factor		Min Strain Normalization Factor		Truss Euler Bucking Control Factor			
Constraint Codes for All Elements with Negative Type CODE. (14I5) (Not required for elements with positive type CODE)															
NFREQ	NSPACE														Frequency Constraint Data
TRF^{Initial}		TRF^{Max}		C$^{Cutoff\ Factor}$		TRF^{Multiplier}		Min Normalization Factor		Eigenvalue Convergence Criteria		Acceleration of Gravity			
CODE^1	Lower Bound$_1$		Upper Bound$_1$												
CODE^2	Lower Bound$_2$		Upper Bound$_2$												
CODE^3	Lower Bound$_3$		Upper Bound$_3$												
CODE^{NFREQ}	LowerBound$_{NFREQ}$		UpperBound$_{NFREQ}$												
NMODE	NORMOD										Flutter Constraint Data (Capability Not Available)				
TRF^{Initial}		TRF^{Max}		C$^{Cutoff\ Factor}$		TRF^{Multiplier}		Min Normalization Factor							
Following 3 cards are the NEWSUMT optimizer control cards For different optimizer, control cards may be different															
JPRINT	MAXSTG	MAYRSF	MAXODM	ISIGNG											
EPSSTG		EPSODM		RACUT		RAMIN		STEPMX		Initial Transition Point		Power Factor Coefficient			
STEPMX Multiplier		STEPMX Lower Limit													

APPENDIX C

Examples

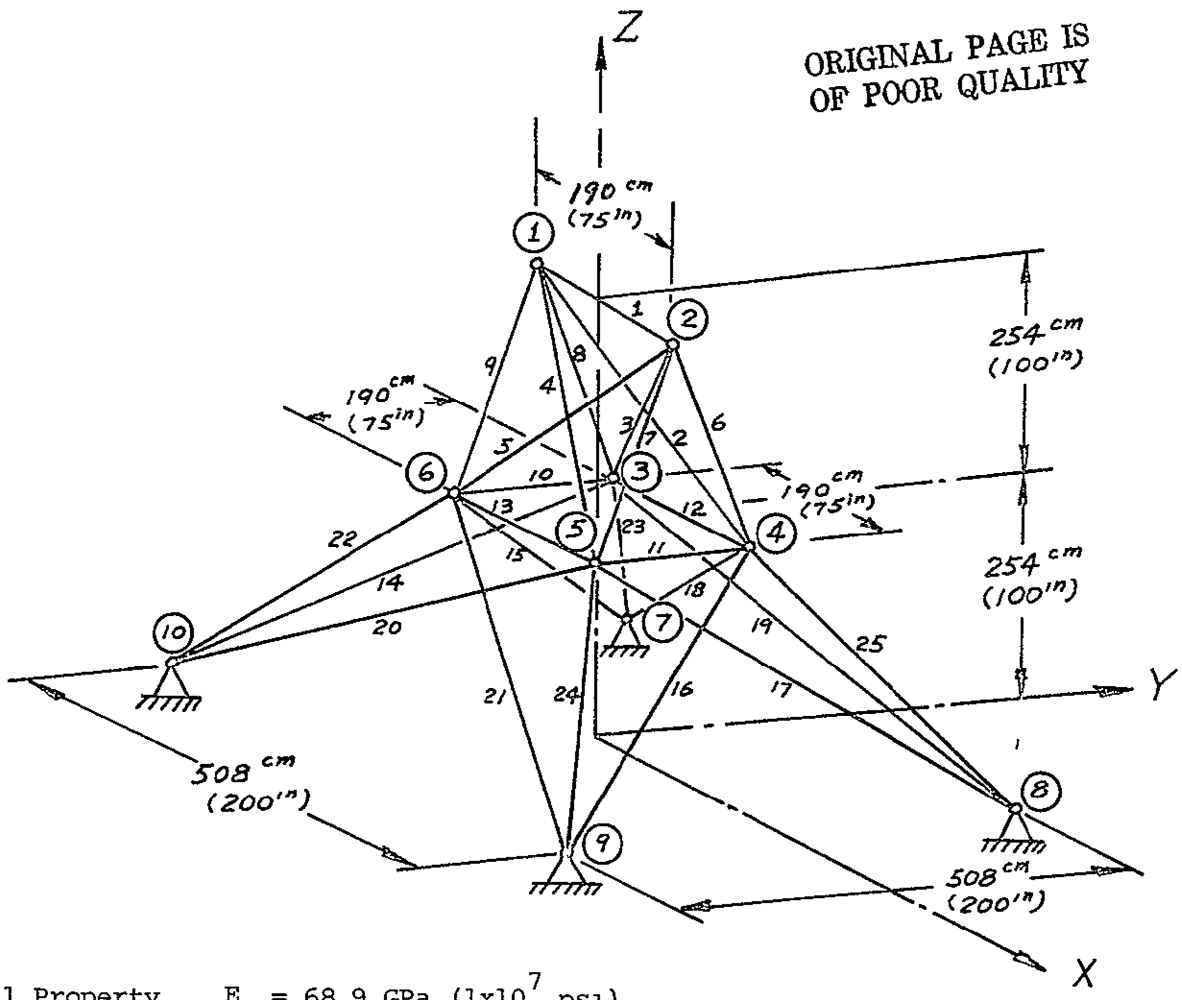
Three examples are given to illustrate input data preparation for various features of the ACCESS-2 computer program.

(1) 25 bar space truss
    static constraints only
    mechanical and thermal loads

(2) 18 element wing box
    static constraints and frequency constraint
    mechanical loads only
    aluminum alloy

(3) 18 element wing box
    static constraints
    mechanical and thermal loads
    composite material skin and aluminum webs

Example 1



<u>Material Property</u>

E = 68.9 GPa (1×10^7 psi)
ρ = 2800 kg/m^3 (0.101 lb,/in^3)
σ_a = 0.276 GPa (40,000 psi)
α = 23.0×10^{-6}/K (12.8×10^{-6}/°F)

<u>Loading</u>

Grid Point	Temperature K	Temperature °F	P_x N	P_x lbf	P_y N	P_y lbf	P_z N	P_z lbf
1	350	170	4448	1000	44 480	10 000	-22 240	-5000
2	350	170	4448		44 480	10 000	-22 240	-5000
3	311	100	2224	500				
4	311	100						
5	311	100						
6	311	100	2224	500				
7	275	35						
8	275	35						
9	275	35						
10	275	35						

Fig. C-1 25 Bar Truss Ref: NASA TND 7965 August 1975

Example 1 Data Card Image (1)

```
 25 BAR TRUSS
 DESIGN VARIABLES = 8
 LOADING -THERMAL AND MECHANICAL LOADS
1
    4    2    0    1    1    0    0
   10    4    1    8    0    8    3    0         0
   25
    1       0.0000E0 -0.2500E2  0.2000E3
    2       0.0000E0  0.2500E2  0.2000E3
    3      -0.3750E2  0.3750E2  0.1000E3
    4       0.3750E2  0.3750E2  0.1000E3
    5       0.3750E2 -0.3750E2  0.1000E3
    6      -0.3750E2 -0.3750E2  0.1000E3
    7      -0.1000E3  0.1000E3  0.0000E0
    8       0.1000E3  0.1000E3  0.0000E0
    9       0.1000E3 -0.1000E3  0.0000E0
   10      -0.1000E3 -0.1000E3  0.0000E0
    7    1    1    1
    8    1    1    1
    9    1    1    1
   10    1    1    1
    1                                                                      TRUSS
    1    1    2                   1    1    1         1   -1
    2    1    4                   2    2    2         2   -1
    3    2    3                   3    2    2         2   -1
    4    1    5                   4    2    2         2   -1
    5    2    6                   5    3    3         3   -1
    6    2    4                   6    3    3         3   -1
    7    2    5                   7    3    3         3   -1
    8    1    3                   8    3    3         3   -1
    9    1    6                   9    3    3         3   -1
   10    3    6                  10    4    4         4   -1
   11    4    5                  11    4    4         4   -1
   12    3    4                  12    5    5         5   -1
   13    5    6                  13    5    5         5   -1
   14    3   10                  14    6    6         6   -1
   15    6    7                  15    6    6         6   -1
   16    4    9                  16    6    6         6   -1
   17    5    8                  17    6    6         6   -1
   18    4    7                  18    7    7         7   -1
   19    3    8                  19    7    7         7   -1

    5   10   15   20   25   30   35   40   45   50   55
```

Example 1 Data Card Image (2)

```
   20    5   10             20    7    7         7   -1
   21    6    9             21    7    7         7   -1
   22    6   10             22    8    8         8   -1
   23    3    7             23    8    8         8   -1
   24    5    9             24    8    8         8   -1
   25    4    8             25    8    8         8   -1
  0.2000E1  0.2000E1  0.2000E1  0.2000E1  0.2000E1  0.2000E1  0.2000E1     INITV
  0.2000E1
  0.0100E0  0.0100E0  0.0100E0  0.0100E0  0.0100E0  0.0100E0  0.0100E0    ILOWG
  0.0100E0
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
  0.1000E8            0.1010E0  0.128E-4 -0.4000E5  0.4000E5
    4
    1       0.1000E4  0.1000E5 -0.5000E4
    2       0.0000E0  0.1000E5 -0.5000E4
    3       0.5000E3  0.0000E0  0.0000E0
    6       0.5000E3  0.0000E0  0.0000E0
    0    0                                                                INERTL
   25
    1
    1    2    3    4    5    6    7    8    9   10   11   12   13   14
   15   16   17   18   19   20   21   22   23   24   25
    1    2    2    2    2    2    2    2    2    3    3    3    3    4
    4    4    4    4    4    4    4    4    4    4    4
  0.1700E3  0.1350E3  0.1000E3  0.6750E2
    0    0                                                                IFLIGH
    0                                                                      NMASS
  0.1000E0  0.6000E0  1.0000E0  1.2000E0
    0                                 NO DISPLACEMENT CONSTRAINTS
    0                                                                       NSLC
    3
  0.1000E0  0.6000E0  0.1000E1  1.2000E0 0.11590E5
    0    0
    0    0
    0   12    2    5    0
  0.0010E0  0.0010E0  0.3000E0 0.100E-14  0.1000E3  0.1000E0  0.5000E0  0.1000E0
  1.0000E0  0.1200E1
2
    5   10    5   20   25   30   35   40   45   50   55   60   65   70   75   80
```

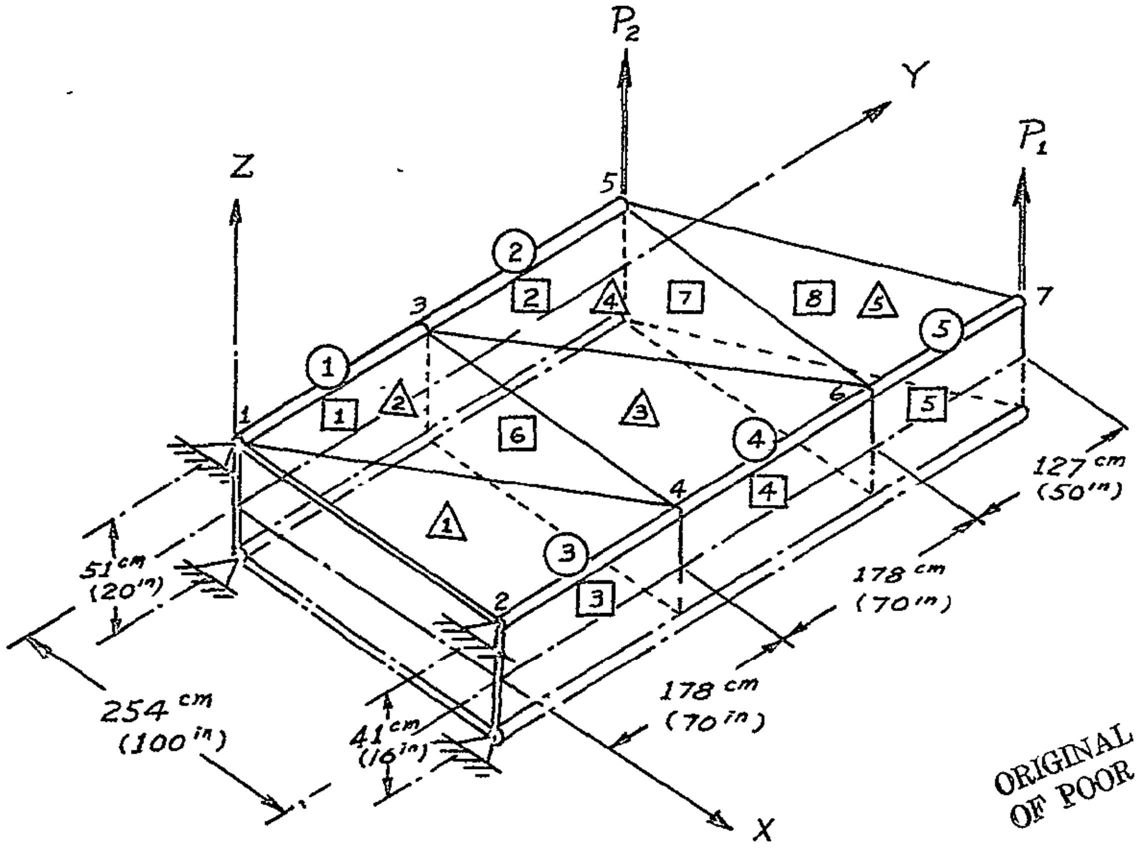
Example 2

○ Truss

△ CST

□ SSP

Numbers Within Symbols Indicate Element No.
Numbers at Element Junctions Indicate Node No.



Lumped Masses: 222.4 Kg m/sec^2 (50 lb)

at nodes 4 & 6

Material properties: $E = 68.9\text{x}10^9$ Pa, N/m^2 ($10\text{x}10^6$ psi)

$\rho = 2800$ Kg/m^3 (0.1 lbs/in.^{3})

$\nu = 0.3$

$\sigma^U = |\sigma^L| = 6.89\text{x}10^7$Pa, N/m^2 (10000 psi)

Fig. C-2 Wing Box with Isotropic Panel

Constraints: Side : $A^L = 0.645\ \text{cm}^2\ (0.1\ \text{in}^2)$

$t^L = 0.0508$ cm (0.02 in)

$\tau^L = 0.0508$ cm (0.02 in)

Stress : $\sigma^U = |\sigma^L| = 6.89\text{x}10^7 P_a$, N/cm^2

(10,000 psi)

Displacements : $U_{zk}^U = |U_{zk}^L| = 5.08$ cm (2.00 in)

nodes 3,4,5,6,7.

Frequency : $f_1^L = 25$ cycles/sec

Loads : Load Condition 1

$P_1 = 22240$ N (5000 lbs)

$P_2 = 0$ (N) (0 lbs)

Load Condition 2

$P_1 = 0$ (N) (0 lbs)

$P_2 = 44480$ N (1000 lbs)

Example 2 Data Card Image (1)

```
18 ELEMENT WING BOX
NUMBER OF INDEPENDENT DESIGN VARIABLES = 16
2 LOAD CONDITIONS
STRESS, DISPLACEMENT, FREQUENCY AND SIDE CONSTRAINTS
TWO LUMPED MASSES
1
    4    2    0    1    1    1    0    0
    7    2    2   16    0   16   16
    5    5         8
    1       0.0000E0  0.0000E0  0.1000E2
    2       0.1000E3  0.0000E0  0.8000E1
    3       0.0000E0  0.7000E2  0.1000E2
    4       0.1000E3  0.7000E2  0.8000E1
    5       0.0000E0  0.1400E3  0.1000E2
    6       0.1000E3  0.1400E3  0.8000E1
    7       0.1000E3  0.1900E3  0.8000E1
    1    1    1    1
    2    1    1    1
    1                                                                            TRUSS
    1    1    3              1    1    1         1   -1
    2    3    5              2    2    2         2   -1
    3    2    4              3    3    3         3   -1
    4    4    6              4    4    4         4   -1
    5    6    7              5    5    5         5   -1
    2                                                                              CST
    1    1    2    4         1    6    6         6   -1
    2    4    3    1         1    6    6         6   -1
    3    3    4    6         2    7    7         7   -1
    4    6    5    3         2    7    7         7   -1
    5    5    6    7         3    8    8         8   -1
    4                                                                              SSP
    1    1    3              1    9    9         9   -1
    2    3    5              2   10   10        10   -1

    5   10   15   20   25   30   35   40   45   50   55
```

Example 2 Data Card Image (2)

```
    3    2    4              3   11   11        11   -1
    4    4    6              4   12   12        12   -1
    5    6    7              5   13   13        13   -1
    6    3    4              6   14   14        14   -1
    7    5    6              7   15   15        15   -1
    8    5    7              8   16   16        16   -1
  0.9800E0  0.9800E0  0.9800E0  0.9800E0  0.9800E0  0.1960E0  0.1960E0
  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0
  0.1960E0  0.1960E0
  0.1000E0  0.1000E0  0.1000E0  0.1000E0  0.1000E0  0.0200E0  0.0200E0
  0.0200E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0
  0.0200E0  0.0200E0
  0.1000E8            0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8            0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8            0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8            0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8            0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E 4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E 4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1000E5  0.1000E5
    1    1
    7          0.0000E0  0.0000E0  0.5000E4
    5          0.0000E0  0.0000E0  0.1000E5
    0    0                                                                INERTL
    0    0                                                                IFLIGH
    2
    4          0.5000E2
    6          0.5000E2
  0.1000E0  0.6000E0  1.0000E0  1.2000E0
    5
  0.1000E0  0.6000E0  0.1000E1  1.2000E0  1.0000E0
    3    3    2      -0.2000E1  0.2000E1
    4    3    2      -0.2000E1  0.2000E1
    5    3    2      -0.2000E1  0.2000E1
    6    3    2      -0.2000E1  0.2000E1
    7    3    2      -0.2000E1  0.2000E1
    0                                                                      NSLC
    3    2         2
  0.1000E0  0.6000E0  1.0000E0  1.2000E0  0.1000E5
    1    0
  0.1000E0  0.6000E0  1.0000E0  1.2000E0  0.0100E0  0.0050E0
    2  2.4675E4  0.5000E5
    0    0    0
    0   15    2    5    0
  0.0010E0  0.0010E0  0.3000E0 0.100E-14  0.1000E3  0.1000E0  0.5000E0  0.1000E0
  1.0000E0  0.1200E1
2
```

5 10 5 20 25 30 35 40 45 50 55 60 65 70 75 80

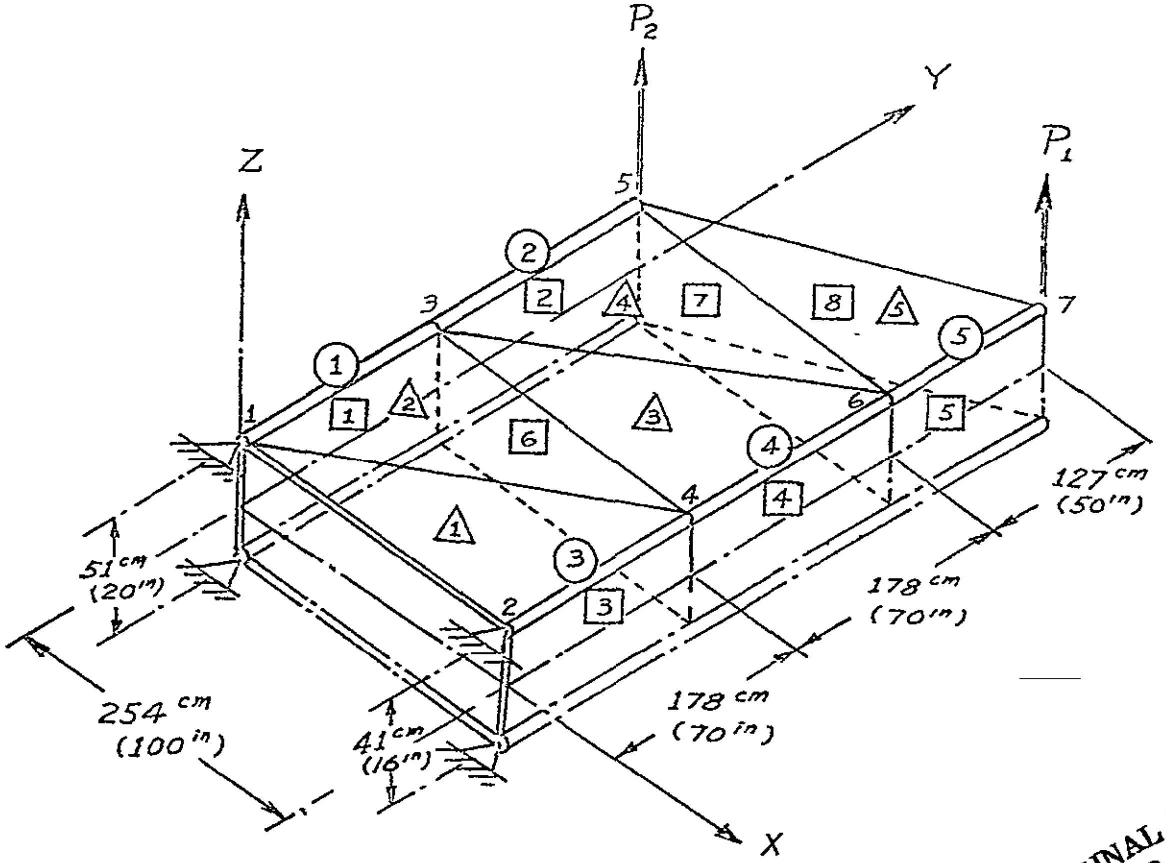
Example 3

○ Truss

△ CST

□ SSP

Numbers within Symbols Indicate Element No.
Numbers at Element Junctions Indicate Node No.



Lumped Masses : $222.4\ K_g\ m/sec^2$ (50 lb)
at nodes 4 & 6

Isotropic Material Properties :
$E = 68.9 \times 10^9\ P_a$, N/m^2 (10×10^6 psi)
$\rho = 2800\ K_g/m^3$ (0.1 lbs/in^3)
$\nu = 0.3$
$\sigma^U = |\sigma^L| = 11.0316 \times 10^7 P_a$, N/m^2 (16000 psi)
$= 23.0 \times 10^{-6}$/°K (12.8×10^{-6}/°F)

Fig. C-3 Wing Box with Composite Panel

Composite Material Properties : E_L = 1.448×10^{11} P , N/m^2 (21×10^6 psi
E_T = 1.172×10^{10} P , N/m^2 (1.7×10^6 psi
G_{LT} = 4.482×10^{9} P , N/m^2 (0.65×10^6 ps
ν_{LT} = 0.21
ρ = 1549 K_g/m^3 (0.056 lbs/in^3)
α_L = -3.779×10^{-7}/°K ($-.21\times10^{-6}$/°F)
α_T = 2.8797×10^{5}/°K (16×10^{-6}/°F)
ε_L^{t} = 0.008571 m/m (0.008571 in/in)
ε_L^{c} = −0.008571 m/m (0.008571 in/in)
ε_T^{t} = 0.004706 m/m (0.004706 in/in)
ε_T^{F} = −0.017647 m/m (−0.017646 in/in)
ν_{LT} = 0.018462 (0.018462)

Constraints: Side : A^L = 0.645 cm^2 (0.1 in^2)
t^L = 0.0508 cm (0.02 in)
τ^L = 0.0508 cm (0.02 in)

Stress and strain: As given in the Material Properties

Displacement: $u_{zk}^{U} = |u_{zk}^{L}|$ = 5.08 cm (2.00 in)
at nodes 3,4,5,6 and 7

Loads:

Mechanical Loads: Load Condition 1

P_1 = 22240 N (5000 lbs)
P_2 = 0(N) (0 lbs)

Load Condition 2

P_1 = 0(N) (0 lbs)
P_2 = 44480 N (10000 lbs)

Load Condition 3

P_1 = -22240 N (5000 lbs)

P_2 = 0(N) (0 lbs)

Load Condition 4

P_1 = 0(N) (0 lbs)

P_2 = -44480 N (10000 lbs)

Thermal Loads: All load conditions 311°K (100°F)

Example 3 Data Card Image (1)

```
WING BOX WITH SKIN MADE UP OF COMPOSITE MATERIALS
NUMBER OF INDEPENDENT DESIGN VARIABLES = 22
4 LOAD CONDITONS  TYPE OF LOADS = MECHANICAL AND THERMAL
STRESS, DISPLACEMNT, AND SIDE CONSTRAINTS
TWO LUMPED MASSES.  HIGH STRENGTH GRAPHITE EPOXY SKIN
1
    4    2    0    1    1    0    0
    7    2    4   13    4   16   16   0     1    0
    5    0   20    8        8
    1       0.0000E0  0.0000E0  0.1000E2
    2       0.1000E3  0.0000E0  0.8000E1
    3       0.0000E0  0.7000E2  0.1000E2
    4       0.1000E3  0.7000E2  0.8000E1
    5       0.0000E0  0.1400E3  0.1000E2
    6       0.1000E3  0.1400E3  0.8000E1
    7       0.1000E3  0.1900E3  0.8000E1
    1    1    1    1
    2    1    1    1
    1                                                                     TRUSS
    1    1    3              1    1    1         1   -1
    2    3    5              2    2    2         2   -1
    3    2    4              3    3    3         3   -1
    4    4    6              4    4    4         4   -1
    5    6    7              5    5    5         5   -1
    3                                                                     CSTOR
    1    1    2    4         1    6    6        -1   -1
    2    1    2    4         2    6    6        -2   -1
    3    1    2    4         2    6    6        -3   -1
    4    1    2    4         3    6    6        -4   -1
    5    4    3    1         1    6    6        -1   -1
    6    4    3    1         2    6    6        -2   -1
    7    4    3    1         2    6    6        -3   -1
    8    4    3    1         3    6    6        -4   -1
    9    3    4    6         4    7    7        -1   -1
   10    3    4    6         5    7    7        -2   -1
   11    3    4    6         5    7    7        -3   -1
   12    3    4    6         6    7    7        -4   -1
   13    6    5    3         4    7    7        -1   -1
   14    6    5    3         5    7    7        -2   -1
   15    6    5    3         5    7    7        -3   -1
   16    6    5    3         6    7    7        -4   -1

    5   10   15   20   25   30   35   40   45   50   55
```

Example 3 Data Card Image (2)

```
   17    5    6    7         7    8    8        -1   -1
   18    5    6    7         8    8    8        -2   -1
   19    5    6    7         8    8    8        -3   -1
   20    5    6    7         9    8    8        -4   -1
    4                                                                       SSP
    1    1    3              1    9    9         6   -1
    2    3    5              2   10   10         7   -1
    3    2    4              3   11   11         8   -1
    4    4    6              4   12   12         9   -1
    5    6    7              5   13   13        10   -1
    6    3    4              6   14   14        11   -1
    7    5    6              7   15   15        12   -1
    8    5    7              8   16   16        13   -1
    6                                                                  TSP
    1    1    3              1    9    9         6   -1
    2    3    5              2   10   10         7   -1
    3    2    4              3   11   11         8   -1
    4    4    6              4   12   12         9   -1
    5    6    7              5   13   13        10   -1
    6    3    4              6   14   14        11   -1
    7    5    6              7   15   15        12   -1
    8    5    7              8   16   16        13   -1
  0.9800E0  0.9800E0  0.9800E0  0.9800E0  0.9800E0  0.1960E0  0.1960E0
  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0  0.1960E0
  0.1960E0  0.1960E0
  0.1000E0  0.1000E0  0.1000E0  0.1000E0  0.1000E0  0.0100E0  0.0100E0
  0.0100E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0  0.0200E0
  0.0200E0  0.0200E0
  0.1000E8            0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8            0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8            0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8            0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8            0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
  0.1000E8  0.3000E0  0.1000E0  0.128E-4 -0.1600E5  0.1600E5
 21.0000E6  1.7000E6  0.5500E6  0.2100E0  0.0560E0-0.2100E-616.0000E-6
  1.0000E0  0.0000E0  0.0000E0 .008571E0-.008571E0 0.4706E-2-1.7647E-2
 1.8462E-2  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0
 21.0000E6  1.7000E6  0.5500E6  0.2100E0  0.0560E0-0.2100E-616.0000E-6
  0.7071E0  0.7071E0  0.0000E0 .008571E0-.008571E0 0.4706E-2-1.7647E-2
 1.8462E-2  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0
 21.0000E6  1.7000E6  0.5500E6  0.2100E0  0.0560E0-0.2100E-616.0000E-6
 -0.7071E0  0.7071E0  0.0000E0 .008571E0-.008571E0 0.4706E-2-1.7647E-2
 1.8462E-2  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0
 21.0000E6  1.7000E6  0.5500E6  0.2100E0  0.0560E0-0.2100E-616.0000E-6
  0.0000E0  1.0000E0  0.0000E0 .008571E0-.008571E0 0.4706E-2-1.7647E-2
 1.8462E-2  0.0000E0  0.0000E0  0.0000E0  0.0000E0  0.0000E0
    1    1    1    1
    7       0.0000E0  0.0000E0  0.5000E4
    5       0.0000E0  0.0000E0  0.1000E5
    7       0.0000E0  0.0000E0 -0.5000E4
    5       0.0000E0  0.0000E0 -0.1000E5
    0    0                                                               INERTL
```

Example 3 Data Card Image (3)

```
    5    0   20    0    0    8
    1    1    1    1
    1    2    3    4    5
    1    2    3    4    5    6    7    8    9   10   11   12   13   14
   15   16   17   18   19   20
    1    2    3    4    5    6    7    8
    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1
    1    1    1    1    1    1    1    1
    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1
    1    1    1    1    1    1    1    1
    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1
    1    1    1    1    1    1    1    1
    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1
    1    1    1    1    1    1    1    1
  0.1000E3
    0    0                                                             IFLIGH
    2
    4            0.5000E2
    6            0.5000E2
  0.1000E0  0.6000E0  1.0000E0  1.2000E0
    5
  0.1000E0  0.6000E0  0.1000E1  1.2000E0  1.0000E0
    3    3    2      -0.2000E1  0.2000E1
    4    3    2      -0.2000E1  0.2000E1
    5    3    2      -0.2000E1  0.2000E1
    6    3    2      -0.2000E1  0.2000E1
    7    3    2      -0.2000E1  0.2000E1
    0                                                                  NSLC
    3    0    1    2    0    0
  0.1000E0  0.6000E0  1.0000E0  1.2000E0  0.1000E5
    0    0                                     NO FREQUENCY CONSTRAINTS
    0    0    0
    0    1    2    5    0
  0.0010E0  0.0010E0  0.3000E0 0.100E-14  0.1000E3  0.1000E0  0.5000E0  0.1000E0
  1.0000E0  0.1200E1

    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

APPENDIX D. Output for 25 Bar Space Truss Example

```
25 BAR TRUSS
DESIGN VARIABLES = 8
LOADING -THERMAL AND MECHANICAL LOADS
```

```
*****************************************************************************************************************************************

                                    COMPLETE OPTIMIZATION BY NEWSUMT OPTIMIZER

                                    ANALYSIS PRINT OUT CONTROL =     2

                                    DESIGN IN LINKED SIZING VARIABLE SPACE

                                    NUMBER OF NODES                     10
                                    NUMBER OF TOTAL ELEMENTS            25
                                    NUMBER OF LINKED VARIABLES          25
                                    NUMBER OF LOAD CONDITIONS            1
                                    NUMBER OF BOUNDARY NODES             4
                                    NUMBER OF ISOTROPIC MATERIALS        8
                                    NUMBER OF ORTHOTROPIC MATERIALS      0

                        TRUSS       CST        CST          SSP         PSP         TSP         TBD         TBD         TBD         TBD
                                 ISOTROPIC  ORTHOTROPIC
        ----------------------------------------------------------------------------------------------------------------------
        ELEMENTS          25
        LINKED VARIABLES  25
        ----------------------------------------------------------------------------------------------------------------------

                          NODE NUMBER            X                      Y                      Z
                          -----------------------------------------------------------------------------------
                                1              0.0                  -25.0000               200.0000
                                2              0.0                   25.0000               200.0000
                                3            -37.5000                37.5000               100.0000
                                4             37.5000                37.5000               100.0000
                                5             37.5000               -37.5000               100.0000
                                6            -37.5000               -37.5000               100.0000
                                7           -100.0000               100.0000                 0.0
                                8            100.0000               100.0000                 0.0
                                9            100.0000              -100.0000                 0.0
                               10           -100.0000              -100.0000                 0.0
                          -----------------------------------------------------------------------------------


                                         DISPLACEMENT BOUNDARY CONDITIONS
                                         --------------------------------

                                  BOUNDARY CODES*                    PRESCRIBED DISPLACEMENT
                         NODE NO.      X      Y      Z              X               Y               Z
                         ---------------------------------------------------------------------------------------
                             7         1      1      1             0.0             0.0             0.0
                             8         1      1      1             0.0             0.0             0.0
                             9         1      1      1             0.0             0.0             0.0
                            10         1      1      1             0.0             0.0             0.0
                         ---------------------------------------------------------------------------------------
                                           * -1=PRESCRIBED, 0=FREE, 1=FIXED

     ELEMENT          NODE NUMBERS          LINKED                        ELEMENT        SIZE                 MATERIAL     SIZE CONSTRAINT
```

```
NO.         N1     N2     N3     N4        GROUP              INITIAL          LOW.BD          UPP.BD          GROUP        CODE*
----------------------------------------------------------------------------------------------------------------------------------
     TRUSS ELEMENTS
  1          1      2                        1               2.000000        0.010000        0.010000          1            -1
  2          1      4                        2               2.000000        0 010000        0.010000          2            -1
  3          2      3                        3               2.000000        0.010000        0.010000          2            -1
  4          1      5                        4               2.000000        0.010000        0.010000          2            -1
  5          2      6                        5               2.000000        0.010000        0.010000          3            -1
  6          2      4                        6               2.000000        0.010000        0.010000          3            -1
  7          2      5                        7               2.000000        0.010000        0.010000          3            -1
  8          1      3                        8               2.000000        0.010000        0.010000          3            -1
  9          1      6                        9               2.000000        0.010000        0.010000          3            -1
 10          3      6                       10               2.000000        0.010000        0.010000          4            -1
 11          4      5                       11               2.000000        0.010000        0.010000          4            -1
 12          3      4                       12               2.000000        0.010000        0.010000          5            -1
 13          5      6                       13               2.000000        0.010000        0.010000          5            -1
 14          3     10                       14               2.000000        0.010000        0.010000          6            -1
 15          6      7                       15               2.000000        0.010000        0.010000          6            -1
 16          4      9                       16               2.000000        0.010000        0.010000          6            -1
 17          5      8                       17               2.000000        0.010000        0.010000          6            -1
 18          4      7                       18               2.000000        0.010000        0.010000          7            -1
 19          3      8                       19               2.000000        0.010000        0.010000          7            -1
 20          5     10                       20               2.000000        0.010000        0.010000          7            -1
 21          6      9                       21               2.000000        0.010000        0.010000          7            -1
 22          6     10                       22               2.000000        0.010000        0.010000          8            -1
 23          3      7                       23               2.000000        0.010000        0.010000          8            -1
 24          5      9                       24               2.000000        0.010000        0.010000          8            -1
 25          4      8                       25               2.000000        0.010000        0.010000          8            -1
----------------------------------------------------------------------------------------------------------------------------------
          * -2=FIXED AT INITIAL VALUE    -1=LOWER BOUNDS ONLY
             0=NON NEGATIVITY ONLY        1=UPPER BOUNDS ONLY
             2=BOTH UPPER AND LOWER BOUNDS


                                                      MATERIAL CONSTANTS - ISOTROPIC MATERIALS
                                                      ----------------------------------------

                  GROUP        YOUNG'S        POISSON'S       SPECIFIC          THERMAL        COMPRESSIVE        TENSILE
                   NO.         MODULUS          RATIO          WEIGHT          EXPANSION        A. STRESS        A. STRESS
                  ------------------------------------------------------------------------------------------------------------
                    1        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    2        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    3        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    4        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    5        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    6        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    7        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                    8        10000000.0          0.0          0.101000        0.00001280       -40000.0          40000.0
                  ------------------------------------------------------------------------------------------------------------


                                                              LOAD CONDITIONS
                                                              ---------------


                                                            LUMPED LOAD AT NODES
                                                            --------------------

                           NODE NUMBER                   X                      Y                     Z
                          ---------------------------------------------------------------------------------------
                          LOAD CONDITION  1
                                 1                 1000.00000             10000.00000            -5000.00000
                                 2                    0.0                 10000.00000            -5000.00000
                                 3                  500.00000                 0.0                    0.0
                                 6                  300.00000                 0.0                    0.0
                          ---------------------------------------------------------------------------------------
```

```
                                        PRESSURE LOAD
                                        -------------

                                 NO PRESSURE LOAD SPECIFIED

                                        GRAVITY LOAD
                                        ------------

               LOAD CONDITION NO.     MAGNITUDE(G)                  DIRECTION  COSINES
               ----------------------------------------------------------------------------
                       0          NO GRAVITY LOAD
               ----------------------------------------------------------------------------

                                        THERMAL LOAD
                                        ------------

                        |                  THERMAL LOAD GROUP NUMBER
                        |---------------------------------------------------------------------------
           ELEMENT      |                       LOAD CONDITIONS
        TYPE     NUMBER |  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20
   -------------------------------------------------------------------------------------------------------------------------
          1         1   |  1
          1         2   |  2
          1         3   |  2
          1         4   |  2
          1         5   |  2
          1         6   |  2
          1         7   |  2
          1         8   |  2
          1         9   |  2
          1        10   |  3
          1        11   |  3
          1        12   |  3
          1        13   |  3
          1        14   |  4
          1        15   |  4
          1        16   |  4
          1        17   |  4
          1        18   |  4
          1        19   |  4
          1        20   |  4
          1        21   |  4
          1        22   |  4
          1        23   |  4
          1        24   |  4
          1        25   |  4
   =========================================================================================================================

                                     THERMAL LOAD MAGNITUDE
                                     ----------------------

          170.0000  135.0000  100.0000   67.5000
       ==============================================================================================================
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
                                    ----------------

                                 INITIAL TRUNCATION FACTOR        0.1000
                                 MAXIMUM TRUNCATION FACTOR        0.6000
                                 BASIS CUTOFF FACTOR              1.0000
                                 MULTIPLIER FOR TRF UPDATING      1.2000
                                 MINIMUM NORMALIZATION FACTOR

                         SIDE CONSTRAINT SPECIFICATIONS ARE GIVEN IN THE ELEMENT DATA

                                    DISPLACEMENT CONSTRAINTS
                                    ------------------------

                                   NO DISPLACEMENT CONSTRAINTS


                               SLOPE/RELATIVE DISPLACEMENT CONSTRAINTS
                               ---------------------------------------

                                      NO SLOPE CONSTRAINTS


                                    STRESS/STRAIN CONSTRAINTS
                                    -------------------------

                                 INITIAL TRUNCATION FACTOR        0.1000
                                 MAXIMUM TRUNCATION FACTOR        0.6000
                                 BASIS CUTOFF FACTOR              1.0000
                                 MULTIPLIER FOR TRF UPDATING      1.2000
                                 MINIMUM NORMALIZATION FACTOR
                                   STRESS                     11590.0000
                                   STRAIN                   0.1000000D-02
                                 NO EULER BUCKLING CONSTRAINTS IMPOSED

                            ELEMENT TYPE    1

                               ALL ELEMENTS ARE CONSTRAINED BY BOTH LOWER AND UPPER BOUNDS


                                 NEWSUMT OPTIMIZER CONTROL PARAMETERS
                                 ------------------------------------

                              PRINT OUT CONTROL                                0
                              MAX. NO. OF STAGES                              12
                              MAX. NO. OF RESPONSE SURFACES / STAGE            2
                              MAX. NO. OF ONE DIM. MIN. / RESP. SURF.          5
                              DEFINITION OF FEASIBLE REGION SIGN               0
                              DIMINISHING RETURN CRITERION AMONG STAGES     0.1000D-02
                              DIMINISHING RETURN CRITERION AMONG O.D.M.     0.1000D-02
                              RESPONSE FACTOR DECREASE RATIO                0.3000D+00
                              MIN. LIMIT OF RESPONSE FACTOR                 0.1000D-14
                              MAX. STEP SIZE ALLOWED IN A SINGLE STAGE      0.1000D+03
                              INITIAL ESTIMATE OF TRANSITION POINT          0.1000D+00
                              TRANSITION POINT COEFFICIENT - F              0.5000D+00
                              TRANSITION POINT COEFFICIENT - C              0.1000D+00
                              STEP SIZE MODIFICATION FACTOR                 0.1000D+01
                              STEP SIZE MINIMUM ALLOWABLE                   0.1200D+01


      TRUSS ELEMENT DATA
     ELEMENT           LENGTH         DIRCX         DIRCY         DIRCZ         E/L

      CONSTRAINT IDENTIFICATION CODES
```

```
 CONSTRAINT TYPE  1            25  CCNSTRAINTS IN THIS TYPE
       -10001      -10002      -10003      -10004      -10005      -10006      -10007      -10008      -10009      -10010
       -10011      -10012      -10013      -10014      -10015      -10016      -10017      -10018      -10019      -10020
       -10021      -10022      -10023      -10024      -10025

 CONSTRAINT TYPE  2             0  CCNSTRAINTS IN THIS TYPE

 CONSTRAINT TYPE  3             0  CCNSTRAINTS IN THIS TYPE

 CONSTRAINT TYPE  4            50  CCNSTRAINTS IN THIS TYPE
    -10010001   10010001   -10010002   10010002   -10010003   10010003   -10010004   10010004   -10010005   10010005
    -10010006   10010006   -10010007   10010007   -10010008   10010008   -10010009   10010009   -10010010   10010010
    -10010011   10010011   -10010012   10010012   -10010013   10010013   -10010014   10010014   -10010015   10010015
    -10010016   10010016   -10010017   10010017   -10010018   10010018   -10010019   10010019   -10010020   10010020
    -10010021   10010021   -10010022   10010022   -10010023   10010023   -10010024   10010024   -10010025   10010025
 CONSTRAINT TYPE  5             0  CCNSTRAINTS IN THIS TYPE

 CONSTRAINT TYPE  6             0  CCNSTRAINTS IN THIS TYPE

 TCTAL NUMBER CF CONSTRAINTS   75
```

```
 ------------------------------------------
 STAGE NO.  1   APPRCXIMATF PROBLFM GENERATCR
 ------------------------------------------

   CURRFNT MFMBER SIZE
   -------------------
      MEMBER TYPE NUMBER  1
          0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01
          0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01
          0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01  0.2000D+01

   CURRFNT WEIGHT DATA
   -------------------
      MEMBER TYPE NUMBFR     1      WEIGHT =    0.658133D+03
      ---------------------------------------------------
           VARIABLE STRUCTURAL WFIGHT    0.658133D+03
           FIXED STRUCTURAL WEIGHT       0.0
                TOTAL STRUCTURAL WEIGHT       0.658133D+03
                NON-STRUCTURAL WFIGHTHT       0.0
                ---------------------------------------
                         TOTAL WEIGHT                 0.658133D+03

      CONVFRGENCE CHECK      STAGE NC.=    1          0.1519D+28     0.1000D+01   MUST BF LFSS THAN   0.100000D-02
         OBJFCTIVE FUNCTION OF THREE CONSECUTIVE STAGES ARE   0.200000D+31   0.100000D+31   0.658133D+03
```

```
                                                              NODAL   DISPLACEMENTS
                                                              -------------------

            NODE              X              Y              Z              NODE              X              Y              Z
          ------------------------------------------------------------------------------------------------------------------

          LOAD CONDITION    1

              1        0.28259D-01    0.33540D+00    0.46479D+00          2        0.12561D-01    0.44583D+00    0.30432D+00
              3       -0.51762D-01    0.74994D-01    0.13367D+00          4        0.59745D-01    0.76652D-01    0.12603D+00
              5        0.48605D-01   -0.23073D-01    0.29102D+00          6       -0.41723D-01   -0.25470D-01    0.30013D+00
              7        0.0            0.0            0.0                  8        0.0            0.0            0.0
              9        0.0            0.0            0.0                 10        0.0            0.0            0.0
          ==================================================================================================================


      25  SIDE CONSTRAINTS                               1    TO   25       MOST CRITICAL CONSTRAINT=   0.995000D+00
       0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00
       0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00
       0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00  0.9950D+00

      MTYP     M    LC               S-COMBINED                SX              SY          SXY        SX-THERM    SY-THERM    SXY-THERM
    ---------------------------------------------------------------------------------------------------------------------------------
         1     1     1             0.339091D+03          0.3391D+03   0.0          0.0
         1     1     1             0.339091D+03          0.3391D+03   0.0          0.0
         1     2     1            -0.499959D+04         -0.5000D+04   0.0          0.0
         1     2     1            -0.499959D+04         -0.5000D+04   0.0          0.0
         1     3     1            -0.444145D+04         -0.4441D+04   0.0          0.0
         1     3     1            -0.444145D+04         -0.4441D+04   0.0          0.0
         1     4     1             0.228350D+04          0.2284D+04   0.0          0.0
         1     4     1             0.228350D+04          0.2284D+04   0.0          0.0
         1     5     1             0.356440D+04          0.3564D+04   0.0          0.0
         1     5     1             0.356440D+04          0.3564D+04   0.0          0.0
         1     6     1            -0.448118D+04         -0.4481D+04   0.0          0.0
         1     6     1            -0.448118D+04         -0.4481D+04   0.0          0.0
         1     7     1             0.361011D+04          0.3610D+04   0.0          0.0
         1     7     1             0.361011D+04          0.3610D+04   0.0          0.0
         1     8     1            -0.432506D+04         -0.4325D+04   0.0          0.0
         1     8     1            -0.432506D+04         -0.4325D+04   0.0          0.0
         1     9     1             0.313107D+04          0.3131D+04   0.0          0.0
         1     9     1             0.313107D+04          0.3131D+04   0.0          0.0
         1    10     1             0.595222D+03          0.5952D+03   0.0          0.0
         1    10     1             0.595222D+03          0.5952D+03   0.0          0.0
         1    11     1             0.763361D+03          0.7634D+03   0.0          0.0
         1    11     1             0.763361D+03          0.7634D+03   0.0          0.0
         1    12     1             0.206754D+04          0.2068D+04   0.0          0.0
         1    12     1             0.206754D+04          0.2069D+04   0.0          0.0
         1    13     1            -0.756386D+03         -0.7564D+03   0.0          0.0
         1    13     1            -0.756386D+03         -0.7564D+03   0.0          0.0
         1    14     1            -0.240960D+04         -0.2410D+04   0.0          0.0
         1    14     1            -0.240960D+04         -0.2410D+04   0.0          0.0
         1    15     1             0.779544D+03          0.7795D+03   0.0          0.0
         1    15     1             0.779544D+03          0.7795D+03   0.0          0.0
         1    16     1            -0.257862D+04         -0.2579D+04   0.0          0.0
         1    16     1            -0.257862D+04         -0.2579D+04   0.0          0.0
         1    17     1             0.270306D+03          0.2703D+03   0.0          0.0
         1    17     1             0.270306D+03          0.2703D+03   0.0          0.0
         1    18     1            -0.373105D+04         -0.3731D+04   0.0          0.0
         1    18     1            -0.373105D+04         -0.3731D+04   0.0          0.0
         1    19     1            -0.382568D+04         -0.3826D+04   0.0          0.0
         1    19     1            -0.382568D+04         -0.3826D+04   0.0          0.0
         1    20     1             0.182649D+04          0.1826D+04   0.0          0.0
```

```
 1   20    1          [illegible]
 1   21    1          0.177018D+04        0.1770D+04   0.0            0.0
 1   21    1          0.177018D+04        0.1770D+04   0.0            0.0
 1   22    1          0.585201D+04        0.5852D+04   0.0            0.0
 1   22    1          0.585201D+04        0.5852D+04   0.0            0.0
 1   23    1         -0.558336D+04       -0.5583D+04   0.0            0.0
 1   23    1         -0.558336D+04       -0.5583D+04   0.0            0.0
 1   24    1          0.518303D+04        0.5183D+04   0.0            0.0
 1   24    1          0.518303D+04        0.5183D+04   0.0            0.0
 1   25    1         -0.630538D+04       -0.6305D+04   0.0            0.0
 1   25    1         -0.630538D+04       -0.6305D+04   0.0            0.0

50   STRESS/STRAIN CONSTRAINTS                        26     TO   75      MOST CRITICAL CONSTRAINT=   0.942356E+00
 0.1008D+01   0.9715D+00   0.8750D+00   0.1125D+01   0.8420D+00   0.1111D+01   0.1057D+01   0.9429D+00   0.1085D+01   0.9199D+00
 0.8880D+00   0.1112D+01   0.1090D+01   0.9097D+00   0.8919D+00   0.1108D+01   0.1078D+01   0.9217D+00   0.1011D+01   0.9951D+00
 0.1019D+01   0.9909D+00   0.1052D+01   0.9483D+00   0.9811D+00   0.1019D+01   0.9398D+00   0.1069D+01   0.1015D+01   0.9895D+00
 0.9355D+00   0.1064D+01   0.1007D+01   0.9932D+00   0.9067D+00   0.1093D+01   0.9044D+00   0.1035D+01   0.1040D+01   0.9543D+00
 0.1044D+01   0.9557D+00   0.1146D+01   0.8537D+00   0.8603D+00   0.1140D+01   0.1130D+01   0.8704D+00   0.8427D+00   0.1158D+01

      25    CONSTRAINTS OUT OF   25      CUTOFF POINT=    0.399500D+00
                1            2            3            4            5            6            7            8            9           10
               11           12           13           14           15           16           17           18           19           20
               21           22           23           24           25

       0    CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.399500D+00

       0    CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.399500D+00

      22    CONSTRAINTS OUT OF   50      CUTOFF POINT=    0.984237D+00
               28           30           33           35           36           39           40           43           47           49
               50           52           55           56           60           62           65           67           69           70
               73           74

      22    CONSTRAINTS OUT OF   22    RETAINED DUE TO VARIABLE LINKING
               28           30           33           35           36           39           40           43           47           49
               50           52           55           56           60           62           65           67           69           70
               73           74

       0    CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.984237D+00

       0    CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.984237D+00

******************************************************** INTEGER ARRAY SIZE       20000    .GT.            601        552

                                                   POSTURE TABLE
                                                   -------------

                 RETAINED      TOTAL     MEMBER     MEMBER        NODE DIRECTION        L.C.       MODE    CONSTRAINT VALUES
               ------------------------------------------------------------------------------------------------------------

                SIDE CONSTRAINTS      MOST CRITICAL =     0.950000D+00
                        1          1          1          1                                         -10        0.950000D+00
                        2          2          1          2                                         -10        0.950000D+00
                        3          3          1          3                                         -10        0.950000D+00
                        4          4          1          4                                         -10        0.950000D+00
                        5          5          1          5                                         -10        0.950000D+00
                        6          6          1          6                                         -10        0.950000D+00
                        7          7          1          7                                         -10        0.950000D+00
                        8          8          1          8                                         -10        0.950000D+00
                        9          9          1          9                                         -10        0.950000D+00
                       10         10          1         10                                         -10        0.950000D+00
                       11         11          1         11                                         -10        0.950000D+00
                       12         12          1         12                                         -10        0.950000D+00
                       13         13          1         13                                         -10        0.950000D+00
                       14         14          1         14                                         -10        0.950000D+00
                       15         15          1         15                                         -10        0.950000D+00
```

```
         17          17           1          17                                                 -10          0.995000D+00
         18          18           1          18                                                 -10          0.995000D+00
         19          19           1          19                                                 -10          0.995000D+00
         20          20           1          20                                                 -10          0.995000D+00
         21          21           1          21                                                 -10          0.995000D+00
         22          22           1          22                                                 -10          0.995000D+00
         23          23           1          23                                                 -10          0.995000D+00
         24          24           1          24                                                 -10          0.995000D+00
         25          25           1          25                                                 -10          0.935000D+00

   STRESS/STRAIN CONSTRAINTS      MOST CRITICAL =    0.842365D+00
         26          28           1           2                                       1          0          0.875010D+00
         27          30           1           3                                       1          0          0.888964D+00
         28          33           1           4                                       1          0          0.942912D+00
         29          35           1           5                                       1          0          0.910890D+00
         30          36           1           6                                       1          0          0.887971D+00
         31          39           1           7                                       1          0          0.909747D+00
         32          40           1           8                                       1          0          0.891874D+00
         33          43           1           9                                       1          0          0.921723D+00
         34          47           1          11                                       1          0          0.930216D+00
         35          49           1          12                                       1          0          0.948311D+00
         36          50           1          13                                       1          0          0.981030D+00
         37          52           1          14                                       1          0          0.939760D+00
         38          55           1          15                                       1          0          0.980011D+00
         39          56           1          16                                       1          0          0.935635D+00
         40          60           1          18                                       1          0          0.906724D+00
         41          62           1          19                                       1          0          0.904358D+00
         42          65           1          20                                       1          0          0.954338D+00
         43          67           1          21                                       1          0          0.955746D+00
         44          69           1          22                                       1          0          0.853700D+00
         45          70           1          23                                       1          0          0.860415D+00
         46          73           1          24                                       1          0          0.870424D+00
         47          74           1          25                                       1          0          0.842365D+00
   ------------------------------------------------------------------------------------------------------------
      * SIDE : -1=LOWER BOUND,  +1=UPPER BOUND
        DISPLACEMENT : -1=LOWER BOUND,  +1=UPPER BOUND
        SLOPE :  ALWAYS UPPER BOUNDS
        STRESS/STRAIN * 10=VON MISES
                         1=LONGITUDINAL STRAIN
                         2=TRANSVERSE STRAIN
                         3=SHEAR STRAIN
        FREQUENCY    ASSOCIATED MODE NUMBER

 ANALYSIS TIME DATA
   ASSEMBLE MASS/STIFFNESS MATRIX    0.608333D-01
   ASSEMBLE LOAD VECTORS             0.456250D-01
   DECOMPOSE STIFFNESS MATRIX        0.105208D-01
   SOLUTION OF DISPLACEMENTS         0.916667D-02
   FREQUENCY ANALYSIS                0.0
   FLUTTER ANALYSIS                  0.104167D-03
   CONSTRAINT EVALUATION             0.728125D-01
   POSTURE TABLE SET                 0.645833D-01
   SELECTIVE GRADIENT EVALUATION     0.573437D+00
 ---------------------------------------------------
      GRAND TOTAL CPU TIME           0.864167D+00

*****************************************************REAL ARRAY SIZE FOR OPTIMIZER      55000   .GE.        1212
                                                     INTEGER                            20000   .GE.        69.
```

```
*******************************************    N E W S U M T   O P T I M I Z E R   ******************************************

                                            CONTROL PARAMETERS
                        INITIAL TRANSITION POINT                               GO  =  0.1000D+00
                        TRANSITION POINT EXPONENT                               P  =  0.5000D+00
                        INITIAL TRANSITION POINT COEFFICIENT                    C  =  0.1000D+00
                        GOLDEN SECTION CONVERGENCE                         EPSGSN  =  0.1000D-02
                        UNCONSTRAINED MINIMIZATION CONVERGENCE             EPSODM  =  0.1000D-02
                        CONVERGENCE AMONG RESPONSE SURFACES                EPSRSF  =  0.5000D-02
                        RESPONSE FACTOR REDUCTION RATIO                     RACUT  =  0.3000D+00
                        MINIMUM ALLOWABLE RESPONSE FACTOR                   RAMIN  =  0.1000D-14
                        MAXIMUM ALLOWABLE STEP SIZE                        STEPMX  =  0.1000D+03
                        MAXIMUM ALLOWABLE GOLDEN SECTIONS                  MAXGSN  =    20
                        MAXIMUM NUMBER OF O.D.M. PER SURFACE               MAXODM  =     5
                        MAXIMUM ALLOWABLE RESPONSE SURFACES                MAXRSF  =     2
                        PRINTOUT CONTROL                                   JPRINT  =     0
                        FINITE DIFFERENCE GRADIENT CONTROL                    IFD  =     0

                                            SYSTEM PARAMETERS
                        NUMBER OF DESIGN VARIABLES                            NDV  =    25
                        NUMBER OF EFFECTIVE CONSTRAINTS                      NTCE  =    22

      INITIAL DESIGN ANALYSIS SUMMARY
      -------------------------------
          INITIAL DESIGN VARIABLE VECTOR
            0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01
            0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01
            0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01  0.1000D+01
          SIDE CONSTRAINTS
                -1           1          -2           2          -3           3          -4           4          -            5
            0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02
                -6           6          -7           7          -8           8          -9           9         -10          10
            0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02
               -11          11         -12          12         -13          13         -14          14         -15          15
            0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02
               -16          16         -17          17         -18          18         -19          19         -20          20
            0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02
               -21          21         -22          22         -23          23         -24          24         -25          25
            0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02  0.9900D+00  0.9900D+02
          CONSTRAINTS
            0.8750D+00  0.3890D+00  0.9429D+00  0.9109D+00  0.8880D+00  0.9097D+00  0.8913D+00  0.9217D+00  0.9295D+00  0.9483D+00
            0.9811D+00  0.9398D+00  0.9805D+00  0.9353D+00  0.9067D+00  0.9044D+00  0.9543D+00  0.9557D+00  0.8537D+00  0.9609D+00
            0.8704D+00  0.8424D+00
          OBJECTIVE FUNCTION =   0.6581327D+03

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.100000D+00      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.274474D-01

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.186264D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.511247D-02

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.197296D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.541527D-02

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.201905D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.553178D-02

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.203024D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.557250D-02

    ----- DIRECTION FINDING -----
          TRANSITION POINT =    0.610023D-02      COEFFICIENT OF TRANSITION POINT CALCULATION =    0.305694D-02

    ----- DIRECTION FINDING -----
```

```
          TRANSITION POINT =   0.14013D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =     [illegible]

  ----- DIRECTION FINDING -----
          TRANSITION POINT =   0.140214D-01      COEFFICIENT OF TRANSITION POINT CALCULATION =   0.702640D+02

     FINAL RESULTS OF OPTIMIZATION
     -----------------------------
          CURRENT DESIGN VARIABLE VECTOR
            0.4312D+02  0.3954D+01  0.4088D+01  0.6619D+01  0.4985D+01  0.4027D+01  0.4867D+01  0.4376D+01  0.5319D+01  0.2961D+02
            0.1565D+02  0.6687D+01  0.1340D+02  0.7636D+01  0.1519D+02  0.8554D+01  0.3933D+02  0.5339D+01  0.3400D+01  0.3521D+01
            0.9800D+01  0.3361D+01  0.3025D+01  0.3877D+01  0.2620D+01
          SIDE CONSTRAINTS
                -1           1          -2           2          -3           3          -4           4          -5           5
            0.4311D+02  0.3688D+02  0.3944D+01  0.9605D+02  0.4078D+01  0.5591D+02  0.6603D+01  0.9338D+02  0.4775D+01  0.9501D+02
                -6           6          -7           7          -8           8          -9           9         -10          10
            0.4017D+01  0.9597D+02  0.4857D+01  0.9513D+02  0.4366D+01  0.9502D+02  0.5304D+01  0.9469D+02  0.2260D+02  0.7039D+02
               -11          11         -12          12         -13          13         -14          14         -15          15
            0.1564D+02  0.8435D+02  0.6677D+01  0.9331D+02  0.1339D+02  0.8660D+02  0.7640D+01  0.9234D+02  0.1319D+02  0.8491D+02
               -16          16         -17          17         -18          18         -19          19         -20          20
            0.8544D+01  0.9145D+02  0.3932D+02  0.6067D+02  0.5389D+01  0.9460D+02  0.3330D+01  0.9456D+02  0.9511D+01  0.9048D+02
               -21          21         -22          22         -23          23         -24          24         -25          25
            0.9790D+01  0.9020D+02  0.3351D+01  0.9664D+02  0.3015D+01  0.9697D+02  0.3867D+01  0.9612D+02  0.2610D+01  0.9738D+02
          CONSTRAINTS
            0.5408D+00  0.5053D+00  0.6526D+00  0.5088D+00  0.5200D+00  0.5275D+00  0.5722D+00  0.6235D+00  0.8540D+00  0.9467D+00
            0.9430D+00  0.6432D+00  0.5989D+00  0.5744D+00  0.5709D+00  0.6632D+00  0.7435D+00  0.7437D+00  0.4530D+00  0.3792D+00
            0.4604D+00  0.3675D+00
          TOTAL FUNCTION     =   0.2840041D+03
          OBJECTIVE FUNCTION =   0.1131500D+03

          FINAL STATISTICS                                                               CUMULATIVE CPU(SEC)
          ----------------
                NUMBER OF RESPONSE SURFACE . . . . .      2                 TOTAL                  0.8690
                NUMBER OF ONE DIMENSIONAL SEARCH .        8                 C.D.M.                 0.2404
                NUMBER OF ANALYSES                                          DIRECTION              0.5219
                                                                            EQ. SOLVER             0.3617
                      OBJECTIVE FUNCTION . . . . . . . . . . . . . . .  174                        0.0348
                      APPROXIMATE OBJECTIVE FUNCTION . . . . . . . .      0                        0.0
                      GRADIENT OF OBJECTIVE FUNCTION . . . . . . . .      8                        0.0027
                      CONSTRAINT FUNCTIONS . . . . . . . . . . . . .     17                        0.0105
                      GRADIENT OF LINEAR CONSTRAINT FUNCTIONS . . .       1                        0.0001
                      GRADIENT OF NONLINEAR CONSTRAINT FUNCTIONS .        0                        0.0
                      APPROXIMATE CONSTRAINT FUNCTIONS . . . . . . .    157                        0.0278
```

```
RESPONSE FACTOR REDUCED TO   0.119465D+01

TRUNCATION FACTORS MODIFIED AS FOLLOWS
  SIDE CONSTRAINT                0.120000D+00
  STRESS/STRAIN CONSTRAINT       0.120000D+00

  UPDATED SCALING FACTORS
      0.2313D-01  0.2529D+00  0.2445D+00  0.1511D+00  0.2006D+00  0.2484D+00  0.2055D+00  0.2283D+00  0.1182D+00  0.3377D-01
      0.6388D-01  0.1495D+00  0.7461D-01  0.1306D+00  0.5583D-01  0.1165D+00  0.2543D-01  0.1952D+00  0.1973D+00  0.1050D+00
      0.1020D+00  0.2976D+00  0.3305D+00  0.2580D+00  0.3816D+00

  UPDATED WEIGHT COEFFICIENTS
      0.2342D+00  0.6322D+01  0.5314D+01  0.7282D+01  0.5014D+01  0.5394D+01  0.5136D+01  0.5712D+01  0.4694D+01  0.5116D+01
      0.9678D+00  0.2266D+01  0.1130D+01  0.4779D+01  0.2409D+01  0.4278D+01  0.9705D+00  0.6777D+01  0.6853D+01  0.3843D+01
      0.3734D+01  0.8022D+01  0.8911D+01  0.6555D+01  0.1029D+02  0.0         0.0
```

```
---------------------------------------------
STAGE NO.  2   APPROXIMATE PROBLEM GENERATOR
---------------------------------------------

 CURRENT MEMBER SIZE
 -------------------
   MEMBER TYPE NUMBER  1
       0.4638D-01  0.5058D+00  0.4893D+00  0.3022D+00  0.4012D+00  0.4567D+00  0.4122D+00  0.4570D+00  0.3754D+00  0.6754D-01
       0.1278D+00  0.2991D+00  0.1492D+00  0.2612D+00  0.1317D+00  0.2338D+00  0.5036D-01  0.3724D+00  0.3745D+00  0.2101D+00
       0.2041D+00  0.5951D+00  0.6611D+00  0.5159D+00  0.7632D+00

 CURRENT WEIGHT DATA
 -------------------
   MEMBER TYPE NUMBER     1      WEIGHT =    0.113150D+03
   ----------------------------------------------------
        VARIABLE STRUCTURAL WEIGHT    0.113150D+03
        FIXED STRUCTURAL WEIGHT       0.0
             TOTAL STRUCTURAL WEIGHT       0.113150D+03
             NON-STRUCTURAL WEIGHTHT       0.0
             -----------------------------------------
                      TOTAL WEIGHT                0.113150D+03

   CONVERGENCE CHECK      STAGE NO.=    2         0.4816D+01      0.1519D+28   MUST BE LESS THAN   0.100000D-02
      OBJECTIVE FUNCTION OF THREE CONSECUTIVE STAGES ARE    0.100000D+31    0.653133D+03    0.113150D+03

                                                 POSTURE TABLE
                                                 -------------
                RETAINED      TOTAL     MEMBER     MEMBER       NODE DIRECTION       L.C.       MODE    CONSTRAINT VALUES
               ---------------------------------------------------------------------------------------------------------

               SIDE CONSTRAINTS       MOST CRITICAL =    0.784401D+00
                     1          1          1          1                                         -10        0.784401D+00
                     2          4          1          4                                         -10        0.965970D+00
                     3          9          1          9                                         -10        0.973432D+00
                     4         10          1         10                                         -10        0.851943D+00
                     5         11          1         11                                         -10        0.921733D+00
                     6         12          1         12                                         -10        0.966566D+00
                     7         13          1         13                                         -10        0.932982D+00
                     8         14          1         14                                         -10        0.961718D+00
                     9         15          1         15                                         -10        0.924043D+00
                    10         16          1         16                                         -10        0.957232D+00
                    11         17          1         17                                         -10        0.803371D+00
                    12         18          1         18                                         -10        0.973003D+00
                    13         19          1         19                                         -10        0.973301D+00
                    14         20          1         20                                         -10        0.952346D+00
                    15         21          1         21                                         -10        0.950998D+00

               STRESS/STRAIN CONSTRAINTS      MOST CRITICAL =    0.467768D+00
                    16         27          1          1                              1           0         0.664451D+00
                    17         28          1          2                              1           0         0.526860D+00
                    18         30          1          3                              1           0         0.527120D+00
                    19         33          1          4                              1           0         0.652749D+00
                    20         35          1          5                              1           0         0.529074D+00
                    21         36          1          6                              1           0         0.536843D+00
                    22         39          1          7                              1           0         0.543974D+00
                    23         40          1          8                              1           0         0.542073D+00
                    24         43          1          9                              1           0         0.600149D+00
                    25         45          1         10                              1           0         0.857226D+00
                    26         47          1         11                              1           0         0.849094D+00
```

```
       2          ,          1          1                                       1                    
      28         55          1         13                                       1          0         0.584[illegible]D+00
      29         56          1         16                                       1          0         0.510460D+00
      30         59          1         17                                       1          0         0.476715D+00
      31         60          1         18                                       1          0         0.712900D+00
      32         62          1         19                                       1          0         0.699759D+00
      33         65          1         20                                       1          0         0.735420D+00
      34         67          1         21                                       1          0         0.737[illegible]D+00
      35         69          1         22                                       1          0         0.477690D+00
      36         70          1         23                                       1          0         0.467760D+00
      37         73          1         24                                       1          0         0.472272D+00
      38         74          1         25                                       1          0         0.500823D+00
                 ------------------------------------------------------------------------------------------------
                   * SIDE : -1=LOWER BOUND,  +1=UPPER BOUND
                     DISPLACEMENT   -1=LOWER BOUND,  +1=UPPER BOUND
                     SLOPE :  ALWAYS UPPER BOUNDS
                     STRESS/STRAIN : 10=VON MISES
                                      1=LONGITUDINAL STRAIN
                                      2=TRANSVERSE STRAIN
                                      3=SHEAR STRAIN
                     FREQUENCY * ASSOCIATED MODE NUMBER

****************************************************REAL ARRAY SIZE FOR OPTIMIZER     55000   .GE.        1292
                                                    INTEGER                            20000   .GE.         688
```

```
 -----------------------------------------------
 STAGE NO. 12   APPROXIMATE PROBLEM GENERATOR
 -----------------------------------------------

   CURRENT MEMBER SIZE
   -------------------
     MEMBER TYPE NUMBER  1
         0.1018D-01  0.2188D+00  0.2303D+00  0.8691D-01  0.1874D+00  0.2431D+00  0.2922D+00  0.2169D+00  0.1585D+00  0.1015D-01
         0.1015D-01  0.7653D-01  0.5323D-01  0.9804D-01  0.6596D-01  0.1034D+00  0.3593D-01  0.1092D-01  0.3723D-01  0.1014D-01
         0.1279D-01  0.3444D+00  0.4267D+00  0.2943D+00  0.4449D+00

   CURRENT WEIGHT DATA
   -------------------
     MEMBER TYPE NUMBER     1      WEIGHT =    0.468926D+02
     ---------------------------------------------------------
          VARIABLE STRUCTURAL WEIGHT    0.468926D+02
          FIXED STRUCTURAL WEIGHT       0.0
               TOTAL STRUCTURAL WEIGHT       0.468926D+02
               NON-STRUCTURAL WEIGHTHT       0.0
               ---------------------------------------
                        TOTAL WEIGHT              0.468926D+02

     CONVERGENCE CHECK      STAGE NO.=   12         0.4981D-02      0.8072D-02    MUST BE LESS THAN    0.100000D-02
        OBJECTIVE FUNCTION OF THREE CONSECUTIVE STAGES ARE    0.475066D+02    0.471262D+02    0.468926D+02
```

```
                                                          NODAL   DISPLACEMENTS
                                                          -------------------

         NODE                 X                Y                Z              NODE                X               Y                Z
       ---------------------------------------------------------------------------------------------------------------------------

       LOAD CONDITION     1

          1          -0.17629D-01    0.35760D+01    0.13072D+01                2          -0.17872D-01    0.3[illegible]33D+01   -0.[illegible]203D+00
          3           0.12837D+00   -0.23396D+00   -0.78283D+00                4          -0.72020D-01   -0.23417D+00   -0.74[illegible]7D+00
          5           0.22102D+00   -0.36317D+00    0.12285D+01                6          -0.16898D+00   -0.36304D+00    0.11960D+01
          7           0.0            0.0            0.0                        8           0.0            0.0            0.0
          9           0.0            0.0            0.0                       10           0.0            0.0            0.0
       ===========================================================================================================================


   25   SIDE CONSTRAINTS                              1    TO   25      MOST CRITICAL CONSTRAINT=  0.1375953D-01
    0.1803D-01   0.9543D+00   0.9566D+00   0.8949D+00   0.9467D+00   0.9589D+00   0.9505D+00   0.9543D+00   0.9371D+00   0.1516D-01
    0.1508D-01   0.8693D+00   0.8121D+00   0.6980D+00   0.8434D+00   0.9033D+00   0.7193D+00   0.6658D+00   0.7314D+00   0.1376D-01
    0.2181D+00   0.9710D+00   0.9766D+00   0.9660D+00   0.9775D+00

   MTYP     M    LC           S-COMBINED               SX            SY            SXY         SX-THERM     SY-THERM    SXY-THERM
   ------------------------------------------------------------------------------------------------------------------------------
      1     1     1         -0.430025D+04        -0.4300D+04    0.0           0.0
      1     1     1         -0.430025D+04        -0.4300D+04    0.0           0.0
      1     2     1         -0.399050D+05        -0.3991D+05    0.0           0.0
      1     2     1         -0.399050D+05        -0.3991D+05    0.0           0.0
      1     3     1         -0.398751D+05        -0.3988D+05    0.0           0.0
      1     3     1         -0.398751D+05        -0.3988D+05    0.0           0.0
      1     4     1          0.398542D+05         0.3985D+05    0.0           0.0
      1     4     1          0.398542D+05         0.3985D+05    0.0           0.0
      1     5     1          0.398671D+05         0.3987D+05    0.0           0.0
      1     5     1          0.398671D+05         0.3987D+05    0.0           0.0
      1     6     1         -0.398968D+05        -0.3990D+05    0.0           0.0
      1     6     1         -0.398968D+05        -0.3990D+05    0.0           0.0
      1     7     1          0.398970D+05         0.3990D+05    0.0           0.0
      1     7     1          0.398970D+05         0.3990D+05    0.0           0.0
      1     8     1         -0.398696D+05        -0.3987D+05    0.0           0.0
      1     8     1         -0.398696D+05        -0.3987D+05    0.0           0.0
      1     9     1          0.398356D+05         0.3984D+05    0.0           0.0
      1     9     1          0.398356D+05         0.3984D+05    0.0           0.0
      1    10     1          0.441152D+04         0.4412D+04    0.0           0.0
      1    10     1          0.441152D+04         0.4412D+04    0.0           0.0
      1    11     1          0.439891D+04         0.4399D+04    0.0           0.0
      1    11     1          0.439891D+04         0.4399D+04    0.0           0.0
      1    12     1         -0.395192D+05        -0.3952D+05    0.0           0.0
      1    12     1         -0.395192D+05        -0.3952D+05    0.0           0.0
      1    13     1          0.391998D+05         0.3920D+05    0.0           0.0
      1    13     1          0.391998D+05         0.3920D+05    0.0           0.0
      1    14     1         -0.398563D+05        -0.3986D+05    0.0           0.0
      1    14     1         -0.398563D+05        -0.3986D+05    0.0           0.0
      1    15     1          0.398033D+05         0.3980D+05    0.0           0.0
      1    15     1          0.398033D+05         0.3980D+05    0.0           0.0
      1    16     1         -0.398794D+05        -0.3988D+05    0.0           0.0
      1    16     1         -0.398794D+05        -0.3988D+05    0.0           0.0
      1    17     1          0.398087D+05         0.3981D+05    0.0           0.0
      1    17     1          0.398087D+05         0.3981D+05    0.0           0.0
      1    18     1         -0.299957D+05        -0.3000D+05    0.0           0.0
      1    18     1         -0.299957D+05        -0.3000D+05    0.0           0.0
      1    19     1         -0.334207D+05        -0.3342D+05    0.0           0.0
      1    19     1         -0.334207D+05        -0.3342D+05    0.0           0.0
      1    20     1          0.311447D+05         0.3114D+05    0.0           0.0
```

```
  1   20     1          0.311-  D+0          0.311-D+0   0.0          0.0
  1   21     1          0.279743D+05         0.27970+05   0.0          0.0
  1   21     1          0.279743D+05         0.27970+05   0.0          0.0
  1   22     1          0.398347D+05         0.39830+05   0.0          0.0
  1   22     1          0.398347D+05         0.39830+05   0.0          0.0
  1   23     1         -0.398747D+05        -0.39870+05   0.0          0.0
  1   23     1         -0.398747D+05        -0.39870+05   0.0          0.0
  1   24     1          0.398310D+05         0.39830+05   0.0          0.0
  1   24     1          0.398310D+05         0.39830+05   0.0          0.0
  1   25     1         -0.398930D+05        -0.39890+05   0.0          0.0
  1   25     1         -0.398930D+05        -0.39890+05   0.0          0.0

 50   STRESS/STRAIN CONSTRAINTS                    26    TO   75      MOST CRITICAL CONSTRAINT=   0.2374677D-02
  0.8925D+00  0.1108D+01  0.2375D-02  0.1998D+01  0.3124D-02  0.1997D+01  0.1996D+01  0.3646D-02  0.1997D+01  0.3324D-02
  0.2580D-02  0.1997D+01  0.1997D+01  0.2575D-02  0.3259D-02  0.1997D+01  0.1996D+01  0.4111D-02  0.1110D+01  0.8937D+00
  0.1110D+01  0.8900D+00  0.1202D-01  0.1988D+01  0.1980D+01  0.2001D-01  0.3593D-02  0.1336D+01  0.1995D+01  0.6912D-02
  0.3016D-02  0.1997D+01  0.1995D+01  0.4783D-02  0.2501D+00  0.1750D+01  0.1645D+00  0.1835D+01  0.1779D+01  0.2214D+00
  0.1699D+01  0.3006D+00  0.1996D+01  0.4132D-02  0.3132D-02  0.1997D+01  0.1996D+01  0.4225D-02  0.2675D-02  0.1997D+01

   5   CONSTRAINTS OUT OF   25      CUTOFF POINT=    0.408256D+00
         1          10          11          20          21

   0   CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.408256D+00

   0   CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.408256D+00

  22   CONSTRAINTS OUT OF   50      CUTOFF POINT=    0.401425D+00
        28          30          33          35          36          39          40          43          49          51
        52          55          56          59          60          62          65          67          69          70
        73          74

  22   CONSTRAINTS OUT OF   22    RETAINED DUE TO VARIABLE LINKING
        28          30          33          35          36          39          40          43          49          51
        52          55          56          59          60          62          65          67          69          70
        73          74

   0   CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.401425D+00

   0   CONSTRAINTS OUT OF    0      CUTOFF POINT=    0.401425D+00

********************************************** INTEGER ARRAY SIZE     20000   .GE.         581       632

                                             POSTURE TABLE
                                             -------------

              RETAINED      TOTAL     MEMBER     MEMBER       NODE DIRECTION        L.C.       MODE    CONSTRAINT VALUES
              ------------------------------------------------------------------------------------------------------------

              SIDE CONSTRAINTS      MOST CRITICAL =    0.137595D-01
                     1           1          1          1                                          -10       0.180264D-01
                     2          10          1         10                                          -10       0.151555D-01
                     3          11          1         11                                          -10       0.150932D-01
                     4          20          1         20                                          -10       0.137595D-01
                     5          21          1         21                                          -10       0.218092D+00

              STRESS/STRAIN CONSTRAINTS       MOST CRITICAL =     0.237468D-02
                     6          28          1          2                            1             0       0.237468D-02
                     7          30          1          3                            1             0       0.312351D-02
                     8          33          1          4                            1             0       0.364608D-02
                     9          35          1          5                            1             0       0.332351D-02
                    10          36          1          6                            1             0       0.258035D-02
                    11          39          1          7                            1             0       0.257537D-02
                    12          40          1          8                            1             0       0.325908D-02
                    13          43          1          9                            1             0       0.411101D-02
                    14          48          1         12                            1             0       0.120208D-01
                    15          51          1         13                            1             0       0.200053D-01
```

```
          16         2          1          14                                  1                  [illegible]
          17        55          1          15                                  1          0       0.[illegible]D-02
          18        56          1          16                                  1          0       0.30153[illegible]D-02
          19        59          1          17                                  1          0       0.47633[illegible]D-02
          20        60          1          18                                  1          0       0.255109D+00
          21        62          1          19                                  1          0       0.154483D+00
          22        65          1          20                                  1          0       0.221392D+00
          23        67          1          21                                  1          0       0.300643D+00
          24        69          1          22                                  1          0       0.413176D-02
          25        70          1          23                                  1          0       0.313166D-02
          26        73          1          24                                  1          0       0.422406D-02
          27        74          1          25                                  1          0       0.267531D-02
      -------------------------------------------------------------------------------------------------------
        * SIDE : -1=LOWER BOUND,  +1=UPPER BOUND
          DISPLACEMENT : -1=LOWER BOUND,  +1=UPPER BOUND
          SLOPE :  ALWAYS UPPER BOUNDS
          STRESS/STRAIN : 10=VON MISES
                           1=LONGITUDINAL STRAIN
                           2=TRANSVERSE STRAIN
                           3=SHEAR STRAIN
          FREQUENCY ' ASSOCIATED MODE NUMBER


 ANALYSIS TIME DATA
   ASSEMBLE MASS/STIFFNESS MATRIX    0.682708D+00
   ASSEMBLE LOAD VECTORS             0.571875D-01
   DECOMPOSE STIFFNESS MATRIX        0.103125D-01
   SOLUTION OF DISPLACEMENTS         0.101042D-01
   FREQUENCY ANALYSIS                0.0
   FLUTTER ANALYSIS                  0.0
   CONSTRAINT EVALUATION             0.771875D-01
   POSTURE TABLE SET                 0.446875D-01
   SELECTIVE GRADIENT EVALUATION     0.601250D+00
 --------------------------------------------------
      GRAND TOTAL CPU TIME           0.895208D+00

      MAXIMUM NUMBER OF STAGES ARE PERFORMED
```

```
    SUMTOP TIME STATISTICS
     TOTAL                        16.2723
        INITIAL PREPARATION        0.0361
        DESIGN PHASE              16.2362
          ANALYSIS TOTAL            9.7252
          OPTIMIZER TOTAL           6.3954

 MAIN PROGRAM TIME STATISTICS
   PRE-PROCESSOR                    0.5224
   DESIGN PHASE                    16.2746
   ----------------------------------------
     GRAND TOTAL                     16.7970
```

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15 Supplementary Notes

W. Jefferson Stroud, Structures and Dynamics Division, Langley Research Center, was technical monitor on this grant.

16 Abstract

This report serves as a user's guide for the ACCESS-2 computer program. ACCESS-2 is a research oriented program which implements a collection of approximation concepts to achieve excellent efficiency in structural synthesis. The finite element method is used for structural analysis and general mathematical programming algorithms are applied in the design optimization procedure.

ACCESS-2 was developed based on ACCESS-1, but a major part of the program was rewritten to accommodate the following new features:

- Dynamic array allocation
- Thermal loading
- Frequency constraints
- Extended element library
  - Constant strain orthotropic triangular element
  - Symmetric pure shear element
  - Thermal symmetric shear element
- Independent optimizer (NEWSUMT)
- Auxiliary data storage files

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