

STARS—An Integrated, Multidisciplinary, Finite-Element, Structural, Fluids, Aeroelastic, and Aeroservoelastic Analysis Computer Program

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ABSTRACT

A multidisciplinary, finite element-based, highly graphics-oriented, linear and nonlinear analysis capability that includes such disciplines as structures, heat transfer, linear aerodynamics, computational fluid dynamics, and controls engineering has been achieved by integrating several new modules in the original STARS (*S*Tructural Analysis Routine*S*) computer program. Each individual analysis module is general-purpose in nature and is effectively integrated to yield aeroelastic and aeroservoelastic solution of complex engineering problems. Examples of advanced NASA Dryden Flight Research Center projects analyzed by the code in recent years include the X-29A, F-18 High Alpha Research Vehicle/Thrust Vectoring Control System, B-52/Pegasus[®], Generic Hypersonics, National AeroSpace Plane (NASP), SR-71/Hypersonic Launch Vehicle, and High Speed Civil Transport (HSCT) projects. Extensive graphics capabilities exist for convenient model development and postprocessing of analysis results. The program is written in modular form in standard FORTRAN language to run on a variety of computers, such as the IBM RISC/6000, SGI, DEC, Cray, and personal computer; associated graphics codes use OpenGL and IBM/graPHIGS language for color depiction. This program is available from COSMIC, the NASA agency for distribution of computer programs.

NOMENCLATURE

ASE	aeroservoelastic
CFD	computational fluid dynamics
CPU	central processing unit
DEM	dynamic-element method
EAS	equivalent airspeed
EPS	solution accuracy parameter
FDBC	finite displacement boundary conditions
GCS	global coordinate system
GUI	graphical user interface
GVS	ground vibration survey
IDBC	interdependent displacement boundary conditions
KEAS	knots equivalent airspeed
LCS	local coordinate system
LGCS	local-global coordinate system
RL	double-precision
STARS	<i>S</i> Tructural Analysis Routine <i>S</i>
TAS	true airspeed
VBO	reduced velocity
ZDBC	zero displacement boundary conditions

1. INTRODUCTION

The highly integrated, digital computer program, STARS (*S*tructural Analysis Routine*S*),¹ has been designed as an efficient tool for analyzing practical engineering problems and for supporting relevant research and development activities. The program has also been an effective teaching aid, because all such activities are mutually enhancing and interrelated (fig. 1). Each individual module (fig. 2) of the program is general-purpose in nature, capable of solving a wide array of problems. The finite-element analysis modules are also appropriately combined to yield unique, multidisciplinary modeling and simulation capabilities of complex engineering problems.

The STRUCTURES (SOLIDS) module is capable of analyzing static, stability, vibration, and dynamic-response problems for all types of structures, including spinning ones subjected to mechanical and thermal loading. Both linear and nonlinear analyses are conveniently performed by the program. The element library consists of an extensive number of one-, two-, and three-dimensional elements with general material properties, including composite and sandwich elements. Structural as well as viscous damping can be included in the analysis. Figure 3 shows an overview of the SOLIDS link.

The heat-conduction analysis capability in the program is effected through the SOLIDS HEAT TRANSFER module. Both steady-state and transient analyses can be performed, including nonlinear effects. The element library consists of line, shell, and solid elements, including composites.

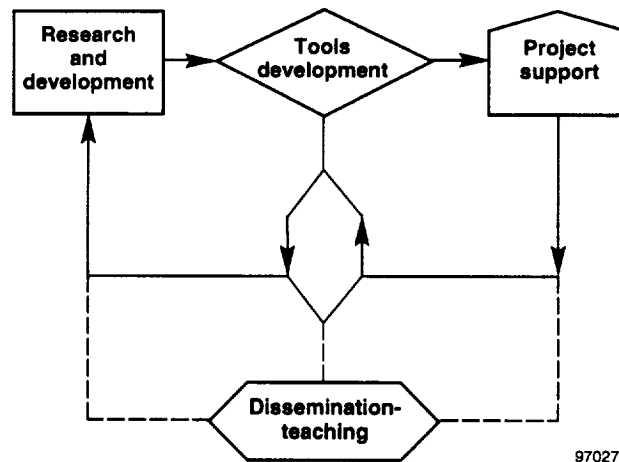


Figure 1. Structural synthesis.

Finite-element structural analysis
Spinning structures
Mechanical and thermal loading
General and composite materials

Static, buckling
Vibration, dynamic responses

Aeroelasticity:
Flutter and divergence
Flow-field analysis
Lift, drag, and moment

Aeroservoelasticity:
Frequency response, damping
and frequencies, digital
and analog controllers

Finite-element heat transfer
Finite-element computational fluid dynamics

Preprocessor - automatic finite-element
method model data generation
Postprocessor - color graphical
depiction of analysis results

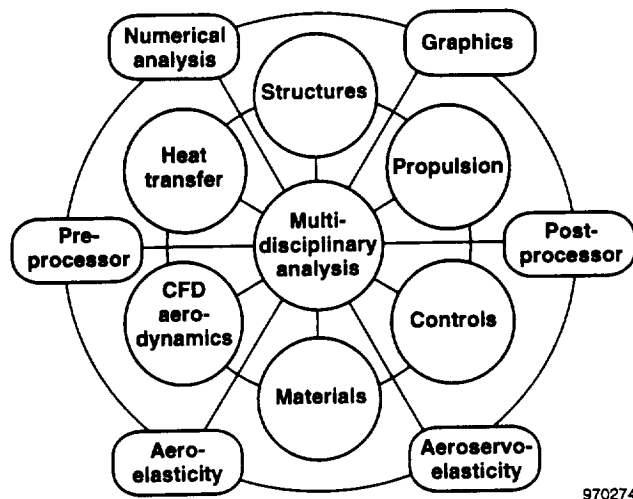


Figure 2. Major modules of STARS.

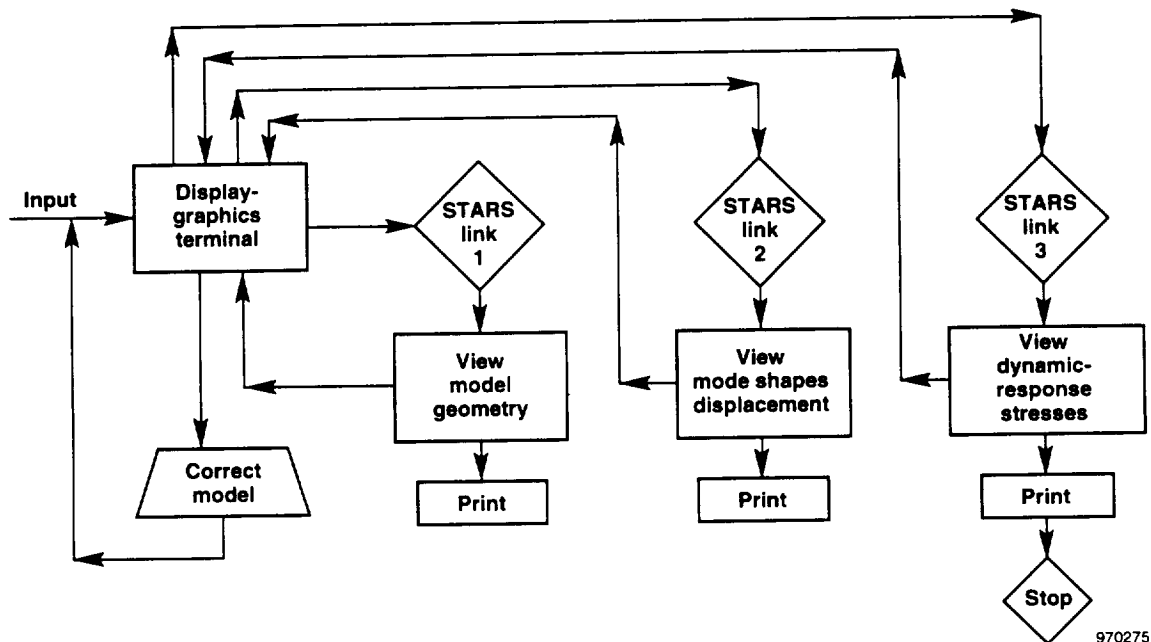
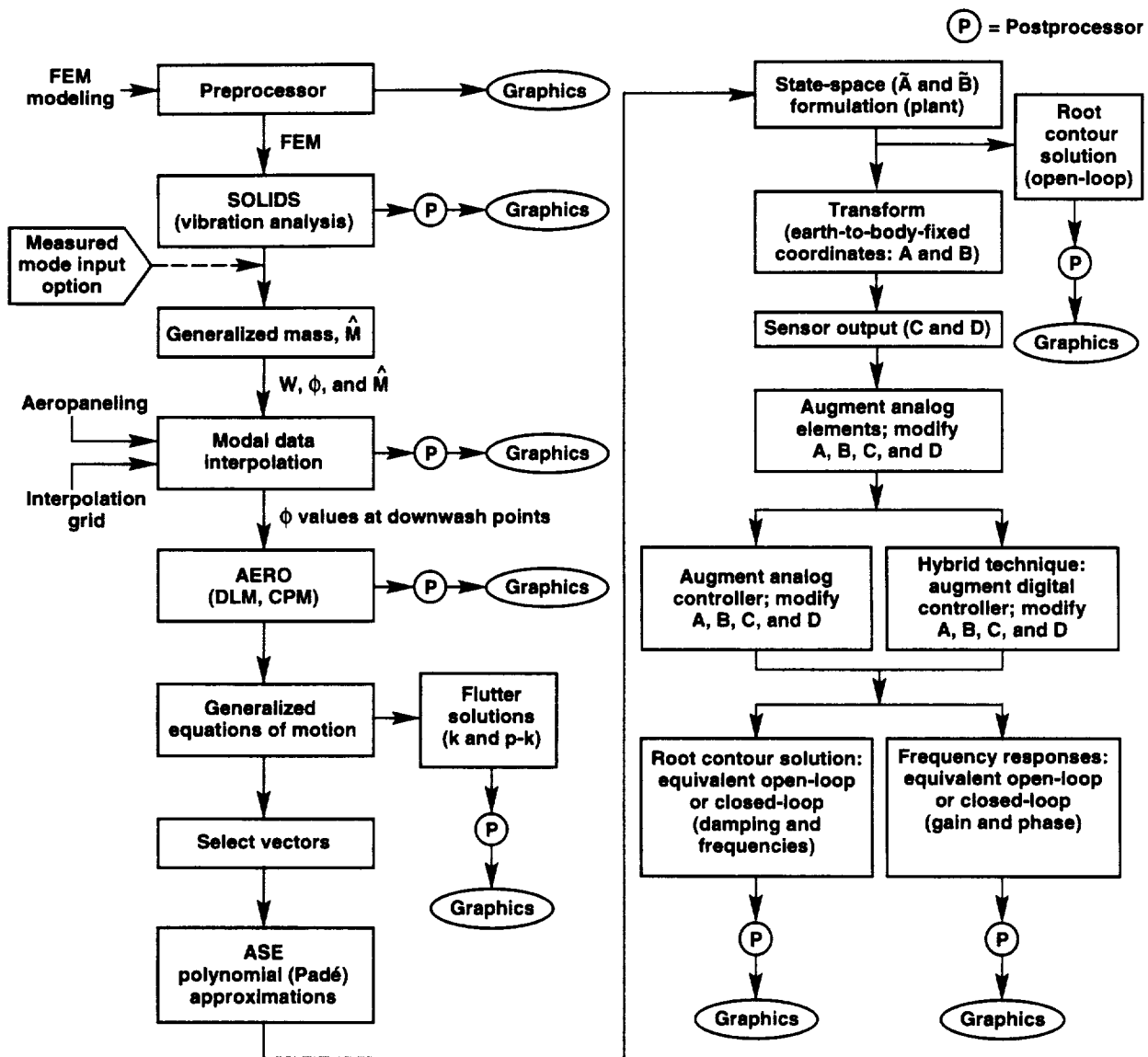


Figure 3. STARS-SOLIDS overview.

Figure 4 shows a schematic of the associated linear aeroelastic and aeroservoelastic (ASE) analyses. When the frequencies and mode shapes of the structure are derived from finite-element analysis employing the STARS-SOLIDS module, the STARS-AEROS module is used to compute the unsteady aerodynamic forces on the structure. An alternative option enables input of measured modal data in lieu of calculated data. A flutter solution is then achieved using the k or p-k methods. The user has to input details of the aerodynamic paneling to achieve the aeroelastic analysis.

Subsequent linear ASE analysis is achieved by employing the STARS-ASE module. The user provides essential data to perform a polynomial curve fitting of unsteady aerodynamic forces resulting in the state-space matrices. For an alternative open-loop flutter analysis, these data consist of information

on polynomial tension coefficients, previously calculated generalized masses, damping and modal characteristics, and a set of velocity values. Additional data, in lieu of velocity values, relating to coordinate transformations from Earth- to body-centered coordinate systems and sensor locations are needed for the subsequent ASE analysis for frequency-response calculations and for determining damping and frequency values. These additional data are achieved by the STARS-ASE-CONTROL submodule in which the primary data input relates to analog or digital controller blocks connectivity, associated transfer function polynomial descriptions and gain input, specifications for system output and input, and connection details between the plant and the blocks. This ASE analysis procedure can also be effectively used as the third flutter solution option.



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Figure 4. STARS-ASE flowchart.

Nonlinear aeroelastic and ASE analysis capability has been implemented in the STARS-CFDASE module. The STEADY submodule, which employs unstructured grids for domain discretization, can be

effectively employed for the solution of fluid flow problems. The STARS-CFDASE module enables effective computation of unsteady aerodynamic forces employing the finite element-based structural and computational fluid dynamics (CFD) computations. Subsequent aeroelastic analysis predicts flutter and divergence characteristics of the structure, whereas the ASE analysis computes the required stability derivatives. The associated PROPULSION module essentially employs CFD techniques for simulation of flow-mixing phenomenon. Data pertaining to advanced material properties are stored in the MATERIALS module.

The NUMERICAL ANALYSIS module contains a number of efficient solution procedures for large, sparse, matrix linear equations and eigenvalue problems. A block Lanczos procedure is available for solution of free-vibration problems for nonspinning and spinning structures as well as the quadratic matrix eigenvalue problem associated with a finite-dynamic element formulation. An alternative procedure, based on a combined Sturm sequence and inverse iteration technique, is also available that enables extraction of roots and associated vectors lying within any specified bound.

A separate preprocessor submodule, PREPROCS, has been developed for automated generation of nodal, element, and other associated input data for any continuum. The PREPROCS submodule is capable of generating complex structural forms through duplication, mirror-imaging, and cross-sectioning of modular representative structures. Appendix A contains the Preprocessor manual. A fully automated, three-dimensional mesh generation capability is an important feature of this module. The STARS postprocessor submodules, POSTPLOTS and POSTPLOTf, are used for extensive color plotting of various structural-, heat-transfer- and CFD-related solution results. Appendix B is the Postprocessor manual.

Section 2 describes the STARS-SOLIDS module of the program and highlights of some of its important features, and section 3 provides the data input procedure. Section 4 provides summaries of input data and analysis results for sample test cases relevant to this module. Section 5 describes the various features of the aeroelastic and ASE analyses capabilities, and section 6 provides data input details of various related submodules. A representative, integrated aero-structural-control sample problem is worked in detail in section 7. Section 8 provides details of CFD analysis, as well as nonlinear aeroelasticity and ASE. Appendix C provides the STARS system descriptions.

2. STARS-SOLIDS MODULE DESCRIPTION

The structure to be analyzed by the STARS program, either linear or nonlinear, can be composed of any suitable combination of one-, two-, and three-dimensional elements. The general features of the STARS-SOLIDS module include the following:

1. A general-purpose, compact, finite-element code.
2. Elements: bars, rods, beams, three-dimensional line elements, rigid bars, membranes, triangular and quadrilateral planes, plates, shells, sandwich panels, composite elements, and tetrahedral and hexahedral solids.
3. Geometry: any relevant structure formed by a suitable combination of the elements.
4. Material: general, isotropic, orthotropic, and anisotropic material.

5. **Analysis:** natural frequencies and mode shapes of nonrotating and rotating structures with or without structural damping, viscous damping, or both, including initial load (prestress) effect; stability (buckling) analysis; dynamic-response analysis of nonrotating and rotating structures; and static analysis for multiple sets of mechanical and thermal loading. Also, steady-state and transient heat-transfer analysis, including nonlinear radiation boundary conditions.

Special features of the STARS–SOLIDS module include the following:

1. Random data input within a subset, using rectangular (Cartesian), cylindrical, and spherical coordinate systems.
2. Automatic node and element generation.
3. Matrix bandwidth minimization.
4. General nodal deflection boundary conditions.
5. Multiple sets of static load input.
6. Preprocessor and postprocessor.
7. Plot of initial geometry.
8. Plots of mode shapes, nodal deformations, and element stresses as a function of time, as required.

Structural geometry is described in terms of the global coordinate system (GCS) or the local-global coordinate system (LGCS) having a right-handed Cartesian set of X-, Y-, and Z-coordinate axes. Each structural node is assumed to have six degrees of freedom, consisting of three translations (UX, UY, UZ) and three rotations (UXR, UYR, UZR), that are the undetermined quantities in the associated solution process. Details of some important features of the module are summarized in the following subsection.

2.1 Nodal and Element Data Generation

The STARS program provides simple linear interpolation schemes that enable automatic generation of nodal and element data. Generation of nodal data depends on the occurrence of such features as nodes lying on straight lines and common nodal displacement boundary conditions. Generation of element data is possible if the finite-element mesh is repetitive in nature and elements possess common basic properties. The module enables input of data employing the GCS or a number of rectangular LGCSes, relevant to various substructures, in which the data can be read in rectangular, cylindrical, and spherical coordinate systems.

A separate preprocessor submodule, PREPROCS, has been developed for automated generation of nodal, element, and other associated input data for any continuum. The preprocessor is an interactive, graphics, structures-modeling submodule. This preprocessor is capable of generating complex structures through duplication, mirror-imaging, and cross-sectioning of modular representative structures.

2.2 Matrix Bandwidth Minimization

This feature enables effective bandwidth minimization of the stiffness, inertia, and all other relevant system matrices by reordering input nodal numbers, taking into consideration first- and second-order nodal connectivity conditions. The existing nodal numbering can be modified² to minimize bandwidth of associated matrices (fig. 5). Therefore, any node with minimum first-order connectivity can be chosen as the starting node. Accordingly, any one of nodes 1, 4, 7, 10, 13, and 16, all of which have a minimum first-order nodal connectivity of two, can be selected as the first node to start the nodal numbering scheme. Nodes 1, 4, 10, and 13, however, possess a higher second-order connectivity condition than do nodes 7 and 16. For example, nodes connected to node 1 (namely, nodes 2 and 18) are, in turn, connected to a total of seven nodes, whereas the connectivity number for nodes 7 and 16 is six. As such, either node 7 or 16 can be chosen as the starting node for the renumbering scheme. Figure 5 shows in parentheses a revised nodal numbering that minimizes matrix bandwidth. The present minimization scheme also takes into consideration the presence of nodal interdependent displacement boundary conditions.

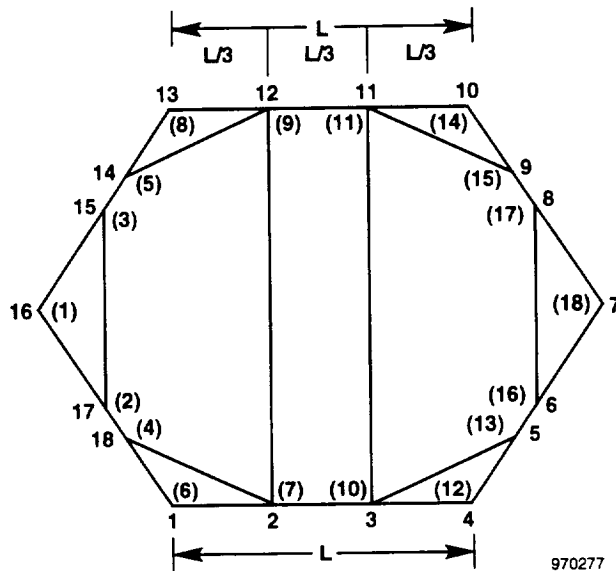


Figure 5. Bandwidth minimization scheme.

2.3 Deflection Boundary Conditions

The nodal displacement relationships can be classified as zero, finite, and interdependent displacement boundary conditions (ZDBC, FDBC, and IDBC). Details of such a formulation are provided in section 3.4. Thus, in addition to prescribed zero and finite displacements, the motion of any node in a particular degree of freedom can be related in any desired manner to the motion of the same or any other combination of nodes in any set of specified directions.

2.4 Prescribed Loads

A structure may be subjected to any combination of mechanical and thermal loadings. The loads in the mechanical category can be either concentrated at nodes or distributed. Thus, uniform pressure can be applied along the length of line elements acting in the direction of the local y and z axes. Such uniform surface loads are assumed to act in the direction of the local z axis of the shell and solid elements, acting respectively on the shell and solid-base surfaces. The effect of thermal loading can be incorporated by the appropriate input of data pertaining to uniform element temperature increases and thermal gradients.

2.5 Static Analysis

Static analysis, performed by setting the parameter IPROB = 8 in the input data, is effected by solving the set of linear simultaneous equations

$$\mathbf{K}\mathbf{u} = \mathbf{p} \quad (1)$$

where

$\mathbf{K}$	= system elastic stiffness matrix
$\mathbf{u}$	= nodal displacement vector
$\mathbf{p}$	= external nodal load vector
IPROB	= integer designating problem type (defined in section 3.1)

A multiple set of load vectors is represented by the matrix $\mathbf{p}$, incorporating effects of both mechanical and thermal loading. The equations are solved once, initially by Gaussian elimination, and solutions pertaining to multiple nodal load cases are obtained by simple back-substitution.

2.6 Elastic Buckling Analysis

A buckling analysis is performed by solving the eigenvalue problem

$$(\mathbf{K}_E + \gamma\mathbf{K}_G)\mathbf{u} = \mathbf{0} \quad (2)$$

in which $\mathbf{K}_E$ and $\mathbf{K}_G$ are elastic stiffness and geometric stiffness matrices, respectively; $\mathbf{u}$ represents the buckled mode shapes; and γ is the buckling load. This analysis is achieved by setting IPROB = 9.

2.7 Free-Vibration Analysis

The matrix equation of free vibration for the general case of a spinning structure with viscous and structural damping is expressed³ as

$$[\mathbf{K}_E(1+i^*g) + \mathbf{K}_G + \mathbf{K}']\mathbf{u} + (\mathbf{C}_C + \mathbf{C}_D)\dot{\mathbf{u}} + \mathbf{M}\ddot{\mathbf{u}} = \mathbf{0} \quad (3)$$

in which a dot indicates differentiation with respect to time. The previously undefined terms are described as follows:

$\mathbf{K}'$	= centrifugal force matrix
$\mathbf{C}_C$	= Coriolis matrix
$\mathbf{C}_D$	= viscous damping matrix
$\mathbf{M}$	= inertia matrix
g	= structural damping parameter
i^*	= imaginary number, $\sqrt{-1}$

Such a structure can have individual nonrotating and rotating components spinning with different spin rates along arbitrary axes.

Various reduced sets of equations pertaining to specific cases of free vibration are given as follows:

1. Free, undamped vibration of nonspinning structures (IPROB = 1):

$$\mathbf{K}_E \mathbf{u} + \mathbf{M} \ddot{\mathbf{u}} = 0 \quad (4)$$

2. Free, undamped vibration of spinning structures (IPROB = 2):

$$\mathbf{K} \mathbf{u} + \mathbf{C}_C \dot{\mathbf{u}} + \mathbf{M} \ddot{\mathbf{u}} = 0 \quad (5)$$

where $\mathbf{K} = \mathbf{K}_E + \mathbf{K}_G + \mathbf{K}'$.

3. Free, damped vibration of spinning structures (IPROB = 4, 5), defined by equation (3).
4. Free, damped vibration of nonspinning structures (IPROB = 6, 7):

$$\mathbf{K}_E(1+i^*g)\mathbf{u} + \mathbf{C}_D \dot{\mathbf{u}} + \mathbf{M} \ddot{\mathbf{u}} = 0 \quad (6)$$

The eigenvalue problems pertaining to the IPROB = 1 and IPROB = 9 cases are real in nature, but the rest of the above problems involve complex-conjugate roots and vectors. In the special case of a prestressed structure, the matrix $\mathbf{K}_G$ is automatically included in equation (6).

In addition, the STARS program solves the quadratic matrix eigenvalue problem (IPROB = 3) associated with a dynamic-element formulation,⁴

$$[\mathbf{K}_E - \lambda^2 \mathbf{M} - \lambda^4 (\mathbf{M}_2 - \mathbf{K}_4)] \mathbf{q} = 0 \quad (7)$$

which is quadratic in terms of the eigenvalues $\chi = \lambda^2$. Both $\mathbf{M}_2$ and $\mathbf{K}_4$ are the higher-order dynamic correction matrices; λ is the natural frequencies; and $\mathbf{q}$ is the eigenvectors. This option is currently being updated to include a number of elements.

Structures prestressed by initial loads can also be analyzed, in which cases the relevant eigenvalue problem for undamped structures has the form

$$(\mathbf{K}_E + \mathbf{K}_G - \lambda^2 \mathbf{M})\mathbf{q} = \mathbf{0} \quad (8)$$

where the geometrical stiffness matrix $\mathbf{K}_G$ is a function of initial stresses. Similar formulations are obtained for structures with various forms of damping.

2.8 Dynamic-Response Analysis

The modal superposition method is employed for the dynamic-response analysis following the computation of structural frequencies and modes. For example, the associated eigenvalue problem of equation (4) for a nonrotating, undamped structure is first solved to obtain the first few eigenvectors, $\mathbf{q}$, and also the eigenvalues. The vectors consist of a set of rigid-body modes, $\mathbf{q}_r$, and a number of elastic modes, $\mathbf{q}_e$, that are next mass-orthonormalized so that the matrix product

$$\mathbf{q}^T \mathbf{M} \mathbf{q} = \mathbf{I} \quad (9)$$

is a unit matrix. A transformation relationship,

$$\mathbf{u} = \mathbf{q} \boldsymbol{\eta} \quad (10)$$

is substituted in the dynamic equation

$$\mathbf{M} \ddot{\mathbf{u}} + \mathbf{K} \mathbf{u} = \mathbf{p}(t) \quad (11)$$

and, when premultiplied by $\mathbf{q}^T$, yields a set of uncoupled equations,

$$\ddot{\boldsymbol{\eta}}_r = \mathbf{q}_r^T \mathbf{p}(t) \quad (12)$$

and

$$\ddot{\boldsymbol{\eta}}_e + \boldsymbol{\Omega}^2 \boldsymbol{\eta}_e = \mathbf{q}_e^T \mathbf{p}(t) \quad (13)$$

that incorporate rigid-body and elastic mode effects, respectively. The symbol $\mathbf{p}(t)$ is the externally applied, time-dependent forcing function; $\boldsymbol{\Omega}^2$ is a diagonal matrix; and ω_i is the natural frequencies. Solutions of equations (12) and (13) can be expressed in terms of Duhamel's integrals, which, in turn, can be evaluated by standard procedures.⁵ In the present analysis, the externally applied, time-dependent forcing function must be applied to the structure in appropriate, small, incremental steps of rectangular pulses. The forcing function can be either load or acceleration vectors; the program also allows application of initial displacement and velocity vectors to the structure. For spinning and damped structures, identified as IPROB = 2, 4, 5, 6, and 7, $\mathbf{q}^T$ is replaced by its transjugate $\bar{\mathbf{q}}^T$ in the relevant dynamic-response formulation.

2.9 Nonlinear Structural Analysis

For geometrical nonlinearity, a Newton-Raphson iterative procedure is used in which the stiffness matrix is supplemented with the geometrical stiffness matrix, $\mathbf{K}_G$, so that large displacement and rotation and the effect of in-plane stretching are taken into consideration.

Thus, for static analysis, the solution algorithm is as follows:

Let

$$\begin{aligned} n &= \text{number of load increments} \\ i &= \text{number of iterations within a loop} \end{aligned}$$

Then, for each load increment ("n" loop), form

$$\begin{aligned} {}_n\mathbf{K}_G, & \text{ geometric stiffness matrix, based on accumulated element stresses } \sigma' (= \mathbf{0}, \text{ for } n = 1); \\ & ' \text{ denotes local coordinate system} \\ {}_n\mathbf{K}_E, & \text{ elastic stiffness matrix, } (= {}_1\mathbf{K}_E^0 \text{ for } n = 1; {}_n\mathbf{K}_E^i \text{ for } n > 1) \\ {}_n\mathbf{r}_s, & \text{ residual forces } (= \mathbf{0}, \text{ for } n = 1; {}_n\mathbf{r}_s^{(i)} \text{ for } n > 1) \end{aligned}$$

Then, for each iteration ("i" loop), solve

$$\left[{}_n\mathbf{K}_E^{(i-1)} + {}_n\mathbf{K}_G \right] \Delta \mathbf{u}^{(i)} = \sum_n \Delta \mathbf{p} - {}_n\mathbf{r}_s^{(i-1)}, \text{ for } \Delta \mathbf{u}^{(i)} \quad (14)$$

Update the geometry:

$$\mathbf{u}^{(i)} = \mathbf{u}^{(i-1)} + \Delta \mathbf{u}^{(i)}$$

Obtain incremental deformation in the local coordinate system (LCS):

$$\Delta \mathbf{u}'^{(i)} = [\mathbf{DIR}]^{(i)} \Delta \mathbf{u}^{(i)}$$

Calculate element stresses in the LCS and accumulate, based on $\Delta \mathbf{u}'^{(i)}$.

Obtain residual forces in the GCS:

$$\Delta \mathbf{s}^{(i)} = \left[{}_n\mathbf{K}_E^{(i-1)} + {}_n\mathbf{K}_G \right] \Delta \mathbf{u}^{(i)} \quad (15)$$

$${}_n\mathbf{r}_s^{(i)} = {}_n\mathbf{r}_s^{(i-1)} + \Delta \mathbf{s}^{(i)} \quad (16)$$

Check for convergence. If $|\Delta \mathbf{u}| > \text{EPS}$, then compute $\mathbf{K}_E'^{(i)}$ and $\mathbf{K}_E^{(i)}$, the element and global stiffness matrices, respectively. Repeat the iteration ("i" loop), if it is not converged. Continue on the incremental load loop ("n" loop) if convergence was achieved in the "i" loop. Stop computation upon completion of the load cycle.

For dynamic-response analysis of geometrically nonlinear structures, a time-integration scheme using a Newton-Raphson iterative technique is adopted for the solution. The associated algorithm is given as follows:

For a j th time increment, Δt_j ("j" loop), form the $j\mathbf{K}_G$ geometric stiffness matrix based on accumulated element stresses, $\sigma' = 0$ (for $j = 1$).

Perform the iteration ("i" loop).

Form

$$\mathbf{K}^{(i-1)}, \mathbf{M}, \mathbf{C}, \mathbf{r}_s^{(i-1)} \quad \left[\mathbf{K}^{(i-1)} = \mathbf{K}_E^{(i-1)} + j\mathbf{K}_G \right] \quad (\mathbf{r}_s^0 = 0, \text{ for } j = 1)$$

Calculate

$$\hat{\mathbf{K}} = \frac{4}{\Delta t^2} \mathbf{M} + \frac{2}{\Delta t} \mathbf{C} + \mathbf{K}^{(i-1)} \quad (17)$$

Calculate

$$\mathbf{F}^{\text{eff}} = \mathbf{F}_{t+\Delta t} + \mathbf{M} \left\{ \frac{4}{\Delta t^2} \mathbf{u}_t + \frac{4}{\Delta t} \dot{\mathbf{u}}_t + \ddot{\mathbf{u}}_t - \frac{4}{\Delta t^2} \mathbf{u}_{t+\Delta t}^{(i-1)} \right\} + \mathbf{C} \left\{ \frac{2}{\Delta t} \mathbf{u}_t + \dot{\mathbf{u}}_t - \frac{2}{\Delta t} \mathbf{u}_{t+\Delta t}^{(i-1)} \right\} - \mathbf{r}_s^{(i-1)} \quad (18)$$

Solve

$$\hat{\mathbf{K}} \Delta \mathbf{u}^{(i)} = \mathbf{F}^{\text{eff}} \quad (19)$$

Update

$$\mathbf{u}_{t+\Delta t}^{(i)} = \mathbf{u}_{t+\Delta t}^{(i-1)} + \Delta \mathbf{u}^{(i)}$$

Obtain deformation in the LCS:

$$\Delta \mathbf{u}'^{(i)} = [\mathbf{DIR}]^{(i)} \Delta \mathbf{u}^{(i)}$$

Calculate element stresses and accumulate, based on $\Delta \mathbf{u}'^{(i)}$.

Obtain residual forces in the GCS:

$$\Delta \mathbf{s}^{(i)} = \left[\mathbf{K}_E^{(i-1)} + j\mathbf{K}_G \right] \Delta \mathbf{u}^{(i)} \quad (20)$$

$$\mathbf{r}_s^{(i)} = \mathbf{r}_s^{(i-1)} + \Delta \mathbf{s}^{(i)} \quad (21)$$

Check for convergence, $|\Delta \mathbf{u}^{(i)}| = 0$. If the loop is not converged, continue the iteration ("i" loop).

If converged, update

$$\dot{\mathbf{u}}_{t+\Delta t} = \frac{2}{\Delta t} (\mathbf{u}_{t+\Delta t} - \mathbf{u}_t) - \dot{\mathbf{u}}_t$$

$$\ddot{\mathbf{u}}_{t+\Delta t} = \frac{4}{\Delta t^2} (\mathbf{u}_{t+\Delta t} - \mathbf{u}_t) - \frac{4}{\Delta t} \dot{\mathbf{u}}_t - \ddot{\mathbf{u}}_t$$

If $t \neq t_{\text{final}}$, update the time ("j" loop). Stop at the end of the time cycle.

In problems that exhibit material nonlinearity, the Prandtl-Reuss equation of the stress-strain relationship is combined with von Mises yield criteria for material characterization. An iterative solution procedure is then employed for solution of the associated problems, as below:

Initialialize:

Set external loads ($\mathbf{R}^E$) and internal loads ($\mathbf{R}^I$) to zero

Set all stresses and deformations ($\mathbf{u}_0$) to zero

Set the yield function $F = -\sigma_{yp}$

Set the slope of the strain hardening curve to its inital value, H'_{in}

Set the plastic strain ϵ_p to zero

Set the incremental load, $\Delta \mathbf{P}$.

For each load ("j" loop):

Calculate the total load at the jth step

$$\mathbf{R}_j^E = \mathbf{R}_{j-1}^E + \Delta \mathbf{P}$$

Calculate the norm

$$\|\mathbf{R}_j^E\|$$

Find the residual force ("i" loop)

$$\mathbf{R}_i^{\text{res}} = \mathbf{R}_j^E - \mathbf{R}_{i-1}^I$$

Calculate $\|\mathbf{R}_i^{\text{res}}\|$; if $\|\mathbf{R}_i^{\text{res}}\| < \text{eps} \times \|\mathbf{R}_j^E\|$, go to the end of the "j" loop.

Calculate $\mathbf{K}_{ep}$ (initially $\mathbf{K}_e$).

Solve the increment of displacement, $\Delta \mathbf{u}_i = \mathbf{K}_{ep}^{-1} \mathbf{R}_i^{\text{res}}$, and the total elastoplastic displacement, $\mathbf{u}_i = \mathbf{u}_{i-1} + \Delta \mathbf{u}_i$.

For each element ("n" loop):

$\Delta \epsilon_i = \mathbf{b} \Delta \mathbf{u}_i$, total increment in element strain (using $\mathbf{e} = \mathbf{b} \mathbf{u}$ for small strain)

Check last value of yield function F_{i-1} .

If $F_{i-1} = 0$, the element is already on yield surface; go to the elastoplastic loop.

If $F_{i-1} < 0$, the element is elastic at the start of the loop.

Calculate $\Delta\sigma_i = \mathbf{D}\Delta\epsilon_i$

$$\sigma_i = \sigma_{i-1} + \Delta\sigma_i$$

Calculate $F_i = \bar{\sigma}_i - \sigma_{yp_{i-1}}$

If $F_i \leq 0$, then it is elastic and store σ_i , F_i ; go to the end of the “n” loop.

If $F_i > 0$, set $s_A = s_{i-1}$, $s_B = s_i$

Loop to bring σ_C onto the yield surface:

$$\sigma_C = (\sigma_A + \sigma_B)/2$$

Calculate $F_C = \bar{\sigma}_C - \sigma_{yp_{i-1}}$

If $F_C < 0$, then $\sigma_A = \sigma_C$

If $F_C > 0$, then $\sigma_B = \sigma_C$

If $|F_C| > \text{TOL}$, return to the top of the loop.

End of loop.

$$\Delta\epsilon_{e_i} = \mathbf{D}_{ep}^{-1}(\sigma_C - \sigma_{i-1})$$

$$\Delta\epsilon_{p_i} = \Delta\epsilon_i - \Delta\epsilon_{e_i}$$

$\sigma_{i-1} = \sigma_C$, F_i becomes 0

Start of elastoplastic loop.

Set $\sigma_i = \sigma_C$, stress on yield surface

$$d\Delta\epsilon_{ep} = \frac{\Delta\epsilon_{p_i}}{20}$$

Loop 20 times, $k = 1, 20$ (“k” loop)

Calculate $\mathbf{D}_{ep}$, based on σ_C

$$\Delta\sigma_k = \mathbf{D}_{ep} d\Delta\epsilon_{ep}$$

$$\sigma_{C+k} = \sigma_C + \Delta\sigma_k$$

Use σ_{C+k} to calculate normal $\frac{\partial F}{\partial \sigma} = \frac{d\bar{\sigma}}{d\sigma}$ and F_k

$$\text{Calculate } d(\Delta\sigma) = \left[-\frac{d\bar{\sigma}/d\sigma}{\sqrt{\left\{\frac{d\bar{\sigma}}{d\sigma}\right\}\left\{\frac{d\bar{\sigma}}{d\sigma}\right\}}} \right] \times F_k$$

$$\sigma_{C+k} = \sigma_{C+k} + d(\Delta\sigma)$$

Set $\sigma_C = \sigma_{C+k}$

End “k” loop.

Calculate F_i , which should be 0; set to 0 if not (may be very small).

Store σ_{C+k} and F_i .

Calculate elastic strain increment:

$$\Delta\epsilon_e = \mathbf{D}_e^{-1} \{ \sigma_{C+k} - \sigma_{i-1} \}$$

$$\Delta\epsilon_p = \Delta\epsilon_i - \Delta\epsilon_e$$

Store $\epsilon_{p_i} = \epsilon_{p_{i-1}} + \Delta\epsilon_p$

Calculate $H_i' = f(\epsilon_{p_i})$ from input data (may be assumed to have a constant slope/value)

End element “n” loop.

End residual force “i” loop.

End load “j” loop.

2.10 Shift Synthesis

The module provides special eigenvalue switching provisions in the analysis to ensure numerical stability. Such a problem may be encountered in the analysis of aerospace structures, which are designed to be strong and lightweight. For example, the elements of the mass matrix of equation (4) may have numerical values much smaller than those of the stiffness matrix. In such cases, the effect of the mass matrix in the $(\mathbf{K} - \lambda^2 \mathbf{M})\mathbf{y} = \mathbf{0}$ formulation may be insignificant. Such a problem also occurs in the presence of rigid-body modes characterized by “zero” frequencies. An eigenvalue shift strategy has been developed to accommodate such situations.

Thus, the eigenvalue problem pertaining to equation (4) representing the problem defined as IPROB = 1 can be written as

$$(\mathbf{K} - \lambda^2 \mathbf{M})\mathbf{y} = \mathbf{0} \quad (22)$$

in which λ is the natural frequency of free vibration and $\mathbf{y}$ is the eigenvector. The stiffness and mass matrices must be suitably perturbed to handle rigid-body modes and to maintain numerical stability by negating effects of rounding error. Thus, equation (22) is rearranged as

$$[\mathbf{K} + \mathbf{I}\hat{\mathbf{M}} - (\tilde{\lambda} + \mathbf{I})\hat{\mathbf{M}}]\mathbf{y} = \mathbf{0} \quad (23)$$

or

$$(\hat{\mathbf{K}} - \hat{\lambda}\hat{\mathbf{M}})\mathbf{y} = \mathbf{0} \quad (24)$$

in which

$$\hat{\mathbf{K}} = \mathbf{K} + \mathbf{I}\hat{\mathbf{M}} \quad (25)$$

$$\hat{\mathbf{M}} = \mathbf{F}\mathbf{M} \quad (26)$$

$$\tilde{\lambda} = \frac{\lambda^2}{F} \quad (27)$$

$$\hat{\lambda} = \frac{\lambda^2}{F} + \mathbf{I} \quad (28)$$

$$F = \frac{\max \left(\frac{|\mathbf{K}_{i,i}|}{|\mathbf{M}_{i,i}|} \right)}{10^7} \quad (29)$$

where $|\mathbf{K}_{i,i}|$ and $|\mathbf{M}_{i,i}|$ typically denote the norms of the diagonal elements, the number 10^7 relates to the computational accuracy of the computer, and $\mathbf{I}$ is a suitable integer factor, such as 4. When the eigenvalue problem defined by equation (24) is solved, the natural frequencies are obtained as

$$\lambda = \sqrt{(\hat{\lambda} - \mathbf{I})F} \quad (30)$$

A similar procedure is adopted for the analysis of free-vibration problems defined by IPROB = 6 and 7 and for the buckling analysis (IPROB = 9). In the case of spinning structures, a somewhat similar strategy is used in perturbing appropriate matrices to ensure effective computation of rigid-body modes as well as numerical stability.

2.11 Formulation for Nodal Centrifugal Forces in Finite Elements

The STARS-SOLIDS module can perform dynamic analyses of structures with nonrotating and rotating parts having different spin rates. A general derivation for the in-plane centrifugal forces generated in various elements because of the arbitrary spin rate, along with related formulation of the associated normal components, has been given in detail.⁶ Details of a block Lanczos algorithm developed for efficient, free-vibration analysis of spinning structures have also been given.⁷

When the nodal centrifugal forces have been derived, as previously mentioned, and stored in array **P**, the element stresses in the structure caused by these forces are simply obtained by solving equation (1), repeated here for convenience:

$$\mathbf{K}\mathbf{u} = \mathbf{p}$$

The stresses are next used to derive the structural geometrical stiffness matrix, $\mathbf{K}_G$, required for solving the free-vibration problems defined in section 2.7.

2.12 Material Properties

The structural material can be general in nature. Thus, the finite-element material properties can be isotropic, orthotropic, or anisotropic. In the most general case of solid elements having anisotropic material properties, defined as material type 3, the stress-strain matrix is expressed as

$$\delta = \mathbf{E}\epsilon \quad (31)$$

with $\mathbf{E}_{i,j}$ being elements of the general material matrix of the order 6, defining the relationship between the stress vector, δ , and the strain vector, ϵ . The elements of the upper symmetric one-half of the $\mathbf{E}$ matrix, as well as coefficients of thermal expansion and material density consisting of 28 coefficients, are the required data input for the pertinent material type. In this connection, the material data input is designed to be quite general; the user can easily incorporate effects of various related features, such as varying material axes orientation, by appropriately calculating the elements of the material matrix. If the material is orthotropic, the input scheme remains the same as for the anisotropic case.

Material type 2 pertains to thin-shell elements displaying anisotropic or orthotropic material properties and requires an input of 13 coefficients. For isotropic material classified as material type 1, only six coefficients constitute the required input data. The isotropic case for sandwich-shell elements is designated as material type 4, and type 5 pertains to the corresponding orthotropic-anisotropic case. For the heat-transfer case, material types 6, 7, and 8 refer to isotropic-line, isotropic-shell, and orthotropic-anisotropic-shell elements, respectively.

2.13 Heat-Transfer Analysis

A heat-conduction analysis capability for solids has been incorporated in the STARS-SOLIDS module. Figure 6 shows a typical heat-transfer problem in a three-dimensional anisotropic solid solution domain, D , bounded by a surface, S . The corresponding thermal energy equation is derived from the law

of conservation of energy and Fourier's law, and the resulting parabolic heat-conduction equation is solved subject to an initial condition and boundary conditions on all portions of the surface. A finite-element discretization of the continuum is achieved by the method of weighted residuals.^{8,9}

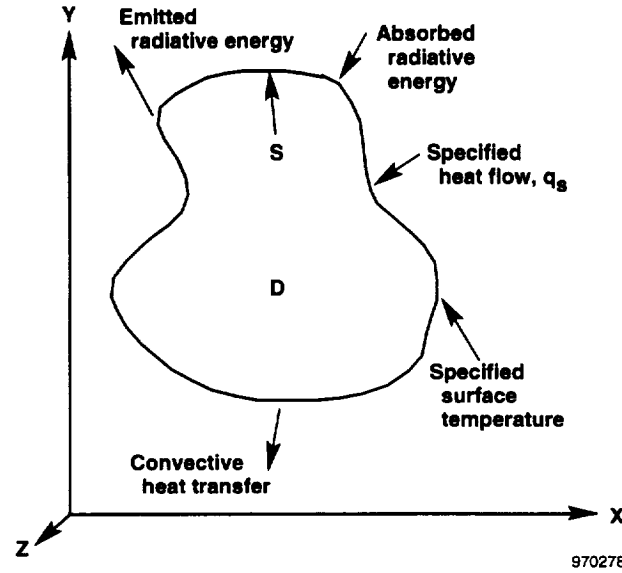


Figure 6. Three-dimensional general heat conduction.

The following analysis types are relevant to the current heat-transfer solution effort:

- Linear steady-state analysis,

$$[[\mathbf{K}_c] + [\mathbf{K}_h]]\{\mathbf{T}\} = \{\mathbf{R}_Q\} + \{\mathbf{R}_q\} + \{\mathbf{R}_h\} \quad (32)$$

in which the element conductance matrix has contributions from conduction and convection, and the heat-load vector has contributions from internal heat generation, surface heating and surface convection. The element matrices and heat-load vectors are constant, and a linear solution of a set of simultaneous equations is required.

- Linear transient analysis,

$$[\mathbf{C}]\{\dot{\mathbf{T}}(t)\} + [[\mathbf{K}_c] + [\mathbf{K}_h(t)]]\{\mathbf{T}(t)\} = \{\mathbf{R}_Q(t)\} + \{\mathbf{R}_q(t)\} + \{\mathbf{R}_h(t)\} \quad (33)$$

in which the element capacitance matrices are also required, element convection matrices and heat-load vectors are time dependent, and a solution of the equations is achieved by the modal superposition method employing a time-integration procedure.

- Nonlinear steady-state analysis,

$$[[\mathbf{K}_c(T)] + [\mathbf{K}_h(T)] + [\mathbf{K}_r(T)]]\{\mathbf{T}\} = \{\mathbf{R}_Q(T)\} + \{\mathbf{R}_q(T)\} + \{\mathbf{R}_h(T)\} + \{\mathbf{R}_r(T)\} \quad (34)$$

in which the element matrices and heat-load vectors have contributions from radiation, and the matrices and vectors are temperature dependent; thus, the equations are nonlinear and require solution by an iterative scheme such as the Newton-Raphson method.

- Nonlinear transient analysis,

$$[C(T)]\{\dot{T}\} + [[K_c(T)] + [K_h(T, t)] + [K_r(T)]]\{T(t)\} = \{R_Q(T, t)\} + \{R_q(T, t)\} + \{R_h(T, t)\} + \{R_r(T, t)\} \quad (35)$$

in which the element matrices and heat-load vectors are both temperature and time dependent, and solution by an iterative, time-marching scheme is required. In general, nonlinearities are caused by temperature-dependent anisotropic material properties, convection coefficients, and nonlinear radiation boundary conditions, and the relevant Newton-Raphson iteration is performed at each time step.

The following definitions pertain to the above numerical formulations and figure 6:

C	=	element capacitance matrix.
K_c, K_h, K_r	=	element conductance matrices related to conduction, convection, and radiation, respectively.
R_T, R_Q, R_q R_h, R_r	=	Heat-load vectors arising from specified nodal temperatures, internal heat generation, specified surface heating, surface convection, and incident surface radiant heating, respectively.
q_s, q_r	=	specified surface and incident radiant heat flow rates/unit area, respectively.

2.14 Output of Analysis Results

A dynamic-response analysis, in general, yields an output of nodal deformations and element stresses as appropriate functions of time. Additional printouts provide summaries of maximum deformations and stresses or loads, as appropriate, as well as principal stresses and relevant angles. For line elements, member end loads and moments constitute the usual output of results. In the case of thin-shell elements, the stresses σ_{xx} , σ_{yy} , and σ_{xy} are calculated at the centroid of the element and at both its top and bottom surfaces. For solid elements, all six components of stresses (σ_{xx} , σ_{yy} , σ_{zz} , σ_{xy} , σ_{yz} , σ_{zx}) are computed at the center of the volume of the element. Because free-vibration analysis provides the necessary data for the dynamic-response analysis, the natural frequencies and associated modes and relevant element strain energies are computed by the module and can be printed out. Similar results are obtained for elastic buckling analysis. For static problems, the nodal displacements and element stresses are computed for multiple-load cases. A heat-transfer analysis yields unknown nodal temperatures as the solution.

Special printout options make possible a selective output of analysis results. Thus, computed data such as stiffness and inertia matrices can be printed out. Initially, the module automatically prints out

the generated nodal coordinates, element data, and other relevant input data. The POSTPLOTS submodule can be effectively used for color graphics depiction of solution results.

2.15 Discussion

Additional analysis features such as finite, dynamic-element discretizations, improved dynamic analysis capabilities, and various efficient numerical techniques are continuously being implemented in the module. A nonlinear analysis capability has also been developed in parallel. Improved preprocessing and postprocessing of data, using a number of graphics terminals, are being used to permit efficient modeling, analysis, and display of the results pertaining to practical structural problems. An automatic data conversion program, NSTARS, has also been developed to convert NASTRAN¹⁰ program data into the STARS format.

3. DATA INPUT PROCEDURE (STARS–SOLIDS and SOLIDS HEAT TRANSFER)

3.1 Basic Data

3.1.1 Primary Job Title Format (FREE)

3.1.1.1 Additional Job Details Format (A1, FREE)

1. Description: Various job-related descriptions; any number of input lines.

2. Notes:

First line input is required, and subsequent lines of input must have a C in the first column; a maximum of 80 characters for each line is accepted.

3.1.2 NN, NEL, NMAT, NMECN, NEP, NET, NLGCS, NMANGL, NSTACK, MAXLEL Format (FREE)

1. Description: Basic data parameters (structural).

2. Notes:

NN = total number of nodes

NEL = total number of elements

NMAT = total number of element material types

NMECN = number of material elastic or heat-transfer constants; a maximum of numbers, as follows:
 = 4, for isotropic material, elastic analysis
 = 6, for isotropic material, elastoplastic analysis
 = 13, for orthotropic-anisotropic material for two-dimensional shell elements (types 2, 3, 6, and 7)
 = 10, for isotropic sandwich-panel material for shell elements (types 2 and 3)
 = 25, for orthotropic-anisotropic sandwich panel material for shell elements (types 2 and 3)
 = 28, for orthotropic-anisotropic material for three-dimensional solid elements (types 4 and 5)
 = 11, for isotropic heat-transfer problem pertaining to line elements (type 1)
 = 41, for isotropic heat-transfer problem pertaining to shell elements (types 2, 3, 6, and 7)
 = 44, for orthotropic-anisotropic heat-transfer problem pertaining to shell elements (types 2, 3, 6, and 7)

NEP = total number of line-element property types (type 1)

NET = total number of shell-element thickness types (types 2 and 3)

NLGCS = total number of local-global coordinate systems

NMANGL = total number of material angle types

NSTACK = total number of composite shell-element stack types

MAXLEL = maximum number of layers in a composite-shell element

3.1.3 NTMP, NPR, NSPIN, NC, NBUN, NLSEC, NCNTRL, NOUT, NEXP, NNA Format (FREE)

1. Description: Basic data parameters (loads and displacements).

2. Notes:

NTMP = total number of element temperature types
 = -1, for analysis involving temperature loading evolved from heat-transfer solution (IPROB = 1, 8, or 9)

NPR = total number of element uniform-pressure types
 = -1, for analysis involving aerodynamic loading evolved from steady-state CFD solution (IPROB = 1, 8, or 9)

NSPIN = total number of different element spin types

NC	= number of sets of nodal loads for IPROB = 8 or 10 = 0, for IPROB = 1–7 = 1, for IPROB = 9 or 10 = NTTTS, for NTTTS ≠ 0 = NTTTS+1, for NTTTS ≠ 0 and IPROB = 10
NBUN	= total number of interdependent and finite nodal displacement connectivity conditions (includes IDBC and FDBC in section 2.3) = total number of nodal temperature inputs for IPROB = 10, equivalent to the FDBC case
NLSEC	= total number of line-element special end conditions, excluding commonly occurring cases of purely rigid or hinged ends
NCNTRL	= total number of control-surface rigid-body modes used for ASE analyses; may also be utilized for generating perfect rigid-body modes
NOUT	= total number of output nodes where direct modal interpolation is effected
NEXP	= total number of uniform external in-plane pressures for membranes
NNA	= number of CFD nodes, if used for structural interpolation of pressure

3.1.4 IPROB, IEIG, IDRS, IBAN, IPLUMP, IMLUMP, INMM, IINTP Format (FREE)

1. Description: Data defining the nature of the required solution.

2. Notes:

IPROB	= index for problem type, to be set as follows: = 1, undamped, free-vibration analysis of nonspinning structures = 2, undamped, free-vibration analysis of spinning structures = 3, quadratic matrix eigenproblem option for dynamic-element method (DEM) analysis = 4, free-vibration analysis of spinning structures with diagonal viscous damping matrix = 5, as for IPROB = 4 with structural damping = 6, free-vibration analysis of nonspinning structures with general viscous damping = 7, as for IPROB = 6 with structural damping = 8, static analysis of structures with thermal and multiple mechanical load cases = 9, elastic buckling analysis = 10, heat-transfer analysis = 11, solids nonlinear analysis, static and dynamic
-------	---

IEIG	= integer defining eigenproblem solution type = 0, for solution based on a modified, combined Sturm sequence and inverse iteration method = 1, for an alternative solution technique based on a block Lanczos procedure (recommended for computation of the first few roots and vectors when the lower bound PL = 0 for cases where IPROB = 1, 2, 3, or 9)
IDRS	= index for dynamic-response analysis = 0, no response analysis required = 1, performs response analysis
IBAN	= bandwidth minimization option = 0, performs minimization = 1, minimization not required = -1, option to perform minimization only and exit
IPLUMP	= index for nodal external loads = 0, no load input = 1, concentrated nodal load input for IPROB = 8 and 9, as well as for IPROB = 1–7 for prestressed structures = -1, for analysis involving loading evolved from CFD solution
IMLUMP	= index for nodal lumped scalar mass = 0, no lumped mass = 1, lumped nodal mass input (IPROB = 1–7)
INMM	= index for a nodal mass matrix of order 6 = 0, no mass matrix = 1, nodal mass matrix input (IPROB = 1–7)
IINTP	= integer defining modal data for direct interpolation = 0, no interpolation required = 1, performs interpolation on STARS–SOLIDS calculated modal data = 2, performs interpolation on externally supplied modal data; for example, ground vibration survey (GVS) results

3. Additional notes:

A dynamic-response analysis is achieved by specifying appropriate values for IPROB and IDRS; at the end of problem solution, extensive options are available for plotting nodal deformations, mode shapes, and element stresses by utilizing the postprocessor submodule, POSTPLOT.

Initial static load (prestress) effect: in the case of dynamic problems, the presence of nonzero values of integers IPLUMP, NPR, or NTMP activates computation of prestressing effect.

Mass matrix: nodal lumped mass matrix is added to consistent mass matrix to evolve the final mass matrix.

3.1.5 IPREC, IPLOT, IPRINT, INDATA, IERCHK, INCFOR, IEZDBC, IIDBC, IMATE, NLOOP
Format (FREE)

1. Description: Additional basic data.

2. Notes:

IPREC = specification for solution precision
 = 1, single precision
 = 2, double precision

IPLOT = index for graphics display
 = 0, no plotting needed
 = 1, performs the display of input geometry; if satisfactory, a restart option enables continuation of the current analysis

IPRINT = output print option
 = 0, prints final results output only
 = 1, prints global stiffness (**K**), mass (**M**), and damping or Coriolis (**C**) matrices, as well as detailed output on deformations, stresses, and root convergence characteristics
 = 2, prints output as in IPRINT = 1 but omits **K**, **M**, and **C** matrices
 = 3, prints output as in IPRINT = 0 but omits eigenvector printouts
 = 4, prints output as in IPRINT = 2 but includes strain energy information

INDATA = input data option
 = 0, basic matrices are automatically computed
 = 1, to read the upper symmetric banded half of basic matrices **K**, **M**, and **C** from user input files by row

IERCHK = integer defining the level of error checks in input data specified by user
 = 0, usual level of error checkouts
 = 1, additional extensive data checkouts

INCFOR = integer defining input data format
 = 0, basic format
 = 1, alternative format
 = 2, free format

IEZDBC = integer to enforce ZDBC for problems with zero on the diagonal of the **K** matrix
 = 0, no enforcement of ZDBC
 = 1, enforce ZDBC

- IIDBC** = integer to enforce the IIDBC solution strategy and to transfer CFD pressure loads to structural mesh
 = 0, out-of-core solution, for a very large number of IIDBC or NNA
 = 1, in-core solution (preferred option)
- IMATE** = index for the deletion of **K** and **M** matrices in EIGLAN
 = 0, do not delete; enables running of EIGSOL and dynamic responses
 = 1, delete
- NLOOP** = number of increments in external load application (used for IPROB = 11);
 default is 1

3.1.6 **INDEX, NR, INORM, PU, PL, TOL** **Format (FREE) (Required if IPROB = 1–7 and 9 and IPROB = 10 with IDRS = 1)**

1. Description: Data specifications for eigenproblem solution.

2. Notes:

- INDEX** = indicator for the number of eigenvalues and vectors to be computed
 = 1, computes NR smallest roots (and vectors) lying within bounds PU, PL
 = 2, computes all roots (and vectors) lying within bounds PU, PL
- NR** = number of roots to be computed (any arbitrary root number input for
 INDEX = 2)
- INORM** = index for vector normalization; any desired vector row number
 = 0, normalizes with respect to a scalar of displacement vector **Y** having
 largest modulus
 = -1, normalizes with respect to a scalar of **Y** or **YD** (velocity) vector having
 largest modulus
- PU** = upper bound of roots, rad/s
- PL** = lower bound of roots, rad/s
- TOL** = tolerance factor (eq. (29))
 = 0, defaults to 25.0E + 08
 = X, defaults to X (X = 1.0E + 07 can be useful for computation)

3.1.7 **IUV, IDDI, NTTS, NDEL T** **Format (FREE) (Required if IDRS = 1)**

1. Description: Data related to dynamic-response analysis.

2. Notes:

IUV = index for the initial displacement (U) and velocity (V) input
= 0, no initial data
= 1, either initial displacement or velocity or both are nonzero vectors

IDDI = index for dynamic data input
= 1, nodal load input
= 2, nodal acceleration input

NTTS = total number of sets of load or acceleration data input

NDELT = number of sets of uniform time increments for response calculation

3.1.8 G (Required if IPROB = 5 or 7)
Format (FREE)

1. Description: Structural damping in formulation $[K = K(1 + i^*G)]$.

2. Notes:

G = structural damping parameter

i^* = imaginary number, $\sqrt{-1}$

K = system stiffness matrix

3.1.9 M11 (Required if INDATA = 1)
Format (FREE)

1. Description: Half bandwidth of K, M, CD, or C.

3.1.10 ((B(I, J), I = 1, N), J = 1, NC) (Required if INDATA = 1 and IPROB = 8)
Format (6E10.4)

1. Description: Load matrix of the order $N = NN \times 6$.

3.1.11 ((K(I, J), J = 1, M11), I = 1, N) (Required if INDATA = 1 and IPROB = 1–8)
Format (6E10.4)

1. Description: Stiffness matrix.

3.1.12 ((M(I, J), J = 1, M11), I = 1, N) (Required if INDATA = 1 and IPROB = 1–7)
Format (6E10.4)

1. Description: Mass matrix.

3.1.13 ((C(I, J), J = 1, M11), I = 1, N) (Required if INDATA = 1 and IPROB = 2–5)
Format (6E10.4)

1. Description: Coriolis (IPROB = 2, 4, or 5) or dynamic correction (IPROB = 3) matrix.

3.1.14 ((CD(I, J), J = 1, M11), I = 1, N) (Required if INDATA = 1 and IPROB = 4–7)
Format (6E10.4)

1. Description: Viscous damping matrix.

General note: If INDATA = 1, no further input is required. Each set of data input in succeeding sections is preceded with a comment statement having a dollar sign (\$) at the first column.

3.2 Nodal Data

3.2.1 \$ Nodal Data

3.2.2 IN, X, Y, Z, UX, UY, UZ, UXR, UYR, UZR, ILGCS, IZDRCS, IINC (INCFOR = 0)
Format (I5, 3E10.4, 9I5) (INCFOR = 1)
or (I5, 3E15.8, 6I2, 3I5) (INCFOR = 2)
or (FREE)

1. Description: NN sets of nodal data input in the GCS/LGCS, at random; table 1 provides a description of the input data.

Table 1. Arrangement of nodal data input.

Node number	Nodal coordinates			Nodal zero displacement boundary conditions (ZDBC)						Local-global coordinate system type	ZDBC reference coordinate system	Increment
(IN)	(X/r)	(Y/θ)	(Z/φ)	(UX)	(UY)	(UZ)	(UXR)	(UYR)	(UZR)	(ILGCS)	(IZDRCS)	(IINC)
				1	2	3	4	5	6			
*	*	*	*	*	*	*	*	*	*	*	*	*

2. Notes:

- A right-handed Cartesian coordinate system (X, Y, Z) is to be chosen to define the GCS.
- The asterisk (*) indicates a required data input in the GCS/LGCS using a rectangular (x, y, z), cylindrical (r, θ, z), or spherical (r, θ, φ) coordinate system; r is the radius, θ is the angle the vector makes with respect to its projection on the X-Y plane and the X axis, and φ is the angle between the vector and the Z axis.
- Each structural node is assumed to have six degrees of freedom consisting of three translations, UX, UY, UZ, and three rotations, UXR, UYR, UZR, usually labeled as displacement degrees of freedom 1, 2, 3, and 4, 5, 6, respectively.

- d. For nodal ZDBC defined in the coordinate system referred to as IZDRCS, set the value to
 = 0, for free motion
 = 1, for constrained motion
- e. For node generation by increment, set IINC to
 = 0, for no increment
 = I, to increment the node number of the previous input by I until the current node number is attained; coordinates of intermediate nodes are linearly interpolated
- f. In automatic node generation (note (e)), all relevant data of generated intermediate nodes pertain to that of the last data set of the sequence.
- g. Third-point nodes for line elements are assumed to lie on the element local x-y plane and can be chosen as any existing active node or dummy nodes with UX through UZR set to 1.
- h. Final data are automatically formed in increasing sequence of node numbers.

3. Additional notes:

ILGCS = integer specifying LGCS number

IZDRCS = integer defining zero displacement boundary condition reference coordinate system (set to 0 for data in the GCS or an ILGCS number)

3.2.3 \$ Local-Global Coordinate System Data (Required if NLGCS ≠ 0)

3.2.4 ILGCS, IDMOD, ICTYP Format (3I5)

3.2.5 XOR, YOR, ZOR, X2, Y2, Z2, X3, Y3, Z3 or (IDMOD = 1) XOR, YOR, ZOR, D11, D12, D13, D21, D22, D23, D31, D32, D33 (IDMOD = 2) Format (2(6E10.4, /))

1. Description: NLGCS sets of LGCS definition data, at random.

2. Notes:

IDMOD = integer specifying nature of input data
 = 1, input involves global coordinates of the origin of the LGCS (XOR, YOR, ZOR) and two data points (X2 through Z3, pertaining to two points located on LGCS X axis and X-Y plane, respectively) in the GCS
 = 2, involves input of the origin of the LGCS (XOR, YOR, ZOR) and elements of the direction cosine matrix of the LGCS

ICTYP = integer defining coordinate system type
 = 0, rectangular
 = 1, cylindrical
 = 2, spherical

3. Special note:

If IINTP = 2, no further data input is required until 3.5.7.

3.3. Element Data

3.3.1 \$ Element Connectivity

3.3.2 IET, IEN, ND1, ND2, ND3, ND4, ND5, ND6, ND7, ND8, IMPP, IEPP/ITHTH, ITMPP, IPRR, IST, INC Format (16I5)

1. Description: NEL sets of element data input at random; table 2 shows the definition.

2. Notes:

* = data as defined; under element type 8, individual rigid elements are characterized by the appropriate data entry

** = third-point node for element types 1 and 8

IECI = integer defining line-element end condition pertaining to end I
 = 0, rigid-ended
 = 1, pin-ended in three rotational degrees of freedom
 = J, denoting special end condition number, to be set greater than 1; for scalar springs, set IEC1 to a negative value less than -1

IMPP = integer defining material property type number

IEPP(x) = integer defining line-element property type

ITHTH(+) = integer defining shell-element thickness type

ITMPP = integer defining element temperature type

IPRR = integer defining element pressure type

IST = integer defining element spin type

- INC = integer for element generation by increment
- = 0, no increment
- = J, increments node numbers of previous elements by J until current element nodal numbers are reached
- ▼ = ILGCS, integer defining the LGCS associated with a zero-length scalar spring element; defaults to the GCS
- ▲ = IMANG, integer defining material angle type number, suitable for layered elements
- = ISTACK, stack type number, used for integrated composite elements (types 6 and 7)
- ◆ = dependent degree of freedom at ND1 to be rigidly connected to all six degrees of freedom at ND2; rules concerning interdependence of nodes and degrees of freedom are defined in section 3.4.4
- = -1, if all six degrees of freedom at ND1 are involved
- = 0, for pin-ended rigid bar elements
- = integer defining prestress type

Rigid elements can be specified to span any length, including 0. Rigid pin-ended bar elements can be simulated by setting $IEC1 = IEC2 = 1$.

In automatic element generation (see INC, above), the generated intermediate elements acquire the same properties as the last element in current sequence. A special option also enables repetitive use of an element with an input format (I3, I2, 15I5); the integer IET is then replaced by NELNO and IET, where NELNO is the total number of similar elements connecting the specified nodes.

Sandwich-shell elements can be generated by individual inputs of membrane, bending, and transverse shear effects. Furthermore, the composite-shell elements consisting of layered composites can be formed for varying stacks of materials.

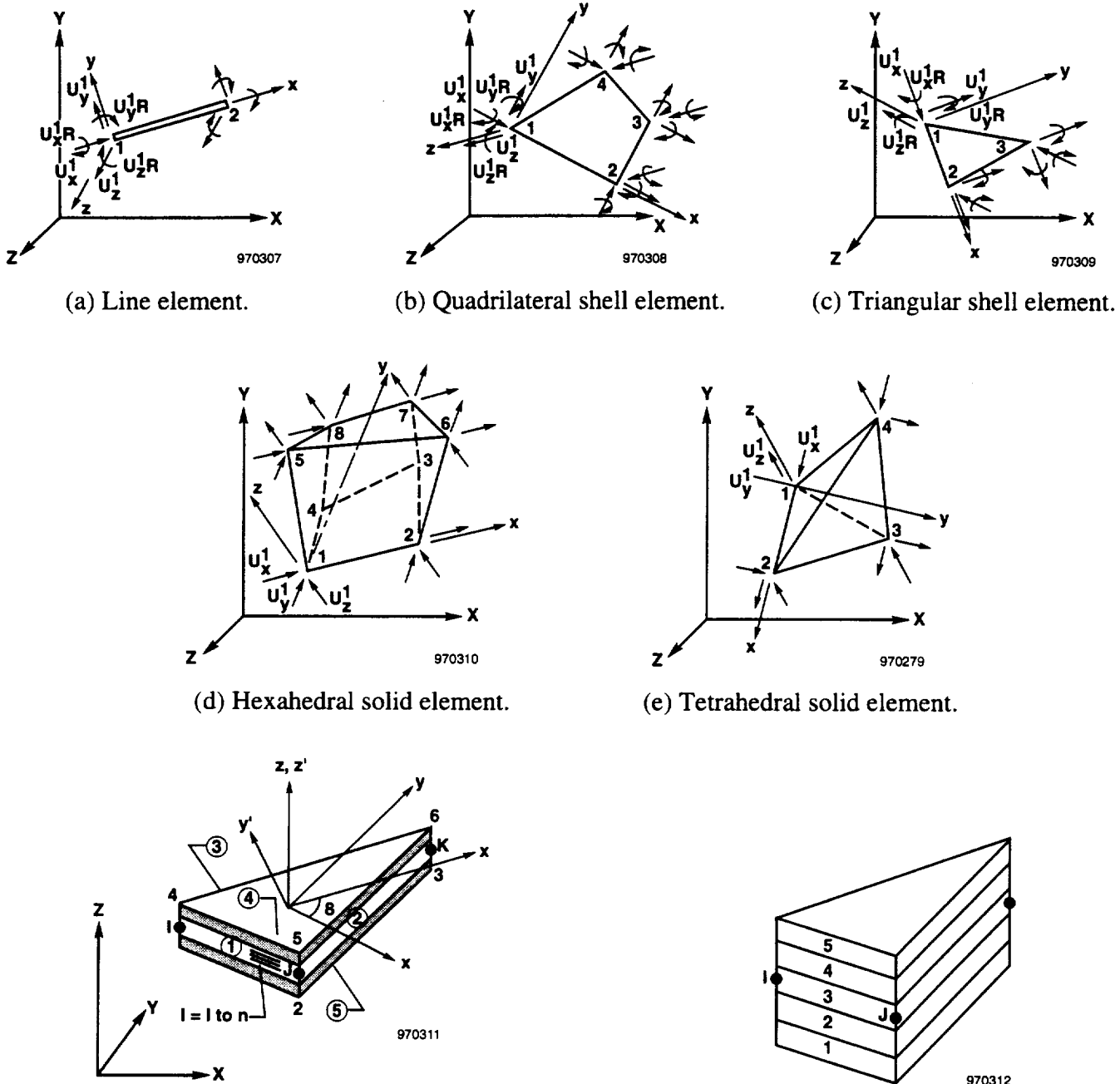
For element type 8, defined by two nodes, if the first node has some ZDBC constraints, the constraints should also be applied to the second node.

Table 2. Element data layout.

Element type (IET)	Element number (IEN)	Node number for vertices								IEPP/				
		1 (ND1)	2 (ND2)	3 (ND3)	4 (ND4)	5 (ND5)	6 (ND6)	7 (ND7)	8 (ND8)	IMPP	ITHTH	ITMPP	IPRR	IST INC
Line (bars, rods, beams, three- dimensional lines) 1	*	*	*	**	IEC1	IEC2	▼			*	X	*	*	*
Shell quadrilateral (plane, plate, shear, usual, and sandwich shell, solid of revolution (22)) 2,22	*	*	*	*	*				▲	*	†	*	*	*
Shell triangular (plane, plate, shear, usual, and sandwich shell, solid of revolution (33)) 3,33	*	*	*	*					▲	*	†	*	*	*
Solid hexahedron 4	*	*	*	*	*	*	*	*	*	*		*	*	*
Solid tetrahedron 5	*	*	*	*	*					*		*	*	*
Shell quadrilateral composite element (plane, plate, shear, and shell) 6	*	*	*	*	*				■	*		*	*	*
Shell triangular composite element (plane, plate, shear, and shell) 7	*	*	*	*					■	*		*	*	*
Rigid element (pin- ended bar, rigid body) 8	*	*	*	**	IEC1	IEC2	◆							*
Prestressed rectangular membrane 11	*	*	*	*	*				●	*	†	*	*	*

3. Element description:

Figure 7 shows the various elements and associated degrees of freedom. The GCS is represented by X, Y, and Z; and x, y, and z relate to the LCS.



(f) Composite shell/prism element.

Figure 7. STARS-SOLIDS typical element types.

4. Notes:

- a. A right-handed Cartesian coordinate system (x, y, z) is to be chosen to define any element LCS.
- b. Any node can be chosen as the first vertex of an element; the local x axis is along the line connecting vertices 1 and 2.
- c. For line elements, the local x - y plane is defined as the plane contained by vertices 1, 2, and the specified third-point node.
- d. The vertices of thin-and thick-shell elements are usually numbered in a counterclockwise sequence when observed from any point along the local positive z axis; the vertices are also used as plane and plate-bending elements, as appropriate. For highly ill-conditioned problems, alternative elements 22 and 33 may yield better results than the preferred element types 2 and 3, respectively.
- e. For solid elements, the y axis lies in the plane formed by vertices 1, 2, and 3 and 1, 2, 3, and 4 for the tetrahedral and hexahedral elements, respectively; the z axis is perpendicular to the x - y plane, heading toward the fourth node for the tetrahedron element and toward the plane containing the other four nodes for the hexahedral element.
- f. The vertices of the solid elements are also numbered in a counterclockwise sequence when viewed from any point on the positive z axis lying above the considered plane; the fifth vertex of the hexahedron is the node directly above vertex 1.
- g. For layered composite-shell element types 6 and 7, the layering sequence starts with the layer that has the maximum $-z$ coordinate expressed in the element LCS.
- h. For element type 7, for heat-transfer analysis, the element also caters to radiation and surface heat flow on all five surfaces. The averaged internal heat generation rate can be applied to the element.
- i. Element type 3 can be used for plane elastoplastic analysis. Element type 7 with eight layers needs to be used for such an analysis for shell structures.

5. Structural modeling:

Because each node is assumed to possess six displacement degrees of freedom, any individual structural form can be simply represented by suppressing appropriate displacement terms. The following rules may be adopted:

Truss structures: to allow only two nodal translational deformations in the plane of the structure; to use line elements.

Plane frame: all three in-plane displacements, namely, two translations and one rotation, are retained in the formulation; to use line elements.

Plane stress/strain: displacement boundary conditions are similar to truss structures; to use shell elements. Also valid for axisymmetric solid elements.

Plate bending: only the three out-of-plane displacements consisting of one translation and two rotations are considered for the analysis; to use shell elements.

Solid structures: the three translational degrees of freedom are retained in the analysis; to use solid elements.

Shell, space frame: all six degrees of freedom are to be retained in the solution process; to use shell and line elements, respectively.

Heat-transfer analysis: only the first two nodal degrees of freedom are used for two-dimensional or linear gradient in three-dimensional heat-transfer analysis. If different temperature gradients in the Z direction are desired, the number of degrees of freedom can be increased accordingly. A maximum of six degrees of freedom and five different temperature gradients through the thickness can exist.

Suppression of derived nodal motion is achieved by using ZBDC and IDBC, defined in sections 3.2 and 3.4, respectively.

3.3.3 \$ Composite Shell Element Stack Description Data
(Required for composite-shell elements (types 6 and 7), and only if NSTACK $\neq$ 0)

3.3.4 ISTACK, NLAYER, NSUBST, SBT1NL, SBT2NL, SBT3NL, SBT4NL, SBT5NL
Format (8I5)

3.3.5 (IMATC(I), THCL(I), IMANGC(I), I = 1, NLAYER)
Format (I5, E10.4, I5)

1. Description: NSTACK sets of composite-shell element data; layers are read from the bottom of the element.

2. Notes:

ISTACK = stack number

NLAYER = total number of layers in the stack

NSUBST = number of substacks in the stack (heat-transfer case only, a maximum of five)

SBT1NL–
SBT5NL = number of layers in the Ith substack; any number of layers allowed within a substack (required for heat-transfer case only)

IMATC(I) = material type number for the composite layer

THCL(I) = thickness of the composite layer

IMANGC(I) = integer specifying material angle type number (IMANG)

Because the module allows a maximum of five substacks, six temperatures at a node are the usual requirement (a substack is allowed to have any number of layers) using all six degrees of freedom, starting from the bottom.

3.3.6 \$ Specification For Material Axes Orientation (Required if NMANGL $\neq$ 0)

3.3.7 IMANG, IMAMD, ILGCS Format (3I5)

3.3.8 D11, D12, D13, D21, D22, D23, D31, D32, D33 (IMAMD = 1) Format (2(6E10.4, /)) or THETA (IMAMD = 2) Format (E10.4)

1. Description: NMANGL sets of material angle definition data.

2. Notes:

IMAMD = integer defining the material angle data input mode
= 1, involves input of elements of the direction cosine matrix of material axes with respect to the LGCS/GCS (set ILGCS = 0 for data in GCS)
= 2, requires input of material axis angle (THETA) with the shell-element local x axis, in radians

ILGCS = integer specifying the LGCS number (set to 0 if data is in the GCS)

THETA = material axis angle with respect to the shell-element local x axis

3.3.9 \$ Line Element Basic Properties (Required for line elements only)

3.3.10 IEPP, A, JX, IY, IZ, SFY, SFZ Format (I5, 6E10.4)

1. Description: NEP sets of line-element basic property data in the element LCS.

2. Notes:

IEPP = integer denoting the line-element property type

A = area of cross section

JX = torsional moment of inertia about the element x axis
= (P, perimeter of cross-sectional area for IPROB = 10)

- IY = moment of inertia about the element y axis
 IZ = moment of inertia about the element z axis
 SFY = A/ASY, shear area (ASY) factor along the y axis
 SFZ = A/ASZ, shear area (ASZ) factor along the z axis

For no shear area effect, SFY and SFZ are to be set at 0.0. Also, for heat-transfer problems (IPROB = 10), only A and P are the required input.

3.3.11 **\$ Line-Element Special End Conditions (Required for line elements only if NLSEC $\neq$ 0)**

3.3.12 **ILSEC, (k(I), I = 1, 6)** **Format (I5, 6E10.4)**

1. Description: NLSEC sets of line-element special end conditions data in the LCS.

2. Notes:

- ILSEC = element end condition type (to be set greater than 1), referring to members attached at the nodes by flexible connections, or members with free-end degrees of freedom in the LCS (corresponds to IEC1 and IEC2)
 = set to a negative value, less than -1, for scalar springs connecting two nodes (corresponds to IEC1)
- k(I) = additional spring stiffness along the Ith translational (x, y, and z direction) degree of freedom and actual rotational Ith spring stiffness (x, y, and z rotational constraint)
 = -2, for rigid rotational Ith constraint
 = -1, for release of corresponding member end degree of freedom, relevant also to ILSEC value set greater than 1
 = stiffness values for scalar springs associated with a negative ILSEC value less than -2

Such elements can have zero or any finite length.

To simulate only a specified end condition, set Young's modulus to $E = 0$ for the corresponding material type, IMPP.

3.3.13 **\$ Shell-Element Thickness (Required for shell elements (types 2, 22 and 3, 33) only)**

3.3.14 **ITHTH, TM, TB, TS** **Format (I5, 3E10.4)**

1. Description: NET sets of element-thickness data.

2. Notes:

ITHTH	= element-thickness type
TM	= membrane element thickness
TB	= bending element thickness
TS	= transverse shear element thickness

The above shell thicknesses pertain to sandwich elements; in the absence of data for TB and TS, the shell-element thickness T is taken as TM.

For consistent mass matrix formulation, the shell thickness T is taken as TM.

3.3.15 \$ Element Material Properties

3.3.16 IMPP, MT, ISSSR Format (3I5)

3.3.17	E, MU, ALP, RHO, SIGYP, HP	(material type 1); or
	E11, E12, E14, E22, E24, E44, E55, E56, E66, ALPX, ALPY, ALPXY, RHO	(material type 2); or
	E11, E12, E13, E14, E15, E16, E22, E23, E24, E25, E26, E33, E34, E35, E36, E44, E45, E46, E55, E56, E66, ALPX, ALPY, ALPZ, ALPXY, ALPYZ, ALPZX, RHO	(material type 3); or
	EM, EB, ES, MUM, MUB, MUS, ALPM, ALPB, ALPS, RHO	(material type 4); or
	E11M, E12M, E14M, E22M, E24M, E44M, E11B, E12B, E14B, E22B, E24B, E44B, E55S, E56S, E66S, ALPXM, ALPYM, ALPXYM, ALPXB, ALPYB, ALPXYB, ALPXS, ALPYS, ALPXYS, RHO	(material type 5); or
	KL, H, Q, QS, TE, QR, STB, EMS, SABS, CP, RHO	(material type 6); or
	KS, H1, H2, H3, H4, HT, HB, Q, QS1, QS2, QS3, QS4, QST, QSB, T1, T2, T3, T4, TT, TB, QR1, QR2, QR3, QR4, QRT, QRB, STB1, STB2, STB3, STB4, STBT, STBB, EMS1, EMS2, EMS3, EMS4, EMST, EMSB, SABS, CP, RHO	(material type 7); or

KS11, KS12, KS22, KS66, H1, H2, H3,
H4, HT, HB, Q, QS1, QS2, QS3,
QS4, QST, QSB, T1, T2, T3, T4,
TT, TB, QR1, QR2, QR3, QR4, QRT,
QRB, STB1, STB2, STB3, STB4, STBT, STBB,
EMS1, EMS2, EMS3, EMS4, EMST, EMSB, SABS,
CP, RHO

(material type 8)

Format (7E10.4, /)

(material types 1–3 and 6–8)

Format (6E10.4, /)

(material types 4 and 5)

1. Description: NMAT sets of element material property data; the individual material matrices are derived from the symmetric matrix of order 6 for general solid material.

2. Notes:

IMPP = material number

MT = material type
= 1, isotropic (= 11, for a plane-strain case, = 12, for a solid of revolution)
= 2, orthotropic-anisotropic, shell elements (= 22, for plane-strain case, = 23, for a solid of revolution)
= 3, orthotropic-anisotropic, solid elements
= 4, isotropic, sandwich-shell elements incorporating individual membrane, bending, and transverse shear effects
= 5, orthotropic-anisotropic sandwich-shell elements with individual effects, as above
= 6, isotropic heat transfer, line elements
= 7, isotropic heat transfer, shell elements
= 8, orthotropic-anisotropic heat transfer, shell elements

ISSSR = integer defining special stress-strain relationship
= 0, no plane strain
= 1, plane strain

E = Young's modulus

EIJ = elements of material stress-strain matrix (I = 1, 6 ; J = 1, 6)

MU = Poisson's ratio

ALP = coefficient of thermal expansion for isotropic material

ALPX, ALPY,

ALPXY = elements of thermal expansion vector, shell elements

ALPX–

ALPZX = elements of thermal expansion vector, solid elements

RHO = mass/unit volume

SIGYP = material yield stress subjected to unit axial loading; can be ignored or set to 0.0 for elastic analysis

HP = slope of strain hardening curve as a function of plastic strain (effect stress as a function of plastic strain), assumed constant; can be ignored or set to 0.0 for elastic analysis

For sandwich elements (material types 4 and 5), relevant notations defining such properties use a postscript of M, B, or S for membrane, bending, or transverse shear stiffness, respectively.

For heat-transfer problems:

KL, KS,
KSIJ = relevant elements of symmetric conductivity tensor ($I = 1, 2, 6$; $J = 1, 2, 6$)

H, HI = convective heat-transfer coefficient for a line element and a quadrilateral/triangular shell element, as pertaining to the edges and the top and bottom surfaces, respectively ($I = 1-4$ and T and B)

TE, TI = convective exchange temperature, for line and other elements, as defined for H, HI

QS, QSI = specified surface heat flow, for line and other elements, defined as above

QR, QRI = specified incident surface radiant heat flow, for line and other elements, defined as above

STB, STBI = Stefan-Boltzmann constant, for line and other elements, defined as above

EMS, EMSI = surface emissivity, for line and other elements, defined as above

Q = appropriate internal heat generation rate for each unit volume

SABS = surface absorptivity

CP = specific heat

3. Additional notes:

For radiation problems, in the absence of specified temperature, an initial temperature input is needed on the radiating surface.

3.3.18 \$ Element Temperature Data/Initial Nodal Temperature Data (Required if NTMP $\neq$ 0)

3.3.19 ITMPP, T, DTDY, DTDZ
Format (2(I5, 3E10.4)) or
IN, NDOF, TEMP
Format (2I5, E10.4)

(If IPROB $\neq$ 10)

(If IPROB = 10)

1. Description: NTMP number of element temperature types; table 3 shows compatible input data.

Table 3. Element temperature data input.

Element type	T	DTDY	DTDZ
1	*	*	*
2, 3, 6, 7	*		*
4, 5	*		

2. Notes:

ITMPP = element temperature-increase type

T = uniform temperature increase; relates to all elements

DTDY = temperature gradient along the element local y axis; relates to line elements only

DTDZ = temperature gradient along the element local z axis; relates to line and shell elements

*

= compatible input data

IN = node number

NDOF = nodal degree of freedom

TEMP = temperature

3. Additional notes:

Each data set for IPROB = 10 is to be terminated by a negative value of IN.

3.3.20 \$ Element Pressure Data

(Required if NPR > 0)

3.3.21 IPRR, PR

Format (5(I5, E10.4)) or

Format (I5, 6E10.4) or (I5, 4E10.4, /, 5x, 4E10.4) for an axisymmetric, a triangular, or a quadrilateral solid element, respectively

1. Description: NPR sets of element pressure data.

2. Notes:

IPRR = element pressure type

PR = uniform pressure

Pressure directions for line elements: uniform pressure is allowed in local y and z directions only, and the module calculates both end loads and moments as input. Although pressure corresponding to a first nodal input pertains to the y direction, a subsequent input for the same node signifies pressure acting in the z direction.

Pressure directions for shell elements: uniform pressure is allowed in the local z direction only; the module computes nodal load input.

Pressure directions for solid elements: uniform pressure is allowed on base surfaces defined by nodes 1, 2, 3, and 4 and 1, 2, and 3 for hexahedral and tetrahedral elements, respectively, acting in the local z direction; the module computes nodal load input data.

Pressure directions for axisymmetric solid elements: linearly varying two end pressures on all three edges for triangular elements and on all four edges for quadrilateral elements, with the pressure direction being inward positive—acting perpendicular to the edges. Edge is defined in relation to internal nodal numbering. For example, the starting input node is considered as internal node 1 and the edge opposite to node 1 is termed as edge 1, and so on. For quadrilateral elements, internal nodes 2 and 3, 3 and 4, 4 and 1, and 1 and 2 define edges 1, 2, 3, and 4, respectively.

3.3.22 \$ Prestressed Rectangular Membrane Element Data (Required if NEXP ≠ 0)

3.3.23 IIEXP, SX, SY Format (I5, 2E10.4)

1. Description: NEXP sets of prestressed membrane stress data.

2. Notes:

IIEXP = integer defining stress combination type

SX, SY = membrane stresses in the element x and y directions, respectively

3.4 Data in the Global or Local-Global Coordinate System

General note: Data input can be at random within each data group.

3.4.1 \$ Element Spin Rate Data (Required if NSPIN ≠ 0)

3.4.2 IST, SPX, SPY, SPZ, ILGCS
Format (I5, 3E10.4, I5)

1. Description: NSPIN sets of spin data.
2. Notes:

IST = spin type

SPX, SPY, SPZ = components of the element spin rate in the GCS/LGCS X, Y, and Z directions, respectively

ILGCS = LGCS number, as defined in section 3.2.2

3.4.3 \$ Displacement/Temperature Boundary-Condition Data (Required if NBUN $\neq$ 0)

3.4.4 INI, IDOFJ, INIP, IDOFJP, CONFCT, IDRCS, NDBCON (If IPROB $\neq$ 10)
INI, IDOFJ, INIP, IDOFJP, TEMP, IDRCS, NDBCON (If IPROB = 10)
Format (4I5, E10.4, 2I5)

1. Description: NBUN sets of nodal IDBC data.
2. Notes:

INI = node number I

IDOFJ = Jth degree of freedom associated with node I

INIP = node number I'

IDOFJP = J'th degree of freedom associated with node I'

CONFCT = connectivity factor

TEMP = temperature at the boundary condition

IDRCS = displacement/temperature boundary-condition reference coordinate system

NDBCON = integer defining displacement/temperature boundary-condition increment

= 0, no increment

= an integer, to increment the IDOFJ and IDOFJP by 1 until the IDOFJ reaches the NDBCON value

J and J' vary between 1 and 6. For IPROB = 10, only INI and CONFCT (nodal temperature) are the required input.

3. Additional notes:

The nodal displacement boundary-conditions relationship is expressed as

$$U_{i,j} = a_{m,n} U_{m,n}$$

$$= a_{i,j} U_{i,j} + a_{i',j'} U_{i',j'} + \dots$$

Table 4 shows the input scheme.

Table 4. Data layout for displacement boundary conditions.

Node 1	Degree of freedom	Node 2	Degree of freedom	Connectivity coefficient	Reference coordinate system	Incremental degree-of- freedom value	Terminology
i	j	i'	j'	$a_{i',j'}$	IDRCS	NDBCON	IDBC
i	j	i	j	$a_{i,j}$	IDRCS	NDBCON	FDBC
i	j	i	j	0	IDRCS	NDBCON	ZDBC

in which

i, i' = node numbers,

j, j' = degrees of freedom,

$a_{i,j}, a_{i',j'}$ = connectivity coefficients.

IDBC, FDBC, and ZDBC are, respectively, the interdependent, finite, and zero displacement boundary conditions. The ZDBC can also be conveniently implemented by following the rules given in table 1, which is generally recommended for such cases. It should be noted that the dependent degrees of freedom appearing in columns 1 and 2 cannot appear subsequently in columns 3 and 4 as independent degrees of freedom. However, the independent degrees of freedom can subsequently be related; although in such an event, an automatic sorting procedure is triggered to rectify the situation.

3.4.5 \$ Nodal Load Data

(Required if IPLUMP $\neq$ 0)

3.4.6 IN, IDOF, P, IDOFE, ILGCS Format (2I5, E10.4, 2I5)

1. Description: NC sets of nodal force data.
2. Notes:

IN = node number

IDOF and IDOFE are, respectively, the start and end degrees of freedom assigned with the same P value; the default value for IDOFE is IDOF.

P = nodal load

Each data set is to be terminated by setting a negative value for IN.

3.4.7 \$ Nodal Mass Data (Required if IMLUMP $\neq$ 0)

**3.4.8 IN, IDOF, M, IDOFE, ILGCS
Format (2I5, E10.4, 2I5)**

1. Description: Nodal lumped mass data.

2. Notes:

M = nodal mass

Other definitions are as given in section 3.4.6.

3.4.9 \$ Nodal Mass Matrix In LGCS/GCS (Required if INMM $\neq$ 0)

**3.4.10 IN, ILGCS
Format (2I5)**

**3.4.11 (VNMDAT(I), I = 1, 36)
Format (6(6E10.4, /))**

1. Description: User input of a nodal mass matrix of order 6.

2. Notes:

The user can input data for only the upper symmetric elements; numbers in the lower one-half can be set to zero as the module automatically symmetrizes the matrix.

For data in the GCS, set ILGCS = 0.

Each data set is to be terminated by setting a negative value for IN.

3.4.12 \$ Nodal Initial Displacement and Velocity Data (Required if IUUV = 1 and IDRS = 1)

**3.4.13 IN, IDOF, UI, VI
Format (2I5, 2E15.5)**

1. Description: Initial displacements and velocities data.

2. Notes:

IN = node number
IDOF = degree of freedom
UI = initial displacement value
VI = initial velocity value

The data set is terminated if IN is read as -1.

3.4.14 \$ Nodal Force Acceleration Data/Element Heat-Transfer Data
(Required if NTTS $\neq$ 0 and IDRS = 1)

3.4.15 TZ
Format (E15.5)

3.4.16 IN, IDOF, PZ (If IPROB $\neq$ 10)
Format (2I5, E15.5) or
IEN, ISURF, Q, QS, TI (If IPROB = 10)
Format(2I5, 3E15.5)

1. Description: NTTS sets of dynamic nodal load (IDDI = 1) or acceleration (IDDI = 2) input data.

2. Notes:

TZ = time duration of load application
PZ = nodal force or acceleration data
IEN = element number
ISURF = element surface indicator (fig. 7 (f.1))

Each data set is terminated by setting the IN value to -1; other definitions are as given in sections 3.3.17 and 3.4.6.

3.4.17 \$ Incremental Time Data For Response Calculation
(Required if NDEL T $\neq$ 0 and IDRS = 1)

3.4.18 DELT, IDELT
Format (E15.5, I5)

1. Description: NDEL T sets of uniform incremental time input data for dynamic-response calculations.

2. Notes:

DELT = uniform incremental time step

IDELT = total number of uniform time steps in the data set

3.5 Additional Basic Data

3.5.1 \$ Viscous-Damping Data (Required if IPROB = 4 or 5)

3.5.2 (C(I, I), I = 1, N)
Format (6E10.4)

1. Description: User input of the diagonal viscous-damping matrix.

2. Notes:

C = diagonal viscous-damping matrix

N = order of matrix

3.5.3 \$ Coefficients For Proportional Viscous Damping (Required if IPROB = 6 or 7)

3.5.4 ALPHA, BETA
Format (2E10.4)

1. Description: Proportional viscous-damping formulation $C = ALPHA \times K + BETA \times M$

2. Notes:

ALPHA and BETA are damping parameters.

K and M are system stiffness and mass matrices.

3.5.5 \$ User Input Option For Viscous-Damping Matrix
(Required if IPROB = 6 or 7 and ALPHA and BETA are set to 0)

3.5.6 ((C(I, J), J = 1, M11), I = 1, 6)
Format (6E10.4)

1. Description: NN sets of user input of the banded viscous-damping matrix C(N,M11) in blocks of six rows of bandwidth M11, one row at a time ($N = 6 \times NN$).

2. Notes:

The data file must conform to IDBC, FDBC, and ZDBC, inherent in the problem.

3.5.7 \$ Measured Modal Data Input

(Required if IINTP = 2)

3.5.8 (INODM(I), (DISPLM(I, J), J = 1, 6), I = 1, NN) Format (I5, 6E10.4)

1. Description: Measured modal displacement data input, NR sets of data.
2. Notes:

Each data set is to be terminated by setting INODM(I) value to -1.

3.5.9 \$ Output Points Specification For Direct Interpolation Of Modal Data

(Required if NOUT ≠ 0)

3.5.10 (IOUTP(I), (ICONP(I, J), J = 1, 6), I = 1, NOUT) Format (7I5)

1. Description: To read the output point and a maximum of six connecting points
2. Notes:

IOUTP(I) = output points on aerodynamic paneling interpolation lines

ICONP(I, J) = STARS-SOLIDS finite-element nodes whose deflections will be averaged to calculate the deflection value at the interpolation point

3.5.11 \$ Rigid Control Modes Data Input

(Required if NCNTRL ≠ 0)

3.5.12 INS, IDOF, DISP, INE, ININC Format (2I5, E10.4, 2I5)

1. Description: Modal displacement data for NCNTRL number of modes.
2. Notes:

INS, INE = start and end node numbers; the default value for INE is INS

IDOF = degree of freedom, a value between 1 and 6

DISP = associated displacement

ININC = integer defining nodal incremental value; increment INS by ININC until INE is attained

Each data set is to be terminated by setting INS value to -1.

4. SAMPLE PROBLEMS

4.1. STARS-SOLIDS (Linear Analysis)

This section provides the input data and relevant outputs of typical test cases involving static, stability, free-vibration, and dynamic-response analyses of representative structures. Other analyses involving solids of revolution problems under mechanical and thermal loading as well as stress analysis for such rotating bodies are not included in this section. Analyses are performed by typing the command "srun." The input data are prepared in accordance with the procedures described in section 3. Details of such analyses are in the descriptions that follow in which each structural geometry is described in a right-handed, rectangular coordinate system, and the associated input data are defined in consistent unit form.

4.1.1 Space Truss: Static Analysis

The static analysis of the space truss shown in figure 8¹¹ was performed to yield nodal deformations and element forces. A load of 300 lbf acts at node 7 along the axial direction of the member connecting nodes 7 and 9; another load of 500 lbf is applied at node 10 in the direction of the structural base centerline. Also, the three members in the upper tier of the structure are subjected to a uniform temperature increase of 100 °F. Two rigid elements are, however, introduced between nodes 5 and 8 and nodes 7 and 9.

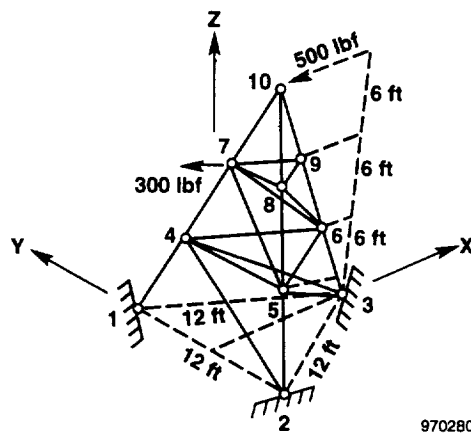


Figure 8. Space truss.

Important data parameters:

Young's modulus, E	$= 1.0 \times 10^7$
Poisson's ratio, μ	$= 0.3$
Coefficient of thermal expansion, α	$= 12.5 \times 10^{-6}$

STARS-SOLIDS input data:

SPACE TRUSS - MECHANICAL AND THERMAL LOADING - RBARS FROM NODES 5-8, 7-9

11,21,1,4,1,0,0,0,0,0

1,0,0,1,0,0,0,0,0

0,0,0,1,1,0,0,0

2,0,1,0,1,0,0,1,0,0

\$ NODAL DATA

1	0.0	72.0	0.0	1	1	1	0	0	0
2	0.0	-72.0	0.0	1	1	1	0	0	0
3	124.68	0.0	0.0	1	1	1	0	0	0
4	13.86	48.0	72.0						
5	13.86	-48.0	72.0						
6	96.972	0.0	72.0						
7	27.708	24.0	144.0						
8	27.708	-24.0	144.0						
9	69.276	0.0	144.0						
10	41.568	0.0	216.0						
11	144.0	36.0	0.0	1	1	1	1	1	1

\$ ELEMENT CONNECTIVITY

1	1	1	4	11	1	1	0	0	0	1	1
1	2	2	4	11	1	1				1	1
1	3	2	5	11	1	1				1	1
1	4	3	5	11	1	1				1	1
1	5	3	6	11	1	1				1	1
1	6	3	4	11	1	1				1	1
1	7	4	5	11	1	1				1	1
1	8	5	6	11	1	1				1	1
1	9	6	4	11	1	1				1	1
1	10	4	7	11	1	1				1	1
1	11	5	7	11	1	1				1	1
8	12	5	8	11			-1				
1	13	6	8	11	1	1				1	1
1	14	6	9	11	1	1				1	1
1	15	6	7	11	1	1				1	1
1	16	7	8	11	1	1				1	1
1	17	8	9	11	1	1				1	1
8	18	9	7	11	1	1					
1	19	7	10	11	1	1				1	1
1	20	8	10	11	1	1				1	1
1	21	9	10	11	1	1				1	1

\$ LINE ELEMENT BASIC PROPERTIES

1 0.01389

\$ ELEMENT MATERIAL PROPERTIES

1 1

10.0E6 0.3 12.5E-06

\$ ELEMENT TEMPERATURE DATA

1 100.0

\$ NODAL LOAD DATA

10 1 -500.0

7 1 -259.8

7 2 150.0

-1

STARS-SOLIDS analysis results: nodal deformations and element stresses are presented below.

LOAD CASE NO. 1

NODE		X-DISPL.	Y-DISPL.	Z-DISPL.	X-ROTN.	Y-ROTN.	Z-ROTN.
EXT	INT						
1	1	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
2	2	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
3	3	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
4	4	-.302075E+00	.233780E+00	-.331469E+00	.000000E+00	.000000E+00	.000000E+00
5	5	-.294400E+00	.233736E+00	-.297468E+00	-.149503E-01	-.310231E-01	-.530793E-01
6	6	-.358099E+00	.344030E+00	.558126E+00	.000000E+00	.000000E+00	.000000E+00
7	7	-.161162E+01	.575100E+00	-.385535E+00	.000000E+00	.000000E+00	.000000E+00
8	8	-.125416E+01	.575114E+00	-.226667E+00	-.149503E-01	-.310231E-01	-.530793E-01
9	9	-.143290E+01	.884643E+00	.696849E+00	.000000E+00	.000000E+00	.000000E+00
10	10	-.460499E+01	.916627E+00	.131711E+00	.000000E+00	.000000E+00	.000000E+00
11	11	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
12	12	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00

ELEMENT STRESSES

ELEMENT NO.	END1	END2	END3	END4	PX1/PX2 SXT SKX	PY1/PY2 SVT SVY	PZ1/PZ2 SKVT SZZ	MX1/MX2 SXB SKY	MY1/MY2 SVB SVZ	MZ1/MZ2 SKVB SZX
1	1	4			.785576E+03 -.785576E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
2	2	4			-.704942E-02 .704942E-02	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
3	2	5			.464122E+03 -.464122E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
4	3	5			.814173E-01 -.814173E-01	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
5	3	6			-.116939E+04 .116939E+04	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
6	3	4			-.146365E+03 .146365E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
7	4	5			-.633498E-01 .633498E-01	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
8	5	6			-.653699E-12 .653699E-12	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
9	6	4			.150008E+03 -.150008E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
10	4	7			.705240E+03 -.705240E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
11	5	7			.463655E-01 -.463655E-01	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
12	5	8			.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
13	6	8			-.178447E+00 .178447E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
14	6	9			-.927915E+03 .927915E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
15	6	7			-.321364E+03 .321364E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
16	7	8			.416932E-01 -.416932E-01	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
17	8	9			.833364E-01 -.833364E-01	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
18	9	7			.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
19	7	10			.463998E+03 -.463998E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
20	8	10			.463998E+03 -.463998E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00
21	9	10			-.927967E+03 .927967E+03	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00	.000000E+00 .000000E+00

4.1.2 Space Frame: Static Analysis

A space frame with rigid connections (fig. 9)¹² is subjected to nodal forces and moments. Results of such an analysis are presented below.

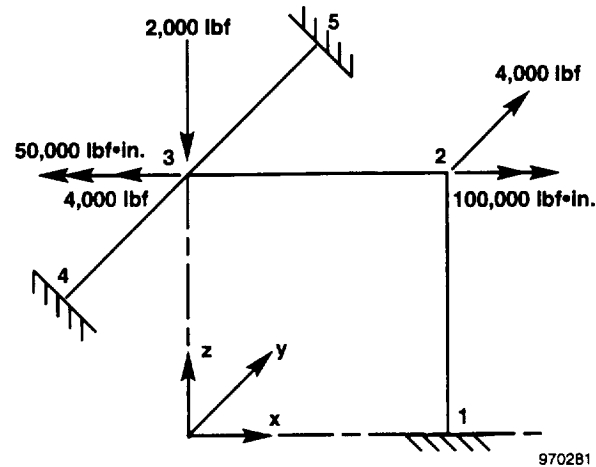


Figure 9. Space frame structure.

Important data parameters:

Young's modulus, E	$= 30.24 \times 10^6$
Poisson's ratio, μ	$= 0.2273$
Cross-sectional area, A	$= 25.13$
Member length, ℓ	$= 120$

STARS-SOLIDS input data:

```
SPACE FRAME CASE
6,4,1,4,1,0,0,0,0,0
0,0,0,1,0,0,0,0,0
0,0,0,1,0,0,0,0
2,0,1,0,1,0,0,1,0,0
$ NODAL DATA
1 120.0 0.0 0.0 1 1 1 1 1 1
2 120.0 0.0 120.0 0 0 0 0 0 0
3 0.0 0.0 120.0 0 0 0 0 0 0
4 0.0 -120.0 120.0 1 1 1 1 1 1
5 0.0 120.0 120.0 1 1 1 1 1 1
6 10.0 10.0 0.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
1 1 1 2 6 0 0 1 1
1 2 2 3 6 0 0 1 1
1 3 3 4 6 0 0 1 1
1 4 3 5 6 0 0 1 1
$ LINE ELEMENT BASIC PROPERTIES
1 25.13 125.7 62.83 62.83
$ ELEMENT MATERIAL PROPERTIES
1 1
30.24E06 0.2273
$ NODAL LOAD DATA
2 4 100000.0
2 2 4000.0
3 1 -4000.0
3 3 -2000.0
3 4 -50000.0
-1
```

STARS-SOLIDS analysis results:

LOAD CASE NO. 1

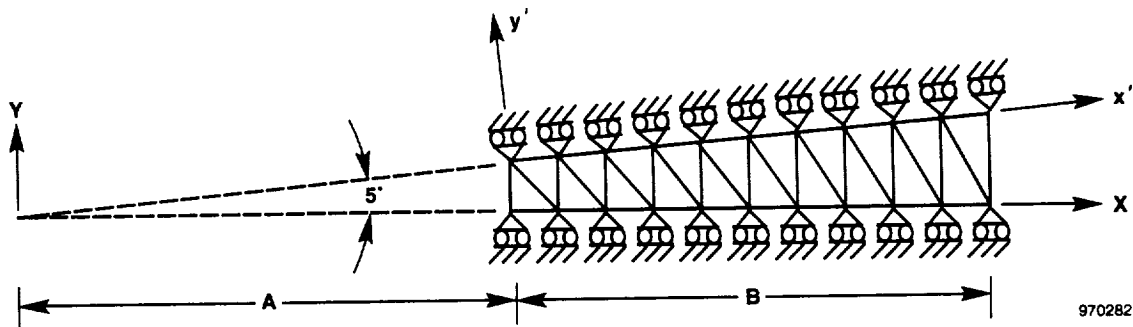
NODE		X-DISPL.		Y-DISPL.		Z-DISPL.		X-ROTN.		Y-ROTN.		Z-ROTN.	
EXT	INT												
1	1	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	2	-0.125288E+00	0.347953E+00	0.196027E-04	-0.239969E-02	-0.121545E-02	0.323397E-02	0.910380E-03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3	3	-0.125397E+00	0.103330E-03	-0.804946E-01	-0.580122E-03	-0.283265E-03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4	4	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5	5	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
6	6	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00

ELEMENT STRESSES

ELEMENT NO.	ENDS				PX1/PX2		PY1/PY2		PZ1/PZ2		MX1/MX2		MY1/MY2		MZ1/MZ2	
	END1	END2	END3	END4	SXT	SXX	SYT	SYX	SZT	SZZ	SXB	SXY	SYB	SYZ	SXB	SZY
1	1	2				-0.124146E+03	-0.931704E+03	0.261767E+04	-0.417341E+05	-0.193156E+06	-0.785077E+05	-0.332968E+05				
						0.124146E+03	0.931704E+03	-0.261767E+04	0.417341E+05	0.193156E+06	0.785077E+05	0.332968E+05				
2	2	3				-0.690886E+03	-0.232402E+03	-0.129390E+04	-0.234814E+05	-0.397456E+05	-0.255976E+05	-0.229060E+04				
						0.690886E+03	0.232402E+03	0.129390E+04	0.234814E+05	0.397456E+05	0.255976E+05	0.229060E+04				
3	3	4				-0.654366E+03	-0.523180E+03	-0.980682E+03	-0.365547E+04	-0.437137E+05	-0.234344E+05	-0.393472E+05				
						0.654366E+03	0.523180E+03	0.980682E+03	0.365547E+04	0.437137E+05	0.234344E+05	0.393472E+05				
4	3	5				-0.654366E+03	-0.131882E+04	-0.249340E+04	-0.365547E+04	-0.164731E+06	-0.870857E+05	-0.711729E+05				
						0.654366E+03	0.131882E+04	0.249340E+04	0.365547E+04	0.164731E+06	0.870857E+05	0.711729E+05				

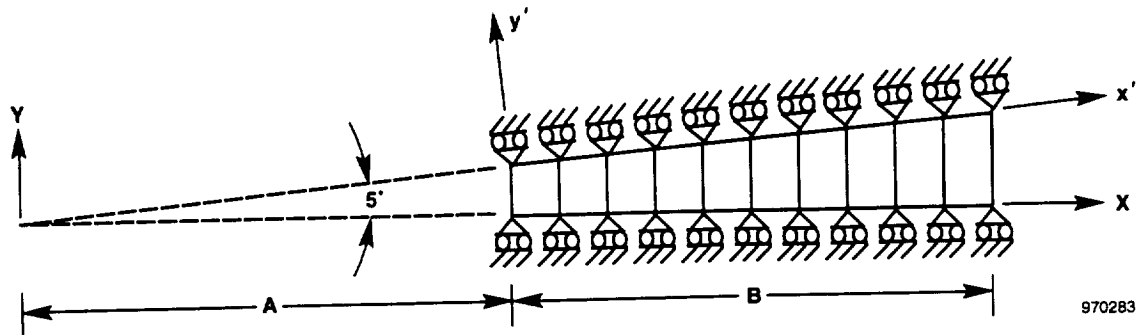
4.1.3 Thick-Wall Cylinder: Plane Strain

A circular cylinder of constant wall thickness¹³ subjected to uniformly distributed internal pressures was analyzed. Figure 10 shows the modeling with triangular and quadrilateral finite elements.



(a) Triangular mesh.

Figure 10. Thick-wall cylinder under internal pressure.



(b) Quadrilateral mesh.

Figure 10. Concluded.

Important data parameters:

Young's modulus, E = 30×10^6
Poisson's ratio, μ = 0.3
Side lengths, A, B = 1.0
Internal pressure, p = 300 lbf/in²

STARS-SOLIDS input data:

```
Plane Strain analysis of a thick wall cylinder
22, 20, 1, 6, 0, 1, 1, 0, 0, 0
0, 0, 0, 0, 0, 0, 0, 0, 0, 0
8, 0, 0, 1, 1, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 1, 0, 1
$ NODAL DATA
1 1.0000 .0000 .0000 0 1 1 1 1 1 0 0 0
11 2.0000 .0000 .0000 0 1 1 1 1 1 0 0 1
12 0.0000 .0000 .0000 0 1 1 1 1 1 1 1 0
22 1.0000 .0000 .0000 0 1 1 1 1 1 1 1 1
$ LOCAL-GLOBAL COORDINATE SYSTEM
1 1
0.996190 0.08716 0.0 1.99238 0.17432 0.0
1.448895 0.38823 0.0
$ ELEMENT CONNECTIVITY CONDITIONS
3 1 1 2 12 0 0 0 0 0 1 1 0 0 0 0
3 10 10 11 21 0 0 0 0 0 1 1 0 0 0 1
3 11 13 12 2 0 0 0 0 0 1 1 0 0 0 0
3 20 22 21 11 0 0 0 0 0 1 1 0 0 0 1
$ SHELL ELEMENT THICKNESSES
1 .1000E+01 .1000E+01 .1000E+01
$ MATERIAL PROPERTIES
1 11
.3000E+08 .3000E+00 .0000E+00 .0000E+00 0.0
$ NODAL LOAD DATA
1 1 21.8166
12 1 21.7335
12 2 1.9015
-1
```

STARS-SOLIDS output summary: table 5 shows the output summary.

Table 5. Radial deformations of a circular cylinder subjected to uniformly distributed internal pressures.

Distance	Deformations		
	Hand calculation	Triangular element	Quadrilateral element
$r = 1.0$	0.3178×10^{-4}	0.3175×10^{-4}	0.3174×10^{-4}
$r = 2.0$	0.2022×10^{-4}	0.2011×10^{-4}	0.2021×10^{-4}
$r = 1.5$	0.2359×10^{-4}	0.2349×10^{-4}	0.2357×10^{-4}

4.1.4 Plate Bending: Vibration Analysis

A square cantilever plate was analyzed to yield the natural frequencies and associated mode shapes. Figure 11 shows the plate with a 4-by-4 finite-element mesh; the bottom edge along the x axis is clamped.

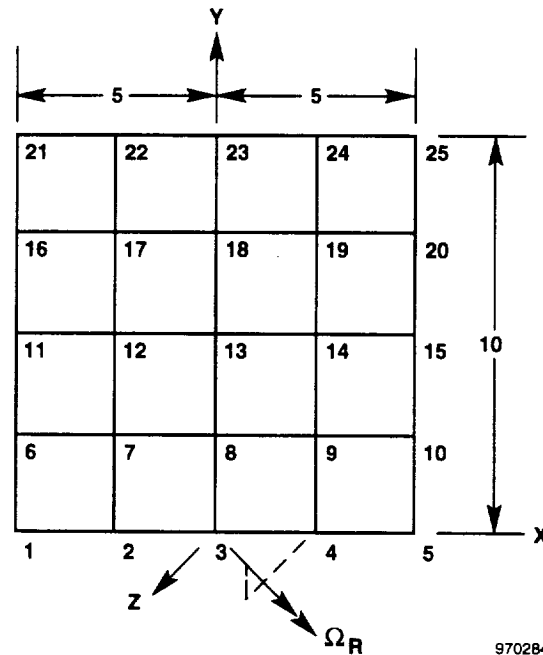


Figure 11. Square cantilever plate.

Important data parameters:

Young's modulus, E	$= 10 \times 10^6$
Side length, L	$= 10$
Plate thickness, t	$= 0.1$
Poisson's ratio, μ	$= 0.3$
Mass density, ρ	$= 0.259 \times 10^{-3}$

STARS-SOLIDS input data:

```

SQUARE 4 BY 4 PLATE    NONSPINNING STRUCTURE
25, 16, 1, 4, 0, 1, 0, 0, 0, 0
0, 0, 0, 1, 0, 0, 0, 0, 0, 0
1, 1, 0, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 1, 0, 0
1, 6, 0, 6000.0, 0.0, 0, 0.0
$ MODAL DATA
1      -5.0      0.0      0.0      1      1      1      1      1      1      0      0      0
5      -5.0      0.0      0.0      1      1      1      1      1      1      0      0      1
6      -5.0      2.5      0.0      0      0      0      0      0      0      0      0      0
10     -5.0      2.5      0.0      0      0      0      0      0      0      0      0      1
11     -5.0      5.0      0.0      0      0      0      0      0      0      0      0      0
15     -5.0      5.0      0.0      0      0      0      0      0      0      0      0      1
16     -5.0      7.5      0.0      0      0      0      0      0      0      0      0      0
20     -5.0      7.5      0.0      0      0      0      0      0      0      0      0      1
21     -5.0      10.0     0.0      0      0      0      0      0      0      0      0      0
25     -5.0      10.0     0.0      0      0      0      0      0      0      0      0      1
$ ELEMENT CONNECTIVITY
2      1      1      2      7      6      0      0      0      0      1      1      0      0      0
2      4      4      5      10     9      0      0      0      0      1      1      0      0      0
2      5      6      7      12     11     0      0      0      0      1      1      0      0      0
2      8      9      10     15     14     0      0      0      0      1      1      0      0      0
2      9      11     12     17     16     0      0      0      0      1      1      0      0      0
2      12     14     15     20     19     0      0      0      0      1      1      0      0      0
2      13     16     17     22     21     0      0      0      0      1      1      0      0      0
2      16     19     20     25     24     0      0      0      0      1      1      0      0      0
$ SHELL ELEMENT THICKNESSES
1      0.1
$ ELEMENT MATERIAL PROPERTIES
1      1
1.0E+07      0.30      0.0      0.259E-3

```

STARS-SOLIDS output summary: table 6 shows the output summary.

Table 6. Natural frequencies of a square cantilever plate.

Mode	Natural frequency (ω), rad/sec	Nondimensional parameter (γ), $\gamma = \omega^2 \sqrt{\rho t / D}$
1	214.02	3.60
2	506.62	8.52
3	1248.40	20.99
4	1538.29	25.87
5	1765.53	29.69

Note: D = plate flexural rigidity
 $= Et^3/12(1 - \mu^2)$

4.1.5 General Shell: Vibration Analysis

Figure 12 shows a cantilevered circular cylindrical shell in which quadrilateral shell elements are used for structural discretization to perform a free-vibration analysis.

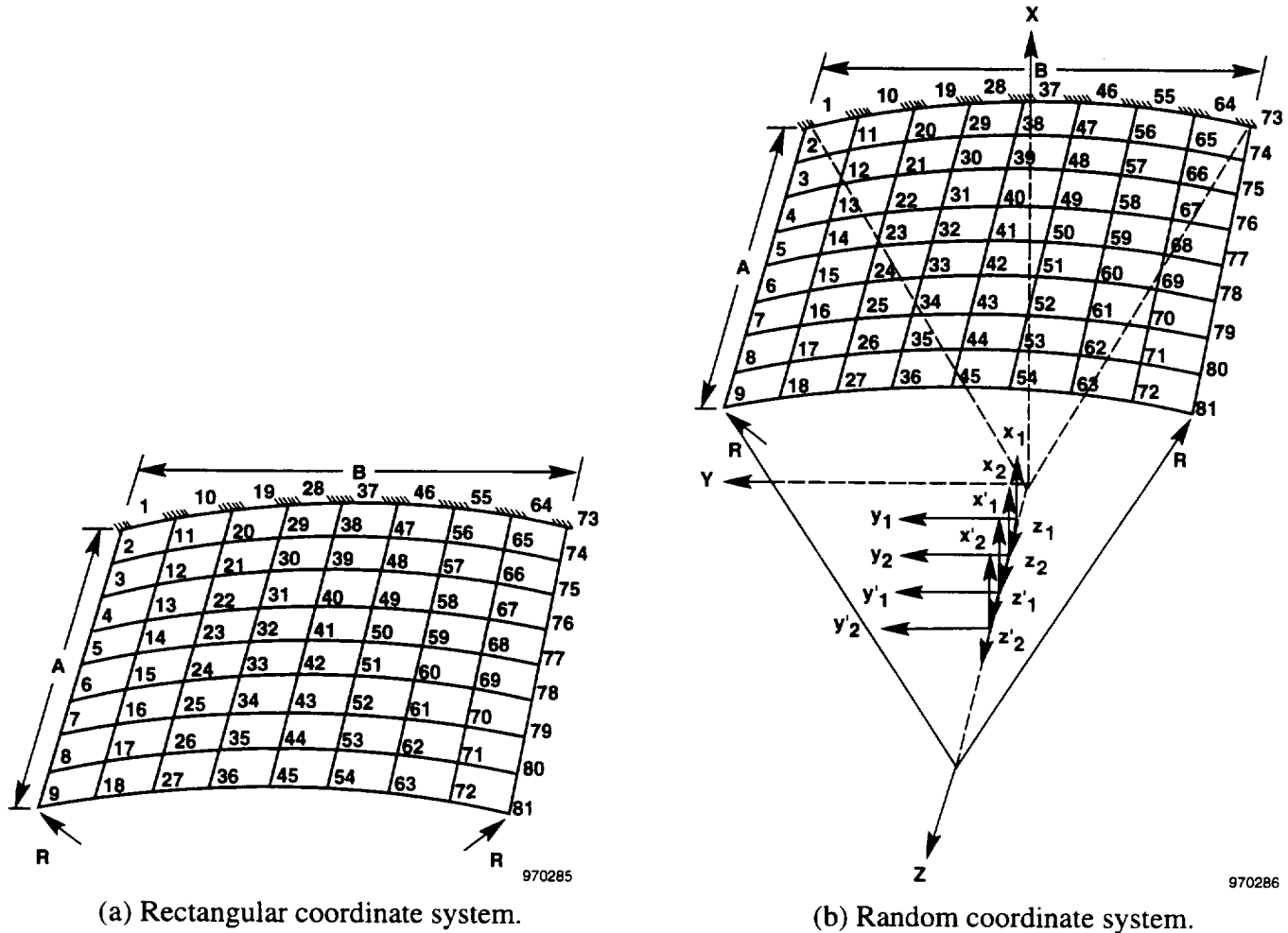


Figure 12. Finite-element model of cylindrical shell.

Important data parameters:

Side length, A, B	$= 10$
Radius, R	$= 20$
Thickness, t	$= 0.1$
Young's modulus, E	$= 29.5 \times 10^6$
Poisson's ratio, μ	$= 0.3$
Mass density, ρ	$= 0.733 \times 10^{-3}$

STARS-SOLIDS input data:

```

SHELL ELEMENT      8 BY 8    CURVED SHELL    FREE VIBRATION ANALYSIS
81, 64, 1, 4, 0, 1, 0, 0, 0, 0
0, 0, 0, 1, 0, 0, 0, 0, 0, 0
1, 1, 0, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 1, 0, 0
1, 6, 0, 90000.0, 0.0, 0.0

$ MODAL DATA
1      0.0      0.0      0.0      1      1      1      1      1      1      0      0      0
2      1.25     0.0      0.0      0      0      0      0      0      0      0      0      0
9      10.0     0.0      0.0      0      0      0      0      0      0      0      0      1
10     0.0      1.25 0.2803754 1      1      1      1      1      1      0      0      0
11     1.25     1.25 0.2803754 0      0      0      0      0      0      0      0      0
18     10.0     1.25 0.2803754 0      0      0      0      0      0      0      0      1
19     0.0      2.5  0.478218 1      1      1      1      1      1      0      0      0
20     1.25     2.5  0.478218 0      0      0      0      0      0      0      0      0
27     10.0     2.5  0.478218 0      0      0      0      0      0      0      0      1
28     0.0      3.75 0.5959826 1      1      1      1      1      1      0      0      0
29     1.25     3.75 0.5959826 0      0      0      0      0      0      0      0      0
36     10.0     3.75 0.5959826 0      0      0      0      0      0      0      0      1
37     0.0      5.0  0.6350833 1      1      1      1      1      1      0      0      0
38     1.25     5.0  0.6350833 0      0      0      0      0      0      0      0      0
45     10.0     5.0  0.6350833 0      0      0      0      0      0      0      0      1
46     0.0      6.25 0.5959826 1      1      1      1      1      1      0      0      0
47     1.25     6.25 0.5959826 0      0      0      0      0      0      0      0      0
54     10.0     6.25 0.5959826 0      0      0      0      0      0      0      0      1
55     0.0      7.5  0.478218 1      1      1      1      1      1      0      0      0
56     1.25     7.5  0.478218 0      0      0      0      0      0      0      0      0
63     10.0     7.5  0.478218 0      0      0      0      0      0      0      0      1
64     0.0      8.75 0.2803754 1      1      1      1      1      1      0      0      0
65     1.25     8.75 0.2803754 0      0      0      0      0      0      0      0      0
72     10.0     8.75 0.2803754 0      0      0      0      0      0      0      0      1
73     0.0      10.0 0.0      1      1      1      1      1      1      0      0      0
74     1.25     10.0 0.0      0      0      0      0      0      0      0      0      0
81     10.0     10.0 0.0      0      0      0      0      0      0      0      0      1

$ ELEMENT CONNECTIVITY
2      1      1      2      11     10     0      0      0      0      1      1
2      8      8      9      18     17     0      0      0      0      1      1      0      0      0      1
2      9      10     11     20     19     0      0      0      0      1      1
2      16     17     18     27     26     0      0      0      0      1      1      0      0      0      1
2      17     19     20     29     28     0      0      0      0      1      1
2      24     26     27     36     35     0      0      0      0      1      1      0      0      0      1
2      25     28     29     38     37     0      0      0      0      1      1
2      32     35     36     45     44     0      0      0      0      1      1      0      0      0      1
2      33     37     38     47     46     0      0      0      0      1      1
2      40     44     45     54     53     0      0      0      0      1      1      0      0      0      1
2      41     46     47     56     55     0      0      0      0      1      1
2      48     53     54     63     62     0      0      0      0      1      1      0      0      0      1
2      49     55     56     65     64     0      0      0      0      1      1
2      56     62     63     72     71     0      0      0      0      1      1      0      0      0      1
2      57     64     65     74     73     0      0      0      0      1      1
2      64     71     72     81     80     0      0      0      0      1      1      0      0      0      1

$ SHELL ELEMENT THICKNESSES
1      0.1
$ ELEMENT MATERIAL PROPERTIES
1      1
0.2950E+080 .3000E+000 .0000E+000 .7332E-03

```

STARS-SOLIDS output summary: table 7 shows the output summary.

Table 7. Natural frequencies of a cylindrical cantilever shell.

Mode	Natural frequency (ω), rad/sec	Nondimensional parameter (γ), $\gamma = \omega a^2 \sqrt{\rho t / D}$
1	686.0899	11.30
2	1108.6006	18.26
3	1918.0497	31.60
4	2703.7123	44.54
5	2962.7424	48.81
6	3904.1954	64.32

Alternative curve shell modeling:

Note: X, Y, and Z are the GCS. x_1, y_1, z_1 and x_2, y_2, z_2 are local-global coordinate systems for data input in a spherical coordinate system. x'_1, y'_1, z'_1 and x'_2, y'_2, z'_2 are local-global coordinate systems for data input in a cylindrical coordinate system.

STARS-SOLIDS alternative input data:

```

SHELL ELEMENT      8 BY 8      CURVED SHELL      FREE-VIBRATION ANALYSIS
81, 64, 1, 4, 0, 1, 6, 0, 0, 0
0, 0, 0, 1, 0, 0, 0, 0, 0
1, 1, 0, 1, 0, 0, 0, 0
2, 0, 2, 0, 1, 1, 0, 1, 0
1, 12, 0, 90000.0, 0.0, 0.0
$ NODE DESCRIPTION
1      20.00000      .25268025      1.57079633 1 1 1 1 120000
73     20.00000      -0.25268025      1.57079633 1 1 1 1 120000      0 9
2      20.00000      .25268025      1.57079633 0 0 0 0 020001
74     20.00000      -0.25268025      1.57079633 0 0 0 0 020001      0 9
3      20.00000      .25268025      1.57079633 0 0 0 0 020002
75     20.00000      -0.25268025      1.57079633 0 0 0 0 020002      0 9
4      20.00000      .25268025      0.0      0 0 0 0 010001
13     20.00000      .18951019      0.0      0 0 0 0 010001
22     20.00000      .12634013      0.0      0 0 0 0 010001
31     20.00000      .06317006      0.0      0 0 0 0 010001
40     20.00000      .00000      0.0      0 0 0 0 010001
49     20.00000      -0.06317006      0.0      0 0 0 0 010001
58     20.00000      -0.12634013      0.0      0 0 0 0 010001
67     20.00000      -0.18951019      0.0      0 0 0 0 010001
76     20.00000      -0.25268025      0.0      0 0 0 0 010001
6      20.00000      .25268025      6.25000 0 0 0 0 010000
9      20.00000      .25268025      10.00000 0 0 0 0 010000      0 1
15     20.00000      .18951019      6.25000 0 0 0 0 010000
18     20.00000      .18951019      10.00000 0 0 0 0 010000      0 1
24     20.00000      .12634013      6.25000 0 0 0 0 010000
27     20.00000      .12634013      10.00000 0 0 0 0 010000      0 1
33     20.00000      .06317006      6.25000 0 0 0 0 010000
36     20.00000      .06317006      10.00000 0 0 0 0 010000      0 1
42     20.00000      .00000      6.25000 0 0 0 0 010000
45     20.00000      .00000      10.00000 0 0 0 0 010000      0 1
51     20.00000      -0.06317006      6.25000 0 0 0 0 010000
54     20.00000      -0.06317006      10.00000 0 0 0 0 010000      0 1
60     20.00000      -0.12634013      6.25000 0 0 0 0 010000
63     20.00000      -0.12634013      10.00000 0 0 0 0 010000      0 1
69     20.00000      -0.18951019      6.25000 0 0 0 0 010000
72     20.00000      -0.18951019      10.00000 0 0 0 0 010000      0 1
78     20.00000      -0.25268025      6.25000 0 0 0 0 010000
81     20.00000      -0.25268025      10.00000 0 0 0 0 010000      0 1
5      19.36491170      5.0      5.0      0 0 0 0 0 0
14     20.00000      .18951019      0.00000 0 0 0 0 010002
32     20.00000      .06317006      0.00000 0 0 0 0 010002      0 9
41     20.0      0.0      5.0      0 0 0 0 0 0
50     20.00000      -0.06317006      0.00000 0 0 0 0 010002
59     20.00000      -0.12634013      0.00000 0 0 0 0 010002
68     20.00000      -0.18951019      0.00000 0 0 0 0 010002
77     19.36491170      -5.0      5.0      0 0 0 0 0 0

```

```

$ LOCAL-GLOBAL COORDINATE SYSTEM DATA
20000 1 2
0.0 0.0 0.00 1.0 0.0 0.00
0.0 1.0 0.00
20001 1 2
0.0 0.0 1.25 1.0 0.0 1.25
0.0 1.0 1.25
20002 1 2
0.0 0.0 2.50 1.0 0.0 2.50
0.0 1.0 2.50
10000 1 1
0.0 0.0 0.00 1.0 0.0 0.00
0.0 1.0 0.00
10001 1 1
0.0 0.0 3.75 1.0 0.0 3.75
0.0 1.0 3.75
10002 1 1
0.0 0.0 5.00 1.0 0.0 5.00
0.0 1.0 5.00

$ ELEMENT CONNECTIVITY
2 1 1 2 11 10 0 0 0 0 1 1
2 8 8 9 18 17 0 0 0 0 1 1 0 0 0 1
2 9 10 11 20 19 0 0 0 0 1 1
2 16 17 18 27 26 0 0 0 0 1 1 0 0 0 1
2 17 19 20 29 28 0 0 0 0 1 1
2 24 26 27 36 35 0 0 0 0 1 1 0 0 0 1
2 25 28 29 38 37 0 0 0 0 1 1
2 32 35 36 45 44 0 0 0 0 1 1 0 0 0 1
2 33 37 38 47 46 0 0 0 0 1 1
2 40 44 45 54 53 0 0 0 0 1 1 0 0 0 1
2 41 46 47 56 55 0 0 0 0 1 1
2 48 53 54 63 62 0 0 0 0 1 1 0 0 0 1
2 49 55 56 65 64 0 0 0 0 1 1
2 56 62 63 72 71 0 0 0 0 1 1 0 0 0 1
2 57 64 65 74 73 0 0 0 0 1 1
2 64 71 72 81 80 0 0 0 0 1 1 0 0 0 1

$ SHELL ELEMENT THICKNESSES
1 0.1
$ ELEMENT MATERIAL PROPERTIES
1 1
0.2950E+080.3000E+000.0000E+000.7332E-03

```

4.1.6 General Solid: Vibration Analysis

Figure 13 shows a cube idealized by hexahedral solid elements. The nodes lying in the X-Y plane are assumed to be fixed. Details of the natural frequency analysis of the cube are presented herein.

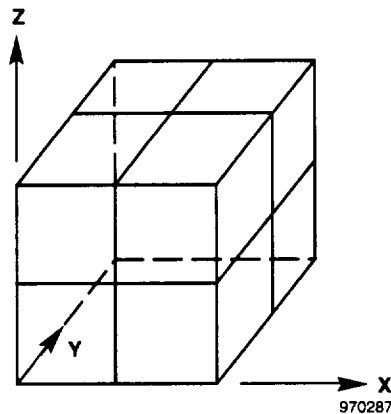


Figure 13. Cube discretized by hexahedral elements.

Important data parameters:

Side length, L	$= 10$
Young's modulus, E	$= 10 \times 10^6$
Poisson's ratio, μ	$= 0.3$
Mass density, ρ	$= 2.349 \times 10^{-4}$

STARS-SOLIDS input data:

```

HEXAHEDRON CASE - 2 BY 2
27,8,1,4,0,0,0,0,0,0
0,0,0,1,0,0,0,0,0
1,1,0,1,0,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,6,0,150000.0,0.0,0.0
$ MODAL DATA
1 00.0 00.0 00.0 1 1 1 1 1 1
2 5.0 00.0 00.0 1 1 1 1 1 1
3 10.0 00.0 00.0 1 1 1 1 1 1
4 10.0 5.0 00.0 1 1 1 1 1 1
5 10.0 10.0 00.0 1 1 1 1 1 1
6 5.0 10.0 00.0 1 1 1 1 1 1
7 00.0 10.0 00.0 1 1 1 1 1 1
8 00.0 5.0 00.0 1 1 1 1 1 1
9 5.0 5.0 00.0 1 1 1 1 1 1
10 00.0 00.0 5.0 1 1 1 1 1 1
11 5.0 00.0 5.0 1 1 1 1 1 1
12 10.0 00.0 5.0 1 1 1 1 1 1
13 10.0 5.0 5.0 1 1 1 1 1 1
14 10.0 10.0 5.0 1 1 1 1 1 1
15 5.0 10.0 5.0 1 1 1 1 1 1
16 00.0 10.0 5.0 1 1 1 1 1 1
17 00.0 5.0 5.0 1 1 1 1 1 1
18 5.0 5.0 5.0 1 1 1 1 1 1
19 00.0 00.0 10.0 1 1 1 1 1 1
20 5.0 00.0 10.0 1 1 1 1 1 1
21 10.0 00.0 10.0 1 1 1 1 1 1
22 10.0 5.0 10.0 1 1 1 1 1 1
23 10.0 10.0 10.0 1 1 1 1 1 1
24 5.0 10.0 10.0 1 1 1 1 1 1
25 00.0 10.0 10.0 1 1 1 1 1 1
26 00.0 5.0 10.0 1 1 1 1 1 1
27 5.0 5.0 10.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
4 1 1 2 9 8 10 11 18 17 1
4 2 2 3 4 9 11 12 13 18 1
4 3 9 4 5 6 18 13 14 15 1
4 4 8 9 6 7 17 18 15 16 1
4 5 10 11 18 17 19 20 27 26 1
4 6 11 12 13 18 20 21 22 27 1
4 7 18 13 14 15 27 22 23 24 1
4 8 17 18 15 16 26 27 24 25 1
$ ELEMENT MATERIAL PROPERTIES
1 1
1.0E+7 0.3 0.0 2.349E-4

```

STARS-SOLIDS output summary: table 8 shows the output summary.

Table 8. Natural frequencies of a solid cube.

Natural frequency parameter ($\hat{\omega}$), $\hat{\omega} = \omega / \sqrt{(E/\rho)}$, rad/sec				
Mode	Mesh size			Exact solution $\hat{\omega}$
	2 by 2	4 by 4	6 by 6	
1	0.07975	0.07195	0.06958	0.06801
2	0.07975	0.07195	0.06958	0.06801
3	0.13149	0.10428	0.09762	0.09288
4	0.17200	0.16453	0.16234	0.16110
5	0.22798	0.19330	0.18504	0.18190
6	0.22798	0.19330	0.18504	0.18190

4.1.7 Cantilever Beam (Spinning and Nonspinning Cases): Vibration Analysis

Figure 14 shows a cantilever beam spinning about the Y axis.

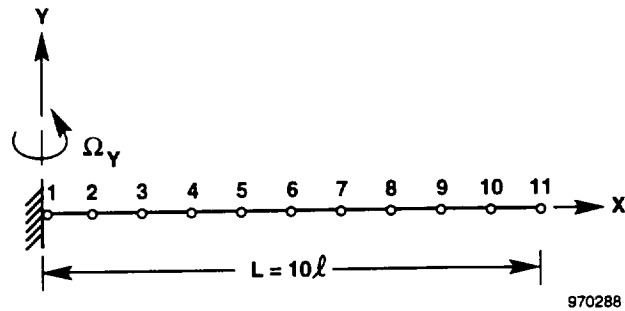


Figure 14. Spinning cantilever beam.

Important data parameters: The structure is assumed to possess both viscous and structural damping.

Young's modulus, E	$= 30 \times 10^6$
Cross-sectional area, A	$= 1.0$
Moment of inertia:	
About y axis	$= 1/12$
About z axis	$= 1/24$
Element length, ℓ	$= 6$
Nodal translational mass	$= 1$
Nodal mass moment of inertia	$= 1/35$
Scalar viscous damping	$= 0.628318$
Structural damping coefficient	$= 0.01$
Spin rate, Hz	$= 0.1$

STARS-SOLIDS input data:

```
SPINNING CANTILEVER BEAM - 10-ELEMENT IDEALIZATION - VISC AND STRUCT DAMPING
12,10,1,4,1,0,0,0,0,0
0,0,1,1,0,0,0,0,0,0
5,0,0,0,0,1,0,0,0
2,0,2,0,1,0,0,1,0,0
1,6,0,500,0,0,0,0,0,0
0.01
$ NODAL DATA
1      0.0      0.0      0.0      1      1      1      1      1      1
2      6.0      0.0      0.0      0      0      0      0      0      0
3      12.0     0.0      0.0      0      0      0      0      0      0
4      18.0     0.0      0.0      0      0      0      0      0      0
5      24.0     0.0      0.0      0      0      0      0      0      0
6      30.0     0.0      0.0      0      0      0      0      0      0
7      36.0     0.0      0.0      0      0      0      0      0      0
8      42.0     0.0      0.0      0      0      0      0      0      0
9      48.0     0.0      0.0      0      0      0      0      0      0
10     54.0     0.0      0.0      0      0      0      0      0      0
11     60.0     0.0      0.0      0      0      0      0      0      0
12     25.0     15.0     0.0      1      1      1      1      1      1
$ ELEMENT CONNECTIVITY
1      1      1      2      12      0      0      0      0      0      1      1      0      0      1      0
1      10     10     11     12      0      0      0      0      0      1      1      0      0      1      1
$ LINE ELEMENT BASIC PROPERTIES
1      1.0      0.125000.083333330.04166667
```

```

$ ELEMENT MATERIAL PROPERTIES
1 1
30.0E+06 0.30
$ ELEMENT SPIN RATE DATA
1 0.0 0.628318 0.0
$ NODAL MASS DATA
2 1 1.0 3
3 1 1.0 3
4 1 1.0 3
5 1 1.0 3
6 1 1.0 3
7 1 1.0 3
8 1 1.0 3
9 1 1.0 3
10 1 1.0 3
11 1 1.0 3
2 4 0.0285714 6
3 4 0.0285714 6
4 4 0.0285714 6
5 4 0.0285714 6
6 4 0.0285714 6
7 4 0.0285714 6
8 4 0.0285714 6
9 4 0.0285714 6
10 4 0.0285714 6
11 4 0.0285714 6
-1
$ VISCOUS DAMPING DATA
0.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.628318000.628318000.628318000.628318000.628318000.628318000.628318000
0.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000

```

STARS-SOLIDS output summary: table 9 shows the output summary.

Table 9. Natural frequencies of a spinning cantilever beam.

Mode	Structure without damping, IPROB = 2	Structure with viscous damping, IPROB = 4	Structure with viscous and structural damping, IPROB = 5
1	2.526	$-0.3107 \pm 2.4885i^*$	$-0.3195 \pm 2.4820i^*$
2	3.449	$-0.3116 \pm 3.4207i^*$	$-0.3255 \pm 3.4132i^*$
3	15.397	$-0.3166 \pm 15.3900i^*$	$-0.3930 \pm 15.3831i^*$
4	21.706	$-0.3166 \pm 21.7015i^*$	$-0.4243 \pm 21.6914i^*$
5	43.161	$-0.3202 \pm 43.1551i^*$	$-0.4849 \pm 43.0627i^*$
6	60.951	$-0.3202 \pm 60.9495i^*$	$-0.6246 \pm 60.9391i^*$

Notes: Natural frequencies for various problem types are caused by a spin rate of $\Omega = 0.1$ Hz (0.6283 rad/sec).

$$i^* = \sqrt{-1}.$$

Additionally, table 10 shows a parametric study of vibration analysis of the nonspinning beam using both the IPROB = 1 and IPROB = 3 (dynamic element) cases using consistent mass formulation (density, $\rho = 0.1666$).

Table 10. Natural frequencies of a nonspinning cantilever beam.

Number of elements	IPROB	Natural frequencies (ω), rad/sec					
		ω_1	ω_2	ω_3	ω_4	ω_5	ω_6
2	1	2.676	3.784	16.901	23.897	57.144	80.770
	3	2.675	3.782	16.766	23.707	49.864	70.494
4	1	2.675	3.783	16.779	23.724	47.277	66.829
	3	2.675	3.782	16.759	23.697	46.924	66.332
6	1	2.675	3.782	16.763	23.702	46.999	66.438
	3	2.675	3.782	16.759	23.696	46.914	66.317
8	1	2.675	3.782	16.760	23.698	46.942	66.357
	3	2.675	3.782	16.759	23.696	46.914	66.317
10	1	2.675	3.782	16.760	23.697	46.926	66.333
	3	2.675	3.782	16.759	23.696	46.914	66.317

4.1.8 Spinning Cantilever Plate: Vibration Analysis

The cantilever plate model described in section 4.1.4 is used for this sample problem. The plate is spun along the Z axis with a uniform spin rate of $\Omega_Z = 0.8 \times \omega_n^1$, ω_n^1 being the first natural frequency of vibration of the nonrotating plate. Table 11 shows the first few natural frequencies of the plate in nondimensional form, ω being the natural frequencies. Also shown in the table are the results of the free-vibration analysis of the plate rotating along an arbitrary axis, the spin rate being $\Omega_R \approx 0.8 \times \omega_n^1$, with components $\Omega_X = \Omega_Y = \Omega_Z \approx 0.8 \times \omega_n^1 / \sqrt{3}$.

STARS-SOLIDS input data:

```

SQUARE 4 BY 4 PLATE    SPINNING STRUCTURE
25,16,1,4,0,1,0,0,0,0
0,0,1,1,0,0,0,0,0,0
2,0,0,1,0,0,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,6,0,6000.0,0,0,0,0,0
$ MODAL DATA
1      -5.0      0.0      0.0      1      1      1      1      1      1      0      0      0
5       5.0      0.0      0.0      1      1      1      1      1      1      0      0      1
6      -5.0      2.5      0.0      0      0      0      0      0      0      0      0      0
10     5.0      2.5      0.0      0      0      0      0      0      0      0      0      1
11     -5.0      5.0      0.0      0      0      0      0      0      0      0      0      0
15     5.0      5.0      0.0      0      0      0      0      0      0      0      0      1
16     -5.0      7.5      0.0      0      0      0      0      0      0      0      0      0
20     5.0      7.5      0.0      0      0      0      0      0      0      0      0      1
21     -5.0     10.0      0.0      0      0      0      0      0      0      0      0      0
25     5.0     10.0      0.0      0      0      0      0      0      0      0      0      1

```

```

$ ELEMENT CONNECTIVITY
2 1 1 2 7 6 0 0 0 0 1 1 0 0 1
2 4 4 5 10 9 0 0 0 0 1 1 0 0 1
2 5 6 7 12 11 0 0 0 0 1 1 0 0 1
2 8 9 10 15 14 0 0 0 0 1 1 0 0 1
2 9 11 12 17 16 0 0 0 0 1 1 0 0 1
2 12 14 15 20 19 0 0 0 0 1 1 0 0 1
2 13 16 17 22 21 0 0 0 0 1 1 0 0 1
2 16 19 20 25 24 0 0 0 0 1 1 0 0 1
$ SHELL ELEMENT THICKNESSES
1 0.1
$ ELEMENT MATERIAL PROPERTIES
1 1
1.0E+07 0.30 0.0 0.259E-3
$ ELEMENT SPIN RATE DATA
1 0. 0. 100.0

```

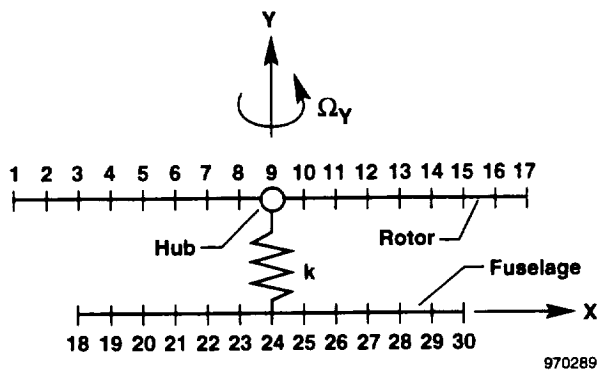
STARS-SOLIDS output summary: table 11 shows the output.

Table 11. Natural frequency parameters of a spinning square cantilever plate.

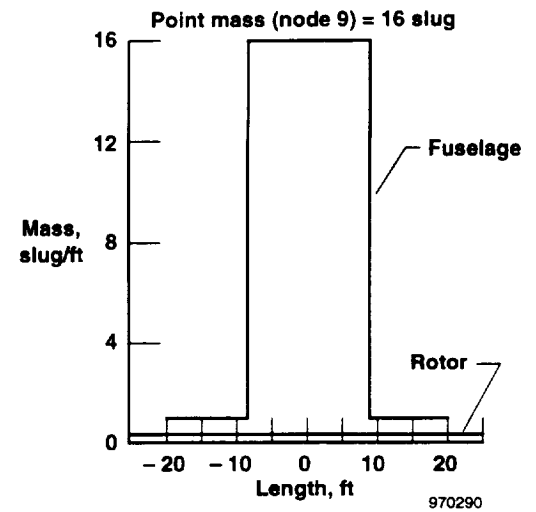
Natural frequency parameter (γ), $\gamma = \omega L^2 \sqrt{\rho t / D}$				
Mode	$\Omega_Z = 0.8\omega_n^1$ = 100.00 rad/sec		$\Omega_R = 100.00$ rad/sec, $\Omega_X = \Omega_Y = \Omega_Z = 57.735$ rad/sec	
	ω	γ	ω	γ
1	242.32	4.0752	155.48	2.6148
2	526.82	8.8598	489.05	8.2246
3	1271.00	21.3750	1250.40	21.0286
4	1551.90	26.0991	1536.40	25.8384
5	1784.50	30.0108	1768.60	29.7434
6	2902.60	48.8144	2891.60	48.6295

4.1.9 Helicopter Structure: Vibration Analysis

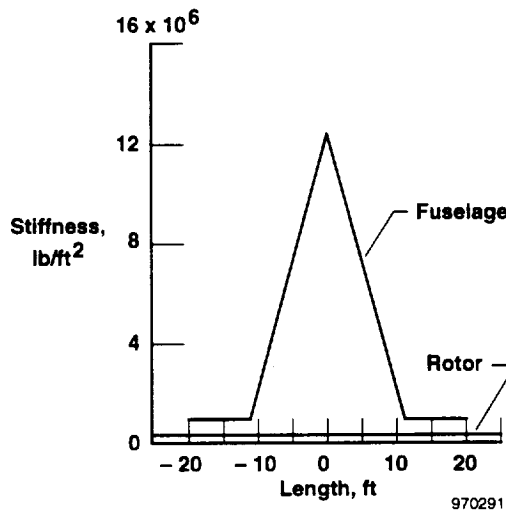
Figure 15 shows a coupled helicopter rotor/fuselage system¹⁴ and the relevant stiffness and mass distributions, which are suitably approximated for the discrete element modeling of the structure. Numerical free-vibration analysis was performed for the structure with the rotor spinning at 10 rad/sec ($\Omega_Y = 10$). Table 12 shows the results, along with the results for the corresponding nonspinning case.



(a) Discrete element model.



(b) Structural mass distribution.



(c) Structural stiffness distribution.

Figure 15. Coupled helicopter rotor/fuselage system.

STARS-SOLIDS input data:

```

HELICOPTER STRUCTURE, JOURNAL CASE, SPIN = 10.0 (FIXED U2, UXA, UVA)
31,29,7,4,2,0,0,0,0,0
0,0,1,0,0,0,0,0,0
2,0,0,1,0,1,0,0
2,0,2,0,1,0,0,1,0,0
1,12,0,53.15,0,0,0,0
$ NODAL DATA
  1 -25.00000    1.0    0.0    0    0    1    1    1    0    0
  8 -3.12500    1.0    0.0    0    0    1    1    1    0    0    0    1
  9  0.00000    1.0    0.0    0    0    1    1    1    0    0
 10  3.12500    1.0    0.0    0    0    1    1    1    0    0
 17 25.00000    1.0    0.0    0    0    1    1    1    0    0    0    1
 18 -20.00000    0.0    0.0    0    0    1    1    1    0    0
 23 -3.33333    0.0    0.0    0    0    1    1    1    0    0    0    1
 24  0.00000    0.0    0.0    0    0    1    1    1    0    0
 25  3.33333    0.0    0.0    0    0    1    1    1    0    0
 30 20.00000    0.0    0.0    0    0    1    1    1    0    0    0    1
 31 10.00000    0.5    0.0    1    1    1    1    1    1    0

```

```

$ ELEMENT CONNECTIVITY
1 1 1 2 24
1 16 16 17 24
1 17 18 19 9
1 18 19 20 9
1 19 20 21 9
1 20 21 22 9
1 21 22 23 9
1 22 23 24 9
1 23 24 25 9
1 24 25 26 9
1 25 26 27 9
1 26 27 28 9
1 27 28 29 9
1 28 29 30 9
1 29 9 24 31

$ LINE ELEMENT BASIC PROPERTIES
1 1. 1. 1. 1.
2 100. 1. 1. 1.

$ ELEMENT MATERIAL PROPERTIES
1 1
2.0E05 0.3 0. 0.3
2 1
1.53E06 0.3 0. 1.23
3 1
2.E06 0.3 0. 1.23
4 1
4.8E06 0.3 0. 8.6
5 1
7.8E06 0.3 0. 16.
6 1
11.E06 0.3 0. 16.
7 1
1.E08 0.3 0. 0.

$ ELEMENT SPIN RATE DATA
1 0.0 10.0 0.0

$ NODAL MASS DATA
9 1 16. 3
-1

```

STARS-SOLIDS output summary: table 12 shows the output summary.

Table 12. Natural frequencies of a helicopter structure.

Mode number	Natural frequencies (ω), rad/sec		Mode shape
	$\Omega_Y = 0$	$\Omega_Y = 10$	
1, 2, 3	0	0	Rigid body
4	4.640	11.791	Rotor first symmetric bending
5	5.041	11.791	Rotor first antisymmetric bending
6	22.134	22.219	Fuselage first bending
7	27.892	36.199	Rotor second antisymmetric bending
8	28.278	37.800	Rotor second symmetric bending
9	37.176	38.478	Rotor third antisymmetric bending

4.1.10 Rocket Structure: Dynamic-Response Analysis

A rocket idealized by four line elements, as shown in figure 16,⁵ is subjected to a pulse loading function at the base. Figures 17 and 18 show results of the dynamic-response analysis.

\$ INCREMENTAL TIME DATA FOR DYNAMIC RESPONSE ANALYSIS
0.10 10
0.20 5

STARS-SOLIDS analysis results at a typical time step:

DYNAMIC RESPONSE AT TIME = 0.7000E+00

NODE		EXT	INT	X-DISPL.	Y-DISPL.	Z-DISPL.	X-ROTN.	Y-ROTN.	Z-ROTN.
1	1			0.646322E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	2			0.490999E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3	3			0.191562E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4	4			-0.102987E-02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5	5			-0.495080E-01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
6	6			0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00

ELEMENT STRESSES

ELEMENT NO.	END1	END2	END3	END4	PX1/PX2		PY1/PY2		PZ1/PZ2		MX1/MX2		MY1/MY2		MZ1/MZ2	
					SXT	SXX	SVT	SVY	SVZ	SXY	SXB	SXV	SYB	SYZ	SYB	SZB
1	1	2			0.621289E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
					-0.621289E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	2	3			0.119775E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
					-0.119775E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3	3	4			0.770366E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
					-0.770366E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4	4	5			0.193913E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
					-0.193913E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00

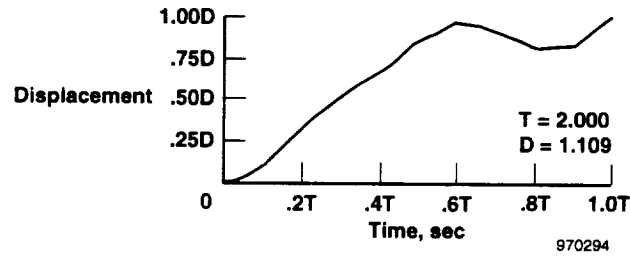


Figure 17. Rocket nodal displacement as a function of time, node 1.

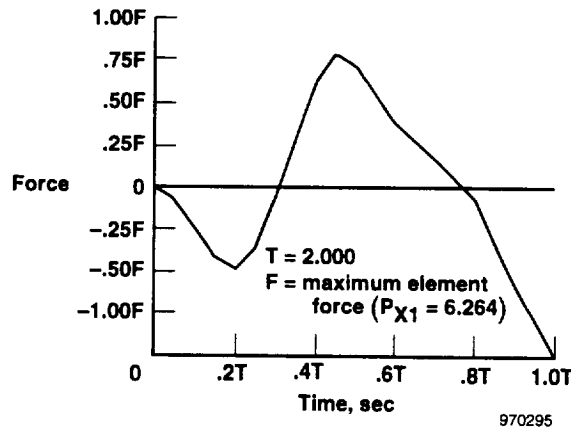


Figure 18. Rocket element force as a function of time, element 4.

4.1.11 Plate, Beam, and Truss Structures: Buckling Analysis

4.1.11.1 Simply-Supported Square Plate

A buckling analysis was performed for a simply-supported square plate model, described in section 4.1.4, that was subjected to a uniform unit stress acting along the two edges parallel to the Y axis. Relevant input data and analysis results are as follows:

STARS-SOLIDS input data:

```
SQUARE 4 BY 4 PLATE,BC U=0, midline x=0,Y(13)=5.0, BUCKLING ANALYSIS
25,16,1,4,0,1,0,0,0,0
0,0,0,1,0,0,0,0,0
9,1,0,1,1,0,0,0
2,0,2,0,1,0,0,1,0,0
1,1,0,20000,0,0,0,0,0
$ MODAL DATA
1 -5.00 0.0 0.0 0 0 1 0 0 1 0 0 0
2 -2.50 0.0 0.0 0 0 1 0 0 1 0 0 0
3 0.0 0.0 0.0 1 0 1 0 1 1 0 0 0
4 2.50 0.0 0.0 0 0 1 0 0 1 0 0 0
5 5.00 0.0 0.0 0 0 1 0 0 1 0 0 0
6 -5.00 2.50 0.0 0 0 1 0 0 1 0 0 0
7 -2.50 2.50 0.0 0 0 0 0 0 1 0 0 0
8 0.0 2.5 0.0 1 0 0 0 1 1 0 0 0
9 2.50 2.50 0.0 0 0 0 0 0 1 0 0 0
10 5.00 2.50 0.0 0 0 1 0 0 1 0 0 0
11 -5.00 5.00 0.0 0 1 1 1 0 1 0 0 0
12 -2.50 5.00 0.0 0 1 0 1 0 1 0 0 0
13 0.0 5.00 0.0 1 1 0 1 1 1 0 0 0
14 2.50 5.00 0.0 0 1 0 1 0 1 0 0 0
15 5.00 5.00 0.0 0 1 1 1 0 1 0 0 0
16 -5.00 7.50 0.0 0 0 1 0 0 1 0 0 0
17 -2.50 7.50 0.0 0 0 0 0 0 1 0 0 0
18 0.0 7.5 0.0 1 0 0 0 1 1 0 0 0
19 2.50 7.50 0.0 0 0 0 0 0 1 0 0 0
20 5.00 7.50 0.0 0 0 1 0 0 1 0 0 0
21 -5.00 10.00 0.0 0 0 1 0 0 1 0 0 0
22 -2.50 10.00 0.0 0 0 1 0 0 1 0 0 0
23 0.0 10.0 0.0 1 0 1 0 1 1 0 0 0
24 2.50 10.00 0.0 0 0 1 0 0 1 0 0 0
25 5.00 10.00 0.0 0 0 1 0 0 1 0 0 0
$ ELEMENT CONNECTIVITY
2 1 1 2 7 6 0 0 0 0 1 1 0 0 0
2 4 4 5 10 9 0 0 0 0 1 1 0 0 0
2 5 6 7 12 11 0 0 0 0 1 1 0 0 0
2 8 9 10 15 14 0 0 0 0 1 1 0 0 0
2 9 11 12 17 16 0 0 0 0 1 1 0 0 0
2 12 14 15 20 19 0 0 0 0 1 1 0 0 0
2 13 16 17 22 21 0 0 0 0 1 1 0 0 0
2 16 19 20 25 24 0 0 0 0 1 1 0 0 0
$ SHELL ELEMENT THICKNESSES
1 0.1
$ ELEMENT MATERIAL PROPERTIES
1 1
1.0E+07 0.30
$ MODAL LOAD DATA
1 1 .125
6 1 .250
11 1 .250
16 1 .250
21 1 .125
5 1 -.125
10 1 -.250
15 1 -.250
20 1 -.250
25 1 -.125
-1
```

STARS–SOLIDS analytical results: table 13 shows the analytical results pertaining to the buckling load.

Table 13. Critical load of a simply-supported square plate.

Buckling load parameter for Mode 1			
STARS solution			Exact solution
4 by 4	8 by 8	14 by 14	
3530.695	3552.620	3570.561	3615.240

4.1.11.2 Cantilever Beam

The cantilever beam described in section 4.1.7 is the subject of a buckling analysis; the relevant details are given below.

STARS–SOLIDS input data:

```

CANTILEVER BEAM - 10-ELEMENT IDEALIZATION - BUCKLING ANALYSIS
C
C TEMPERATURE LOADING ADDED
C
12,10,1,4,1,0,0,0,0,0
1,0,0,1,0,0,0,0,0,0
9,1,0,1,1,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,1,0,12000.0,0,0,0,0,0
$ MODAL DATA
1      0.0      0.0      0.0      1      1      1      1      1      1
2      6.0      0.0      0.0      0      0      1      1      1      0
3     12.0      0.0      0.0      0      0      1      1      1      0
4     18.0      0.0      0.0      0      0      1      1      1      0
5     24.0      0.0      0.0      0      0      1      1      1      0
6     30.0      0.0      0.0      0      0      1      1      1      0
7     36.0      0.0      0.0      0      0      1      1      1      0
8     42.0      0.0      0.0      0      0      1      1      1      0
9     48.0      0.0      0.0      0      0      1      1      1      0
10    54.0      0.0      0.0      0      0      1      1      1      0
11    60.0      0.0      0.0      0      0      1      1      1      0
12    25.0     15.0      0.0      1      1      1      1      1      1
$ ELEMENT CONNECTIVITY
1      1      1      2      12      0      0      0      0      0      1      1      1      0      0      0
1     10     10     11     12      0      0      0      0      0      1      1      1      0      0      1
$ LINE ELEMENT BASIC PROPERTIES
1      1.0      0.125 0.083333 0.041667
$ ELEMENT MATERIAL PROPERTIES
1      1
30.0E+06      0.30 6.6E-06
$ ELEMENT TEMPERATURE DATA
1      -1.0
$ MODAL LOAD DATA
11      1      -1.0
-1

```

STARS–SOLIDS analytical results: table 14 shows the analytical results.

Table 14. Critical load of a cantilever beam.

Mode	Buckling load parameter	
	STARS solution	Exact solution
1	7011.14	7010.42

4.1.11.3 Truss Problem

The simple truss of figure 19⁵ has also been analyzed to determine the critical loads. The associated input data and analytical results are given below.

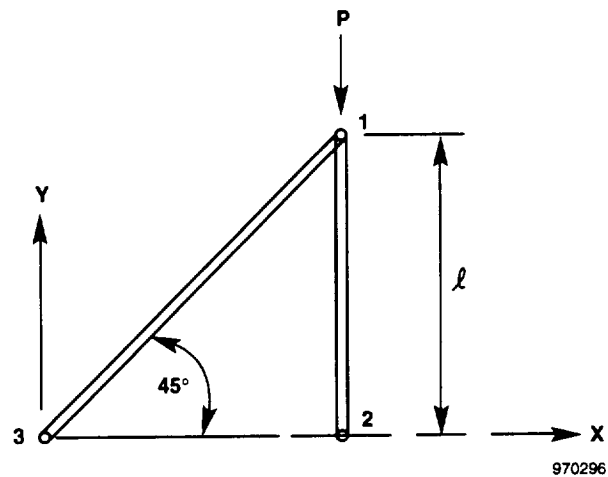


Figure 19. Truss structure.

STARS–SOLIDS input data:

```
PR2 - TRUSS BUCKLING ANALYSIS
4,2,1,4,1,0,0,0,0,0
0,0,0,1,0,0,0,0,0
9,0,0,1,1,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,2,0,20000.0,0,0,0,0,0
$ NODAL DATA
1 100.0 100.0 0.0 0 0 1 1 1 1
2 100.0 0.0 0.0 1 1 1 1 1 1
3 0.0 0.0 0.0 1 1 1 1 1 1
4 0.0 50.0 0.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
1 1 3 1 4 1 1 0 0 0 1 1
1 2 2 1 4 1 1 0 0 0 1 1
$ LINE ELEMENT BASIC PROPERTIES
1 0.1
$ ELEMENT MATERIAL PROPERTIES
1 1
10.0E03 0.2
$ NODAL LOAD DATA
1 2 -1.0
-1
```

STARS–SOLIDS analytical results: table 15 shows the analytical results.

Table 15. Critical load of a simple truss.

Mode	Buckling load parameter	
	STARS solution	Exact solution
1	261.20387	261.20387

4.1.12 Composite Plate Bending: Vibration Analysis

To illustrate the use of multiple material angles (as in layered elements) and the diverse coordinate system capabilities, a square composite plate (fig. 20) similar to that in section 4.1.4 is considered for vibration analysis. The plate, fixed along two opposite edges, is analyzed for uniform temperature loading.

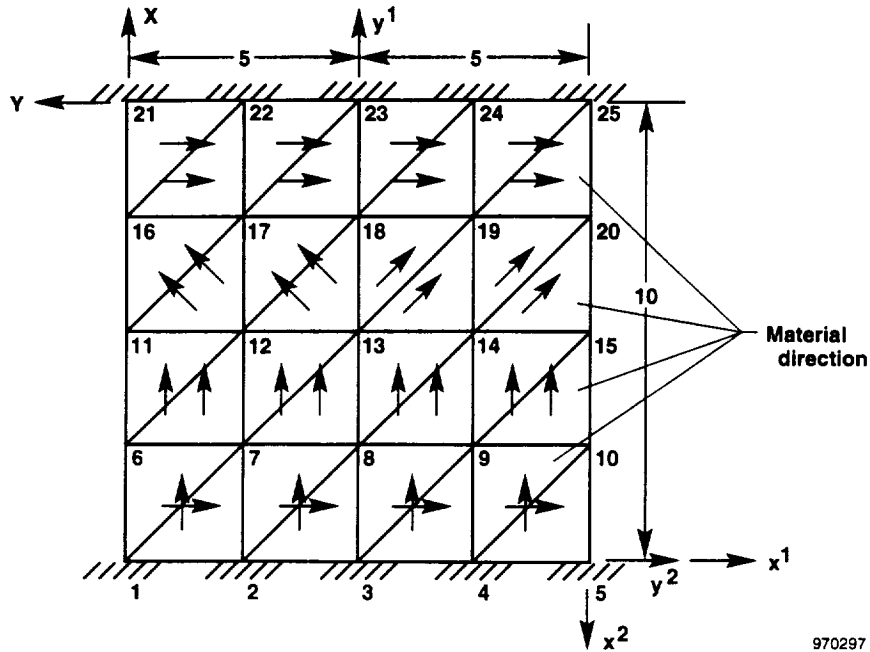


Figure 20. Square composite plate.

Important data parameters:

Side length, L = 10
 Plate thickness, t = 0.063
 Mass density, ρ = 0.259×10^{-3}
 Material properties: anisotropic, as shown in input data.

STARS-SOLIDS input data:

TRIANGULAR 4 BY 4 PLATE / COMPOSITE LAYERS / ILGCS TEST CASE / MMANGL TEST CASE

```

25, 32, 1, 13, 0, 0, 2, 8, 10, 2
1, 0, 0, 0, 0, 0, 0, 0, 0, 0
1, 1, 0, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 1, 0, 0
1, 10, 0, 6000.0, 0.0, 0.0
$ MODAL DATA
1      -5.0      0.0      0.0      1      1      1      1      1      1      0      0
5       5.0      0.0      0.0      1      1      1      1      1      1      0      1
6      -2.5     -10.0      0.0      0      0      0      0      0      0      2      0
10     -2.5      0.0      0.0      0      0      0      0      0      0      2      1
11     -5.0      5.0      0.0      0      0      0      0      0      0      1      0
15      5.0      5.0      0.0      0      0      0      0      0      0      1      1
16     -2.5      0.0      0.0      0      0      0      0      0      0      0      0
20     -2.5     -10.0      0.0      0      0      0      0      0      0      0      1
21     -5.0     10.0      0.0      1      1      1      1      1      1      0      0
25      5.0     10.0      0.0      1      1      1      1      1      1      0      1
    
```

\$ LOCAL-GLOBAL COORDINATE SYSTEM DATA

```

1 2
-10.0 -5.0 0.0 0.0 -1.0 0.0
1.0 0.0 0.0 0.0 0.0 1.0
2 1
-10.0 -10.0 0.0 -15.0 -10.0 0.0
-15.0 -15.0 0.0

```

\$ ELEMENT CONNECTIVITY

```

7 1 1 2 7 0 0 0 0 1 1 0 1 0 0
7 4 4 5 10 0 0 0 0 1 1 0 1 0 0 1
7 5 6 7 12 0 0 0 0 2 1 0 1 0 0
7 8 9 10 15 0 0 0 0 2 1 0 1 0 0 1
7 9 11 12 17 0 0 0 0 3 1 0 1 0 0
7 10 12 13 18 0 0 0 0 3 1 0 1 0 0
7 11 13 14 19 0 0 0 0 4 1 0 1 0 0
7 12 14 15 20 0 0 0 0 4 1 0 1 0 0
7 13 16 17 22 0 0 0 0 5 1 0 1 0 0
7 16 19 20 25 0 0 0 0 5 1 0 1 0 0 1
7 17 7 6 1 0 0 0 0 6 1 0 1 0 0
7 20 10 9 4 0 0 0 0 6 1 0 1 0 0 1
7 21 12 11 6 0 0 0 0 7 1 0 1 0 0
7 24 15 14 9 0 0 0 0 7 1 0 1 0 0 1
7 25 17 16 11 0 0 0 0 8 1 0 1 0 0
7 26 18 17 12 0 0 0 0 8 1 0 1 0 0
7 27 19 18 13 0 0 0 0 9 1 0 1 0 0
7 28 20 19 14 0 0 0 0 9 1 0 1 0 0
7 29 22 21 16 0 0 0 0 10 1 0 1 0 0
7 32 25 24 19 0 0 0 0 10 1 0 1 0 0 1

```

\$ COMPOSITE SHELL ELEMENT STACK DESCRIPTION DATA

```

1 2
1 .0315 3
1 .0315 1
2 2
1 .0315 3
1 .0315 3
3 2
1 .0315 4
1 .0315 4
4 2
1 .0315 2
1 .0315 2
5 2
1 .0315 1
1 .0315 1
6 2
1 .0315 6
1 .0315 5
7 2
1 .0315 6
1 .0315 6
8 2
1 .0315 7
1 .0315 7
9 2
1 .0315 8
1 .0315 8
10 2
1 .0315 5
1 .0315 5

```

\$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION

```

1 2 0
0.0
2 2 0
0.7854
3 2 0
1.5708
4 2 0
2.3562
5 2 0
3.1416
6 2 0
4.7120
7 2 0
5.4980
8 2 0
3.9260

```

\$ ELEMENT MATERIAL PROPERTIES

```

1 2
.7966E+07 .6638E+06 0.0 .2566E+07 0.0 0.125E+7 .1042E+7
0.0 .1042E+07 .35E-5 .114E-4 0.0 0.259E-3

```

\$ ELEMENT TEMPERATURE DATA

```

1 10.

```

STARS-SOLIDS output summary: table 16 shows the results.

Table 16. Natural frequencies of a square composite plate.

Mode	Natural frequency (ω), rad/sec	
	T = 0	T = 10
1	505.41	373.38
2	611.98	486.79
3	967.78	851.04
4	1434.66	1275.97
5	1523.71	1361.70
6	1765.22	1641.70

4.1.13 Thermally Prestressed Rectangular Plate: Vibration Analysis

To illustrate the thermal prestress vibration analysis capability, a free-free rectangular plate (fig. 21) subjected to varying temperature loading and having varying material properties has been analyzed to obtain natural frequencies and modes.

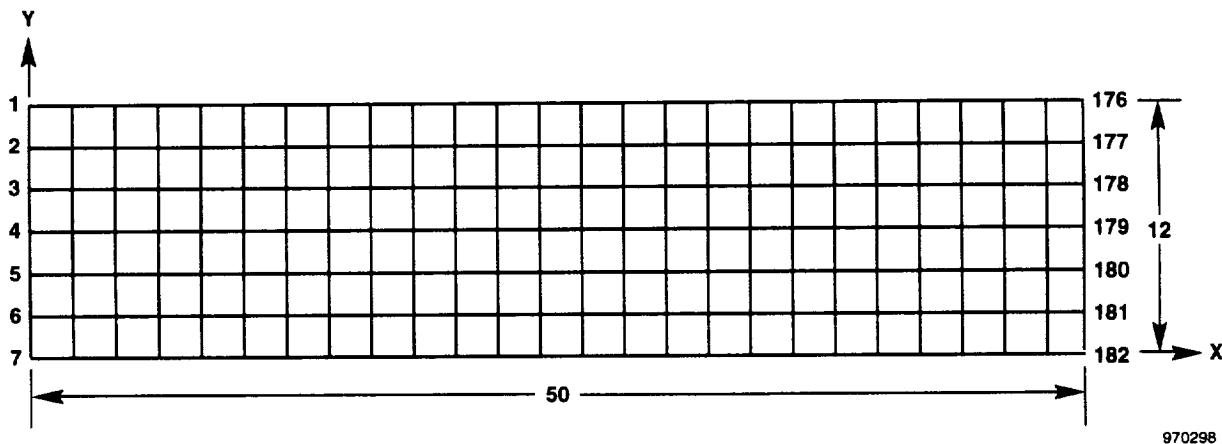


Figure 21. Rectangular plate.

Important data parameters:

Rectangular Plate = 12×50
 Plate thickness, t = 0.19
 Mass density, ρ = 2.614×10^{-4}
 Temperature = varying along the X axis

STARS-SOLIDS input data:

50" x 12" Aluminum Plate; NON-UNIFORM HEAT; Free-free

```
182, 150, 15, 4, 0, 1, 0, 0, 0, 0
15, 0, 0, 0, 0, 0, 0, 0, 0, 0
1, 0, 0, 0, 0, 0, 1, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 1, 0, 0
1, 20, 0, 2000.0, 0.0, 1.0E+05
```

\$ MODAL DATA

1	0.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
7	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
8	2.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
14	2.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
15	4.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
21	4.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
22	6.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
28	6.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
29	8.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
35	8.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
36	10.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
42	10.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
43	12.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
49	12.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
50	14.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
56	14.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
57	16.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
63	16.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
64	18.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
70	18.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
71	20.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
77	20.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
78	22.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
84	22.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
85	24.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
91	24.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
92	26.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
98	26.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
99	28.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
105	28.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
106	30.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
112	30.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
113	32.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
119	32.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
120	34.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
126	34.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
127	36.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
133	36.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
134	38.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
140	38.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
141	40.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
147	40.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
148	42.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
154	42.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
155	44.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
161	44.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
162	46.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
168	46.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
169	48.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
175	48.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
176	50.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
182	50.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1

\$ ELEMENT CONNECTIVITY CONDITIONS

2	1	1	2	9	8	0	0	0	0	1	1	1	0	0	0
2	6	6	7	14	13	0	0	0	0	1	1	1	0	0	1
2	7	8	9	16	15	0	0	0	0	1	1	1	0	0	0
2	12	13	14	21	20	0	0	0	0	1	1	1	0	0	1
2	13	15	16	23	22	0	0	0	0	1	1	1	0	0	0
2	18	20	21	28	27	0	0	0	0	1	1	1	0	0	1
2	19	22	23	30	29	0	0	0	0	2	1	2	0	0	0
2	24	27	28	35	34	0	0	0	0	2	1	2	0	0	1
2	25	29	30	37	36	0	0	0	0	3	1	3	0	0	0
2	30	34	35	42	41	0	0	0	0	3	1	3	0	0	1
2	31	36	37	44	43	0	0	0	0	4	1	4	0	0	0
2	36	41	42	49	48	0	0	0	0	4	1	4	0	0	1
2	37	43	44	51	50	0	0	0	0	5	1	5	0	0	0
2	42	48	49	56	55	0	0	0	0	5	1	5	0	0	1
2	43	50	51	58	57	0	0	0	0	6	1	6	0	0	0
2	48	55	56	63	62	0	0	0	0	6	1	6	0	0	1
2	49	57	58	65	64	0	0	0	0	6	1	6	0	0	0
2	54	62	63	70	69	0	0	0	0	6	1	6	0	0	1
2	55	64	65	72	71	0	0	0	0	6	1	6	0	0	0
2	60	69	70	77	76	0	0	0	0	6	1	6	0	0	1
2	61	71	72	79	78	0	0	0	0	7	1	7	0	0	0
2	66	76	77	84	83	0	0	0	0	7	1	7	0	0	1
2	67	78	79	86	85	0	0	0	0	7	1	7	0	0	0
2	72	83	84	91	90	0	0	0	0	7	1	7	0	0	1
2	73	85	86	93	92	0	0	0	0	8	1	8	0	0	0
2	78	90	91	98	97	0	0	0	0	8	1	8	0	0	1
2	79	92	93	100	99	0	0	0	0	9	1	9	0	0	0
2	84	97	98	105	104	0	0	0	0	9	1	9	0	0	1
2	85	99	100	107	106	0	0	0	0	9	1	9	0	0	0

2	90	104	105	112	111	0	0	0	0	9	1	9	0	0	1
2	91	106	107	114	113	0	0	0	0	10	1	10	0	0	0
2	96	111	112	119	118	0	0	0	0	10	1	10	0	0	1
2	97	113	114	121	120	0	0	0	0	10	1	10	0	0	0
2	102	118	119	126	125	0	0	0	0	10	1	10	0	0	1
2	103	120	121	128	127	0	0	0	0	10	1	10	0	0	0
2	108	125	126	133	132	0	0	0	0	10	1	10	0	0	1
2	109	127	128	135	134	0	0	0	0	11	1	11	0	0	0
2	114	132	133	140	139	0	0	0	0	11	1	11	0	0	1
2	115	134	135	142	141	0	0	0	0	12	1	12	0	0	0
2	120	139	140	147	146	0	0	0	0	12	1	12	0	0	1
2	121	141	142	149	148	0	0	0	0	13	1	13	0	0	0
2	126	146	147	154	153	0	0	0	0	13	1	13	0	0	1
2	127	148	149	156	155	0	0	0	0	14	1	14	0	0	0
2	132	153	154	161	160	0	0	0	0	14	1	14	0	0	1
2	133	155	156	163	162	0	0	0	0	15	1	15	0	0	0
2	138	160	161	168	167	0	0	0	0	15	1	15	0	0	1
2	139	162	163	170	169	0	0	0	0	15	1	15	0	0	0
2	144	167	168	175	174	0	0	0	0	15	1	15	0	0	1
2	145	169	170	177	176	0	0	0	0	15	1	15	0	0	0
2	150	174	175	182	181	0	0	0	0	15	1	15	0	0	1

\$ SHELL ELEMENT THICKNESSES

1	0.1900	0.0000	0.0000
---	--------	--------	--------

\$ MATERIAL PROPERTIES

1	1		
9.909e+06	0.3205	12.9e-06	2.614e-04
2	1		
9.895e+06	0.3205	12.9e-06	2.614e-04
3	1		
9.872e+06	0.3205	12.9e-06	2.614e-04
4	1		
9.848e+06	0.3205	12.9e-06	2.614e-04
5	1		
9.832e+06	0.3205	12.9e-06	2.614e-04
6	1		
9.825e+06	0.3205	12.9e-06	2.614e-04
7	1		
9.813e+06	0.3205	12.9e-06	2.614e-04
8	1		
9.796e+06	0.3205	12.9e-06	2.614e-04
9	1		
9.793e+06	0.3205	12.9e-06	2.614e-04
10	1		
9.789e+06	0.3205	12.9e-06	2.614e-04
11	1		
9.780e+06	0.3205	12.9e-06	2.614e-04
12	1		
9.741e+06	0.3205	12.9e-06	2.614e-04
13	1		
9.677e+06	0.3205	12.9e-06	2.614e-04
14	1		
9.618e+06	0.3205	12.9e-06	2.614e-04
15	1		
9.565e+06	0.3205	12.9e-06	2.614e-04

\$ TEMPERATURE DATA

1	37.4490	0.0	0.0	2	46.6670	0.0	0.0
3	62.4640	0.0	0.0	4	79.2340	0.0	0.0
5	89.9840	0.0	0.0	6	94.7030	0.0	0.0
7	101.8660	0.0	0.0	8	109.8280	0.0	0.0
9	111.3230	0.0	0.0	10	113.2400	0.0	0.0
11	117.2770	0.0	0.0	12	135.4120	0.0	0.0
13	164.4520	0.0	0.0	14	191.7370	0.0	0.0
15	205.9110	0.0	0.0				

\$ NODAL MASS DATA

1	1	1.792E-04	3
4	1	1.792E-04	3
7	1	1.792E-04	3
36	1	1.792E-04	3
39	1	1.792E-04	3
42	1	1.792E-04	3
71	1	1.792E-04	3
74	1	1.792E-04	3
77	1	1.792E-04	3
106	1	1.792E-04	3
109	1	1.792E-04	3
112	1	1.792E-04	3
141	1	1.792E-04	3
144	1	1.792E-04	3
147	1	1.792E-04	3
176	1	1.792E-04	3
179	1	1.792E-04	3
182	1	1.792E-04	3

-1

STARS-SOLIDS output summary: table 17 shows the results.

Table 17. Natural frequencies of a rectangular free-free plate.

Mode number	Natural frequencies (ω), rad/sec			
	Quadrilateral element		Triangular element	
	Zero temperature	Varying temperature	Zero temperature	Varying temperature
1-6	0.00	0.00	0.00	0.00
7	91.11	90.42	87.60	87.17
8	217.28	213.98	211.08	208.83
9	250.38	248.31	241.37	239.56
10	445.35	440.89	433.49	428.85
11	488.57	487.77	472.26	471.35
12	693.44	695.54	677.19	678.29

4.1.14 Thermally Prestressed Composite Square Plate: Vibration Analysis

A composite square plate (fig. 22) subjected to temperature varying along the X axis was analyzed to yield natural frequencies and modes. Table 18 shows the results of the vibration analysis.

STARS-SOLIDS output summary: table 18 shows the results.

Table 18. Natural frequencies of a free-free square composite plate.

Mode number	Natural frequencies (ω), rad/sec			
	Quadrilateral element		Triangular element	
	Zero temperature	Varying temperature	Zero temperature	Varying temperature
1-6	0.00	0.00	0.00	0.00
7	1368.08	1566.65	1320.18	1503.57
8	1654.79	1762.14	1584.41	1683.26
9	3631.85	3749.15	3506.99	3610.58
10	3856.04	3857.21	3702.82	3705.50
11	3968.35	4192.31	3858.03	4074.09
12	5838.15	5888.37	5630.24	5673.17

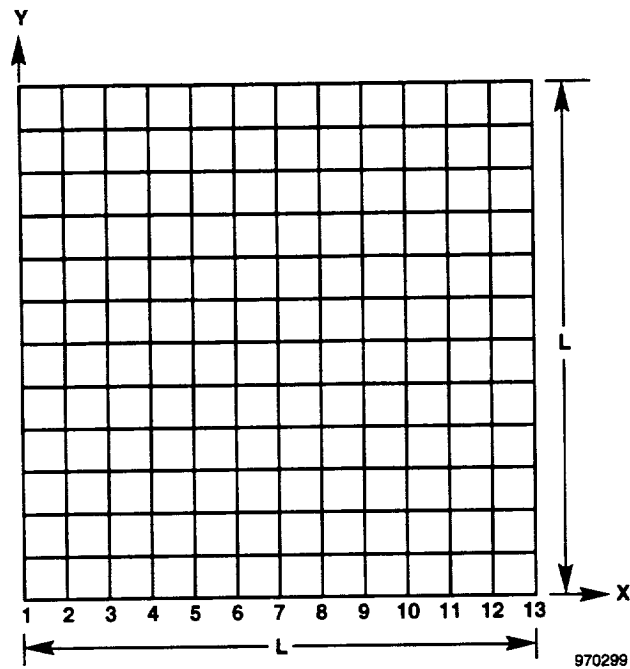


Figure 22. Free-free composite square plate.

Important data parameters:

Side length, L = 12
 Plate thickness, t = 0.24
 Mass density, ρ = 0.1475×10^{-3}
 Composite stacking = $[30^\circ/-30^\circ/-30^\circ/30^\circ]$

STARS-SOLIDS input data:

TRIANGULAR 12-BV-12 PLATE / COMPOSITE LAYERS / temperature 1 case.

169, 144, 1, 13, 0, 0, 0, 2, 1, 4
 12, 0, 0, 0, 0, 0, 0, 0, 0
 1, 1, 0, 1, 0, 0, 0, 0
 2, 0, 2, 0, 1, 0, 0, 1, 0, 0
 1, 12, 0, 6000.0, 0.0, 0.0

\$ MODAL DATA

1	0.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	0
13	12.0000	0.0000	0.0000	0	0	0	0	0	0	0	0	1
14	0.0000	1.0000	0.0000	0	0	0	0	0	0	0	0	0
26	12.0000	1.0000	0.0000	0	0	0	0	0	0	0	0	1
27	0.0000	2.0000	0.0000	0	0	0	0	0	0	0	0	0
39	12.0000	2.0000	0.0000	0	0	0	0	0	0	0	0	1
40	0.0000	3.0000	0.0000	0	0	0	0	0	0	0	0	0
52	12.0000	3.0000	0.0000	0	0	0	0	0	0	0	0	1
53	0.0000	4.0000	0.0000	0	0	0	0	0	0	0	0	0
65	12.0000	4.0000	0.0000	0	0	0	0	0	0	0	0	1
66	0.0000	5.0000	0.0000	0	0	0	0	0	0	0	0	0
78	12.0000	5.0000	0.0000	0	0	0	0	0	0	0	0	1
79	0.0000	6.0000	0.0000	0	0	0	0	0	0	0	0	0
91	12.0000	6.0000	0.0000	0	0	0	0	0	0	0	0	1
92	0.0000	7.0000	0.0000	0	0	0	0	0	0	0	0	0
104	12.0000	7.0000	0.0000	0	0	0	0	0	0	0	0	1
105	0.0000	8.0000	0.0000	0	0	0	0	0	0	0	0	0
117	12.0000	8.0000	0.0000	0	0	0	0	0	0	0	0	1
118	0.0000	9.0000	0.0000	0	0	0	0	0	0	0	0	0
130	12.0000	9.0000	0.0000	0	0	0	0	0	0	0	0	1
131	0.0000	10.0000	0.0000	0	0	0	0	0	0	0	0	0
143	12.0000	10.0000	0.0000	0	0	0	0	0	0	0	0	1
144	0.0000	11.0000	0.0000	0	0	0	0	0	0	0	0	0
156	12.0000	11.0000	0.0000	0	0	0	0	0	0	0	0	1
157	0.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	0
169	12.0000	12.0000	0.0000	0	0	0	0	0	0	0	0	1

\$ ELEMENT CONNECTIVITY

6	1	1	2	15	14	0	0	0	1	1	0	1	0	0	0
6	2	2	3	16	15	0	0	0	1	1	0	2	0	0	0
6	3	3	4	17	16	0	0	0	1	1	0	3	0	0	0
6	4	4	5	18	17	0	0	0	1	1	0	4	0	0	0
6	5	5	6	19	18	0	0	0	1	1	0	5	0	0	0
6	6	6	7	20	19	0	0	0	1	1	0	6	0	0	0
6	7	7	8	21	20	0	0	0	1	1	0	7	0	0	0
6	8	8	9	22	21	0	0	0	1	1	0	8	0	0	0
6	9	9	10	23	22	0	0	0	1	1	0	9	0	0	0
6	10	10	11	24	23	0	0	0	1	1	0	10	0	0	0
6	11	11	12	25	24	0	0	0	1	1	0	11	0	0	0
6	12	12	13	26	25	0	0	0	1	1	0	12	0	0	0
6	13	14	15	28	27	0	0	0	1	1	0	2	0	0	0
6	14	15	16	29	28	0	0	0	1	1	0	3	0	0	0
6	15	16	17	30	29	0	0	0	1	1	0	4	0	0	0
6	16	17	18	31	30	0	0	0	1	1	0	5	0	0	0
6	17	18	19	32	31	0	0	0	1	1	0	6	0	0	0
6	18	19	20	33	32	0	0	0	1	1	0	7	0	0	0
6	19	20	21	34	33	0	0	0	1	1	0	8	0	0	0
6	20	21	22	35	34	0	0	0	1	1	0	9	0	0	0
6	21	22	23	36	35	0	0	0	1	1	0	10	0	0	0
6	22	23	24	37	36	0	0	0	1	1	0	11	0	0	0
6	23	24	25	38	37	0	0	0	1	1	0	12	0	0	0
6	24	25	26	39	38	0	0	0	1	1	0	1	0	0	0
6	25	27	28	41	40	0	0	0	1	1	0	2	0	0	0
6	26	28	29	42	41	0	0	0	1	1	0	3	0	0	0
6	27	29	30	43	42	0	0	0	1	1	0	4	0	0	0
6	28	30	31	44	43	0	0	0	1	1	0	5	0	0	0
6	29	31	32	45	44	0	0	0	1	1	0	6	0	0	0
6	30	32	33	46	45	0	0	0	1	1	0	7	0	0	0
6	31	33	34	47	46	0	0	0	1	1	0	8	0	0	0
6	32	34	35	48	47	0	0	0	1	1	0	9	0	0	0
6	33	35	36	49	48	0	0	0	1	1	0	10	0	0	0
6	34	36	37	50	49	0	0	0	1	1	0	11	0	0	0
6	35	37	38	51	50	0	0	0	1	1	0	12	0	0	0
6	36	38	39	52	51	0	0	0	1	1	0	1	0	0	0
6	37	40	41	54	53	0	0	0	1	1	0	2	0	0	0
6	38	41	42	55	54	0	0	0	1	1	0	3	0	0	0
6	39	42	43	56	55	0	0	0	1	1	0	4	0	0	0
6	40	43	44	57	56	0	0	0	1	1	0	5	0	0	0
6	41	44	45	58	57	0	0	0	1	1	0	6	0	0	0
6	42	45	46	59	58	0	0	0	1	1	0	7	0	0	0
6	43	46	47	60	59	0	0	0	1	1	0	8	0	0	0
6	44	47	48	61	60	0	0	0	1	1	0	9	0	0	0
6	45	48	49	62	61	0	0	0	1	1	0	10	0	0	0
6	46	49	50	63	62	0	0	0	1	1	0	11	0	0	0
6	47	50	51	64	63	0	0	0	1	1	0	12	0	0	0
6	48	51	52	65	64	0	0	0	1	1	0	1	0	0	0
6	49	53	54	67	66	0	0	0	1	1	0	2	0	0	0
6	50	54	55	68	67	0	0	0	1	1	0	3	0	0	0
6	51	55	56	69	68	0	0	0	1	1	0	4	0	0	0
6	52	56	57	70	69	0	0	0	1	1	0	5	0	0	0
6	53	57	58	71	70	0	0	0	1	1	0	6	0	0	0
6	54	58	59	72	71	0	0	0	1	1	0	7	0	0	0
6	55	59	60	73	72	0	0	0	1	1	0	8	0	0	0
6	56	60	61	74	73	0	0	0	1	1	0	9	0	0	0
6	57	61	62	75	74	0	0	0	1	1	0	10	0	0	0
6	58	62	63	76	75	0	0	0	1	1	0	11	0	0	0
6	59	63	64	77	76	0	0	0	1	1	0	12	0	0	0
6	60	64	65	78	77	0	0	0	1	1	0	1	0	0	0
6	61	66	67	80	79	0	0	0	1	1	0	2	0	0	0
6	62	67	68	81	80	0	0	0	1	1	0	3	0	0	0
6	63	68	69	82	81	0	0	0	1	1	0	4	0	0	0
6	64	69	70	83	82	0	0	0	1	1	0	5	0	0	0
6	65	70	71	84	83	0	0	0	1	1	0	6	0	0	0
6	66	71	72	85	84	0	0	0	1	1	0	7	0	0	0
6	67	72	73	86	85	0	0	0	1	1	0	8	0	0	0
6	68	73	74	87	86	0	0	0	1	1	0	9	0	0	0
6	69	74	75	88	87	0	0	0	1	1	0	10	0	0	0
6	70	75	76	89	88	0	0	0	1	1	0	11	0	0	0
6	71	76	77	90	89	0	0	0	1	1	0	12	0	0	0
6	72	77	78	91	90	0	0	0	1	1	0	1	0	0	0
6	73	79	80	93	92	0	0	0	1	1	0	2	0	0	0
6	74	80	81	94	93	0	0	0	1	1	0	3	0	0	0
6	75	81	82	95	94	0	0	0	1	1	0	4	0	0	0
6	76	82	83	96	95	0	0	0	1	1	0	5	0	0	0
6	77	83	84	97	96	0	0	0	1	1	0	6	0	0	0
6	78	84	85	98	97	0	0	0	1	1	0	7	0	0	0
6	79	85	86	99	98	0	0	0	1	1	0	8	0	0	0
6	80	86	87	100	99	0	0	0	1	1	0	9	0	0	0
6	81	87	88	101	100	0	0	0	1	1	0	10	0	0	0
6	82	88	89	102	101	0	0	0	1	1	0	11	0	0	0
6	83	89	90	103	102	0	0	0	1	1	0	12	0	0	0
6	84	90	91	104	103	0	0	0	1	1	0	1	0	0	0
6	85	92	93	106	105	0	0	0	1	1	0	2	0	0	0
6	86	93	94	107	106	0	0	0	1	1	0	3	0	0	0
6	87	94	95	108	107	0	0	0	1	1	0	4	0	0	0
6	88	95	96	109	108	0	0	0	1	1	0	5	0	0	0
6	89	96	97	110	109	0	0	0	1	1	0	6	0	0	0
6	90	97	98	111	110	0	0	0	1	1	0	7	0	0	0
6	91	98	99	112	111	0	0	0	1	1	0	8	0	0	0
6	92	99	100	113	112	0	0	0	1	1	0	8	0	0	0

6	93	100	101	114	113	0	0	0	1	1	0	9	0	0	0
6	94	101	102	115	114	0	0	0	1	1	0	10	0	0	0
6	95	102	103	116	115	0	0	0	1	1	0	11	0	0	0
6	96	103	104	117	116	0	0	0	1	1	0	12	0	0	0
6	97	105	106	119	118	0	0	0	1	1	0	1	0	0	0
6	98	106	107	120	119	0	0	0	1	1	0	2	0	0	0
6	99	107	108	121	120	0	0	0	1	1	0	3	0	0	0
6	100	108	109	122	121	0	0	0	1	1	0	4	0	0	0
6	101	109	110	123	122	0	0	0	1	1	0	5	0	0	0
6	102	110	111	124	123	0	0	0	1	1	0	6	0	0	0
6	103	111	112	125	124	0	0	0	1	1	0	7	0	0	0
6	104	112	113	126	125	0	0	0	1	1	0	8	0	0	0
6	105	113	114	127	126	0	0	0	1	1	0	9	0	0	0
6	106	114	115	128	127	0	0	0	1	1	0	10	0	0	0
6	107	115	116	129	128	0	0	0	1	1	0	11	0	0	0
6	108	116	117	130	129	0	0	0	1	1	0	12	0	0	0
6	109	118	119	132	131	0	0	0	1	1	0	1	0	0	0
6	110	119	120	133	132	0	0	0	1	1	0	2	0	0	0
6	111	120	121	134	133	0	0	0	1	1	0	3	0	0	0
6	112	121	122	135	134	0	0	0	1	1	0	4	0	0	0
6	113	122	123	136	135	0	0	0	1	1	0	5	0	0	0
6	114	123	124	137	136	0	0	0	1	1	0	6	0	0	0
6	115	124	125	138	137	0	0	0	1	1	0	7	0	0	0
6	116	125	126	139	138	0	0	0	1	1	0	8	0	0	0
6	117	126	127	140	139	0	0	0	1	1	0	9	0	0	0
6	118	127	128	141	140	0	0	0	1	1	0	10	0	0	0
6	119	128	129	142	141	0	0	0	1	1	0	11	0	0	0
6	120	129	130	143	142	0	0	0	1	1	0	12	0	0	0
6	121	131	132	145	144	0	0	0	1	1	0	1	0	0	0
6	122	132	133	146	145	0	0	0	1	1	0	2	0	0	0
6	123	133	134	147	146	0	0	0	1	1	0	3	0	0	0
6	124	134	135	148	147	0	0	0	1	1	0	4	0	0	0
6	125	135	136	149	148	0	0	0	1	1	0	5	0	0	0
6	126	136	137	150	149	0	0	0	1	1	0	6	0	0	0
6	127	137	138	151	150	0	0	0	1	1	0	7	0	0	0
6	128	138	139	152	151	0	0	0	1	1	0	8	0	0	0
6	129	139	140	153	152	0	0	0	1	1	0	9	0	0	0
6	130	140	141	154	153	0	0	0	1	1	0	10	0	0	0
6	131	141	142	155	154	0	0	0	1	1	0	11	0	0	0
6	132	142	143	156	155	0	0	0	1	1	0	12	0	0	0
6	133	144	145	158	157	0	0	0	1	1	0	1	0	0	0
6	134	145	146	159	158	0	0	0	1	1	0	2	0	0	0
6	135	146	147	160	159	0	0	0	1	1	0	3	0	0	0
6	136	147	148	161	160	0	0	0	1	1	0	4	0	0	0
6	137	148	149	162	161	0	0	0	1	1	0	5	0	0	0
6	138	149	150	163	162	0	0	0	1	1	0	6	0	0	0
6	139	150	151	164	163	0	0	0	1	1	0	7	0	0	0
6	140	151	152	165	164	0	0	0	1	1	0	8	0	0	0
6	141	152	153	166	165	0	0	0	1	1	0	9	0	0	0
6	142	153	154	167	166	0	0	0	1	1	0	10	0	0	0
6	143	154	155	168	167	0	0	0	1	1	0	11	0	0	0
6	144	155	156	169	168	0	0	0	1	1	0	12	0	0	0

\$ COMPOSITE SHELL ELEMENT STACK DESCRIPTION DATA

1	4
1	.0600 1
1	.0600 2
1	.0600 2
1	.0600 1

\$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION

1	2	0
0.5236		
2	2	0
2.61799		

\$ MATERIAL PROPERTIES

1	2
30.1169E+65.56559E+50.0000E+002.65029E+60.0000E+007.8400E+057.8400E+05	
0.0000E+007.8400E+050.2420E-050.1370E-040.0000E+000.1475E-03	

\$ ELEMENT TEMPERATURE DATA

1	29.0278	0.0000	0.0000	2	81.8056	0.0000	0.0000
3	124.0278	0.0000	0.0000	4	155.6945	0.0000	0.0000
5	176.8056	0.0000	0.0000	6	187.3611	0.0000	0.0000
7	187.3611	0.0000	0.0000	8	176.8056	0.0000	0.0000
9	155.6944	0.0000	0.0000	10	124.0278	0.0000	0.0000
11	81.8056	0.0000	0.0000	12	29.0278	0.0000	0.0000

4.2. STARS-SOLIDS (Nonlinear Analysis)

In this section, the input data, as well as relevant outputs, of several typical nonlinear test cases are provided in some detail. The input data are prepared in accordance with the procedures described in section 3 and are defined in consistent unit form.

4.2.1 Clamped Square Plate: Uniform Load

Figure 23 shows a square plate with all edges fixed under uniform load. The results of the geometric nonlinearity analysis involving large displacement and rotation are presented herein.

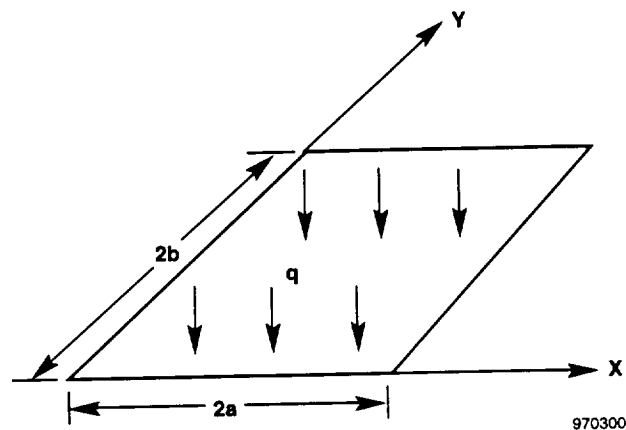


Figure 23. Clamped plate with uniform load.

Important data parameters:

Thickness, h	=	1.0
Young's modulus, E	=	2.0×10^{11}
Poisson's ratio, μ	=	0.3
Length, $a = b$	=	50
Uniform pressure, q	=	6.0×10^4 , in 30 equal increments of $\Delta q = 2000.0$

A symmetric, one-quarter plate was modeled using a 5-by-5 mesh.

STARS-SOLIDS input data:

```

Large deflection analysis of a quarter plate
36, 25, 1, 4, 0, 1, 0, 0, 0, 0
0, 1, 0, 0, 0, 0, 0, 0, 0, 0
11, 0, 0, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 30
$ NODAL DATA
1 .0000 .0000 .0000 1 1 1 1 1 1
2 20.0000 .0000 .0000 1 1 1 1 1 1
3 40.0000 .0000 .0000 1 1 1 1 1 1
4 60.0000 .0000 .0000 1 1 1 1 1 1
5 80.0000 .0000 .0000 1 1 1 1 1 1
6 100.0000 .0000 .0000 1 1 1 1 1 1
7 .0000 20.0000 .0000 1 1 1 1 1 1
8 20.0000 20.0000 .0000 0 0 0 0 0 0

```

```

9 40.0000 20.0000 .0000 0 0 0 0 0 0
10 60.0000 20.0000 .0000 0 0 0 0 0 0
11 80.0000 20.0000 .0000 0 0 0 0 0 0
12 100.0000 20.0000 .0000 1 0 0 0 1 1
13 .0000 40.0000 .0000 1 1 1 1 1 1
14 20.0000 40.0000 .0000 0 0 0 0 0 0
15 40.0000 40.0000 .0000 0 0 0 0 0 0
16 60.0000 40.0000 .0000 0 0 0 0 0 0
17 80.0000 40.0000 .0000 0 0 0 0 0 0
18 100.0000 40.0000 .0000 1 0 0 0 1 1
19 .0000 60.0000 .0000 1 1 1 1 1 1
20 20.0000 60.0000 .0000 0 0 0 0 0 0
21 40.0000 60.0000 .0000 0 0 0 0 0 0
22 60.0000 60.0000 .0000 0 0 0 0 0 0
23 80.0000 60.0000 .0000 0 0 0 0 0 0
24 100.0000 60.0000 .0000 1 0 0 0 1 1
25 .0000 80.0000 .0000 1 1 1 1 1 1
26 20.0000 80.0000 .0000 0 0 0 0 0 0
27 40.0000 80.0000 .0000 0 0 0 0 0 0
28 60.0000 80.0000 .0000 0 0 0 0 0 0
29 80.0000 80.0000 .0000 0 0 0 0 0 0
30 100.0000 80.0000 .0000 1 0 0 0 1 1
31 .0000 100.0000 .0000 1 1 1 1 1 1
32 20.0000 100.0000 .0000 0 1 0 1 0 1
33 40.0000 100.0000 .0000 0 1 0 1 0 1
34 60.0000 100.0000 .0000 0 1 0 1 0 1
35 80.0000 100.0000 .0000 0 1 0 1 0 1
36 100.0000 100.0000 .0000 1 1 0 1 1 1

$ ELEMENT CONNECTIVITY CONDITIONS
2 1 1 2 8 7 0 0 0 0 1 1 0 1 0 0
2 2 2 3 9 8 0 0 0 0 1 1 0 1 0 0
2 3 3 4 10 9 0 0 0 0 1 1 0 1 0 0
2 4 4 5 11 10 0 0 0 0 1 1 0 1 0 0
2 5 5 6 12 11 0 0 0 0 1 1 0 1 0 0
2 6 7 8 14 13 0 0 0 0 1 1 0 1 0 0
2 7 8 9 15 14 0 0 0 0 1 1 0 1 0 0
2 8 9 10 16 15 0 0 0 0 1 1 0 1 0 0
2 9 10 11 17 16 0 0 0 0 1 1 0 1 0 0
2 10 11 12 18 17 0 0 0 0 1 1 0 1 0 0
2 11 13 14 20 19 0 0 0 0 1 1 0 1 0 0
2 12 14 15 21 20 0 0 0 0 1 1 0 1 0 0
2 13 15 16 22 21 0 0 0 0 1 1 0 1 0 0
2 14 16 17 23 22 0 0 0 0 1 1 0 1 0 0
2 15 17 18 24 23 0 0 0 0 1 1 0 1 0 0
2 16 19 20 26 25 0 0 0 0 1 1 0 1 0 0
2 17 20 21 27 26 0 0 0 0 1 1 0 1 0 0
2 18 21 22 28 27 0 0 0 0 1 1 0 1 0 0
2 19 22 23 29 28 0 0 0 0 1 1 0 1 0 0
2 20 23 24 30 29 0 0 0 0 1 1 0 1 0 0
2 21 25 26 32 31 0 0 0 0 1 1 0 1 0 0
2 22 26 27 33 32 0 0 0 0 1 1 0 1 0 0
2 23 27 28 34 33 0 0 0 0 1 1 0 1 0 0
2 24 28 29 35 34 0 0 0 0 1 1 0 1 0 0
2 25 29 30 36 35 0 0 0 0 1 1 0 1 0 0

$ SHELL ELEMENT THICKNESSES
1 .1000E+01 .1000E+01 .1000E+01

$ MATERIAL PROPERTIES
1
.2000E+12 .3000E+00 .0000E+00 .0000E+00

$ ELEMENT PRESSURE DATA
1 -2000.000

```

STARS–SOLIDS output summary: table 19 shows the results. Figure 24 shows the maximum plate displacement ($W_{\max}$) as a function of the load plot.

Table 19. Center deflection for a clamped square plate with a uniform load.

$\frac{qa^4}{Dh}$	$\frac{W_{\max}}{h}$		
	Theory (plot)	STARS	Difference, percent
109.3 (P)	1.20	1.21	0.8
218.6 (2P)	1.66	1.70	2.4
327.9 (3P)	2.00	2.03	1.5

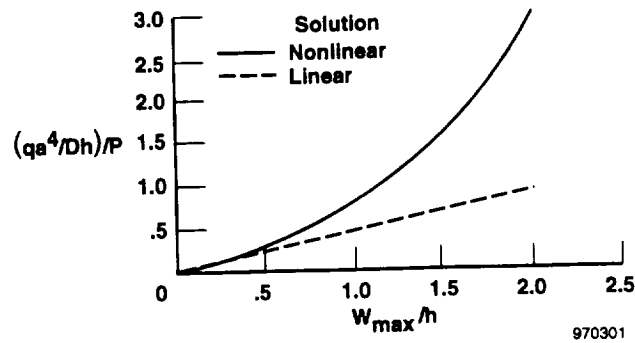


Figure 24. Clamped plate center displacement as a function of load curve.

4.2.2 Cantilever Beam: Moment at Tip

A static, nonlinear analysis of a cantilever beam (fig. 25) was performed using line elements. The results are given below.

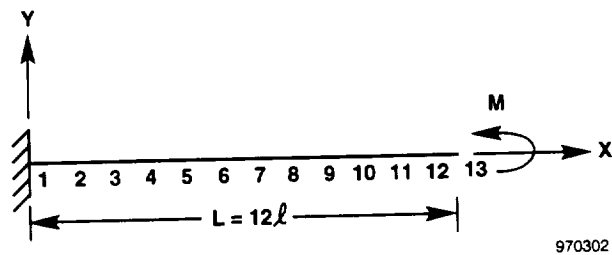


Figure 25. Cantilever beam with moment at tip.

Important data parameters:

Young's modulus, E	$= 2.0 \times 10^7$
Cross-sectional area, A	$= 0.15$
Moment of inertia:	
About y axis	$= 2.813 \times 10^{-4}$
About z axis	$= 2.813 \times 10^{-4}$
Member length, ℓ	$= 1.0$
Tip moment, M	$= 3000.0$, in 600 equal increments of $\Delta M = 5.0$

STARS-SOLIDS input data:

```

LARGE ROTATION ANALYSIS OF CANTILEVER BEAM WITH MOMENT AT TIP
14, 12, 1, 4, 1, 0, 0, 0, 0, 0
0, 0, 0, 0, 0, 0, 0, 0, 0, 0
11, 0, 0, 1, 1, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 600
$ MODAL DATA
1 .0000 .0000 .0000 1 1 1 1 1 1
2 1.0000 .0000 .0000 0 0 1 1 1 0
3 2.0000 .0000 .0000 0 0 1 1 1 0
4 3.0000 .0000 .0000 0 0 1 1 1 0
5 4.0000 .0000 .0000 0 0 1 1 1 0
6 5.0000 .0000 .0000 0 0 1 1 1 0
7 6.0000 .0000 .0000 0 0 1 1 1 0
8 7.0000 .0000 .0000 0 0 1 1 1 0
9 8.0000 .0000 .0000 0 0 1 1 1 0

```

```

10 9.0000 .0000 .0000 0 0 1 1 1 0
11 10.0000 .0000 .0000 0 0 1 1 1 0
12 11.0000 .0000 .0000 0 0 1 1 1 0
13 12.0000 .0000 .0000 0 0 1 1 1 0
14 .0000 3.0000 .0000 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY CONDITIONS
1 1 1 2 14 0 0 0 0 1 1 0 0 0 0
1 12 12 13 14 0 0 0 0 1 1 0 0 0 1
$ LINE ELEMENT BASIC PROPERTIES
1 .1500E+00 .1000E+01 .28125E-3 .28125E-3
$ MATERIAL PROPERTIES
1 1
.2000E+08 .3000E+00
$ NODAL LOAD DATA
13 6 5.0
-1

```

STARS–SOLIDS output summary: table 20 shows the output summary, and figures 26 and 27 show deflection curves.

Table 20. Tip displacement, v , for a cantilever beam with end moment.

M	Tip Y displacement (v)	
	STARS	Theory
300	3.7048	3.7107
600	6.6675	6.6860
900	8.3599	8.3884
1200	8.5825	8.6043
1500	7.4971	7.4936
1800	5.5581	5.5183
2100	3.3671	3.2954
2400	1.4980	1.4146
2700	0.3452	0.2787
3000	0.0385	0.0128

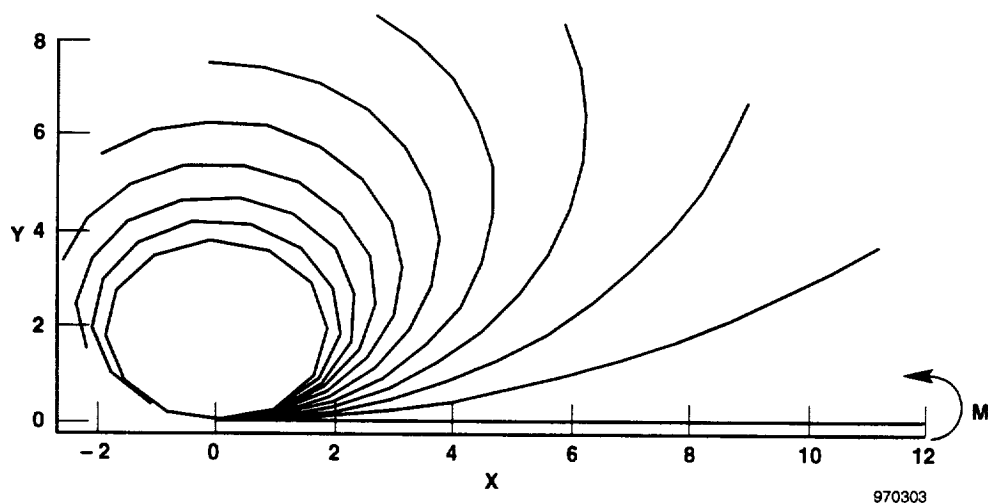
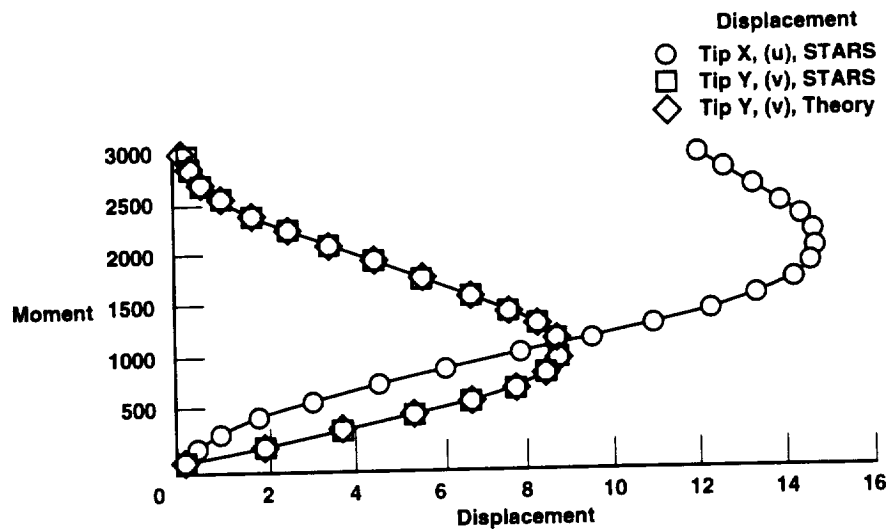


Figure 26. Deflection curves for cantilever beam with end moment.

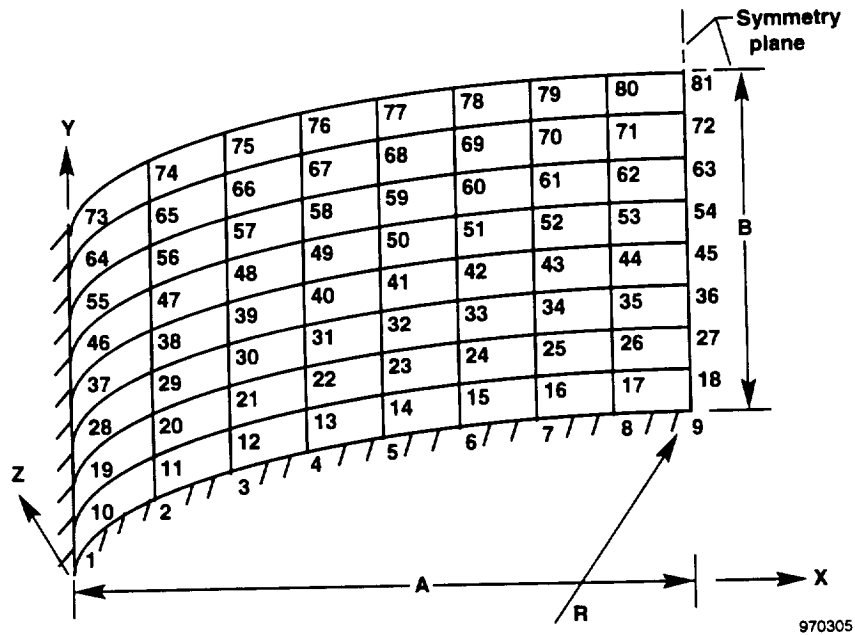


970304

Figure 27. Cantilever tip deflection as a function of moment curve.

4.2.3 Clamped Cylindrical Shell: Uniform Load

A nonlinear analysis of a clamped cylindrical shell under uniform load (fig. 28) was performed. An 8-by-8 mesh was employed for one-quarter of the panel, and the results are presented herein.



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Figure 28. Clamped cylindrical shell with uniform load.

Important data parameters:

Thickness, h	= 0.125
Young's modulus, E	= 450,000
Poisson's ratio, μ	= 0.3
Length, $A = B$	= 10
R	= 100
Total q	= 0.3, in 30 equal increments of $\Delta q = 0.01$

STARS-SOLIDS input data:

Large deflection analysis of a quarter shell

81, 64, 1, 4, 0, 1, 0, 0, 0, 0
0, 1, 0, 0, 0, 0, 0, 0, 0, 0
11, 0, 0, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 30

\$	NODE	DESCRIPTION								
1	.00000	.00000	.00000	1	1	1	1	1	1	1
2	1.25000	.00000	.11771	1	1	1	1	1	1	1
3	2.50000	.00000	.21961	1	1	1	1	1	1	1
4	3.75000	.00000	.30575	1	1	1	1	1	1	1
5	5.00000	.00000	.37618	1	1	1	1	1	1	1
6	6.25000	.00000	.43072	1	1	1	1	1	1	1
7	7.50000	.00000	.47000	1	1	1	1	1	1	1
8	8.75000	.00000	.49344	1	1	1	1	1	1	1
9	10.00000	.00000	.50126	1	1	1	1	1	1	1
10	.00000	1.25000	.00000	1	1	1	1	1	1	1
11	1.25000	1.25000	.11771	0	0	0	0	0	0	0
12	2.50000	1.25000	.21961	0	0	0	0	0	0	0
13	3.75000	1.25000	.30575	0	0	0	0	0	0	0
14	5.00000	1.25000	.37618	0	0	0	0	0	0	0
15	6.25000	1.25000	.43072	0	0	0	0	0	0	0
16	7.50000	1.25000	.47000	0	0	0	0	0	0	0
17	8.75000	1.25000	.49344	0	0	0	0	0	0	0
18	10.00000	1.25000	.50126	1	0	0	0	0	1	1
19	.00000	2.50000	.00000	1	1	1	1	1	1	1
20	1.25000	2.50000	.11771	0	0	0	0	0	0	0
21	2.50000	2.50000	.21961	0	0	0	0	0	0	0
22	3.75000	2.50000	.30575	0	0	0	0	0	0	0
23	5.00000	2.50000	.37618	0	0	0	0	0	0	0
24	6.25000	2.50000	.43072	0	0	0	0	0	0	0
25	7.50000	2.50000	.47000	0	0	0	0	0	0	0
26	8.75000	2.50000	.49344	0	0	0	0	0	0	0
27	10.00000	2.50000	.50126	1	0	0	0	0	1	1
28	.00000	3.75000	.00000	1	1	1	1	1	1	1
29	1.25000	3.75000	.11771	0	0	0	0	0	0	0
30	2.50000	3.75000	.21961	0	0	0	0	0	0	0
31	3.75000	3.75000	.30575	0	0	0	0	0	0	0
32	5.00000	3.75000	.37618	0	0	0	0	0	0	0
33	6.25000	3.75000	.43072	0	0	0	0	0	0	0
34	7.50000	3.75000	.47000	0	0	0	0	0	0	0
35	8.75000	3.75000	.49344	0	0	0	0	0	0	0
36	10.00000	3.75000	.50126	1	0	0	0	0	1	1
37	.00000	5.00000	.00000	1	1	1	1	1	1	1
38	1.25000	5.00000	.11771	0	0	0	0	0	0	0
39	2.50000	5.00000	.21961	0	0	0	0	0	0	0
40	3.75000	5.00000	.30575	0	0	0	0	0	0	0
41	5.00000	5.00000	.37618	0	0	0	0	0	0	0
42	6.25000	5.00000	.43072	0	0	0	0	0	0	0
43	7.50000	5.00000	.47000	0	0	0	0	0	0	0
44	8.75000	5.00000	.49344	0	0	0	0	0	0	0
45	10.00000	5.00000	.50126	1	0	0	0	0	1	1
46	.00000	6.25000	.00000	1	1	1	1	1	1	1
47	1.25000	6.25000	.11771	0	0	0	0	0	0	0
48	2.50000	6.25000	.21961	0	0	0	0	0	0	0
49	3.75000	6.25000	.30575	0	0	0	0	0	0	0
50	5.00000	6.25000	.37618	0	0	0	0	0	0	0
51	6.25000	6.25000	.43072	0	0	0	0	0	0	0
52	7.50000	6.25000	.47000	0	0	0	0	0	0	0
53	8.75000	6.25000	.49344	0	0	0	0	0	0	0
54	10.00000	6.25000	.50126	1	0	0	0	0	1	1
55	.00000	7.50000	.00000	1	1	1	1	1	1	1
56	1.25000	7.50000	.11771	0	0	0	0	0	0	0
57	2.50000	7.50000	.21961	0	0	0	0	0	0	0
58	3.75000	7.50000	.30575	0	0	0	0	0	0	0
59	5.00000	7.50000	.37618	0	0	0	0	0	0	0
60	6.25000	7.50000	.43072	0	0	0	0	0	0	0
61	7.50000	7.50000	.47000	0	0	0	0	0	0	0
62	8.75000	7.50000	.49344	0	0	0	0	0	0	0
63	10.00000	7.50000	.50126	1	0	0	0	0	1	1
64	.00000	8.75000	.00000	1	1	1	1	1	1	1
65	1.25000	8.75000	.11771	0	0	0	0	0	0	0
66	2.50000	8.75000	.21961	0	0	0	0	0	0	0
67	3.75000	8.75000	.30575	0	0	0	0	0	0	0
68	5.00000	8.75000	.37618	0	0	0	0	0	0	0
69	6.25000	8.75000	.43072	0	0	0	0	0	0	0
70	7.50000	8.75000	.47000	0	0	0	0	0	0	0
71	8.75000	8.75000	.49344	0	0	0	0	0	0	0
72	10.00000	8.75000	.50126	1	0	0	0	0	1	1
73	.00000	10.00000	.00000	1	1	1	1	1	1	1
74	1.25000	10.00000	.11771	0	1	0	1	0	1	1

75	2.50000	10.00000	.21961	0	1	0	1	0	1
76	3.75000	10.00000	.30575	0	1	0	1	0	1
77	5.00000	10.00000	.37618	0	1	0	1	0	1
78	6.25000	10.00000	.43072	0	1	0	1	0	1
79	7.50000	10.00000	.47000	0	1	0	1	0	1
80	8.75000	10.00000	.49344	0	1	0	1	0	1
81	10.00000	10.00000	.50126	1	1	0	1	1	1

\$ ELEMENT CONNECTIVITY

2	1	1	2	11	10	0	0	0	0	1	1	0	1	0
2	2	2	3	12	11	0	0	0	0	1	1	0	1	0
2	3	3	4	13	12	0	0	0	0	1	1	0	1	0
2	4	4	5	14	13	0	0	0	0	1	1	0	1	0
2	5	5	6	15	14	0	0	0	0	1	1	0	1	0
2	6	6	7	16	15	0	0	0	0	1	1	0	1	0
2	7	7	8	17	16	0	0	0	0	1	1	0	1	0
2	8	8	9	18	17	0	0	0	0	1	1	0	1	0
2	9	10	11	20	19	0	0	0	0	1	1	0	1	0
2	10	11	12	21	20	0	0	0	0	1	1	0	1	0
2	11	12	13	22	21	0	0	0	0	1	1	0	1	0
2	12	13	14	23	22	0	0	0	0	1	1	0	1	0
2	13	14	15	24	23	0	0	0	0	1	1	0	1	0
2	14	15	16	25	24	0	0	0	0	1	1	0	1	0
2	15	16	17	26	25	0	0	0	0	1	1	0	1	0
2	16	17	18	27	26	0	0	0	0	1	1	0	1	0
2	17	19	20	29	28	0	0	0	0	1	1	0	1	0
2	18	20	21	30	29	0	0	0	0	1	1	0	1	0
2	19	21	22	31	30	0	0	0	0	1	1	0	1	0
2	20	22	23	32	31	0	0	0	0	1	1	0	1	0
2	21	23	24	33	32	0	0	0	0	1	1	0	1	0
2	22	24	25	34	33	0	0	0	0	1	1	0	1	0
2	23	25	26	35	34	0	0	0	0	1	1	0	1	0
2	24	26	27	36	35	0	0	0	0	1	1	0	1	0
2	25	28	29	38	37	0	0	0	0	1	1	0	1	0
2	26	29	30	39	38	0	0	0	0	1	1	0	1	0
2	27	30	31	40	39	0	0	0	0	1	1	0	1	0
2	28	31	32	41	40	0	0	0	0	1	1	0	1	0
2	29	32	33	42	41	0	0	0	0	1	1	0	1	0
2	30	33	34	43	42	0	0	0	0	1	1	0	1	0
2	31	34	35	44	43	0	0	0	0	1	1	0	1	0
2	32	35	36	45	44	0	0	0	0	1	1	0	1	0
2	33	37	38	47	46	0	0	0	0	1	1	0	1	0
2	34	38	39	48	47	0	0	0	0	1	1	0	1	0
2	35	39	40	49	48	0	0	0	0	1	1	0	1	0
2	36	40	41	50	49	0	0	0	0	1	1	0	1	0
2	37	41	42	51	50	0	0	0	0	1	1	0	1	0
2	38	42	43	52	51	0	0	0	0	1	1	0	1	0
2	39	43	44	53	52	0	0	0	0	1	1	0	1	0
2	40	44	45	54	53	0	0	0	0	1	1	0	1	0
2	41	46	47	56	55	0	0	0	0	1	1	0	1	0
2	42	47	48	57	56	0	0	0	0	1	1	0	1	0
2	43	48	49	58	57	0	0	0	0	1	1	0	1	0
2	44	49	50	59	58	0	0	0	0	1	1	0	1	0
2	45	50	51	60	59	0	0	0	0	1	1	0	1	0
2	46	51	52	61	60	0	0	0	0	1	1	0	1	0
2	47	52	53	62	61	0	0	0	0	1	1	0	1	0
2	48	53	54	63	62	0	0	0	0	1	1	0	1	0
2	49	55	56	65	64	0	0	0	0	1	1	0	1	0
2	50	56	57	66	65	0	0	0	0	1	1	0	1	0
2	51	57	58	67	66	0	0	0	0	1	1	0	1	0
2	52	58	59	68	67	0	0	0	0	1	1	0	1	0
2	53	59	60	69	68	0	0	0	0	1	1	0	1	0
2	54	60	61	70	69	0	0	0	0	1	1	0	1	0
2	55	61	62	71	70	0	0	0	0	1	1	0	1	0
2	56	62	63	72	71	0	0	0	0	1	1	0	1	0
2	57	64	65	74	73	0	0	0	0	1	1	0	1	0
2	58	65	66	75	74	0	0	0	0	1	1	0	1	0
2	59	66	67	76	75	0	0	0	0	1	1	0	1	0
2	60	67	68	77	76	0	0	0	0	1	1	0	1	0
2	61	68	69	78	77	0	0	0	0	1	1	0	1	0
2	62	69	70	79	78	0	0	0	0	1	1	0	1	0
2	63	70	71	80	79	0	0	0	0	1	1	0	1	0
2	64	71	72	81	80	0	0	0	0	1	1	0	1	0

\$ SHELL ELEMENT THICKNESSES

1	.1250E+00	.1250E+00	.1250E+00
---	-----------	-----------	-----------

\$ MATERIAL PROPERTIES

1	1	.4500E+06	.3000E+00	.0000E+00	.0000E+00
---	---	-----------	-----------	-----------	-----------

\$ ELEMENT PRESSURE DATA

1	-0.01
---	-------

STARS-SOLIDS output summary: table 21 shows the results, and figure 29 shows the load deflection curve.

Table 21. Center deflection for a clamped cylindrical shell under uniform load.

Pressure (q)	Center deflection (w)
0.01	0.00289
0.02	0.00586
0.03	0.00891
0.04	0.01206
0.05	0.01531
0.06	0.01868
0.07	0.02217
0.08	0.02580
0.09	0.02958
0.10	0.03354
0.11	0.03771
0.12	0.04211
0.13	0.04680
0.14	0.05181
0.15	0.05724
0.16	0.06318
0.17	0.06979
0.18	0.07729
0.19	0.08606
0.20	0.09672
0.21	0.11043
0.22	0.12921
0.23	0.15481
0.24	0.18135
0.25	0.20372
0.26	0.22284
0.27	0.23953
0.28	0.25427
0.29	0.26749
0.30	0.27951

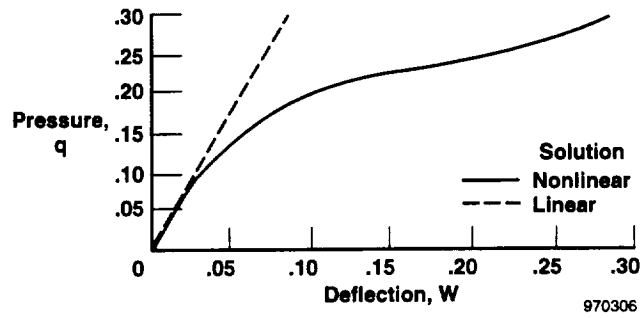


Figure 29. Center deflection of a clamped cylindrical shell under uniform load.

4.2.4 Clamped Beam: Dynamic-Response Analysis

Figure 30 shows a beam with both ends clamped under concentrated load. The results of a nonlinear static and response analysis involving large displacement and rotation are presented herein.

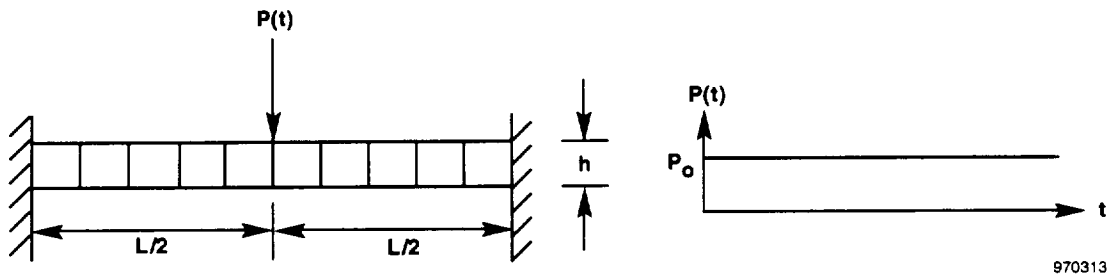


Figure 30. Clamped beam with concentrated load.

Important data parameters:

Young's modulus, E	= 3.0×10^7
Length, L	= 20.0
Width, B	= 1.0
Thickness, h	= 0.125
Mass density, ρ	= 2.5389×10^{-4}
Static load, P	= 700
Δp	= 10
Dynamic load, P_o	= 640
Δt	= $2.0 \mu s$

Ten ideal beam elements were used.

STARS-SOLIDS input data:

```

NONLINEAR RESPONSE OF CLAMPED BEAM WITH CONCENTRATED LOAD
12, 10, 1, 4, 1, 0, 0, 0, 0, 0
0, 0, 0, 0, 0, 0, 0, 0, 0, 0
11, 0, 1, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 1
0, 1, 1, 1, 1, 1, 1, 1, 1, 1
$ NODAL DATA
1 .0000 .0000 .0000 1 1 1 1 1 1
2 2.0000 .0000 .0000 0 1 0 1 0 1
3 4.0000 .0000 .0000 0 1 0 1 0 1
4 6.0000 .0000 .0000 0 1 0 1 0 1
5 8.0000 .0000 .0000 0 1 0 1 0 1
6 10.0000 .0000 .0000 0 1 0 1 0 1
7 12.0000 .0000 .0000 0 1 0 1 0 1
8 14.0000 .0000 .0000 0 1 0 1 0 1
9 16.0000 .0000 .0000 0 1 0 1 0 1
10 18.0000 .0000 .0000 0 1 0 1 0 1
11 20.0000 .0000 .0000 1 1 1 1 1 1
12 10.0000 15.0000 .0000 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY CONDITIONS
1 1 1 2 12 0 0 0 0 1 1 0 0 0 0
1 10 10 11 12 0 0 0 0 1 1 0 0 0 1
$ LINE ELEMENT BASIC PROPERTIES
1 .1250E+00 .16276E-3 .16276E-3
$ MATERIAL PROPERTIES
1 1
.3000E+08 .0000E+00 .0000E+00 .25389E-3
$ DYNAMIC NODAL LOAD DATA
5.0
6 3 -640.000
-1
$ INCREMENTAL TIME DATA FOR DYNAMIC RESPONSE ANALYSIS
2.0E-6 2500

```

STARS-SOLIDS output summary: table 22 shows the results for a nonlinear static solution. Figure 31 shows the displacement as a function of the load plot. Figure 32 shows the displacement as a function of the time plot for the nonlinear response solution.

Table 22. Center displacement for a clamped beam with concentrated load.

Load increment	Displacement
10	0.03128
20	0.06983
30	0.10049
40	0.12539
50	0.14623
60	0.16420
70	0.18004
80	0.19425
90	0.20719
100	0.21908
200	0.30605
300	0.36525
400	0.41177
500	0.45075
600	0.48465
700	0.51485

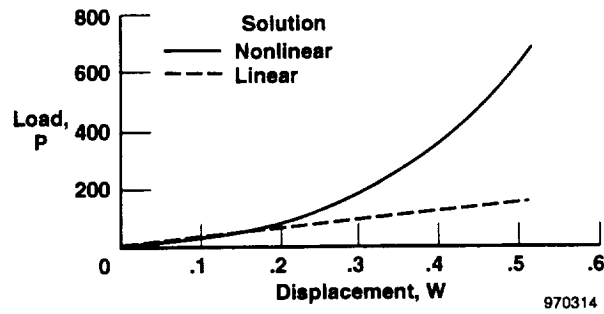


Figure 31. Center displacement: load curve of a clamped beam.

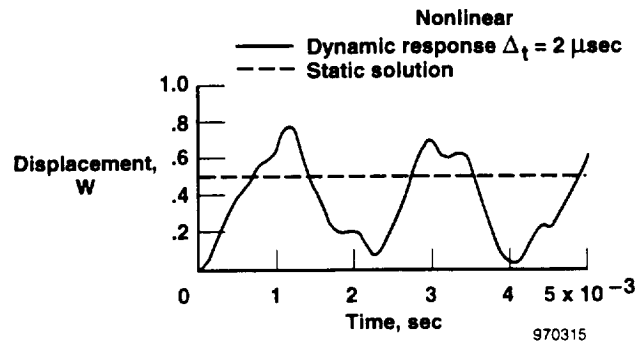


Figure 32. Center displacement: time curve of a clamped beam.

4.2.5 Shallow Spherical Cap: Dynamic-Response Analysis

Figure 33 shows a clamped spherical cap under apex load. Both triangular and quadrilateral element meshes (fig. 34) were used for modeling one-quarter of the cap for the nonlinear static analysis. The triangular element mesh was also used for the nonlinear response analysis. The results are presented herein.

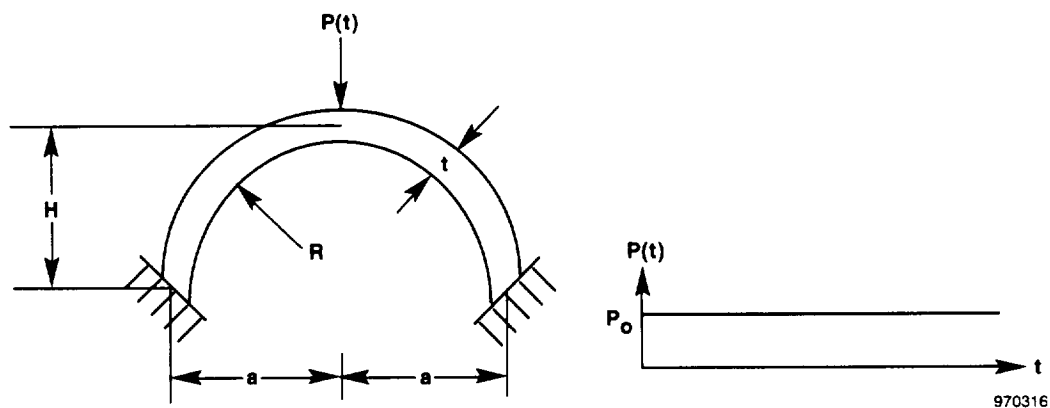


Figure 33. Clamped spherical cap with apex load.

Important data parameters:

Young's modulus, E	$= 1.0 \times 10^7$
Poisson's ratio, μ	$= 0.3$

Thickness, t	= 0.01576
Radius, R	= 4.76
Height, H	= 0.08589
Length, a	= 0.9
Mass density, ρ	= 2.45×10^{-4}
Static load, P	= 100
Δp	= 1
Dynamic load, P_0	= 100
Δt	= $0.5 \mu s$

STARS-SOLIDS input data:

Nonlinear response of spherical cap under apex load (Triangular mesh)

```

37, 54, 1, 4, 0, 1, 1, 0, 0, 0
0, 0, 0, 0, 0, 0, 0, 0, 0, 0
11, 0, 1, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 1
0, 1, 1, 1, 1, 1, 1, 1, 1, 1

$ MODAL DATA
1 4.7600 .0000 .0000 1 1 0 1 1 120000 0 0
2 4.7600 0.0000 0.0262 0 1 0 1 0 120000 0 0
3 4.7600 0.7854 0.0332 0 0 0 0 0 120000 0 0
4 4.7600 1.5707 0.0262 1 0 0 0 0 1 120000 0 0
5 4.7600 0.0000 0.0524 0 1 0 1 0 120000 0 0
6 4.7600 0.3927 0.0559 0 0 0 0 0 120000 0 0
7 4.7600 0.7854 0.0646 0 0 0 0 0 120000 0 0
8 4.7600 1.1780 0.0559 0 0 0 0 0 120000 0 0
9 4.7600 1.5707 0.0524 1 0 0 0 1 120000 0 0
10 4.7600 0.0000 0.0785 0 1 0 1 0 120000 0 0
11 4.7600 0.2618 0.0785 0 0 0 0 0 120000 0 0
12 4.7600 0.5239 0.0820 0 0 0 0 0 120000 0 0
13 4.7600 0.7854 0.0890 0 0 0 0 0 120000 0 0
14 4.7600 1.0472 0.0820 0 0 0 0 0 120000 0 0
15 4.7600 1.3090 0.0785 0 0 0 0 0 120000 0 0
16 4.7600 1.5707 0.0785 1 0 0 0 1 120000 0 0
17 4.7600 0.0000 0.1152 0 1 0 1 0 120000 0 0
18 4.7600 0.2618 0.1152 0 0 0 0 0 120000 0 0
19 4.7600 0.5239 0.1152 0 0 0 0 0 120000 0 0
20 4.7600 0.7854 0.1152 0 0 0 0 0 120000 0 0
21 4.7600 1.0472 0.1152 0 0 0 0 0 120000 0 0
22 4.7600 1.3090 0.1152 0 0 0 0 0 120000 0 0
23 4.7600 1.5707 0.1152 1 0 0 0 1 120000 0 0
24 4.7600 0.0000 0.1518 0 1 0 1 0 120000 0 0
25 4.7600 0.2618 0.1518 0 0 0 0 0 120000 0 0
26 4.7600 0.5239 0.1518 0 0 0 0 0 120000 0 0
27 4.7600 0.7854 0.1518 0 0 0 0 0 120000 0 0
28 4.7600 1.0472 0.1518 0 0 0 0 0 120000 0 0
29 4.7600 1.3090 0.1518 0 0 0 0 0 120000 0 0
30 4.7600 1.5707 0.1518 1 0 0 0 1 120000 0 0
31 4.7600 0.0000 0.1902 1 1 1 1 1 120000 0 0
32 4.7600 0.2618 0.1902 1 1 1 1 1 120000 0 0
33 4.7600 .5239 0.1902 1 1 1 1 1 120000 0 0
34 4.7600 .7854 0.1902 1 1 1 1 1 120000 0 0
35 4.7600 1.0472 0.1902 1 1 1 1 1 120000 0 0
36 4.7600 1.3090 0.1902 1 1 1 1 1 120000 0 0
37 4.7600 1.5707 0.1902 1 1 1 1 1 120000 0 0

$ LOCAL-GLOBAL COORDINATE SYSTEM DATA
20000 1 2
0.0 0.0 0.0 1.0 0.0 0.0
0.0 1.0 0.0

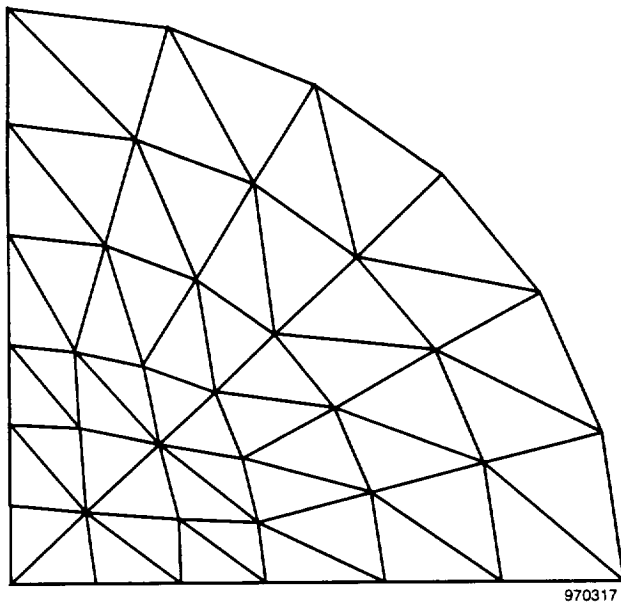
$ ELEMENT CONNECTIVITY CONDITIONS
3 1 1 2 3 0 0 0 0 0 1 1 0 0 0 0
3 2 1 3 4 0 0 0 0 0 1 1 0 0 0 0
3 3 2 5 3 0 0 0 0 0 1 1 0 0 0 0
3 4 5 6 3 0 0 0 0 0 1 1 0 0 0 0
3 5 6 7 3 0 0 0 0 0 1 1 0 0 0 0
3 6 7 8 3 0 0 0 0 0 1 1 0 0 0 0
3 7 8 9 3 0 0 0 0 0 1 1 0 0 0 0
3 8 9 4 3 0 0 0 0 0 1 1 0 0 0 0
3 9 10 6 5 0 0 0 0 0 1 1 0 0 0 0
3 10 10 11 6 0 0 0 0 0 1 1 0 0 0 0
3 11 11 7 6 0 0 0 0 0 1 1 0 0 0 0
3 12 11 12 7 0 0 0 0 0 1 1 0 0 0 0
3 13 12 13 7 0 0 0 0 0 1 1 0 0 0 0
3 14 13 14 7 0 0 0 0 0 1 1 0 0 0 0
3 15 14 15 7 0 0 0 0 0 1 1 0 0 0 0
3 16 15 8 7 0 0 0 0 0 1 1 0 0 0 0
3 17 15 16 8 0 0 0 0 0 1 1 0 0 0 0
3 18 16 9 8 0 0 0 0 0 1 1 0 0 0 0
3 19 10 17 11 0 0 0 0 0 1 1 0 0 0 0
3 20 17 18 11 0 0 0 0 0 1 1 0 0 0 0
3 21 18 12 11 0 0 0 0 0 1 1 0 0 0 0

```

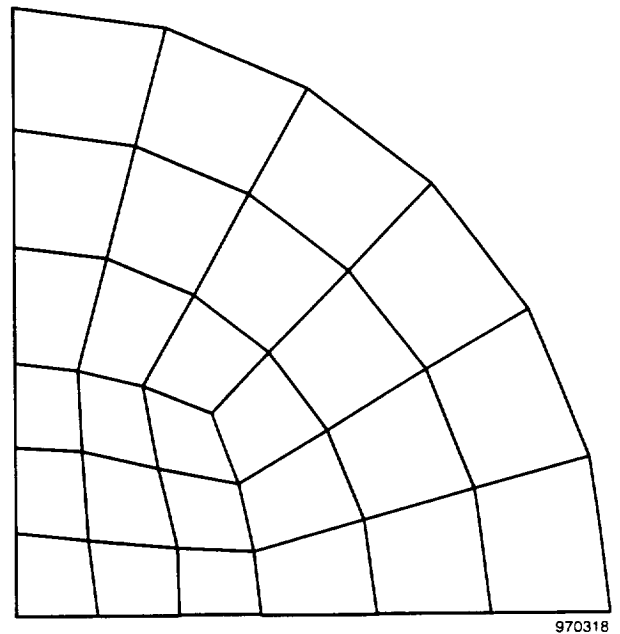
```

3  22  18  19  12  0  0  0  0  0  1  1  0  0  0  0
3  23  19  13  12  0  0  0  0  0  1  1  0  0  0  0
3  24  19  20  13  0  0  0  0  0  1  1  0  0  0  0
3  25  20  21  13  0  0  0  0  0  1  1  0  0  0  0
3  26  21  14  13  0  0  0  0  0  1  1  0  0  0  0
3  27  21  22  14  0  0  0  0  0  1  1  0  0  0  0
3  28  22  15  14  0  0  0  0  0  1  1  0  0  0  0
3  29  22  23  15  0  0  0  0  0  1  1  0  0  0  0
3  30  23  16  15  0  0  0  0  0  1  1  0  0  0  0
3  31  24  18  17  0  0  0  0  0  1  1  0  0  0  0
3  32  24  25  18  0  0  0  0  0  1  1  0  0  0  0
3  33  25  19  18  0  0  0  0  0  1  1  0  0  0  0
3  34  25  26  19  0  0  0  0  0  1  1  0  0  0  0
3  35  26  20  19  0  0  0  0  0  1  1  0  0  0  0
3  36  26  27  20  0  0  0  0  0  1  1  0  0  0  0
3  37  27  28  20  0  0  0  0  0  1  1  0  0  0  0
3  38  28  21  20  0  0  0  0  0  1  1  0  0  0  0
3  39  28  29  21  0  0  0  0  0  1  1  0  0  0  0
3  40  29  22  21  0  0  0  0  0  1  1  0  0  0  0
3  41  29  30  22  0  0  0  0  0  1  1  0  0  0  0
3  42  30  23  22  0  0  0  0  0  1  1  0  0  0  0
3  43  31  25  24  0  0  0  0  0  1  1  0  0  0  0
3  44  31  32  25  0  0  0  0  0  1  1  0  0  0  0
3  45  32  26  25  0  0  0  0  0  1  1  0  0  0  0
3  46  32  33  26  0  0  0  0  0  1  1  0  0  0  0
3  47  33  27  26  0  0  0  0  0  1  1  0  0  0  0
3  48  33  34  27  0  0  0  0  0  1  1  0  0  0  0
3  49  34  35  27  0  0  0  0  0  1  1  0  0  0  0
3  50  35  28  27  0  0  0  0  0  1  1  0  0  0  0
3  51  35  36  28  0  0  0  0  0  1  1  0  0  0  0
3  52  36  29  28  0  0  0  0  0  1  1  0  0  0  0
3  53  36  37  29  0  0  0  0  0  1  1  0  0  0  0
3  54  37  30  29  0  0  0  0  0  1  1  0  0  0  0
$ SHELL ELEMENT THICKNESSES
1  .01576 .01576 .01576
$ MATERIAL PROPERTIES
1  1
10.E+06 .3000E+00 .0000E+00 2.450E-04
$ DYNAMIC MODAL FORCE DATA
0.5
1  3  -25.0
-1
$ INCREMENTAL TIME DATA FOR DYNAMIC RESPONSE ANALYSIS
2.0E-06 250

```



(a) Triangular mesh.



(b) Quadrilateral mesh.

Figure 34. One-quarter cap model.

STARS-SOLIDS output summary: table 23 shows the results for the nonlinear static solution. Figure 35 shows the displacement as a function of the load plot. Figure 36 shows the displacement as a function of the time plot for the nonlinear response solution.

Table 23. Center deflection for a clamped spherical cap under apex load.

Load increment	Displacement, W/H	
	Quadrilateral mesh	Triangular mesh
4	0.0384	0.03694
12	0.1601	0.15374
20	0.4542	0.41541
24	0.5859	0.56075
28	0.7007	0.69837
32	0.8103	0.82891
36	0.9186	0.9522
40	1.0308	1.0753
44	1.1575	1.2173
48	1.3470	1.4091
52	1.5054	1.5400
56	1.6313	1.6211
60	1.7058	1.6794
70	1.8159	1.7827
80	1.8882	1.8576
90	1.9444	1.9179
100	1.9891	1.9689

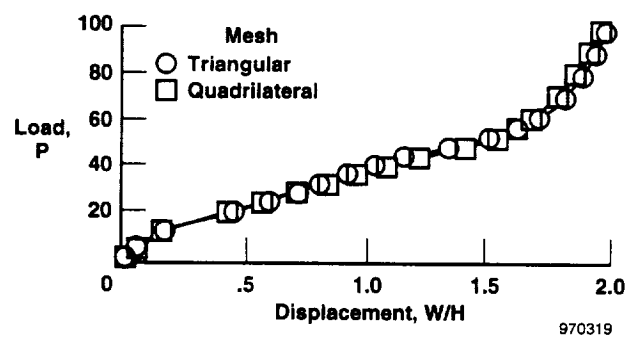


Figure 35. Cap center displacement as a function of load.

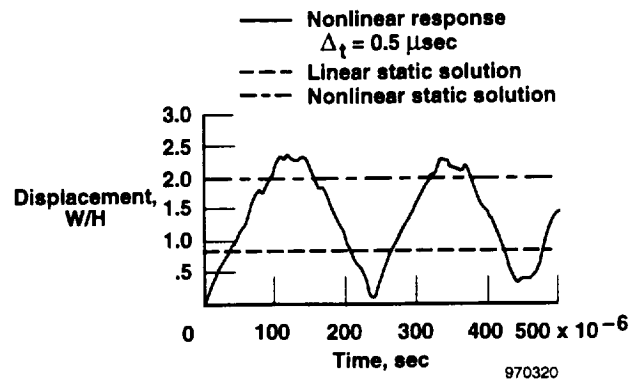
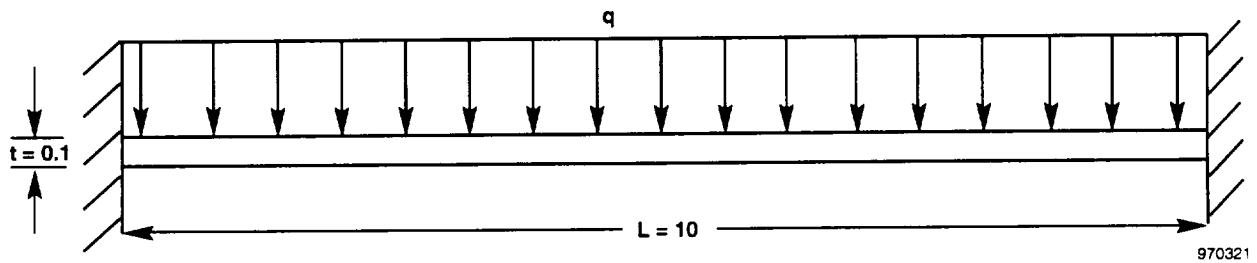


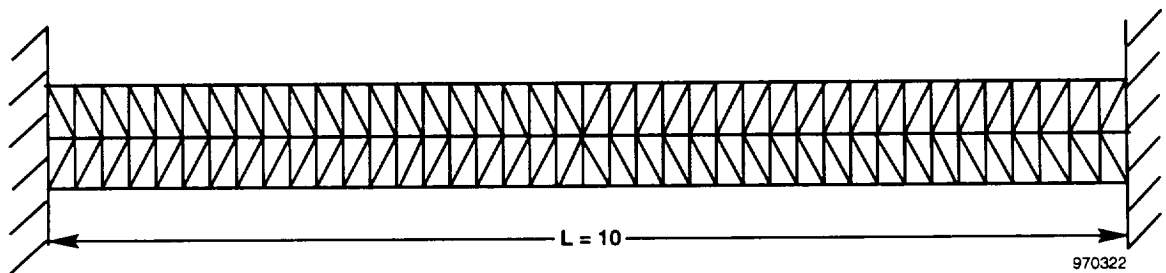
Figure 36. Cap center displacement as a function of time.

4.2.6 Clamped Beam: Elastoplastic Analysis

Figure 37 shows a clamped beam under uniformly distributed load. A triangular shell-element mesh was used for modeling; the beam is considered to consist of several layers of elements. Table 24 and figure 38 show the results.

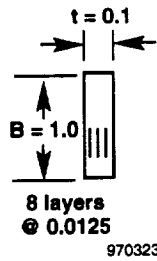


(a) Uniform distributed load on the beam.



(b) Finite element model of the beam.

Figure 37. Clamped beam under uniformly distributed load.



(c) Cross section.

Figure 37. Concluded.

Important data parameters:

Young's modulus, E	= 1.0×10^7
Poisson's ratio, μ	= 0.3
Thickness, t	= 0.1
Length, L	= 10.0
Width, B	= 1.0
Yield stress, σ_y	= 35,000
Hardening, H'	= 0

STARS-SOLIDS input data:

Elasto-Plastic analysis of a strip with both ends fixed

```

123 160 1 6 0 0 0 1 1 8
0 1 0 1 0 0 0 0 0 0
11 0 0 1 0 0 0 0 0 0
2 0 2 0 1 0 0 1 0 18
$ NODE DESCRIPTION
1 .00000 .00000 .00000 1 1 1 1 1 1
2 .00000 .50000 .00000 1 1 1 1 1 1
3 .00000 1.00000 .00000 1 1 1 1 1 1
4 .25000 .00000 .00000 0 0 0 0 0 0
118 9.75000 .00000 .00000 0 0 0 0 0 0 3
5 .25000 .50000 .00000 0 0 0 0 0 0
119 9.75000 .50000 .00000 0 0 0 0 0 0 3
6 .25000 1.00000 .00000 0 0 0 0 0 0
120 9.75000 1.00000 .00000 0 0 0 0 0 0 3
121 10.00000 .00000 .00000 1 1 1 1 1 1
122 10.00000 .50000 .00000 1 1 1 1 1 1
123 10.00000 1.00000 .00000 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
7 1 1 4 5 0 0 0 0 1 1 0 0 1 0
7 20 58 61 62 0 0 0 0 1 1 0 0 1 0 3
7 21 5 2 1 0 0 0 0 1 1 0 0 1 0
7 40 62 59 58 0 0 0 0 1 1 0 0 1 0 3
7 41 2 5 3 0 0 0 0 1 1 0 0 1 0
7 60 59 62 60 0 0 0 0 1 1 0 0 1 0 3
7 61 6 3 5 0 0 0 0 1 1 0 0 1 0
7 80 63 60 62 0 0 0 0 1 1 0 0 1 0 3
7 81 61 64 62 0 0 0 0 1 1 0 0 1 0
7 100 118 121 119 0 0 0 0 1 1 0 0 1 0 3
7 101 65 62 64 0 0 0 0 1 1 0 0 1 0
7 120 122 119 121 0 0 0 0 1 1 0 0 1 0 3
7 121 62 65 66 0 0 0 0 1 1 0 0 1 0
7 140 119 122 123 0 0 0 0 1 1 0 0 1 0 3
7 141 66 63 62 0 0 0 0 1 1 0 0 1 0
7 160 123 120 119 0 0 0 0 1 1 0 0 1 0 3
$ COMPOSITE SHELL ELEMENT STACK DESCRIPTION DATA
1 8
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1
1 0.0125 1

```

```

$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION
1 2 0
0.0
$ ELEMENT MATERIAL PROPERTIES
1 1
10.0E+6 0.3 0.0 0.0 35.0E+3 0.0
$ PRESSURE DATA
1 0.875

```

STARS-SOLIDS output summary: table 24 shows the results for the elastoplastic analysis. Figure 38 shows the displacement as a function of load plot.

Table 24. Maximum uniformly distributed load for a clamped beam.

$q_{\max}$		Difference, percent
STARS	Theory	
14.875	14.0	6.25

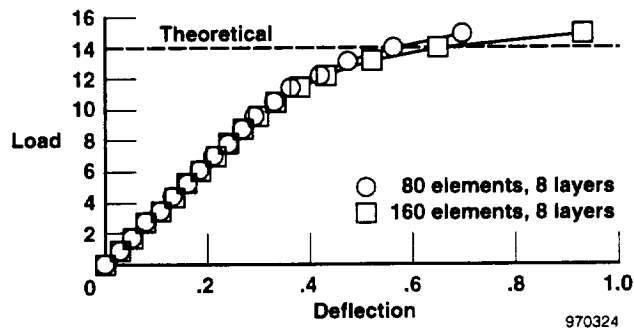


Figure 38. Load-deflection curve for a clamped beam.

4.3 STARS-SOLIDS Heat Transfer (Linear Analysis)

In this section, the input data and relevant outputs of typical heat-transfer test cases are provided in detail. The input data are prepared in accordance with the procedures described in section 3 and are defined in consistent unit form.

4.3.1 Cooling Fin: Convection Boundary Condition

A linear steady-state heat-transfer analysis of a cooling fin (fig. 39) was performed using heat-transfer line elements. The results are given below.

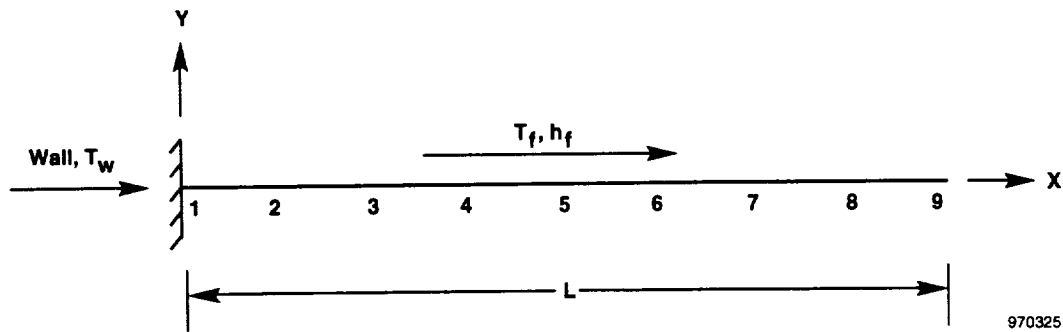


Figure 39. Cooling fin with convection.

Important data parameters: arbitrary available element and material properties data are used for the analysis to correlate results with existing ones expressed in parametric form.

Coefficient of conductivity, k	= 132.0
Convective heat transfer coefficient, h_f	= 1.6
Fluid temperature, T_f	= 70
Wall temperature, T_w	= 250
Length, L	= 1
Area, A	= 0.001365
Perimeter, P	= 0.13091
specific heat, c_p	= 0.2

STARS-SOLIDS HEAT-TRANSFER input data:

```

HEAT TRANSFER - TRUSS
10,0,1,11,1,0,0,0,0,0
0,0,0,1,1,0,0,0,0
10,0,0,1,0,0,0,0,0
2,0,1,0,0,0,0,1,0,0
$ NODAL DATA
 1 0.0 0.0 0.0 0 1 1 1 1 1
 2 0.125 0.0 0.0 0 1 1 1 1 1
 3 0.250 0.0 0.0 0 1 1 1 1 1
 4 0.375 0.0 0.0 0 1 1 1 1 1
 5 0.500 0.0 0.0 1 1 1 1 1 1
 6 0.625 0.0 0.0 0 1 1 1 1 1
 7 0.750 0.0 0.0 0 1 1 1 1 1
 8 0.875 0.0 0.0 0 1 1 1 1 1
 9 1.000 0.0 0.0 0 1 1 1 1 1
10 0.0 50.0 0.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
 1 1 1 2 10 0 0 0 0 1 1 1
 1 2 2 3 10 0 0 0 0 1 1 1
 1 3 3 4 10 0 0 0 0 1 1 1
 1 4 4 5 10 0 0 0 0 1 1 1
 1 5 5 6 10 0 0 0 0 1 1 1
 1 6 6 7 10 0 0 0 0 1 1 1
 1 7 7 8 10 0 0 0 0 1 1 1
 1 8 8 9 10 0 0 0 0 1 1 1
$ LINE ELEMENT BASIC PROPERTIES
 1 0.001365 0.13091
$ ELEMENT MATERIAL PROPERTIES
 1 6
13.2E01 1.6 0 0.0 70.0 0.0 0.0
 0.0 0.0 0 0.0
$ TEMPERATURE BOUNDARY CONDITION DATA
 1 1 1 1 250.

```

STARS-SOLIDS HEAT-TRANSFER analysis results:

NODE							
EXT	INT	TEM-SUR 1	TEM-SUR 2	TEM-SUR 3	TEM-SUR 4	TEM-SUR 5	TEM-SUR 6
1	1	0.250000E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2	2	0.232333E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3	3	0.217624E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4	4	0.205605E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5	5	0.196056E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
6	6	0.188803E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
7	7	0.183715E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
8	8	0.180699E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
9	9	0.179700E+03	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
10	10	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00

4.3.2 Three-Dimensional Box: Specified Nodal Temperature

Figure 40 shows a three-dimensional box that is characterized by orthotropic material. The results of a linear steady-state heat-transfer analysis of the problem are presented herein.

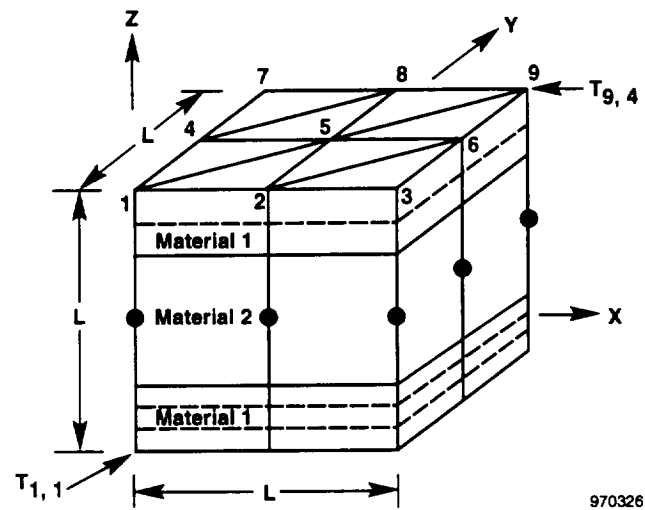


Figure 40. Three-dimensional box with conduction.

Important data parameters:

Length, L	= 1.0
Node temperature, $T_{1,1}$	= 500
Node temperature, $T_{9,4}$	= 0
Material 1:	
Coefficients of conductivity, k	
k_{xx}	= 3.0
k_{yy}	= 1.0
k_{zz}	= 1.0
Thickness, t	= 0.3
Material 2:	
Coefficients of conductivity, k	
k_{xx}	= 1.0
k_{yy}	= 3.0
k_{zz}	= 3.0
Thickness, t	= 0.4

STARS-SOLIDS HEAT-TRANSFER input data:

A UNIT LENGTH FIRECLAY BRICK - 2X2 TRIANGLE MESH - HEAT TRANSFER - C2

9,0,2,44,0,0,0,2,1,6

0,0,0,1,2,0,0,0,0

10,0,0,1,0,0,0,0

2,0,2,0,1,0,0,1,0,0

\$ MODAL DATA

1	0.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	0
2	0.5000	0.0000	0.0000	0	0	0	0	1	1	0	0	0
3	1.0000	0.0000	0.0000	0	0	0	0	1	1	0	0	0
4	0.0000	0.5000	0.0000	0	0	0	0	1	1	0	0	0
5	0.5000	0.5000	0.0000	0	0	0	0	1	1	0	0	0
6	1.0000	0.5000	0.0000	0	0	0	0	1	1	0	0	0
7	0.0000	1.0000	0.0000	0	0	0	0	1	1	0	0	0
8	0.5000	1.0000	0.0000	0	0	0	0	1	1	0	0	0
9	1.0000	1.0000	0.0000	0	0	0	0	1	1	0	0	0

\$ ELEMENT CONNECTIVITY

7	1	1	2	5	0	0	0	0	1	1	0	0	0
7	2	5	4	1	0	0	0	0	1	1	0	0	0
7	3	2	3	6	0	0	0	0	1	1	0	0	0
7	4	6	5	2	0	0	0	0	1	1	0	0	0
7	5	4	5	8	0	0	0	0	1	1	0	0	0
7	6	8	7	4	0	0	0	0	1	1	0	0	0
7	7	5	6	9	0	0	0	0	1	1	0	0	0
7	8	9	8	5	0	0	0	0	1	1	0	0	0

\$ COMPOSITE SHELL ELEMENT, STACKS AND SUBSTACKS DEFINITION

1	6	3	3	1	2	0	0
1	.15000	2					
1	.15000	1					
2	.40000	1					
1	.10000	1					
1	.10000	2					
1	.10000	1					

\$ SPECIFICATION FOR MATERIAL AXES ORIENTATION

1	2	0
	0.0	
2	2	0
	1.5708	

\$ ELEMENT MATERIAL PROPERTIES

1	8						
	3.	0.	1.	1.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
2	8						
	1.	0.	3.	3.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.

\$ TEMPERATURE BOUNDARY CONDITION DATA

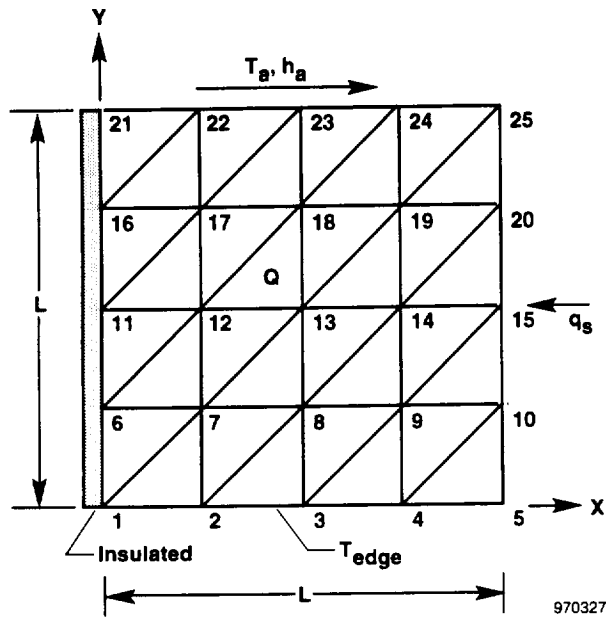
1	1	1	1	500.
9	4	9	4	0.

STARS-SOLIDS HEAT-TRANSFER analysis results:

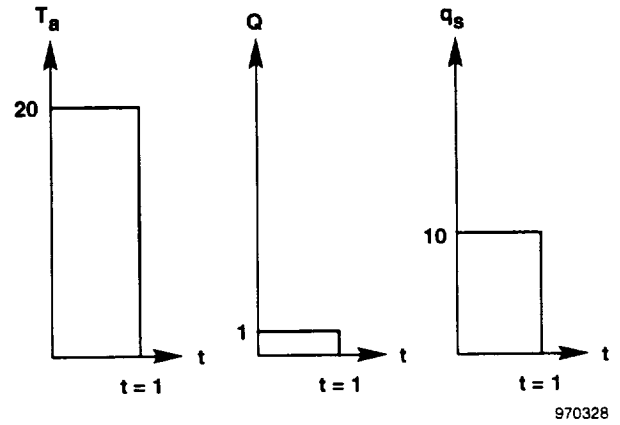
NODE		TEM-SUR 1	TEM-SUR 2	TEM-SUR 3	TEM-SUR 4	TEM-SUR 5	TEM-SUR 6
EXT	INT						
1	1	0.500000E+03	0.224775E+03	0.212203E+03	0.200333E+03	0.000000E+00	0.000000E+00
2	2	0.267260E+03	0.223166E+03	0.207237E+03	0.199651E+03	0.000000E+00	0.000000E+00
3	3	0.232398E+03	0.211402E+03	0.203162E+03	0.197953E+03	0.000000E+00	0.000000E+00
4	4	0.205148E+03	0.208393E+03	0.196695E+03	0.196979E+03	0.000000E+00	0.000000E+00
5	5	0.185295E+03	0.202975E+03	0.188997E+03	0.199701E+03	0.000000E+00	0.000000E+00
6	6	0.189722E+03	0.193493E+03	0.185473E+03	0.187941E+03	0.000000E+00	0.000000E+00
7	7	0.193992E+03	0.186909E+03	0.178882E+03	0.164663E+03	0.000000E+00	0.000000E+00
8	8	0.191341E+03	0.181805E+03	0.169013E+03	0.142837E+03	0.000000E+00	0.000000E+00
9	9	0.190919E+03	0.176588E+03	0.169369E+03	0.000000E+00	0.000000E+00	0.000000E+00

4.3.3 Square Plate: Transient Heating

A heat-transfer analysis of a square plate (fig. 41) with transient internal heating, heat flow, and convective heating was performed. The results are presented here.



(a) Plate model.



(b) Pulse heating.

Figure 41. Square plate with transient heating.

Important data parameters:

Coefficient of conductivity, k	= 1.0
Internal heat generation rate, Q	= 1.0
Surface heat flow rate, q_s	= 10.0
Convective heat-transfer coefficient, h_a	= 3.0
Air temperature, T_a	= 20
Edge temperature, T_{edge}	= 10
Length, L	= 1
Thickness, t	= 0.1
Time step, Δt	= 0.05
Total time period for response	= 4.0

STARS-SOLIDS HEAT-TRANSFER input data:

SHELL -4x4- Isotropic plate - Transient heat loading

25,32,2,44,0,0,0,1,2,1

0,0,0,2,10,0,0,0,0

10,0,1,1,0,0,0,0

2,0,2,0,1,0,0,1,0,0

1,20,0,1675.,3.0,0.0

0,1,1,2

\$ NODAL DATA

1	0.000	0.000	0.000	0	0	1	1	1	1	0	0	0
2	0.250	0.000	0.000	0	0	1	1	1	1	0	0	0
3	0.500	0.000	0.000	0	0	1	1	1	1	0	0	0
4	0.750	0.000	0.000	0	0	1	1	1	1	0	0	0
5	1.000	0.000	0.000	0	0	1	1	1	1	0	0	0
6	0.000	0.250	0.000	0	0	1	1	1	1	0	0	0
7	0.250	0.250	0.000	0	0	1	1	1	1	0	0	0
8	0.500	0.250	0.000	0	0	1	1	1	1	0	0	0
9	0.750	0.250	0.000	0	0	1	1	1	1	0	0	0
10	1.000	0.250	0.000	0	0	1	1	1	1	0	0	0
11	0.000	0.500	0.000	0	0	1	1	1	1	0	0	0
12	0.250	0.500	0.000	0	0	1	1	1	1	0	0	0
13	0.500	0.500	0.000	0	0	1	1	1	1	0	0	0
14	0.750	0.500	0.000	0	0	1	1	1	1	0	0	0
15	1.000	0.500	0.000	0	0	1	1	1	1	0	0	0
16	0.000	0.750	0.000	0	0	1	1	1	1	0	0	0
17	0.250	0.750	0.000	0	0	1	1	1	1	0	0	0
18	0.500	0.750	0.000	0	0	1	1	1	1	0	0	0
19	0.750	0.750	0.000	0	0	1	1	1	1	0	0	0
20	1.000	0.750	0.000	0	0	1	1	1	1	0	0	0
21	0.000	1.000	0.000	0	0	1	1	1	1	0	0	0
22	0.250	1.000	0.000	0	0	1	1	1	1	0	0	0
23	0.500	1.000	0.000	0	0	1	1	1	1	0	0	0
24	0.750	1.000	0.000	0	0	1	1	1	1	0	0	0
25	1.000	1.000	0.000	0	0	1	1	1	1	0	0	0

\$ ELEMENT CONNECTIVITY CONDITIONS

7	1	1	7	6	0	0	0	1	1	0	0	0	0	0
7	2	7	1	2	0	0	0	0	1	1	0	0	0	0
7	3	2	8	7	0	0	0	0	1	1	0	0	0	0
7	4	8	2	3	0	0	0	0	1	1	0	0	0	0
7	5	3	9	8	0	0	0	0	1	1	0	0	0	0
7	6	9	3	4	0	0	0	0	1	1	0	0	0	0
7	7	4	10	9	0	0	0	0	1	1	0	0	0	0
7	8	10	4	5	0	0	0	0	1	1	0	0	0	0
7	9	6	12	11	0	0	0	0	1	1	0	0	0	0
7	10	12	6	7	0	0	0	0	1	1	0	0	0	0
7	11	7	13	12	0	0	0	0	1	1	0	0	0	0
7	12	13	7	8	0	0	0	0	1	1	0	0	0	0
7	13	8	14	13	0	0	0	0	1	1	0	0	0	0
7	14	14	8	9	0	0	0	0	1	1	0	0	0	0
7	15	9	15	14	0	0	0	0	1	1	0	0	0	0
7	16	15	9	10	0	0	0	0	1	1	0	0	0	0
7	17	11	17	16	0	0	0	0	1	1	0	0	0	0
7	18	17	11	12	0	0	0	0	1	1	0	0	0	0
7	19	12	18	17	0	0	0	0	1	1	0	0	0	0
7	20	18	12	13	0	0	0	0	1	1	0	0	0	0
7	21	13	19	18	0	0	0	0	1	1	0	0	0	0
7	22	19	13	14	0	0	0	0	1	1	0	0	0	0
7	23	14	20	19	0	0	0	0	1	1	0	0	0	0
7	24	20	14	15	0	0	0	0	1	1	0	0	0	0
7	25	16	22	21	0	0	0	0	2	1	0	0	0	0
7	26	22	16	17	0	0	0	0	1	1	0	0	0	0
7	27	17	23	22	0	0	0	0	2	1	0	0	0	0
7	28	23	17	18	0	0	0	0	1	1	0	0	0	0
7	29	18	24	23	0	0	0	0	2	1	0	0	0	0
7	30	24	18	19	0	0	0	0	1	1	0	0	0	0
7	31	19	25	24	0	0	0	0	2	1	0	0	0	0
7	32	25	19	20	0	0	0	0	1	1	0	0	0	0

\$ COMPOSITE SHELL ELEMENT

1	1	1	1	0	0	0
1	0.1000	1				
2	1	1	1	0	0	0
2	0.1000	1				

\$ SPECIFICATION FOR MATERIAL AXES ORIENTATION

1	2	0
		0.0

\$ ELEMENT MATERIAL PROPERTIES

1	8						
	1.	0.	1.	1.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	1.	1.					
2	8						
	1.	0.	1.	1.	0.	3.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	1.	1.					

\$ TEMPERATURE BOUNDARY CONDITION DATA

1	1	1	1	10.
1	2	1	2	10.
2	1	2	1	10.
2	2	2	2	10.
3	1	3	1	10.
3	2	3	2	10.
4	1	4	1	10.
4	2	4	2	10.
5	1	5	1	10.
5	2	5	2	10.

\$ MODAL FORCE ACCELERATION/ELEMENT HEAT TRANSFER DATA

		1.0		
1	1	1.0	0.0	0.0
2	1	1.0	0.0	0.0
3	1	1.0	0.0	0.0
4	1	1.0	0.0	0.0
5	1	1.0	0.0	0.0
6	1	1.0	0.0	0.0
7	1	1.0	0.0	0.0
8	3	1.0	10.0	0.0
9	1	1.0	0.0	0.0
10	1	1.0	0.0	0.0
11	1	1.0	0.0	0.0
12	1	1.0	0.0	0.0
13	1	1.0	0.0	0.0
14	1	1.0	0.0	0.0
15	1	1.0	0.0	0.0
16	3	1.0	10.0	0.0
17	1	1.0	0.0	0.0
18	1	1.0	0.0	0.0
19	1	1.0	0.0	0.0
20	1	1.0	0.0	0.0
21	1	1.0	0.0	0.0
22	1	1.0	0.0	0.0
23	1	1.0	0.0	0.0
24	3	1.0	10.0	0.0
25	2	1.0	0.0	20.0
26	1	1.0	0.0	0.0
27	2	1.0	0.0	20.0
28	1	1.0	0.0	0.0
29	2	1.0	0.0	20.0
30	1	1.0	0.0	0.0
31	2	1.0	0.0	20.0
32	3	1.0	10.0	0.0

-1

\$ INCREMENTAL TIME DATA FOR DYNAMIC RESPONSE ANALYSIS

0.05	20
0.05	60

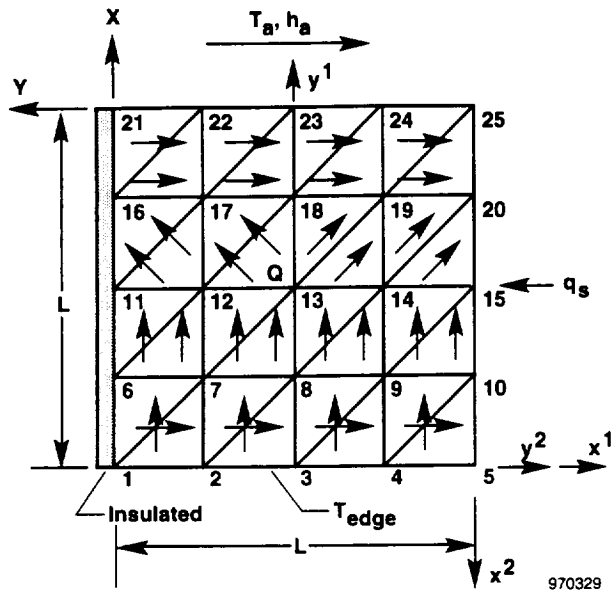
STARS-SOLIDS HEAT-TRANSFER output summary: table 25 shows the results.

Table 25. Heat-transfer analysis results of a square plate with transient heating.

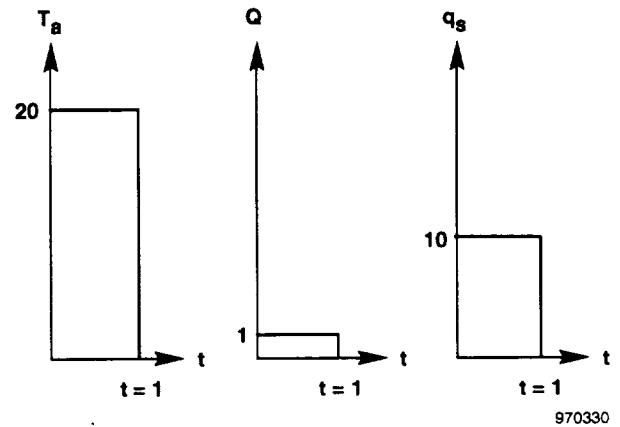
Node	Temperature	
	Time = 1.0	Time = 4.0
1	10.0000	10.0000
2	10.0000	10.0000
3	10.0000	10.0000
4	10.0000	10.0000
5	10.0000	10.0000
6	12.4740	8.1250
7	12.5685	8.1250
8	12.9048	8.1250
9	13.6278	8.1250
10	15.1516	8.1250
11	14.6934	6.2500
12	14.8553	6.2500
13	15.3559	6.2500
14	16.4015	6.2500
15	18.3025	6.2500
16	16.5866	4.3750
17	16.7153	4.3750
18	17.2313	4.3750
19	18.2784	4.3750
20	20.1826	4.3750
21	18.0622	2.5000
22	18.1970	2.5000
23	18.5183	2.5000
24	19.2186	2.5000
25	20.8599	2.5000

4.3.4 Composite Square Plate: Transient Heating

This problem repeats the problem in section 4.3.3 with composite material (fig. 42), and the solution results are given below.



(a) Plate model.



(b) Pulse heating.

Figure 42. Composite square plate with transient heating.

Important data parameters:

Coefficient of conductivity, k_x	= 3.0
Coefficient of conductivity, k_y	= 1.0
Coefficient of conductivity, k_z	= 1.0
Internal heat generation rate, Q	= 1.0
Heat flow rate, q_s	= 10.0
Convective heat transfer coefficient, h_a	= 3.0
Air temperature, T_a	= 20
Edge temperature, T_{edge}	= 10
Length, L	= 1
Thickness, t of each layer	= 0.0315
Time step, Δt	= 0.05
Total time period for response	= 4.0

STARS-SOLIDS HEAT-TRANSFER input data:

SHELL -4x4- composite element - Transient heat loading

25,32,2,44,0,0,2,4,6,2

0,0,0,2,10,0,0,0,0

10,0,1,1,0,0,0,0

2,0,2,0,1,0,0,1,0,0

2,20,0,1675.,3.0,0.0

0,1,1,2

\$ MODAL DATA

1	-0.5	0.0	0.0	0	0	0	0	0	0	1	0	0
5	0.5	0.0	0.0	0	0	0	0	0	0	1	0	1
6	-0.25	-1.0	0.0	0	0	0	0	0	0	2	0	0
10	-0.25	0.0	0.0	0	0	0	0	0	0	2	0	1
11	-0.5	0.5	0.0	0	0	0	0	0	0	1	0	0
15	0.5	0.5	0.0	0	0	0	0	0	0	1	0	1
16	-0.25	0.0	0.0	0	0	0	0	0	0	0	0	0
20	-0.25	-1.0	0.0	0	0	0	0	0	0	0	0	1
21	-0.5	1.0	0.0	0	0	0	0	0	0	1	0	0
25	0.5	1.0	0.0	0	0	0	0	0	0	1	0	1

\$ LOCAL-GLOBAL COORDINATE SYSTEM DATA

1	2											
	-1.0	-0.5	0.0	0.0	-1.0	0.0						
	1.0	0.0	0.0	0.0	0.0	1.0						
2	1											
	-1.0	-1.0	0.0	-1.5	-1.0	0.0						
	-1.5	-1.5	0.0									

\$ ELEMENT CONNECTIVITY CONDITIONS

7	1	7	6	1	0	0	0	0	1	1	0	0	0	0	0
7	2	1	2	7	0	0	0	0	1	1	0	0	0	0	0
7	3	8	7	2	0	0	0	0	1	1	0	0	0	0	0
7	4	2	3	8	0	0	0	0	1	1	0	0	0	0	0
7	5	9	6	3	0	0	0	0	1	1	0	0	0	0	0
7	6	3	4	9	0	0	0	0	1	1	0	0	0	0	0
7	7	10	9	4	0	0	0	0	1	1	0	0	0	0	0
7	8	4	5	10	0	0	0	0	1	1	0	0	0	0	0
7	9	12	11	6	0	0	0	0	2	1	0	0	0	0	0
7	10	6	7	12	0	0	0	0	2	1	0	0	0	0	0
7	11	13	12	7	0	0	0	0	2	1	0	0	0	0	0
7	12	7	8	13	0	0	0	0	2	1	0	0	0	0	0
7	13	14	13	8	0	0	0	0	2	1	0	0	0	0	0
7	14	8	9	14	0	0	0	0	2	1	0	0	0	0	0
7	15	15	14	9	0	0	0	0	2	1	0	0	0	0	0
7	16	9	10	15	0	0	0	0	2	1	0	0	0	0	0
7	17	17	16	11	0	0	0	0	3	1	0	0	0	0	0
7	18	11	12	17	0	0	0	0	3	1	0	0	0	0	0
7	19	18	17	12	0	0	0	0	3	1	0	0	0	0	0
7	20	12	13	18	0	0	0	0	3	1	0	0	0	0	0
7	21	19	18	13	0	0	0	0	4	1	0	0	0	0	0
7	22	13	14	19	0	0	0	0	4	1	0	0	0	0	0
7	23	20	19	14	0	0	0	0	4	1	0	0	0	0	0
7	24	14	15	20	0	0	0	0	4	1	0	0	0	0	0
7	25	22	21	16	0	0	0	0	5	1	0	0	0	0	0
7	26	16	17	22	0	0	0	0	6	1	0	0	0	0	0
7	27	23	22	17	0	0	0	0	5	1	0	0	0	0	0
7	28	17	18	23	0	0	0	0	6	1	0	0	0	0	0
7	29	24	23	18	0	0	0	0	5	1	0	0	0	0	0
7	30	18	19	24	0	0	0	0	6	1	0	0	0	0	0
7	31	25	24	19	0	0	0	0	5	1	0	0	0	0	0
7	32	19	20	25	0	0	0	0	6	1	0	0	0	0	0

\$ COMPOSITE SHELL ELEMENT

1	2	1	2	0	0	0	0
1	0.0315	3					
1	0.0315	1					
2	2	1	2	0	0	0	0
1	0.0315	3					
1	0.0315	3					
3	2	1	2	0	0	0	0
1	0.0315	4					
1	0.0315	4					
4	2	1	2	0	0	0	0
1	0.0315	2					
1	0.0315	2					
5	2	1	2	0	0	0	0
2	0.0315	1					
2	0.0315	1					
6	2	1	2	0	0	0	0
1	0.0315	1					
1	0.0315	1					

\$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION

1 2 0
0.0
2 2 0
0.7854
3 2 0
1.5708
4 2 0
2.3562

\$ ELEMENT MATERIAL PROPERTIES

1 8
3. 0. 1. 1. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
1. 1.
2 8
3. 0. 1. 1. 3. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
1. 1.

\$ TEMPERATURE BOUNDARY CONDITION DATA

1 1 1 1 10.
1 2 1 2 10.
2 1 2 1 10.
2 2 2 2 10.
3 1 3 1 10.
3 2 3 2 10.
4 1 4 1 10.
4 2 4 2 10.
5 1 5 1 10.
5 2 5 2 10.

\$ NODAL FORCE ACCELERATION/ELEMENT HEAT TRANSFER DATA

1.0
1 1 1.0 0.0 0.0
2 1 1.0 0.0 0.0
3 1 1.0 0.0 0.0
4 1 1.0 0.0 0.0
5 1 1.0 0.0 0.0
6 1 1.0 0.0 0.0
7 1 1.0 0.0 0.0
8 2 1.0 10.0 0.0
9 1 1.0 0.0 0.0
10 1 1.0 0.0 0.0
11 1 1.0 0.0 0.0
12 1 1.0 0.0 0.0
13 1 1.0 0.0 0.0
14 1 1.0 0.0 0.0
15 1 1.0 0.0 0.0
16 2 1.0 10.0 0.0
17 1 1.0 0.0 0.0
18 1 1.0 0.0 0.0
19 1 1.0 0.0 0.0
20 1 1.0 0.0 0.0
21 1 1.0 0.0 0.0
22 1 1.0 0.0 0.0
23 1 1.0 0.0 0.0
24 2 1.0 10.0 0.0
25 1 1.0 0.0 20.0
26 1 1.0 0.0 0.0
27 1 1.0 0.0 20.0
28 1 1.0 0.0 0.0
29 1 1.0 0.0 20.0
30 1 1.0 0.0 0.0
31 1 1.0 0.0 20.0
32 2 1.0 10.0 0.0
-1

\$ INCREMENTAL TIME DATA FOR DYNAMIC RESPONSE ANALYSIS

0.05 20
0.05 60

STARS–SOLIDS HEAT-TRANSFER output summary: table 26 shows the results.

Table 26. Heat-transfer analysis results of a composite square plate with transient heating.

Node	Temperature			
	Time = 1.0		Time = 4.0	
	Top	Bottom	Top	Bottom
1	10.0000	10.0000	10.0000	10.0000
2	10.0000	10.0000	10.0000	10.0000
3	10.0000	10.0000	10.0000	10.0000
4	10.0000	10.0000	10.0000	10.0000
5	10.0000	10.0000	10.0000	10.0000
6	12.5207	12.5276	8.0513	8.1142
7	12.5298	12.3328	8.2472	8.1142
8	12.6465	12.4670	8.3308	8.2436
9	13.0094	12.8265	8.4126	8.3416
10	13.8595	13.4883	8.5948	8.3604
11	13.8247	13.8107	6.9806	6.9805
12	13.7669	13.8069	7.1627	7.1480
13	13.9385	14.0073	7.2813	7.2948
14	14.4600	14.5245	7.4240	7.4280
15	15.4611	15.5969	7.5932	7.6121
16	15.3499	15.3530	5.5599	5.5594
17	15.1669	15.1641	5.7781	5.7804
18	15.2786	15.2635	5.9394	5.9396
19	16.6615	15.6458	6.0931	6.0905
20	16.3046	16.2685	6.2944	6.2907
21	17.2782	17.2771	3.2639	3.2643
22	17.3640	17.3634	3.3176	3.3171
23	17.4679	17.4722	3.3927	3.3919
24	17.7457	17.7525	3.4643	3.4648
25	18.3890	18.4030	3.5143	3.5162

4.4. STARS–SOLIDS Heat-Transfer (Nonlinear Analysis)

In this section, the input data and relevant outputs of typical nonlinear heat-transfer test cases are provided in detail. The input data are prepared in accordance with the procedures described in section 3 and are defined in consistent unit form.

4.4.1 Cooling Fin: Radiation Boundary Condition

A nonlinear steady-state radiation analysis of a cooling fin (fig. 43) was performed using heat-transfer line elements. The results are given below.

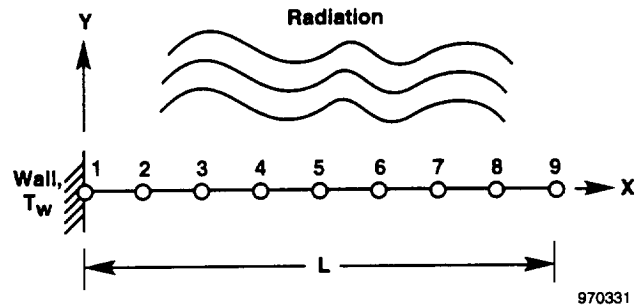


Figure 43. Cooling fin with radiation.

Important data parameters:

Coefficient of conductivity, k	= 132.0
Wall temperature, T_w	= 1500
Length, L	= 1
Area, A	= 0.001365
Stefan-Boltzmann constant, σ	= 0.1713×10^{-8}
Emissivity, ϵ	= 0.6

STARS-SOLIDS HEAT-TRANSFER input data:

```

RADIATION HEAT TRANSFER - TRUSS
10,8,1,11,1,0,0,0,0,0
0,0,0,1,1,0,0,0,0,0
10,0,0,1,0,0,0,0,0
2,0,1,0,0,0,0,1,0,0
$ NODAL DATA
1      0.0      0.0      0.0      0      1      1      1      1      1
2      0.125     0.0      0.0      0      1      1      1      1      1
3      0.250     0.0      0.0      0      1      1      1      1      1
4      0.375     0.0      0.0      0      1      1      1      1      1
5      0.500     0.0      0.0      0      1      1      1      1      1
6      0.625     0.0      0.0      0      1      1      1      1      1
7      0.750     0.0      0.0      0      1      1      1      1      1
8      0.875     0.0      0.0      0      1      1      1      1      1
9      1.000     0.0      0.0      0      1      1      1      1      1
10     0.0      50.0     0.0      1      1      1      1      1      1
$ ELEMENT CONNECTIVITY
1      1      1      2      10      0      0      0      0      0      1      1      1
1      2      2      3      10      0      0      0      0      0      1      1      1
1      3      3      4      10      0      0      0      0      0      1      1      1
1      4      4      5      10      0      0      0      0      0      1      1      1
1      5      5      6      10      0      0      0      0      0      1      1      1
1      6      6      7      10      0      0      0      0      0      1      1      1
1      7      7      8      10      0      0      0      0      0      1      1      1
1      8      8      9      10      0      0      0      0      0      1      1      1
$ LINE ELEMENT BASIC PROPERTIES
1      0.001365  0.13091
$ ELEMENT MATERIAL PROPERTIES
1      6
10.5      0.0      0      0.0      0.0      0.0      0.1713E-8
0.6      0.0      0      0.0
$ TEMPERATURE BOUNDARY CONDITION DATA
1      1      1      1      1500.

```

STARS-SOLIDS HEAT-TRANSFER analysis results:

MODAL TEMPERATURE							
NODE							
EXT	INT	TEM-SUR 1	TEM-SUR 2	TEM-SUR 3	TEM-SUR 4	TEM-SUR 5	TEM-SUR 6
1	1	.150000E+04	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
2	2	.105848E+04	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
3	3	.850319E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
4	4	.727245E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
5	5	.647702E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
6	6	.594974E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
7	7	.561119E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
8	8	.542098E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
9	9	.535953E+03	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
10	10	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00

4.4.2 Three-Dimensional Box: Radiation Boundary Condition

Figure 44 shows a three-dimensional box that is characterized by orthotropic material. The results of a nonlinear steady-state radiation heat-transfer analysis of the problem are presented herein.

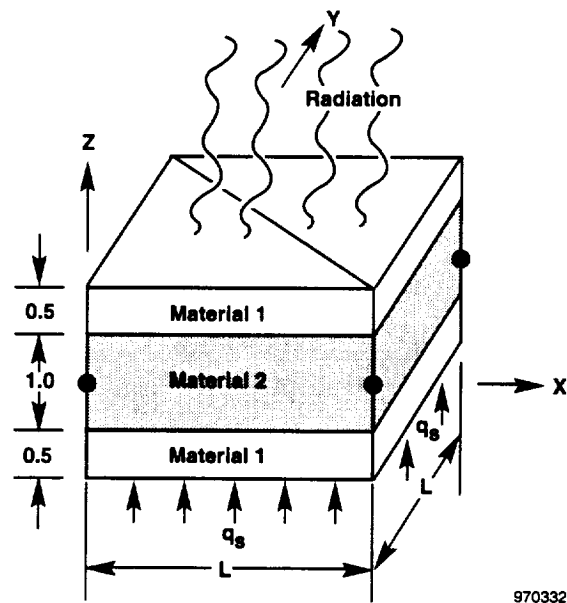


Figure 44. Three-dimensional box with radiation.

Important data parameters:

Length, L = 1.0
 Stefan-Boltzmann constant, σ = 0.1713×10^{-8}
 Emissivity, ϵ = 0.6

Material 1:

Coefficient of conductivity, k
 k_{xx} = 10.5
 k_{yy} = 10.5
 k_{zz} = 10.5
 thickness, t = 0.5

Material 2:

Coefficient of conductivity, k
 k_{xx} = 2.1
 k_{yy} = 2.1
 k_{zz} = 2.1
 thickness, t = 1.0

STARS-SOLIDS HEAT-TRANSFER input data

```

RADIATION HEAT TRANSFER - COMPOSITE BOX
4,2,3,4,0,0,0,1,1,3
1,0,0,1,0,0,0,0,0
10,0,0,1,0,0,0,0
2,0,2,0,1,0,0,1,0,0
$ NODAL DATA
1 0.0000 0.0000 0.0000 0 0 0 0 1 1 0 0 0
2 2.0000 0.0000 0.0000 0 0 0 0 1 1 0 0 0
3 0.0000 2.0000 0.0000 0 0 0 0 1 1 0 0 0
4 2.0000 2.0000 0.0000 0 0 0 0 1 1 0 0 0
$ ELEMENT CONNECTIVITY
7 1 1 2 3 0 0 0 0 1 1 0 0 0
7 2 4 3 2 0 0 0 0 1 1 0 0 0
$ COMPOSITE SHELL ELEMENT
1 3 3 1 1 1 0 0
3 .50000 1
2 1.0000 1
1 .50000 1
$ SPECIFICATION FOR MATERIAL AXES ORIENTATION
1 2 0
0.0
$ ELEMENT MATERIAL PROPERTIES
1 8
10.5 0. 10.5 10.5 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 1000. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0.
2 6
2.1 0. 2.1 2.1 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0.
3 8
10.5 0. 10.5 10.5 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0.1713E-8 0.
0. 0. 0. 0. 0.6 0. 0.
0. 0.
$ INITIAL NODAL TEMPERATURE DATA
1 4 800.0
2 4 800.0
3 4 800.0
4 4 800.0
-1

```

STARS-SOLIDS HEAT-TRANSFER analysis results:

NODE		TEM-SUR 1	TEM-SUR 2	TEM-SUR 3	TEM-SUR 4	TEM-SUR 5	TEM-SUR 6
EXT	INT						
1	1	.156460E+04	.151698E+04	.104079E+04	.993168E+03	.000000E+00	.000000E+00
2	2	.156460E+04	.151698E+04	.104079E+04	.993168E+03	.000000E+00	.000000E+00
3	3	.156460E+04	.151698E+04	.104079E+04	.993168E+03	.000000E+00	.000000E+00
4	4	.156460E+04	.151698E+04	.104079E+04	.993168E+03	.000000E+00	.000000E+00

4.4.3 Composite Square Plate: Radiation Boundary Condition

A radiation heat-transfer analysis of a composite square plate (fig. 45) with a specified temperature was performed. Table 27 shows the results.

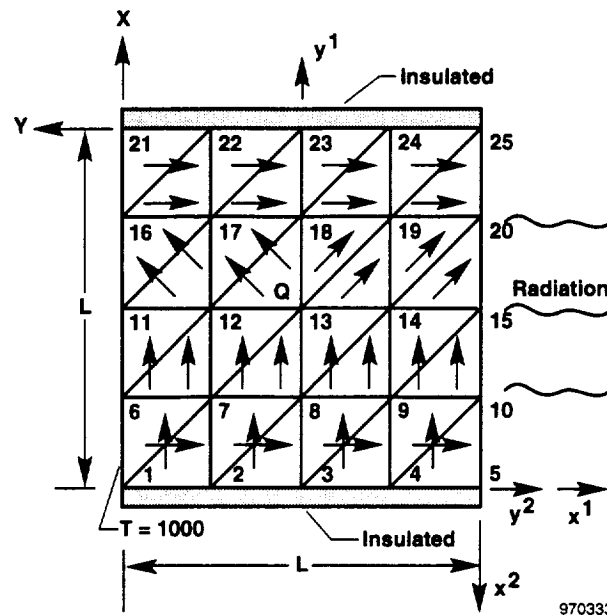


Figure 45. Composite square plate with radiation.

Important data parameters:

Coefficient of conductivity, k_x	= 3.0
Coefficient of conductivity, k_y	= 1.0
Coefficient of conductivity, k_z	= 1.0
Length, L	= 1
Thickness of each layer, t	= 0.0315
Temperature, T	= 1000
Emissivity, ϵ	= 0.6
Stefan-Boltzmann constant, σ	= 0.1713×10^{-8}

STARS-SOLIDS HEAT-TRANSFER input data:

```

SHELL -4x4- composite element - Radiation
25,32,2,44,0,0,2,8,9,2
0,0,0,1,10,0,0,0,0
10,0,0,1,0,0,0,0,0
2,0,2,0,1,0,0,1,0,0
$ MODAL DATA
1      -0.5      0.0      0.0      0      0      0      0      0      0      0      1      0      0
5       0.5      0.0      0.0      0      0      0      0      0      0      0      1      0      1
6      -0.25     -1.0      0.0      0      0      0      0      0      0      0      2      0      0
10     -0.25      0.0      0.0      0      0      0      0      0      0      0      2      0      1
11     -0.5      0.5      0.0      0      0      0      0      0      0      0      1      0      0
15      0.5      0.5      0.0      0      0      0      0      0      0      0      1      0      1
16     -0.25      0.0      0.0      0      0      0      0      0      0      0      0      0      0
20     -0.25     -1.0      0.0      0      0      0      0      0      0      0      0      0      1
21     -0.5      1.0      0.0      0      0      0      0      0      0      0      1      0      0
25      0.5      1.0      0.0      0      0      0      0      0      0      0      1      0      1
$ LOCAL-GLOBAL COORDINATE SYSTEM DATA
1      2
-1.0    -0.5      0.0      0.0    -1.0      0.0
1.0      0.0      0.0      0.0      0.0      1.0
2      1
-1.0    -1.0      0.0    -1.5    -1.0      0.0
-1.5    -1.5      0.0
$ ELEMENT CONNECTIVITY CONDITIONS
7      1      1      7      6      0      0      0      0      1      1      0      0      0      0      0
7      2      7      1      2      0      0      0      0      1      1      0      0      0      0      0
7      3      2      8      7      0      0      0      0      1      1      0      0      0      0      0
7      4      8      2      3      0      0      0      0      1      1      0      0      0      0      0

```

7	5	3	9	8	0	0	0	0	1	1	0	0	0	0	0
7	6	9	3	4	0	0	0	0	1	1	0	0	0	0	0
7	7	4	10	9	0	0	0	0	1	1	0	0	0	0	0
7	8	10	4	5	0	0	0	0	2	1	0	0	0	0	0
7	9	6	12	11	0	0	0	0	3	1	0	0	0	0	0
7	10	12	6	7	0	0	0	0	3	1	0	0	0	0	0
7	11	7	13	12	0	0	0	0	3	1	0	0	0	0	0
7	12	13	7	8	0	0	0	0	3	1	0	0	0	0	0
7	13	8	14	13	0	0	0	0	3	1	0	0	0	0	0
7	14	14	8	9	0	0	0	0	3	1	0	0	0	0	0
7	15	9	15	14	0	0	0	0	3	1	0	0	0	0	0
7	16	15	9	10	0	0	0	0	4	1	0	0	0	0	0
7	17	11	17	16	0	0	0	0	5	1	0	0	0	0	0
7	18	17	11	12	0	0	0	0	5	1	0	0	0	0	0
7	19	12	18	17	0	0	0	0	5	1	0	0	0	0	0
7	20	18	12	13	0	0	0	0	5	1	0	0	0	0	0
7	21	13	19	18	0	0	0	0	6	1	0	0	0	0	0
7	22	19	13	14	0	0	0	0	6	1	0	0	0	0	0
7	23	14	20	19	0	0	0	0	6	1	0	0	0	0	0
7	24	20	14	15	0	0	0	0	7	1	0	0	0	0	0
7	25	16	22	21	0	0	0	0	8	1	0	0	0	0	0
7	26	22	16	17	0	0	0	0	8	1	0	0	0	0	0
7	27	17	23	22	0	0	0	0	8	1	0	0	0	0	0
7	28	23	17	18	0	0	0	0	8	1	0	0	0	0	0
7	29	18	24	23	0	0	0	0	8	1	0	0	0	0	0
7	30	24	18	19	0	0	0	0	8	1	0	0	0	0	0
7	31	19	25	24	0	0	0	0	8	1	0	0	0	0	0
7	32	25	19	20	0	0	0	0	9	1	0	0	0	0	0

\$ COMPOSITE SHELL ELEMENT

1	2	1	2	0	0	0	0
1	0.0315	2					
1	0.0315	7					
2	2	1	2	0	0	0	0
2	0.0315	2					
2	0.0315	7					
3	2	1	2	0	0	0	0
1	0.0315	2					
1	0.0315	2					
4	2	1	2	0	0	0	0
2	0.0315	2					
2	0.0315	2					
5	2	1	2	0	0	0	0
1	0.0315	3					
1	0.0315	3					
6	2	1	2	0	0	0	0
1	0.0315	1					
1	0.0315	1					
7	2	1	2	0	0	0	0
2	0.0315	1					
2	0.0315	1					
8	2	1	2	0	0	0	0
1	0.0315	7					
1	0.0315	7					
9	2	1	2	0	0	0	0
2	0.0315	7					
2	0.0315	7					

\$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION

1	2	0
	0.0	
2	2	0
	0.7854	
3	2	0
	1.5708	
4	2	0
	2.3562	
5	2	0
	3.1416	
6	2	0
	4.7120	
7	2	0
	5.4980	
8	2	0
	3.9260	

\$ ELEMENT MATERIAL PROPERTIES

1	8						
	3.	0.	1.	1.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	1.	1.					
2	8						
	3.	0.	1.	1.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.1713E-8	0.	0.	0.	0.
	0.	0.	0.6	0.	0.	0.	0.
	1.	1.					

\$ TEMPERATURE BOUNDARY CONDITION DATA

1	1	1	1	1000.
1	2	1	2	1000.
6	1	6	1	1000.
6	2	6	2	1000.
11	1	11	1	1000.
11	2	11	2	1000.
16	1	16	1	1000.
16	2	16	2	1000.
21	1	21	1	1000.
21	2	21	2	1000.

STARS-SOLIDS HEAT-TRANSFER output summary: table 27 shows the results.

Table 27. Heat-transfer analysis results for a composite plate with a radiation boundary condition.

Node	Temperature	
	Top	Bottom
1	1000.00	1000.00
2	928.91	930.53
3	866.21	867.33
4	805.83	806.62
5	769.79	771.48
6	1000.00	1000.00
7	940.31	941.10
8	878.29	878.84
9	816.77	818.55
10	762.80	759.63
11	1000.00	1000.00
12	939.80	938.08
13	877.30	875.68
14	814.73	812.71
15	754.18	754.65
16	1000.00	1000.00
17	938.23	938.40
18	875.09	875.52
19	808.93	809.36
20	746.37	746.86
21	1000.00	1000.00
22	938.15	938.12
23	875.23	875.10
24	811.48	811.30
25	761.17	760.90

4.4.4 Three-Dimensional Box: Transient Heating with a Radiation Boundary Condition

The three-dimensional box described in section 4.4.2 is used for this sample problem and is subjected to transient loading (fig. 46). The results of a nonlinear transient heat-transfer analysis for a composite box with radiation at the top and transient heat flow at the bottom are presented herein.

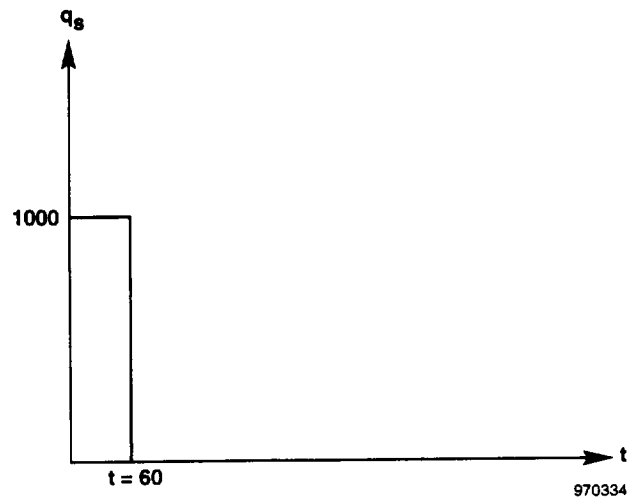


Figure 46. Three-dimensional box pulse heat flow.

STARS-SOLIDS HEAT-TRANSFER input data:

```

RADIATION HEAT TRANSFER - COMPOSITE BOX
4,2,3,4,0,0,0,1,1,3
0,0,0,1,0,0,0,0,0
10,0,1,1,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,10,0,1300.0,0.0,0
0,1,1,2
$ NODAL DATA
1 0.0000 0.0000 0.0000 0 0 0 0 1 1 0 0 0
2 2.0000 0.0000 0.0000 0 0 0 0 1 1 0 0 0
3 0.0000 2.0000 0.0000 0 0 0 0 1 1 0 0 0
4 2.0000 2.0000 0.0000 0 0 0 0 1 1 0 0 0
$ ELEMENT CONNECTIVITY
7 1 1 2 3 0 0 0 0 1 1 0 0 0
7 2 4 3 2 0 0 0 0 1 1 0 0 0
$ COMPOSITE SHELL ELEMENT
1 3 3 1 1 1 0 0
3 .50000 1
2 1.0000 1
1 .50000 1
$ SPECIFICATION FOR MATERIAL AXES ORIENTATION
1 2 0
0.0
$ ELEMENT MATERIAL PROPERTIES
1 8
10.5 0. 10.5 10.5 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0.038 658.
2 8
2.1 0. 2.1 2.1 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0.038 658.

```

```

3      0
10.5   0.    10.5  10.5   0.    0.    0.
0.     0.    0.    0.    0.    0.    0.
0.     0.    0.    0.    0.    0.    0.
0.     0.    0.    0.    0.    0.    0.
0.     0.    0.    0.    0.  0.1713E-8  0.
0.     0.    0.    0.    0.6    0.    0.
0.038  658.
$ ELEMENT HEAT TRANSFER DATA
60.0
1  6      0.0    1000.0    0.0
2  6      0.0    1000.0    0.0
-1
$ INCREMENTAL TIME DATA FOR RESPONSE CALCULATION
1.0  60
1.0  200

```

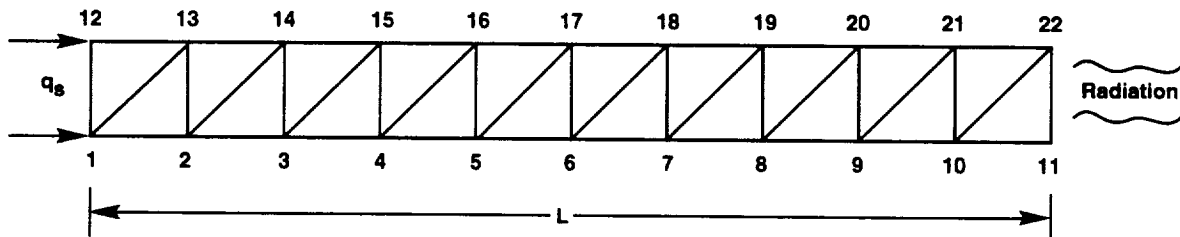
STARS-SOLIDS HEAT-TRANSFER output summary: table 28 shows the results.

Table 28. Nonlinear transient heat-transfer analysis results for a composite box with a radiation boundary condition.

Surface	Temperature	
	Time = 60	Time = 260
1	1255.12	447.864
2	1211.06	447.632
3	868.263	438.458
4	841.579	436.887

4.4.5 Two-Dimensional Strip: Transient Heating with a Radiation Boundary Condition

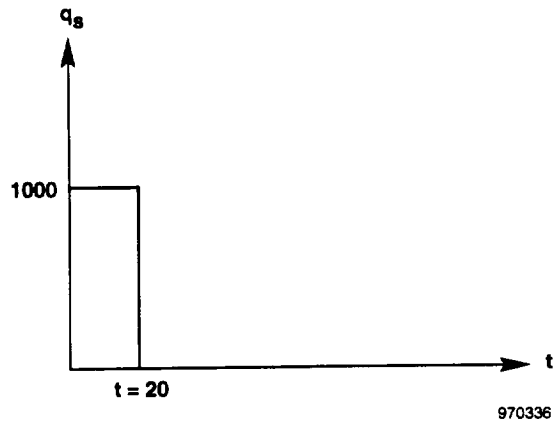
A radiation heat-transfer analysis of a two-dimensional strip (fig. 47) with a transient heat flow was performed. Table 29 shows the results.



970335

(a) Strip model.

Figure 47. Two-dimensional strip with transient heat flow and radiation boundary condition.



(b) Pulse heat flow.

Figure 47. Concluded.

Important data parameters:

Coefficient of conductivity, k	= 10.5
Length, L	= 1.0
Thickness, t	= 0.1
Emissivity, ϵ	= 0.6
Stefan-Boltzmann constant, σ	= 0.1713×10^{-8}
Density, ρ	= 658
Capacity, c	= 0.038

STARS-SOLIDS HEAT-TRANSFER input data:

```

TRANSIENT NONLINEAR (RADIATION) HEAT TRANSFER - 2-D STRIP
22,20,2,44,0,0,0,1,2,1
0,0,0,1,0,0,0,0,0
10,0,1,1,0,0,0,0
2,0,2,0,1,0,0,1,0,0
1,10,0,1300,0,0,0
0,1,1,2
$ MODAL DATA
1 0.0000 0.0000 0.0000 0 0 1 1 1 1
2 0.1000 0.0000 0.0000 0 0 1 1 1 1
3 0.2000 0.0000 0.0000 0 0 1 1 1 1
4 0.3000 0.0000 0.0000 0 0 1 1 1 1
5 0.4000 0.0000 0.0000 0 0 1 1 1 1
6 0.5000 0.0000 0.0000 0 0 1 1 1 1
7 0.6000 0.0000 0.0000 0 0 1 1 1 1
8 0.7000 0.0000 0.0000 0 0 1 1 1 1
9 0.8000 0.0000 0.0000 0 0 1 1 1 1
10 0.9000 0.0000 0.0000 0 0 1 1 1 1
11 1.0000 0.0000 0.0000 0 0 1 1 1 1
12 0.0000 0.1000 0.0000 0 0 1 1 1 1
13 0.1000 0.1000 0.0000 0 0 1 1 1 1
14 0.2000 0.1000 0.0000 0 0 1 1 1 1
15 0.3000 0.1000 0.0000 0 0 1 1 1 1
16 0.4000 0.1000 0.0000 0 0 1 1 1 1
17 0.5000 0.1000 0.0000 0 0 1 1 1 1
18 0.6000 0.1000 0.0000 0 0 1 1 1 1
19 0.7000 0.1000 0.0000 0 0 1 1 1 1
20 0.8000 0.1000 0.0000 0 0 1 1 1 1
21 0.9000 0.1000 0.0000 0 0 1 1 1 1
22 1.0000 0.1000 0.0000 0 0 1 1 1 1

```

```

$ ELEMENT CONNECTIVITY
7 1 1 2 13 0 0 0 0 1 1 0 0 0 0
7 2 2 3 14 0 0 0 0 1 1 0 0 0 0
7 3 3 4 15 0 0 0 0 1 1 0 0 0 0
7 4 4 5 16 0 0 0 0 1 1 0 0 0 0
7 5 5 6 17 0 0 0 0 1 1 0 0 0 0
7 6 6 7 18 0 0 0 0 1 1 0 0 0 0
7 7 7 8 19 0 0 0 0 1 1 0 0 0 0
7 8 8 9 20 0 0 0 0 1 1 0 0 0 0
7 9 9 10 21 0 0 0 0 1 1 0 0 0 0
7 10 10 11 22 0 0 0 0 1 1 0 0 0 0
7 11 13 12 1 0 0 0 0 1 1 0 0 0 0
7 12 14 13 2 0 0 0 0 1 1 0 0 0 0
7 13 15 14 3 0 0 0 0 1 1 0 0 0 0
7 14 16 15 4 0 0 0 0 1 1 0 0 0 0
7 15 17 16 5 0 0 0 0 1 1 0 0 0 0
7 16 18 17 6 0 0 0 0 1 1 0 0 0 0
7 17 19 18 7 0 0 0 0 1 1 0 0 0 0
7 18 20 19 8 0 0 0 0 1 1 0 0 0 0
7 19 21 20 9 0 0 0 0 1 1 0 0 0 0
7 20 22 21 10 0 0 0 0 1 1 0 0 0 0

$ COMPOSITE SHELL ELEMENT
1 1 1 1 0 0 0 0
1 .10000 1
2 1 1 1 0 0 0 0
2 .10000 1

$ SPECIFICATION FOR MATERIAL AXES ORIENTATION
1 2 0
0.0

$ ELEMENT MATERIAL PROPERTIES
1 8
10.5 0. 10.5 10.5 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0.038 658
2 8
10.5 0. 10.5 10.5 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0.1713E-8 0. 0. 0. 0.
0. 0.6 0. 0. 0. 0. 0.
0.038 658

$ ELEMENT HEAT TRANSFER DATA
20.0
11 2 0.0 1000.0 0.0
-1

$ INCREMENTAL TIME DATA FOR RESPONSE CALCULATION
0.2 100
0.2 500

```

STARS–SOLIDS HEAT-TRANSFER output summary: table 29 shows the results.

Table 29. Nonlinear transient heat-transfer analysis results for a two-dimensional strip with a radiation boundary condition.

Node	Temperature	
	Time = 20	Time = 120
1	785.204	410.808
2	775.962	410.793
3	767.581	410.751
4	759.767	410.682
5	752.689	410.586
6	746.294	410.461
7	740.585	410.310
8	735.559	410.130
9	731.208	409.924
10	727.530	409.689
11	724.538	409.427
12	785.072	410.805
13	776.128	410.792
14	767.529	410.751
15	759.777	410.682
16	752.687	410.586
17	746.294	410.461
18	740.585	410.310
19	735.558	410.130
20	731.205	409.924
21	727.516	409.690
22	724.461	409.430

5. STARS-AEROS AND STARS-ASE MODULE DESCRIPTIONS: LINEAR AEROELASTIC AND AEROSERVOELASTIC ANALYSIS

The aeroelastic and aeroservoelastic modules (fig. 2) are recent additions to the original STARS program¹ that are capable of predicting related stability of such structures as aircraft and spacecraft. Thus, when the vibration analysis is performed using the STARS-SOLIDS module, the program continues to determine flutter and divergence characteristics as well as open- and closed-loop stability analyses, as desired. Figure 48 shows a typical feedback control system. Some details of the current analysis techniques have previously been provided.^{15,16}

Section 5.1 gives the detailed numerical formulation in connection with the present aero-structural-control analysis. The unsteady aerodynamic forces for supersonic flow are computed by a constant pressure method,¹⁷ and the doublet lattice method^{18,19} is used for the subsonic case. Both k and p-k stability (flutter and divergence) solution procedures are available to the user.

For the ASE analysis, the aerostructural problem is recast in the Laplace domain when the generalized aerodynamic forces are curve-fitted using Padé and least-squares approximations, thereby yielding the state-space matrices.²⁰ Such matrices can then be augmented by analog elements such as actuators, sensors, prefilters, and notch filters and by the analog controller. The associated equivalent-open-loop (loop-gain) or open-loop transfer function is obtained by standard procedure. The closed-loop formulation is similarly derived by appropriately taking into account the feedback equation. The system frequency responses are obtained from the appropriate transfer matrices. Associated modal damping and frequency values can also be derived by solving the eigenvalue problem of the augmented state-space plant dynamics matrix.

In the case of a digital controller, a hybrid equivalent open-loop or closed-loop transfer function is achieved by suitably combining the controller, the open-loop transfer function of the original analog system of the plant, and other analog elements. Frequency responses are then obtained in a routine manner. The modal damping and frequency values are obtained by transferring the augmented analog state-space plant dynamics matrix from its usual Laplace (s) plane to the digital z plane, adding the same to the corresponding matrix for the controller, and solving the associated eigenvalue problem.

Furthermore, the open-loop stability analyses (flutter and divergence) can also be effected with or without the controller (analog or digital). Effecting the analyses is achieved by solving eigenvalue problems of the appropriately augmented and transformed, as the case may be, plant dynamics matrix for a number of reduced frequency values and noting the change in sign of the real part of the eigenvalues. Such a solution without a controller can be compared with the aeroelastic analysis using the k and p-k methods, whereas the relevant solution in the presence of a controller is useful for comparing relevant flight test results of modern, high-performance, unstable aircraft.

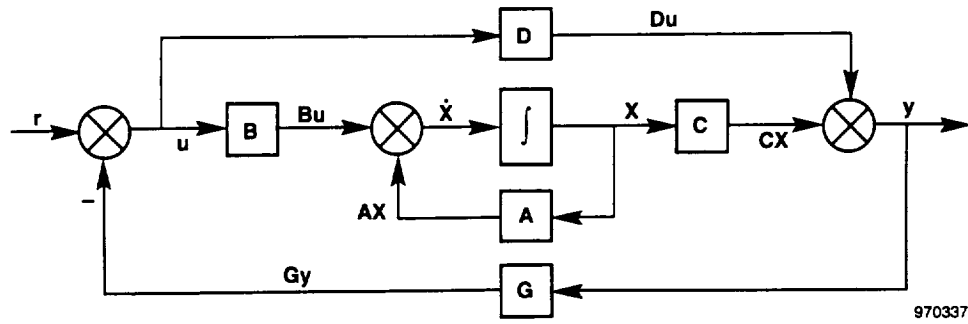


Figure 48. Feedback control system

Summing junction outputs:

$$\mathbf{u} = \mathbf{r} - \mathbf{G}\mathbf{y}$$

$$\dot{\mathbf{X}} = \mathbf{A}\mathbf{X} + \mathbf{B}u$$

$$\mathbf{y} = \mathbf{C}\mathbf{X} + \mathbf{D}\mathbf{u}$$

5.1 Numerical Formulation for Linear Aeroelastic and Aeroservoelastic Analysis

In the numerical formulation presented here, structural discretization is based on the finite-element method, whereas the panel methods are adopted for computation of unsteady aerodynamic forces. The more specialized matrix equation of motion of such structures relevant to the current analysis has the form

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} + \bar{\mathbf{q}}\mathbf{A}_e(\mathbf{k})\mathbf{q} = \mathbf{P}(\mathbf{t}) \quad (36)$$

in which the relevant terms are defined as follows:

- M** = inertia matrix
- C** = damping matrix
- K** = elastic stiffness matrix
- $\bar{q}$ = dynamic pressure $1/2\rho V^2$ (ρ and V are the air density and true airspeed, respectively)
- k = reduced frequency $\omega b/V$ (ω and b are the natural frequency and wing semichord length, respectively)
- A_e(k)** = aerodynamic influence-coefficient matrix for a given Mach number (M_∞) and a set of k_j values
- q** = displacement vector
- P(t)** = external forcing function
- s = Laplace variable ($= i^* \omega$, i^* being $\sqrt{-1}$)

A solution¹ of the related free-vibration problem

$$\mathbf{M}\ddot{\eta} + \mathbf{C}\dot{\eta} + \mathbf{K}\eta + \bar{\mathbf{q}}\mathbf{Q}(\mathbf{k})\eta = \hat{\mathbf{P}}(\mathbf{t})$$

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{k}\mathbf{q} = \mathbf{0} \quad (37)$$

yields the desired roots, ω , and vectors, Φ . Next, by applying a transformation

$$\mathbf{q} = \Phi \eta \quad (38)$$

to equation (36) and premultiplying both sides by Φ^T , the generalized equation of motion is derived as

$$\hat{\mathbf{M}}\ddot{\eta} + \hat{\mathbf{C}}\dot{\eta} + \hat{\mathbf{K}}\eta + \bar{\mathbf{q}}\mathbf{Q}(k)\eta = \hat{\mathbf{P}}(t) \quad (39)$$

in which $\hat{\mathbf{M}} = \Phi^T \mathbf{M} \Phi$, and so forth. The modal matrix $\Phi = [\Phi_r \ \Phi_e \ \Phi_\delta]$ and the generalized coordinate $\eta = [\eta_r \ \eta_e \ \eta_\delta]$ incorporate rigid-body, elastic, and control-surface motions, respectively.

By expressing the generalized aerodynamic force matrix $\mathbf{Q}(k)$ as Padé polynomials¹⁵ in i^*k ($=i^* \omega b/V = sb/V$), equation (39) results in

$$\mathbf{Q}(k) = \mathbf{A}_0 + i^*k\mathbf{A}_1 + (i^*k)^2\mathbf{A}_2 + \frac{i^*k}{i^*k + \beta_1}\mathbf{A}_3 + \frac{i^*k}{i^*k + \beta_2}\mathbf{A}_4 + \dots \quad (40)$$

where β_j are the aerodynamic lag terms (assuming $j = 1, 2$), and

$$\frac{i^*k}{i^*k + \beta_j} = \frac{k^2}{k^2 + \beta_j^2} + \frac{i^*k\beta_j}{k^2 + \beta_j^2} \quad (40(a))$$

Further, separation of the real and imaginary parts in equation (40) yields

$$\begin{aligned} \tilde{\mathbf{Q}}_R(k) &= (\mathbf{Q}_R(k) - \mathbf{A}_0) \\ &= \begin{bmatrix} -k^2\mathbf{I} & \frac{k^2}{k^2 + \beta_1^2}\mathbf{I} & \frac{k^2}{k^2 + \beta_2^2}\mathbf{I} \end{bmatrix} \begin{bmatrix} \mathbf{A}_2 \\ \mathbf{A}_3 \\ \mathbf{A}_4 \end{bmatrix} \end{aligned} \quad (41)$$

$$= \mathbf{S}_R(k)\tilde{\mathbf{A}}$$

$$\tilde{\mathbf{Q}}_I(k) = \frac{\mathbf{Q}_I(k)}{k} - \mathbf{A}_1$$

$$= \begin{bmatrix} \mathbf{0} & \frac{\beta_1}{k^2 + \beta_1^2}\mathbf{I} & \frac{\beta_2}{k^2 + \beta_2^2}\mathbf{I} \end{bmatrix} \begin{bmatrix} \mathbf{A}_2 \\ \mathbf{A}_3 \\ \mathbf{A}_4 \end{bmatrix} \quad (41(a))$$

$$= \mathbf{S}_I(k)\tilde{\mathbf{A}}$$

in which for a small value of $k = k_1$, the coefficients assume the following form:

$$\mathbf{A}_0 = \mathbf{Q}_R(k_1) \quad (42)$$

$$\mathbf{A}_1 = \frac{\mathbf{Q}_I(k_1)}{k_1} - \frac{\mathbf{A}_3}{\beta_1} - \frac{\mathbf{A}_4}{\beta_2} \quad (42(a))$$

By substituting equation (42(a)) in equation (41(a)), the unknown coefficients $\mathbf{A}_3$ and $\mathbf{A}_4$ can be determined; however, the resulting solution will be sensitive to the choice of β_j . Conversely, if the elements of the $\mathbf{A}_1$ matrix are replaced by measured damping coefficients without any lag terms, then the solution will be insensitive to the β_j values.

Equations (41) and (41(a)), computed for a number of values of reduced frequencies k_i , can be combined as

$$\begin{bmatrix} \tilde{\mathbf{Q}}_R(k_2) \\ \tilde{\mathbf{Q}}_I(k_2) \\ \vdots \\ \tilde{\mathbf{Q}}_R(k_{NF-1}) \\ \tilde{\mathbf{Q}}_I(k_{NF-1}) \end{bmatrix} = \begin{bmatrix} \mathbf{S}_R(k_2) \\ \mathbf{S}_I(k_2) \\ \vdots \\ \mathbf{S}_R(k_{NF-1}) \\ \mathbf{S}_I(k_{NF-1}) \end{bmatrix} \begin{bmatrix} \mathbf{A}_2 \\ \mathbf{A}_3 \\ \mathbf{A}_4 \end{bmatrix} \quad (43)$$

or

$$\tilde{\mathbf{Q}} = \tilde{\mathbf{S}} \tilde{\mathbf{A}} \quad (44)$$

and a least-square solution

$$\tilde{\mathbf{A}} = [\tilde{\mathbf{S}}^T \tilde{\mathbf{S}}]^{-1} \tilde{\mathbf{S}}^T \tilde{\mathbf{Q}} \quad (45)$$

yields the required coefficients $\mathbf{A}_2$, $\mathbf{A}_3$, and $\mathbf{A}_4$. This procedure may be easily extended for a larger number of lag terms, if desired. Equation (39) may be rewritten as

$$\hat{\mathbf{M}}\ddot{\eta} + \hat{\mathbf{C}}\dot{\eta} + \hat{\mathbf{K}}\eta + \bar{q} \left[\mathbf{A}_0\eta + \mathbf{A}_1 \left(\frac{sb}{V} \right) \eta + \mathbf{A}_2 \left(\frac{sb}{V} \right)^2 \eta + \mathbf{A}_3 \mathbf{X}_1 + \mathbf{A}_4 \mathbf{X}_2 + \dots \right] = \mathbf{0} \quad (46)$$

and collecting like terms gives

$$(\hat{\mathbf{K}} + \bar{q}\mathbf{A}_0)\eta + \left[\hat{\mathbf{C}} + \bar{q} \left(\frac{b}{V} \right) \mathbf{A}_1 \right] \dot{\eta} + \left[\hat{\mathbf{M}} + \bar{q} \left(\frac{b}{V} \right)^2 \mathbf{A}_2 \right] \ddot{\eta} + \bar{q}\mathbf{A}_3 \mathbf{X}_1 + \bar{q}\mathbf{A}_4 \mathbf{X}_2 + \dots = \mathbf{0} \quad (47)$$

or

$$\hat{\mathbf{K}}\eta + \hat{\mathbf{C}}\dot{\eta} + \hat{\mathbf{M}}\ddot{\eta} + \bar{q}\mathbf{A}_3 \mathbf{X}_1 + \bar{q}\mathbf{A}_4 \mathbf{X}_2 + \dots = \mathbf{0} \quad (48)$$

Also

$$\mathbf{X}_j = \frac{s\eta}{s + \left(\frac{V}{b}\right)\beta_j} \quad (49)$$

from which

$$\dot{\mathbf{X}}_j + \left(\frac{V}{b}\right)\beta_j \mathbf{X}_j = \dot{\eta} \quad (50)$$

Equations (48), (49), and (50) can be rewritten as one set of matrix equations,

$$\begin{bmatrix} \mathbf{I} & \hat{\mathbf{M}} & & \\ & \mathbf{I} & & \\ & & \mathbf{I} & \\ & & & \mathbf{I} \end{bmatrix} \begin{bmatrix} \dot{\eta} \\ \ddot{\eta} \\ \dot{\mathbf{X}}_1 \\ \dot{\mathbf{X}}_2 \end{bmatrix} = \begin{bmatrix} 0 & \mathbf{I} & 0 & 0 \\ -\hat{\mathbf{K}} & -\hat{\mathbf{C}} & -\bar{q}\mathbf{A}_3 & -\bar{q}\mathbf{A}_4 \\ 0 & \mathbf{I} & -\frac{V}{b}\beta_1\mathbf{I} & 0 \\ 0 & \mathbf{I} & 0 & -\frac{V}{b}\beta_2\mathbf{I} \end{bmatrix} \begin{bmatrix} \eta \\ \dot{\eta} \\ \mathbf{X}_1 \\ \mathbf{X}_2 \end{bmatrix} \quad (51)$$

or

$$\mathbf{M}'\dot{\mathbf{X}}' = \mathbf{K}'\mathbf{X}' \quad (52)$$

from which

$$\begin{aligned} \dot{\mathbf{X}}' &= (\mathbf{M}')^{-1} \mathbf{K}'\mathbf{X}' \\ &= \mathbf{R}\mathbf{X}' \end{aligned} \quad (53)$$

Also, the state-space vector $\mathbf{X}'$ may be rearranged as

$$\begin{aligned} \mathbf{X}'' &= [(\eta_r \ \eta_e \ \dot{\eta}_r \ \dot{\eta}_e \ \mathbf{X}_1 \ \mathbf{X}_2)(\eta_\delta \ \dot{\eta}_\delta)] \\ &= [\hat{\mathbf{X}} \ \mathbf{u}] \end{aligned} \quad (54)$$

and equation (53) may be partitioned as

$$\begin{bmatrix} \dot{\hat{\mathbf{X}}} \\ \dot{\mathbf{u}} \end{bmatrix} = \begin{bmatrix} \mathbf{R}_{I,I} & \mathbf{R}_{I,II} \\ \mathbf{R}_{II,I} & \mathbf{R}_{II,II} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{X}} \\ \mathbf{u} \end{bmatrix} \quad (55)$$

where the first set of matrix equations denotes the plant dynamics, and the second set represents the dynamics of control modes. In the case of plant dynamics, the state-space equations become

$$\dot{\hat{\mathbf{X}}} = \hat{\mathbf{A}}\hat{\mathbf{X}} + \hat{\mathbf{B}}\mathbf{u} \quad (56)$$

in which the relevant matrices and vectors are defined as

$$\hat{\mathbf{A}} = \text{plant dynamics matrix}$$

$\hat{\mathbf{B}}$ = control-surface influence matrix

$\hat{\mathbf{X}}$ = generalized coordinates in inertial frame

$\mathbf{u}$ = control-surface motion input into plant

and where the terms $\hat{\mathbf{A}}\hat{\mathbf{X}}$ and $\hat{\mathbf{B}}\mathbf{u}$ represent, for example, the airplane dynamics and the forcing function on the airplane caused by control-surface motion, respectively.

Coordinate Transformation

To incorporate control laws and feedback, it is necessary to transform equation (56) from the Earth-fixed (inertial) to the body-fixed coordinate system. Because no transformations are applied to elastic and aerodynamic lag state vectors, a transformation of the form

$$\begin{aligned}\dot{\mathbf{X}} &= \tilde{\mathbf{T}}_2^{-1}(\hat{\mathbf{A}}\tilde{\mathbf{T}}_1 - \tilde{\mathbf{T}}_3)\mathbf{X} + \tilde{\mathbf{T}}_2^{-1}\hat{\mathbf{B}}\mathbf{u} \\ &= \mathbf{A}\mathbf{X} + \mathbf{B}\mathbf{u}\end{aligned}\tag{57}$$

in which

$$\tilde{\mathbf{T}}_1 = \begin{bmatrix} \mathbf{T}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{I} \end{bmatrix}$$

and so forth. $\mathbf{T}_1$ is the coordinate transformation matrix on order of 12 and yields the required state-space equation in the body-fixed coordinate system.

Determination of Sensor Outputs

The structural nodal displacements are related to the generalized coordinates by equation (38), and the related sensor motion can be expressed as

$$\begin{aligned}\mathbf{q}_s &= \mathbf{T}_s\Phi\boldsymbol{\eta} \\ &= \mathbf{C}_0\mathbf{X}\end{aligned}\tag{58}$$

where $\mathbf{C}_0 = [\mathbf{T}_s\Phi \ \mathbf{0} \ \mathbf{0} \ \mathbf{0}]$ and in which $\mathbf{T}_s$ is an interpolation matrix. Similar relations can be derived for sensor velocities and accelerations as

$$\begin{aligned}\begin{bmatrix} \dot{\mathbf{q}}_s \\ \ddot{\mathbf{q}}_s \end{bmatrix} &= \begin{bmatrix} \mathbf{T}_s\Phi\dot{\boldsymbol{\eta}} \\ \mathbf{T}_s\Phi\ddot{\boldsymbol{\eta}} \end{bmatrix} \\ &= \mathbf{C}_1\dot{\mathbf{X}}\end{aligned}\tag{59}$$

where

$$\mathbf{C}_1 = \begin{bmatrix} \mathbf{T}_s\Phi & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{T}_s\Phi & \mathbf{0} & \mathbf{0} \end{bmatrix}$$

Equation (57) is next premultiplied by C_1 to yield

$$\begin{aligned} C_1 \dot{X} &= C_1 A X + C_1 B u \\ &= C_2 X + D_2 u \end{aligned} \quad (60)$$

and by adjoining equations (58) and (60), the following expression is obtained:

$$y = \begin{bmatrix} q_s \\ \dot{q}_s \\ \ddot{q}_s \end{bmatrix} = \begin{bmatrix} C_0 \\ C_2 \end{bmatrix} X + \begin{bmatrix} 0 \\ D_2 \end{bmatrix} u$$

or

$$y = C X + D u \quad (61)$$

which is the required sensor output relationship. The matrices C and D signify output at the sensor caused by body and control-surface motions, respectively.

Augmentation of Analog Elements and Controller

The complete state-space formulation for an aircraft incorporating structural and aeroelastic effects is represented by equations (57) and (61). To conduct an aeroservoelastic analysis, it is essential to augment such a formulation with associated analog elements (for example, actuators, sensors, notch filters, and prefilters) along with the controller. Thus, the state-space equations of one such element can be expressed as

$$\dot{X}^{(i)} = A^{(i)} X^{(i)} + B^{(i)} u^{(i)} \quad (62)$$

$$y^{(i)} = C^{(i)} X^{(i)} + D^{(i)} u^{(i)} \quad (63)$$

which can be augmented to the original equations (57) and (61), as appropriate. Typically, for the case of a connection from the plant output to the external input, the relevant formulation is as follows:

$$\begin{bmatrix} \dot{X} \\ \dot{X}^{(i)} \end{bmatrix} = \begin{bmatrix} A & 0 \\ B^{(i)} C & A^{(i)} \end{bmatrix} \begin{bmatrix} X \\ X^{(i)} \end{bmatrix} + \begin{bmatrix} B \\ B^{(i)} D \end{bmatrix} [u] \quad (64)$$

or

$$\dot{X}_{(i)} = A_{(i)} X_{(i)} + B_{(i)} u \quad (65)$$

noting that $u^{(1)} = y$. Also

$$\begin{bmatrix} y \\ y^{(i)} \end{bmatrix} = \begin{bmatrix} C & 0 \\ D^{(i)} C & C^{(i)} \end{bmatrix} \begin{bmatrix} X \\ X^{(i)} \end{bmatrix} + \begin{bmatrix} D \\ D^{(i)} D \end{bmatrix} [u]$$

or

$$\mathbf{y}_{(i)} = \mathbf{C}_{(i)}\mathbf{X}_{(i)} + \mathbf{D}_{(i)}\mathbf{u} \quad (66)$$

which is the new sensor output expression.

Any analog element, including a controller, can be augmented in a similar manner. Figure 48 shows a typical feedback control system. For such a system, the three sets of relevant matrix equations are

$$\dot{\mathbf{X}} = \mathbf{A}\mathbf{X} + \mathbf{B}\mathbf{u} \quad (67)$$

$$\mathbf{y} = \mathbf{C}\mathbf{X} + \mathbf{D}\mathbf{u} \quad (67(a))$$

$$\mathbf{u} = \mathbf{r} - \mathbf{G}\mathbf{y} \quad (67(b))$$

where equation (67(b)) is the feedback equation. By applying Laplace transformations to equations (67), (67(a)), and (67(b)), the following relationships are obtained:

$$s\mathbf{X}(s) = \mathbf{A}\mathbf{X}(s) + \mathbf{B}\mathbf{u}(s) \quad (68)$$

$$\mathbf{y}(s) = \mathbf{C}\mathbf{X}(s) + \mathbf{D}\mathbf{u}(s) \quad (68(a))$$

$$\mathbf{u}(s) = \mathbf{r}(s) - \mathbf{G}(s)\mathbf{y}(s) \quad (68(b))$$

Further, from equation (68)

$$\mathbf{X}(s) = [s\mathbf{I} - \mathbf{A}]^{-1}\mathbf{B}\mathbf{u}(s) \quad (69)$$

and the substitution of equation (69) into equation (68(a)) yields the required open-loop frequency-response relationship

$$\begin{aligned} \mathbf{y}(s) &= [\mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}\mathbf{B} + \mathbf{D}]\mathbf{u}(s) \\ &= \mathbf{H}(s)\mathbf{u}(s) \end{aligned} \quad (70)$$

$\mathbf{H}(s)$ is the equivalent open-loop (loop-gain) transfer function with the analog controller, or the open-loop transfer function without the controller. To obtain the closed-loop frequency-response relationship, equation (70) is substituted in equation (68(b)), resulting in

$$\mathbf{u}(s) = \mathbf{r}(s) - \mathbf{G}(s)\mathbf{H}(s)\mathbf{u}(s) \quad (71)$$

or

$$\mathbf{u}(s) = [\mathbf{I} + \mathbf{G}(s)\mathbf{H}(s)]^{-1}\mathbf{r}(s) \quad (71(a))$$

Again, substitution of equation (70) yields

$$\mathbf{y}(s) = \left(\mathbf{H}(s) [\mathbf{I} + \mathbf{G}(s) \mathbf{H}(s)]^{-1} \right) \mathbf{r}(s) \quad (71(b))$$

$$= \hat{\mathbf{H}}(s) \mathbf{r}(s) \quad (72)$$

in which $\hat{\mathbf{H}}(s)$ is the desired closed-loop transfer function. The frequency-responses plots can be obtained from the transfer matrices $\mathbf{H}(s)$ or $\hat{\mathbf{H}}(s)$, as appropriate. Associated damping and frequency values for the system for the loop-gain or open-loop case can also be calculated by solving the eigenvalue problem of the relevant $\mathbf{A}$ matrix for various k_j values and observing the changes in sign of the real part of an eigenvalue.

In the presence of a digital controller, a hybrid approach¹⁵ is adopted for the frequency-response solution. Thus, if $\mathbf{A}'$, $\mathbf{B}'$, $\mathbf{C}'$, and $\mathbf{D}'$ are the state-space matrices associated with the controller, the related transfer function is given by

$$\mathbf{G}(z) = \mathbf{C}' [\mathbf{zI} - \mathbf{A}']^{-1} \mathbf{B}' + \mathbf{D}' \quad (73)$$

The frequency-response relationship for the hybrid analog/digital system can be written as

$$\mathbf{y}(s) = \mathbf{G}(z) \Big|_{\text{at } z=e^{sT}} \left\{ \frac{\mathbf{H}(s) [\text{ZOH}]}{T} \right\} \mathbf{u}(s) \quad (74)$$

$$= \mathbf{G}(s, T) \mathbf{H}^*(s, \tau, T) \mathbf{u}(s) \quad (74(a))$$

in which $\mathbf{H}(s)$ is the open-loop transfer function for the plant and other analog elements, [ZOH] is the zero-order hold complex expression

$$\left(= e^{-s\tau} \left(\frac{1 - e^{-sT}}{s} \right) \right)$$

and where $\mathbf{H}^*(s)$ is now the equivalent open-loop (loop-gain) transfer function of the hybrid system. The closed-loop frequency-response relationship can be obtained as before by using equations (74(a)) and (68(b)):

$$\begin{aligned} \mathbf{y}(s) &= \left\{ \mathbf{H}^*(s, \tau, T) [\mathbf{I} + \mathbf{G}(s, T) \mathbf{H}^*(s, \tau, T)]^{-1} \right\} \mathbf{r}(s) \\ &= \hat{\mathbf{H}}^*(s, \tau, T) \mathbf{r}(s) \end{aligned} \quad (75)$$

To compute the damping and frequencies, the analog plant dynamics matrix $\mathbf{A}$ is transformed into the z plane by the standard discretization procedure, which is then augmented to the $\mathbf{A}'$ matrix. The appropriate eigenproblem solution of the final matrix yields the required results, as before. The STARS program has been extended to include capabilities representative of formulations presented in this section.

6. DATA INPUT PROCEDURE (STARS-AEROS and ASE)

Figure 49 shows the data input strategy for the entire ASE analysis procedure; section 3 describes the input for the STARS-SOLIDS module. In the following, the data pertaining to the other related analyses are given in the appropriate order, in which the STARS-AEROS module data input is compatible with the program previously described.¹⁸

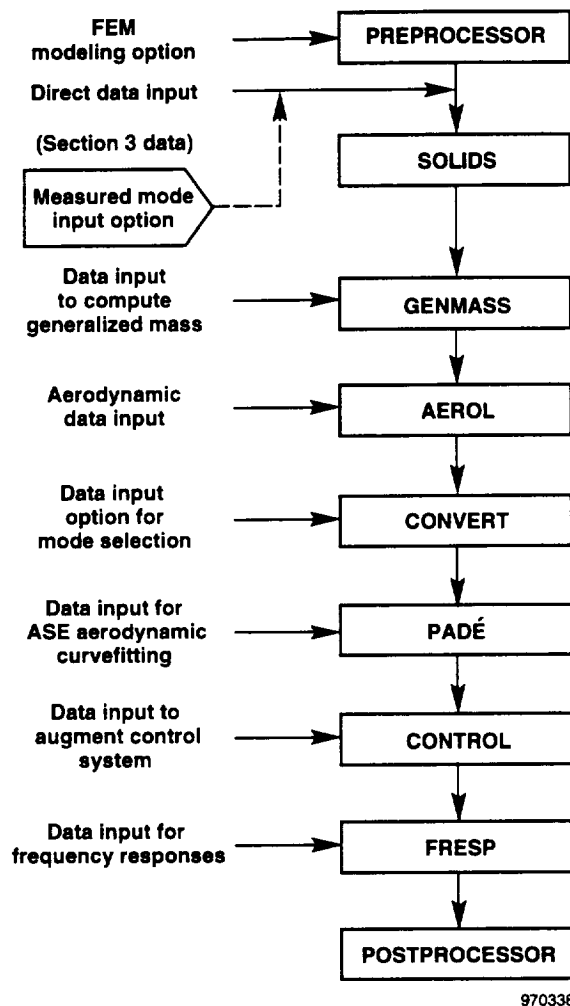


Figure 49. ASE analysis data input scheme.

6.1 GENMASS Data (STARS-AEROS-GENMASS)

Purpose: Prepare genmass.dat data file.

Description: Computes a generalized mass matrix.

6.1.1 \$ Job Description Format (FREE)

6.1.2 ISTMN, NLVN, GR **Format (2I5, E10.4)**

1. Description: Generalized mass-matrix generation data.

2. Notes:

ISTMN = integer specifying the starting mode number

NLVN = number of laterally vibrating nodes

GR = gravitational constant

6.1.3 \$ Laterally Moving Nodal Numbers Data **Format (FREE)**

(Required if NLVN > 0)

6.1.3.1 (LN(I), I = 1, NLVN) **Format (I5)**

1. Description: NLVN number of nodes input data.

2. Notes:

Input of a GR value is needed to convert generalized mass data into a generalized weight acceptable to the AEROS module.

If direct STARS interpolation is used, then the LN refers to the nodes as defined in STARS-SOLIDS (that is, the output vector, as defined in section 3.5.10 of the STARS manual).

3. Note:

The data are to be stored in the file genmass.dat.

6.2 AEROL Data (STARS-AEROS-AEROL)

Purpose: Prepare the aerodynamic data file.

Description: Computes unsteady aerodynamic forces by panel methods.

6.2.1 Job Title: 1:6 (six lines of title cards) **Format (FREE)**

6.2.2 (LC(I), I = 1, 40) **Format (10I5)**

1. Description: Basic data parameters.

2. Notes:

- LC(1) = integer defining the flutter and divergence solution algorithm
= -1, p-k type of solution
= 0, pressure calculations only
= 1, k and state-space solutions
= 2, divergence analysis
- LC(2) = maximum number of vibration modes to be used in the analysis
 $0 \leq LC(2) \leq 50$
- LC(3) = number of lifting surfaces
 $0 \leq LC(3) \leq 30$, for the doublet lattice method or constant pressure method
- LC(4) = number of reduced velocities (VBOs), used in the analysis
If $LC(1) = -1$, set $LC(4) = 6$
If $LC(1) = 0$ or 1 , set $1 \leq LC(4) \leq 50$
If $LC(1) = 2$, set $LC(4) = 1$
LC(4) and LC(13) apply to the reduced velocities described in sections 6.2.5 and 6.2.7
- LC(5) = number of air densities at which flutter and divergence solutions are to be found
 $0 \leq LC(5) \leq 10$
If $LC(1) = 0$, set $LC(5) = 0$
- LC(6) = print option for tested aerodynamic forces used to check the aerodynamic force interpolation
= 1, print
= 0, no print
- LC(7) = print option for aerodynamic pressures
= 1, print data
= 0, no print
- LC(8) = print option for lift and moment coefficients
= 1, print data
= 0, no print
- LC(9) = input frequency-independent additions to the aerodynamic matrix $\bar{q}$
= 1, make additions
= 0, no additions
- LC(10) = print option for a full set of interpolated generalized forces when used in k solutions
= 1, print data
= 0, no print

- LC(11) = index of the mode whose frequency is to be used in normalizing flutter determinant
Frequency chosen must be nonzero
Suggested index is 1
- LC(12) = index defining the flutter-determinant formulation
= 1, for nonzero frequencies $[D = K^{-1} (M + A_E)]$
= 0, in presence of zero frequencies $[D = (M + A_E)^{-1} K]$
where K = generalized stiffness matrix
 M = generalized mass matrix
 A_E = aerodynamic force matrix
If LC(1) = 0, set LC(12) = 0
- LC(13) = index defining the interpolation of aerodynamic forces
= 0, no interpolation, compute at each input VBO
= 1, compute directly at only six VBOs, interpolate to others
If LC(1) = -1, set LC(13) = 1
If LC(1) = 0 or 2, set LC(13) = 0
If LC(1) = 1, set LC(13) = 0 or 1, as desired
- LC(14) = not used. .Set = 0
- LC(15) = index defining the velocity scale in the flutter solution output
= 1, use true airspeed, TAS
= 0, use equivalent airspeed, EAS
- LC(16) = index defining the addition of structural damping to the complex stiffness matrix
= 1, add a single damping value to all modes
= -1, add an individual damping value to each mode
= 0, no damping added
- LC(17) = print option to display the number of iterations required to find each root in a p-k solution
= 1, print
= 0, no print
- LC(18) = option for root extrapolation in a p-k solution
= 1, use root values at two previous velocities for initial estimation of a root
= 0, use root value at previous velocity as the root estimate
If LC(1) $\neq$ -1, set LC(18) = 0
- LC(19) = option for ordering of roots following a p-k solution
= 1, to perform ordering
= 0, no ordering required
If LC(1) $\neq$ -1, set LC(19) = 0

- LC(20) = print option for the iterated roots in a p-k analysis or intermediate results in a k analysis
= 1, print
= 0, no print
- LC(21) = index for aerodynamics
= 1, use the doublet lattice method or constant pressure method (subsonic and supersonic Mach numbers, respectively)
- LC(22) = index defining the generation and storage of the aerodynamic influence coefficients matrix
= 0, compute and save
= 1, read precomputed values from a file
- LC(23) = print option for the input modal vector
= 1, print
= 0, no print
- LC(24) = print option for the interpolated deflections and slopes of aerodynamic elements
= 1, print
= 0, no print
- LC(25) = number of modal elimination cycles
 $0 \leq \text{LC}(25) \leq 25$
- LC(26) = index defining the additional flutter analysis
= 0, no additional cycles
> 0, perform additional flutter analysis cycles with stiffness variations applied to a mode
 $0 \leq \text{LC}(26) \leq 20$
- LC(27) = index of mode whose frequency and stiffness is to be varied for the LC(26) cycles
If $\text{LC}(26) = 0$, set $\text{LC}(27) = 0$
- LC(28) = print option for the modal eigenvectors
= 1, print
= 0, no print
If $\text{LC}(1) = -1$, the eigenvectors for the critical flutter root in a user-chosen velocity interval are displayed
If $\text{LC}(1) = 0$ or 2, set $\text{LC}(28) = 0$
If $\text{LC}(1) = 1$, the eigenvectors for all roots between user-chosen VBOs and real frequencies are displayed
- LC(29) = print option for physical vectors corresponding to modal eigenvectors
= 1, print
= 0, no print

- LC(30) = print option for the k solution flutter-determinant matrix analysis
 = 1, print
 = 0, no print
 If LC(1) = -1 or 0, set LC(30) = 0
- LC(31) = index defining revisions to generalized mass matrix and modal frequencies
 = 1, revise
 = 0, no change
- LC(32) = index defining revisions to the generalized stiffness matrix
 = 1, revise
 = 0, no change
- LC(33) = index defining the type of aerodynamics
 = 1, steady state
 = 0, oscillatory
 If LC(1) = 2, set LC(33) = 1
- LC(34) = not used. Set = 0
- LC(35) = not used. Set = 0
- LC(36) = not used. Set = 0
- LC(37) = print option for aerodynamic element geometric data associated with doublet lattice and constant pressure methods
 = 1, print
 = 0, no print
 If LC(21) $\neq$ 1, set LC(37) = 0
- LC(38) = tape unit for an ASCII printout of generalized forces and associated information. Suggest LC(38) = 99
- LC(39) = not used. Set = 0
- LC(40) = not used. Set = 0

6.2.3 INV Format (I5)

1. Description: Input vibration data location flag.

2. Notes:

- INV = integer defining the location of input vectors, modal frequencies, and generalized masses
 = 1, STARS-SOLIDS binary file
 = 2, this input file

6.2.3.1 NMDOF
Format (I5)

(Required if INV = 2)

1. Description: Input vector degrees of freedom.
2. Notes:

NMDOF = total number of modal degrees of freedom used to define an input mode shape
 $0 \leq \text{NMDOF} \leq 1000$

6.2.3.2 (QZ(I), I = 1, NMDOF)
Format (7E10.0)

(Required if INV = 2)

1. Description: LC(2) sets of NMDOF input deflections.
2. Note:

QZ(I) = principal out-of-plane deflection at point I of the input vector

6.2.3.3 NCARD
Format (I5)

(Required if INV = 2)

1. Description: Mass matrix specifications.
2. Note:

NCARD = Number of nonzero generalized mass matrix elements

6.2.3.4 I, J, WW(I, J)
Format (2I5, E10.0)

(Required if INV = 2)

1. Description: NCARD sets of data specifying nonzero generalized mass matrix elements.
2. Notes:

I = row index of the generalized mass matrix
J = column index of the generalized mass matrix
WW(I, J) = generalized mass (weight) matrix value, lbf

6.2.3.5 (OMG(I), I = LC(2))
Format (7E10.0)

(Required if INV = 2)

1. Description: LC(2) modal frequencies.
2. Note:

OMG(I) = modal frequency in proper order, Hz

6.2.4 BR, FMACH Format (2E10.4)

1. Description: Reference values for aerodynamics.

2. Notes:

BR = reference semichord, in.

FMACH = reference freestream Mach number

If FMACH < 1.0, the doublet lattice method is used

If FMACH ≥ 1.0, the constant pressure method is used (LC(13) must equal 0)

6.2.5 (VBO(I), I = 1, LC(4)) Format (7F10.4)

(Required if LC(1) = 1)

1. Description: LC(4) reduced velocities.

2. Notes:

VBO(I) = reduced velocity ($V/b\omega$) for flutter-divergence analysis

If aerodynamic interpolation is chosen, then aerodynamic forces will be interpolated at each of these VBO(I) values, using the values for the RVBO input in section 6.2.7. If direct calculation is used, the aerodynamic forces will be calculated at each of these reduced velocities.

$0 \leq LC(4) \leq 30$

6.2.6 NV, V1, DV Format (I5, 2F10.0)

(Required if LC(1) = -1)

1. Description: Airspeed velocity specification for p-k analysis.

2. Notes:

NV = number of velocities used in initial analysis, knots
 $1 < NV \leq 20$

V1 = lowest velocity from which to start analysis, knots
 $V1 \geq 200$, suggested

DV = velocity increment to be summed to V1 during initial analysis, knots
 $DV \leq 250$, suggested

6.2.7 TOLI, (RVBO(I), I = 1, 6)
Format (7E10.0)

(Required if LC(1) = -1 or LC(13) = 1)

1. Description: Aerodynamic forces interpolation data.
2. Notes:

TOLI = tolerance value used for testing the interpolation fit; a nominal value of 1.0E-03 is recommended

RVBO(I) = reduced velocity at which aerodynamic forces will be computed, to be used as part of the basis in interpolating forces at other reduced velocities

If aerodynamic interpolation is used, the RVBOs should span the entire range of VBOs of section 6.2.5.

For LC(1) = -1, use the following approximations:

1. $RVBO(1) \leq 1.69 \times 12.0 \times V1 / (BR \times WMAX)$, where
WMAX = maximum modal frequency, rad/sec.
2. $RVBO(6) \geq 1.69 \times 12.0 \times VMAX / (BR \times WMIN)$, where
VMAX = $V1 + (NV - 1) \times DV$, and
WMIN = minimum modal frequency, rad/sec.

6.2.8 MADD, IADD, MSYM
Format (3I5)

(Required if LC(31) = 1)

1. Description: Specifications for changes to mass matrix and modal frequencies.
2. Notes:

MADD = number of changes to mass matrix

IADD = number of changes to modal frequencies

MSYM = integer specifying the symmetry of mass matrix modifications
= 0, changes are symmetric
= 1, changes are nonsymmetric

6.2.8.1 I, J, WW(I, J)
Format (2I5, F10.0)

(Required if MADD > 0)

1. Description: MADD changes to the mass matrix.

2. Notes:

I = row index of the mass matrix element

J = column index of the mass matrix element

WW(I, J) = value to be substituted for the existing element in mass matrix, lbm

If MSYM = 0, specify only changes to upper triangular elements

6.2.8.2 I, OMG(I) (Required if IADD > 0)
Format (I5, F10.0)

1. Description: IADD changes to modal frequencies.

2. Notes:

I = index of the mode to be changed

OMG(I) = new frequency to be substituted for the old, Hz

6.2.9 GDD (Required if LC(16) = 1)
Format (E10.4)

1. Description: General structural damping factor.

2. Note:

GDD = A single value for hysteretic damping to be applied to all modes; the imaginary term on the diagonal of the complex stiffness matrix will be multiplied by the term GDD

6.2.10 NCD (Required if LC(16) = -1)
Format (I5)

1. Description: Integer specifying individual structural damping.

2. Note:

NCD = number of individual modes for which hysteretic damping will be specified

6.2.10.1 (I, GDP(I)) (Required if LC(16) = -1 and NCD ≠ 0)
Format (I5, E10.0)

1. Description: NCD individual structural damping values.

2. Notes:

I = mode index

GDP(I) = hysteretic damping applied to mode I

6.2.11 GMAX, GMIN, VMAX, FMAX
Format (4F10.0)

(Required if LC(1) ≠ 2)

1. Description: Maximum and minimum scales for V-g and V-f print plots.

2. Notes:

GMAX = maximum value of damping scales for V-g plots

GMIN = minimum value of damping scale for V-g plots

VMAX = maximum value of velocity scale for V-g and V-f plots, knots

FMAX = maximum value of frequency scale for V-f plots, Hz

6.2.12 (RHOR(I), I = 1, LC(5))
Format (7F10.0)

(Required if LC(1) ≠ 0)

1. Description: LC(5) values of air density ratios.

2. Notes:

RHOR(I) = density ratio with respect to sea level
 $0 < \text{RHOR}(I) \leq 10$

A separate flutter and/or divergence analysis is performed at each density ratio in which the aerodynamic force matrix is multiplied by the square root of the density ratio.

6.2.13 NADDF, NSYM
Format (2I5)

(Required if LC(9) = 1)

1. Description: Specifications for frequency-independent additions to aerodynamic matrix.

2. Notes:

NADDF = number of following additions to the flutter-determinant aerodynamic matrix

NSYM = index defining symmetry of additions
= 0, additions are symmetric; input only upper triangular elements
= 1, additions are not symmetric

6.2.13.1 I, J, DETAD(I, J)
Format (2I5, 2E10.0)

(Required if LC(9) = 1)

1. Description: NADDF frequency-independent additions to the aerodynamic matrix.

2. Notes:

I = row index of additions

J = column index of additions

DETAD(I, J) = value of addition; DETAD(I, J) is a complex value

Additions to the aerodynamic matrix QBAR are done in the following manner:

$$QBAR = QBAR + \frac{DETAD_{REAL}}{k^2} + i^* \frac{DETAD_{IMAG}}{k}$$

where k is the reduced frequency and $i^* = \sqrt{-1}$

6.2.14 NADDS, NSYM
Format (2I5)

(Required if LC(32) = 1)

1. Description: Specifications for changes to the generalized stiffness matrix.

2. Notes:

NADDS = number of following changes to the stiffness matrix

NSYM = index specifying symmetry of changes
= 0, changes are symmetric ($B(I, J) = B(J, I)$)
= 1, changes are not symmetric

6.2.14.1 I, J, B(I, J)
Format (2I5, 2E10.0)

(Required if LC(32) = 1)

1. Description: NADDS changes to the stiffness matrix.

2. Notes:

I = row index of changes

J = column index of changes

B(I, J) = new value of the complex stiffness matrix element

If NSYM = 0, only the upper triangular elements are input

6.2.15 RATOM(I)
Format (7E10.0)

(Required if LC(26) > 0)

1. Description: LC(26) values of stiffness variations for an input mode.
2. Note:

RATOM(I) = ratio of modal frequency with respect to the original input value, OMG(I)

6.2.15.1 NOTIR, (NINZ(J), J=1, NOTIR)
Format (10I5)

(Required if LC(25) ≠ 0)

1. Description: LC(25) sets of modal elimination specification for flutter and divergence analysis.
2. Notes:

NOTIR = number of deleted modes in a given modal elimination cycle

NINZ = index of the individual deleted mode for a given cycle

It should be noted that the AEROS module always does an initial analysis without modal deletions before doing any modal elimination analyses as defined in this section.

6.2.16 VA, VB
Format (2E10.0)

(Required if LC(28) = 1 and LC(1) ≠ 2)

1. Description: Eigenvector calculation range.
2. Notes:

VA = lower bound of the range for which the eigenvectors are to be calculated

VB = upper bound of the range for which the eigenvectors are to be calculated

If LC(1) = -1, the range is for velocity, V, knots

If LC(1) = 1, the range is for reduced velocity, $\frac{V}{B\omega}$

6.2.17 FLO, FHI
Format (2E10.0)

(Required if LC(28) = 1 and LC(1) = 1)

1. Description: Eigenvector display range.
2. Notes:

FLO = lower bound of the frequency range for which the eigenvectors are to be displayed, Hz

FHI = upper bound of the frequency range for which the eigenvectors are to be displayed, Hz

6.2.18 FL, ACAP
Format (2F10.0)

1. Description: Reference length and area.

2. Notes:

FL = reference chord of the model, in. ($2.0 \times BR$, normally)

ACAP = reference area of the model, in²

6.2.19 NDELT, NP, NB, NCORE, N3, N4, N7
Format (7I5)

1. Description: Doublet lattice and constant pressure methods geometrical paneling data.

2. Notes:

NDELT = index defining aerodynamic symmetry
= 1, aerodynamics are symmetrical about $Y = 0$
= -1, aerodynamics are antisymmetrical about $Y = 0$
= 0, no symmetry about $Y = 0$ (single surface only)

NP = total number of "panels" on all lifting surfaces

NB = body identification flag
= 0, no bodies of any kind
> 0, number of slender bodies used for doublet lattice analysis
= -1, constant pressure method body elements exist
 $0 \leq NB \leq 20$ for doublet lattice method

NCORE = problem size, $N \times M$, where
N = total number of aerodynamic elements, and
M = number of modes

N3 = print option for pressure influence coefficients
= 1, print
= 0, no print

N4 = print option for influence coefficients relating downwash on lifting surfaces to body element pressures
= 1, print
= 0, no print

N7 = index specifying the calculation of pressures and generalized forces
 = 1, calculate
 = 0, cease computations after influence coefficients are determined
 If LC(1) = -1 or 1, set N7 = 1

6.2.20 IBOD1, IBOD2
Format (2I5)

(Required if NB = -1)

1. Description: Aerodynamic elements defining contiguous panels that describe a supersonic body for the constant pressure method.

2. Notes:

IBOD1 = first aerodynamic element on first panel (lowest index)

IBOD2 = last aerodynamic element on last panel (highest index)

6.2.21 Sections 6.2.21.1 to 6.2.21.5 are Repeated for NP Sets of Surface Paneling Data.

6.2.21.1 XO, YO, ZO, GGMAS
Format (4F10.0)

6.2.21.2 X1, X2, X3, X4, Y1, Y2
Format (6F10.0)

6.2.21.3 Z1, Z2, NEBS, NEBC, COEFF
Format (2F10.0, 1X, 2I3, 3X, F10.0)

6.2.21.4 (TH(I), I = 1, NEBC)
Format (6F10.0)

6.2.21.5 (TAU(I), I = 1, NEBS)
Format (6F10.0)

1. Description: NP sets of data defining aerodynamic panels and their component aerodynamic elements. Section 6.2.21.1 translates and rotates panels. Such coordinates are in the global (aircraft) system indicating the position of the origin of the LCS for each panel. Section 6.2.21.2 contains coordinates of points defining an aerodynamic panel, and section 6.2.21.3 defines boundaries of "aerodynamic elements" in the panel. The panel is divided into a number of smaller trapezoids, called "aerodynamic elements," by lines of a constant-percent panel chord and constant-percent panel span. Section 6.2.21.4 defines chordwise panel stations, and section 6.2.21.5 defines spanwise panel stations.

2. Notes:

- XO = translational value to be applied to x coordinates, in.
YO = translational value to be applied to y coordinates, in.
ZO = translational value to be applied to z coordinates, in.
GGMAS = panel dihedral or rotation about a global X axis, deg

GGMAS is in a right-handed coordinate system; an upright panel would require a positive rotation of 90°. Deflections are applied to the aerodynamic panel, then the panel is translated and rotated into position.

- X1 = x coordinate of the panel inboard leading edge, in.
X2 = x coordinate of the panel inboard trailing edge, in.
X3 = x coordinate of the panel outboard leading edge, in.
X4 = x coordinate of the panel outboard trailing edge, in.
Y1 = y coordinate of the panel inboard edge, in.
Y2 = y coordinate of the panel outboard edge, in.
Z1 = z coordinate of the panel inboard edge, in.
Z2 = z coordinate of the panel outboard edge, in.

Coordinates are in the LCS.

- NEBS = number of element boundaries in the spanwise direction
 $2 \leq \text{NEBS} \leq 50$
NEBS must be set = 2 for each body interference panel
- NEBC = number of element boundaries in the chordwise direction
 $2 \leq \text{NEBC} \leq 50$
- COEFF = entered as 0.0
- TH(I) = chordwise element boundaries for the panel in a fraction of the chord
 $0.0 \leq \text{TH} \leq 1.0$
(TH(1) = 0.0, TH(NEBC) = 1.0)
- TAU(I) = spanwise element boundaries for the panel in a fraction of the span
 $0.0 \leq \text{TAU} \leq 1.0$
(TAU(1) = 0.0, TAU(NEBS) = 1.0)

The data are to be repeated NP times in the following sequence:

1. Vertical panels or a plane of symmetry ($Y = 0$).
2. Panels on other surfaces.
3. Body interference panels. These panels must be one element wide (that is, $NEBS = 2$).

There are $(NEBS - 1) \times (NEBC - 1)$ aerodynamic elements on a primary or control surface.

Indices for aerodynamic elements start at the inboard leading-edge element and increase while traveling aft down a strip, then outward strip-by-strip, and ending at the outboard trailing-edge element.

6.2.22 Sections 6.2.22.1 to 6.2.22.4 are Repeated for NB Sets of Slender-Body Data
(Required if $NB > 0$)

6.2.22.1 XBO, YBO, ZBO
Format (3F10.0)

6.2.22.2 ZSC, YSC, NF, NZ, NY, COEFF, MRK1, MRK2
Format (2F10.0, 1X, 3I2, 3X, 1F10.0, 2I3)

6.2.22.3 (F(I), I = 1, NF)
Format (6F10.0)

6.2.22.4 (RAD(I), I = 1, NF)
Format (6F10.0)

1. Description: NB sets of data defining subsonic slender bodies and their component elements. Section 6.2.22.1 defines X, Y, and Z global reference coordinates. Section 6.2.22.2 defines slender-body origin, elements, and any related interference panels. Section 6.2.22.3 defines slender-body element stations, and section 6.2.22.4 defines slender-body radii.

2. Notes:

XBO = translational value to be added to the x coordinate, in.
YBO = translational value to be added to the y coordinate, in.
ZBO = translational value to be added to the z coordinate, in.
ZSC = local z coordinate of the body axis, in.
YSC = local y coordinate of the body axis, in.
NF = number of slender-body element boundaries along the axis
 $2 \leq NF \leq 50$

NZ = flag for body vibration in the Z direction
 = 1, body vibrating
 = 0, body not vibrating

NY = flag for body vibration in the Y direction
 = 1, body vibrating
 = 0, body not vibrating

COEFF = entered as 0.0

MRK1 = index of the first aerodynamic element on the first interference panel associated with this slender body

MRK2 = index of the last aerodynamic element on the last interference panel associated with this slender body

F(I) = x coordinate of the body station defining a slender-body element in local coordinates, in. (starting with the body nose and proceeding aft)

RAD(I) = radii of body elements at the stations F(J), in.

NZ must never equal NY.

Vertically vibrating bodies should be input before laterally vibrating ones. If both vertical and lateral body vibrations are desired in a single body, two bodies are input at the same location with corresponding NZ and NY.

A slender body, as defined here, is a frustum of a right-angle cone; there are (NF - 1) slender-body elements.

6.2.23 NSTRIP, NPR1, JSPECS, NSV, NBV, NYAW Format (6I5)

1. Description: General aerodynamics data.

2. Notes:

NSTRIP = number of chordwise strips of panel elements on all panels.
 For LC(8) = 0, set NSTRIP = 1
 Printouts of lift and moment coefficients for the strips occur for NSTRIP > 1
 Never set NSTRIP = 0

NPR1 = print option for pressures in subroutines QUAS or FUTSOL. Use only for debugging
 = 1, print
 = 0, no print

JSPECS = index describing plane aerodynamic symmetry about $Z = 0$
 = 1, antisymmetrical aerodynamics about $Z = 0$ (biplane or jet effect)
 = -1, symmetrical about $Z = 0$ (ground effect)
 = 0, no symmetry about plane $Z = 0$

NSV = number of strips lying on all vertical panels on the symmetric plane $Y = 0$

NBV = number of elements on all vertical panels lying on the plane $Y = 0$

NYAW = symmetry flag
 = 0, if NDELT = 1 (symmetric about $Y = 0$)
 = 1, if NDELT = -1 (antisymmetric about $Y = 0$)
 = 0 or 1, if NDELT = 0 (asymmetric about $Y = 0$)

6.2.23.1 (LIM(I, 1), LIM(I, 2), LIM(I, 3), I = 1, NSTRIP)
Format (3I3)

1. Description: NSTRIP sets of data defining chordwise strips for aerodynamic coefficient calculations.

2. Notes:

LIM(I,1) = index of the first element on each chordwise strip

LIM(I,2) = index of the last element on each chordwise strip

LIM(I,3) = 0

For NSTRIP = 1, a blank card is used.

6.2.24 Sections 6.2.24.1 and 6.2.24.2 are Repeated for LC(3) Sets of Primary Surface Data.

6.2.24.1 KSURF, NBOXS, NCS
Format (1L5, 2I5)

6.2.24.2 NLINES, NELAXS, NICH, NISP
Format (4I5)

6.2.25 Sections 6.2.25.1 and 6.2.25.2 are Repeated for NLINES Subsets of Data.

6.2.25.1 NGP, XTERM1, YTERM1, XTERM2, YTERM2
Format (I5, 4E10.0)

6.2.25.2 (YGP(I), I = 1, NGP)
Format (8E10.0)

- 6.2.26** **DIST** **(Required if NELAXS = 1)**
 Format (E10.0)
- 6.2.27** **(X1(I), Y1(I), X2(I), Y2(I), I = 1, NCS)** **(Required if KSURF = T)**
 Format (4E10.0)
- 6.2.28** **NLINES, NELAXS, NICH, NISP** **(Required if KSURF = T)**
 Format (4I5)
- 6.2.29** **Sections 6.2.29.1 and 6.2.29.2 are Repeated for NLINES Subsets of Data.**
(Required if KSURF = T)
- 6.2.29.1** **NGP, XTERM1, YTERM1, XTERM2, YTERM2**
 Format (I5, 4E10.0)
- 6.2.29.2** **(YGP(I), I = 1, NGP)**
 Format (8E10.0)
- 6.2.30** **DIST** **(Required if NELAXS = 1 and KSURF = T)**
 Format (E10.0)

1. Description: LC(3) sets of input modal vector data to be applied to the interpolation of deflections for primary and control-surface aerodynamic elements.

2. Notes:

- KSURF** = flag indicating control surfaces on a primary surface
 = T, this surface has one or more control surfaces with forward hinge lines
 = F, this surface has no control surfaces
- NBOXS** = number of elements on this surface, including those elements on control surfaces
- NCS** = number of control surfaces on primary surface
 $0 \leq \text{NCS} \leq 5$
- NLINES** = number of lines along which input modal vector data are prescribed
 $1 \leq \text{NLINES} \leq 50$
- NELAXS** = index defining input vector components
 = 1, translation and pitch rotation are prescribed at each input point
 = 0, only translation is prescribed
- NICH** = index defining the chordwise interpolation/extrapolation from the input vector to aerodynamic elements
 = 0, linear
 = 1, quadratic
 = 2, cubic

NISP = index defining the spanwise interpolation/extrapolation from the input vector to aerodynamic elements
 = 0, linear
 = 1, quadratic
 = 2, cubic

NGP = number of points on an input vector line
 $2 \leq \text{NGP} \leq 50$

XTERM1 = x coordinate specifying the inboard end of an input vector line in the LCS

YTERM1 = y coordinate specifying the inboard end of an input vector line in the LCS

XTERM2 = x coordinate specifying the outboard end of an input vector line in the LCS

YTERM2 = y coordinate specifying the outboard end of an input vector line in the LCS

YGP(I) = spanwise coordinate of a point along an input vector line, going inboard to outboard in the LCS

X1(I) = x coordinate of the inboard terminus of the Ith control-surface leading edge in the LCS

Y1(I) = y coordinate of the inboard terminus of the Ith control-surface leading edge in the LCS

X2(I) = x coordinate of the outboard terminus of the Ith control-surface leading edge in the LCS

Y2(I) = y coordinate of the outboard terminus of the Ith control-surface leading edge in the LCS

DIST = displacement reference distance

6.2.31 The Following Sets of Data are Repeated NB Times. (Required if NB > 0)

6.2.31.1 NGP, NSTRIP, IPANEL
Format (3I5)

6.2.31.2 (XGP(I), I = 1, NGP)
Format (6F10.0)

1. Description: NB sets of data describing the input modal vector to be applied to the slender-body aerodynamic elements deflection.

2. Notes:

- NGP = number of points on a slender-body axis at which input vector data are prescribed
 $2 \leq \text{NGP} \leq 50$
- NSTRIP = number of interference panels (or strips) associated with a slender body
- IPANEL = index of the first interference panel associated with a slender body
- XGP(I) = streamwise coordinate of each point at which input modal data are prescribed in the LCS

These data are not to be input for a constant pressure method model.

6.2.32 KLUGLB Format (I5)

1. Description: Print option for global geometry.

2. Notes:

- KLUGLB = print option for aerodynamic elements in the GCS
= 1, print
= 0, no print

6.2.33 Notes On Module Usage

Aerodynamic Modules

The STARS-AEROS-AEROL aerodynamic module consists of two unsteady, linear, inviscid, aerodynamic codes: the doublet lattice method for subsonic analyses, and the constant pressure method¹⁷ for supersonic analyses. Flutter and divergence solutions can be obtained by k, p-k, or state-space methods.

Aerodynamic Modeling

The aerodynamic elements on lifting and interfering surfaces consist of trapezoidal elements parallel to the free stream. The aspect ratio of an element should be, ideally, on the order of unity or less.

The number of elements required for accurate analysis varies with the model and the reduced frequency values. Increasing the number of elements will increase the computational time. Higher reduced-frequency values require smaller and, therefore, more elements than lower reduced-frequency values. A guide for element size in the streamwise direction is $k \Delta x \leq 0.04$, where k is reduced frequency and Δx is element length.

Elements should be concentrated near wing tips, leading and trailing edges, control-surface hinges, and so forth. As a guide, a cosine distribution of elements over the chord and full span of the wing can be adopted.

The surface element can be considered as having an unsteady horseshoe vortex bound along the one-quarter chord of the element and trailing aft to infinity. The downwash from the unsteady vortices is calculated at a control point located at the three-quarter chord of the centerline of an element. Because the induced downwash at the center of a vortex is infinite, no control point should ever lie on any vortex line, such as along the extension of any element edge, either upstream or downstream.

6.3 CONVERT Data (STARS-ASE-CONVERT)

Purpose: Prepare convert.dat data file.

Description: Enables the selection of desired modes.

6.3.1 \$ Job Title
Format (FREE)

6.3.2 NM
Format (I5)

1. Description: General data.

2. Note:

NM = total number of desired modes to form reduced generalized matrices

6.3.3 \$ Modal Selection and Ordering
Format (FREE)

6.3.3.1 IOLD, INEW
Format (2I5)

1. Description: Orders the modes to be used for ASE analysis, NM sets of data.

2. Notes:

IOLD = old modal number

INEW = new modal number

3. Note:

Output is the reduced generalized force matrix and is stored in the GFORCE_PADE.DAT file for subsequent input into the ASE module.

6.4 ASE PADÉ Data (STARS-ASE-PADÉ)

Purpose: Prepare pade.dat data file.

Description: Performs Padé curve fitting of unsteady aerodynamic forces and the state-space matrix formulation.

6.4.1 \$ Job Title

Format (FREE)

6.4.2 NRM, NEM, NCM, NG, NS, NK, NA, RHOR, VEL, CREF, IWNDT, NQD

Format (FREE)

1. Description: General input data.

2. Notes:

NRM = number of rigid-body modes

NEM = number of elastic modes

NCM = number of control modes

NG = number of gusts

NS = number of sensors

NK = number of sets of input data at discrete reduced frequencies

NA = order of Padé equation, $0 \leq NA \leq 4$

RHOR = relative aerodynamic density with respect to sea level

VEL = true airspeed, ft/sec

CREF = reference chord, ft

IWNDT = wind-tunnel correction index

= 0, uses formulation as in reference 16

= 1, uses wind-tunnel data to modify aerodynamic generalized force matrix as in reference 16

NQD = number of velocities for flutter and divergence analysis, to be set to 0 for ASE analysis as in reference 16

6.4.3 \$ Tension Coefficients

Format (FREE)

6.4.3.1 (BETA(I), I = 1, NA)
Format (FREE)

1. Description: Padé approximation data.
2. Note:

BETA(I) = tension coefficients

6.4.4 \$ Generalized Masses
Format (FREE)

6.4.4.1 ((GMASS(I, J), J = I, NM), I = 1, NM)
Format (FREE)

1. Description: Generalized mass data, upper symmetric one-half, starting with the diagonal element.
2. Notes:

NM = total number of modes
= NRM + NEM + NCM

GMASS(I) = generalized mass of mode I, slugs

6.4.5 \$ Generalized Damping
Format (FREE)

6.4.5.1 (DAMP(I), I = 1, NM)
Format (FREE)

1. Description: Generalized damping data.
2. Note:

DAMP(I) = generalized damping applied to mode I

6.4.6 \$ Natural Frequencies
Format (FREE)

6.4.6.1 (OMEGA(I), I = 1, NM)
Format (FREE)

1. Description: Modal frequency data.
2. Note:

OMEGA(I) = natural frequency of mode I, rad/sec

6.4.7 \$ Velocities for Flutter and Divergence Analyses (Required if NQD > 1)
Format (FREE)

6.4.7.1 (VEL(I), I = 1, NQD) (Required if NQD > 0)
Format (FREE)

1. Description: True airspeed data for flutter and divergence analyses, ft/sec.
2. Note:

VEL(I) = airspeed values to be used to calculate the frequency and damping

6.4.8 \$ Aircraft Angles, Degrees of Freedom (Required if NQD = 0)
Format (FREE)

6.4.8.1 PHI, THETA, PSI, US, VS, WS, PS, QS, RS, PHID, THAD, PSID, NDOF
Format (FREE) (Required if NQD = 0)

1. Description: Data for transformation of Earth- to body-centered coordinate systems.
2. Notes:

PHI = roll angle, deg

THETA = pitch angle, deg

PSI = yaw angle, deg

US, VS, WS = body axes velocities

PS, QS, RS = angular rates

PHID, THAD, PSID = Euler angle rates

NDOF = number of aircraft degrees of freedom; a negative sign indicates antisymmetric case

6.4.9 \$ Sensor Data (Required if NQD = 0 and NS > 0)
Format (FREE)

6.4.9.1 IFLSI
Format (FREE)

1. Description: Flag for identification of sensor interpolation points in the presence of GVS data only.

2. Notes:

IFLSI = 1, for an antisymmetric case
= -1, for a symmetric case
= 0, for a non-GVS case

6.4.9.2 XS, YS, ZS

(Required if NQD = 0 and NS > 0)

Format (FREE)

LX, MY, NZ, THX, THY, THZ

Format (FREE)

1. Description: Sensor location and orientation; NS sets of data.

2. Notes:

XS = X coordinate of the sensor
YS = Y coordinate of the sensor
ZS = Z coordinate of the sensor
LX = direction cosine for an accelerometer normal in X
MY = direction cosine for an accelerometer normal in Y
NZ = direction cosine for an accelerometer normal in Z
THX = direction cosine for the pitch axis about X
THY = direction cosine for the pitch axis about Y
THZ = direction cosine for the pitch axis about Z

3. Notes:

For the case IFLSI $\neq$ 0, the user must modify the file VEC_AND_COORDS.DAT by defining the appropriate sensor location. This modification is done by setting the fourth column of the relevant nodes in the nodal coordinates section of the data file to the appropriate value of IFLSI. Sections 6.4.4 through 6.4.6.1 are generated by STARS-ASE-CONVERT and can be obtained from the file MDF_PADE.DAT.

6.5 ASE CONTROL Data (STARS-ASE-CONTROL)

Purpose: Prepare controls-related data.

Description: Augments control elements.

6.5.1 \$ Job Title
Format (FREE)

6.5.2 NX, NY, NU, NV, NXC, DELTAT, TDELAY, MAXBC, MAXPO
Format (FREE)

1. Description: System parameters.

2. Notes:

NX = number of states in the plant
= $[2 \times (\text{NRM} + \text{NEM}) + \text{NA} \times (\text{NRM} + \text{NEM} + \text{NCM})]$ (Refer to section 6.4)

NY = number of outputs from the plant
= (number of rows of **C** matrix)
= $(2 \times \text{NS} \times 3)$

NU = number of inputs to the plant
= $(2 \times \text{NCM})$

NV = number of external inputs to the system

NXC = total number of continuous states (the plant plus analog elements)

DELTAT = sample time for digital elements

TDELAY = system time delay

MAXBC = maximum number of block connectivity

MAXPO = maximum polynomial order plus one

6.5.3.1 NB, NYBTUV, IADDRA, IADDCB, IADDRC, NLST, NDRESP, IRP, ITRP
Format (FREE)

6.5.3.2 MAXA, MAXB, MAXC, NBSS
Format (FREE)

1. Notes:

NB = number of blocks of analog and digital elements in the system, including the summing elements and excluding the plant

NYBTUV = NYTOV + NBTOU (See section 6.5.10.2 for definitions.)

IADDRA = additional rows of **A** caused by the augmentation of control elements; appropriate summation of orders of polynomials of all analog elements for open- and closed-loop solutions are derived from the block connectivity input

IADDCB	= additional columns of B caused by the augmentation of control elements
IADDRC	= additional rows of C caused by the augmentation of control elements, equal to the number of connecting links into the block/connecting junction
NLST	= total number of frequency-range specifications for frequency-response computations
NDRESP	= number of times the loops are broken for open-loop response evaluation
IRP	= frequency-response problem number to be evaluated
ITRP	= total number of frequency-response cases
MAXA	= maximum row dimension of the direct input A matrix
MAXB	= maximum row dimension of the direct input B matrix
MAXC	= maximum row dimension of the direct input C matrix
NBSS	= number of control block state-space matrices as direct input

6.5.4.1 \$ Block Connectivity

Format (FREE)

1. Note:

Analog blocks are to precede digital blocks

6.5.4.2 IBN, ICN1, ICN2, ICN3, IEXI, IELPCL, ISLPCL

Format (7I5)

1. Notes:

IBN	= integer defining the block number
ICN1, ICN2, ICN3	= connecting block numbers (a maximum of 3)
IEXI	= integer defining the external input number
IELPCL	= integer defining the closing block (feedback signal) of the closed-loop system
ISLPCL	= integer defining the starting block of the closed-loop system

2. Note:

A symbolic gain block indicating the closing of loop is identified by the presence of starting and closing blocks.

The feedback signal is assumed to be negative. For positive feedback, set IELPCL to its negative.

6.5.5.1 \$ Transfer Function Description, as Order of Polynomials, for Each Block
Format (FREE)

1. Note:

The polynomial descriptions pertain to either analog or digital elements, as appropriate.

6.5.5.2 IBN, ICNP, ICDP, ICROW
Format (4I5)

1. Notes:

ICNP = integer defining the number of coefficients in the numerator polynomial
= NA, row number for the A matrix (for the direct state-space matrix input option)

ICDP = integer defining the number of coefficients in the denominator polynomial
= NCB, column number for the B matrix (for the direct state-space matrix input option)

ICROW = integer defining the number of coefficients in the denominator polynomial
= NCR, row number for the C matrix (for the direct state-space matrix input option)
= 0, for a polynomial input

6.5.6.1 \$ Listing of Polynomial Coefficients
Format (FREE)

6.5.6.2 IBN, (POLCON(I), I=1, MAXPO)
Format (I5, < MAXPO > (E10.4))

6.5.6.3 IBN, (POLCOD(I), I=1, MAXPO)
Format (I5, < MAXPO > (E10.4))

1. Notes:

1. The coefficients are to be listed in increasing order of polynomials.

2. The numerator coefficients (POLCON) are placed in one row, and the denominator (POLCOD) coefficients in the next row, for each block, one block at a time.

3. Data to be prepared for each block; NB sets of data are the input.

6.5.6.4 \$ Listing of State-Space Matrices of Control Blocks as Direct Input

(Required if NBSS $\neq$ 0)

6.5.6.5 IBN, NA, NCB, NCR

Format (FREE)

6.5.6.6 ((A(I, J), J=1, NA, B(I, J), J=1, NCB), I=1, NA)

Format (FREE)

6.5.6.7 ((C(I, J), J=1, NA, D(I, J), J=1, NCB), I=1, NCR)

Format (FREE)

1. Description: NBSS sets of directly input state-space matrix data.

6.5.7.1 \$ Gain Inputs for Each Block

Format (FREE)

6.5.7.2 IBN, Gain

Format (5(I5, E10.4))

1. Note:

Gains alternatively can be the input as the multiplier of polynomial coefficients in the numerator. NB sets of data are the input.

6.5.8.1 \$ Specification for System Outputs, NYB = NY + NB Number of Data

Format (FREE)

6.5.8.2 ISO1, ISO2, . . . ISONYB

Format (16I5)

1. Description: These data are needed for closed-loop frequency-response analysis only.

2. Notes:

1. Plant outputs are numbered 1 through NY.

2. Each block output is numbered as NY + IBN.

3. Note:

ISOI = desired output from any sensor (the corresponding row of the **C** matrix for the plant) and any control element (augmented thereafter)

**6.5.9.1 \$ Specification for System Inputs, NUV = NU + NV Number of Data
Format (FREE)**

**6.5.9.2 ISI1, ISI2, . . ., ISINUV
Format (16I5)**

1. Notes:

1. Plant input are numbered 1 through NU.
2. Each block input is numbered as NU + IEXI.

2. Note:

ISII = plant input (the corresponding column of the **B** matrix for the plant) and external input

**6.5.10.1 \$ Connection Details From Plant to Blocks
Format (FREE)**

**6.5.10.2 NYTOV, NBTOU, NBTOK
Format (3I5)**

1. Notes:

NYTOV = number of connections from plant outputs to external inputs

NBTOU = number of block outputs connected to plant inputs

NBTOK = number of digital element outputs connected to analog element inputs

**6.5.10.3 IYTOV1, IYTOV2
Format (2I5)**

1. Notes:

IYTOV1 = row number of the **C** matrix corresponding to output from the plant to the feedback control system

IYTOV2 = external input number that describes the connection of the plant output to the control system

2. Note:

Repeat NYTOV times, ISO to IEXI.

6.5.10.4 IBTOU1, IBTOU2
Format (2I5)

1. Notes:

IBTOU1 = block number to be connected to the plant input

IBTOU2 = column of the **B** matrix to which the block is connected

2. Note:

Output NBTOU times, IBN to ISI.

6.5.10.5 IBTOK1, IBTOK2
Format (2I5)

1. Note:

Output NBTOK times, IBN (analog) to IBN (digital).

6.5.11.1 \$ Frequency Range Specification
Format (FREE)

(Required if NLST $\neq$ 0)

6.5.11.2 FREQI, FREQF, NFREQ
Format (2F10.4,I5)

1. Description: NLST sets of frequency data.

2. Notes:

FREQI = initial frequency

FREQF = final frequency

NFREQ = number of frequencies within the range, logarithmically spaced

6.5.12.1 \$ Loop Definitions
Format (FREE)

6.5.12.2 ILOOP, IPRINT
Format (FREE)

6.5.12.3 NBRAK1, NBRAK2, NOUTBL, NINBL Format (4I5)

(Required if ILOOP = 0 or 1)

1. Notes:

ILOOP = integer defining the loop type
 = 0, for the closed-loop response case
 = 1, for the open-loop response case
 = 2, for eigensolution of the system

IPRINT = eigensolution print option for the closed-loop case
 = 0, prints eigenvalues only
 = 1, prints eigenvalues and vectors

NBRAK1 = block having the output signal

NBRAK2 = block having the input signal

NOUTBL = output of block NBRAK1

NINBL = input of block NBRAK2

2. Note:

Data of section 6.5.12.3 are to be repeated NDRESP times.

3. Additional notes:

Input data for STARS-ASE-FRESP are created from running STARS-ASE-CONTROL. No additional input data are required from the user.

A transfer function can be obtained between any two blocks in a loop, provided the input block has an output signal going in the direction of the plant.

7. SAMPLE PROBLEMS

(STARS INTEGRATED AERO-STRUCTURAL-CONTROL SYSTEMS ANALYSIS)

A simplified aircraft test model has been selected as a standard problem for the full spectrum of ASE analyses. In this section, the relevant data (fig. 49) for associated SOLIDS, AEROS, and ASE modules are presented in detail. Each data set is followed by relevant output of results. The input data are prepared in accordance with the procedures described in section 6. Details for running the aircraft test model appear in section 7.7.

Three perfect rigid-body modes (Y translation, X-rotation roll, and Z-rotation yaw about the center of gravity, Φ_{PR}), two rigid-control modes (aileron and rudder deflections, Φ_C), eight elastic modes (Φ_E), and three usual rigid-body modes (Φ_R) are generated in this module, of which the latter are excluded from consideration as GENMASS data input ($\Phi = \Phi_R + \Phi_E + \Phi_{PR} + \Phi_C$). The perfect rigid-body modes (Φ_{PR}) are moved in the front through data input to the CONVERT submodule for subsequent ASE analysis ($\Phi = \Phi_{PR} + \Phi_E + \Phi_C$).

7.1 Aircraft Test Model: Free-Vibration Analysis (STARS-SOLIDS)

The input data pertain to the free-vibration analysis of the finite-element model. The direct modal interpolation option is used for subsequent flutter and ASE analyses.

The finite-element model (fig. 50) of the symmetric one-half of the aircraft is used for the vibration analysis. Only the typical antisymmetric case is presented here; figure 51 shows a direct interpolation scheme for subsequent aeroelastic and ASE analyses.

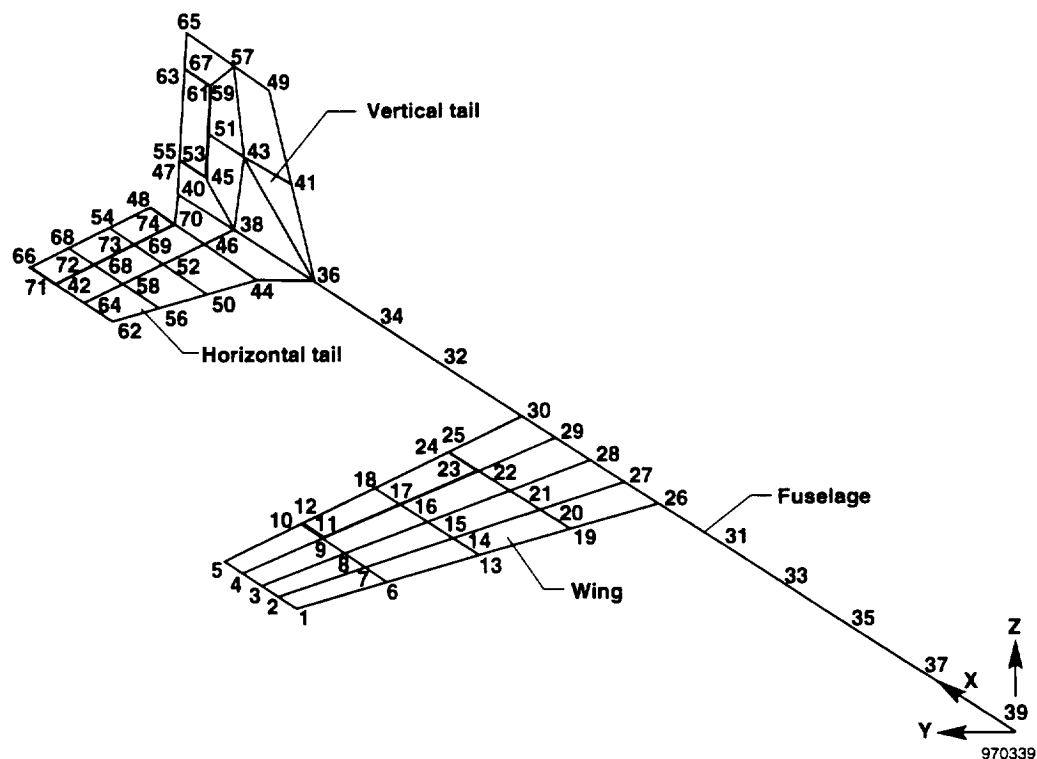


Figure 50. Aircraft test model symmetric one-half finite-element model with nodes.

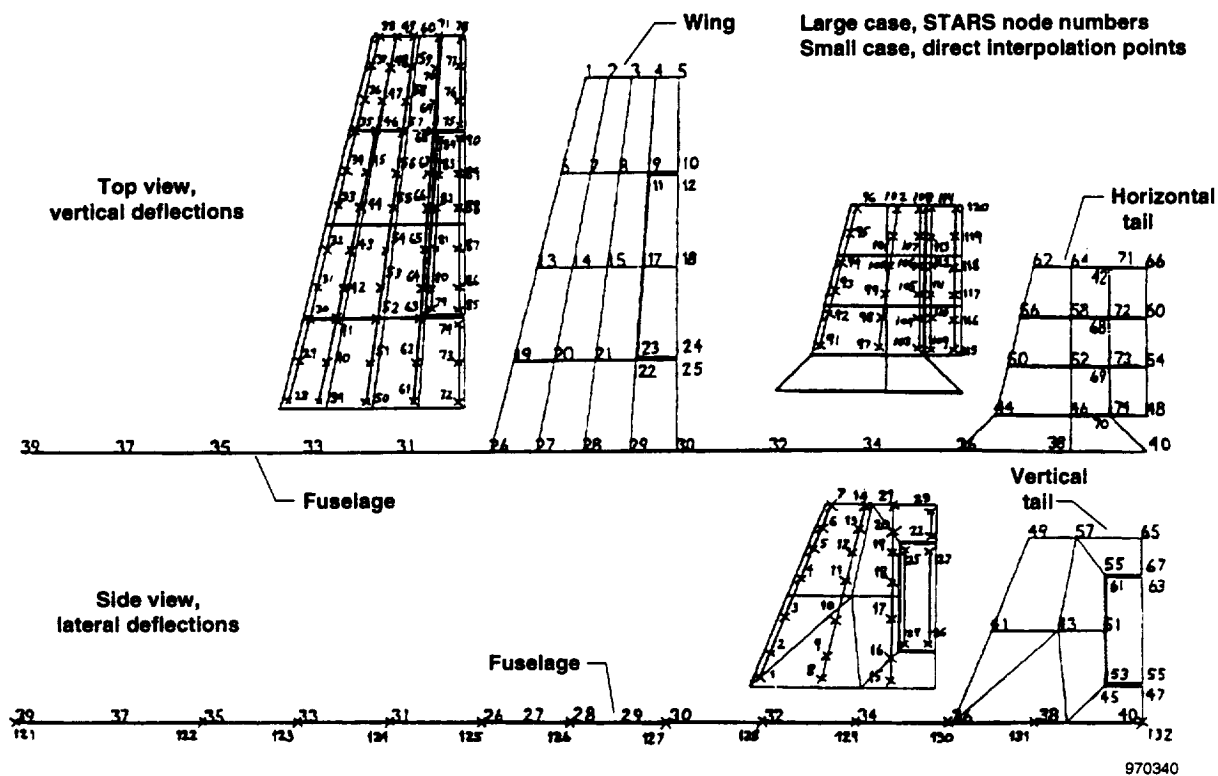


Figure 51. Aircraft test model antisymmetric case, direct-surface interpolation scheme.

STARs-SOLIDS input data (atm_solids.dat):

```

AIRCRAFT TEST MODEL
C
C ANTISYMMETRIC HALF MODEL
C IINTP = 1, DIRECT INTERPOLATION OF MODAL DATA
C
C MCNTAL = 5, FIRST THREE TO GENERATE PERFECT RIGID BODY MODES
C Y TRANSLATION, ROLL AND YAW, PLUS AILERONS AND RUDDER CONTROL
C MODES.
C //////////////////////////////////////
74, 149, 1, 4, 22, 5, 0, 0, 0, 0
0, 0, 0, 0, 0, 0, 5, 132, 0
1, 1, 0, 0, 0, 1, 0, 1
2, 0, 2, 0, 1, 0, 1, 0, 0
1, 11, 0, 7500.0, 0.0, 0.0
$ MODAL DATA
1 300.0000 200.0000 0.0000 0 0 0 0 0 0 0 0
2 312.5000 200.0000 0.0000 0 0 0 0 0 0 0 0
3 325.0000 200.0000 0.0000 0 0 0 0 0 0 0 0
4 337.5000 200.0000 0.0000 0 0 0 0 0 0 0 0
5 350.0000 200.0000 0.0000 0 0 0 0 0 0 0 0
6 287.5000 150.0000 0.0000 0 0 0 0 0 0 0 0
7 303.1250 150.0000 0.0000 0 0 0 0 0 0 0 0
8 318.7500 150.0000 0.0000 0 0 0 0 0 0 0 0
9 334.3750 150.0000 0.0000 0 0 0 0 0 0 0 0
10 350.0000 150.0000 0.0000 0 0 0 0 0 0 0 0
11 335.3750 149.0000 0.0000 0 0 0 0 0 0 0 0
12 350.0000 149.0000 0.0000 0 0 0 0 0 0 0 0
13 275.0000 100.0000 0.0000 0 0 0 0 0 0 0 0
14 293.7500 100.0000 0.0000 0 0 0 0 0 0 0 0
15 312.5000 100.0000 0.0000 0 0 0 0 0 0 0 0
16 331.2500 100.0000 0.0000 0 0 0 0 0 0 0 0
17 332.2500 100.0000 0.0000 0 0 0 0 0 0 0 0
18 350.0000 100.0000 0.0000 0 0 0 0 0 0 0 0
19 262.5000 50.0000 0.0000 0 0 0 0 0 0 0 0
20 284.3750 50.0000 0.0000 0 0 0 0 0 0 0 0
21 306.2500 50.0000 0.0000 0 0 0 0 0 0 0 0

```

22	328.1250	50.0000	0.0000	0	0	0	0	0	0	0	0
23	329.1250	51.0000	0.0000	0	0	0	0	0	0	0	0
24	350.0000	51.0000	0.0000	0	0	0	0	0	0	0	0
25	350.0000	50.0000	0.0000	0	0	0	0	0	0	0	0
26	250.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
27	275.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
28	300.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
29	325.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
30	350.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
31	200.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
32	400.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
33	150.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
34	450.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
35	100.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
36	500.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
37	50.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
38	560.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
39	0.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
40	600.0000	0.0000	0.0000	1	0	1	0	1	0	0	0
41	520.0000	0.0000	50.0000	1	0	1	0	1	0	0	0
42	580.0000	100.0000	0.0000	0	0	0	0	0	0	0	0
43	555.0000	0.0000	50.0000	1	0	1	0	1	0	0	0
44	520.0000	20.0000	0.0000	0	0	0	0	0	0	0	0
45	580.0000	0.0000	20.0000	1	0	1	0	1	0	0	0
46	560.0000	20.0000	0.0000	0	0	0	0	0	0	0	0
47	600.0000	0.0000	20.0000	1	0	1	0	1	0	0	0
48	600.0000	20.0000	0.0000	0	0	0	0	0	0	0	0
49	540.0000	0.0000	100.0000	1	0	1	0	1	0	0	0
50	526.6666	46.6667	0.0000	0	0	0	0	0	0	0	0
51	580.0000	0.0000	50.0000	1	0	1	0	1	0	0	0
52	560.0000	46.6667	0.0000	0	0	0	0	0	0	0	0
53	581.0000	0.0000	21.0000	1	0	1	0	1	0	0	0
54	600.0000	46.6667	0.0000	0	0	0	0	0	0	0	0
55	600.0000	0.0000	21.0000	1	0	1	0	1	0	0	0
56	533.3331	73.3333	0.0000	0	0	0	0	0	0	0	0
57	565.0000	0.0000	100.0000	1	0	1	0	1	0	0	0
58	560.0000	73.3333	0.0000	0	0	0	0	0	0	0	0
59	580.0000	0.0000	80.0000	1	0	1	0	1	0	0	0
60	600.0000	73.3333	0.0000	0	0	0	0	0	0	0	0
61	581.0000	0.0000	79.0000	1	0	1	0	1	0	0	0
62	540.0000	100.0000	0.0000	0	0	0	0	0	0	0	0
63	600.0000	0.0000	79.0000	1	0	1	0	1	0	0	0
64	560.0000	100.0000	0.0000	0	0	0	0	0	0	0	0
65	600.0000	0.0000	100.0000	1	0	1	0	1	0	0	0
66	600.0000	100.0000	0.0000	0	0	0	0	0	0	0	0
67	600.0000	0.0000	80.0000	1	0	1	0	1	0	0	0
68	580.0000	73.3333	0.0000	0	0	0	0	0	0	0	0
69	580.0000	46.6667	0.0000	0	0	0	0	0	0	0	0
70	580.0000	20.0000	0.0000	0	0	0	0	0	0	0	0
71	581.0000	100.0000	0.0000	0	0	0	0	0	0	0	0
72	581.0000	73.3333	0.0000	0	0	0	0	0	0	0	0
73	581.0000	46.6667	0.0000	0	0	0	0	0	0	0	0
74	581.0000	20.0000	0.0000	0	0	0	0	0	0	0	0

\$ ELEMENT CONNECTIVITY CONDITIONS

2	1	6	7	2	1	0	0	0	0	1	1	0	0	0	0
2	2	7	8	3	2	0	0	0	0	1	1	0	0	0	0
2	3	8	9	4	3	0	0	0	0	1	1	0	0	0	0
2	4	9	10	5	4	0	0	0	0	1	1	0	0	0	0
2	5	13	14	7	6	0	0	0	0	1	1	0	0	0	0
2	6	14	15	8	7	0	0	0	0	1	1	0	0	0	0
2	7	15	16	9	8	0	0	0	0	1	1	0	0	0	0
2	8	19	20	14	13	0	0	0	0	1	1	0	0	0	0
2	9	20	21	15	14	0	0	0	0	1	1	0	0	0	0
2	10	21	22	16	15	0	0	0	0	1	1	0	0	0	0
2	11	26	27	20	19	0	0	0	0	1	1	0	0	0	0
2	12	27	28	21	20	0	0	0	0	1	1	0	0	0	0
2	13	28	29	22	21	0	0	0	0	1	1	0	0	0	0
2	14	29	30	25	22	0	0	0	0	1	1	0	0	0	0
2	15	17	18	12	11	0	0	0	0	1	2	0	0	0	0
2	16	23	24	18	17	0	0	0	0	1	2	0	0	0	0
1	17	1	2	39	0	0	0	0	0	1	11	0	0	0	0
1	18	2	3	39	0	0	0	0	0	1	11	0	0	0	0
1	19	3	4	39	0	0	0	0	0	1	1	0	0	0	0
1	20	4	5	39	0	0	0	0	0	1	1	0	0	0	0
1	21	6	7	39	0	0	0	0	0	1	11	0	0	0	0
1	22	7	8	39	0	0	0	0	0	1	11	0	0	0	0
1	23	8	9	39	0	0	0	0	0	1	1	0	0	0	0
1	24	9	10	39	0	0	0	0	0	1	1	0	0	0	0
1	25	6	1	39	0	0	0	0	0	1	11	0	0	0	0
1	26	7	2	39	0	0	0	0	0	1	11	0	0	0	0
1	27	8	3	39	0	0	0	0	0	1	1	0	0	0	0
1	28	9	4	39	0	0	0	0	0	1	1	0	0	0	0
1	29	10	5	39	0	0	0	0	0	1	1	0	0	0	0

1	30	13	14	39	0	0	0	0	0	1	11	0	0	0	0
1	31	14	15	39	0	0	0	0	0	1	11	0	0	0	0
1	32	15	16	39	0	0	0	0	0	1	1	0	0	0	0
1	33	13	6	39	0	0	0	0	0	1	11	0	0	0	0
1	34	14	7	39	0	0	0	0	0	1	11	0	0	0	0
1	35	15	8	39	0	0	0	0	0	1	1	0	0	0	0
1	36	16	9	39	0	0	0	0	0	1	1	0	0	0	0
1	37	19	20	1	0	0	0	0	0	1	11	0	0	0	0
1	38	20	21	1	0	0	0	0	0	1	11	0	0	0	0
1	39	21	22	1	0	0	0	0	0	1	1	0	0	0	0
1	40	22	25	1	0	0	0	0	0	1	1	0	0	0	0
1	41	19	13	39	0	0	0	0	0	1	11	0	0	0	0
1	42	20	14	39	0	0	0	0	0	1	11	0	0	0	0
1	43	21	15	39	0	0	0	0	0	1	1	0	0	0	0
1	44	22	16	39	0	0	0	0	0	1	1	0	0	0	0
1	45	26	27	1	0	0	0	0	0	1	11	0	0	0	0
1	46	27	28	1	0	0	0	0	0	1	11	0	0	0	0
1	47	28	29	1	0	0	0	0	0	1	1	0	0	0	0
1	48	29	30	1	0	0	0	0	0	1	1	0	0	0	0
1	49	26	19	39	0	0	0	0	0	1	11	0	0	0	0
1	50	27	20	39	0	0	0	0	0	1	11	0	0	0	0
1	51	28	21	39	0	0	0	0	0	1	1	0	0	0	0
1	52	29	22	39	0	0	0	0	0	1	1	0	0	0	0
1	53	30	25	39	0	0	0	0	0	1	1	0	0	0	0
1	54	11	12	39	0	0	0	0	0	1	2	0	0	0	0
1	55	17	18	39	0	0	0	0	0	1	2	0	0	0	0
1	56	23	24	39	0	0	0	0	0	1	2	0	0	0	0
1	57	23	17	39	0	0	0	0	0	1	2	0	0	0	0
1	58	17	11	39	0	0	0	0	0	1	2	0	0	0	0
1	59	24	18	39	0	0	0	0	0	1	2	0	0	0	0
1	60	18	12	39	0	0	0	0	0	1	2	0	0	0	0
1	61	11	9	39	0	0	0	0	0	1	5	0	0	0	0
1	62	16	17	39	0	0	0	0	0	1	5	0	0	0	0
1	63	22	23	1	0	0	0	0	0	1	5	0	0	0	0
2	64	56	58	64	62	0	0	0	0	1	3	0	0	0	0
2	65	58	68	42	64	0	0	0	0	1	3	0	0	0	0
2	66	50	52	58	56	0	0	0	0	1	3	0	0	0	0
2	67	52	69	68	58	0	0	0	0	1	3	0	0	0	0
2	68	44	46	52	50	0	0	0	0	1	3	0	0	0	0
2	69	46	70	69	52	0	0	0	0	1	3	0	0	0	0
1	70	62	64	1	0	0	0	0	0	1	3	0	0	0	0
1	71	64	42	1	0	0	0	0	0	1	3	0	0	0	0
1	72	56	58	1	0	0	0	0	0	1	3	0	0	0	0
1	73	58	68	1	0	0	0	0	0	1	3	0	0	0	0
1	74	56	62	1	0	0	0	0	0	1	3	0	0	0	0
1	75	58	64	1	0	0	0	0	0	1	3	0	0	0	0
1	76	60	66	1	0	0	0	0	0	1	2	0	0	0	0
1	77	50	52	1	0	0	0	0	0	1	3	0	0	0	0
1	78	52	69	1	0	0	0	0	0	1	3	0	0	0	0
1	79	50	56	1	0	0	0	0	0	1	3	0	0	0	0
1	80	52	58	1	0	0	0	0	0	1	3	0	0	0	0
1	81	54	60	1	0	0	0	0	0	1	2	0	0	0	0
1	82	44	46	1	0	0	0	0	0	1	3	0	0	0	0
1	83	46	70	1	0	0	0	0	0	1	3	0	0	0	0
1	84	44	50	1	0	0	0	0	0	1	3	0	0	0	0
1	85	46	52	1	0	0	0	0	0	1	3	0	0	0	0
1	86	48	54	1	0	0	0	0	0	1	2	0	0	0	0
3	87	36	38	43	0	0	0	0	0	1	4	0	0	0	0
3	88	36	43	41	0	0	0	0	0	1	4	0	0	0	0
2	89	41	43	57	49	0	0	0	0	1	4	0	0	0	0
2	90	38	45	51	43	0	0	0	0	1	4	0	0	0	0
2	91	43	51	59	57	0	0	0	0	1	4	0	0	0	0
2	92	38	40	47	45	0	0	0	0	1	4	0	0	0	0
2	93	59	67	65	57	0	0	0	0	1	4	0	0	0	0
2	94	53	55	63	61	0	0	0	0	1	5	0	0	0	0
1	95	36	41	1	0	0	0	0	0	1	4	0	0	0	0
1	96	41	49	1	0	0	0	0	0	1	4	0	0	0	0
1	97	36	43	1	0	0	0	0	0	1	4	0	0	0	0
1	98	43	57	1	0	0	0	0	0	1	4	0	0	0	0
1	99	49	57	1	0	0	0	0	0	1	4	0	0	0	0
1	100	38	43	1	0	0	0	0	0	1	4	0	0	0	0
1	101	38	45	1	0	0	0	0	0	1	4	0	0	0	0
1	102	45	51	1	0	0	0	0	0	1	4	0	0	0	0
1	103	41	43	1	0	0	0	0	0	1	4	0	0	0	0
1	104	43	51	1	0	0	0	0	0	1	4	0	0	0	0
1	105	51	59	1	0	0	0	0	0	1	4	0	0	0	0
1	106	59	57	1	0	0	0	0	0	1	4	0	0	0	0
1	107	59	67	1	0	0	0	0	0	1	4	0	0	0	0
1	108	57	65	1	0	0	0	0	0	1	4	0	0	0	0
1	109	67	65	1	0	0	0	0	0	1	4	0	0	0	0
1	110	40	47	1	0	0	0	0	0	1	4	0	0	0	0
1	111	45	47	1	0	0	0	0	0	1	4	0	0	0	0
1	112	53	55	1	0	0	0	0	0	1	9	0	0	0	0

1	113	53	61	1	0	0	0	0	0	1	9	0	0	0	0
1	114	55	63	1	0	0	0	0	0	1	9	0	0	0	0
1	115	61	63	1	0	0	0	0	0	1	9	0	0	0	0
1	116	45	53	1	0	0	0	0	0	1	10	0	0	0	0
1	117	61	59	1	0	0	0	0	0	1	10	0	0	0	0
1	118	38	46	1	0	0	0	0	0	1	8	0	0	0	0
1	119	36	44	1	0	0	0	0	0	1	8	0	0	0	0
1	120	39	37	1	0	0	0	0	0	1	120	0	0	0	0
1	121	37	35	1	0	0	0	0	0	1	121	0	0	0	0
1	122	35	33	1	0	0	0	0	0	1	122	0	0	0	0
1	123	33	31	1	0	0	0	0	0	1	123	0	0	0	0
1	124	31	26	1	0	0	0	0	0	1	124	0	0	0	0
1	125	26	28	1	0	0	0	0	0	1	125	0	0	0	0
1	126	28	30	1	0	0	0	0	0	1	126	0	0	0	0
1	127	30	32	1	0	0	0	0	0	1	127	0	0	0	0
1	128	32	34	1	0	0	0	0	0	1	128	0	0	0	0
1	129	34	36	1	0	0	0	0	0	1	129	0	0	0	0
1	130	36	38	1	0	0	0	0	0	1	130	0	0	0	0
1	131	38	40	1	0	0	0	0	0	1	131	0	0	0	0
2	132	72	60	66	71	0	0	0	0	1	2	0	0	0	0
2	133	73	54	60	72	0	0	0	0	1	2	0	0	0	0
2	134	74	48	54	73	0	0	0	0	1	2	0	0	0	0
1	135	42	71	1	0	0	0	0	0	1	5	0	0	0	0
1	136	68	72	1	0	0	0	0	0	1	5	0	0	0	0
1	137	69	73	1	0	0	0	0	0	1	5	0	0	0	0
1	138	70	74	1	0	0	0	0	0	1	5	0	0	0	0
1	139	74	73	1	0	0	0	0	0	1	2	0	0	0	0
1	140	73	72	1	0	0	0	0	0	1	2	0	0	0	0
1	141	72	71	1	0	0	0	0	0	1	2	0	0	0	0
1	142	70	69	1	0	0	0	0	0	1	3	0	0	0	0
1	143	69	68	1	0	0	0	0	0	1	3	0	0	0	0
1	144	68	42	1	0	0	0	0	0	1	3	0	0	0	0
1	145	71	66	65	0	0	0	0	0	1	2	0	0	0	0
1	146	72	60	65	0	0	0	0	0	1	2	0	0	0	0
1	147	73	54	65	0	0	0	0	0	1	2	0	0	0	0
1	148	74	48	65	0	0	0	0	0	1	2	0	0	0	0
1	149	40	70	65	0	0	0	0	0	1	8	0	0	0	0

\$ LINE ELEMENT BASIC PROPERTIES

1	1.5000	37.5000	18.8000	18.8000
2	0.5300	3.8000	1.9000	1.9000
3	0.7500	19.0000	9.0000	9.0000
4	0.0600	1.5000	0.7500	0.7500
5	0.4000	1.5000	0.7500	0.7500
6	19.0000	750.0000	375.0000	375.0000
8	3.7500	1500.0000	750.0000	750.0000
9	0.0300	0.8000	0.4000	0.4000
10	0.0100	0.4000	0.2000	0.2000
11	1.1250	28.1250	14.0600	14.0600
120	11.2500	675.0	338.0	338.0
121	18.7500	900.0	900.0	900.0
122	18.7500	1050.0	1575.0	1575.0
123	18.7500	1200.0	2250.0	2250.0
124	18.7500	1650.0	2625.0	2625.0
125	18.7500	1875.0	1875.0	1875.0
126	18.7500	2250.0	1125.0	1125.0
127	18.7500	3000.0	1275.0	1275.0
128	18.7500	3000.0	1275.0	1275.0
129	18.7500	3000.0	1275.0	1275.0
130	16.5000	2250.0	975.0	975.0
131	15.0000	1500.0	675.0	675.0

\$ SHELL ELEMENT THICKNESSES

1	0.1130
2	0.0530
3	0.0900
4	0.0400
5	0.0100

\$ MATERIAL PROPERTIES

1	1	
1.0E+07	0.30	0.259E-03

\$ MODAL MASS DATA

39	1	0.0195	3
37	1	0.0389	3
35	1	0.0584	3
33	1	0.0972	3
31	1	0.1943	3
26	1	0.2915	3
28	1	0.2915	3
30	1	0.2915	3
32	1	0.2915	3
34	1	0.2915	3
36	1	0.2915	3
38	1	0.2915	3
40	1	0.1943	3

-1

\$ OUTPUT POINT SPECIFICATION FOR DIRECT INTERPOLATION OF MODAL DATA

1	36			
2	36	36	41	
3	36	41	41	41
4	41			
5	41	49		
6	41	49	49	
7	49			
8	36	38		
9	38	38	43	
10	38	43	43	43
11	43			
12	43	57		
13	43	57	57	
14	57			
15	38	40		
16	45			
17	45	51	51	
18	51			
19	51	59	59	59
20	59			
21	57	65		
22	67			
23	65			
24	53			
25	61			
26	55			
27	63			
28	26			
29	19	26		
30	19			
31	13	19	19	
32	13	13	19	
33	13			
34	6	13		
35	6			
36	1	6	6	
37	1	1	6	
38	1			
39	27			
40	20	27		
41	20			
42	14	20	20	
43	14	14	20	
44	14			
45	7	14		
46	7			
47	2	7	7	
48	2	2	7	
49	2			
50	28			
51	21	28		
52	21			
53	15	21	21	
54	15	15	21	
55	15			
56	8	15		
57	8			
58	3	8	8	
59	3	3	8	
60	3			
61	29			
62	22	29		
63	22			
64	16	22	22	
65	16	16	22	
66	16			
67	9	16		
68	9			
69	4	9	9	
70	4	4	9	
71	4			
72	30			
73	25	30		
74	25			
75	10			
76	5	10	10	
77	5	5	10	
78	5			
79	23			
80	17	23	23	
81	17	17	23	

82	17			
83	11	17		
84	11			
85	24			
86	18	24	24	
87	18	18	24	
88	18			
89	12	18		
90	12			
91	44			
92	44	50	50	50
93	50	50	56	
94	56			
95	56	62		
96	62			
97	46			
98	46	52	52	52
99	52	52	58	
100	58			
101	58	64		
102	64			
103	70			
104	69	70	70	70
105	68	68	69	
106	68			
107	42	68		
108	42			
109	74			
110	73	74	74	74
111	72	72	73	
112	72			
113	71	72		
114	71			
115	48			
116	48	54	54	54
117	54	54	60	
118	60			
119	60	66		
120	66			
121	39			
122	35			
123	33			
124	31			
125	26			
126	28			
127	30			
128	32			
129	34			
130	36			
131	38			
132	40			

\$ RIGID BODY CONTROL MODE DATA

1	2	-1.0	74	1	<--- RIGID BODY Y TRANSLATION
-1					
1	2	-0.6908			<--- RIGID BODY X ROTATION (ROLL)
1	3	16.6089			
1	4	1.0000			
2	2	-0.6908			
2	3	16.6089			
2	4	1.0000			
3	2	-0.6908			
3	3	16.6089			
3	4	1.0000			
4	2	-0.6908			
4	3	16.6089			
4	4	1.0000			
5	2	-0.6908			
5	3	16.6089			
5	4	1.0000			
6	2	-0.5181			
6	3	12.4567			
6	4	1.0000			
7	2	-0.5181			
7	3	12.4567			
7	4	1.0000			
8	2	-0.5181			
8	3	12.4567			
8	4	1.0000			
9	2	-0.5181			
9	3	12.4567			
9	4	1.0000			
10	2	-0.5181			
10	3	12.4567			

10	4	1.0000
11	2	-0.5147
11	3	12.3737
11	4	1.0000
12	2	-0.5147
12	3	12.3737
12	4	1.0000
13	2	-0.3454
13	3	8.3045
13	4	1.0000
14	2	-0.3454
14	3	8.3045
14	4	1.0000
15	2	-0.3454
15	3	8.3045
15	4	1.0000
16	2	-0.3454
16	3	8.3045
16	4	1.0000
17	2	-0.3454
17	3	8.3045
17	4	1.0000
18	2	-0.3454
18	3	8.3045
18	4	1.0000
19	2	-0.1727
19	3	4.1522
19	4	1.0000
20	2	-0.1727
20	3	4.1522
20	4	1.0000
21	2	-0.1727
21	3	4.1522
21	4	1.0000
22	2	-0.1727
22	3	4.1522
22	4	1.0000
23	2	-0.1762
23	3	4.2353
23	4	1.0000
24	2	-0.1762
24	3	4.2353
24	4	1.0000
25	2	-0.1727
25	3	4.1522
25	4	1.0000
26	4	1.0000
27	4	1.0000
28	4	1.0000
29	4	1.0000
30	4	1.0000
31	4	1.0000
32	4	1.0000
33	4	1.0000
34	4	1.0000
35	4	1.0000
36	4	1.0000
37	4	1.0000
38	4	1.0000
39	4	1.0000
40	4	1.0000
41	2	-4.1522
41	3	-0.1727
41	4	1.0000
42	2	-0.3454
42	3	8.3045
42	4	1.0000
43	2	-4.1522
43	3	-0.1727
43	4	1.0000
44	2	-0.0691
44	3	1.6609
44	4	1.0000
45	2	-1.6609
45	3	-0.0691
45	4	1.0000
46	2	-0.0691
46	3	1.6609
46	4	1.0000
47	2	-1.6609
47	3	-0.0691
47	4	1.0000
48	2	-0.0691

48	3	1.6609
48	4	1.0000
49	2	-8.3045
49	3	-0.3454
49	4	1.0000
50	2	-0.1612
50	3	3.8754
50	4	1.0000
51	2	-4.1522
51	3	-0.1727
51	4	1.0000
52	2	-0.1612
52	3	3.8754
52	4	1.0000
53	2	-1.7439
53	3	-0.0725
53	4	1.0000
54	2	-0.1612
54	3	3.8754
54	4	1.0000
55	2	-1.7439
55	3	-0.0725
55	4	1.0000
56	2	-0.2533
56	3	6.0899
56	4	1.0000
57	2	-8.3045
57	3	-0.3454
57	4	1.0000
58	2	-0.2533
58	3	6.0899
58	4	1.0000
59	2	-6.6436
59	3	-0.2763
59	4	1.0000
60	2	-0.2533
60	3	6.0899
60	4	1.0000
61	2	-6.5605
61	3	-0.2729
61	4	1.0000
62	2	-0.3454
62	3	8.3045
62	4	1.0000
63	2	-6.5605
63	3	-0.2729
63	4	1.0000
64	2	-0.3454
64	3	8.3045
64	4	1.0000
65	2	-8.3045
65	3	-0.3454
65	4	1.0000
66	2	-0.3454
66	3	8.3045
66	4	1.0000
67	2	-6.6436
67	3	-0.2763
67	4	1.0000
68	2	-0.2533
68	3	6.0899
68	4	1.0000
69	2	-0.1612
69	3	3.8754
69	4	1.0000
70	2	-0.0691
70	3	1.6609
70	4	1.0000
71	2	-0.3454
71	3	8.3045
71	4	1.0000
72	2	-0.2533
72	3	6.0899
72	4	1.0000
73	2	-0.1612
73	3	3.8754
73	4	1.0000
74	2	-0.0691
74	3	1.6609
74	4	1.0000
-1		
1	1	16.5227
1	2	-2.7670

<--- RIGID BODY Z ROTATION (YAW) AT 275 IN.

1	6	1.0000
2	1	16.4795
2	2	-3.8050
2	6	1.0000
3	1	16.4364
3	2	-4.8431
3	6	1.0000
4	1	16.3932
4	2	-5.8812
4	6	1.0000
5	1	16.3500
5	2	-6.9192
5	6	1.0000
6	1	12.4137
6	2	-1.5562
6	6	1.0000
7	1	12.3596
7	2	-2.8538
7	6	1.0000
8	1	12.3057
8	2	-4.1514
8	6	1.0000
9	1	12.2517
9	2	-5.4489
9	6	1.0000
10	1	12.1978
10	2	-6.7465
10	6	1.0000
11	1	12.1652
11	2	-5.5285
11	6	1.0000
12	1	12.1147
12	2	-6.7431
12	6	1.0000
13	1	8.3045
13	2	-0.3454
13	6	1.0000
14	1	8.2398
14	2	-1.9025
14	6	1.0000
15	1	8.1750
15	2	-3.4596
15	6	1.0000
16	1	8.1102
16	2	-5.0167
16	6	1.0000
17	1	8.1068
17	2	-5.0998
17	6	1.0000
18	1	8.0455
18	2	-6.5738
18	6	1.0000
19	1	4.1955
19	2	0.8654
19	6	1.0000
20	1	4.1199
20	2	-0.9512
20	6	1.0000
21	1	4.0443
21	2	-2.7679
21	6	1.0000
22	1	3.9688
22	2	-4.5845
22	6	1.0000
23	1	4.0483
23	2	-4.6710
23	6	1.0000
24	1	3.9763
24	2	-6.4046
24	6	1.0000
25	1	3.8932
25	2	-6.4011
25	6	1.0000
26	1	0.0863
26	2	2.0761
26	6	1.0000
27	1	0.0000
27	2	0.0000
27	6	1.0000
28	1	-0.0864
28	2	-2.0761
28	6	1.0000
29	1	-0.1727

29	2	-4.1523
29	6	1.0000
30	1	-0.2591
30	2	-6.2284
30	6	1.0000
31	1	0.2591
31	2	6.2284
31	6	1.0000
32	1	-0.4318
32	2	-10.3807
32	6	1.0000
33	1	0.4318
33	2	10.3807
33	6	1.0000
34	1	-0.6045
34	2	-14.5330
34	6	1.0000
35	1	0.6045
35	2	14.5330
35	6	1.0000
36	1	-0.7772
36	2	-18.6852
36	6	1.0000
37	1	0.7772
37	2	18.6852
37	6	1.0000
38	1	-0.9845
38	2	-23.6680
38	6	1.0000
39	1	0.9499
39	2	22.8375
39	6	1.0000
40	1	-1.1227
40	2	-26.9898
40	6	1.0000
41	1	-0.8463
41	2	-20.3461
41	6	1.0000
42	1	7.2510
42	2	-25.6743
42	6	1.0000
43	1	-0.9672
43	2	-23.2527
43	6	1.0000
44	1	0.8146
44	2	-20.4152
44	6	1.0000
45	1	-1.0536
45	2	-25.3289
45	6	1.0000
46	1	0.6765
46	2	-23.7371
46	6	1.0000
47	1	-1.1227
47	2	-26.9898
47	6	1.0000
48	1	0.5383
48	2	-27.0589
48	6	1.0000
49	1	-0.9154
49	2	-22.0071
49	6	1.0000
50	1	3.0061
50	2	-21.0610
50	6	1.0000
51	1	-1.0536
51	2	-25.3289
51	6	1.0000
52	1	2.8910
52	2	-23.8291
52	6	1.0000
53	1	-1.0570
53	2	-25.4119
53	6	1.0000
54	1	2.7528
54	2	-27.1510
54	6	1.0000
55	1	-1.1227
55	2	-26.9898
55	6	1.0000
56	1	5.1977
56	2	-21.7067
56	6	1.0000

```

57 1 -1.0017
57 2 -24.0832
57 6 1.0000
58 1 5.1056
58 2 -23.9212
58 6 1.0000
59 1 -1.0536
59 2 -25.3289
59 6 1.0000
60 1 4.9674
60 2 -27.2431
60 6 1.0000
61 1 -1.0570
61 2 -25.4119
61 6 1.0000
62 1 7.3892
62 2 -22.3525
62 6 1.0000
63 1 -1.1227
63 2 -26.9898
63 6 1.0000
64 1 7.3201
64 2 -24.0134
64 6 1.0000
65 1 -1.1227
65 2 -26.9898
65 6 1.0000
66 1 7.1819
66 2 -27.3352
66 6 1.0000
67 1 -1.1227
67 2 -26.9898
67 6 1.0000
68 1 5.0365
68 2 -25.5822
68 6 1.0000
69 1 2.8219
69 2 -25.4901
69 6 1.0000
70 1 0.6074
70 2 -25.3980
70 6 1.0000
71 1 7.2475
71 2 -25.7573
71 6 1.0000
72 1 5.0330
72 2 -25.6652
72 6 1.0000
73 1 2.8185
73 2 -25.5731
73 6 1.0000
74 1 0.6039
74 2 -25.4810
74 6 1.0000
-1
11 3 0.0833 <--- AILERON DEFLECTION, T.E. UP
17 3 0.0833
23 3 0.0833
24 3 1.8229
18 3 1.5625
12 3 1.3020
11 5 1.0
17 5 1.0
23 5 1.0
24 5 1.0
18 5 1.0
12 5 1.0
-1
53 2 -.08333 <--- RUDDER DEFLECTION, T.E. NEGATIVE
53 6 1.00000
61 2 -.08333
61 6 1.00000
55 2 -1.66667
55 6 1.00000
63 2 -1.66667
63 6 1.00000
-1

```

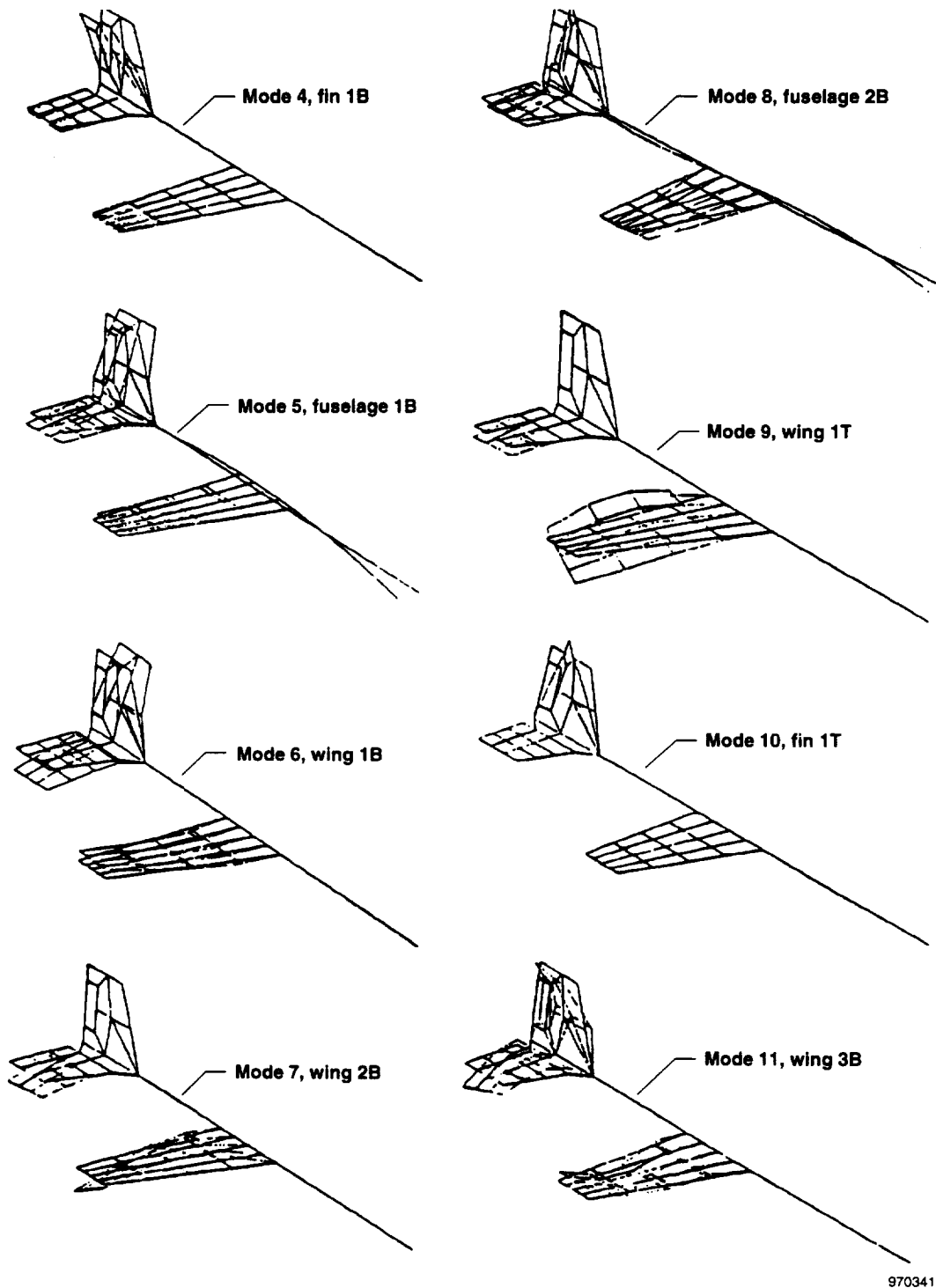
Note: k and p-k solutions can be run with or without the rigid-body control-mode data. When the data are not included, appropriate changes must be made to the above file and subsequent input files.

Aircraft Test Model STARS–SOLIDS analysis results:

Table 30 shows the results of the free-vibration analysis. Figure 52 shows the eight elastic mode shapes, and figure 53 shows the three perfect rigid-body and two control modes. In order to effect a correct response from the controllers, the perfect rigid-body and control modes need to be defined in the manner shown in table 31.

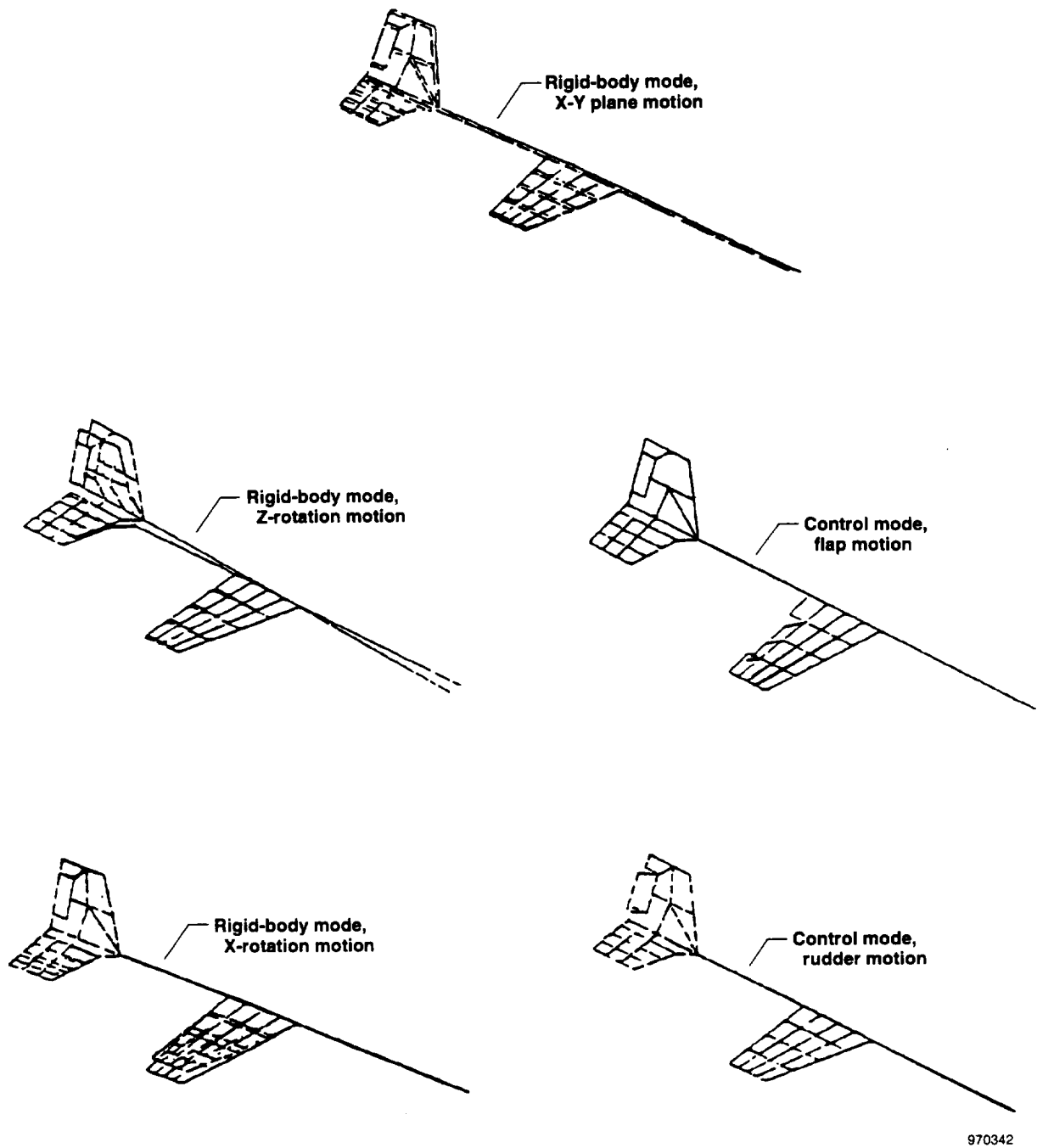
Table 30. Aircraft test model: Antisymmetric free-vibration analysis results.

Mode shape		Eigenvalue		Generalized mass, lbm	Mode shape	
SOLIDS	AEROS–ASE	Hz	rad/sec			
1	---	---	---	114.1	Rigid-body X rotation	(Φ_R)
2	---	---	---	2,533	Rigid-body Y translation	(Φ_R)
3	---	---	---	531.8	Rigid-body Z rotation	(Φ_R)
4	1	10.141	63.715	8.2	Vertical fin first bending	(Φ_E)
5	2	12.450	78.224	235.2	Fuselage first bending	(Φ_E)
6	3	14.684	92.262	46.51	Wing first bending	(Φ_E)
7	4	28.751	180.649	60.54	Wing second bending	(Φ_E)
8	5	29.809	187.296	204.3	Fuselage second bending	(Φ_E)
9	6	32.448	203.879	47.87	Wing first torsion	(Φ_E)
10	7	35.736	224.535	3.228	Fin first torsion	(Φ_E)
11	8	51.137	321.303	239.3	Fuselage third bending	(Φ_E)
12	9	---	---	2,534	Rigid-body Y translation	(Φ_{PR})
13	10	---	---	151,200	Rigid-body roll	(Φ_{PR})
14	11	---	---	589,000	Rigid-body yaw at 275 in.	(Φ_{PR})
15	12	---	---	128.60	Flap deflection	(Φ_C)
16	13	---	---	14.22	Rudder deflection	(Φ_C)



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Figure 52. Aircraft test model antisymmetric case, elastic (Φ_E) mode shapes.



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Figure 53. Aircraft test model antisymmetric case, perfect rigid body (Φ_{PR}) and control (Φ_C) modes.

Table 31. Aircraft test model rigid-body and control-mode generation parameters.

Motion	Symmetric analysis	Antisymmetric analysis
X translation	1.0 in X	
Y translation		1.0 in Y
Z translation	-1.0 in Z	
X rotation		$-\Delta$ in Z
Y rotation	$-\Delta$ in Z	
Z rotation		$-\Delta$ in Y
Flap	$-\Delta$ in Z	
Aileron		Δ in Z
Elevator	$-\Delta$ in Z	
Rudder		$-\Delta$ in Y

In table 31, the term Δ is defined as $\Delta = (d_N - d_A)/12$, where d_N and d_A represent the coordinates of the node under consideration and the axis of rotation, respectively.

7.2 Aircraft Test Model: Generalized Mass Analysis (STARS-AEROS-GENMASS)

This run is made by deleting the first three-rigid body modes so that

$$\Phi = \Phi_E + \Phi_{PR} + \Phi_C$$

STARS-AEROS-GENMASS input data (atm_genmass.dat):

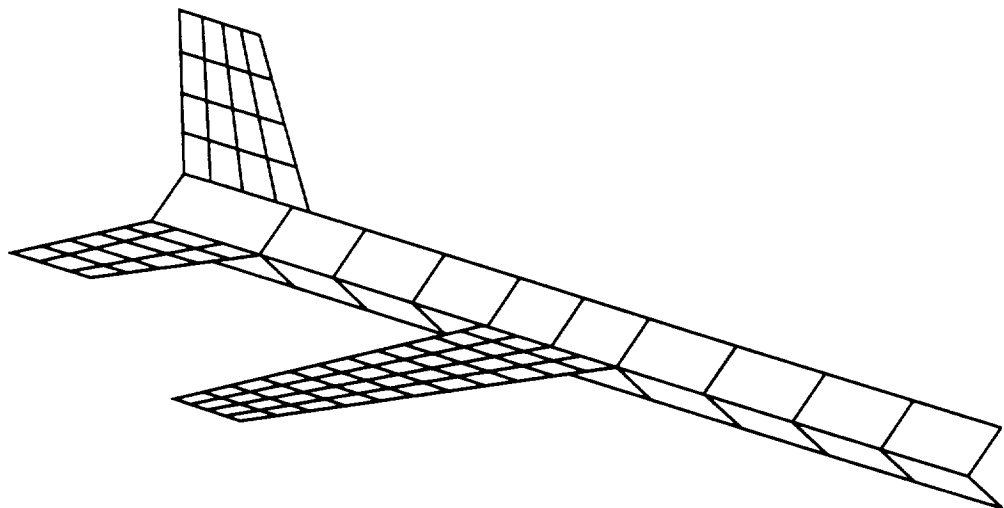
```
$ AERO TEST MODES, ANTISYMMETRIC VERSION
1 39 386.088
$ Laterally moving direct interpolation output MODE NUMBERS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
```

20
21
22
23
24
25
26
27
121
122
123
124
125
126
127
128
129
130
131
132

Table 30 shows the calculated generalized mass.

7.3 Aircraft Test Model: Aeroelastic Analysis (STARS–AEROS–AEROL)

The input data used for the eventual ASE response analysis are given in this section. These data also enable flutter and divergence analysis of the aircraft. For a k method of flutter solution, the number of reduced frequencies in the data is increased from 10 to 28, and all rigid-body and control modes must be eliminated. For p-k solution, the number of reduced frequencies is fixed at 6, and all rigid-body and control modes must also be eliminated. Figures 54 to 56 show the aircraft test model–relevant aerodynamic model arrangements.



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Figure 54. Aircraft test model antisymmetric case, one-half aircraft aerodynamic boxes.

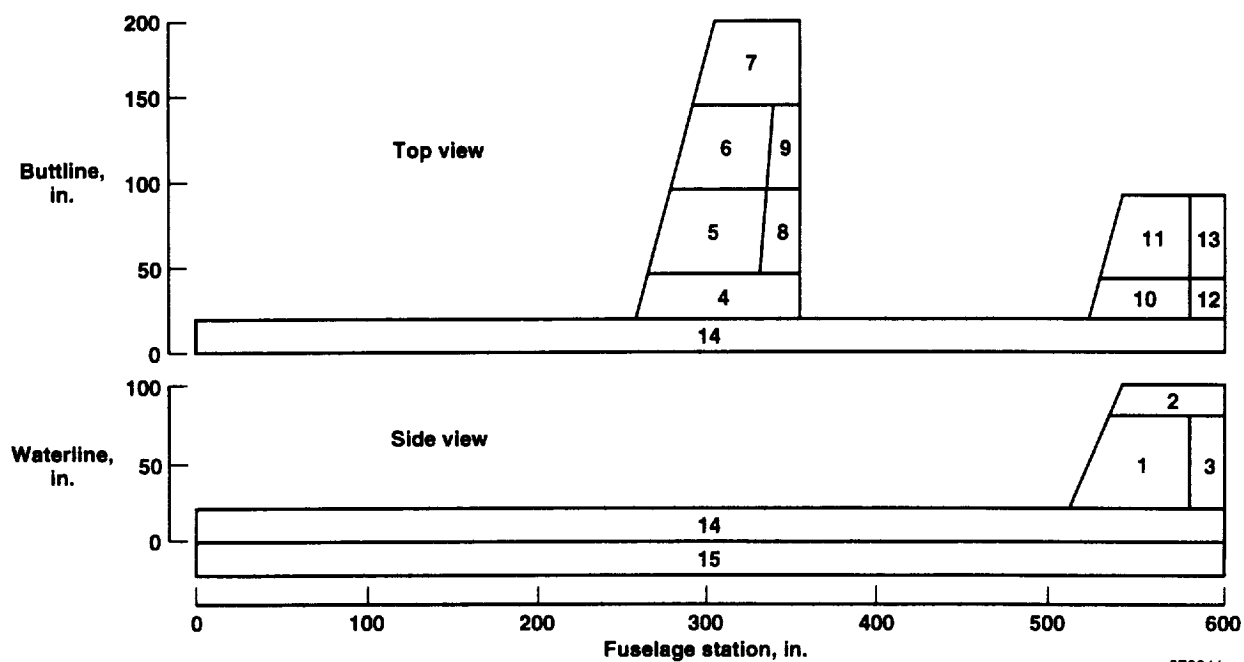
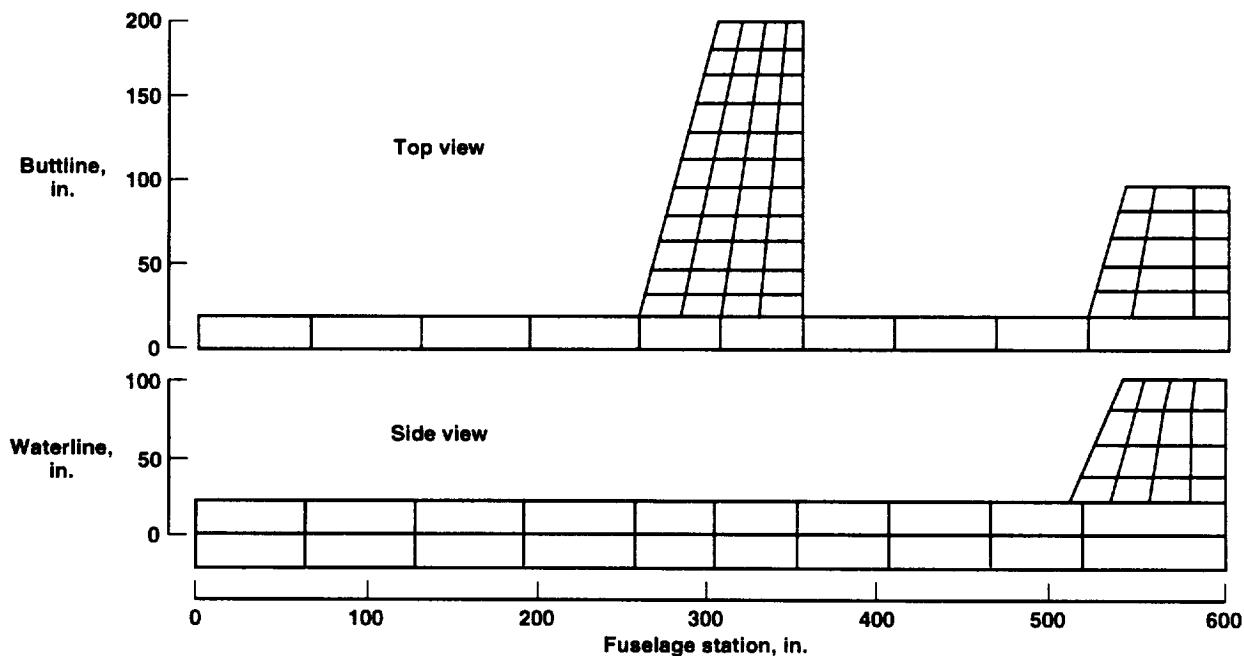
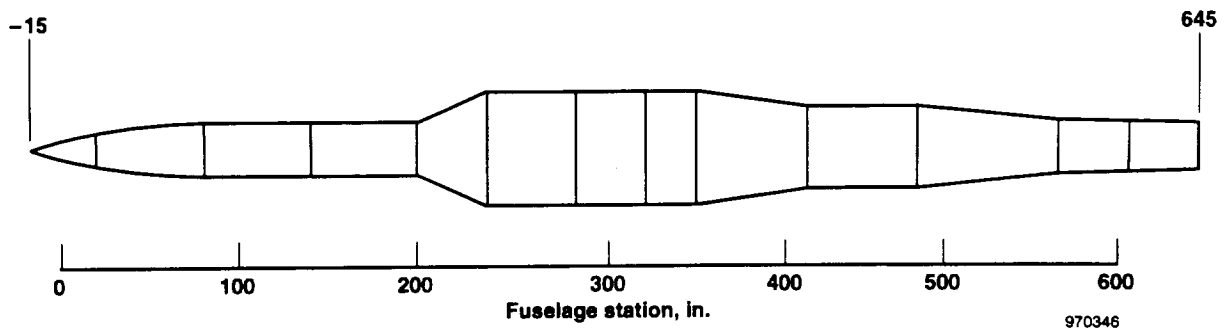


Figure 55. Aircraft test model antisymmetric case, aerodynamic panels.



(a) Aerodynamic boxes.

Figure 56. Aircraft test model antisymmetric case, aerodynamic boxes.



(b) Slender-body definitions.

Figure 56. Concluded.

STARS-AEROS-AEROL input data (atm_aero_ase.dat), ASE flutter analysis:

```

AIRCRAFT TEST MODEL - ANTISYMMETRIC CASE - NCNTAL = 5
SET UP FOR ASE SOLUTION.
DIRECT SURFACE INTERPOLATION.
8 ELASTIC MODES FROM 11 SOLIDS (-3 AT GENMASS) + 3 PERF. RIG. + 2 CONTROL
FILE FOR ASE, FOR FLUTTER USE CONVERT TO EXCLUDE ABC'S, FOR FRESF USE ALL
MACH NO. = 0.90      ALTITUDE: SEA LEVEL
1  13  3  10  1  0  0  0  0  0
1  0  0  0  0  0  0  0  0  0
1  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  99  0  0
1
38.89  0.90
11000.0 1000.0 100.0 50.0 10.0 5.0 1.0
0.667 0.500 0.25
.10 -.40 1400. 80.0
1.0
77.78 15000.
-1 15 1 1200 0 0 1
90.0
508.0 580.0 532.0 580.0 20.0 80.0
0.0 0.0 4 4 0.0
0.0 0.3333 0.6666 1.0
0.0 0.3333 0.6666 1.0
90.0
532.0 600.0 540.0 600.0 80.0 100.0
0.0 0.0 2 5 0.0
0.0 0.2353 0.4705 0.7059 1.0
0.0 1.0
90.0
580.0 600.0 580.0 600.0 20.0 80.0
0.0 0.0 4 2 0.0
0.0 1.0
0.0 0.3333 0.6666 1.0
255.0 350.0 262.5 350.0 20.0 50.0
0.0 0.0 3 5 0.0
0.0 0.25 0.50 0.75 1.0
0.0 0.5 1.0
262.5 328.125 275.0 331.25 50.0 100.0
0.0 0.0 4 4 0.0
0.0 0.3333 0.6666 1.0
0.0 0.34 0.66 1.0
275.0 331.25 287.5 334.375 100.0 150.0
0.0 0.0 4 4 0.0
0.0 0.3333 0.6666 1.0
0.0 0.34 0.66 1.0
287.5 350.0 300.0 350.0 150.0 200.0
0.0 0.0 4 5 0.0
0.0 0.25 0.50 0.75 1.0
0.0 0.34 0.66 1.0
328.125 350.0 331.25 350.0 50.0 100.0
0.0 0.0 4 2 0.0
0.0 1.0
0.0 0.34 0.66 1.0
331.25 350.0 334.375 350.0 100.0 150.0
0.0 0.0 4 2 0.0
0.0 1.0
0.0 0.34 0.66 1.0

```


12	2	14				
0.0	100.0	150.0	200.0	250.0	300.0	
350.0	400.0	450.0	500.0	560.0	600.0	
0						

STARS-AEROS-AEROL input data (atm_aero_k.dat), k-type flutter analysis:

The data presented here pertain only to changes required in the corresponding ASE analysis case and occur within the first 16 lines, which are replaced by these 19 lines.

```

AERO TEST MODEL - ANTISYMMETRIC CASE
K-FLUTTER SOLUTION
8 ELASTIC FROM 11 IN SOLIDS (-3 AT GENMASS, 1c(25) = 1, - 3 PERF. RIGID - 2 CONTROL)
DIRECT SURFACE INTERPOLATION /// CORRECTED INTERP FORMAT AND POINTS
STARS STRUCTURAL MODEL, BYPASS RIGID BODY MODES IN GENMASS
MACH NO.=0.90      ALTITUDE: SEA LEVEL
1 13 3 28 1 0 0 0 0 0
1 1 0 0 0 0 0 0 0 0
1 0 0 0 1 0 0 0 0 0
0 0 0 0 0 0 0 99 0 0
1
38.89 0.90
.350 .745 .940 1.491 1.615 1.698 1.864
2.000 2.450 2.750 3.150 3.270 3.400 3.850
4.150 4.551 5.250 7.000 9.000 11.110 15.000
19.000 24.070 50.000 140.000 315.774 616.746 1200.000
.10 -.40 1400. 80.0
1.0
5 9 10 11 12 13

```

STARS-AEROS-AEROL input data (atm_aero_pk.dat), p-k-type flutter analysis:

The data presented here pertain only to changes required in the corresponding ASE analysis case and occur within the first 16 lines, which are replaced by these 17 lines.

```

AERO TEST MODEL - ANTISYMMETRIC CASE -
PK-FLUTTER SOLUTION
8 ELASTIC FROM 11 IN SOLIDS (-3 AT GENMASS, 1c(25) = 1, - 3 PERF. RIGID - 2 CONTROL)
DIRECT SURFACE INTERPOLATION /// CORRECTED INTERP FORMAT AND POINTS
STARS STRUCTURAL MODEL, BYPASS RIGID BODY MODES IN GENMASS
MACH NO.=0.90      ALTITUDE: SEA LEVEL
-1 13 3 6 1 0 0 0 0 0
1 1 1 0 0 0 0 0 1 0
1 0 0 0 1 0 0 0 0 0
0 0 0 0 0 0 0 99 0 0
1
38.89 0.90
20 200.0 40.0
10.0E-04 .21 2.0 4.0 6.0 7.0 8.0
.10 -.40 1400. 80.0
1.0
5 9 10 11 12 13

```

STARS-AEROS-AEROL analysis results:

Table 32 shows the results of flutter analysis by various methods using direct interpolation of modal data. The flutter solution based on the ASE method using state-space formulation employs a data file (as in section 6.4) and is presented in sections 7.4 and 7.5. Figures 57 to 59 show the pattern of root location as a function of velocity for the k, p-k, and ASE methods. In this connection, it should be noted that only the elastic modes are considered in these analyses. In the ASE method, the real (α) and imaginary (β)

parts of the eigenvalues, termed as damping and frequencies, of the state-space plant dynamics matrix (**A**) are plotted against the airspeed. In the k and p-k methods, the damping term is expressed as $g' = 2\alpha\beta / \omega_n^2$, where $\omega_n = \sqrt{\alpha^2 + \beta^2}$ and is the magnitude of the eigenvalue of the closed-loop control system **A** matrix.

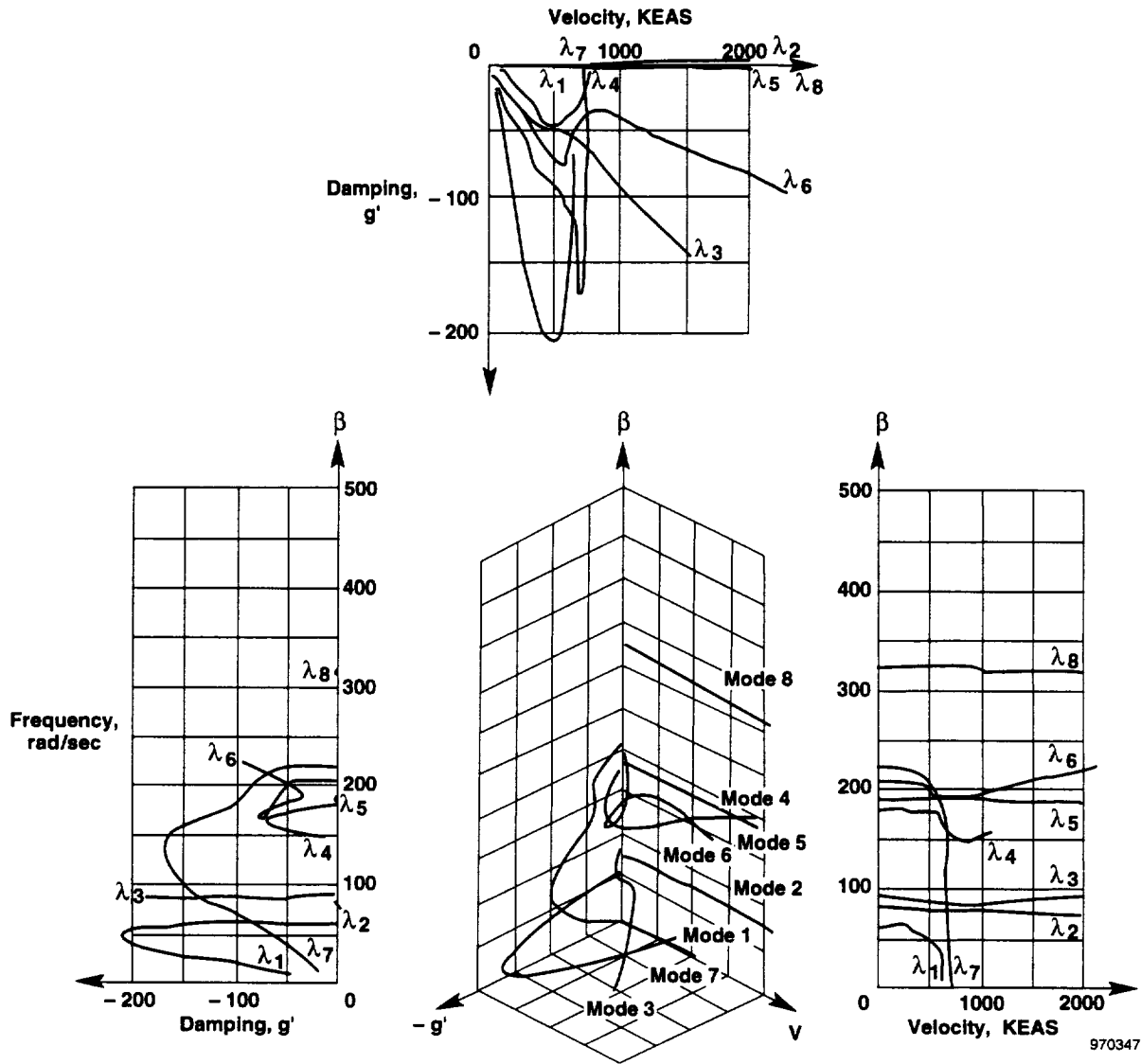


Figure 57. Aircraft test model k flutter analysis — damping (g'), frequency (β), velocity (v) plot, antisymmetric case, using direct interpolation where $g' = g \times 200$.

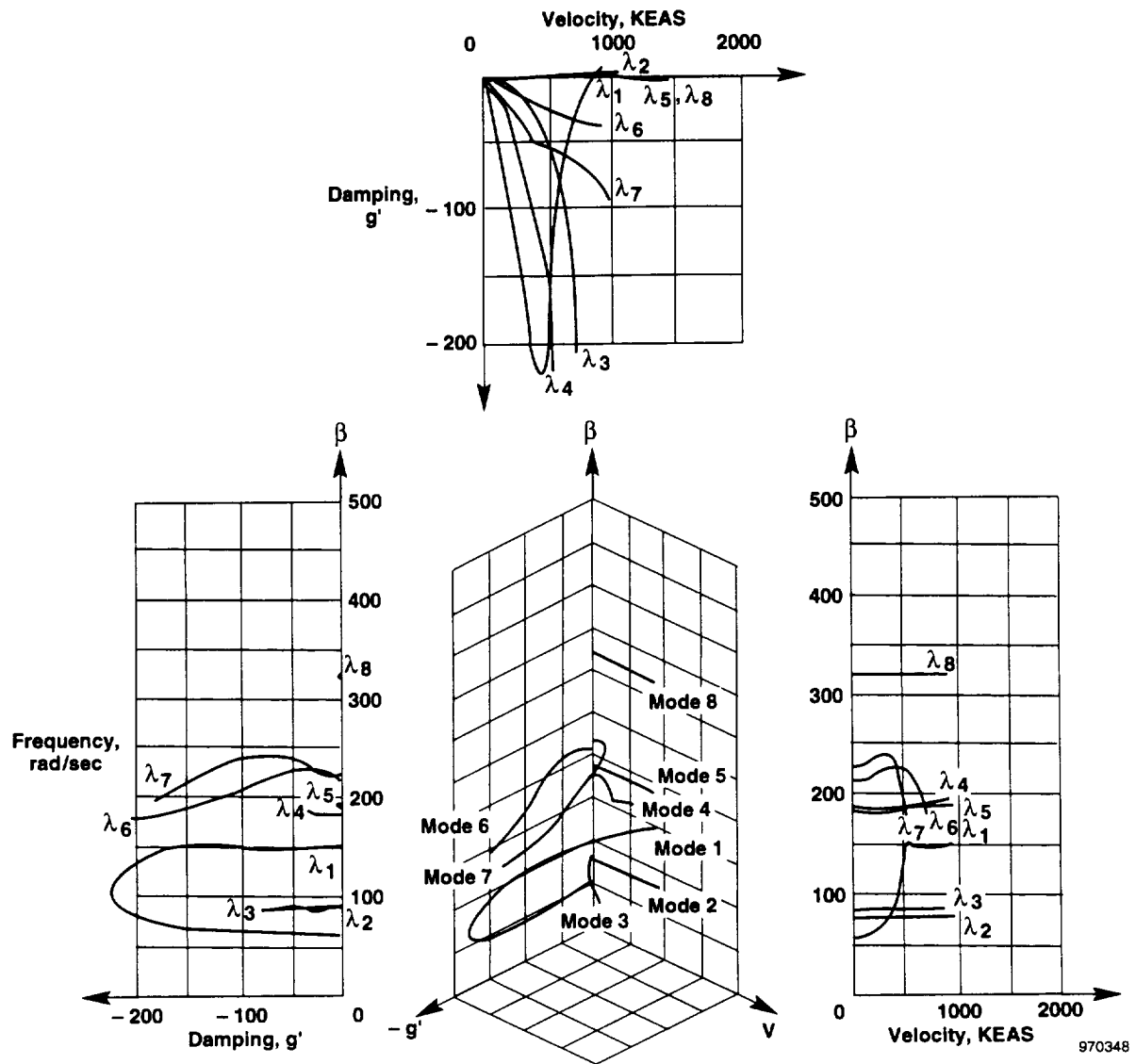
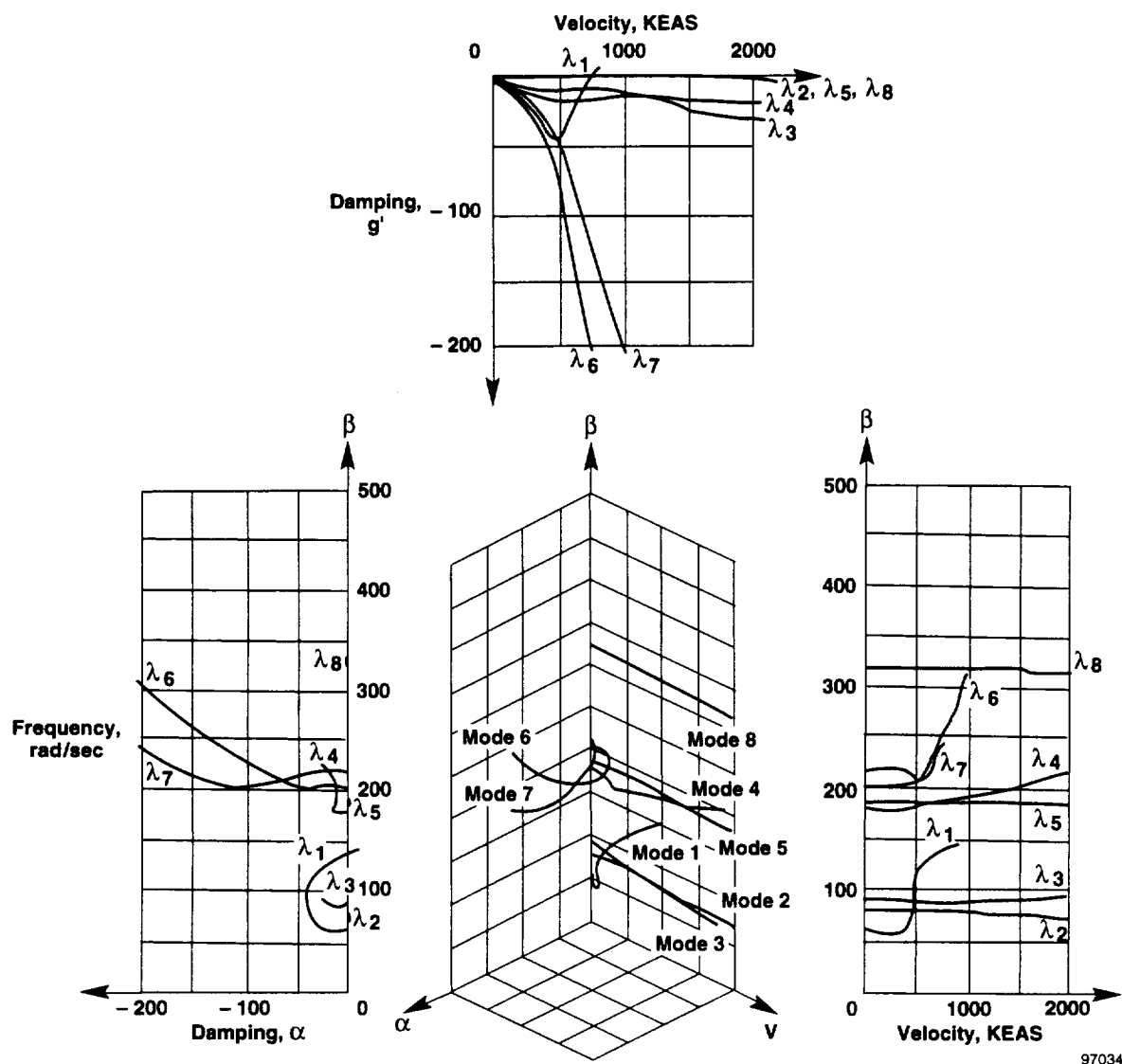


Figure 58. Aircraft test model p-k flutter analysis — damping (g'), frequency (β), velocity (v) plot, antisymmetric case, using direct interpolation where $g' = g \times 200$.



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Figure 59. Aircraft test model ASE flutter analysis — damping (a), frequency (b), velocity (v) plot, antisymmetric case, using direct interpolation.

7.4 Aircraft Test Model: Aeroelastic Analysis (STARS-ASE-CONVERT)

The input data presented here enable the appropriate reordering of generalized matrices. For the flutter analysis, only the eight elastic modes (Φ_E) are used. For the ASE solution, the three perfect rigid-body modes (Φ_{PR}) are placed in the front, followed by eight elastic modes (Φ_E) and two rigid-control modes (Φ_C).

STARS-ASE-CONVERT input data (atm_aero_convert.dat), ASE flutter solution:

```
$ CONVERT FILE FOR ASE FLUTTER AND DIVERGENCE SOLUTION
8
$ MODAL SELECTION AND ORDERING
1,1
2,2
```

3,3
4,4
5,5
6,6
7,7
8,8

STARS-ASE-CONVERT input data (atm_ase_convert.dat), ASE frequency response and damping solution:

```
$ CONVERT FILE FOR ASE SOLUTION
13
$ MODAL SELECTION AND ORDERING
9,1
10,2
11,3
1,4
2,5
3,6
4,7
5,8
6,9
7,10
8,11
12,12
13,13
```

7.5 Aircraft Test Model: Aeroservoelastic Analysis (STARS-ASE-PADÉ)

The input data presented here effect curve fitting of unsteady aerodynamic forces employing Padé polynomials. The state-space matrices are also formed in this module. Version I of the input file pertains to the ASE flutter solution, whereas version II corresponds to the subsequent ASE frequency-response and damping solution. The generalized mass, generalized damping, and natural frequencies are output by STARS-ASE-CONVERT into the file MDF_PADE.DAT, which can then be cut and pasted into the PADÉ input files.

STARS-ASE-PADÉ input data (atm_aero_pade.dat), ASE flutter solution:

```
$ ATM ASE FLUTTER ANALYSIS, 0.9 MACH AT SEA LEVEL - VERSION I DATA
0, 8, 0, 0, 0, 10, 2, 1.0, 1004.79, 3.2, 0, 69
$ TENSION COEFFICIENTS
0.4 0.2
$ GENERALIZED MASS
.2543E+00 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.7310E+01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.1446E+01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.1882E+01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.6351E+01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.1488E+01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.1003E+00 0.0 0.0 0.0 0.0 0.0 0.0 0.0
.7438E+01
$ GENERALIZED DAMPING
.00000000E+00 .00000000E+00 .00000000E+00 .00000000E+00
.00000000E+00 .00000000E+00 .00000000E+00 .00000000E+00
$ Natural Frequencies (radians)
.63715276E+02 .78224005E+02 .92261642E+02 .18064940E+03
.18729576E+03 .20387943E+03 .22453529E+03 .32130318E+03
$ VELOCITIES FOR FLUTTER AND DIVERGENCE ANALYSIS
1.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
```

800.0
 900.0
 1000.0
 1100.0
 1200.0
 1210.0
 1220.0
 1230.0
 1240.0
 1250.0
 1260.0
 1270.0
 1280.0
 1290.0
 1300.0
 1400.0
 1500.0
 1600.0
 1700.0
 1800.0
 1900.0
 2000.0
 2050.0
 2100.0
 2150.0
 2200.0
 2250.0
 2300.0
 2350.0
 2400.0
 2450.0
 2500.0
 2550.0
 2600.0
 2650.0
 2700.0
 2710.0
 2730.0
 2740.0
 2750.0
 2760.0
 2780.0
 2790.0
 2800.0
 2850.0
 2875.0
 2900.0
 2950.0
 3000.0
 3050.0
 3100.0
 3150.0
 3200.0
 3250.0
 3300.0
 3350.0
 3400.0
 3450.0
 3500.0
 3550.0
 3600.0

STARS-ASE-PADÉ input data (atm_ase_pade.dat), ASE frequency response and damping solution:

```

$ ATM ASE ANALYSIS, 0.9 MACH AT 40K FEET - VERSION 11 DATA
      3,  8,  2,  0,  2, 10,  2, 0.24708, 871.27, 3.2,    0,  0
$ TENSION COEFFICIENTS
      0.4      0.2
$ GENERALIZED MASS
0.7875E+02  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.4701E+04  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.1831E+05  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.2543E+00  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.7310E+01  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.1446E+01  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.1882E+01  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  
```

```

0.6351E+01 0.0 0.0 0.0 0.0 0.0
0.1488E+01 0.0 0.0 0.0 0.0 0.0
0.1003E+00 0.0 0.0 0.0
0.7438E+01 0.0 0.0
0.3996E+01 0.0
0.4419E+00
$ GENERALIZED DAMPING
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00
$ Natural Frequencies (radians)
0.0 0.0 0.0 .63715276E+02
.78224005E+02 .92261642E+02 .18064940E+03 .18729576E+03
.20387943E+03 .22453529E+03 .32130318E+03 0.0
0.0
$ PHI, THETA, PSI, US, US, US, PS, QS, RS, PHID, THAD, PSID, NDOF
0.0, 0.0, 0.0, 871.27, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, -3
$ SENSOR DATA
0
300.00 0.0 50.0
0.0 0.0 0.0 1.0 0.0 0.0
300.00 0.0 50.0
0.0 0.0 0.0 0.0 0.0 1.0

```

STARS-ASE-PADÉ analysis results:

The state-space matrices generated in this module by the Version I data file are used for the flutter solution. Table 32 shows the results. Results derived through use of Version II data are used for subsequent ASE frequency-response and damping analyses in the next section.

Table 32. Aircraft test model: An aeroelastic antisymmetric analysis using a direct interpolation for AEROS paneling.

Mode	Instability number	Solution					
		k		p-k		ASE	
		Velocity, KEAS	Frequency, rad/sec	Velocity, KEAS	Frequency, rad/sec	Velocity, KEAS	Frequency rad/sec
Fuselage first bending	F1	443.3	77.4	441.7	77.4	474.1	77.3
Vertical fin first bending	F2	861.3	147.3	863.4	147.1	728.9	136.2
Fin first bending	D1	647.7	0.0	---	---	651.9	0.0
Fin first torsion	D2	728.7	0.0	---	---	728.9	0.0

Analysis notes:

- 1) F: Flutter point
- 2) D: Divergence point
- 3) Mach = 0.90
- 4) Altitude = Sea level

7.6 Aircraft Test Model: Aeroservoelastic Analysis (STARS-ASE-CONTROL)

The input data presented here pertain to the frequency-response analysis of the aircraft test model at Mach 0.9 and an altitude of 40,000 ft. Thus, phase and gain margins as well as damping and frequency values are generated from this module. Figure 60 shows the block diagram for the aircraft test model lateral-mode analog control system.

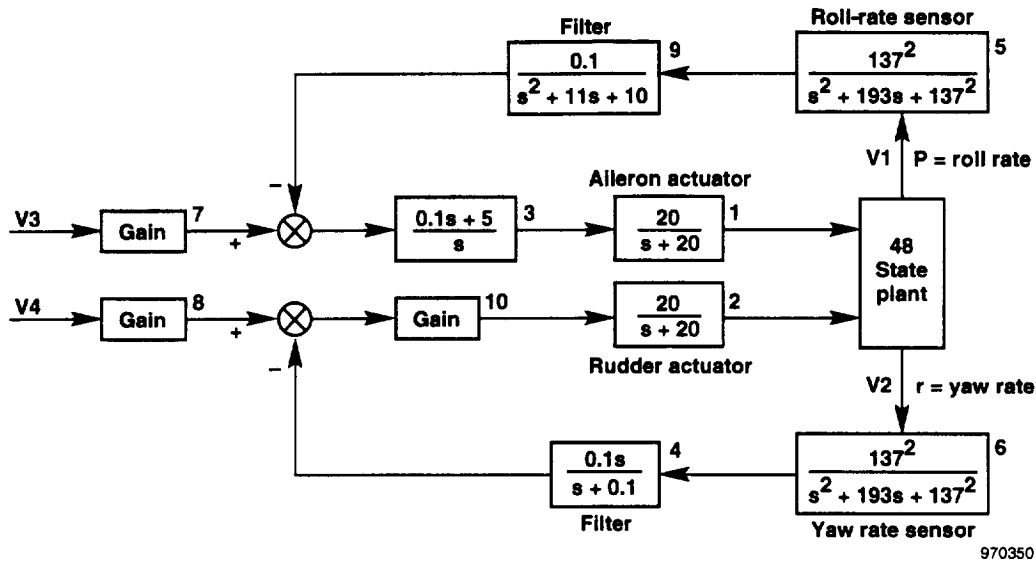


Figure 60. Aircraft test model lateral mode analog control system.

STARS-ASE-CONTROL input data (atm_ase_controlo.dat), open-loop case:

```
$ ATM ANTI-SYMMETRIC 3 RIGID, 8 ELASTIC, AND 2 CONTROL MODES- OPEN LOOP CASE
C LOOP OPEN BETWEEN BLOCKS 3 AND 9 AS WELL AS BETWEEN 4 AND 10
 48, 12, 4, 4, 58, 0.0, 0.0, 3, 3
 10 4 10 6 10 4 2 1 1
 2 1 1 2
$ BLOCK CONNECTIVITY
 1 3 0 0 0 0 0
 2 10 0 0 0 0 0
 3 7 0 0 0 0 0
 4 6 0 0 0 0 0
 5 0 0 0 1 0 0
 6 0 0 0 2 0 0
 7 0 0 0 3 0 0
 8 0 0 0 4 0 0
 9 5 0 0 0 0 0
10 8 0 0 0 0 0
$ TRANSFER FUNCTION DESCRIPTIONS
 1 1 2 0
 2 1 2 0
 3 2 2 0
 4 2 2 0
 5 2 1 1
 6 1 3 0
 7 1 1 0
 8 1 1 0
 9 2 1 1
10 1 1 0
$ LISTING OF POLYNOMIAL COEFFICIENTS
 1 .2000E+02 .0000E+00 .0000E+00
 0 .2000E+02 .1000E+01 .0000E+00
 2 .2000E+02 .0000E+00 .0000E+00
 0 .2000E+02 .1000E+01 .0000E+00
 3 .5000E+01 .1000E+00 .0000E+00
 0 .0000E+00 .1000E+01 .0000E+00
```

```

4 .0000E+00 .1000E+01 .0000E+00
0 .1000E+00 .1000E+01 .0000E+00
6 .1877E+05 .0000E+00 .0000E+00
0 .1877E+05 .1930E+03 .1000E+01
7 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
8 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
10 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
$ Listing of state space matrices of control block
5 2 1 1
.000 1.000 0.0
-18770.000 -193.000 18770.
1.000 0. 0.
9 2 1 1
.000 1.000 .000
-10.000 -11.000 .100
1.000 .000 .000
$ GAIN INPUTS FOR EACH BLOCK
1 .1000E+01 2 .1000E+01 3 .1000E+01 4 .1000E+00 5 .1000E+01
6 .1000E+01 7 .1000E+01 8 .1000E+01 9 .1000E+01 10 .1000E+01
$ SPECIFICATION FOR SYSTEM OUTPUTS
7 8 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
$ SPECIFICATION FOR SYSTEM INPUTS
7 8 0 0 0 0 0 0 0
$ CONNECTION DETAILS FROM PLANT TO BLOCKS
2 2 0
7 1
8 2
1 1
2 2
$ FREQUENCY RANGE SPECIFICATIONS
0.1 .9 200
1.0 9. 200
10. 90. 200
100. 500. 100
$ LOOP DEFINITIONS - out block inp block outblock row input block row
1 0
4 8 1 1
9 7 1 1

```

STARS-ASE-CONTROL input data (atm_ase_controlc.dat), closed-loop case:

```

$ ATM ANTI-SYMMETRIC 3 RIGID, 8 ELASTIC, AND 2 CONTROL MODES- CLOSED-LOOP CASE
C LOOP CLOSED BETWEEN BLOCKS 3 AND 9 AS WELL AS BETWEEN 4 AND 10
18, 12, 4, 4, 58, 0.0, 0.0, 3, 3
10 4 10 6 10 4 2 1 1
2 1 1 2
$ BLOCK CONNECTIVITY
1 3 0 0 0 0 0
9 0 0 0 0 5 3
3 7 0 0 0 0 0
5 0 0 0 1 0 0
6 0 0 0 2 0 0
7 0 0 0 3 0 0
8 0 0 0 4 0 0
2 10 0 0 0 0 0
4 0 0 0 0 6 10
10 8 0 0 0 0 0
$ TRANSFER FUNCTION DESCRIPTIONS
1 1 2 0
2 1 2 0
3 2 2 0
4 2 2 0
5 2 1 1
6 1 3 0
7 1 1 0
8 1 1 0
9 2 1 1
10 1 1 0
$ LISTING OF POLYNOMIAL COEFFICIENTS
1 .2000E+02 .0000E+00 .0000E+00
0 .2000E+02 .1000E+01 .0000E+00
2 .2000E+02 .0000E+00 .0000E+00
0 .2000E+02 .1000E+01 .0000E+00
3 .5000E+01 .1000E+00 .0000E+00
0 .0000E+00 .1000E+01 .0000E+00

```

```

4 .0000E+00 .1000E+01 .0000E+00
0 .1000E+00 .1000E+01 .0000E+00
6 .1877E+05 .0000E+00 .0000E+00
0 .1877E+05 .1930E+03 .1000E+01
7 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
8 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
10 .1000E+01 .0000E+00 .0000E+00
0 .1000E+01 .0000E+00 .0000E+00
$ Listing of state space matrices of control block
5 2 1 1
.000 1.000 0.0
-18770.000 -193.000 18770.
1.000 0. 0.
9 2 1 1
.000 1.000 .000
-10.000 -11.000 .100
1.000 .000 .000
$ GAIN INPUTS FOR EACH BLOCK
1 .1000E+01 2 .1000E+01 3 .1000E+01 4 .1000E+00 5 .1000E+01
6 .1000E+01 7 .1000E+01 8 .1000E+01 9 .1000E+01 10 .1000E+01
$ SPECIFICATION FOR SYSTEM OUTPUTS
7 8 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
$ SPECIFICATION FOR SYSTEM INPUTS
7 8 0 0 0 0 0 0 0
$ CONNECTION DETAILS FROM PLANT TO BLOCKS
2 2 0
7 1
8 2
1 1
2 2
$ FREQUENCY RANGE SPECIFICATIONS
0.1 .9 200
1.0 9. 200
10. 90. 200
100. 500. 100
$ LOOP DEFINITIONS - out block inp block outblock row input block row
0 0
999 8 8 1
999 7 7 1

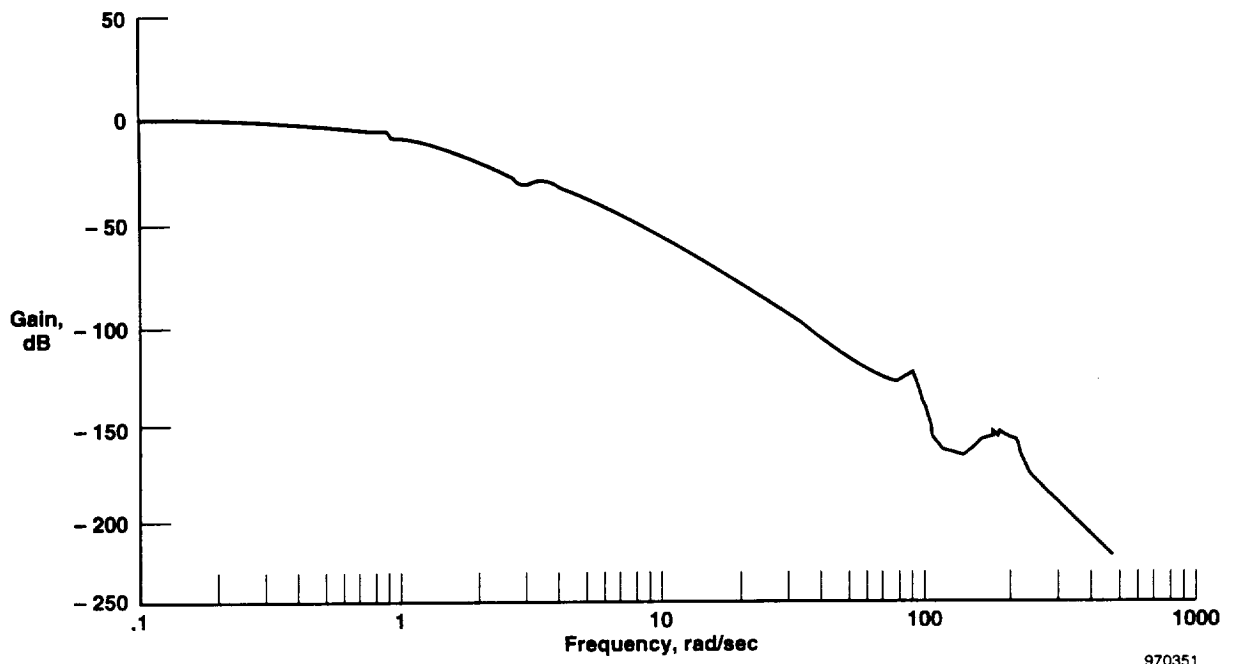
```

STARS-ASE-PADÉ analysis results:

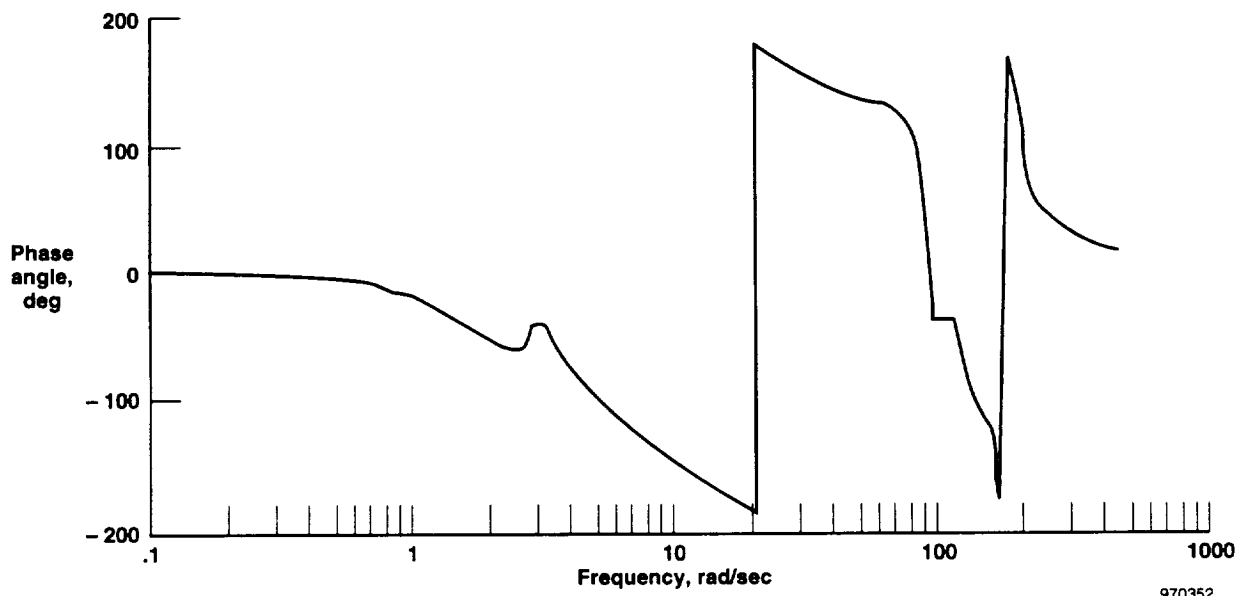
Figures 61 and 62 show the lateral-loop gains for the roll and yaw modes, respectively. The gain margins are tabulated in table 33.

Table 33. Aircraft test model gain and phase margins.

Mode	Phase crossover, rad	Gain margin, dB
Roll	20.20	78.26
Yaw	2.90	-0.80

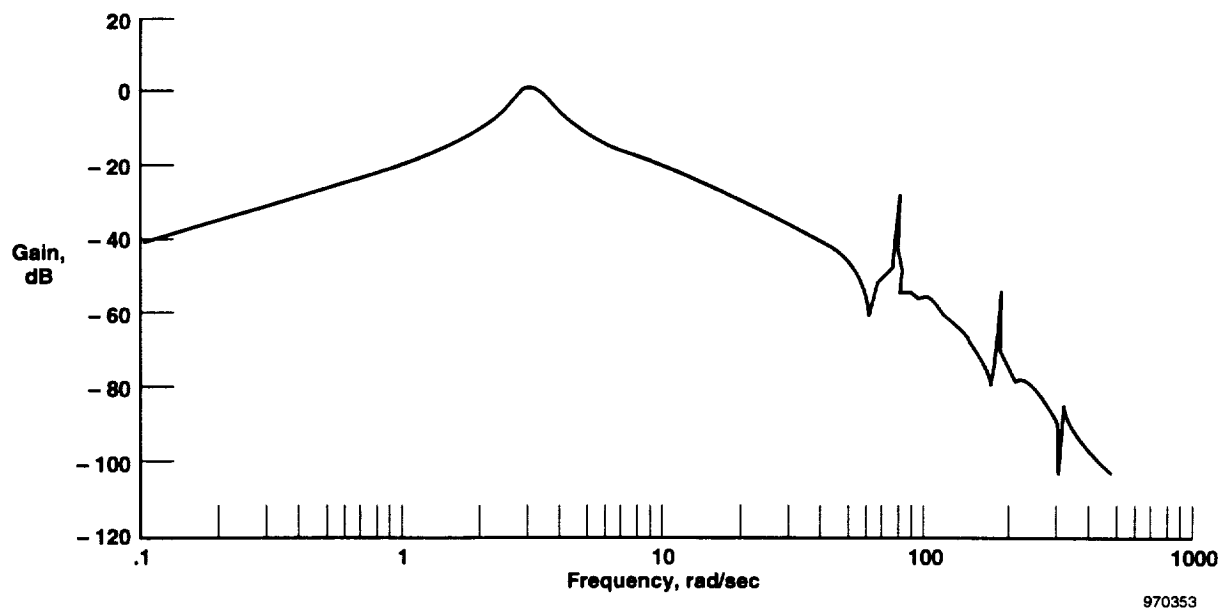


(a) Gain.

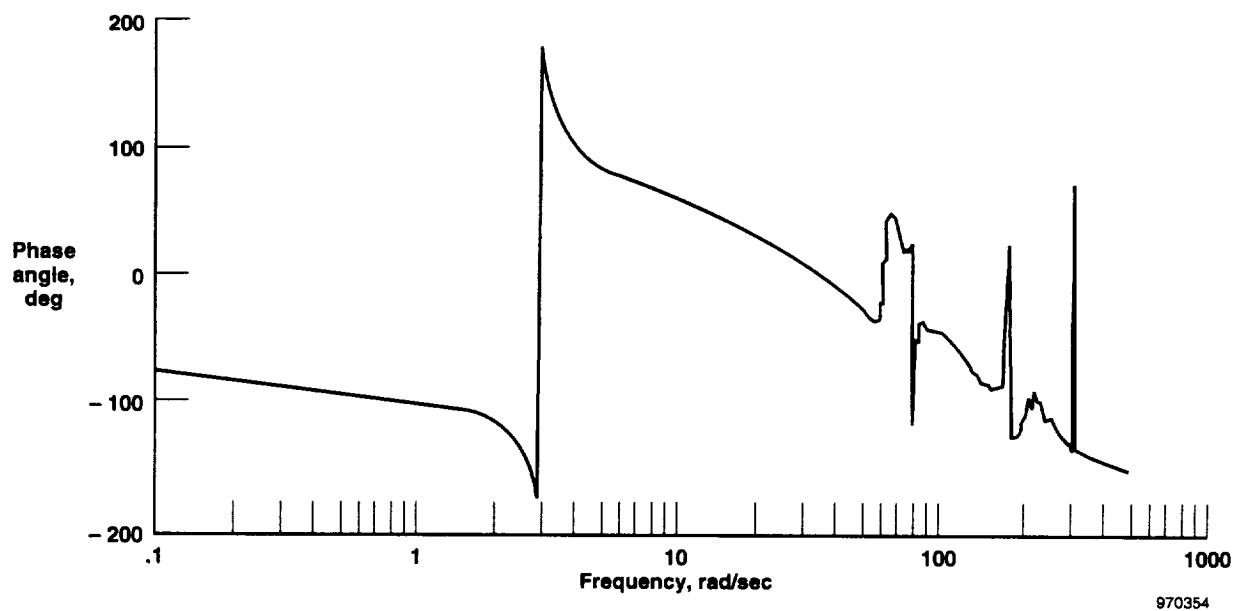


(b) Phase.

Figure 61. Aircraft test model lateral loop gains, roll mode.



(a) Gain.



(b) Phase.

Figure 62. Aircraft test model lateral loop gains, yaw mode.

Figure 63 shows the closed-loop damping and frequency plots. These results were obtained by running the output of STARS-ASE-CONTROL through STARS-ASE-FRESP. Approximately 20 altitudes, represented by pairs RHOR and VEL data in STARS-ASE-PADÉ, were required to track

the modes, starting at an altitude of 80,000 ft, where aerodynamic forces are negligible and frequencies approximate the structural frequencies, and descending to sea level. Most of the analyses were performed between altitudes of 10,000 and 30,000 ft, and the remainder were performed at each 10,000-ft increment. Root locus plots (either of real against imaginary frequency or frequency magnitude against gain) can be made to help in the tracking process. Frequency coalescence of the first two modes occurs at approximately 77.42 rad/sec and an equivalent velocity of 263 knots; around this point, mode 2 goes unstable (damping goes negative), and the aircraft flutters.

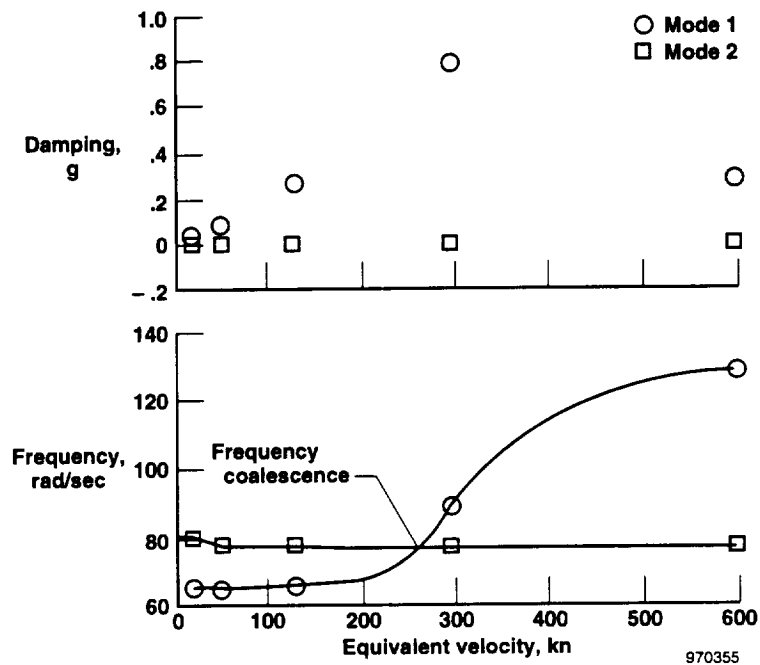


Figure 63. Aircraft test model closed-loop damping, v-g, and frequencies, v-f.

7.7 Aircraft Test Model: Run-Stream Details

This section provides details for analyzing the aircraft test model. Most of these details are applicable to any analysis to be performed with these modules. All aircraft test model analyses were performed using double-precision (RL) arithmetic. Any file name can be chosen by the user for the input and output, although a large number of FORTRAN tapes (for example, fort.20, in Unix notation) are used by the module and should be avoided. Table 34 shows the file names used for the aircraft test model.

In each analysis, the user is requested to give an output file name. The standard STARS procedure is to use *filename.out*. The modules automatically append the ".1" (and in the case of STARS-SOLIDS, ".2") to the ".out" file extension and should not be added by the user.

Table 34. Input files for linear aeroelastic and aeroservoelastic analysis.

DATA INPUT FILES (atm_*.dat)			
Aeroelastic analysis (flutter and divergence)			ASE analysis (frequency response and damping)
k method	p-k method	State-space method	State-space method
solids (SRUN)	solids	solids	solids
genmass (ARUN)	genmass	genmass	genmass
aero_k (ARUN)	aero_pk (ARUN)	aero_ase (ARUN)	aero_ase
		aero_convert (ASERUN)	ase_convert (ASERUN)
		aero_pade (ASERUN)	ase_pade (ASERUN)
Note: Run-stream type indicated at the first appearance of the analysis mode (appendix C).			ase_controlo (ASERUN)
			ase_controlc (ASERUN)

STARS-SOLIDS (SRUN):

The solids analysis is performed with MAINIB (matrix assembly) and EIGLAN (eigensolver) but without RESPONSE (static or dynamic response). The input file is atm_solids.dat, and the output files are atm_solids.out.1 and atm_solids.out.2.

STARS-AEROS-GENMASS (ARUN):

The generalized mass is calculated using atm_genmass.dat as the input file. The output file is atm_genmass.out.1.

STARS-AEROS-AEROL (ARUN):

The k flutter solution is achieved using atm_aero_k.dat as the input file. The output file is atm_aero_k.out.1. An input file, atm_aero_pk.dat, is used to obtain the p-k flutter solution. The output file is atm_aero_pk.out.1. The ASE flutter solution is obtained by using atm_aero_ase.dat as the input file; the output file is atm_aero_ase.out.1.

In both k and p-k methods, for a particular combination of Mach numbers and altitudes (density ratios), analyses are performed for a number of reduced velocities ($V/b\omega$). In the k method, any change in sign of damping value between two reduced velocities indicates the occurrence of flutter. In the p-k method, results are obtained for each mode corresponding to a specified number of equivalent velocities, and a flutter occurrence is indicated by a sign change in damping. In the ASE method, the state-space matrices are computed for a number of equivalent velocities, and the onset of flutter is detected similarly.

The k flutter solution is determined by tracking modes. The heading "FLUTTER SOLUTIONS" can be used to find the tracking data in the file. In the case of the aircraft test model, the rigid-body and control modes were included in the STARS-SOLIDS input file and not eliminated in the STARS-AEROS-GENMASS run, so removal of these modes was required within the STARS-AEROS-AEROL

run. Removal of these modes in this way is evidenced by two (or more) modal-elimination cycles left in the output file: the first cycle occurs without modal elimination, and the subsequent cycles occur with the specified nodes eliminated. These subsequent cycles are the ones required for modal tracking, and the keyword "ELIM" can be used to find each cycle. In this procedure, solutions are achieved for each reduced velocity involving all input modes.

The k flutter solution takes the following form:

```

1          FLUTTER SOLUTIONS

MACH NO = .900    RHO/RHO(SL) = 1.0000    UBO = 2.7500

C.P.S.    U,EQUIV.    DAMPING    RAD/SEC    UTRUE
9.4611    313.8998    -.809525    59.4460    313.8998
12.3253    408.9283    -.001258    77.4424    408.9283
13.7619    456.5897    -.241010    86.4685    456.5897
20.8653    692.2663    -.859586    131.1006    692.2663
23.5406    781.0279    -.096159    147.9102    781.0279
29.6637    984.1816    -.001318    186.3832    984.1816
31.0034    1028.6278    -.208656    194.8004    1028.6278
50.6584    1680.7408    -.004821    318.2968    1680.7408

```

ALL ROOTS CHECK AND ARE UNIQUE

```

1          FLUTTER SOLUTIONS

MACH NO = .900    RHO/RHO(SL) = 1.0000    UBO = 3.1500

C.P.S.    U,EQUIV.    DAMPING    RAD/SEC    UTRUE
9.1879    349.1747    -.887537    57.7293    349.1747
12.3159    468.0528    .000904    77.3835    468.0528
13.7629    523.0422    -.250741    86.4750    523.0422
17.9128    680.7542    -.812183    112.5496    680.7542
23.4177    889.9632    .034412    147.1383    889.9632
29.6160    1125.5208    -.001017    186.0833    1125.5208
31.5363    1198.4995    -.240497    198.1489    1198.4995
50.5581    1921.4016    -.005552    317.6668    1921.4016

```

Divergence occurs when the frequency becomes 0 with nonzero velocity. In this case, divergence is assumed to occur when the frequency comes close to zero:

```

1          FLUTTER SOLUTIONS

MACH NO = .900    RHO/RHO(SL) = 1.0000    UBO = 1200.0000

C.P.S.    U,EQUIV.    DAMPING    RAD/SEC    UTRUE
.0447    647.6351    -.004645    .2811    647.6351
.0503    728.6937    -.002378    .3162    728.6937
.3518    5092.5231    .000631    2.2101    5092.5231
.6277    9087.7691    .000319    3.9440    9087.7691
1.0180    14738.4153    -.001101    6.3964    14738.4153
.0000    .0000    .000000    .0000    .0000
.0000    .0000    .000000    .0000    .0000
.0000    .0000    .000000    .0000    .0000

```

The p-k flutter solution takes the following form:

```

1          VELOCITY, DAMPING, AND FREQUENCY VARIATIONS
-----
          VELOCITY, KNOTS          DAMPING          FREQUENCY
MODE  NO  EQUIVALENT    TRUE    RATIO    CYC/SEC    RAD/SEC
1     1    200.0000    200.0000    -.482503E+00    10.3220    64.8519
1     2    208.0000    208.0000    -.503228E+00    10.3706    65.1604
1     3    216.0000    216.0000    -.524200E+00    10.4226    65.4870
1     4    224.0000    224.0000    -.545422E+00    10.4782    65.8366
1     5    232.0000    232.0000    -.566906E+00    10.5378    66.2111
1     6    240.0000    240.0000    -.588644E+00    10.6017    66.6124
1     7    248.0000    248.0000    -.610640E+00    10.6701    67.0427

```

1	8	256.0000	256.0000	-.632889E+00	10.7436	67.5044
1	9	264.0000	264.0000	-.656156E+00	10.8196	67.9820
1	10	272.0000	272.0000	-.680545E+00	10.8989	68.4800
1	11	280.0000	280.0000	-.705171E+00	10.9855	69.0240
1	12	288.0000	288.0000	-.729992E+00	11.0800	69.6179
1	13	296.0000	296.0000	-.754972E+00	11.1831	70.2655
1	14	304.0000	304.0000	-.780058E+00	11.2955	70.9716
1	15	312.0000	312.0000	-.805191E+00	11.4179	71.7410
1	16	320.0000	320.0000	-.830310E+00	11.5513	72.5794
1	17	328.0000	328.0000	-.855324E+00	11.6967	73.4927
1	18	336.0000	336.0000	-.880149E+00	11.8550	74.4875
1	19	344.0000	344.0000	-.904681E+00	12.0275	75.5710
1	20	352.0000	352.0000	-.928800E+00	12.2153	76.7514
1	21	360.0000	360.0000	-.952380E+00	12.4199	78.0368
1	22	368.0000	368.0000	-.975270E+00	12.6427	79.4368
1	23	376.0000	376.0000	-.997305E+00	12.8854	80.9617
1	24	384.0000	384.0000	-.101830E+01	13.1498	82.6227
1	25	392.0000	392.0000	-.103806E+01	13.4377	84.4319
1	26	400.0000	400.0000	-.105635E+01	13.7514	86.4027
1	27	408.0000	408.0000	-.107294E+01	14.0931	88.5499
1	28	416.0000	416.0000	-.108758E+01	14.4654	90.8893
1	29	424.0000	424.0000	-.109998E+01	14.8712	93.4385
1	30	432.0000	432.0000	-.110985E+01	15.3134	96.2174
1	31	440.0000	440.0000	-.111685E+01	15.7956	99.2471
1	32	441.6702	441.6702	-.111792E+01	15.9017	99.9135
1	33	448.0000	448.0000	-.112063E+01	16.3216	102.5521
1	34	456.0000	456.0000	-.112078E+01	16.8958	106.1598
1	35	464.0000	464.0000	-.111676E+01	17.5233	110.1023
1	36	472.0000	472.0000	-.110791E+01	18.2101	114.4175
1	37	480.0000	480.0000	-.109325E+01	18.9636	119.1522
1	38	488.0000	488.0000	-.107116E+01	19.7932	124.3645
1	39	496.0000	496.0000	-.103952E+01	20.7511	130.3832
1	40	504.0000	504.0000	-.988966E+00	22.0363	138.4584
1	41	512.0000	512.0000	-.872770E+00	23.4992	147.6503
1	42	520.0000	520.0000	-.740957E+00	23.9871	150.7160
1	43	528.0000	528.0000	-.658212E+00	24.0359	151.0224
1	44	536.0000	536.0000	-.597452E+00	23.9970	150.7777
1	45	544.0000	544.0000	-.548848E+00	23.9279	150.3436
1	46	552.0000	552.0000	-.508324E+00	23.8488	149.8466
1	47	560.0000	560.0000	-.473635E+00	23.7701	149.3525
1	48	568.0000	568.0000	-.443306E+00	23.6974	148.8955
1	49	576.0000	576.0000	-.415878E+00	23.6303	148.4737
1	50	584.0000	584.0000	-.391273E+00	23.5740	148.1200
1	51	592.0000	592.0000	-.369042E+00	23.5291	147.8379
1	52	600.0000	600.0000	-.348601E+00	23.4930	147.6111
1	53	608.0000	608.0000	-.329573E+00	23.4635	147.4260
1	54	616.0000	616.0000	-.311710E+00	23.4390	147.2720
1	55	624.0000	624.0000	-.294838E+00	23.4183	147.1417
1	56	632.0000	632.0000	-.278831E+00	23.4004	147.0296
1	57	640.0000	640.0000	-.263592E+00	23.3849	146.9322
1	58	648.0000	648.0000	-.249045E+00	23.3714	146.8469
1	59	656.0000	656.0000	-.235127E+00	23.3594	146.7718
1	60	664.0000	664.0000	-.221787E+00	23.3489	146.7058
1	61	672.0000	672.0000	-.208978E+00	23.3397	146.6480
1	62	680.0000	680.0000	-.196662E+00	23.3317	146.5978
1	63	688.0000	688.0000	-.184804E+00	23.3248	146.5547
1	64	696.0000	696.0000	-.173373E+00	23.3191	146.5183
1	65	704.0000	704.0000	-.162341E+00	23.3143	146.4885
1	66	712.0000	712.0000	-.151684E+00	23.3106	146.4650
1	67	720.0000	720.0000	-.141379E+00	23.3078	146.4477
1	68	728.0000	728.0000	-.131407E+00	23.3060	146.4363
1	69	736.0000	736.0000	-.121748E+00	23.3051	146.4309
1	70	744.0000	744.0000	-.112385E+00	23.3052	146.4312
1	71	752.0000	752.0000	-.103305E+00	23.3062	146.4373
1	72	760.0000	760.0000	-.944923E-01	23.3080	146.4489
1	73	768.0000	768.0000	-.859339E-01	23.3107	146.4661
1	74	776.0000	776.0000	-.776179E-01	23.3143	146.4887
1	75	784.0000	784.0000	-.695336E-01	23.3188	146.5167
1	76	792.0000	792.0000	-.616707E-01	23.3241	146.5500
1	77	800.0000	800.0000	-.540198E-01	23.3302	146.5885
1	78	808.0000	808.0000	-.465723E-01	23.3372	146.6322
1	79	816.0000	816.0000	-.393199E-01	23.3450	146.6811
1	80	824.0000	824.0000	-.322551E-01	23.3535	146.7350
1	81	832.0000	832.0000	-.253710E-01	23.3629	146.7939
1	82	840.0000	840.0000	-.186608E-01	23.3731	146.8578
1	83	848.0000	848.0000	-.121184E-01	23.3840	146.9265
1	84	856.0000	856.0000	-.573800E-02	23.3958	147.0002
1	85	863.3683	863.3683	.190619E-06	23.4072	147.0723
1	86	864.0000	864.0000	.485787E-03	23.4082	147.0786
1	87	872.0000	872.0000	.655809E-02	23.4215	147.1618
1	88	880.0000	880.0000	.124896E-01	23.4355	147.2499
1	89	888.0000	888.0000	.182745E-01	23.4502	147.3425
1	90	896.0000	896.0000	.239220E-01	23.4657	147.4398

1	91	904.0000	904.0000	.294363E-01	23.4819	147.5416
1	92	912.0000	912.0000	.348190E-01	23.4989	147.6482
1	93	920.0000	920.0000	.400774E-01	23.5166	147.7592
1	94	928.0000	928.0000	.452131E-01	23.5349	147.8747
1	95	936.0000	936.0000	.129788E-01	12.2056	76.6904
1	96	944.0000	944.0000	.131716E-01	12.2022	76.6690
1	97	952.0000	952.0000	.133626E-01	12.1988	76.6473
1	98	960.0000	960.0000	.135516E-01	12.1953	76.6252

In the above table, flutter mode 2 is tracked first, and zero damping can be noted corresponding to an equivalent velocity of 863.3 *KEAS*. The first flutter is listed in the next table in the file, and so forth. Divergence cannot be found with the p-k technique. Elimination cycles are also permitted with the p-k method, similar to the k method, and the information applicable to the k method also applies to the p-k method.

The ASE flutter solution does not use modal-elimination cycles, so the rigid-body and control modes are included in the run. The results in the file atm_aero_ase.out.1 are not useful to examine because the run is an intermediate step toward the solution.

STARS-ASE-CONVERT (ASERUN):

This module converts the results from the STARS-AEROS-AEROL ASE flutter solution into a form that can be used with the Padé curve-fitting module, STARS-ASE-PADÉ. Modes can also be eliminated.

The input file for flutter solution is atm_aero_convert.dat, and the output file is atm_aero_convert.out.1. This solution method eliminates all rigid-body and control modes.

The input file for response analysis is atm_ase_convert.dat, and the output file is atm_ase_convert.out.1. Because control and perfect rigid-body modes are desired for this analysis, they are not eliminated.

STARS-ASE-PADÉ (ASERUN):

For flutter solution, the input file is atm_aero_pade.dat, and the output file is atm_aero_pade.out.1. A file to store the A, B, C, and D matrices is requested for flutter solution. These matrices are not stored after the solution, so this file can be anything the user desires because it will be empty.

The first flutter is shown below, wherein flutter has not occurred at an equivalent velocity of 414.8 *KEAS* but has occurred by 474.1 *KEAS*. The column labeled "1" is the damping, and the column labeled "2" is the frequency (rad/sec). The modes are ordered by velocity (knots).

```
DENSITY RATIO : 1.0000000000000000
VELOCITY (FPS): 700.0000000000000000
VELOCITY EQUIV, TRUE (KTS): 414.814814814781 414.814814814781
DYNAMIC PRESSURE (PSF): 582.609986886382103
```

ROOT

	1	2
1	-.2831E+00	.3205E+03
2	-.2831E+00	-.3205E+03
3	-.5420E+02	.2141E+03
4	-.5420E+02	-.2141E+03
5	-.3040E+02	.2057E+03

```

6  -.3040E+02 -.2057E+03
7  -.2144E+00 .1870E+03
8  -.2144E+00 -.1870E+03
9  -.1544E+02 .1789E+03
10 -.1544E+02 -.1789E+03
11 -.7873E+01 .8676E+02
12 -.7873E+01 -.8676E+02
13 -.3130E-01 .7737E+02
14 -.3130E-01 -.7737E+02
15 -.4080E+02 .7863E+02
16 -.4080E+02 -.7863E+02
17 -.1007E+03 .3933E+01
18 -.1007E+03 -.3933E+01
19 -.2821E+02 .2382E+02
20 -.2821E+02 -.2382E+02
21 -.3657E+02 .2775E+02
22 -.3657E+02 -.2775E+02
23 -.9187E+02 .0000E+00
24 -.3723E+02 .0000E+00
25 -.8742E+02 .0000E+00
26 -.8750E+02 .0000E+00
27 -.8751E+02 .0000E+00
28 -.4186E+02 .0000E+00
29 -.4313E+02 .0000E+00
30 -.4380E+02 .0000E+00
31 -.4375E+02 .4767E-02
32 -.4375E+02 -.4767E-02

```

```

DENSITY RATIO : 1.0000000000000000
VELOCITY (FPS): 800.0000000000000000
VELOCITY EQUIV, TRUE (KTS): 474.074074074019 474.074074074019
DYNAMIC PRESSURE (PSF): 760.959982872009277

```

ROOT

```

      1      2
1  -.3242E+00 .3204E+03
2  -.3242E+00 -.3204E+03
3  -.7224E+02 .2091E+03
4  -.7224E+02 -.2091E+03
5  -.4511E+02 .2045E+03
6  -.4511E+02 -.2045E+03
7  -.2121E+00 .1869E+03
8  -.2121E+00 -.1869E+03
9  -.1690E+02 .1812E+03
10 -.1690E+02 -.1812E+03
11 -.4300E+02 .9909E+02
12 -.4300E+02 -.9909E+02
13 -.7930E+01 .8671E+02
14 -.7930E+01 -.8671E+02
15 .7707E-01 .7730E+02
16 .7707E-01 -.7730E+02
17 -.1162E+03 .5194E+01
18 -.1162E+03 -.5194E+01
19 -.2488E+02 .2008E+02
20 -.2488E+02 -.2008E+02
21 -.3325E+02 .3279E+02
22 -.3325E+02 -.3279E+02
23 -.1061E+03 .0000E+00
24 -.4139E+02 .0000E+00
25 -.9990E+02 .0000E+00
26 -.9999E+02 .0000E+00
27 -.1000E+03 .0000E+00
28 -.4737E+02 .0000E+00
29 -.4911E+02 .0000E+00
30 -.5006E+02 .0000E+00
31 -.5000E+02 .7061E-02
32 -.5000E+02 -.7061E-02

```

The keyword “DENSITY” can be used to find each mode.

For response analysis, the input file is atm_ase_pade.dat, and the output file is atm_ase_pade.out.1. The file to store the A, B, C, and D matrices is abcd.dat.

STARS-ASE-CONTROL (ASERUN):

Open- and closed-loop analyses are performed with this module. Open-loop analyses need to be run through the module STARS-ASE-FRESP, as described later.

For closed-loop analysis, the input file is atm_ase_controlc.dat. The file containing the A, B, C, and D input matrices is abcd.dat. The loop condition must be set to closed; the closed-loop eigensolution is set to root40k.dat for the 40,000-ft altitude case presented in the manual. The closed-loop output file name is set to atm_ase_controlc.out.1.

The closed-loop eigensolution of the state-space A matrix contains five columns of data: the mode number; columns for the real, imaginary, and magnitude of the frequency (rad/sec); and the damping.

```

THE CLOSED LOOP EIGENVALUE SOLUTIONS
MODE #   REAL      IMAG      DAMP FRQ (rad)    DAMP 1
1 -.104187E+00 .321131E+03 .321131E+03 .648879E-03
2 -.104187E+00 -.321131E+03 .321131E+03 .648879E-03
3 -.212778E+02 .220098E+03 .221124E+03 .191557E+00
4 -.212778E+02 -.220098E+03 .221124E+03 .191557E+00
5 -.100747E+02 .203305E+03 .203554E+03 .988669E-01
6 -.100747E+02 -.203305E+03 .203554E+03 .988669E-01
7 -.157889E+00 .187182E+03 .187182E+03 .168700E-02
8 -.157889E+00 -.187182E+03 .187182E+03 .168700E-02
9 -.710996E+01 .178727E+03 .178869E+03 .794364E-01
10 -.710996E+01 -.178727E+03 .178869E+03 .794364E-01
11 -.965000E+02 .972510E+02 .137004E+03 .999970E+00
12 -.965000E+02 -.972510E+02 .137004E+03 .999970E+00
13 -.963736E+02 .972677E+02 .136927E+03 .999957E+00
14 -.963736E+02 -.972677E+02 .136927E+03 .999957E+00
15 -.253805E+01 .909924E+02 .910278E+02 .557426E-01
16 -.253805E+01 -.909924E+02 .910278E+02 .557426E-01
17 -.109440E+00 .777426E+02 .777427E+02 .281544E-02
18 -.109440E+00 -.777426E+02 .777427E+02 .281544E-02
19 -.866177E+01 .642722E+02 .648533E+02 .264726E+00
20 -.866177E+01 -.642722E+02 .648533E+02 .264726E+00
21 -.711187E+02 .186862E+02 .735327E+02 .491559E+00
22 -.711187E+02 -.186862E+02 .735327E+02 .491559E+00
23 -.685767E+02 .160566E+02 .704314E+02 .443943E+00
24 -.685767E+02 -.160566E+02 .704314E+02 .443943E+00
25 -.114222E+03 .608432E+00 .114224E+03 .106532E-01
26 -.114222E+03 -.608432E+00 .114224E+03 .106532E-01
27 -.212286E+02 .000000E+00 .212286E+02 .000000E+00
28 -.199939E+02 .000000E+00 .199939E+02 .000000E+00
29 -.110663E+03 .000000E+00 .110663E+03 .000000E+00
30 -.100750E+02 .000000E+00 .100750E+02 .000000E+00
31 .384948E-01 .289516E+01 .289541E+01 .265879E-01
32 .384948E-01 -.289516E+01 .289541E+01 .265879E-01
33 -.192633E+01 .896479E+00 .212472E+01 .765065E+00
34 -.192633E+01 -.896479E+00 .212472E+01 .765065E+00
35 .991211E+00 .000000E+00 .991211E+00 .000000E+00
36 -.501516E+02 .000000E+00 .501516E+02 .000000E+00
37 .357147E-03 .000000E+00 .357147E-03 .000000E+00
38 -.233887E-03 .000000E+00 .233887E-03 .000000E+00
39 -.802861E-02 .000000E+00 .802861E-02 .000000E+00
40 -.108601E+03 .873500E-01 .108601E+03 .160864E-02
41 -.108601E+03 -.873500E-01 .108601E+03 .160864E-02
42 -.996977E-01 .000000E+00 .996977E-01 .000000E+00
43 -.539246E+02 .160797E+00 .539249E+02 .596371E-02
44 -.539246E+02 -.160797E+00 .539249E+02 .596371E-02
45 -.547465E+02 .000000E+00 .547465E+02 .000000E+00
46 -.544839E+02 .000000E+00 .544839E+02 .000000E+00
47 -.108890E+03 .000000E+00 .108890E+03 .000000E+00
48 -.108903E+03 .465731E-02 .108903E+03 .855313E-04
49 -.108903E+03 -.465731E-02 .108903E+03 .855313E-04
50 -.544333E+02 .000000E+00 .544333E+02 .000000E+00
51 -.544496E+02 .000000E+00 .544496E+02 .000000E+00
52 -.544520E+02 .000000E+00 .544520E+02 .000000E+00
53 -.108900E+03 .000000E+00 .108900E+03 .000000E+00
54 -.544500E+02 .000000E+00 .544500E+02 .000000E+00
55 -.544500E+02 .000000E+00 .544500E+02 .000000E+00
56 -.108900E+03 .000000E+00 .108900E+03 .000000E+00
57 -.108900E+03 .000000E+00 .108900E+03 .000000E+00
58 -.544500E+02 .000000E+00 .544500E+02 .000000E+00

```

As with the k flutter solution, modes must be tracked. This tracking is accomplished by starting with an altitude with a low-density ratio (for example, an altitude of 80,000 ft), and working down to sea level. The required data for the STARS-ASE-PADÉ input file (density ratio and true velocity) can be obtained from a reference such as *U. S. Standard Atmosphere*.^{*} True velocity is defined as $V_{TRUE} = C_s \times M$, where C_s is the speed of sound at altitude and M is the Mach number. Figure 63 shows the damping and frequency for the first two elastic structural modes plotted as a function of the equivalent velocity, where equivalent velocity is defined as $V_E = V_{TRUE} \times$ the square root of the density ratio at altitude.

For this altitude, flutter mode 1 corresponds to modes 19 and 20 in the above table; flutter mode 2 corresponds to modes 17 and 18.

For open-loop analysis, the input file is atm_ase_control0.dat, and the file containing the A, B, C, and D input matrices is abcd.dat. The loop condition must be set to open. The file containing the augmented A, B, C, and D matrices is abcd.aug. The STARS-ASE-FRESP input file created by this module is atm_ase_frespo.dat, and the open-loop output file name is set to atm_ase_control0.out.1.

STARS-ASE-FRESP (ASERUN):

Open-loop analyses must be run with this module. The STARS-ASE-FRESP parameter file is the one created in STARS-ASE-CONTROL, atm_ase_frespo.dat. The file containing the augmented A, B, C, and D matrices is abcd.aug, and the output file is atm_ase_frespo.out.1. The response is contained in files named RESP*.DAT, where the * are numbers ranging from 001 through 999, based on the number of loop definitions in the STARS-ASE-CONTROL input file. The first twenty lines of the first-loop definition response are shown below:

```
.1000  -.415401E+02  -.782232E+02
.1040  -.411397E+02  -.785038E+02
.1080  -.407553E+02  -.787834E+02
.1120  -.403856E+02  -.790614E+02
.1160  -.400298E+02  -.793375E+02
.1200  -.396868E+02  -.796112E+02
.1240  -.393560E+02  -.798821E+02
.1280  -.390365E+02  -.801500E+02
.1320  -.387277E+02  -.804144E+02
.1360  -.384289E+02  -.806753E+02
.1400  -.381395E+02  -.809324E+02
.1440  -.378590E+02  -.811856E+02
.1480  -.375869E+02  -.814348E+02
.1520  -.373227E+02  -.816800E+02
.1560  -.370660E+02  -.819210E+02
.1600  -.368164E+02  -.821579E+02
.1640  -.365736E+02  -.823906E+02
.1680  -.363371E+02  -.826192E+02
.1720  -.361067E+02  -.828436E+02
.1760  -.358820E+02  -.830640E+02
```

The columns show the frequency (rad/sec), gain (dB), and phase angle (deg) for the response.

^{*}National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, United States Air Force, *U.S. Standard Atmosphere*, 1976, Washington, D.C., 1976.

8. STARS-CFDASE MODULE DESCRIPTION: COMPUTATIONAL FLUID DYNAMICS, NONLINEAR AEROELASTICITY, AND AEROSERVOELASTICITY

A number of consistent disciplines and innovative algorithms must be incorporated into an integrated system that is required to simulate nonlinear performance characteristics of advanced engineering systems such as aerospace vehicles. Because the finite-element technique can be commonly used to discretize relevant solids and fluids continua, its employment ensures accurate interaction of various disciplines. Figure 1 shows a number of disciplines that are involved in the multidisciplinary modeling simulation of such systems. Some relevant details of finite-element formulations, adopted for computational fluid dynamics (CFD) and nonlinear-stability analysis, are presented next.

8.1 Finite-Element Computational Fluid Dynamics

The CFD analysis requires two major fundamental solution capabilities, effective generation of unstructured and solution adaptive fluids domain meshes and finite-element analysis of the relevant flow problem; and effective development of related numerical tools that are vital to the efficient solution of complex practical problems. These two solution capabilities have been appropriately incorporated in the STARS program.

8.1.1 Mesh Generation

An advancing front technique, developed for automated generation of unstructured meshes, has been found suitable for discretization of complex domains. This procedure has the advantages of flexibility with regard to the specification of arbitrary shapes and varying grid density throughout the domain and facility in adaptive mesh generation in accordance with the solution trend.

Such an algorithm was initially developed²¹ for arbitrary, multiconnected, planar domains in which the interior nodes are generated first, then suitably linked to yield the best possible triangulation. During this process, the generation front is continually updated each time a new element is constructed. Further improvement and extension of this technique in three dimensions have previously been described.²² The nodes and triangles here are formed simultaneously for all boundary surfaces. This formation is followed by the generation of tetrahedra by the advancing front approach to fill the entire solution domain. Suitable background grids are used to specify important mesh parameters defining node spacing, stretching parameters, and directions.

The three-dimensional, automated, unstructured mesh generation scheme, as above, has been versatile for modeling the practical CFD solution domain around complex structural forms such as an aircraft. However, because the advancing front technique involves an extensive search for nodes and faces on the front, the grid generation time tends to be large for such complex configurations. A simple modification of the procedure, implemented during the current effort, has proven to be efficient and economical. In this method, the usual technique is first used to generate a grid whose cells have linear dimensions approximately twice the desired size, and then each cell is reduced locally to its desired size.²³

8.1.2 Finite-Element Computational Fluid Dynamics Analysis

The dynamic equation for a viscous, heat-conducting, compressible fluid obeying the conservation of mass, momentum, and energy can be expressed by a set of partial differential equations,

$$\frac{\partial \mathbf{V}}{\partial t} + \frac{\partial \mathbf{F}_i}{\partial x_i} = \mathbf{f}_b, \quad i = 1, 2, 3 \quad (76)$$

where the solution, flux, and body-forces column vectors and the viscous stress tensor are defined as follows:

$$\mathbf{V} = \{\rho \quad \rho u_j \quad \rho E\} \quad (77)$$

$$\mathbf{F}_i = \left\{ \rho u_i \quad \rho u_i u_j + p \delta_{ij} + \sigma_{ij} \quad u_i (\rho E + p) + u_i \sigma_{1i} + k \frac{\partial T}{\partial x_i} \right\} \quad (78)$$

$$\mathbf{f}_b = \{0 \quad \mathbf{f}_{b_j} \quad u_1 \mathbf{f}_{b_1}\} \quad (79)$$

$$\sigma_{ij} = -\frac{2}{3} \mu \frac{\partial u_k}{\partial x_k} \delta_{ij} + \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \quad (80)$$

in which ρ , p , and E are the density, average pressure intensity, and total energy, respectively; δ_{ij} is the Kronecker delta; u_j is the velocity component in the direction x_j of a Cartesian coordinate system; μ is the viscosity; k is the thermal conductivity; and $\mathbf{f}_b$ is the body forces. The above equations are supplemented with state equations

$$p = (\gamma - 1) \rho \left[E - \frac{1}{2} u_i u_i \right] \quad (81)$$

and

$$T = \left[E - \frac{1}{2} u_i u_i \right] c_v \quad (82)$$

for a complete solution, in which γ is the ratio of specific heats and c_v is the specific heat at constant volume. Such a formulation is valid for a perfect gas.

Solution of the nonviscous form of equation (76) is achieved by first obtaining a Taylor series expansion of $\mathbf{V}$ in the time domain. The spatial domain, Ω , is next discretized by unstructured meshes consisting of three-dimensional tetrahedron elements. Using linear finite-element approximations $\mathbf{V} = \mathbf{a} \hat{\mathbf{V}}$, $\hat{\mathbf{V}}$ being nodal variable values, and employing a Galerkin weighted residual procedure, a time-dependent form of the governing equations can be obtained as follows:

$$\mathbf{M} \delta \hat{\mathbf{V}} = -\Delta [\mathbf{C} \hat{\mathbf{V}}] + \mathbf{R} \quad (83)$$

in which $\mathbf{R}$ includes artificial viscosity effects essential for capturing shocks. Solution of equation (83) is effected by advancing this time-dependent form until steady conditions are obtained. An explicit time-stepping iterative scheme²² and an alternative quasi-implicit solution scheme has been implemented in the STARS program to that effect. An accelerated Euler solution procedure based on the Aitken acceleration technique that effects considerable improvement in the solution convergence rate has recently been implemented.²⁴

8.2 Nonlinear, Computational Fluid Dynamics–Based Aeroelastic and Aeroservoelastic Analysis (CFDASE)

This process starts with the finite-element structural modeling and subsequently computes the natural frequencies, ω , and modes, ϕ , that consist of rigid-body, elastic, and control-surface motions, by solving

$$\mathbf{M}\ddot{\mathbf{u}} + \mathbf{K}\mathbf{u} = \mathbf{0} \quad (84)$$

in which $\mathbf{M}$ and $\mathbf{K}$ are the inertial and stiffness matrices, respectively, and $\mathbf{u}$ is the displacement vector. This solution is achieved by an efficient block Lanczos procedure that fully exploits matrix sparsity.^{7,25} Next, a steady-state Euler solution is effected in which optimum solution convergence is achieved through an explicit or alternative quasi-implicit, local time-stepping solution procedure that also employs a residual smoothing strategy. The resulting vehicle equation of motion is then cast into the frequency domain as follows:

$$\hat{\mathbf{M}}\ddot{\mathbf{q}} + \hat{\mathbf{C}}\dot{\mathbf{q}} + \hat{\mathbf{K}}\mathbf{q} + \hat{\mathbf{f}}_a(t) + \hat{\mathbf{f}}_I(t) = \mathbf{0} \quad (85)$$

in which the generalized matrices and vectors are as follows:

$\hat{\mathbf{M}}$	= inertia matrix ($= \Phi^T \mathbf{M} \Phi$)
$\hat{\mathbf{K}}, \hat{\mathbf{C}}$	= stiffness ($= \Phi^T \mathbf{K} \Phi$) and damping ($= \Phi^T \mathbf{C} \Phi$) matrices
$\mathbf{q}$	= displacement vector ($= \Phi^T \mathbf{u}$)
$\hat{\mathbf{f}}_a(t)$	= aerodynamic (CFD) load vector ($= \Phi_a^T p A$), where p is the Euler pressure, A is the appropriate surface area, and Φ_a is the modal vector pertaining to the aerodynamic grid points interpolated from relevant structural nodes
$\hat{\mathbf{f}}_I(t)$	= impulse force vector ($= \Phi^T \mathbf{f}_I$)

and where $\mathbf{f}_I$ is the user input that contains a number of modes of interest. Equation (85) can next be formulated in the state-space matrix equation form as

$$\dot{\mathbf{X}} = \mathbf{A}\mathbf{X} + \mathbf{b}_a(t) + \mathbf{b}_I(t) \quad (86)$$

where

$$\mathbf{X} = \begin{bmatrix} \mathbf{q} \\ \dot{\mathbf{q}} \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} \mathbf{0} & \mathbf{I} \\ -\hat{\mathbf{M}}^{-1}\hat{\mathbf{K}} & -\hat{\mathbf{M}}^{-1}\hat{\mathbf{C}} \end{bmatrix}$$

$$\mathbf{b}_a(t) = \begin{bmatrix} \mathbf{0} \\ -\hat{\mathbf{M}}^{-1}\hat{\mathbf{f}}_a(t) \end{bmatrix}$$

$$\mathbf{b}_I(t) = \begin{bmatrix} \mathbf{0} \\ -\hat{\mathbf{M}}^{-1}\hat{\mathbf{f}}_I(t) \end{bmatrix}$$

and a time-response solution of equation (86) in an interval $\Delta t (= t_{n+1} - t_n)$ is obtained as

$$\mathbf{X}_{n+1} = e^{\mathbf{A}\Delta t}\mathbf{X}_n + \mathbf{A}^{-1} [e^{\mathbf{A}\Delta t} - \mathbf{I}] [\mathbf{b}_a(t_n) + \mathbf{b}_I(t_n)] \quad (87)$$

Data consisting of $\mathbf{q}$ and $\dot{\mathbf{q}}$ vectors are then stored for later processing. The structural deformations, $\mathbf{u}$, and velocities, $\dot{\mathbf{u}}$, are then computed from $\mathbf{q}$ and $\dot{\mathbf{q}}$, respectively, and the aerodynamic mesh is updated only if large motions are encountered. The $\mathbf{u}$ and $\dot{\mathbf{u}}$ values are fed into the CFD code to change velocity boundary conditions at the solid boundary, which is then followed by a one-step Euler solution using a global time-stepping scheme.²⁵ The entire solution process is repeated for the required number of time steps.

The response data can be resolved into modal components using a fast Fourier transform as follows:

$$\mathbf{X} = \sum_{m=1}^p e^{i\omega_m t} (a_m \cos \omega_m t + b_m \sin \omega_m t) \quad (88)$$

which yields the damping, ζ , and frequency, ω , values. This process is repeated for a number of dynamic pressure values,

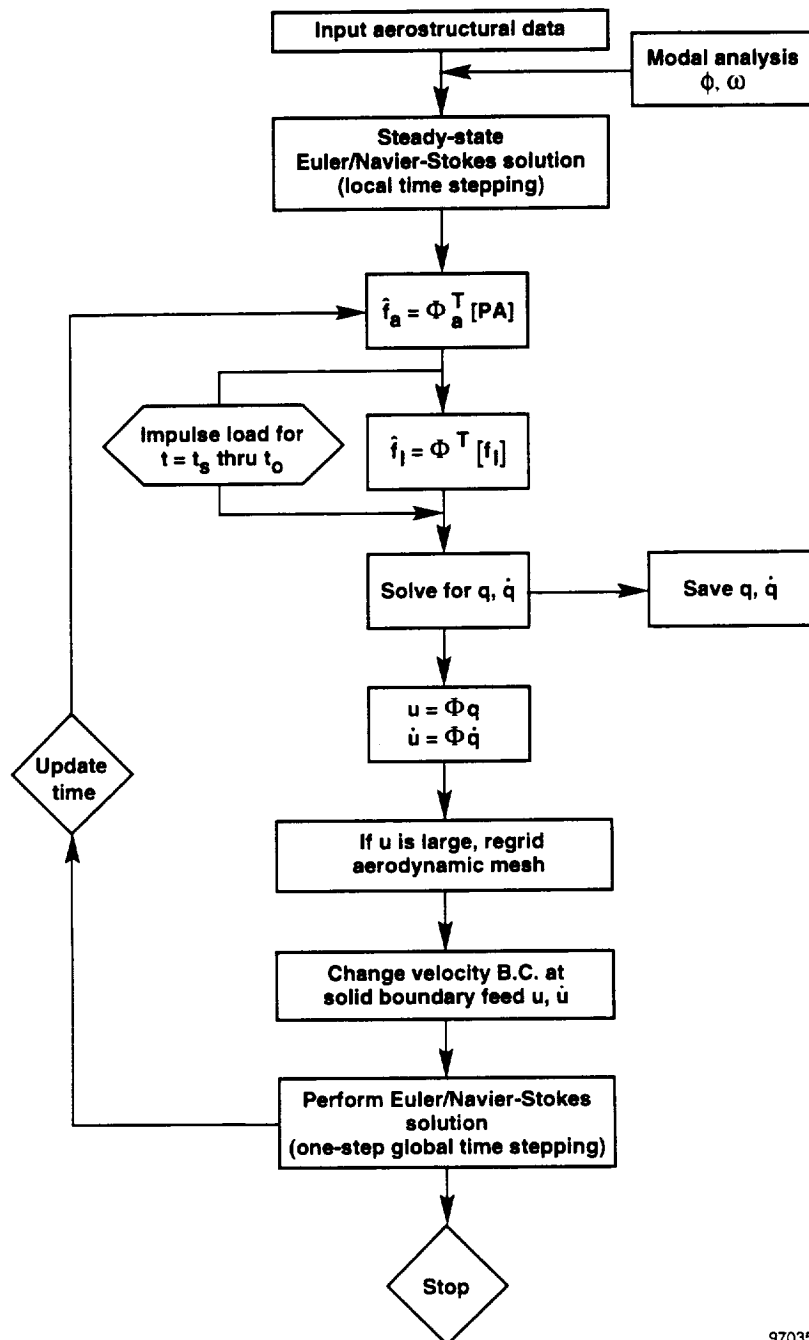
$$\bar{q} = \frac{1}{2} \rho V^2$$

and the ζ and ω values plotted against $\bar{q}$ or Mach number. A plot depicting stability characteristics of the vehicle enables the prediction of the onset of flutter or divergence occurring within the entire flight regime. Figure 64 shows a flowchart of the nonlinear flutter analysis methodology adopted in the STARS program. Alternatively, the generalized modal velocity values are also plotted as a function of time, and an onset of flutter can also be predicted from their pattern of convergence. A similar solution is also effected by a root tracking procedure that identifies the coalescence of the roots.

In ASE analysis, assuming that a control law has been designed based on the linear characteristics of the control derivatives, the control law can be interfaced with the CFD analysis procedure. Thus, the input to the control law will consist of angle of attack, α , and also $\mathbf{q}$, $\dot{\mathbf{q}}$, $\ddot{\mathbf{q}}$, and the control hinge moment, $\mathbf{M}_c$. Based on such input, the flight control derives the necessary control-surface deflections to alleviate the aircraft response.

For a more realistic case, where the control derivatives are not known beforehand because the nonlinear CFD analysis has been used, an autoregression procedure can be used to reconstruct a model based on the past history of the aircraft input and output information. Thus, for a small incremental motion of a control surface, the vehicle body forces and moments are first computed from the surface pressure distribution. This computation is followed by an estimation of parameters such as angle of attack (α),

angle of side slip (β), control-surface deflections and hinge moments, and roll, pitch, and yaw rates employing $\mathbf{q}$ and $\dot{\mathbf{q}}$ values computed from appropriate equations of motion. These calculations are performed for a large number of time steps that represent the entire range of control-surface motion, and the resulting data are then employed to obtain static and dynamic stability derivatives for the vehicle simulation analysis.



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Figure 64. Nonlinear flutter analysis methodology.

9. DATA INPUT PROCEDURE (STARS-CFDASE)

Figure 65 shows the analysis flow chart for nonlinear aeroelastic and ASE analyses. This module is activated by typing the command "cfdaserun." Thus, a steady-state solution of the flow is first implemented that requires input data²⁶ for two-dimensional surface and three-dimensional volume generation involving triangular and tetrahedral elements, respectively. For surface and volume grid generation, two input files having background (job.bac) and surface (job.sur) definitions are generated; plots of these surfaces are achieved by the XPLT program. The input data file,²⁶ job.bco, is used to set up boundary conditions, and the file job.cons is the required input file for steady-state flow analysis. An alternative procedure for only steady-state flow analysis can also be performed in double precision by using the STEADYDP solution module (fig. 65).

The data files needed for subsequent CFD-based aeroelastic analysis relate to structural vibration analysis. The data files solids.dat (the term "solids" is a generic identifier that can be set to any name) and genmass.dat need to be prepared in accordance with the input procedures detailed in sections 3 and 6, respectively. These data inputs are to be followed by data related to structural damping (damp.dat).

For subsequent unsteady flow analysis, related input data²⁶ are represented by the file job.scalars. The control file data, job.conu, contains parameters that dictate the pattern of solution convergence. In all such data sets, the term "job" is generic and signifies the problem under consideration.

Detailed, color graphic plots of solution results are conveniently obtained by using the POSTPLOT submodule of the STARS program. The unsteady generalized displacements can also be plotted by employing the QUICKPLOT program (activated by typing "qp"), and black-and-white contour plots of solution results are achieved by the XPLT²⁶ program, which is part of POSTPLOT.

9.1 Input Data for Background Grid (job.bac)

9.1.1 \$ Title for Background Grid File Format (FREE)

1. Description: Title card for the background grid file.
2. Note:

A maximum of 80 characters on one line of data.

9.1.2 NPBG, NEBG, NPS, NLS, NTS Format (FREE)

1. Description: Basic data parameters.

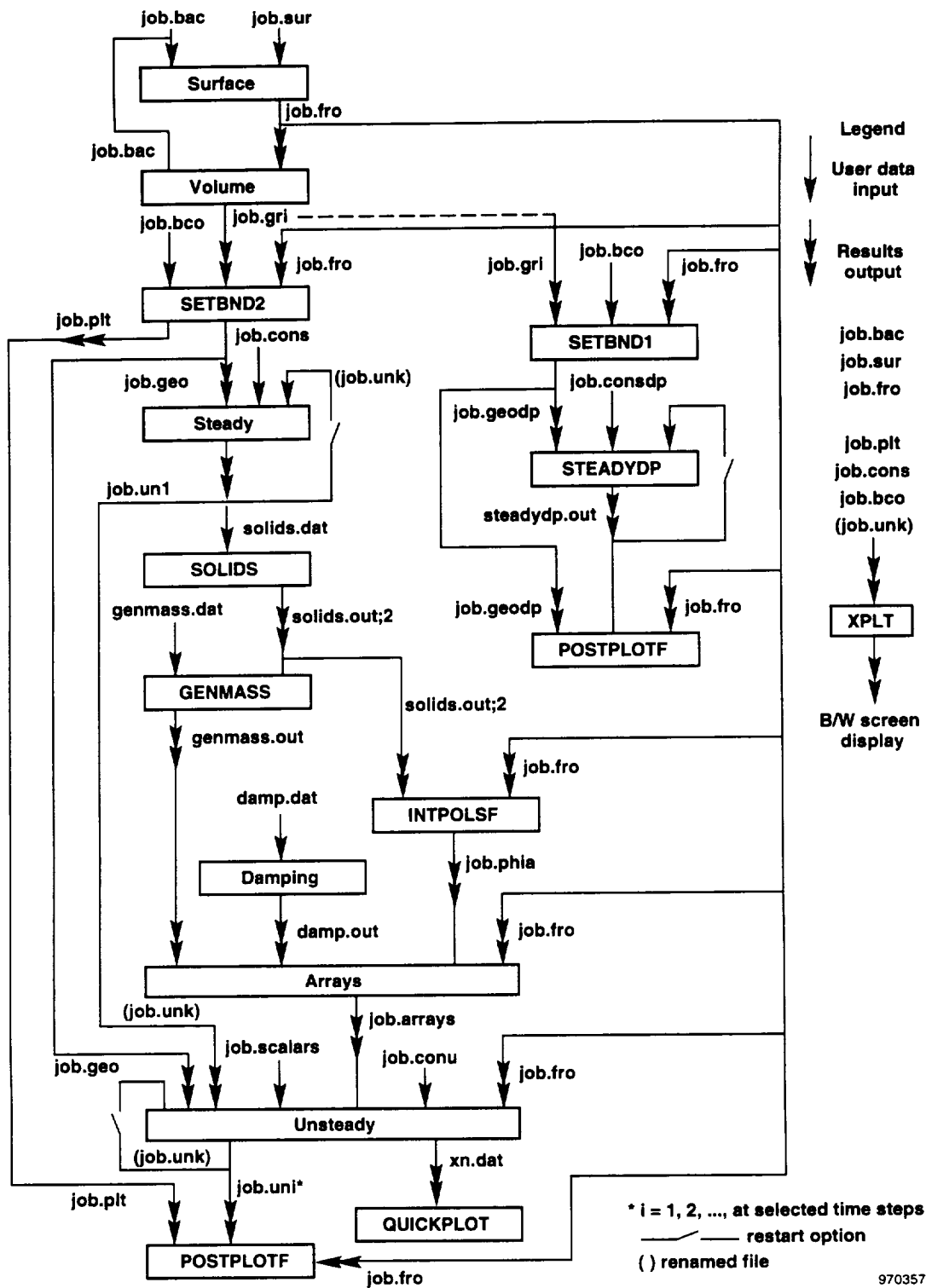


Figure 65. Flowchart for CFD-based aeroelastic analysis.

2. Notes:

NPBG = number of points in the background grid
NEPG = number of tetrahedral elements in the background grid
NPS = number of point sources
NLS = number of line sources
NTS = number of triangular plane sources

9.1.3 JP, XP, YP, ZP
Format (FREE)

9.1.4 (DBG(I, 1), DBG(I, 2), DBG(I, 3), DBG(I, 4)), I=1, 3)
Format (FREE)

1. Description: NPBG sets of background grid nodal data.

2. Notes:

JP = index defining the point number
XP = X coordinate of the point
YP = Y coordinate of the point
ZP = Z coordinate of the point
DBG(I, 1) = x local-global coordinate
DBG(I, 2) = y local-global coordinate
DBG(I, 3) = z local-global coordinate
DBG(I, 4) = scale factor; a unit length along this axis is subdivided into approximately $1.0/\text{DBG(I,4)}$ divisions, with finer divisions being made near point I.

9.1.5 (JE, KEL(I), I=1, 4)
Format (FREE)

1. Description: NEBG sets of background grid element data.

2. Notes:

JE = index defining the element number

KEL(I) = node defining a vertex of the tetrahedral element

The background grid is required to completely enclose the computational domain as defined in the surface data file. The fineness of the generated grid is controlled mainly by the parameter DBG(I,4). The smaller this value is, the larger the number of elements there are.

9.1.6 \$ Point Sources Data Format (FREE)

9.1.6.1 \$ Text Format (FREE)

9.1.6.2 X, Y, Z, S, R, D Format (FREE)

1. Description: Localized background weighting caused by point sources.

2. Notes:

X, Y, Z = Cartesian coordinates at the point sources

S = weight at the point source

R = radius of the sphere with a constant weight, S

D = distance from the source at which the spacing is $2 \times S$

Data for sections 9.1.6.1 and 9.1.6.2 are repeated NPS times.

9.1.7 \$ Line Sources Data Format (FREE)

9.1.7.1 \$ Text Format (FREE)

9.1.7.2 X1, Y1, Z1, S1, R1, D1 Format (FREE)

9.1.7.3 X2, Y2, Z2, S2, R2, D2 Format (FREE)

1. Description: Localized background weighting caused by line sources.

2. Note:

Data for sections 9.1.7.1 through 9.1.7.3 are repeated NLS times; definition as above pertains to two points defining the line source.

9.1.8 \$ Plane Triangular Sources Data
Format (FREE)

9.1.8.1 \$ Text
Format (FREE)

9.1.8.2 X1, Y1, Z1, S1, R1, D1
Format (FREE)

9.1.8.3 X2, Y2, Z2, S2, R2, D2
Format (FREE)

9.1.8.4 X3, Y3, Z3, S3, R3, D3
Format (FREE)

1. Description: Localized background weighting caused by triangular surface sources.

2. Note:

Data for sections 9.1.8.1 through 9.1.8.4 are repeated NTS times; definition as above pertains to three points defining the triangular plane source.

9.2 Input Data for Surface Grid (job.sur)

9.2.1 \$ Title for Surface Definition File
Format (FREE)

1. Description: Title card for the surface definition file.

2. Note:

A maximum of 80 characters on one line of data.

9.2.1.1 NIS, NSF
Format (FREE)

1. Description: Basic data parameters.

2. Notes:

NIS = number of boundary edges for defining normals

NSF = number of support surfaces defining normals

Multiple surfaces can be defined in each support surface region.

9.2.2 \$ Boundary-Edge Definitions
Format (FREE)

9.2.2.1 JS, ITIS
Format (FREE)

9.2.2.2 NIP
Format (FREE)

9.2.2.3 ((CIP(I, J), J=1, 3), I=1, NIP)
Format (FREE)

1. Description: NIS sets of boundary-edge definition data.

2. Notes:

JS = index defining the boundary edge

ITIS = index defining the type of boundary edge
= 1, normal generation (Ferguson)

NIP = number of points on the boundary edge

CIP(I, 1) = X coordinate of a point defining the boundary edge

CIP(I, 2) = Y coordinate of a point defining the boundary edge

CIP(I, 3) = Z coordinate of a point defining the boundary edge

9.2.3 \$ Support-Surface Definitions and Orientation
Format (FREE)

9.2.3.1 ISS, ITSF,
Format (FREE)

9.2.3.2 NU, NV
Format (FREE)

9.2.3.3 ((CSP(I, J), J=1, 3), I=1, NU*NV)
Format (FREE)

1. Description: NSF sets of support-surface definition data.

2. Notes:

ISS = index defining the support surface

ITSF = index defining support-surface type
= 1, composite surfaces, curved (Ferguson)

NU = number of points in the U parametric direction

NV = number of points in the V parametric direction

CSP(I, 1) = X coordinate of a point defining the support surface

CSP(I, 2) = Y coordinate of a point defining the support surface

CSP(I, 3) = Z coordinate of a point defining the support surface

For $NV > 1$, the first set of NU is read, then the second, and so forth. The normal for a plane determined by these points should point into the computational domain. For a composite surface, the u axis is along the first input line, and the v axis is along the line connecting the first node on each line.

9.2.4 \$ Curved-Edge Definition Format (FREE)

9.2.4.1 NSG, NRG Format (FREE)

1. Description: Number of surface-region data sets.

2. Notes:

NSG = number of curved segments

NRG = number of surfaces regions

These data define the regions of interest on each support surface; see section 9.2.1.1.

9.2.4.2 \$ Text Format (FREE)

9.2.4.3 ISG IDCV ITSG Format (FREE)

1. Description: NSG sets of curved-segment data.

2. Notes:

ISG = index defining the curved segment

IDCV = index defining the boundary edge from section 9.2.1.1

ITSG = index defining the generation type
= 1

9.2.5 \$ Support-Region Definition by Boundary Edges Format (FREE)

9.2.5.1 IRG, IDSF, ITRG Format (FREE)

9.2.5.2 NN Format (FREE)

(ISBS(I), I=1, NN)
Format (FREE)

1. Description: NRG sets of surface-region data.

2. Notes:

IRG = index defining the surface number

IDSF = index defining the support-surface from section 9.2.1.1

ITRG = index defining the generation type
= 1

NN = number of curved segments

ISBS(I) = indices of curved segments along the mesh region

The edges should be listed in such a manner that the direction of the normal points into the computational domain, and the edges are traversed in the opposite sense of their above definition when given a negative sign.

3. Additional notes:

This data file contains the geometrical definition of the boundary of the computational domain. The general data are the number of boundary edges and the number of support surfaces. First, each support surface is defined as a plane, composite, or degenerate surface. Second, each support surface is defined by traveling about it, along the boundary edges, so that the direction normal to the surface points into the computational domain for all of the

surfaces (using the right-hand rule). The normals in sections 9.2.3.1 and 9.2.5.1 should be consistent. If one is traveling along a boundary edge in the opposite sense of its original definition, its index is given a negative value.

9.3 Input Data for Boundary Conditions (job.bco)

9.3.1 \$ Title for Boundary-Condition File Format (FREE)

1. Description: Title card for the boundary-condition file.
2. Note:

A maximum of 80 characters on one line of data.

9.3.2 NRG, NSG Format (FREE)

1. Description: Number of data sets.
2. Notes:

NRG = number of boundary surfaces

NSG = number of boundary segments

These numbers should match those in section 9.2.4.1.

9.3.3 \$ Surface-Region Boundary-Condition Definitions Format (FREE)

9.3.4 IRG, IBCO Format (FREE)

1. Description: NRG sets of surface-region boundary-condition data.
2. Notes:

IRG = index defining the surface number

IBCO = index defining the surface boundary condition
 = 1, wall
 = 2, symmetry
 = 3 and 4, far field
 = 5 and 6, engine inlet
 = 7 and 8, engine outlet

9.3.5 \$ Curve-Segment Boundary-Condition Definitions Format (FREE)

9.3.6 JS, ICBCO Format (FREE)

1. Description: NSG sets of curved-segment boundary-condition data.
2. Notes:

JS = index defining the curved segment

IBCO = index defining the curved-segments boundary-condition
= 0, no singularity
= 1, all are singular
= 2, singular point at first and last
= 3, singular point at first only
= 4, singular point at last only

9.4 Input Data of Control File for Steady-State Computational Fluid Dynamics (Euler) Solution (job.cons)

1. Description: Parameters for a name list control file used in the steady-state Euler solution.
2. Notes:

Each name parameter must begin with "&control" and end with "/". These parameters are on their own lines with no other data appearing on the lines. Each parameter must be separated with a comma, even if each appears on a separate line. Parameters not included by the user will be automatically set to their default values, listed in parentheses after each definition.

&control

nstep = total number of solution time steps (1)

nstou = number of time substeps for writing the unknowns file job.un1 (ncycl
substeps for each time step) (5)
writing also occurs after each solution time step
if nstou $\geq$ ncycl, writing occurs once every solution time step

nstage = number of stages in the Runge-Kutta time integration, to a maximum of 5 (5)

cfl = value of the CFL (Courant-Friederich-Lax) number (2.8)

diss1 = first dissipation constant (1.0)

diss2 = second dissipation constant (1.0)

relax = boundary-condition relaxation factor (1.0)

mach = free stream Mach number (0.6)

alpha = free-stream angle of attack (0.0)

beta = free-stream angle of sideslip (0.0)

restart = index defining restart option (.false.)
= .true., restart run

```

nlimit      = .false., initial run
            = limiter function type (1)
            = 1, minmod
            = 2, Thomas
lg          = multigrid cycle (1)
nite0      = presmoothing iterations (1)
nite1      = smoothing iterations (1)
nite2      = postsmoothing iterations (1)
ncycl      = number of substeps for each time step (1000)
ncycl      = ncycl (1000)
tlr        = stopping tolerance (0.0)
debug      = debugging option (.false.)
            = .true., debug
            = .false., do not debug
meshc      = coarsest mesh (mmesh from the file *.geo)
meshf      = starting mesh (1)
cbt(1), cbt(2), cbt(3), cbt(4),
cbt(5)      = beta1, beta2, beta3, beta4, beta5 (1.0, 0.5, 0.0, 0.0, 0.0)
bulkvis    = index for computing bulk viscosity (.false.)
            = .true., compute bulk viscosity
            = .false., do not compute bulk viscosity
            for Mach > 2.5, set bulkvis = .true.
disx, xc1, xc2,
xc3, xc4    = parameters defining the bulk viscosity (6.0, -1.2, -0.2, 0.014, 0.0714)
nsmth      = number of residual smoothing iterations (0)
smofc      = residual smoothing coefficient (0.25)
low        = order of solution (.false.)
            = .true., low-order solution
            = .false., high-order solution
trans      = index for defining transient analysis (.false.)
            = .true., transient analysis
            = .false., no transient analysis
            for steady flow, set to .false.
gamma      = ratio of specific heats (1.4)
epslm      = harten fix constant, (0.05)
/          = end file

```

9.5 STARS–SOLIDS Vibration Analysis Data (solids.dat)

See section 3 for details regarding the STARS–SOLIDS input format.

9.6 STARS–AEROS–GENMASS Data (genmass.dat)

See section 6.1 for details regarding the STARS–AEROS–GENMASS input format.

9.7 Input Data for Damping (damp.dat)

9.7.1 \$ Number of Roots
Format (FREE)

9.7.2 NR
Format (FREE)

1. Description: Number of roots for the damping solution.
2. Note:

NR = number of roots

9.7.3 \$ Scaling Factor from Solid.Out.1
Format (FREE)

9.7.4 SCF
Format (FREE)

1. Description: Scaling factor listed in the STARS–SOLIDS output file.
2. Note:

SCF = shift factor from the solids analysis out.1 file

9.7.5 \$ Generalized Stiffness Matrix
Format (FREE)

9.7.6 (GK(I, J), J=1, NR), I=1, NR)
Format (FREE)

1. Description: Components of the generalized stiffness matrix.
2. Note:

GK(I, J) = generalized stiffness matrix components

9.7.7 \$ Generalized Mass Matrix
Format (FREE)

9.7.8 (GM(I, J), J=1, NR), I=1, NR)
Format (FREE)

1. Description: Components of the generalized mass matrix.

2. Note:

GM(I, J) = generalized mass matrix components

9.7.9 \$ Frequency
Format (FREE)

9.7.10 FREQ(I)
Format (FREE)

1. Description: Frequency of each root used in the damping solution.

2. Note:

FREQ = structural frequency, Hz

9.8 Input Data for Unsteady Flow (job.scalars)

9.8.1 \$ Title for Scalars File
Format (FREE)

1. Description: Title card for the scalars file.

2. Note:

A maximum of 80 characters on one line of data.

9.8.2 \$ Basic Parameters
Format (FREE)

9.8.3 NR, IBC, RBCX
Format (FREE)

1. Description: Basic data parameters.

2. Notes:

NR = number of mode shapes used in the unsteady analysis

IBC = index defining the debug switch
= 0, displacement is calculated from the response
= 1, displacement is set to the RBCX value
= 2, displacement is set to the velocity vectors
= 3, displacement is set to RBCX plus velocity

RBCX = mode-shape multiplication factor

9.8.4 NNR, (NS(I), I=1, NNR)
Format (FREE)

1. Description: Boundary-condition modification data.

2. Notes:

NNR = number of surfaces upon which the boundary condition needs to be modified

NS = index defining the surface number

9.8.5 \$ I/O Parameters
Format (FREE)

9.8.6 IRFORM, IPFORM
Format (FREE)

1. Description: Indices to set data input and output formats.

2. Notes:

IRFORM = index defining the input read format

= 1, free format, ASCII file

= 2, binary file

IPRINT = index defining the output print format

= 0, no print out

= 2, print out k, m, and c generalized matrices

9.8.7 \$ Dimensional Parameters
Format (FREE)

9.8.8 MACHI, RHOI, AI, GAMMA, PINF
Format (FREE)

1. Description: Dimensional parameters at infinity.

2. Notes:

MACHI = Mach number at infinity

RHOI = density at infinity

AI = speed of sound at infinity

GAMMA = gamma constant, c_v/c_p

PINF = air pressure at infinity

9.8.9 \$ Shift Factor and Gravitational Constant
Format (FREE)

9.8.10 SCF, GR
Format (FREE)

1. Description: Basic constants.

2. Notes:

SCF = scaling factor, as defined in section 9.7.4

GR = gravity constant, as defined in section 6.1.2

9.8.11 \$ Impulse-Force Data
Format (FREE)

9.8.12 IFLAG, FFI, NS/XS, NE/XE
Format (FREE)

1. Description: Data for specifying the impulse force.

2. Notes:

IFLAG = index defining the generalized impulse-force input mode
 = 1, applied from times XS to XE (real time)
 = 2, applied from steps NS to NE step

FFI = magnitude of the generalized impulse force

NS/XS = starting step or time

NE/XE = ending step or time

9.8.13 \$ Force Activation Parameters
Format (FREE)

9.8.14 ICFA, ICFI
Format (FREE)

1. Description: Parameters to activate aerodynamic and applied generalized forces.

2. Notes:

ICFA = index defining the activation of aerodynamic force
 = 0, do not activate
 = 1, activate

ICFI = index defining the activation of applied generalized force
 = 0, do not activate
 = 1, activate

9.8.15 \$ Transition Matrix Parameters Format (FREE)

9.8.16 NTERMS, NSTEPS Format (FREE)

1. Description: Parameters used in calculating the transition matrix, $e^{A\Delta t}$.
2. Notes:

NTERMS = number of terms used in the calculation of $e^{A\Delta t}$

NSTEPS = option to calculate the transition matrix $e^{A\Delta t}$ at specified intervals

9.9 Input Data of Control File for Unsteady Computational Fluid Dynamics (Euler) Solution (job.conu)

1. Description: Parameters for a name list control file used in the unsteady Euler solution.
2. Notes:

The data below are to be augmented with the data in section 9.4; nstou from section 9.4 is replaced by nout. See section 9.4 for other details regarding using the name list.

&control

nout = number of time steps for writing the unknowns file job.uni (1)

restart = index defining the restart option (1)

 = 0, start from a far-field boundary condition

 = 1, start from the steady-state solution unknowns

 = 2, restart from the last unsteady solution

freq = size adjustment of the time step for a transient analysis (0.0)

nstpe = size adjustment of the time step of the transient analysis (1)

x0, y0 ,z0 = center of rotation (0.0, 0.0, 0.0)

wux, wuy,

wyz = axis of rotation (0.0, 0.0, 0.0)

phase = angle, phi, used to switch an input signal from a sine to a cosine wave,
 $A \times \sin(\omega t + \phi)$, in the pitching problem (0.0)

amplitude = magnitude, A, of the input signal (0.0)

pistonn_sol = index for solution type (0)

 = 0, use the CFD unsteady Euler solver

 = 1, use the alternative piston and modified Newtonian impact theory

 = 2, use the perturbation method

/ = end file

9.10 Input Data of Control File for STEADYDP (job.consdp)

9.10.1 NLINES Format (FREE)

1. Description: Specifies the number of the following comment lines.
2. Note:

NLINES = number of comment lines to follow

9.10.1.1 \$ Comment Lines Format (FREE)

1. Description: NLINES sets of comment lines.
2. Note:

A maximum of 80 characters for each line of comments.

9.10.2 \$ Problem Dimension Format (FREE)

1. Note:

Comment line. Not included in NLINES.

9.10.2.1 NDIM Format (FREE)

1. Description: Problem dimension size.
2. Note:

NDIM = number of dimensions in the problem
= 3

9.10.3 \$ Problem Size Parameters Format (FREE)

9.10.3.1 NELEM, NPOIN, NBOUN Format (FREE)

1. Description: Basic data parameters.

2. Notes:

NELEM = number of tetrahedral elements

NPOIN = number of points

NBOUN = number of boundary elements

9.10.4 \$ Solution Acceleration Parameters
Format (FREE)

9.10.4.1 KACCEL, NACCEL
Format (FREE)

1. Description: Parameters to accelerate the solution.

2. Notes:

KACCEL = number of iterations between acceleration

NACCEL = index defining the starting acceleration time step

If no acceleration is desired, set NACCEL to significantly exceed the expected value of NTIME+ITIN, as defined in sections 9.10.10.1 and 9.10.18.1, respectively.

9.10.5 \$ General Parameters
Format (FREE)

9.10.5.1 GAMMA, C1, IDIFF, EPS, IVISC, WBR
Format (FREE)

1. Description: Basic fluid data parameters.

2. Notes:

GAMMA = gas constant
= 1.4, for air

C1 = pressure switch coefficient
= 0.3, recommended for completely subsonic
= 0.5–0.8, recommended for transonic
= 1.0, recommended for transonic to hypersonic

IDIFF = index defining the smoothing type for artificial dissipation
= 0, metric weighted, acting on the sides
= 1, area weighted, acting on the sides (old code)
= 2, area weighted, acting at the element level (new code)
= 3, new diffusion scheme with side eigenvalues

EPS = pressure switch tolerance; it must be set to a small number or 0.0
 = 0.1, normally

If $EPS = 0.0$, a pressure switch of the type $(M_c - M_L)p / (M_c - M_L)$ is evaluated; otherwise, the pressure switch is evaluated as $psw = \sum (P_i - P_j) / \sum (|P_i - P_j|)$, and EPS is used to avoid division by zero. Because of the way that the division by zero has been avoided, if $EPS = 1$, the pressure switch is evaluated as $\sum (P_i - P_j) / P_{MEAN}$, where P_{MEAN} is the mean value in the surrounding elements.

IVISC = viscous flow indicator
 = 0, for Euler

WBR = wall boundary relaxation parameter, to be used when strong boundary conditions are applied (pointwise velocity projection at wall)

WBR normalizes wall boundary conditions at each step to avoid big jumps. At each step, 0.2 would normalize by 20 percent. Even 1.0 will normally work. Hypersonically, problems may exist. For unsteady flow, set WBR to 1.0 to be time accurate.

9.10.6 \$ Far-Field Boundary Condition Parameter **Format (FREE)**

9.10.6.1 NFFBC **Format (FREE)**

1. Description: Number of far-field boundary conditions.
2. Note:

NFFBC = number of far-field boundary conditions

9.10.7 \$ Far-Field Boundary Condition Data **Format (FREE)**

9.10.7.1 ROINF, UXINF, UYINF, UZINF, PINF, MACHINF **Format (FREE)**

1. Description: NFFBC sets of far-field boundary-condition data.
2. Notes:

ROINF = density at infinity

UXINF = velocity in X at infinity

UYINF = velocity in Y at infinity

UZINF = velocity in Z at infinity

PINF = pressure at infinity
= $ROINF/(GAMMA*MACHINF**2)$

MACHINF = Mach number at infinity

9.10.8 \$ Engine Intake/Outlet Boundary-Condition Parameter Format (FREE)

9.10.8.1 NENBC Format (FREE)

1. Description: Number of engine inlet/exit boundary conditions.

2. Note:

NENBC = number of engine inlet/exit boundary conditions

9.10.9 \$ Engine Boundary-Condition Data (Required if NENBC ≠ 0) Format (FREE)

9.10.9.1 ROENG, UXENG, UYENG, UZENG, PENG, MACHENG (Required if NENBC ≠ 0) Format (FREE)

1. Description: NENBC sets of far-field boundary-condition data.

2. Notes:

ROENG = specified density

UXENG = velocity in X

UYENG = velocity in Y

UZENG = velocity in Z

PENG = specified pressure

MACHENG = specified Mach number

9.10.10 \$ Iteration Parameters Format (FREE)

9.10.10.1 NTIME, NITER, ILOT **Format (FREE)**

1. Description: Parameters to set the number of solution time steps.
2. Notes:

NTIME = maximum number of iterations

NITER = number of mass-consistent iterations
= 1, mass-lumped solution used (steady state)
= 2, mass-consistent solution used (transient)

ILOTS = time-stepping indicator
= 0, global time stepping (steady or transient)
= 1, local time stepping (steady, faster than 0)

9.10.11 \$ General Convergence Parameters **Format (FREE)**

9.10.11.1 CSAFE, IFCT, NQUAN, (IDO(I), I = 1, NQUAN), CLIMAX **Format (FREE)**

1. Description: Data to specify solution convergence.
2. Notes:

CSAFE = Taylor-Galerkin safety factor; usually, $0.0 \leq \text{CSAFE} \leq 1.0$
= 0.7, a reasonable value

IFCT = FCT routine switch
= 0, no FCT
= 1, FCT
= -1, low order only (not generally used)

NQUAN = number of FCT quantities to limit; set to 1, 2, or 3

IDO(I) = variable to be limited for FCT
= 1, density
= 2, energy
= 3, pressure

CLIMAX = maximum limiter allowed; usually 0.00 to 0.95

The FCT should decrease “smearing” near a strong shock but does not always work and increases the solution time. Normally, this option would not be used.

9.10.12 \$ File Formats and I/O Direction Format (FREE)

9.10.12.1 INFOG, INFOU, OUFO, NIOUT Format (FREE)

1. Description: Indices to specify input and output.
2. Notes:

INFOG = index defining the geometry file format specification
= 0, input file is formatted in ASCII
= -1, input file is unformatted

INFOU = index defining the restart initial values file format specification
= 0, input file is formatted in ASCII
= -1, input file is unformatted
= -2, input file is not required, initial values are generated from far-field specifications

OUFO = index defining the output file specification
= 3, unformatted output on channel 15 (graphics)
= 2, formatted output to channel 4; five unknowns at each point in mesh
= 1, unformatted output to the front end (VAX)
= 0, formatted output to the front end
= -1, formatted output to a Cray computer with the name FILE3 and overwriting
= -2, no output file written
= -3, unformatted output to a Cray computer with the name FILE3 and overwriting
= -4, formatted output to a Cray computer with a new file generated every NIOUT iteration with the name FILE3iter
= -5, unformatted output to a Cray computer with a new file generated every NIOUT iteration with the name FILE3iter

NIOUT = number of iterations between outputs
= 0, output written only at the end of the job

WARNING: If OUFO = 0 or 1, (for example, a result file sent to the front end), an unformatted copy of the file (named FILE3) is also sent to the Cray computer.

Note: For INFOU set to 0 or -1, use the previous output file for FILE4 in section 9.10.19.1 for the initial values. Remember to update ITIN in section 9.10.18.1 as well.

9.10.13 \$ Residuals Smoothing Parameters Format (FREE)

9.10.13.1 CSMOO, NSMOO

Format (FREE)

1. Description: Data for defining residuals smoothing.

2. Notes:

CSMOO = residual smoothing coefficient
= 0.25 for Jamesons's method

NSMOO = number of smoothing iterations
= 2 for Jamesons's method

9.10.14 \$ Enthalpy Damping Coefficient

Format (FREE)

9.10.14.1 ALPHA

Format (FREE)

1. Description: Enthalpy damping coefficient.

2. Notes:

ALPHA = enthalpy damping coefficient to enforce constant enthalpy; does not always work
= 1.0, normally

9.10.15 \$ Residuals and Lift Parameters

Format (FREE)

9.10.15.1 IRPR, IRLOG, ILPR, ILLOG, AXIS(I, I = 1, 3), RCHORD

Format (FREE)

1. Description: Data for residuals and lift.

2. Notes:

IRPR = number of iterations between evaluations of diffusive fluxes for a Taylor-Galerkin scheme

IRLOG = type of logging for residuals
= 0, print to log file only
= 1, print to RESID, and print to log file
= 2, print to RESID

ILPR = number of iterations between outputs of lift, drag, and moment coefficients; uses the centroids of the elements with a boundary condition of 2
= 0, no output for lift

ILLOG = type of logging for lift
= 0, print to log file
= 1, print to LIFT, and print to log file
= 2, print to LIFT

AXIS(I) = end points of a position vector, in x, y, and z, parallel to which the lift acts

RCHORD = reference chord for use in lift and moment calculations

9.10.16 \$ Residual Smoothing Iteration Parameters **Format (FREE)**

9.10.16.1 IRFR, IRFS **Format (FREE)**

1. Description: Data for defining residuals smoothing iterations.

2. Notes:

IRFR = number of iterations between smoothing residuals, starting from iteration N;
this parameter is a tradeoff with the CSAFE parameter
= 1, if CSAFE = 1.2
= 3, if CSAFE $\approx$ 0.9

IRFS = number of initial iterations before an alternate evaluation of diffusive fluxes

For Taylor-Galerkin schemes, irrespective of IRFR, the diffusive fluxes are evaluated at every time step for the first IRFS iterations. This option is not presently used.

9.10.17 \$ Boundary-Condition Types and Geometry Checking **Format (FREE)**

9.10.17.1 ISTRON, ICHECK **Format (FREE)**

1. Description: Specifies boundary-condition types.

2. Notes:

ISTRON = boundary-condition type
= 0, weak boundary conditions; flux is corrected on the outer bounds
= 1, strong boundary conditions with velocity projection at the sides included into the right-side boundary integral
= 2, strong boundary conditions with full boundary integral evaluation

ICHECK = geometry consistency-checking parameter
= 0, no checking
= 1, checking done

9.10.18 \$ Initial Time and Iterations
Format (FREE)

9.10.18.1 TIMEIN, ITIN
Format (FREE)

1. Description: Parameters to control starting times.

2. Notes:

TIMEIN = initial time (only for transient)

ITIN = initial iteration number; the iteration counter starts at (ITIN+1)

3. Additional notes:

This code does not check itself for convergence and stop automatically. Convergence is generally said to have occurred when a drop of 4 to 5 orders of magnitude has occurred in the average of the residuals. The lower the Mach number is, the slower the convergence is.

9.10.19 \$ File Names
Format (FREE)

9.10.19.1 FILE3, FILE2, FILE4
Format (FREE)

1. Description: Listing of files for input and output control.

2. Notes:

FILE3 = output file for the results

FILE2 = input geometry file

FILE4 = restart the input file with initial values

Each file name can have a maximum of 16 characters. Only the prefix is required.

9.10.20 \$ CPU Parameters
Format (FREE)

9.10.20.1 NCPU
Format (FREE)

1. Description: Number of central processing units (CPUs) to be used in the solution.

2. Notes:

NCPU = Number of CPUs requested

Set to 0 or 1 for a nonmultitasked version.

10. NUMERICAL EXAMPLE (STARS-CFDASE)

A large number of CFD-based aeroelastic analyses has been performed in support of NASA projects such as Pegasus®, the SR-71 airplane, SR-71/Hypersonic Launch Vehicle, High Speed Civil Transport (HSCT), National Aerospace Plane (NASP), and generic hypersonic vehicle projects, among others. Some analysis results have been correlated with those obtained from flight testing. In the area of aeroelasticity, the associated solution module has been checked out by comparing results with those obtained from tests as well as other analysis methods. A typical example problem of a detailed, CFD-based, aeroelastic analysis is presented next.

10.1 Cantilever Wing Nonlinear Aeroelastic Analysis

Figure 66 shows a cantilever plate with a NACA 0012 airfoil and solution domain. The figure also shows the edges and surfaces, marked appropriately. Figure 67 shows the background mesh.

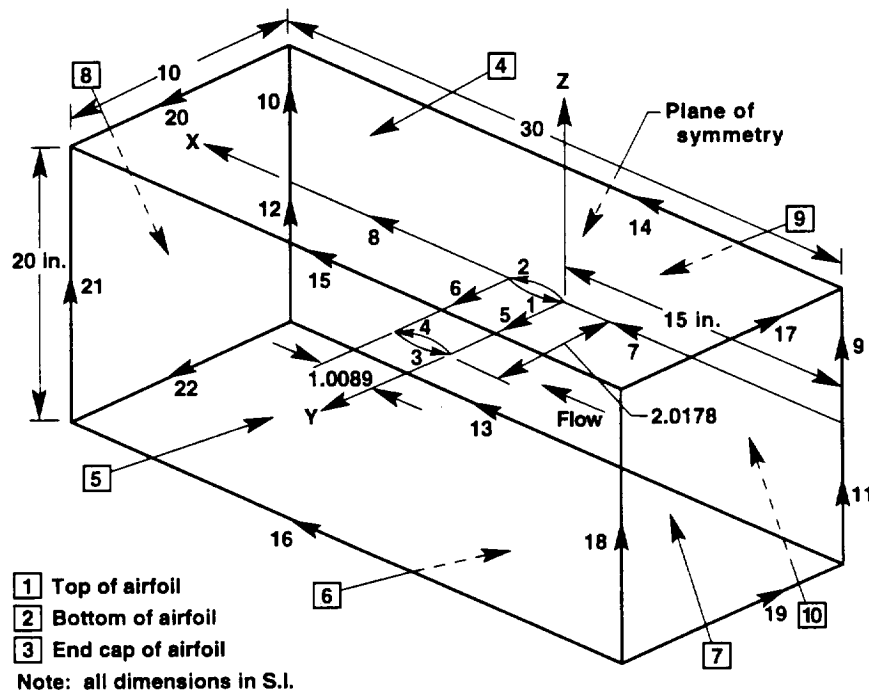


Figure 66. Cantilever wing with aeroelastic solution domain.

Important data parameters are as follows:

Wing span	= 2.0178
Wing chord length	= 1.0089
Mach number	= 0.5
Angle of attack	= 0°
Speed of sound at infinity	= 340.29
Structural data	
Young's modulus	= 6.8947E+10
Poisson's ratio	= 0.3
Density	= 2764.925

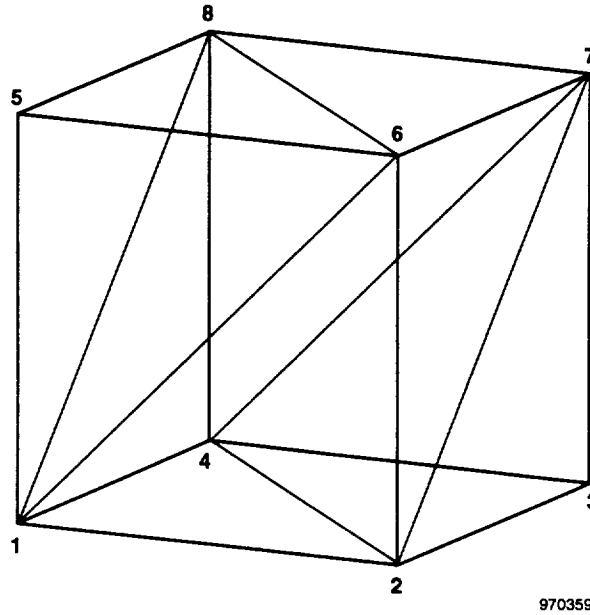


Figure 67. Background domain for aeroelastic analysis.

Data pertaining to the finite-element CFD models are as follows:

Number of fluid nodes	=	54,759
Number of fluid elements	=	297,700
Number of structural nodes	=	861
Number of structural elements	=	1,610

Detailed data input in this connection is given next.

10.1.1 Input Data

Data for the surface file, wing.sur, are given first.

STARS-CFDASE input data:

```
$ nis nef ..... quasi-2D naca0012
22 10
$ segments
1 1
41
0.10009E+01 0.0 0.00000E+00
0.10069E+01 0.0 -0.28900E-03
0.10013E+01 0.0 -0.10810E-02
0.99239E+00 0.0 -0.23220E-02
0.98043E+00 0.0 -0.39740E-02
0.96555E+00 0.0 -0.59930E-02
0.94792E+00 0.0 -0.83390E-02
0.92771E+00 0.0 -0.10971E-01
0.90508E+00 0.0 -0.13843E-01
0.88019E+00 0.0 -0.16915E-01
0.85323E+00 0.0 -0.20146E-01
0.82436E+00 0.0 -0.23494E-01
0.79375E+00 0.0 -0.26920E-01
0.76160E+00 0.0 -0.30386E-01
0.72808E+00 0.0 -0.33853E-01
0.69336E+00 0.0 -0.37281E-01
```

0.65765E+00	0.0	-0.40632E-01
0.62111E+00	0.0	-0.43863E-01
0.58394E+00	0.0	-0.46931E-01
0.54633E+00	0.0	-0.49791E-01
0.50846E+00	0.0	-0.52398E-01
0.47053E+00	0.0	-0.54701E-01
0.43273E+00	0.0	-0.56653E-01
0.39526E+00	0.0	-0.58203E-01
0.35831E+00	0.0	-0.59303E-01
0.32208E+00	0.0	-0.59908E-01
0.28677E+00	0.0	-0.59978E-01
0.25259E+00	0.0	-0.59475E-01
0.21973E+00	0.0	-0.58374E-01
0.18841E+00	0.0	-0.56655E-01
0.15882E+00	0.0	-0.54310E-01
0.13117E+00	0.0	-0.51339E-01
0.10564E+00	0.0	-0.47753E-01
0.82428E-01	0.0	-0.43572E-01
0.61717E-01	0.0	-0.38825E-01
0.43684E-01	0.0	-0.33541E-01
0.28501E-01	0.0	-0.27752E-01
0.16337E-01	0.0	-0.21479E-01
0.73750E-02	0.0	-0.14730E-01
0.18480E-02	0.0	-0.75170E-02
0.00000E+00	0.0	0.00000E+00
2	1	
41		
0.00000E+00	0.0	0.00000E+00
0.18480E-02	0.0	0.75170E-02
0.73750E-02	0.0	0.14730E-01
0.16338E-01	0.0	0.21479E-01
0.28501E-01	0.0	0.27752E-01
0.43684E-01	0.0	0.33541E-01
0.61716E-01	0.0	0.38825E-01
0.82428E-01	0.0	0.43572E-01
0.10564E+00	0.0	0.47753E-01
0.13117E+00	0.0	0.51339E-01
0.15882E+00	0.0	0.54310E-01
0.18841E+00	0.0	0.56656E-01
0.21973E+00	0.0	0.58374E-01
0.25259E+00	0.0	0.59476E-01
0.28677E+00	0.0	0.59978E-01
0.32208E+00	0.0	0.59909E-01
0.35831E+00	0.0	0.59304E-01
0.39526E+00	0.0	0.58203E-01
0.43273E+00	0.0	0.56653E-01
0.47054E+00	0.0	0.54702E-01
0.50846E+00	0.0	0.52398E-01
0.54633E+00	0.0	0.49792E-01
0.58394E+00	0.0	0.46931E-01
0.62111E+00	0.0	0.43863E-01
0.65765E+00	0.0	0.40632E-01
0.69336E+00	0.0	0.37282E-01
0.72808E+00	0.0	0.33853E-01
0.76160E+00	0.0	0.30387E-01
0.79375E+00	0.0	0.26920E-01
0.82436E+00	0.0	0.23494E-01
0.85323E+00	0.0	0.20146E-01
0.88019E+00	0.0	0.16915E-01
0.90508E+00	0.0	0.13843E-01
0.92771E+00	0.0	0.10971E-01
0.94792E+00	0.0	0.83390E-02
0.96555E+00	0.0	0.59930E-02
0.98043E+00	0.0	0.39740E-02
0.99239E+00	0.0	0.23220E-02
0.10013E+01	0.0	0.10810E-02
0.10069E+01	0.0	0.28900E-03
0.10089E+01	0.0	0.00000E+00
3	1	
41		
0.10089E+01	2.0178	0.00000E+00
0.10069E+01	2.0178	-0.28900E-03
0.10013E+01	2.0178	-0.10810E-02
0.99239E+00	2.0178	-0.23220E-02
0.98043E+00	2.0178	-0.39740E-02
0.96555E+00	2.0178	-0.59930E-02
0.94792E+00	2.0178	-0.83390E-02
0.92771E+00	2.0178	-0.10971E-01
0.90508E+00	2.0178	-0.13843E-01
0.88019E+00	2.0178	-0.16915E-01
0.85323E+00	2.0178	-0.20146E-01
0.82436E+00	2.0178	-0.23494E-01
0.79375E+00	2.0178	-0.26920E-01

0.76160E+00	2.0178	-0.30386E-01
0.72808E+00	2.0178	-0.33853E-01
0.69336E+00	2.0178	-0.37281E-01
0.65765E+00	2.0178	-0.40632E-01
0.62111E+00	2.0178	-0.43863E-01
0.58394E+00	2.0178	-0.46931E-01
0.54633E+00	2.0178	-0.49791E-01
0.50846E+00	2.0178	-0.52398E-01
0.47053E+00	2.0178	-0.54701E-01
0.43273E+00	2.0178	-0.56653E-01
0.39526E+00	2.0178	-0.58203E-01
0.35831E+00	2.0178	-0.59303E-01
0.32208E+00	2.0178	-0.59908E-01
0.28677E+00	2.0178	-0.59978E-01
0.25259E+00	2.0178	-0.59475E-01
0.21973E+00	2.0178	-0.58374E-01
0.18841E+00	2.0178	-0.56655E-01
0.15882E+00	2.0178	-0.54310E-01
0.13117E+00	2.0178	-0.51339E-01
0.10564E+00	2.0178	-0.47753E-01
0.82428E-01	2.0178	-0.43572E-01
0.61717E-01	2.0178	-0.38825E-01
0.43684E-01	2.0178	-0.33541E-01
0.28501E-01	2.0178	-0.27752E-01
0.16337E-01	2.0178	-0.21479E-01
0.73750E-02	2.0178	-0.14730E-01
0.18480E-02	2.0178	-0.75170E-02
0.00000E+00	2.0178	0.00000E+00

4 1

41

0.00000E+00	2.0178	0.00000E+00
0.18480E-02	2.0178	0.75170E-02
0.73750E-02	2.0178	0.14730E-01
0.16338E-01	2.0178	0.21479E-01
0.28501E-01	2.0178	0.27752E-01
0.43684E-01	2.0178	0.33541E-01
0.61716E-01	2.0178	0.38825E-01
0.82428E-01	2.0178	0.43572E-01
0.10564E+00	2.0178	0.47753E-01
0.13117E+00	2.0178	0.51339E-01
0.15882E+00	2.0178	0.54310E-01
0.18841E+00	2.0178	0.56656E-01
0.21973E+00	2.0178	0.58374E-01
0.25259E+00	2.0178	0.59476E-01
0.28677E+00	2.0178	0.59978E-01
0.32208E+00	2.0178	0.59909E-01
0.35831E+00	2.0178	0.59304E-01
0.39526E+00	2.0178	0.58203E-01
0.43273E+00	2.0178	0.56653E-01
0.47054E+00	2.0178	0.54702E-01
0.50846E+00	2.0178	0.52398E-01
0.54633E+00	2.0178	0.49792E-01
0.58394E+00	2.0178	0.46931E-01
0.62111E+00	2.0178	0.43863E-01
0.65765E+00	2.0178	0.40632E-01
0.69336E+00	2.0178	0.37282E-01
0.72808E+00	2.0178	0.33853E-01
0.76160E+00	2.0178	0.30387E-01
0.79375E+00	2.0178	0.26920E-01
0.82436E+00	2.0178	0.23494E-01
0.85323E+00	2.0178	0.20146E-01
0.88019E+00	2.0178	0.16915E-01
0.90508E+00	2.0178	0.13843E-01
0.92771E+00	2.0178	0.10971E-01
0.94792E+00	2.0178	0.83390E-02
0.96555E+00	2.0178	0.59930E-02
0.98043E+00	2.0178	0.39740E-02
0.99239E+00	2.0178	0.23220E-02
0.10013E+01	2.0178	0.10810E-02
0.10069E+01	2.0178	0.28900E-03
0.10089E+01	2.0178	0.00000E+00

5 1

2

0.	0.	0.
0.	2.0178	0.

6 1

2

1.0089	0	0.
1.0089	2.0178	0.

7 1

2

-15.	0.	0.
0.	0.	0.

```

8 1
2
1.0089 0. 0.
15. 0. 0.
9 1
2
-15. 0. 0.
-15. 0. 10.
10 1
2
15. 0. 0.
15. 0. 10.
11 1
2
-15. 0. -10.
-15. 0. 0.
12 1
2
15. 0. -10.
15. 0. 0.
13 1
2
-15. 0. -10.
15. 0. -10.
14 1
2
-15. 0. 10.
15. 0. 10.
15 1
2
-15. 10. 10.
15. 10. 10.
16 1
2
-15. 10. -10.
15. 10. -10.
17 1
2
-15. 0. 10.
-15. 10. 10.
18 1
2
-15. 10. 10.
-15. 10. -10.
19 1
2
-15. 0. -10.
-15. 10. -10.
20 1
2
15. 0. 10.
15. 10. 10.
21 1
2
15. 10. 10.
15. 10. -10.
22 1
2
15. 0. -10.
15. 10. -10.
$ support surfaces
1 1
41 2
0.10089E+01 0.0 0.00000E+00
0.10069E+01 0.0 -0.28900E-03
0.10013E+01 0.0 -0.10810E-02
0.99239E+00 0.0 -0.23220E-02
0.98043E+00 0.0 -0.39740E-02
0.96555E+00 0.0 -0.59930E-02
0.94792E+00 0.0 -0.83390E-02
0.92771E+00 0.0 -0.10971E-01
0.90508E+00 0.0 -0.13843E-01
0.88019E+00 0.0 -0.16915E-01
0.85323E+00 0.0 -0.20146E-01
0.82436E+00 0.0 -0.23494E-01
0.79375E+00 0.0 -0.26920E-01
0.76160E+00 0.0 -0.30386E-01
0.72808E+00 0.0 -0.33853E-01
0.69336E+00 0.0 -0.37281E-01
0.65765E+00 0.0 -0.40632E-01
0.62111E+00 0.0 -0.43863E-01
0.58394E+00 0.0 -0.46931E-01
0.54633E+00 0.0 -0.49791E-01

```

0.50846E+00	0.0	-0.52398E-01
0.47053E+00	0.0	-0.54701E-01
0.43273E+00	0.0	-0.56653E-01
0.39526E+00	0.0	-0.58203E-01
0.35831E+00	0.0	-0.59303E-01
0.32208E+00	0.0	-0.59908E-01
0.28677E+00	0.0	-0.59978E-01
0.25259E+00	0.0	-0.59475E-01
0.21973E+00	0.0	-0.58374E-01
0.18841E+00	0.0	-0.56655E-01
0.15882E+00	0.0	-0.54310E-01
0.13117E+00	0.0	-0.51339E-01
0.10564E+00	0.0	-0.47753E-01
0.82428E-01	0.0	-0.43572E-01
0.61717E-01	0.0	-0.38825E-01
0.43684E-01	0.0	-0.33541E-01
0.28501E-01	0.0	-0.27752E-01
0.16337E-01	0.0	-0.21479E-01
0.73750E-02	0.0	-0.14730E-01
0.18480E-02	0.0	-0.75170E-02
0.00000E+00	0.0	0.00000E+00
0.10089E+01	2.0178	0.00000E+00
0.10069E+01	2.0178	-0.28900E-03
0.10013E+01	2.0178	-0.10810E-02
0.99239E+00	2.0178	-0.23220E-02
0.98043E+00	2.0178	-0.39740E-02
0.96555E+00	2.0178	-0.59930E-02
0.94792E+00	2.0178	-0.83390E-02
0.92771E+00	2.0178	-0.10971E-01
0.90508E+00	2.0178	-0.13843E-01
0.88019E+00	2.0178	-0.16915E-01
0.85323E+00	2.0178	-0.20146E-01
0.82436E+00	2.0178	-0.23494E-01
0.79375E+00	2.0178	-0.26920E-01
0.76160E+00	2.0178	-0.30386E-01
0.72808E+00	2.0178	-0.33853E-01
0.69336E+00	2.0178	-0.37281E-01
0.65765E+00	2.0178	-0.40632E-01
0.62111E+00	2.0178	-0.43863E-01
0.58394E+00	2.0178	-0.46931E-01
0.54633E+00	2.0178	-0.49791E-01
0.50846E+00	2.0178	-0.52398E-01
0.47053E+00	2.0178	-0.54701E-01
0.43273E+00	2.0178	-0.56653E-01
0.39526E+00	2.0178	-0.58203E-01
0.35831E+00	2.0178	-0.59303E-01
0.32208E+00	2.0178	-0.59908E-01
0.28677E+00	2.0178	-0.59978E-01
0.25259E+00	2.0178	-0.59475E-01
0.21973E+00	2.0178	-0.58374E-01
0.18841E+00	2.0178	-0.56655E-01
0.15882E+00	2.0178	-0.54310E-01
0.13117E+00	2.0178	-0.51339E-01
0.10564E+00	2.0178	-0.47753E-01
0.82428E-01	2.0178	-0.43572E-01
0.61717E-01	2.0178	-0.38825E-01
0.43684E-01	2.0178	-0.33541E-01
0.28501E-01	2.0178	-0.27752E-01
0.16337E-01	2.0178	-0.21479E-01
0.73750E-02	2.0178	-0.14730E-01
0.18480E-02	2.0178	-0.75170E-02
0.00000E+00	2.0178	0.00000E+00

2 1
41 2

0.00000E+00	0.0	0.00000E+00
0.18480E-02	0.0	0.75170E-02
0.73750E-02	0.0	0.14730E-01
0.16338E-01	0.0	0.21479E-01
0.28501E-01	0.0	0.27752E-01
0.43684E-01	0.0	0.33541E-01
0.61716E-01	0.0	0.38825E-01
0.82428E-01	0.0	0.43572E-01
0.10564E+00	0.0	0.47753E-01
0.13117E+00	0.0	0.51339E-01
0.15882E+00	0.0	0.54310E-01
0.18841E+00	0.0	0.56656E-01
0.21973E+00	0.0	0.58374E-01
0.25259E+00	0.0	0.59476E-01
0.28677E+00	0.0	0.59978E-01
0.32208E+00	0.0	0.59909E-01
0.35831E+00	0.0	0.59304E-01
0.39526E+00	0.0	0.58203E-01
0.43273E+00	0.0	0.56653E-01

0.47054E+00	0.0	0.54702E-01
0.50846E+00	0.0	0.52398E-01
0.54633E+00	0.0	0.49792E-01
0.58394E+00	0.0	0.46931E-01
0.62111E+00	0.0	0.43863E-01
0.65765E+00	0.0	0.40632E-01
0.69336E+00	0.0	0.37282E-01
0.72808E+00	0.0	0.33853E-01
0.76160E+00	0.0	0.30387E-01
0.79375E+00	0.0	0.26920E-01
0.82436E+00	0.0	0.23494E-01
0.85323E+00	0.0	0.20146E-01
0.88019E+00	0.0	0.16915E-01
0.90508E+00	0.0	0.13843E-01
0.92771E+00	0.0	0.10971E-01
0.94792E+00	0.0	0.83390E-02
0.96555E+00	0.0	0.59930E-02
0.98043E+00	0.0	0.39740E-02
0.99239E+00	0.0	0.23220E-02
0.10013E+01	0.0	0.10810E-02
0.10069E+01	0.0	0.28900E-03
0.10089E+01	0.0	0.00000E+00
0.00000E+00	2.0178	0.00000E+00
0.18480E-02	2.0178	0.75170E-02
0.73750E-02	2.0178	0.14730E-01
0.16338E-01	2.0178	0.21479E-01
0.28501E-01	2.0178	0.27752E-01
0.43684E-01	2.0178	0.33541E-01
0.61716E-01	2.0178	0.38825E-01
0.82428E-01	2.0178	0.43572E-01
0.10564E+00	2.0178	0.47753E-01
0.13117E+00	2.0178	0.51339E-01
0.15882E+00	2.0178	0.54310E-01
0.18841E+00	2.0178	0.56656E-01
0.21973E+00	2.0178	0.58374E-01
0.25259E+00	2.0178	0.59476E-01
0.28677E+00	2.0178	0.59978E-01
0.32208E+00	2.0178	0.59909E-01
0.35831E+00	2.0178	0.59304E-01
0.39526E+00	2.0178	0.58203E-01
0.43273E+00	2.0178	0.56653E-01
0.47054E+00	2.0178	0.54702E-01
0.50846E+00	2.0178	0.52398E-01
0.54633E+00	2.0178	0.49792E-01
0.58394E+00	2.0178	0.46931E-01
0.62111E+00	2.0178	0.43863E-01
0.65765E+00	2.0178	0.40632E-01
0.69336E+00	2.0178	0.37282E-01
0.72808E+00	2.0178	0.33853E-01
0.76160E+00	2.0178	0.30387E-01
0.79375E+00	2.0178	0.26920E-01
0.82436E+00	2.0178	0.23494E-01
0.85323E+00	2.0178	0.20146E-01
0.88019E+00	2.0178	0.16915E-01
0.90508E+00	2.0178	0.13843E-01
0.92771E+00	2.0178	0.10971E-01
0.94792E+00	2.0178	0.83390E-02
0.96555E+00	2.0178	0.59930E-02
0.98043E+00	2.0178	0.39740E-02
0.99239E+00	2.0178	0.23220E-02
0.10013E+01	2.0178	0.10810E-02
0.10069E+01	2.0178	0.28900E-03
0.10089E+01	2.0178	0.00000E+00
3 1		
2 41		
0.00000E+00	2.0178	0.00000E+00
0.00000E+00	2.0178	0.00000E+00
0.18480E-02	2.0178	-0.75170E-02
0.18480E-02	2.0178	0.75170E-02
0.73750E-02	2.0178	-0.14730E-01
0.73750E-02	2.0178	0.14730E-01
0.16338E-01	2.0178	-0.21479E-01
0.16338E-01	2.0178	0.21479E-01
0.28501E-01	2.0178	-0.27752E-01
0.28501E-01	2.0178	0.27752E-01
0.43684E-01	2.0178	-0.33541E-01
0.43684E-01	2.0178	0.33541E-01
0.61716E-01	2.0178	-0.38825E-01
0.61716E-01	2.0178	0.38825E-01
0.82428E-01	2.0178	-0.43572E-01
0.82428E-01	2.0178	0.43572E-01
0.10564E+00	2.0178	-0.47753E-01
0.10564E+00	2.0178	0.47753E-01

0.13117E+00	2.0178	-0.51339E-01
0.13117E+00	2.0178	0.51339E-01
0.15882E+00	2.0178	-0.54310E-01
0.15882E+00	2.0178	0.54310E-01
0.18841E+00	2.0178	-0.56656E-01
0.18841E+00	2.0178	0.56656E-01
0.21973E+00	2.0178	-0.58374E-01
0.21973E+00	2.0178	0.58374E-01
0.25259E+00	2.0178	-0.59476E-01
0.25259E+00	2.0178	0.59476E-01
0.28677E+00	2.0178	-0.59978E-01
0.28677E+00	2.0178	0.59978E-01
0.32208E+00	2.0178	-0.59909E-01
0.32208E+00	2.0178	0.59909E-01
0.35831E+00	2.0178	-0.59304E-01
0.35831E+00	2.0178	0.59304E-01
0.39526E+00	2.0178	-0.58203E-01
0.39526E+00	2.0178	0.58203E-01
0.43273E+00	2.0178	-0.56653E-01
0.43273E+00	2.0178	0.56653E-01
0.47054E+00	2.0178	-0.54702E-01
0.47054E+00	2.0178	0.54702E-01
0.50846E+00	2.0178	-0.52398E-01
0.50846E+00	2.0178	0.52398E-01
0.54633E+00	2.0178	-0.49792E-01
0.54633E+00	2.0178	0.49792E-01
0.58394E+00	2.0178	-0.46931E-01
0.58394E+00	2.0178	0.46931E-01
0.62111E+00	2.0178	-0.43863E-01
0.62111E+00	2.0178	0.43863E-01
0.65765E+00	2.0178	-0.40632E-01
0.65765E+00	2.0178	0.40632E-01
0.69336E+00	2.0178	-0.37282E-01
0.69336E+00	2.0178	0.37282E-01
0.72808E+00	2.0178	-0.33853E-01
0.72808E+00	2.0178	0.33853E-01
0.76160E+00	2.0178	-0.30387E-01
0.76160E+00	2.0178	0.30387E-01
0.79375E+00	2.0178	-0.26920E-01
0.79375E+00	2.0178	0.26920E-01
0.82436E+00	2.0178	-0.23494E-01
0.82436E+00	2.0178	0.23494E-01
0.85323E+00	2.0178	-0.20146E-01
0.85323E+00	2.0178	0.20146E-01
0.88019E+00	2.0178	-0.16915E-01
0.88019E+00	2.0178	0.16915E-01
0.90508E+00	2.0178	-0.13843E-01
0.90508E+00	2.0178	0.13843E-01
0.92771E+00	2.0178	-0.10971E-01
0.92771E+00	2.0178	0.10971E-01
0.94792E+00	2.0178	-0.83390E-02
0.94792E+00	2.0178	0.83390E-02
0.96555E+00	2.0178	-0.59930E-02
0.96555E+00	2.0178	0.59930E-02
0.98043E+00	2.0178	-0.39740E-02
0.98043E+00	2.0178	0.39740E-02
0.99239E+00	2.0178	-0.23220E-02
0.99239E+00	2.0178	0.23220E-02
0.10013E+01	2.0178	-0.10810E-02
0.10013E+01	2.0178	0.10810E-02
0.10069E+01	2.0178	-0.28900E-03
0.10069E+01	2.0178	0.28900E-03
0.10089E+01	2.0178	0.00000E+00
0.10089E+01	2.0178	0.00000E+00

4	1			
2	2			
		-15.	10.	10.
		15.	10.	10.
		-15.	0.	10.
		15.	0.	10.
5	1			
2	2			
		-15.	10.	-10.
		15.	10.	-10.
		-15.	10.	10.
		15.	10.	10.
6	1			
2	2			
		-15.	0.	-10.
		15.	0.	-10.
		-15.	10.	-10.
		15.	10.	-10.
7	1			

```

2 2
-15. 0. -10.
-15. 10. -10.
-15. 0. 10.
-15. 10. 10.

8 1
2 2
15. 0. 10.
15. 10. 10.
15. 0. -10.
15. 10. -10.

9 1
2 2
-15. 0 10.
15. 0 10.
-15. 0. 0.
15. 0. 0.

10 1
2 2
-15 0. 0.
15. 0. 0.
-15. 0. -10.
15. 0. -10.

$ mesh generation
22 10
$
1 1 1
2 2 1
3 3 1
4 4 1
5 5 1
6 6 1
7 7 1
8 8 1
9 9 1
10 10 1
11 11 1
12 12 1
13 13 1
14 14 1
15 15 1
16 16 1
17 17 1
18 18 1
19 19 1
20 20 1
21 21 1
22 22 1

$ regions
1 1 1
4
5 -3 -6 1
2 2 1
4
2 6 -4 -5
3 3 1
2
4 3
4 4 1
4
-20 -14 17 15
5 5 1
4
18 16 -21 -15
6 6 1
4
13 22 -16 -19
7 7 1
5
-18 -17 -9 -11 19
8 8 1
5
20 21 -22 12 10
9 9 1
6
14 -10 -8 -2 -7 9
10 10 1
6
7 -1 8 -12 -13 11

```

Data for the background grid file, wing.bac, are given below.

STARS-CFDASE input data:

```
* background mesh ... quasi-2D MACR0012
  8  6  0  4  2
  1  .10000E+06 -.10000E+06 -.10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  2  .10000E+06 .10000E+06 -.10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  3  -.10000E+06 .10000E+06 -.10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  4  -.10000E+06 -.10000E+06 -.10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  5  .10000E+06 -.10000E+06 .10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  6  .10000E+06 .10000E+06 .10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  7  -.10000E+06 .10000E+06 .10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  8  -.10000E+06 -.10000E+06 .10000E+06
  1.00 .00 .00 3.000
  .00 1.00 .00 3.000
  .00 .00 1.00 3.000
  1  1  2  4  8
  2  1  2  8  6
  3  1  6  8  5
  4  2  3  4  7
  5  2  7  4  8
  6  2  7  8  6

* points
* lines
1.- leading edge
-.00000E+00 .00000E+00 .00000E+00 .040 .100 .308
-.00000E+00 .21000E+01 .00000E+01 .040 .100 .308
2.- leading edge
-.00000E+00 .00000E+00 .00000E+00 .015 .050 .089
-.00000E+00 .21000E+01 .00000E+01 .015 .050 .089
3.- trailing edge
.1007E+01 .00000E+00 .00000E+00 .040 .100 .377
.1007E+01 .21000E+01 .00000E+00 .040 .100 .377
4.- trailing edge
.1007E+01 .00000E+00 .00000E+00 .025 .050 .179
.1007E+01 .21000E+01 .00000E+00 .025 .050 .179

* triangles
1.- wing
-.10000E+00 .000000E+00 .00000E+00 .04 .160 .500
-.10000E+00 .210000E+01 .00000E+00 .04 .160 .500
.101E+01 .210000E+01 .00000E+00 .04 .160 .500
2.- wing
.101E+01 .21000E+01 .00000E+00 .04 .160 .500
.101E+01 .00000E+00 .00000E+00 .04 .160 .500
-.10000E+00 .00000E+00 .00000E+00 .04 .160 .50
1a.- wing
-.10000E+00 .000000E+00 .00000E+00 .055 .090 1.500
-.10000E+00 .210000E+01 .00000E+00 .055 .090 1.500
.101E+01 .210000E+01 .00000E+00 .055 .090 1.500
2a.- wing
.101E+01 .21000E+01 .00000E+00 .055 .090 1.500
.101E+01 .00000E+00 .00000E+00 .055 .090 1.500
-.10000E+00 .00000E+00 .00000E+00 .055 .090 1.500
```

Data for the boundary-condition file, wing.bco, are given below.

STARS-CFDASE input data:

Boundary Condition Flags

10, 22

\$ Surface Regions

1 1

2 1

3 1

4 1

5 1

6 1

7 3

8 3

9 2

10 2

\$ Curved Segments

1 0

2 0

3 0

4 0

5 0

6 0

7 0

8 0

9 0

10 0

11 0

12 0

13 0

14 0

15 0

16 0

17 0

18 0

19 0

20 0

21 0

22 0

Data for the steady CFD solution control file, wing.cons, are given below.

STARS-CFDASE input data:

&control

nstep = 270,

nstou = 10,

nstage = 4,

cfl = 1.0,

diss1 = 1.0,

diss2 = 1.0,

relax = 1.0,

mach = 0.5,

alpha = 0.0,

beta = 0.0,

restart = .false.,

nlimit = 2,

lg = 1,

nite0 = 1,

nite1 = 1,

nite2 = 0,

ncycl = 25,

ncycl = 25,

tir = 0.0001,

debug = .false.,

meshc = 1,

meshf = 1,

cbt(1) = 1.0,

cbt(2) = 0.5,

cbt(3) = 0.0,

cbt(4) = 0.0,

trans = .false.,

/

Data for the solids file, wing.dat, are given below.

STARS-SOLIDS input data:

manual solids metric units - solids model for vibration analysis - 20x10

```

861, 1610, 1, 4, 1, 1, 0, 0, 0, 0
0, 0, 0, 0, 0, 0, 0, 0, 0
1, 1, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 1
1, 8, 0, 6.0000E+04, .0000E+00, .0000E+00
$ MODAL DATA
1 .0000 .0000 .0000 1 1 1 1 1 1 0 0 0
21 1.0089 .0000 .0000 1 1 1 1 1 1 0 0 1
22 .0000 .0504 .0000 0 0 0 0 0 0 0 0 0
42 1.0089 .0504 .0000 0 0 0 0 0 0 0 0 1
43 .0000 .1009 .0000 0 0 0 0 0 0 0 0 0
63 1.0089 .1009 .0000 0 0 0 0 0 0 0 0 1
64 .0000 .1513 .0000 0 0 0 0 0 0 0 0 0
84 1.0089 .1513 .0000 0 0 0 0 0 0 0 0 1
85 .0000 .2018 .0000 0 0 0 0 0 0 0 0 0
105 1.0089 .2018 .0000 0 0 0 0 0 0 0 0 1
106 .0000 .2522 .0000 0 0 0 0 0 0 0 0 0
126 1.0089 .2522 .0000 0 0 0 0 0 0 0 0 1
127 .0000 .3027 .0000 0 0 0 0 0 0 0 0 0
147 1.0089 .3027 .0000 0 0 0 0 0 0 0 0 1
148 .0000 .3531 .0000 0 0 0 0 0 0 0 0 0
168 1.0089 .3531 .0000 0 0 0 0 0 0 0 0 1
169 .0000 .4036 .0000 0 0 0 0 0 0 0 0 0
189 1.0089 .4036 .0000 0 0 0 0 0 0 0 0 1
190 .0000 .4540 .0000 0 0 0 0 0 0 0 0 0
210 1.0089 .4540 .0000 0 0 0 0 0 0 0 0 1
211 .0000 .5045 .0000 0 0 0 0 0 0 0 0 0
231 1.0089 .5045 .0000 0 0 0 0 0 0 0 0 1
232 .0000 .5549 .0000 0 0 0 0 0 0 0 0 0
252 1.0089 .5549 .0000 0 0 0 0 0 0 0 0 1
253 .0000 .6053 .0000 0 0 0 0 0 0 0 0 0
273 1.0089 .6053 .0000 0 0 0 0 0 0 0 0 1
274 .0000 .6558 .0000 0 0 0 0 0 0 0 0 0
294 1.0089 .6558 .0000 0 0 0 0 0 0 0 0 1
295 .0000 .7062 .0000 0 0 0 0 0 0 0 0 0
315 1.0089 .7062 .0000 0 0 0 0 0 0 0 0 1
316 .0000 .7567 .0000 0 0 0 0 0 0 0 0 0
336 1.0089 .7567 .0000 0 0 0 0 0 0 0 0 1
337 .0000 .8071 .0000 0 0 0 0 0 0 0 0 0
357 1.0089 .8071 .0000 0 0 0 0 0 0 0 0 1
358 .0000 .8576 .0000 0 0 0 0 0 0 0 0 0
378 1.0089 .8576 .0000 0 0 0 0 0 0 0 0 1
379 .0000 .9080 .0000 0 0 0 0 0 0 0 0 0
399 1.0089 .9080 .0000 0 0 0 0 0 0 0 0 1
400 .0000 .9585 .0000 0 0 0 0 0 0 0 0 0
420 1.0089 .9585 .0000 0 0 0 0 0 0 0 0 1
421 .0000 1.0089 .0000 0 0 0 0 0 0 0 0 0
441 1.0089 1.0089 .0000 0 0 0 0 0 0 0 0 1
442 .0000 1.0593 .0000 0 0 0 0 0 0 0 0 0
462 1.0089 1.0593 .0000 0 0 0 0 0 0 0 0 1
463 .0000 1.1098 .0000 0 0 0 0 0 0 0 0 0
483 1.0089 1.1098 .0000 0 0 0 0 0 0 0 0 1
484 .0000 1.1602 .0000 0 0 0 0 0 0 0 0 0
504 1.0089 1.1602 .0000 0 0 0 0 0 0 0 0 1
505 .0000 1.2107 .0000 0 0 0 0 0 0 0 0 0
525 1.0089 1.2107 .0000 0 0 0 0 0 0 0 0 1
526 .0000 1.2611 .0000 0 0 0 0 0 0 0 0 0
546 1.0089 1.2611 .0000 0 0 0 0 0 0 0 0 1
547 .0000 1.3116 .0000 0 0 0 0 0 0 0 0 0
567 1.0089 1.3116 .0000 0 0 0 0 0 0 0 0 1
568 .0000 1.3620 .0000 0 0 0 0 0 0 0 0 0
588 1.0089 1.3620 .0000 0 0 0 0 0 0 0 0 1
589 .0000 1.4125 .0000 0 0 0 0 0 0 0 0 0
609 1.0089 1.4125 .0000 0 0 0 0 0 0 0 0 1
610 .0000 1.4629 .0000 0 0 0 0 0 0 0 0 0
630 1.0089 1.4629 .0000 0 0 0 0 0 0 0 0 1
631 .0000 1.5134 .0000 0 0 0 0 0 0 0 0 0
651 1.0089 1.5134 .0000 0 0 0 0 0 0 0 0 1
652 .0000 1.5638 .0000 0 0 0 0 0 0 0 0 0
672 1.0089 1.5638 .0000 0 0 0 0 0 0 0 0 1
673 .0000 1.6142 .0000 0 0 0 0 0 0 0 0 0
693 1.0089 1.6142 .0000 0 0 0 0 0 0 0 0 1
694 .0000 1.6647 .0000 0 0 0 0 0 0 0 0 0
714 1.0089 1.6647 .0000 0 0 0 0 0 0 0 0 1
715 .0000 1.7151 .0000 0 0 0 0 0 0 0 0 0

```

735	1.0089	1.7151	.0000	0	0	0	0	0	0	0	0	1
736	.0000	1.7656	.0000	0	0	0	0	0	0	0	0	0
756	1.0089	1.7656	.0000	0	0	0	0	0	0	0	0	1
757	.0000	1.8160	.0000	0	0	0	0	0	0	0	0	0
777	1.0089	1.8160	.0000	0	0	0	0	0	0	0	0	1
778	.0000	1.8665	.0000	0	0	0	0	0	0	0	0	0
798	1.0089	1.8665	.0000	0	0	0	0	0	0	0	0	1
799	.0000	1.9169	.0000	0	0	0	0	0	0	0	0	0
819	1.0089	1.9169	.0000	0	0	0	0	0	0	0	0	1
820	.0000	1.9674	.0000	0	0	0	0	0	0	0	0	0
840	1.0089	1.9674	.0000	0	0	0	0	0	0	0	0	1
841	.0000	2.0178	.0000	0	0	0	0	0	0	0	0	0
861	1.0089	2.0178	.0000	0	0	0	0	0	0	0	0	1

\$ ELEMENT CONNECTIVITY CONDITIONS

3	1	1	2	23	0	0	0	0	1	1	0	0	0	0
3	20	20	21	42	0	0	0	0	0	1	1	0	0	1
3	21	23	22	1	0	0	0	0	0	1	1	0	0	0
3	40	42	41	20	0	0	0	0	0	1	1	0	0	1
3	41	22	23	44	0	0	0	0	0	1	1	0	0	0
3	60	41	42	63	0	0	0	0	0	1	1	0	0	1
3	61	44	43	22	0	0	0	0	0	1	1	0	0	0
3	80	63	62	41	0	0	0	0	0	1	1	0	0	1
3	81	43	44	65	0	0	0	0	0	1	1	0	0	0
3	100	62	63	84	0	0	0	0	0	1	1	0	0	1
3	101	65	64	43	0	0	0	0	0	1	1	0	0	0
3	120	84	83	62	0	0	0	0	0	1	1	0	0	1
3	121	64	65	86	0	0	0	0	0	1	1	0	0	0
3	140	83	84	105	0	0	0	0	0	1	1	0	0	1
3	141	86	85	64	0	0	0	0	0	1	1	0	0	0
3	160	105	104	83	0	0	0	0	0	1	1	0	0	1
3	161	85	86	107	0	0	0	0	0	1	1	0	0	0
3	180	104	105	126	0	0	0	0	0	1	1	0	0	1
3	181	107	106	85	0	0	0	0	0	1	1	0	0	0
3	200	126	125	104	0	0	0	0	0	1	1	0	0	1
3	201	106	107	128	0	0	0	0	0	1	1	0	0	0
3	220	125	126	147	0	0	0	0	0	1	1	0	0	1
3	221	128	127	106	0	0	0	0	0	1	1	0	0	0
3	240	147	146	125	0	0	0	0	0	1	1	0	0	1
3	241	127	128	149	0	0	0	0	0	1	1	0	0	0
3	260	146	147	168	0	0	0	0	0	1	1	0	0	1
3	261	149	148	127	0	0	0	0	0	1	1	0	0	0
3	280	168	167	146	0	0	0	0	0	1	1	0	0	1
3	281	148	149	170	0	0	0	0	0	1	1	0	0	0
3	300	167	168	189	0	0	0	0	0	1	1	0	0	1
3	301	170	169	148	0	0	0	0	0	1	1	0	0	0
3	320	189	188	167	0	0	0	0	0	1	1	0	0	1
3	321	169	170	191	0	0	0	0	0	1	1	0	0	0
3	340	188	189	210	0	0	0	0	0	1	1	0	0	1
3	341	191	190	169	0	0	0	0	0	1	1	0	0	0
3	360	210	209	188	0	0	0	0	0	1	1	0	0	1
3	361	190	191	212	0	0	0	0	0	1	1	0	0	0
3	380	209	210	231	0	0	0	0	0	1	1	0	0	1
3	381	212	211	190	0	0	0	0	0	1	1	0	0	0
3	400	231	230	209	0	0	0	0	0	1	1	0	0	1
3	401	211	212	233	0	0	0	0	0	1	1	0	0	0
3	420	230	231	252	0	0	0	0	0	1	1	0	0	1
3	421	233	232	211	0	0	0	0	0	1	1	0	0	0
3	440	252	251	230	0	0	0	0	0	1	1	0	0	1
3	441	232	233	254	0	0	0	0	0	1	1	0	0	0
3	460	251	252	273	0	0	0	0	0	1	1	0	0	1
3	461	254	253	232	0	0	0	0	0	1	1	0	0	0
3	480	273	272	251	0	0	0	0	0	1	1	0	0	1
3	481	253	254	275	0	0	0	0	0	1	1	0	0	0
3	500	272	273	294	0	0	0	0	0	1	1	0	0	1
3	501	275	274	253	0	0	0	0	0	1	1	0	0	0
3	520	294	293	272	0	0	0	0	0	1	1	0	0	1
3	521	274	275	296	0	0	0	0	0	1	1	0	0	0
3	540	293	294	315	0	0	0	0	0	1	1	0	0	1
3	541	296	295	274	0	0	0	0	0	1	1	0	0	0
3	560	315	314	293	0	0	0	0	0	1	1	0	0	1
3	561	295	296	317	0	0	0	0	0	1	1	0	0	0
3	580	314	315	336	0	0	0	0	0	1	1	0	0	1
3	581	317	316	295	0	0	0	0	0	1	1	0	0	0
3	600	336	335	314	0	0	0	0	0	1	1	0	0	1
3	601	316	317	338	0	0	0	0	0	1	1	0	0	0
3	620	335	336	357	0	0	0	0	0	1	1	0	0	1
3	621	338	337	316	0	0	0	0	0	1	1	0	0	0
3	640	357	356	335	0	0	0	0	0	1	1	0	0	1
3	641	337	338	359	0	0	0	0	0	1	1	0	0	0
3	660	356	357	378	0	0	0	0	0	1	1	0	0	1
3	661	359	358	337	0	0	0	0	0	1	1	0	0	0
3	680	378	377	356	0	0	0	0	0	1	1	0	0	1
3	681	358	359	380	0	0	0	0	0	1	1	0	0	0

3	700	377	378	399	0	0	0	0	0	1	1	0	0	0	1
3	701	380	379	358	0	0	0	0	0	1	1	0	0	0	0
3	720	399	398	377	0	0	0	0	0	1	1	0	0	0	1
3	721	379	380	401	0	0	0	0	0	1	1	0	0	0	0
3	740	398	399	420	0	0	0	0	0	1	1	0	0	0	1
3	741	401	400	379	0	0	0	0	0	1	1	0	0	0	0
3	760	420	419	398	0	0	0	0	0	1	1	0	0	0	1
3	761	400	401	422	0	0	0	0	0	1	1	0	0	0	0
3	780	419	420	441	0	0	0	0	0	1	1	0	0	0	1
3	781	422	421	400	0	0	0	0	0	1	1	0	0	0	0
3	800	441	440	419	0	0	0	0	0	1	1	0	0	0	1
3	801	421	422	443	0	0	0	0	0	1	1	0	0	0	0
3	820	440	441	462	0	0	0	0	0	1	1	0	0	0	1
3	821	443	442	421	0	0	0	0	0	1	1	0	0	0	0
3	840	462	461	440	0	0	0	0	0	1	1	0	0	0	1
3	841	442	443	464	0	0	0	0	0	1	1	0	0	0	0
3	860	461	462	483	0	0	0	0	0	1	1	0	0	0	1
3	861	464	463	442	0	0	0	0	0	1	1	0	0	0	0
3	880	483	482	461	0	0	0	0	0	1	1	0	0	0	1
3	881	463	464	485	0	0	0	0	0	1	1	0	0	0	0
3	900	482	483	504	0	0	0	0	0	1	1	0	0	0	1
3	901	485	484	463	0	0	0	0	0	1	1	0	0	0	0
3	920	504	503	482	0	0	0	0	0	1	1	0	0	0	1
3	921	484	485	506	0	0	0	0	0	1	1	0	0	0	0
3	940	503	504	525	0	0	0	0	0	1	1	0	0	0	1
3	941	506	505	484	0	0	0	0	0	1	1	0	0	0	0
3	960	525	524	503	0	0	0	0	0	1	1	0	0	0	1
3	961	505	506	527	0	0	0	0	0	1	1	0	0	0	0
3	980	524	525	546	0	0	0	0	0	1	1	0	0	0	1
3	981	527	526	505	0	0	0	0	0	1	1	0	0	0	0
3	1000	546	545	524	0	0	0	0	0	1	1	0	0	0	1
3	1001	526	527	548	0	0	0	0	0	1	1	0	0	0	0
3	1020	545	546	567	0	0	0	0	0	1	1	0	0	0	1
3	1021	548	547	526	0	0	0	0	0	1	1	0	0	0	0
3	1040	567	566	545	0	0	0	0	0	1	1	0	0	0	1
3	1041	547	548	569	0	0	0	0	0	1	1	0	0	0	0
3	1060	566	567	588	0	0	0	0	0	1	1	0	0	0	1
3	1061	569	568	547	0	0	0	0	0	1	1	0	0	0	0
3	1080	588	587	566	0	0	0	0	0	1	1	0	0	0	1
3	1081	568	569	590	0	0	0	0	0	1	1	0	0	0	0
3	1100	587	588	609	0	0	0	0	0	1	1	0	0	0	1
3	1101	590	589	568	0	0	0	0	0	1	1	0	0	0	0
3	1120	609	608	587	0	0	0	0	0	1	1	0	0	0	1
3	1121	589	590	611	0	0	0	0	0	1	1	0	0	0	0
3	1140	608	609	630	0	0	0	0	0	1	1	0	0	0	1
3	1141	611	610	589	0	0	0	0	0	1	1	0	0	0	0
3	1160	630	629	608	0	0	0	0	0	1	1	0	0	0	1
3	1161	610	611	632	0	0	0	0	0	1	1	0	0	0	0
3	1180	629	630	651	0	0	0	0	0	1	1	0	0	0	1
3	1181	632	631	610	0	0	0	0	0	1	1	0	0	0	0
3	1200	651	650	629	0	0	0	0	0	1	1	0	0	0	1
3	1201	631	632	653	0	0	0	0	0	1	1	0	0	0	0
3	1220	650	651	672	0	0	0	0	0	1	1	0	0	0	1
3	1221	653	652	631	0	0	0	0	0	1	1	0	0	0	0
3	1240	672	671	650	0	0	0	0	0	1	1	0	0	0	1
3	1241	652	653	674	0	0	0	0	0	1	1	0	0	0	0
3	1260	671	672	693	0	0	0	0	0	1	1	0	0	0	1
3	1261	674	673	652	0	0	0	0	0	1	1	0	0	0	0
3	1280	693	692	671	0	0	0	0	0	1	1	0	0	0	1
3	1281	673	674	695	0	0	0	0	0	1	1	0	0	0	0
3	1300	692	693	714	0	0	0	0	0	1	1	0	0	0	1
3	1301	695	694	673	0	0	0	0	0	1	1	0	0	0	0
3	1320	714	713	692	0	0	0	0	0	1	1	0	0	0	1
3	1321	694	695	716	0	0	0	0	0	1	1	0	0	0	0
3	1340	713	714	735	0	0	0	0	0	1	1	0	0	0	1
3	1341	716	715	694	0	0	0	0	0	1	1	0	0	0	0
3	1360	735	734	713	0	0	0	0	0	1	1	0	0	0	1
3	1361	715	716	737	0	0	0	0	0	1	1	0	0	0	0
3	1380	734	735	756	0	0	0	0	0	1	1	0	0	0	1
3	1381	737	736	715	0	0	0	0	0	1	1	0	0	0	0
3	1400	756	755	734	0	0	0	0	0	1	1	0	0	0	1
3	1401	736	737	758	0	0	0	0	0	1	1	0	0	0	0
3	1420	755	756	777	0	0	0	0	0	1	1	0	0	0	1
3	1421	758	757	736	0	0	0	0	0	1	1	0	0	0	0
3	1440	777	776	755	0	0	0	0	0	1	1	0	0	0	1
3	1441	757	758	779	0	0	0	0	0	1	1	0	0	0	0
3	1460	776	777	798	0	0	0	0	0	1	1	0	0	0	1
3	1461	779	778	757	0	0	0	0	0	1	1	0	0	0	0
3	1480	798	797	776	0	0	0	0	0	1	1	0	0	0	1
3	1481	778	779	800	0	0	0	0	0	1	1	0	0	0	0
3	1500	797	798	819	0	0	0	0	0	1	1	0	0	0	1
3	1501	800	799	778	0	0	0	0	0	1	1	0	0	0	0
3	1520	819	818	797	0	0	0	0	0	1	1	0	0	0	1

```

3 1521 799 800 821 0 0 0 0 0 1 1 0 0 0
3 1540 818 819 840 0 0 0 0 0 1 1 0 0 0
3 1541 821 820 799 0 0 0 0 0 1 1 0 0 0
3 1560 840 839 818 0 0 0 0 0 1 1 0 0 0
3 1561 820 821 842 0 0 0 0 0 1 1 0 0 0
3 1580 839 840 861 0 0 0 0 0 1 1 0 0 0
3 1581 842 841 820 0 0 0 0 0 1 1 0 0 0
3 1600 861 860 839 0 0 0 0 0 1 1 0 0 0
1 1601 6 90 11 0 0 0 0 0 1 1
1 1610 762 846 11 0 0 0 0 0 1 1
$ line element properties
1 6.4516e-46.93719e-83.46859e-83.46859e-8
$ element thickness
1 0.0127
$ material properties
1 1
6.8947e+10 0.3 0.0 2764.925

```

Data for the generalized mass file, genmass.dat, are given below.

STARS-AEROS-GENMASS input data:

```

$ Genmass input panel for flat plate
1 0 1.0
$ Laterally moving nodes

```

Data for the damping file, damp.dat, are given below.

STARS-CFDASE input data:

```

$ nr
8
$ scaling factor from solids.out.1
.349360438E+02
$ COMPLETE GENERALIZED STIFFNESS MATRIX
.806021E+04 .418052E-06 .379135E-06 -.425624E-08 .223142E-06 -.399296E-07
.233825E-06 .477367E-07
.493117E-06 .130742E+05 .988797E-07 -.314734E-07 .118463E-06 -.775960E-07
.147543E-07 .237048E-07
.249164E-06 .121627E-06 .351742E+05 .728556E-08 .348321E-07 .854473E-08
.407196E-07 -.500201E-07
-.244357E-07 -.522126E-07 .116631E-07 .817425E+05 .209431E-08 .137403E-07
-.120515E-07 .646512E-07
.198223E-06 .140394E-06 .128440E-07 -.480750E-08 .827184E+05 .289550E-07
.408151E-08 .225324E-07
-.581061E-07 -.710594E-07 .403392E-08 .192696E-07 .319938E-07 .650692E+05
-.168824E-07 .246665E-07
.256499E-06 .104723E-07 .438142E-07 -.134610E-07 .319909E-09 -.239153E-07
.135508E+06 -.197322E-07
.509064E-07 .317361E-07 -.482843E-07 .693115E-07 .199359E-07 .240971E-07
-.308757E-07 .175971E+06
$ COMPLETE GENERALIZED MASS MATRIX
.643225E+03 -.938282E-12 -.141859E-11 .849467E-12 -.775268E-12 .256675E-12
.276248E-12 -.186761E-12
-.821309E-12 .867958E+02 -.105381E-12 -.268356E-11 .187751E-11 -.657684E-11
.141576E-10 .786985E-11
-.161489E-11 -.943559E-13 .105094E+03 .164435E-12 .378709E-13 .881064E-13
.188706E-12 -.277491E-13
.850017E-12 -.265596E-11 .121782E-12 .527647E+02 .176344E-13 -.419275E-12
-.252774E-12 .433612E-12
-.769083E-12 .187845E-11 -.562751E-13 .433663E-13 .320364E+02 .249026E-12
-.113669E-12 -.310070E-12
.261829E-12 -.657559E-11 .824586E-13 -.438865E-12 .246023E-12 .116968E+02
.149394E-11 .225871E-11
.277767E-12 .141633E-10 .179429E-12 -.241234E-12 -.108202E-12 .149770E-11
.235345E+02 -.124289E-11
-.183677E-12 .787373E-11 -.364222E-13 .431543E-12 -.301428E-12 .226022E-11
-.123894E-11 .180567E+02
$ frequency
2.747612098619857
11.39123359704445
17.10682426130278
36.97839054058097
47.76388409022645
70.13817875845710
71.35699307350842
92.84741756506145

```

Data for the aeroelastic scalars file, wing.scalars, are given below.

STARS-CFDASE input data:

```
$ aeroelastic scalars data file, supercritical, fp=0.95xsl
$ nr, ibc ( 0=full modes, 1=q(1) = 0.01, 2=q(nr+1)=0.01 )
  2, 0, 0.001
  6, 1, 2, 3, 4, 5, 6
$ iread, lprint
  2, 1
$ dimensional parameters; mach=inf, rho=inf(kg/m**3), a=inf(m/sec), gamma, pinf
                                0.5 1.16375 340.29 1.4 0
$ shift factor and gravity constant
  .349360438E+02, 1.0
$ flag, ffi, ns, ne
  2, 10., 3, 5
$ cfa, cfi
  1, 1
$ nterms, nsteps
  20, 2
```

Data for the unsteady CFD solution control file, wing.conu, are given below.

STARS-CFDASE input data:

```
&control
  nstep = 230,
  nout = 50,
  nstage = 3,
  cfl = 1.0,
  mach = .5,
  alpha = 0.0,
  beta = 0.0,
  restart = 1,
  ncycl = 40,
  ncycl = 40,
  tlr = 0.01,
  debug = .false.,
  aeshc = 1,
  aeshf = 1,
  cbt(1) = 1.,
  cbt(2) = 0.5,
  cbt(3) = 0.,
  cbt(4) = 0.,
  nsath = 2,
  smofc = 0.2,
  low = .false.,
  trans = .true.,
  freq = 0.0125,
  nstep = 500,
  x0 = 0.0,
  y0 = 0.0,
  z0 = 0.0,
  wux = 0.0,
  wuy = 0.0,
  wuz = 1.0,
  phase = 0.0,
  amplitude = .1,
/
```

Data for the alternate steady CFD solution control file, wing.consdp, are given below.

STARS-CFDASE input data:

```
4 (lines of title)
$ VERSION USING FILES FROM SURFACE, VOLUME, AND 'CFDASERUN' ROUTINE, JUNE 1990
$ cantilever wing
$ mach=0.5 alpha=0
$
$ PROBLEM DIMENSION
  3
$ NELEN, NPOIN, NBDUN
  297700, 54759, 12594
$ KACCEL, NACCEL
  100, 25000
$ GAMMA, C1, IDIFF, EPS, IUSC, WBR
  1.4, 1.0, 2, 0.1, 0, 0.2
$ NFFBC
  1
$ ROINF, UXINF, UYINF, UZINF, PINF, MACHINF
  1.0, 1.0, 0.0, 0.0, 2.8571428, 0.5
```

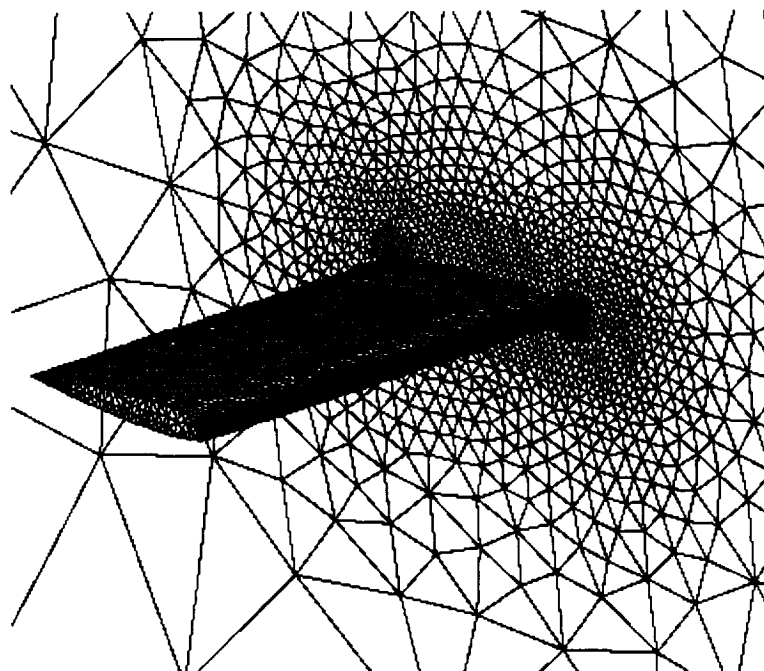
```

$ MEMBC
0
$ NTIME, NITER, ILOT
2000, 1, 1
$ CSAFE, IFCT, NQUAN, IDO(1), IDO(2), CLIMAX
0.7, 0, 2, 3, 1, 0.90
$ INFOG, INFOU, DUFO, NIOUT
-1, -2, 3, 500
$ CSMOD, NSMOD
-2, 0
$ ENTHALPY DAMPING COEFFICIENT
1.0
$ IRPR, IRLOG, ILPR, ILLOG, AX(1), AX(2), AX(3), RCHORD
1, 1, 1, 1, 1.0, 0.0, 0.0, 2.5
$ IRFR, IRFS
3, 5500
$ ISTRON, ICHECK
2, 1
$ TIMEIN, ITIM
0.0, 0
$ FILE3, FILE2, FILE4 ( Output file name - geo file name - input file name )
fort.15_dp
manual.geodp
IN
$ MCPU
1

```

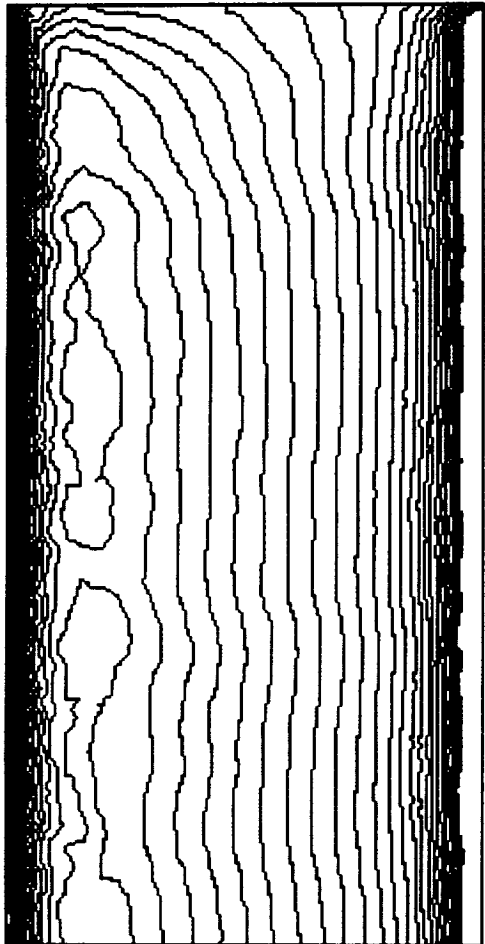
10.1.2 Analysis Results

Figure 68 shows the aerodynamic surface grid on the wing and the solution domain. Figure 69 shows the Mach and pressure distribution on the wing for the steady-state solution. Figure 70 shows the first few structural modes. For stability analysis, the damping values are calculated from the generalized displacements, and figure 71 shows some typical plots in this connection. Figure 72 shows analysis results from when the flutter parameter (density ratio) is calculated to be 0.934, pertaining to a zero damping value.



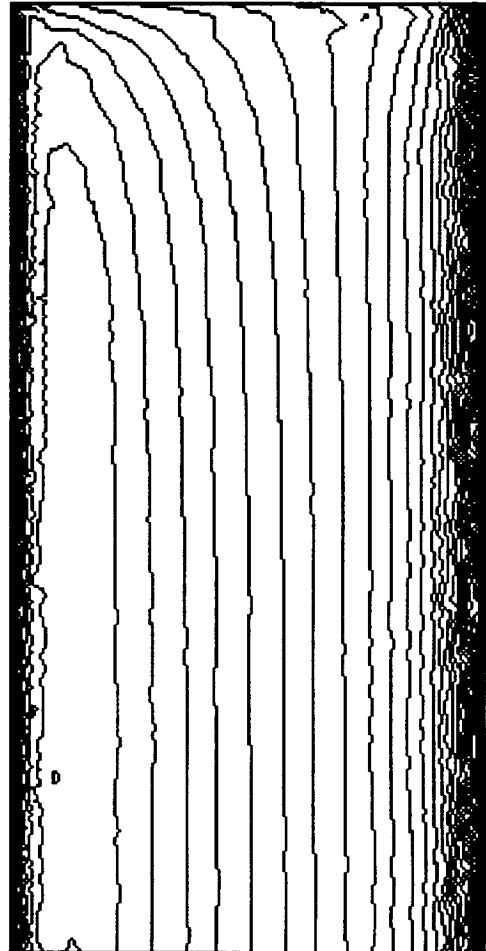
970360

Figure 68. Aerodynamic surface grid of wing and solution domain.



970361

(a) Mach distribution.



970362

(b) Pressure distribution.

Figure 69. Cantilever wing steady-state Mach and pressure distributions.



Mode 1, first bending
2.748 Hz



Mode 2, first torsion
11.39 Hz



Mode 3, second bending
17.11 Hz



Mode 4, second torsion
36.98 Hz



Mode 5, third bending
70.14 Hz



Mode 6, third torsion
71.36 Hz

970363

Figure 70. Structural modes of cantilever wing.

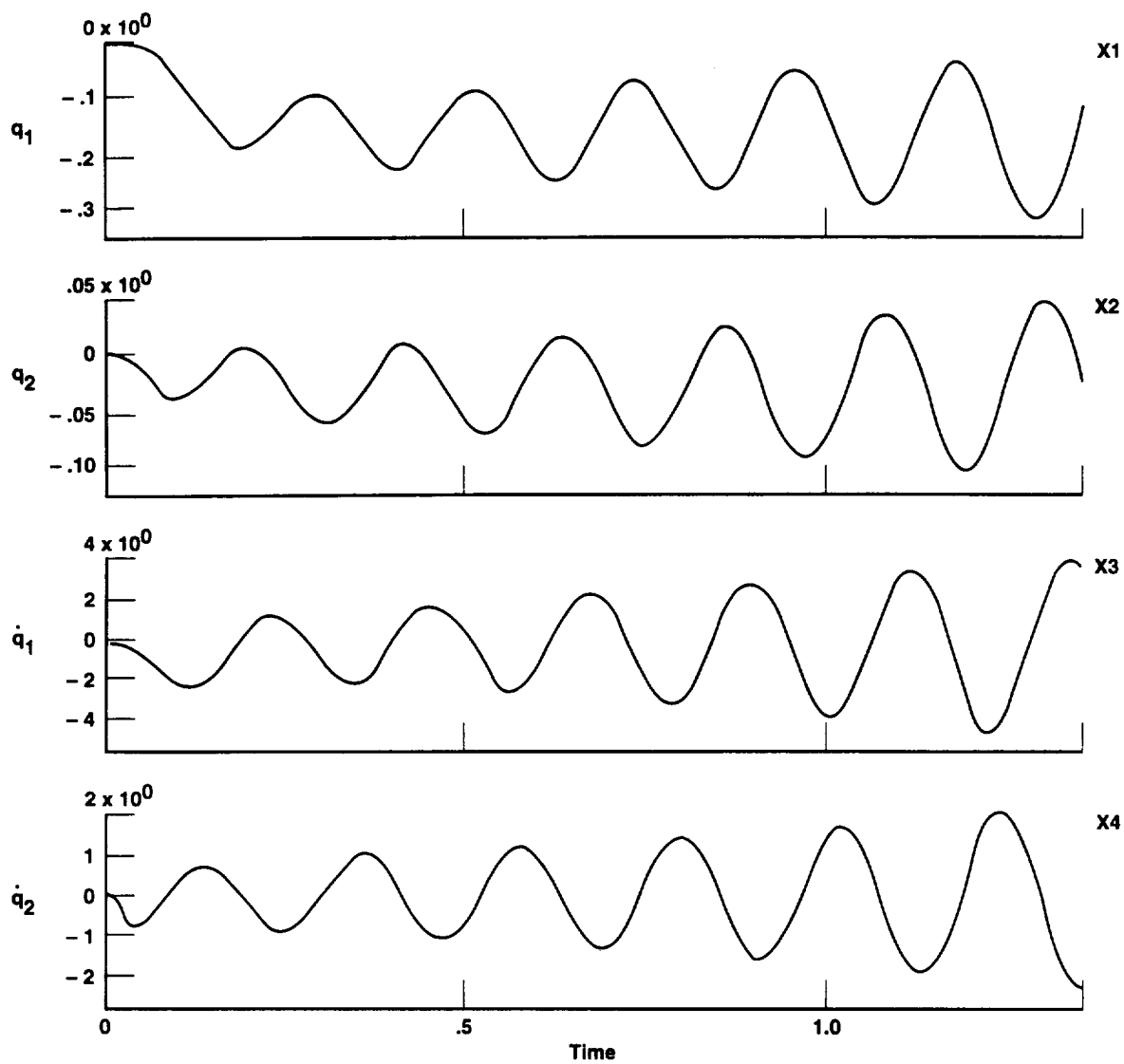


Figure 71. Typical wing generalized displacement plots for flutter parameter $(f_p) = 0.95$.

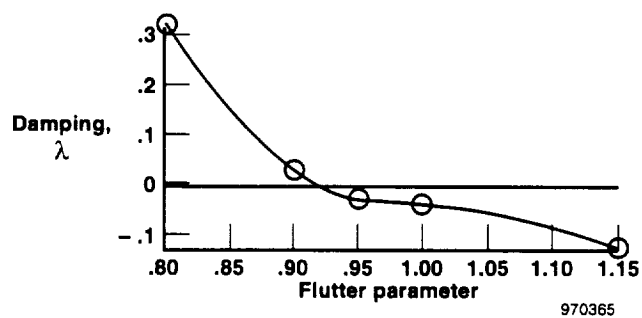


Figure 72. Aeroelastic stability plot for cantilever wing.

11. COUPLED HEAT TRANSFER AND STRUCTURAL ANALYSIS

In this section, the input data and relevant outputs of several typical test cases involving heat-transfer analysis results, interpolating to structural model as thermal loading, are provided in detail. The input data are prepared in accordance with the procedures described in section 3 and are defined in consistent unit form.

11.1 Clamped-Clamped Beam: Thermal Loading

A beam with both ends fixed (fig. 73) has been subjected to varying temperatures. Results of vibration, static, and buckling analysis with thermal loading, derived from heat-transfer analysis, are presented as follows:

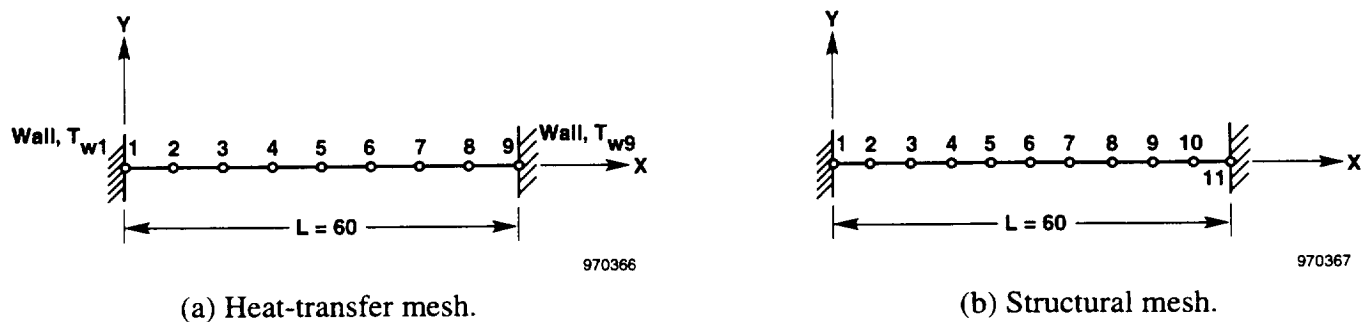


Figure 73. Finite-element model of a beam.

Important data parameters:

Heat-transfer analysis:

Coefficient of conductivity, k	$= 132.0$
Length, L	$= 60$
Area, A	$= 0.001365$
Perimeter, P	$= 0.13091$
Wall temperature, T_{w1}	$= 10.0$
T_{w9}	$= 0.0$

Structural analysis:

Young's modulus, E	$= 30 \times 10^6$
Cross-sectional area, A	$= 1.0$
Moment of inertia:	
About the y axis	$= 1/12$
About the z axis	$= 1/24$
Length, L	$= 60$
Mass density, ρ	$= 0.1666$
Coefficients of thermal expansion, α	$= 6.6 \times 10^{-6}$

STARS-SOLIDS thermal input data for heat-transfer analysis:

```

HEAT TRANSFER - LINE
10,8,1,11,1,0,0,0,0
0,0,0,1,2,0,0,0,0
10,0,0,1,0,0,0,0
2,0,1,0,0,0,0,1,0,0
$ MODAL DATA
1 0.0 0.0 0.0 0 1 1 1 1 1
2 7.500 0.0 0.0 0 1 1 1 1 1
3 15.000 0.0 0.0 0 1 1 1 1 1
4 22.500 0.0 0.0 0 1 1 1 1 1
5 30.000 0.0 0.0 0 1 1 1 1 1
6 37.500 0.0 0.0 0 1 1 1 1 1
7 45.000 0.0 0.0 0 1 1 1 1 1
8 52.500 0.0 0.0 0 1 1 1 1 1
9 60.000 0.0 0.0 0 1 1 1 1 1
10 0.0 100.0 0.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
1 1 1 2 10 0 0 0 0 0 1 1 1
1 2 2 3 10 0 0 0 0 0 1 1 1
1 3 3 4 10 0 0 0 0 0 1 1 1
1 4 4 5 10 0 0 0 0 0 1 1 1
1 5 5 6 10 0 0 0 0 0 1 1 1
1 6 6 7 10 0 0 0 0 0 1 1 1
1 7 7 8 10 0 0 0 0 0 1 1 1
1 8 8 9 10 0 0 0 0 0 1 1 1
$ LINE ELEMENT BASIC PROPERTIES
1 0.001365 0.13091
$ ELEMENT MATERIAL PROPERTIES
1 6
13.2ED1 0.0 0 0.0 00.0 0.0 0.0
0.0 0.0 0 0.0
$ DISPLACEMENT/TEMPERATURE BOUNDARY CONDITION DATA
1 1 1 1 10.
9 1 9 1 0.

```

STARS-SOLIDS coupled heat-transfer/structures input data:

```

BEAM WITH BOTH ENDS FIXED - 10 ELEMENT IDEALIZATION
12, 10, 1, 4, 1, 0, 0, 0, 0, 0
-1, 0, 0, 0, 0, 0, 0, 0, 0, 0
1, 1, 0, 0, 0, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 1
1, 6, 0, 500.0, 0.0, 0.0
$ MODAL DATA
1 0.0 0.0 0.0 1 1 1 1 1 1
2 6.0 0.0 0.0 0 0 0 0 0 0
3 12.0 0.0 0.0 0 0 0 0 0 0
4 18.0 0.0 0.0 0 0 0 0 0 0
5 24.0 0.0 0.0 0 0 0 0 0 0
6 30.0 0.0 0.0 0 0 0 0 0 0
7 36.0 0.0 0.0 0 0 0 0 0 0
8 42.0 0.0 0.0 0 0 0 0 0 0
9 48.0 0.0 0.0 0 0 0 0 0 0
10 54.0 0.0 0.0 0 0 0 0 0 0
11 60.0 0.0 0.0 1 1 1 1 1 1
12 25.0 15.0 0.0 1 1 1 1 1 1
$ ELEMENT CONNECTIVITY
1 1 1 2 12 0 0 0 0 0 1 1 0 0 1 0
1 10 10 11 12 0 0 0 0 0 1 1 0 0 1 1
$ LINE ELEMENT BASIC PROPERTIES
1 1.0 0.125000.083333330.04166667
$ ELEMENT MATERIAL PROPERTIES
1 1
30.0E+06 0.30 6.6E-6 0.166666

```

STARS-SOLIDS output summary: tables 35(a), (b) and (c) show the output summary of vibration, static, and buckling analysis, respectively.

Table 35(a). Thermally prestressed vibration analysis results.

Mode	Natural frequencies (ω), rad/sec		
	Without temperature	With temperature input from heat-transfer mesh	With temperature input from data file
1	17.019	16.416	16.416
2	24.067	23.645	23.645
3	46.916	46.105	46.105
4	66.331	65.761	65.761
5	92.013	91.128	91.128
6	130.051	129.428	129.428

Table 35(b). Nodal deformation for static analysis.

Node	X displacement
1	0.0
2	0.1733E-03
3	0.2970E-03
4	0.3960E-03
5	0.4703E-03
6	0.49590E-03
7	0.4703E-03
8	0.3960E-03
9	0.2970E-03
10	0.1733E-03
11	0.0

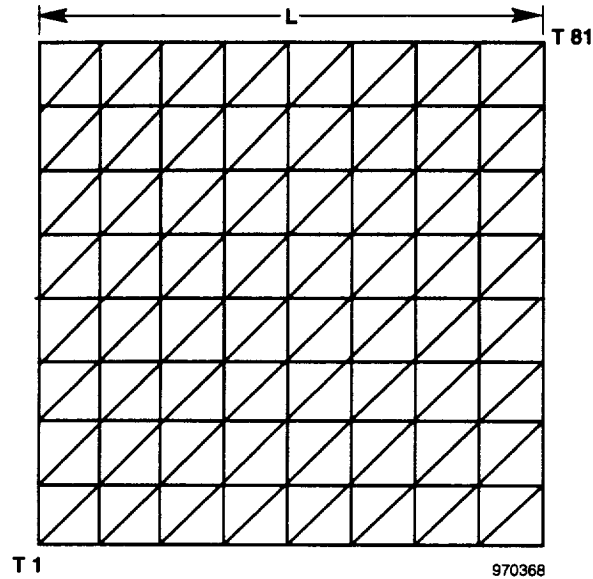
Table 35(c). Buckling load factor for buckling analysis.

Mode	Buckling load parameter
1	13.849

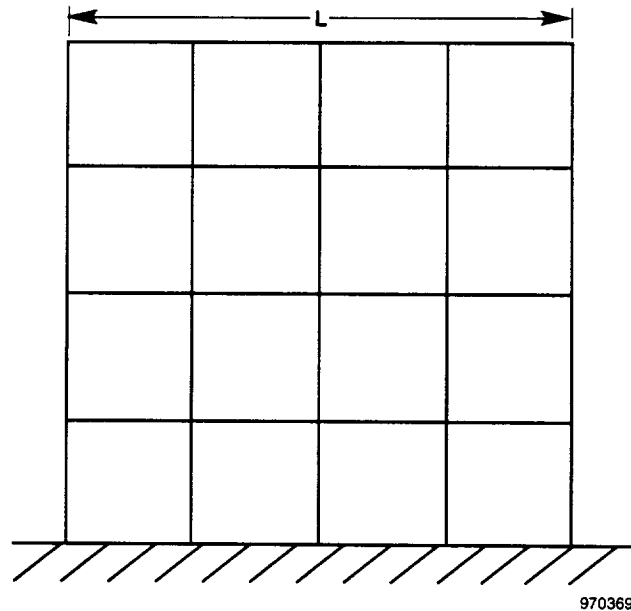
Results shown in tables 35(b) and 35(c) have also been verified by direct temperature data input.

11.2 Cantilever Plate: Thermal Loading

A cantilever plate model, described in section 4.1.4, has been used for vibration and static analysis, and the same plate with two opposite edges fixed has been chosen for buckling analysis. Figure 74 shows a different finite-element mesh for heat-transfer analysis; relevant input data and analysis results are given as follows:



(a) Heat-transfer mesh.



(b) Structural mesh.

Figure 74. Finite-element model of a plate.

Important data parameters:

Heat-transfer analysis:

Coefficient of conductivity, k = 1.0
 Length, L = 10
 Thickness, t = 0.1
 Nodal temperature, T_1 = 10.0
 T_{81} = 0.0

Structural analysis:

Young's modulus, E = 10×10^6
 Thickness, t = 0.1
 Poisson's ratio, μ = 0.3
 Length, L = 10
 Mass density, ρ = 0.259×10^{-3}
 Coefficients of thermal expansion, α = 3.5×10^{-6}

STARS-SOLIDS thermal input data for heat-transfer analysis:

```

PLATE 8X8 MESH - HEAT TRANSFER ANALYSIS
81, 128, 1, 44, 0, 0, 0, 1, 1, 1
0, 0, 0, 1, 4, 0, 0, 0, 0
10, 0, 0, 1, 0, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 0, 0, 0
$ NODAL DATA
1 .0000 .0000 .0000 0 0 1 1 1 1 0 0 0
9 .0000 10.0000 .0000 0 0 1 1 1 1 0 0 1
10 1.2500 0.0000 .0000 0 0 1 1 1 1 0 0 0
18 1.2500 10.0000 .0000 0 0 1 1 1 1 0 0 1
19 2.5000 .0000 .0000 0 0 1 1 1 1 0 0 0
27 2.5000 10.0000 .0000 0 0 1 1 1 1 0 0 1
28 3.7500 0.0000 .0000 0 0 1 1 1 1 0 0 0
36 3.7500 10.0000 .0000 0 0 1 1 1 1 0 0 1
37 5.0000 .0000 .0000 0 0 1 1 1 1 0 0 0
45 5.0000 10.0000 .0000 0 0 1 1 1 1 0 0 1
46 6.2500 .0000 .0000 0 0 1 1 1 1 0 0 0
54 6.2500 10.0000 .0000 0 0 1 1 1 1 0 0 1
55 7.5000 .0000 .0000 0 0 1 1 1 1 0 0 0
63 7.5000 10.0000 .0000 0 0 1 1 1 1 0 0 1
64 8.7500 .0000 .0000 0 0 1 1 1 1 0 0 0
72 8.7500 10.0000 .0000 0 0 1 1 1 1 0 0 1
73 10.0000 .0000 .0000 0 0 1 1 1 1 0 0 0
81 10.0000 10.0000 .0000 0 0 1 1 1 1 0 0 1
$ ELEMENT CONNECTIVITY CONDITIONS
7 1 1 2 11 0 0 1 1 1 1 0 0 0 0 0
7 8 8 9 18 0 0 1 1 1 1 0 0 0 0 1
7 9 11 10 1 0 0 1 1 1 1 0 0 0 0 0
7 16 18 17 8 0 0 1 1 1 1 0 0 0 0 1
7 17 10 11 20 0 0 1 1 1 1 0 0 0 0 0
7 24 17 18 27 0 0 1 1 1 1 0 0 0 0 1
7 25 20 19 10 0 0 1 1 1 1 0 0 0 0 0
7 32 27 26 17 0 0 1 1 1 1 0 0 0 0 1
7 33 19 20 29 0 0 1 1 1 1 0 0 0 0 0
7 40 26 27 36 0 0 1 1 1 1 0 0 0 0 1
7 41 29 28 19 0 0 1 1 1 1 0 0 0 0 0
7 48 36 35 26 0 0 1 1 1 1 0 0 0 0 1
7 49 28 29 38 0 0 1 1 1 1 0 0 0 0 0
7 56 35 36 45 0 0 1 1 1 1 0 0 0 0 1
7 57 38 37 28 0 0 1 1 1 1 0 0 0 0 0
7 64 45 44 35 0 0 1 1 1 1 0 0 0 0 1
    
```

```

7 65 37 38 47 0 0 1 1 1 1 0 0 0 0 0
7 72 44 45 54 0 0 1 1 1 1 0 0 0 0 1
7 73 47 46 37 0 0 1 1 1 1 0 0 0 0 0
7 80 54 53 44 0 0 1 1 1 1 0 0 0 0 1
7 81 46 47 56 0 0 1 1 1 1 0 0 0 0 0
7 88 53 54 63 0 0 1 1 1 1 0 0 0 0 1
7 89 56 55 46 0 0 1 1 1 1 0 0 0 0 0
7 96 63 62 53 0 0 1 1 1 1 0 0 0 0 1
7 97 55 56 65 0 0 1 1 1 1 0 0 0 0 0
7 104 62 63 72 0 0 1 1 1 1 0 0 0 0 1
7 105 65 64 55 0 0 1 1 1 1 0 0 0 0 0
7 112 72 71 62 0 0 1 1 1 1 0 0 0 0 1
7 113 64 65 74 0 0 1 1 1 1 0 0 0 0 0
7 120 71 72 81 0 0 1 1 1 1 0 0 0 0 1
7 121 74 73 64 0 0 1 1 1 1 0 0 0 0 0
7 128 81 80 71 0 0 1 1 1 1 0 0 0 0 1
$ COMPOSITE SHELL ELEMENT STACK DESCRIPTION DATA
1 1 1 1 0 0 0 0
1 .1000E+00 1
$ SPECIFICATION FOR MATERIAL AXIS ORIENTATION
1 2 0
0.0
$ ELEMENT MATERIAL PROPERTIES
1 8
1. 0. 1. 1. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0.
0. 0.
$ TEMPERATURE BOUNDARY CONDITIONS DATA
1 1 1 1 10.
1 2 1 2 10.
81 1 81 1 0.
81 2 81 2 0.

```

STARS–SOLIDS coupled heat-transfer/structures input data:

```

CANTILEVER SQUARE 4 BY 4 PLATE TEMPERATURE LOADING
25, 16, 1, 4, 0, 1, 0, 0, 0, 0
-1, 0, 0, 1, 0, 0, 0, 0, 0
1, 1, 0, 1, 0, 0, 0, 0
2, 0, 2, 0, 1, 0, 0, 1, 0, 0
1, 6, 0, 6000.0, 0.0, 0, 0.0
$ MODAL DATA
1 0.0 0.0 0.0 1 1 1 1 1 1 0 0 0
5 10.0 0.0 0.0 1 1 1 1 1 1 0 0 1
6 0.0 2.5 0.0 0 0 0 0 0 0 0 0 0
10 10.0 2.5 0.0 0 0 0 0 0 0 0 0 1
11 0.0 5.0 0.0 0 0 0 0 0 0 0 0 0
15 10.0 5.0 0.0 0 0 0 0 0 0 0 0 1
16 0.0 7.5 0.0 0 0 0 0 0 0 0 0 0
20 10.0 7.5 0.0 0 0 0 0 0 0 0 0 1
21 0.0 10.0 0.0 0 0 0 0 0 0 0 0 0
25 10.0 10.0 0.0 0 0 0 0 0 0 0 0 1
$ ELEMENT CONNECTIVITY
2 1 1 2 7 6 0 0 0 0 1 1 0 0 0
2 4 4 5 10 9 0 0 0 0 1 1 0 0 0 1
2 5 6 7 12 11 0 0 0 0 1 1 0 0 0
2 8 9 10 15 14 0 0 0 0 1 1 0 0 0 1
2 9 11 12 17 16 0 0 0 0 1 1 0 0 0
2 12 14 15 20 19 0 0 0 0 1 1 0 0 0 1
2 13 16 17 22 21 0 0 0 0 1 1 0 0 0
2 16 19 20 25 24 0 0 0 0 1 1 0 0 0 1
$ SHELL ELEMENT THICKNESSES
1 0.1
$ ELEMENT MATERIAL PROPERTIES
1 1
1.0E+07 0.30 0.35E-5 0.259E-3

```

STARS–SOLIDS output summary: tables 36(a), (b), and (c) show the output summary of vibration, static, and buckling analysis, respectively.

Table 36(a). Thermally prestressed vibration analysis results for a cantilever plate with varying temperature distribution.

Mode	Natural frequencies (ω), rad/sec		
	Without temperature	With temperature input from heat-transfer mesh	With temperature input from data file
1	214.02	213.92	213.92
2	506.62	507.58	507.58
3	1248.40	1249.69	1249.69
4	1538.29	1537.72	1537.72
5	1765.53	1766.13	1766.13
6	2889.11	2888.35	2888.35

Table 36(b). Nodal deformation for static analysis.

Node	X displacement	Y displacement
6	-0.809997E-04	0.631047E-04
7	-0.242790E-04	0.734264E-04
8	0.719179E-05	0.650178E-04
9	0.346446E-04	0.580581E-04
10	0.735603E-04	0.354295E-04
11	-0.771033E-04	0.125418E-03
12	-0.299133E-04	0.120472E-03
13	0.154035E-04	0.113178E-03
14	0.555337E-04	0.993192E-04
15	0.919275E-04	0.842963E-04
16	-0.615285E-04	0.177819E-03
17	-0.163020E-04	0.164476E-03
18	0.276178E-04	0.151509E-03
19	0.669176E-04	0.136094E-03
20	0.959403E-04	0.124534E-03
21	-0.435429E-04	0.222953E-03
22	0.108579E-05	0.206311E-03
23	0.452413E-04	0.188285E-03
24	0.834809E-04	0.164283E-03
25	0.104933E-03	0.146110E-03

Table 36(c). Buckling load parameter for thermal load buckling analysis.

Buckling load parameter	
Mode	
1	19.048

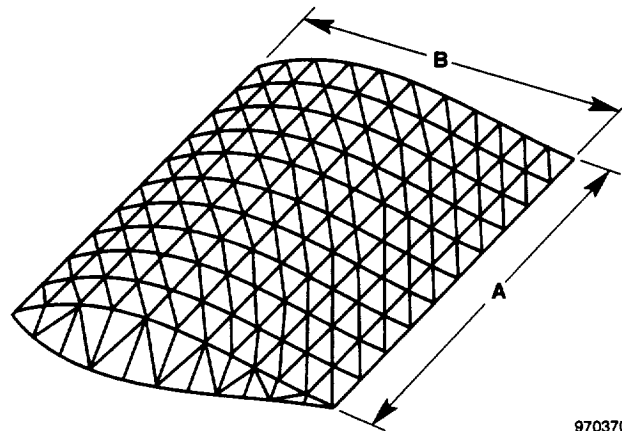
Results shown in tables 36(b) and 36(c) have also been verified by direct temperature data input.

12. COUPLED COMPUTATIONAL FLUID DYNAMICS AND STRUCTURAL LOAD TRANSFER PROBLEMS

In this section, an example problem illustrating the transfer of CFD pressure data on structural mesh is presented. The input data are prepared in accordance with the procedures described in section 3 and are defined in consistent unit form.

12.1 Cantilever Wing: Coupled Computational Fluid Dynamics and Structural Analysis

The cantilever wing described in section 10.1 has been chosen for static and vibration analysis. Figure 75 shows the finite-element mesh for structural analysis. Pressures are converted from CFD steady-state analysis; relevant input data and analysis results are as follow:



970370

Figure 75. Cantilever wing with structural mesh.

Important data parameters:

Young's modulus, E	= 6.8947×10^6
Poisson's ratio, μ	= 0.3
Wing span, A	= 2.0178
Wing chord length, B	= 1.0089
Shell thickness, t	= 0.0254
Mass density, ρ	= 2765.0

STARS-SOLIDS input data

```

CANTILEVER WING PRESSURES VIBRATION - PRESSURE LOADING
462,980,1,6,0,1,0,0,0,0,0
0,-1,0,1,0,0,0,0,0,0,0,4805
1,0,0,0,0,0,0,0,0,0,0
2,0,2,0,1,0,0,1,1,0
1,10,0,600,0,0,0,0,0,0
NODAL DATA
1 0.0000 .0000 .0000 1 1 1 1 1 1 0 0 0
2 .0000 .1000 .0000 0 0 0 0 0 0 0 0 0
21 0.0000 2.0178 .0000 0 0 0 0 0 0 0 0 1

```

22	.0074	0.0000	.0147	1	1	1	1	1	1	0	0	0
23	.0074	.1000	.0147	0	0	0	0	0	0	0	0	0
42	0.0074	2.0178	.0147	0	0	0	0	0	0	0	0	1
43	.0285	0.0000	.0277	1	1	1	1	1	1	0	0	0
44	.0285	.1000	.0277	0	0	0	0	0	0	0	0	0
63	0.0285	2.0178	.0277	0	0	0	0	0	0	0	0	1
64	0.1056	.0000	.0478	1	1	1	1	1	1	0	0	0
65	.1056	.1000	.0478	0	0	0	0	0	0	0	0	0
84	0.1056	2.0178	.0478	0	0	0	0	0	0	0	0	1
85	0.2197	.0000	.0584	1	1	1	1	1	1	0	0	0
86	.2197	.1000	.0584	0	0	0	0	0	0	0	0	0
105	0.2197	2.0178	.0584	0	0	0	0	0	0	0	0	1
106	0.3583	.0000	.0593	1	1	1	1	1	1	0	0	0
107	.3583	.1000	.0593	0	0	0	0	0	0	0	0	0
126	0.3583	2.0178	.0593	0	0	0	0	0	0	0	0	1
127	0.5085	.0000	.0524	1	1	1	1	1	1	0	0	0
128	.5085	.1000	.0524	0	0	0	0	0	0	0	0	0
147	0.5085	2.0178	.0524	0	0	0	0	0	0	0	0	1
148	0.6576	.0000	.0406	1	1	1	1	1	1	0	0	0
149	.6576	.1000	.0406	0	0	0	0	0	0	0	0	0
168	0.6576	2.0178	.0406	0	0	0	0	0	0	0	0	1
169	0.7937	.0000	.0269	1	1	1	1	1	1	0	0	0
170	.7937	.1000	.0269	0	0	0	0	0	0	0	0	0
189	0.7937	2.0178	.0269	0	0	0	0	0	0	0	0	1
190	0.9051	.0000	.0138	1	1	1	1	1	1	0	0	0
191	.9051	.1000	.0138	0	0	0	0	0	0	0	0	0
210	0.9051	2.0178	.0138	0	0	0	0	0	0	0	0	1
211	0.9804	.0000	.0040	1	1	1	1	1	1	0	0	0
212	.9804	.1000	.0040	0	0	0	0	0	0	0	0	0
231	0.9804	2.0178	.0040	0	0	0	0	0	0	0	0	1
232	1.0089	.0000	.0000	1	1	1	1	1	1	0	0	0
233	1.0089	.1000	.0000	0	0	0	0	0	0	0	0	0
252	1.0089	2.0178	.0000	0	0	0	0	0	0	0	0	1
253	.0074	0.0000	-.0147	1	1	1	1	1	1	0	0	0
254	.0074	.1000	-.0147	0	0	0	0	0	0	0	0	0
273	0.0074	2.0178	-.0147	0	0	0	0	0	0	0	0	1
274	.0285	0.0000	-.0277	1	1	1	1	1	1	0	0	0
275	.0285	.1000	-.0277	0	0	0	0	0	0	0	0	0
294	0.0285	2.0178	-.0277	0	0	0	0	0	0	0	0	1
295	0.1056	.0000	-.0478	1	1	1	1	1	1	0	0	0
296	.1056	.1000	-.0478	0	0	0	0	0	0	0	0	0
315	0.1056	2.0178	-.0478	0	0	0	0	0	0	0	0	1
316	0.2197	.0000	-.0584	1	1	1	1	1	1	0	0	0
317	.2197	.1000	-.0584	0	0	0	0	0	0	0	0	0
336	0.2197	2.0178	-.0584	0	0	0	0	0	0	0	0	1
337	0.3583	.0000	-.0593	1	1	1	1	1	1	0	0	0
338	.3583	.1000	-.0593	0	0	0	0	0	0	0	0	0
357	0.3583	2.0178	-.0593	0	0	0	0	0	0	0	0	1
358	0.5085	.0000	-.0524	1	1	1	1	1	1	0	0	0
359	.5085	.1000	-.0524	0	0	0	0	0	0	0	0	0
378	0.5085	2.0178	-.0524	0	0	0	0	0	0	0	0	1
379	0.6576	.0000	-.0406	1	1	1	1	1	1	0	0	0
380	.6576	.1000	-.0406	0	0	0	0	0	0	0	0	0
399	0.6576	2.0178	-.0406	0	0	0	0	0	0	0	0	1
400	0.7937	.0000	-.0269	1	1	1	1	1	1	0	0	0
401	.7937	.1000	-.0269	0	0	0	0	0	0	0	0	0
420	0.7937	2.0178	-.0269	0	0	0	0	0	0	0	0	1
421	0.9051	.0000	-.0138	1	1	1	1	1	1	0	0	0
422	.9051	.1000	-.0138	0	0	0	0	0	0	0	0	0
441	0.9051	2.0178	-.0138	0	0	0	0	0	0	0	0	1
442	0.9804	.0000	-.0040	1	1	1	1	1	1	0	0	0
443	.9804	.1000	-.0040	0	0	0	0	0	0	0	0	0
462	0.9804	2.0178	-.0040	0	0	0	0	0	0	0	0	1
ELEMENT CONNECTIVITY CONDITIONS												
3	1	1	2	23	0	0	0	0	1	1	0	0
3	20	20	21	42	0	0	0	0	1	1	0	0
3	21	23	22	1	0	0	0	0	1	1	0	0
3	40	42	41	20	0	0	0	0	1	1	0	0
3	41	22	23	44	0	0	0	0	1	1	0	0
3	60	41	42	63	0	0	0	0	1	1	0	0
3	61	44	43	22	0	0	0	0	1	1	0	0
3	80	63	62	41	0	0	0	0	1	1	0	0
3	81	43	44	65	0	0	0	0	1	1	0	0
3	100	62	63	84	0	0	0	0	1	1	0	0
3	101	65	64	43	0	0	0	0	1	1	0	0
3	120	84	83	62	0	0	0	0	1	1	0	0
3	121	64	65	86	0	0	0	0	1	1	0	0
3	140	83	84	105	0	0	0	0	1	1	0	0
3	141	86	85	64	0	0	0	0	1	1	0	0
3	160	105	104	83	0	0	0	0	1	1	0	0
3	161	85	86	107	0	0	0	0	1	1	0	0
3	180	104	105	126	0	0	0	0	1	1	0	0
3	181	107	106	85	0	0	0	0	1	1	0	0

3	200	126	125	104	0	0	0	0	0	1	1	0	0	0	1
3	201	106	107	128	0	0	0	0	0	0	1	1	0	0	0
3	220	125	126	147	0	0	0	0	0	0	1	1	0	0	1
3	221	128	127	106	0	0	0	0	0	0	1	1	0	0	0
3	240	147	146	125	0	0	0	0	0	0	1	1	0	0	1
3	241	127	128	149	0	0	0	0	0	0	1	1	0	0	0
3	260	146	147	168	0	0	0	0	0	0	1	1	0	0	1
3	261	149	148	127	0	0	0	0	0	0	1	1	0	0	0
3	280	168	167	146	0	0	0	0	0	0	1	1	0	0	1
3	281	148	149	170	0	0	0	0	0	0	1	1	0	0	0
3	300	167	168	189	0	0	0	0	0	0	1	1	0	0	1
3	301	170	169	148	0	0	0	0	0	0	1	1	0	0	0
3	320	189	188	167	0	0	0	0	0	0	1	1	0	0	1
3	321	169	170	191	0	0	0	0	0	0	1	1	0	0	0
3	340	188	189	210	0	0	0	0	0	0	1	1	0	0	1
3	341	191	190	169	0	0	0	0	0	0	1	1	0	0	0
3	360	210	209	188	0	0	0	0	0	0	1	1	0	0	1
3	361	190	191	212	0	0	0	0	0	0	1	1	0	0	0
3	380	209	210	231	0	0	0	0	0	0	1	1	0	0	1
3	381	212	211	190	0	0	0	0	0	0	1	1	0	0	0
3	400	231	230	209	0	0	0	0	0	0	1	1	0	0	1
3	401	211	212	233	0	0	0	0	0	0	1	1	0	0	0
3	420	230	231	252	0	0	0	0	0	0	1	1	0	0	1
3	421	233	232	211	0	0	0	0	0	0	1	1	0	0	0
3	440	252	251	230	0	0	0	0	0	0	1	1	0	0	1
3	441	2	1	253	0	0	0	0	0	0	1	1	0	0	0
3	460	21	20	272	0	0	0	0	0	0	1	1	0	0	1
3	461	253	254	2	0	0	0	0	0	0	1	1	0	0	0
3	480	272	273	21	0	0	0	0	0	0	1	1	0	0	1
3	481	254	253	274	0	0	0	0	0	0	1	1	0	0	0
3	500	273	272	293	0	0	0	0	0	0	1	1	0	0	1
3	501	274	275	254	0	0	0	0	0	0	1	1	0	0	0
3	520	293	294	273	0	0	0	0	0	0	1	1	0	0	1
3	521	275	274	295	0	0	0	0	0	0	1	1	0	0	0
3	540	294	293	314	0	0	0	0	0	0	1	1	0	0	1
3	541	295	296	275	0	0	0	0	0	0	1	1	0	0	0
3	560	314	315	294	0	0	0	0	0	0	1	1	0	0	1
3	561	296	295	316	0	0	0	0	0	0	1	1	0	0	0
3	580	315	314	335	0	0	0	0	0	0	1	1	0	0	1
3	581	316	317	296	0	0	0	0	0	0	1	1	0	0	0
3	600	335	336	315	0	0	0	0	0	0	1	1	0	0	1
3	601	317	316	337	0	0	0	0	0	0	1	1	0	0	0
3	620	336	335	356	0	0	0	0	0	0	1	1	0	0	1
3	621	337	338	317	0	0	0	0	0	0	1	1	0	0	0
3	640	356	357	336	0	0	0	0	0	0	1	1	0	0	1
3	641	338	337	358	0	0	0	0	0	0	1	1	0	0	0
3	660	357	356	377	0	0	0	0	0	0	1	1	0	0	1
3	661	358	359	338	0	0	0	0	0	0	1	1	0	0	0
3	680	377	378	357	0	0	0	0	0	0	1	1	0	0	1
3	681	359	358	379	0	0	0	0	0	0	1	1	0	0	0
3	700	378	377	398	0	0	0	0	0	0	1	1	0	0	1
3	701	379	380	359	0	0	0	0	0	0	1	1	0	0	0
3	720	398	399	378	0	0	0	0	0	0	1	1	0	0	1
3	721	380	379	400	0	0	0	0	0	0	1	1	0	0	0
3	740	399	398	419	0	0	0	0	0	0	1	1	0	0	1
3	741	400	401	380	0	0	0	0	0	0	1	1	0	0	0
3	760	419	420	399	0	0	0	0	0	0	1	1	0	0	1
3	761	401	400	421	0	0	0	0	0	0	1	1	0	0	0
3	780	420	419	440	0	0	0	0	0	0	1	1	0	0	1
3	781	421	422	401	0	0	0	0	0	0	1	1	0	0	0
3	800	440	441	420	0	0	0	0	0	0	1	1	0	0	1
3	801	422	421	442	0	0	0	0	0	0	1	1	0	0	0
3	820	441	440	461	0	0	0	0	0	0	1	1	0	0	1
3	821	442	443	422	0	0	0	0	0	0	1	1	0	0	0
3	840	461	462	441	0	0	0	0	0	0	1	1	0	0	1
3	841	443	442	232	0	0	0	0	0	0	1	1	0	0	0
3	860	462	461	251	0	0	0	0	0	0	1	1	0	0	1
3	861	232	233	443	0	0	0	0	0	0	1	1	0	0	0
3	880	251	252	462	0	0	0	0	0	0	1	1	0	0	1
3	881	21	42	273	0	0	0	0	0	0	1	1	0	0	0
3	882	42	63	273	0	0	0	0	0	0	1	1	0	0	1
3	883	294	273	63	0	0	0	0	0	0	1	1	0	0	0
3	884	63	84	315	0	0	0	0	0	0	1	1	0	0	1
3	885	315	294	63	0	0	0	0	0	0	1	1	0	0	0
3	886	84	105	315	0	0	0	0	0	0	1	1	0	0	1
3	887	336	315	105	0	0	0	0	0	0	1	1	0	0	0
3	888	105	126	357	0	0	0	0	0	0	1	1	0	0	1
3	889	357	336	105	0	0	0	0	0	0	1	1	0	0	0
3	890	126	147	357	0	0	0	0	0	0	1	1	0	0	1
3	891	378	357	147	0	0	0	0	0	0	1	1	0	0	0
3	892	147	168	399	0	0	0	0	0	0	1	1	0	0	1
3	893	399	378	147	0	0	0	0	0	0	1	1	0	0	0
3	894	168	189	399	0	0	0	0	0	0	1	1	0	0	1

3	895	420	399	189	0	0	0	0	0	1	1
3	896	189	210	441	0	0	0	0	0	0	1
3	897	441	420	189	0	0	0	0	0	0	1
3	898	210	231	441	0	0	0	0	0	0	1
3	899	462	441	231	0	0	0	0	0	0	1
3	900	231	252	462	0	0	0	0	0	0	1
3	901	17	38	269	0	0	0	0	0	0	1
3	902	38	59	269	0	0	0	0	0	0	1
3	903	290	269	59	0	0	0	0	0	0	1
3	904	59	80	311	0	0	0	0	0	0	1
3	905	311	290	59	0	0	0	0	0	0	1
3	906	80	101	311	0	0	0	0	0	0	1
3	907	332	311	101	0	0	0	0	0	0	1
3	908	101	122	353	0	0	0	0	0	0	1
3	909	353	332	101	0	0	0	0	0	0	1
3	910	122	143	353	0	0	0	0	0	0	1
3	911	374	353	143	0	0	0	0	0	0	1
3	912	143	164	395	0	0	0	0	0	0	1
3	913	395	374	143	0	0	0	0	0	0	1
3	914	164	185	395	0	0	0	0	0	0	1
3	915	416	395	185	0	0	0	0	0	0	1
3	916	185	206	437	0	0	0	0	0	0	1
3	917	437	416	185	0	0	0	0	0	0	1
3	918	206	227	437	0	0	0	0	0	0	1
3	919	458	437	227	0	0	0	0	0	0	1
3	920	227	248	458	0	0	0	0	0	0	1
3	921	13	34	265	0	0	0	0	0	0	1
3	922	34	55	265	0	0	0	0	0	0	1
3	923	286	265	55	0	0	0	0	0	0	1
3	924	55	76	307	0	0	0	0	0	0	1
3	925	307	286	55	0	0	0	0	0	0	1
3	926	76	97	307	0	0	0	0	0	0	1
3	927	328	307	97	0	0	0	0	0	0	1
3	928	97	118	349	0	0	0	0	0	0	1
3	929	349	328	97	0	0	0	0	0	0	1
3	930	118	139	349	0	0	0	0	0	0	1
3	931	370	349	139	0	0	0	0	0	0	1
3	932	139	160	391	0	0	0	0	0	0	1
3	933	391	370	139	0	0	0	0	0	0	1
3	934	160	181	391	0	0	0	0	0	0	1
3	935	412	391	181	0	0	0	0	0	0	1
3	936	181	202	433	0	0	0	0	0	0	1
3	937	433	412	181	0	0	0	0	0	0	1
3	938	202	223	433	0	0	0	0	0	0	1
3	939	454	433	223	0	0	0	0	0	0	1
3	940	223	244	454	0	0	0	0	0	0	1
3	941	9	30	261	0	0	0	0	0	0	1
3	942	30	51	261	0	0	0	0	0	0	1
3	943	282	261	51	0	0	0	0	0	0	1
3	944	51	72	303	0	0	0	0	0	0	1
3	945	303	282	51	0	0	0	0	0	0	1
3	946	72	93	303	0	0	0	0	0	0	1
3	947	324	303	93	0	0	0	0	0	0	1
3	948	93	114	345	0	0	0	0	0	0	1
3	949	345	324	93	0	0	0	0	0	0	1
3	950	114	135	345	0	0	0	0	0	0	1
3	951	366	345	135	0	0	0	0	0	0	1
3	952	135	156	387	0	0	0	0	0	0	1
3	953	387	366	135	0	0	0	0	0	0	1
3	954	156	177	387	0	0	0	0	0	0	1
3	955	408	387	177	0	0	0	0	0	0	1
3	956	177	198	429	0	0	0	0	0	0	1
3	957	429	408	177	0	0	0	0	0	0	1
3	958	198	219	429	0	0	0	0	0	0	1
3	959	450	429	219	0	0	0	0	0	0	1
3	960	219	240	450	0	0	0	0	0	0	1
3	961	5	26	257	0	0	0	0	0	0	1
3	962	26	47	257	0	0	0	0	0	0	1
3	963	278	257	47	0	0	0	0	0	0	1
3	964	47	68	299	0	0	0	0	0	0	1
3	965	299	278	47	0	0	0	0	0	0	1
3	966	68	89	299	0	0	0	0	0	0	1
3	967	320	299	89	0	0	0	0	0	0	1
3	968	89	110	341	0	0	0	0	0	0	1
3	969	341	320	89	0	0	0	0	0	0	1
3	970	110	131	341	0	0	0	0	0	0	1
3	971	362	341	131	0	0	0	0	0	0	1
3	972	131	152	383	0	0	0	0	0	0	1
3	973	383	362	131	0	0	0	0	0	0	1
3	974	152	173	383	0	0	0	0	0	0	1
3	975	404	383	173	0	0	0	0	0	0	1
3	976	173	194	425	0	0	0	0	0	0	1
3	977	425	404	173	0	0	0	0	0	0	1

```

3  978  194  215  425  0  0  0  0  0  1  1
3  979  446  425  215  0  0  0  0  0  1  1
3  980  215  236  446  0  0  0  0  0  1  1
$ SHELL ELEMENT THICKNESSES
1  .2540E-01  .2540E-01  .2540E-01
$ MATERIAL PROPERTIES
1  1
.6895E+11  .3000E+00  .0000E+00  .2765E+04  .0000E+00  .0000E+00

```

STARS-SOLIDS output summary: tables 37(a) and (b) show the results of static and vibration analysis, respectively.

Table 37(a). Maximum deflection in the Z direction for static analysis (free-edge deformation).

Node	Z displacement (10E-04)	Node	Z displacement (10E-04)
252	-0.392772	230	-0.372728
231	-0.391481	251	-0.372621
462	-0.391467	209	-0.371897
210	-0.387958	377	-0.371267
441	-0.387896	461	-0.370395
420	-0.383524	357	-0.370059
189	-0.383506	126	-0.369516
399	-0.378819	335	-0.368904
168	-0.378722	336	-0.366274
378	-0.374320	398	-0.366066
147	-0.373934	105	-0.365630
356	-0.373760		

Table 37(b). Natural frequencies from vibration analysis.

Mode	Natural frequencies (ω), rad/sec	
	Free vibration	Prestressed vibration
1	162.497	162.491
2	623.103	623.114
3	762.972	762.959
4	1041.57	1041.59
5	1467.85	1467.86
6	1911.79	1911.77

APPENDIX A

PREPROCESSOR MANUAL

The preprocessor routine PREPROCS is an integral part of the set of routines that form the STARS program. This routine has been developed to automate the generation of finite-element models and corresponding data files. Instead of defining a complete structure by independently describing each node and element, the preprocessor allows the automatic formation of such data. The preprocessor minimizes data input and eliminates data editing, thereby enhancing the efficiency of the STARS program.

To run the preprocessor, the user types the command PREPROCS; the program will prompt a list of different terminals. The user then chooses the type of terminal to be used (for example, IBM, Tektronix, and various compatible terminals). Next, the user is prompted with menu options in a progressive fashion. At any level of the menu, the user can exit by entering Control-C.

A brief description of the primary menu is given here; because of the interactive nature of the program, the user is automatically exposed to more extensive details.

PREPROC MENU

MENU OPTIONS:

- 0 STOP
Stop the program.
- 1 COMPUTER-AIDED DESIGN
Generate graphics objects.
- 2 PROPERTIES AND ANALYSIS SPECIFICATION
Specify STARS data.
- 3 READ
Read the STARS data file.
- 4 WRITE
Write the STARS data file.
- 5 DELETE
Delete the current structure.

1 COMPUTER-AIDED DESIGN

DESIGN OPTIONS:

- 0 QUIT
Quit this menu.
- 1 LINES
Generate line segments.
- 2 SURFACES
Generate surface segments.

- 3 SOLIDS
Generate solid segments.
- 4 SYNTHESIS
Generate surfaces from existing line segments.
- 5 REPRODUCE
Generate new segments using existing ones.
- 6 DRAW
Plot the current structure.
- 7 EDITOR
Modify existing data.
- 8 AUTOMESH
Generate the surface/solid automatically.

1.1 LINES

- 0 QUIT
Quit this menu.
- 1 STRAIGHT LINE
Generate a straight line segment.
- 2 PARABOLIC CURVE
Generate a parabolic line segment.
- 3 CIRCULAR CURVE
Generate a circular line segment.
- 4 ELLIPTIC CURVE
Generate an elliptical line segment.

1.2 SURFACES

- 0 QUIT
Quit this menu.
- 1 SIMPLE SURFACE
Generate a four-node surface segment.
- 2 COMPLEX SURFACE
Generate a nine-node surface segment.
- 3 ELLIPTICAL SURFACE
Generate an elliptical surface segment.

1.3 SOLIDS

- 0 QUIT
Quit this menu.

- 1 8-POINT SOLID
Generate an eight-node segment.
- 2 ELLIPTICAL SOLID
Generate a solid cylinder.
- 3 4-POINT SOLID
Generate a four-node segment.
- 4 6-POINT SOLID (PRISM)
Generate a six-node segment.

1.4 SYNTHESIS

- 0 QUIT
Quit this menu.
- 1 ARC: LINE SEGMENT → SURFACE
Generate surface segments by moving a line segment along a curve.
- 2 GLIDE: 2-LINE SEGMENT → SURFACE
Generate surface segments using two line segments.

1.5 REPRODUCE

- 0 QUIT
Quit this menu.
- 1 COPY
Reproduce by directly copying.
- 2 MIRROR
Produce a mirror image.
- 3 ROTATE
Reproduce by rotating the original about an axis.

1.6 DRAW

The preprocessor will draw the generated structure on a standard terminal with multiple options.

1.7 EDITOR

- 0 QUIT
Quit this menu.
- 1 STRUCTURE STATUS
Display the structure status.
- 2 LOCATION
Display nodes at the nearest location.
- 3 ADDNODE
Add nodes to the current structure.

- 4 ADDELEM
Add elements to the current structure.
- 5 MOVE NODE
Move nodes to another location.
- 6 MOVE SEGMENT
Move segments to another location.
- 7 DELETE NODES
Delete nodes from the current structure.
- 8 DELETE ELEMS
Delete elements from the current structure.
- 9 DELETE SEGMENT
Delete segments.
- 10 ELEMENT SPECIFICATION
Define element properties.

1.8 AUTOMESH

- 0 QUIT
Quit this menu.
- 1 SURFACE
Automatically generate two-dimensional surfaces.
- 2 VOLUME
Automatically generate a three-dimensional solid with tetrahedron elements.
- 3 XPLT
Plot the mesh generated from automesh in black-and-white (not available on the PC version).

2 PROPERTIES AND ANALYSIS

This option enables the automatic generation of a complete STARS data set in which the user is prompted for the appropriate input.

APPENDIX B

POSTPROCESSOR MANUAL

The POSTPLOTS, POSTPLOTA, and POSTPLOTf routines are designed to provide graphic depiction of analysis results pertaining to the major SOLIDS, AEROS, ASE, and FLUIDS (CFDASE, including CFD) modules. This graphic depiction is effected by the POSTPLOTS, POSTPLOTA, and POSTPLOTf commands. The program runs on a variety of terminals, such as IBM, Tektronix, and other PLOT10/PHIGS-compatible machines.

POSTPLOTS is menu-driven and has the following features:

1.0 BASIC MENU

- 1.1 On/off switches
- 1.2 Load database
- 1.3 Delete database
- 1.4 Miscellaneous
- 1.5 Edit color
- 1.6 Exit

1.1 ON/OFF SWITCHES

- 1.1.1 Original structure
- 1.1.2 Deformed structure
- 1.1.3 Dynamic response
- 1.1.4 Displacement as a function of time
- 1.1.5 Stress as a function of time
- 1.1.6 Node number
- 1.1.7 Element number
- 1.1.8 Element group
- 1.1.9 Depth clipping
- 1.1.10 Hard copy
- 1.1.11 Save plot

1.2 LOAD DATA BASE

- 1.2.1 Deformed or mode shape

- 1.2.2 Rendering deformed or mode shape
- 1.2.3 Dynamic response
- 1.2.4 Rendering stress
- 1.2.5 Rendering deformation
- 1.2.6 Displacement as a function of time
- 1.2.7 Stress as a function of time
- 1.2.8 Node numbers
- 1.2.9 Element numbers
- 1.2.10 CFD density, Mach, and pressure plots (an alternative to some POSTPLOT options)

1.3 DELETE DATA BASE

Essentially any one of the loaded data bases, given above.

1.4 MISCELLANEOUS

A host of additional options.

1.5 EDIT COLOR

- 1.5.1 Index location (left, center, right)
- 1.5.2 Color octave
- 1.5.3 Number of colors (9, 10, 14)

The POSTPLOT is also menu-driven and has the following features:

- 2.1 Aerodynamic paneling plots
- 2.2 Interpolated mode shape for aerodynamic load calculation
- 2.3 Aerodynamic pressure distribution
- 2.4 Frequency-damping-velocity plots, k, p-k, and ASE solutions
- 2.5 Phase and gain plots as a function of frequency for analog and digital systems
- 2.6 ASE damping and frequency plots as a function of velocity

The POSTPLOT program is graphical user interface–based (GUI-based) and is self-explanatory.

APPENDIX C

SYSTEMS DESCRIPTION

The STARS computer program is set up using a main directory and many subdirectories. The setup described in this section uses the directory names employed on various computer systems at NASA Dryden. Figure C-1 shows the top-level directories; /trial is the main directory that contains the six major subdirectories named as commands, sources, objects, executions, test cases, and utilities. The commands subdirectory contains the command files that are used to guide the user in running the STARS program system. The sources subdirectory contains the source elements for the program. This subdirectory is further subdivided into the solids, aerodynamics (linear), ASE (linear), CFDASE (nonlinear), utilities and associated graphics subdirectories. The latter subdirectory includes the preprocessor, which performs the automatic generation of finite-element meshes and subsequent STARS analysis data, and the postprocessor, which performs the depiction of solution results. The objects subdirectory contains the object elements required for creating the execution elements. The object elements have been combined into various object libraries to ease the linking process. The executions subdirectory contains the execution elements used to run the program. The test cases subdirectory contains representative example problems that facilitate the learning and debugging of the program. Additional data manipulation capabilities are facilitated by the use of the routines in the utilities subdirectory.

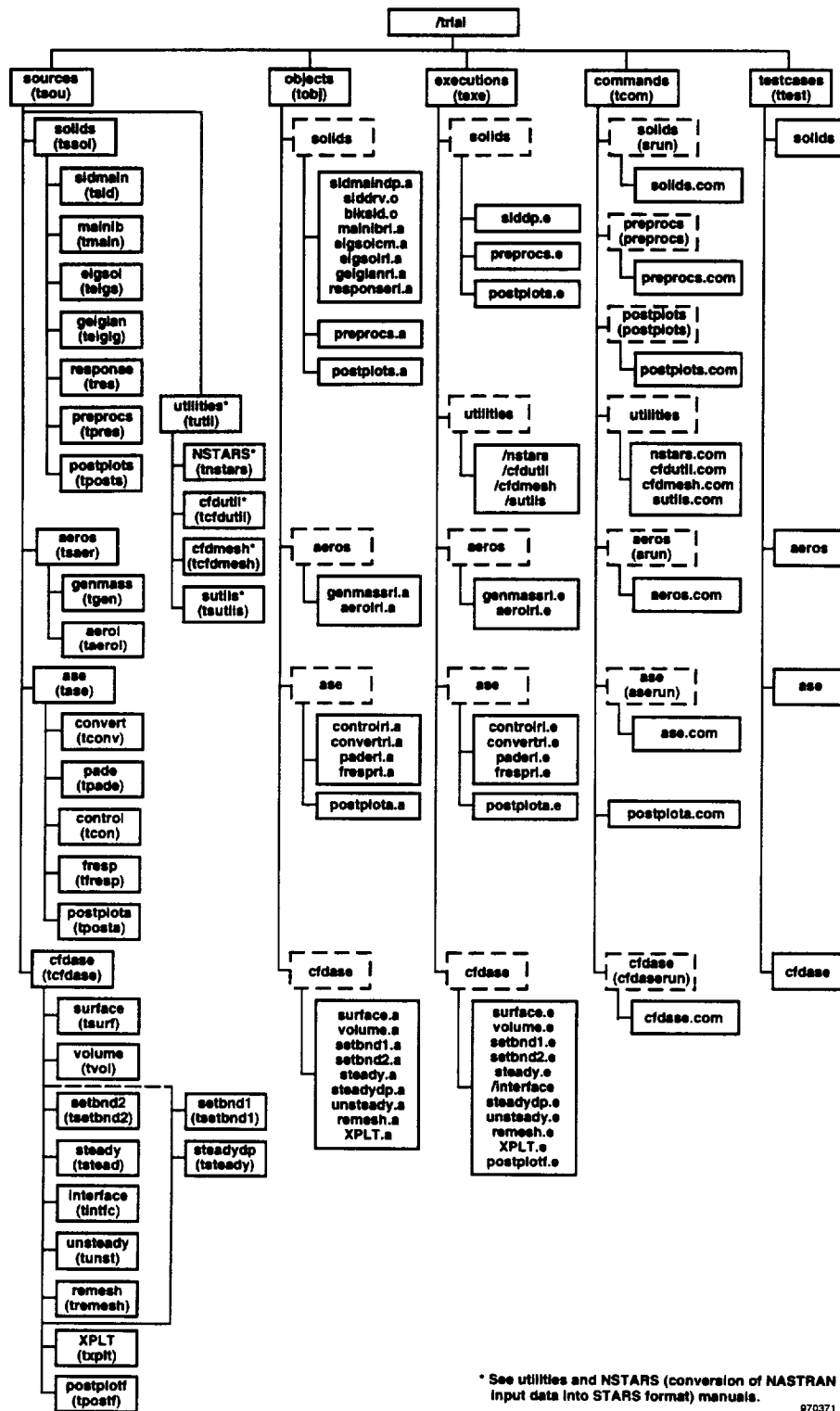


Figure C-1. STARS systems description.

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13. ABSTRACT (Maximum 200 words) A multidisciplinary, finite element-based, highly graphics-oriented, linear and nonlinear analysis capability that includes such disciplines as structures, heat transfer, linear aerodynamics, computational fluid dynamics, and controls engineering has been achieved by integrating several new modules in the original STARS (STructural Analysis RoutineS) computer program. Each individual analysis module is general-purpose in nature and is effectively integrated to yield aeroelastic and aeroservoelastic solution of complex engineering problems. Examples of advanced NASA Dryden Flight Research Center projects analyzed by the code in recent years include the X-29A, F-18 High Alpha Research Vehicle/Thrust Vectoring Control System, B-52/Pegasus®, Generic Hypersonics, National AeroSpace Plane (NASP), SR-71/Hypersonic Launch Vehicle, and High Speed Civil Transport (HSCT) projects. Extensive graphics capabilities exist for convenient model development and postprocessing of analysis results. The program is written in modular form in standard FORTRAN language to run on a variety of computers, such as the IBM RISC/6000, SGI, DEC, Cray, and personal computer; associated graphics codes use OpenGL and IBM/graPHIGS language for color depiction. This program is available from COSMIC, the NASA agency for distribution of computer programs.				
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