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## NASTRAN® User's Guide (Level 17.5)

E. I. Field, D. N. Herting, and M. J. Morgan

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The NASA logo, consisting of the word "NASA" in a bold, sans-serif font.

**NASA Contractor Report 3146**

**NASTRAN<sup>®</sup> User's Guide (Level 17.5)**

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### INTRODUCTION

The User's Guide is designed to assist the current and potential users of NASTRAN<sup>1</sup> (NASA STRuctural ANalysis) to make full use of the program's capabilities. NASTRAN is intended to serve the engineering community by integrating the state-of-the-art in engineering and numerical methods into a single program for the analysis of large and complex structures.

Four technical manuals serve to document the NASTRAN program. The Theoretical Manual presents a topic-by-topic discourse of the theory, assumptions, and methods of analysis for those interested in the analytical techniques. The User's Manual is the primary reference document which describes those items related to the use of NASTRAN that are independent of the computing systems being used. The third document is the Programmer's Manual which presents the details of the program, its organization, its file structure, and its implementation on each of the three computer systems, IBM 360/370, UNIVAC 1100 Series, and CDC 6000/CYBER Series for which NASTRAN is maintained. The fourth document is the Demonstration Problem Manual which serves to describe and illustrate sample problems used to verify the proper functioning of the program. These problems are selected to demonstrate the program capabilities with its many options for modeling, loading, selection of output and control of analyses.

Each of these four manuals provides a wealth of information useful to the understanding, use and development of NASTRAN. However, in that they were designed for reference purposes primarily, the organization of each does not readily lend itself to easy access except by experienced users and programmers. Therefore, the User's Guide was developed and organized so as to present the many options available in the logical sequence in which the input data would be prepared. These options are briefly described and tabulated according to purpose to help the user select the alternative best suited to his needs. References are given to the location in the standard documentation where detail descriptions may be found. The User's Guide also contains many examples illustrating typical applications of NASTRAN modeling and control features which may be used as models for input data preparation.

The user is expected to be familiar with the rudiments of finite element structural analysis and to be aware of basic modeling concepts. The Theoretical Manual, of course, can be referred

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<sup>1</sup>NASTRAN: Registered trademark of the National Aeronautics and Space Administration.

to for a detail discussion of each of NASTRAN's analytical capabilities. The Guide directs the user to the application of this knowledge and suggests extensions of it to new problem areas. The User's Manual defines all the input and control options, outlines the steps taken for each type of analysis, and summarizes the error messages which may then be issued by NASTRAN. The sophisticated user will want to understand NASTRAN's organization, its controlling functions, and its data handling techniques which are fully described in the Programmer's Manual. Execution of the sample problems set out in the Demonstration Problem Manual will give the user invaluable exposure and practice in actual operation of the program.

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## 1. INTRODUCTION

### 1.1 ORIENTATION TO THE USER'S GUIDE

The overall organization of the User's Guide is subdivided into two parts. The first part begins with a review of NASTRAN design philosophy, specific instructions and suggestions on how to use the program documentation, data descriptions for model and load definition and descriptions of the program control options. The description of these basic tools of NASTRAN is followed by examples and guidelines for the execution of each of the standard forms of analysis available in NASTRAN and a summary review of the computer and plotter output that can be obtained with NASTRAN. The Guide then discusses some of the utility functions available for user convenience, provides examples of machine-dependent card deck setup for execution of NASTRAN on the three computer systems for which NASTRAN is maintained. The communication devices designed to help keep the user up to date with the current developments and for him to share this experience with other NASTRAN users are outlined. The operating principles and means of estimating computer resource requirements, the special NASTRAN matrix abstraction language (DMAP) for controlling execution, and the means of interfacing NASTRAN with other programs are presented. All three sections of the Guide serve to introduce the capabilities which are then discussed in terms of their applications in the second part of the Guide. The second part of the Guide describes in separate sections the analytical capabilities for which NASTRAN is especially designed: static and dynamic analyses, substructuring, aerodynamics, heat transfer, and a variety of other special purpose modeling facilities.

The User's Guide is not intended to represent the full detail of NASTRAN's capabilities. NASTRAN provides such a flexible array of analytical options, the user will find unending combinations of alternatives. As the user becomes familiar and comfortable with the use of NASTRAN, he will want to use the more sophisticated features of NASTRAN. The User's Guide will serve to help direct these users to effectively apply their imagination and analytical abilities. However, to keep the volume of this Guide within manageable proportions, the user is expected and encouraged to make full use of the references provided to the standard NASTRAN manuals.

## ORIENTATION TO NASTRAN

### 1.2 ORIENTATION TO NASTRAN

NASTRAN is a general purpose computer program designed to analyze the behavior of structures under a wide variety of operating environments. Its nature is general purpose which makes the program useable for structures of any size, shape, class, or configuration, for any geometric representations which can be identified by any convenient coordinate system, for elastic relations which may range from isotropic to general anisotropy, for non-linear behavior that can be represented by piecewise linear approximations, for complex as well as real matrix operations, for vibration frequency and mode determination, and for a wide variety of loading conditions. The various loading conditions may be concentrated or distributed, transient, steady-state sinusoidal; static temperature profiles; enforced deformations; time-varying as well as static surface and body forces; and stationary Gaussian random excitation. NASTRAN will also perform aerodynamic, hydroelastic, and heat transfer analyses.

NASTRAN, as a computer program, is organized to permit future modification and continued expansion to new disciplines. NASTRAN is maintained and supported by the National Aeronautics and Space Administration (NASA). New releases of the program are made periodically to meet the rapidly expanding needs of government agencies and the aerospace industry. It also has received wide acceptance in the petro-chemical, nuclear reactor, transportation, and construction industries both domestically and abroad.

NASTRAN may be obtained from COSMIC, 112 Barrow Hall, University of Georgia, Athens, Georgia 30602. Versions of NASTRAN are available for installation on each of three computer systems: the CDC 6000 Series, the IBM 360/370 Series, and the UNIVAC 1100 Series computers.

The following sections provide an introduction to NASTRAN as a computer program system for structural analysis and structural design. The final two sections focus on the management topics of planning and controlling an analysis activity using NASTRAN.

## NASTRAN AND STRUCTURAL ANALYSIS

### 1.3 NASTRAN AND STRUCTURAL ANALYSIS

NASTRAN analyzes models by the displacement method of the finite element approach. With this approach, the distributed physical properties of a structure are represented by a model which consists of a finite number of idealized components or structural elements. These elements are defined by, and serve to interconnect a finite number of grid points to which loads may be applied. The grid point is the basic framework for the structural model and all aspects of the model definition are referenced either directly or indirectly to these grid points. The structural element (which may be a line, a surface, or a solid element) is a convenient means for specifying many of the properties of the structure, including material properties, mass distribution, and some types of applied loads. In addition, various kinds of constraints can be applied to grid points. Single-point constraints are used to specify boundary support conditions and multi-point constraints may be used to specify a linear relationship among selected degrees of freedom.

Structural elements are provided in NASTRAN for the specific representation of the more common types of construction including rods, beams, solids, shear panels, plates, and shells of revolution. More general types of construction are treated by combinations of these elements and/or the use of "general" or user specified elements. For sophisticated dynamic and control systems analyses, aerodynamic transfer functions and other non-structural features also may be incorporated into the analytical model.

NASTRAN has been specifically designed to treat large problems with many degrees of freedom. The only limitations on problem size are those imposed by practical considerations of running time and by the ultimate capacity of auxiliary storage devices provided by the computer facility being used. Computational procedures implemented in NASTRAN have been selected to provide the maximum obtainable efficiency for large problems with particular attention given to processing sparse matrices. Though NASTRAN is decidedly not constrained to in-core processing only, the more core memory that can be made available, the more efficient that processing will be.

NASTRAN also provides an automated multi-stage substructuring capability for static and dynamic analyses. This capability is particularly useful for handling large or complex models and for modeling structures with repetitive components. The capability may be used to realize significant processing and model development efficiencies for very large models.

## INTRODUCTION

The needs of the structural analyst have been considered in all aspects of the design of the program. However, in view of the wide range of possible applications of the program now and in the future, all the analytical and user needs could not be anticipated in advance. For this reason, a high degree of flexibility and generality has been incorporated into the program. For example, in addition to the usual list of structural elements that refer to specific types of construction, the user may elect to define a "general" element to represent part of a structure by providing deflection influence coefficients, or to represent part of a structure by its vibration modes. The user is provided with a number of convenience features, including plotting, selective output, checkpoint/restart, and diagnostic facilities which are definite necessities for large problems.

A major difficulty that the user faces in the solution of large problems is the avoidance of errors in the preparation of input data. Card formats and card ordering are made as simple and flexible as possible in order to avoid errors caused by trivial violations of format rules. A number of aids such as automatic data generation, extensive plotter capability, grid point singularity tests, and grid point force balance printout have been provided to help the user develop and validate his model. The sophisticated checkpoint/restart capability is designed for recovery from data or system error conditions, to allow for examination of intermediate results, and to allow for retrieval of additional selective output following completion of the analysis.

## NASTRAN AND STRUCTURAL DESIGN

### 1.4 NASTRAN AND STRUCTURAL DESIGN

NASTRAN may be effectively used to support the task of structural design as well as perform detailed structural analyses.

The automated multi-stage substructuring capability is an ideal tool for the support of design activities. The substructuring capability may be used to model as separate components those segments of the overall structure which may require design iterations. The substructure least likely to be changed would then be incorporated in the early stages of model development since it would not need to be regenerated in order to study the effects of design changes made to components added in the later stages of model development.

NASTRAN also provides a capability for an iterative fully stressed property design option with static analysis. This capability automatically minimizes cross sectional area thickness, or moments of inertia to permit the structure to carry prescribed loads as maximum stress.

Special facilities have been incorporated to help a user interface NASTRAN with other programs for pre- and post-processing. Thus, automated data generation and/or output interpretation can be utilized with special user programs designed to meet his special needs.

Whether for design or for analysis, exploiting NASTRAN's capabilities requires planning and control to obtain reliable results efficiently.



## PLANNING A NASTRAN ANALYSIS

### 1.5 PLANNING A NASTRAN ANALYSIS

Detailed modeling of complex structures for analysis can be expensive in terms of both human and computer resources. Control of these costs is usually required, and control can be best maintained by adherence to an analysis project plan. In this section, guidelines to the preparation of a NASTRAN analysis plan are presented.

A suggested approach to planning a NASTRAN analysis involves separating the activity into three phases: the problem definition phase, the analysis set-up phase, and the analysis execution phase.

The problem definition phase provides the framework for the remaining NASTRAN planning activity. Key activities in this phase include:

1. Identify the structure to be modeled using references to drawings, layouts, or other documents.
2. Carefully define the purpose and objectives of the analysis.
3. Identify the desired results to be obtained from the analysis.
4. Define the budget, computer resources, and timeframe for the analysis.
5. Define the engineering assumptions which are to be made.

The analysis set-up phase involves a variety of tasks. Some pertinent questions to be answered are also indicated for some tasks.

1. Locate and collect descriptive data of the model. Can automatic data generation be used?
2. Define normal NASTRAN output requirements. What theoretical or experimental data are available for model checkout and validation?
3. Identify external input or output interfaces with NASTRAN. Are pre- or post-processors to be used or developed?
4. Select the required Rigid Format and note any special requirements of that Rigid Format. Will several Rigid Formats be used at different stages in the analysis?

## INTRODUCTION

5. Plan for documentation at this stage of the analysis. What structural plots are required for documentation?
6. Prepare a detailed cost resource requirement and schedule plans for the analysis. Are there plans consistent with the budget computer resources, and timeframe established in the problem definition phase?

The plan for execution phase should include a description of the tasks and provide answers to the questions which follow.

1. Specify data base management procedures. Will the User's Master File (UMF) or Sub-structure Operating File (SOF) be used, or will other computer system file utilities be used?
2. Specify methods for checking the model and/or its components. Can plotting be effectively used? Can simplified loadings and boundary conditions be used at intermediate stages of model development and checkout?
3. Plan for tracking the analysis progress in terms of cost, model validity, and model accuracy. How can NASTRAN diagnostics or special Cost Control output be used?
4. If the analysis will involve using an unfamiliar Rigid Format, DMAP alters, or other new modeling procedures, plan a "pilot model" analysis. With the pilot model, test all NASTRAN features to be exercised in the final analysis. This will assure the planned analysis methods will satisfy the analysis objectives.

## MANAGEMENT OF NASTRAN PROCESSING

### 1.6 MANAGEMENT OF NASTRAN PROCESSING

The organization of the NASTRAN system provides many means for management control and monitoring of NASTRAN processing. NASTRAN provides standard solution techniques called Rigid Formats for executing different types of static, dynamic, stability, or heat transfer analyses. The Rigid Formats provide the principal form of management control because they provide a proven, well documented procedure for a given analysis sequence. In conjunction with each Rigid Format, NASTRAN provides a checkpoint/restart capability. This capability allows running a problem in multiple steps to obtain intermediate results, as required, for checking the model and its response. Also, the checkpoint/restart capability can be used for efficient error recovery. With this capability, costly and unnecessary repetition of valid data calculations may be avoided when recovering from errors.

NASTRAN also provides an extensive diagnostic-output capability. The diagnostic messages can be used in several ways to monitor the progress of an analysis.

The concept of NASTRAN Rigid Formats is described in Section 4 of this guide. The use of checkpoints, restarts, and diagnostics is presented in Section 6.

NASTRAN documentation also contains other information which can be used to effectively manage a structural analysis project with NASTRAN. For example, Section 14 presents information to help the user estimate resource requirements (machine time and core) prior to beginning processing. These estimates can also be used to support cost projections for the analysis.

## 2. USE OF NASTRAN DOCUMENTATION

### 2.1 INTRODUCTION

Documentation for NASTRAN consists of five manuals; the User's Guide, the User's Manual, the Theoretical Manual, the Programmer's Manual, and the Demonstration Problem Manual. Each document's purpose, content, and use is described in this section. Other sources of NASTRAN information pertaining to reported errors or corrections, and user's experience, for example, are described in Section 12.

## USER'S GUIDE (UG)

### 2.2 USER'S GUIDE (UG)

The User's Guide is designed to assist both the current and potential user of NASTRAN to make full, efficient application of the program's capabilities. An important function of the Guide is to provide engineering management with an overview of NASTRAN's technical capabilities. With this concise overview, management may better direct NASTRAN activities from an informed position not previously possible without extensive reading of NASTRAN documentation or personal hands-on experience with the program.

The first thirteen sections of the guide are designed to provide the new and occasional user with an awareness of the access to standard NASTRAN analysis capabilities. These sections provide much of the information required and the reader will be directed to the appropriate NASTRAN reference manuals for technical details of model building, selection of analysis to be performed, data deck and system control deck creation.

The remaining sections of the User's Guide are designed to provide the more sophisticated NASTRAN user with information needed to execute large, complex, or unusual analyses of structures and coupled structural/non-structural component systems. For example, material presented in "Operating Principles of NASTRAN" and a section on the introduction to the matrix abstraction language (DMAP) provide an understanding of program design and guidance needed to exploit many non-standard NASTRAN capabilities.

A significant portion of the User's Guide, beginning with Section 17, consists of independent sections describing specialized NASTRAN capabilities in engineering terms. These are intended to aid the sophisticated user with substructuring with modal synthesis, aeroelasticity, heat transfer analyses, and other capabilities including acoustic analysis, cyclic symmetry, hydroelastic analysis, and fully stressed design.

Examples are presented throughout the Guide which can be carefully examined to help the user set up his own problem for execution. Also, references are given to locations in the NASTRAN manuals where additional or more detailed information is available. The contents of the manuals provided with NASTRAN are summarized below.

## USER'S MANUAL

### 2.3 USER'S MANUAL

The User's Manual presents the more practical subjects, in a reference manual style on how to input data to NASTRAN and on how to control its processing. This manual begins with a general discussion of structural modeling with a description, in physical terms, of each modeling tool available.

Many structural elements are provided in NASTRAN. Each type of element is discussed in terms of how it can be used, what input is required, and what type of output can be obtained as results. The reader is shown how to use the constraints and partitioning features of NASTRAN. The many types of static and dynamic load capabilities are summarized. Both the direct and modal formulations of the dynamic equations of motion are presented.

The specific detail of format and card content for each input and control option of the Executive Control, Case Control, and Bulk Data Decks is presented separately in Sections 2.2, 2.3, and 2.4, respectively. In each section, the card mnemonics are listed alphabetically for easy reference. Also, since large problems may require sizable input decks, a description of how to use the User's Master File feature for storing the data on tapes is given in Section 2.5. The automated data generating feature and substructuring with modal synthesis are presented in Sections 2.6 and 2.7, respectively. The extensive plotting capability and its control options are discussed separately in Section 4.

Section 3 presents a general description on how to use the current Rigid Formats which direct the flow of all NASTRAN's standard analysis. Here is also discussed the input data for processing, how to use the checkpoint/restart feature, and how to alter the Rigid Format for special purposes. A subsection is devoted for each available Rigid Format. Each section contains a detail description of the processing steps, a summary of the Case Control requirements, a list of the output options, and a list of the special parameters provided for execution control and special output requests.

Section 5 contains all the detail instructions with examples for using the Direct Matrix Abstraction Program (DMAP) commands. These DMAP commands are used to control all of NASTRAN processing. They are used to build and to alter the standard Rigid Formats or to create entirely new sequences for matrix processing with NASTRAN.

Section 6 lists and explains all of the error and diagnostic messages issued by NASTRAN. Section 7 contains a very useful dictionary of the common terms and mnemonics used throughout the NASTRAN documentation.

## THEORETICAL MANUAL

### 2.4 THEORETICAL MANUAL

The Theoretical Manual presents the design concepts and the mathematical basis for all of NASTRAN's capabilities. The user will find an overall view of the basic philosophy of NASTRAN, a summary definition of how the program is organized, and a mathematical description of the operations it performs. The assumptions and approximations are identified. The available finite element modeling tools such as grid points, coordinate systems, element connectivities, direct matrix input, multipoint constraints, modal coordinates, transfer functions are described.

Suggestions are made on how to use these capabilities. Sections are included on special topics such as heat transfer analysis, aeroelasticity, plotter graphics, special modeling techniques, error analysis, and interaction between structures and fluids. An index for the Theoretical Manual is included to help the NASTRAN user locate additional references to the specific subjects of interest.

## PROGRAMMER'S MANUAL

### 2.5 PROGRAMMER'S MANUAL

The Programmer's Manual contains the detailed descriptions of the many modules and sub-routines of NASTRAN and the data blocks on which they operate. The frequent user of NASTRAN would do well to read the first section. It contains information on how NASTRAN processes data and how it controls that processing. Though understanding these processes is not required, it will help to visualize what happens during the execution of an analysis and may help the user thereby to efficiently organize his processing requests. Also, NASTRAN offers such a plethora of options, not all combinations of which can be adequately described. Hence, an understanding of how the program executes will help the user interpret the documentation as needed to exploit the system.

Section 2 is also of value to an experienced user. Here he will find a detailed description of the many data pools generated by and maintained within NASTRAN. Occasionally the user will encounter the need for some of this data to help him locate an error in his model. NASTRAN provides the facilities for retrieving this data and printing it out with special DMAP utilities. An alphabetical index of the data block names is provided to help locate the pertinent data descriptions.

The remaining sections are devoted to describing the utility subroutines, the functional modules, the matrix processing modules, the routines that generate the element matrices, and the interfaces of NASTRAN with resident computer operating systems. Also, instructions are given for adding new program capabilities and new input cards to NASTRAN. Finally, attention is given to describing the utility programs available to help support and maintain NASTRAN.



## DEMONSTRATION PROBLEM MANUAL

### 2.6 DEMONSTRATION PROBLEM MANUAL

The Demonstration Problem Manual contains a discussion of each of the demonstration problems supplied with the NASTRAN program. The manual is subdivided into separate sections for each of the major analytic disciplines addressed by NASTRAN. Each section describes the problems to be solved, the models selected, the loads applied, and a discussion of the NASTRAN results with a comparison to the theoretical solution, where possible. Each Rigid Format analysis is demonstrated at least once, and practically all of the NASTRAN input options are exemplified. Listings of the Executive Control, Substructure Control, and Case Control decks for each problem are included. Additionally, there is at least one example of how to use each Bulk Data card type. The complete data decks for all of the demonstration problems are supplied with the NASTRAN system delivery package so that they may be executed by the user if he so desires.

Whenever a user contemplates exercising a new capability, he is encouraged to execute the demonstration problem exemplifying that feature.

### 3. MODELING WITH NASTRAN

#### 3.1 INTRODUCTION

The basic methods and options for creating NASTRAN models are summarized in this section. The purpose of a model is to represent the properties of an actual physical system by a system of matrix equations which provide accurate approximations to the expected system response. This mathematical model may be used to simulate many types of physical phenomena including static and dynamic response, stability, and heat transfer in structures as well as fluid dynamics, aerodynamics, and control system interactions with structures.

The basis for most NASTRAN modeling is the finite element. The finite element method assumes the physical system is subdivided geometrically into elementary components. In structural analysis, these components are represented by typical structural elements such as beams, plates, shear panels, and solids. Because each element mathematically represents only a simple response pattern, those sections of the physical system which are expected to undergo complex response patterns must be subdivided into many elements. When the required number of elements becomes large, user aids such as automated data generators (User's Guide, Section 9.4; User's Manual, Section 2.6) are helpful in preparing the NASTRAN data. Also, NASTRAN's automated multi-stage substructuring (AMSS) facilities (User's Guide, Section 20) help build and analyze these large and complex models.

From the data describing the finite element representation of the physical system, NASTRAN computes the finite element matrix coefficients defining the stiffness, mass, conduction, etc., properties of each element. These finite element matrices are combined together to form the overall system matrices which are used to represent the behavior of the basic model. Special features of the physical system may be defined and then added to complete the model using direct input matrix terms and general elements. Further processing is then undertaken to impose environmental constraints, loads, and/or perform matrix transformations in preparation for the solution phase (User's Guide, Section 4.0).

Once the physical system is defined by the finite element model, NASTRAN may be used to process that data for several different types of analyses. The basic finite element mathematical model used for structural static analysis may also be used as the basis for all types of dynamic analyses, heat transfer analyses, buckling, etc. The basic structural model matrices must be augmented with additional data appropriate to each specific type of analysis to define mass inertias, damping, radiation effects, control system input, and/or aerodynamic surface effects, etc.

## MODELING WITH NASTRAN

In many cases, Guyan reduction techniques, modal formulations, and substructuring methods may be used to reduce the problem size to more manageable proportions. These topics are discussed later in Section 4.

Described below are basic considerations and general options for formulating a mathematical model in NASTRAN. The topics discussed start with building the basic finite element structural model and how to use substructuring techniques. Non-structural considerations such as for aerodynamics and fluid/structure interaction are then presented followed by available options for thermal heat transfer analysis. General capabilities of NASTRAN for research and development are then illustrated in the discussions of options for control systems and direct matrix input for special effects. The final section lists a number of the modeling restrictions imposed by NASTRAN. The methods of obtaining solutions for models defined by these data are summarized later in Section 4.

## STRUCTURES

### 3.2 STRUCTURES

In NASTRAN structural analysis, finite elements are used to represent the stiffness, mass, and damping properties of the physical system. Although the elements are pure mathematical entities, they have been chosen to simulate frequently-occurring structural components such as beams, plates, shear panels, solids, etc. The more complex structural components, themselves, may be subdivided into sets of elementary finite elements to obtain sufficient detail to represent their desired physical properties and anticipated stress patterns.

Table 1 lists available NASTRAN elements, their characteristics, and their application. Some groups of elements are computationally similar and are listed together. For instance, IHEX1 represents three solid elements, IHEX1, IHEX2, and IHEX3, with different numbers of connected points. Individual descriptions of all these elements are given in the User's Manual, Section 1.3.

Four types of input data are used to define the finite elements: grid points, connection cards, property cards, and material data. The grid point data card (GRID) defines the location of the points connected by the elements and the orientation of the resulting displacement components defining the translation and rotation of these points. The connection data card (CBAR, CQUAD1, etc.) also points to data cards defining material and properties of the element. Material data (MAT1, MAT2, etc.) are used to define elastic, mass, and damping properties. Physical data define element cross-sectional area and other properties. Many elements may reference the same set of property data and many sets of property data may reference the same material data.

Table 1. NASTRAN Finite Element Characteristics

Element Name	AERO1	AXIF1	BAR	CONEAX	DAMP1	ELAS1	FLUID1	HBDY	HEXA1	IHEX1	MASS1	CNNM1	CNNR0	QDMEM1	QDPLT	QUAD1	R0D	SHEAR	SL0T1	TRTRA	T0RPRG	TRAPAX	TRAPRG	TRBSC	TRIAAX	TRIARG	TRIA1	TRMEM	TRPLT	TUBE	TWIST	VISC	WEDGE		
Dimensions	2	3	1	2	0	0	3	2	3	3	0	0	1	2	2	2	1	2	2	3	2	3	3	2	3	3	2	2	1	2	1	3			
Max Points	∞	4	2	2	2	2	4	8	8	32	2	1	2	4	4	4	2	4	4	4	2	4	4	3	3	3	3	2	4	4	2	6			
Scalar Points					•			•			•																								
Rotational DOF			•	•								•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			
Axisymmetric		•					•												•																
Thermal Loads			•	•				•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
Stiffness			•	•				•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
Lumped Mass			•	•				•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
Consist. Mass			•										•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
Viscous																																•			
Diff. Stiffness			•										•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Plasticity			•										•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Heat Transfer			•											•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Plotted		•	•	•									•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Property Opt.			•											•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Hydroelastic																																			•
Acoustic																																			•
Aeroelastic																																			•

Note:  
i = 1,2,...

## SUBSTRUCTURES

### 3.3 SUBSTRUCTURES

In cases when finite element models become too large for efficient NASTRAN processing, substructuring may be used as a method to subdivide the model into more convenient and/or manageable components. Each component substructure itself may be further subdivided into even more basic components. These basic components may be modeled independently and combined directly with other components at the matrix data level to build the final desired model for solution analysis. This procedure is also convenient for redesign and remodeling problems. Changes in one section of the structure would not necessarily require reformulation of the entire model.

The automated multi-level substructure system (AMSS), described in Section 20, provides a three-phase system for modeling with substructures. Each elementary or basic substructure component model is submitted in a Phase 1 run. The only restrictions on the model are that boundary grid points have compatible locations with adjoining components. Grid point and element identification numbers and responses are unrestricted. All required data for the models are automatically generated and permanently stored in files provided and maintained by the user.

In the second phase of substructuring, the substructures may be combined; they may be reduced in matrix size using the Guyan reduction or modal synthesis methods; and they may be combined again to form even more complex models. At any stage the user maintains direct control over each operation using simple linguistic commands (COMBINE, REDUCE, SOLVE, etc.) All data is stored on the user provided substructure operating file at each stage providing each of restarting and recovering from data errors. Any substructure may be analyzed using standard NASTRAN Rigid Formats modified automatically for substructuring to provide for a solution and data recovery.

For detail data recovery at the level of the original basic substructure, the Phase 3 execution can be made from a restart tape or from the original model input data itself. Again, the user-provided substructure operating file is accessed by NASTRAN to automatically retrieve the required solution vectors needed for computing detail element stresses and preparing deformed plots, etc.

## AERODYNAMICS

### 3.4 AERODYNAMICS

Aerodynamic elements are strips, boxes, or bodies which represent the surfaces for computation of aerodynamic interactions with the structure. These elements, like structural elements, are defined by their geometry. Their motions are defined by degrees of freedom at associated aerodynamic grid points. Often, requirements of aerodynamic theory will dictate the geometry of the boxes. For example, the doublet lattice theory requires trapezoidal boxes with their parallel edges aligned to the streamlines. Also, if one box lies in the wake of another, their edges must be on the same two streamlines. Aerodynamic elements and grid points are generated to reduce the labor for the user and to enforce the theoretical restrictions on the geometry.

Structural and aerodynamic degrees of freedom are connected to the structure by interpolation. This feature allows selection of grid points and elements for structures and for aerodynamics, each to be defined in a manner which is well suited to the particular problem. The structural model for a wing may consist of a one-, two-, or three-dimensional array of grid points. The aerodynamic theory may utilize a strip theory or lifting surface theory. For further details on the aeroelastic theory and modeling procedures, refer to Theoretical Manual, Section 17, to User's Manual, Section 1.11 and to User's Guide, Section 21.

## FLUIDS

### 3.5 FLUIDS

The hydroelastic capability of NASTRAN is designed primarily to solve for small motion dynamic response of models with combined structure and fluid effects. The options include both rigid and flexible container boundaries, free surface effects and compressibility. The fluid is described with axisymmetric finite elements. The structure, however, is described with conventional non-axisymmetric elements to form matching boundaries with the fluid. The analysis assumes small perturbations about static equilibrium. Second-order velocity terms are ignored. See Theoretical Manual, Section 16.1; and User's Manual, Section 1.7, for full explanation.



## ACOUSTIC CAVITIES

### 3.6 ACOUSTIC CAVITIES

An acoustic cavity analysis may be performed to obtain the stationary waves in the steady-state flow of a gas through an axisymmetric chamber with radial slots. The width and depth of the slots and the diameter of the center volume may vary along the axis of the chamber. The boundaries of the chamber are assumed to be rigid. A Fourier series expansion is used to analyze each series harmonic as a separate NASTRAN run. See Theoretical Manual, Section 16.2; and User's Manual, Section 1.9 for details.

## HEAT TRANSFER

### 3.7 HEAT TRANSFER

Modeling procedures using finite elements for heat transfer analysis closely parallel standard structural modeling methods. Normal NASTRAN rod, plate, and solid elements may be used to model conduction and capacitance for heat transfer analysis in structures. At each grid point, temperature is the generalized degree of freedom rather than displacement. Heat input rates on grid points, surfaces, and volumes are the generalized loads.

A set of specialized "boundary elements" (HBDY) are also provided for heat transfer modeling. These elements are used to define convection between structural surfaces and fluids or other structural surfaces. They are also used in the definition of radiation "view factor" terms and as receivers of thermal flux inputs. Other non-convective boundaries may be specified using conventional constraints (SPC or MPC).

For further details, refer to descriptions given in Section 22 of the User's Guide, in Section 8 of the Theoretical Manual, and Section 1.8 of the User's Manual.

## OTHER MODELING OPTIONS

### 3.8 OTHER MODELING OPTIONS

In addition to the conventional finite elements, NASTRAN offers several alternative procedures for modeling special effects. Non-elastic structures and mechanisms may be modeled using multipoint constraint equations or rigid elements. Portions of structures may be modeled with general elements (GENEL) defined by experiment or by analysis using other programs. Direct matrix inputs (DMI, DMIG) may be used to model specific phenomena using real or complex stiffness, mass, or damping matrices.

Scalar points, extra points, scalar elements, and transfer functions are available for modeling non-structural phenomena and defining non-structural degrees of freedom. Use of scalar quantities in NASTRAN is illustrated in the NASTRAN Demonstration Problem Manual and in the User's Guide, Sections 18 and 19. Used in conjunction with solution techniques described in Section 4, a wide variety of advanced problems may be analyzed.

## MODELING RESTRICTIONS

### 3.9 MODELING RESTRICTIONS

Aside from theoretical restrictions due to finite element formulation, very few general modeling restrictions are imposed by NASTRAN. The most frequently encountered restrictions are limits on the model size which occur due to cost and computer resource restrictions. These factors are discussed in Section 14. Some of the more general modeling restrictions:

a. Element Connection Order

Most element geometries require that the connected grid points be defined in a specific order. This order is used to define the element coordinate system which, in turn, is used to define the orientation for the input of loads and for the output of stresses.

b. Element Geometry

The accuracy of some elements such as membranes and plates may be seriously effected by their geometry. Large aspect ratios and severely warped surfaces should be avoided. See Theoretical Manual, Section 15.2.

c. Engineering Units

No unit conversions are built into NASTRAN. All models must be specified using a consistent set of units for force, mass, displacement, and time. A common user error is the use of force units (pounds) for defining mass. In the metric system a common mistake is the use of mass units (kilograms) for the definition of forces or elastic constraints.

d. Numerical Roundoff

The potential errors caused by numerical roundoff require some modeling considerations. For instance, elements having stiffness terms many orders of magnitude larger than those for adjacent elements may cause numerical problems. The use of rigid elements or multi-point constraints in these cases is recommended. See Theoretical Manual, Section 15.1.

e. Uniqueness of Element ID's

Element identification numbers must be unique within each type. Although different element types may use the same identifications, it is recommended that all elements use unique IDs for the purpose of specifying loads and selecting output print and plot sets.

## MODELING WITH NASTRAN

### f. Axisymmetric Problems

Axisymmetric formulations use Fourier series expansions (CONEAX, TRAPAX, TRIAAX elements) are thus limited in their scope. Because of this they are incompatible with many of the general three-dimensional capabilities of other NASTRAN elements. See User's Manual, Section 1.3 for details.

## 4. ENGINEERING ANALYSES WITH NASTRAN

### 4.1 INTRODUCTION

The NASTRAN system provides capabilities briefly described here for many types of engineering analyses which can be performed with a particular finite element model. NASTRAN performs these analyses using the Direct Matrix Abstraction Program (DMAP) that is an integral part of the system to define and control the required sequence of matrix generation, assembly, and processing operations.

The NASTRAN user may write his own solution sequence using DMAP, or as is most often the case, he may use one or more of the twenty DMAP sequences which are stored in NASTRAN. The standard DMAP solution sequences are called Rigid Formats. They relieve the user of having to know details and/or how to control each step of an analysis. Execution of a structural problem may proceed to final solution all in one run or, at the option of the user, the DMAP sequence may be terminated at any desired intermediate point. Restart capabilities are provided for both scheduled and unscheduled interruptions in processing.

DMAP instructions may also be used to modify the existing Rigid Formats in order to change the processing sequence, to obtain printouts of selected data blocks, to provide for additional input which was generated by other programs, to output results to be used as input to other programs, and to construct entirely independent sequences of DMAP instructions to solve nearly any problem that can be formatted in matrix notation.

The different engineering analysis approaches available with NASTRAN Rigid Formats are described here. Also included are relationships between different structural and non-structural modeling options and Rigid Format applications.

Listings of each Rigid Format are presented in Section 3 of the User's Manual with descriptions and equations for all the key steps. The rules and formats for using DMAP statements are presented in Section 15 of the Guide and Section 5 of the User's Manual.

Rigid Formats are identified with an integer number, i.e., 1, 2, etc., and an analysis approach. There are three approaches: displacement (APPROACH DISP), heat transfer (APPROACH HEAT), and aerodynamic (APPROACH AERO). The user selects the Rigid Format and approach by using commands in the NASTRAN Executive Control Deck described in Section 6.

## LINEAR STATIC ANALYSIS (RIGID FORMATS 1, 2, and 14, APP DISP)

### 4.2 LINEAR STATIC ANALYSIS (RIGID FORMATS 1, 2, and 14, APP DISP)

The Linear Static Analyses provided by Rigid Formats 1, 2 and 14 use most of the features available for model definition in NASTRAN. These include specification of special coordinate systems, grid point locations, element connectivities, material properties, constraints, and temperature distributions as well as direct grid point force and element loadings. The results available for output consist of weight and balance information, displacements, element forces and stresses, grid point loadings, and support reactions. The user may also request plots of the undeformed as well as the deformed structural model.

Rigid Format 2, which provides all the features of Rigid Format 1, also treats structural models which are not fully constrained. It computes the inertia effects of unconstrained rigid body accelerations. These effects are added to the user-specified loadings; the rigid body motions are constrained; and then the normal static analysis is performed.

Rigid Format 14 is a special case of Rigid Format 1 and provides for efficient modeling and analysis of structures exhibiting cyclic symmetry. Many structures, including pressure vessels, rotating machines and antennae for space communications, are made up of virtually identical segments that are symmetrically arranged with respect to a centroidal axis. There are two types of cyclic symmetry: simple rotational symmetry, in which the segments do not have planes of reflective symmetry and the boundaries between segments may be general doubly-curved surfaces; and dihedral symmetry, in which each segment has a plane of reflective symmetry and the boundaries between segments are planar. The use of cyclic symmetry allows the user to model only one of the identical substructures. There will also be a large saving of computer time for most problems.

Procedures for using the static analysis Rigid Formats are outlined in Section 18. The procedure for using cyclic symmetry in NASTRAN is described in detail in Section 23 of the Guide. The theoretical treatment for cyclic symmetry is given in Section 4.5 of the Theoretical Manual.

## NONLINEAR STATIC ANALYSIS AND BUCKLING (RIGID FORMATS 4, 5 and 6, APP DISP)

### 4.3 NONLINEAR STATIC ANALYSIS AND BUCKLING (RIGID FORMATS 4, 5 AND 6, APP DISP)

NASTRAN provides for two types of static nonlinearities, differential stiffness and material plasticity. The differential stiffness effects treated by Rigid Formats 4 and 5 provide the user with a second order approximation to the nonlinear effects of large deflections. The differential stiffness matrix is computed as a correction to the original stiffness matrix from the work done by each element in response to a user-specified preload. Rigid Format 4 adjusts the differential stiffness matrix as a load correction in accordance with user specified convergence criteria. In Rigid Format 4, the applied loads are not linearly related to the internal loads. In Rigid Format 5, the applied loads are assumed to move with their points of application and they remain fixed in magnitude and direction.

Rigid Format 5 adds the differential stiffness matrix to the original stiffness matrix, and solves an eigenvalue problem to obtain the critical load factor that would produce buckling. This critical load factor, or the eigenvalue, multiplied into the preload vector gives the critical loading at which the structure would go unstable. The eigenvector obtained is the mode shape in which the structure would buckle.

Rigid Format 6, on the other hand, is used for problems involving non-linear materials. That is, the material properties are assumed to be stress dependent. The loading is applied in piecewise linear increments. After each increment, a new stiffness matrix is generated based on the current state of stress in each element. This new matrix is used to solve for a corresponding increment of displacement and stress. These increments are accumulated to produce the final nonlinear results. Since each increment in load requires a new solution, the user is faced with the compromise between accuracy, which requires small increments, and efficiency, which suggests using the largest possible increments. All static load options are allowed except for those due to temperature and enforced element displacements.

Section 18 of the Guide includes descriptive detail on how to use each of these three Rigid Formats. The theoretical treatments for material non-linearities and differential stiffness can be found in the Theoretical Manual, Sections 3.8 and 7.0, respectively.



## NORMAL MODES ANALYSIS (RIGID FORMATS 3, 13, and 15, APP DISP)

### 4.4 NORMAL MODES ANALYSIS (RIGID FORMATS 3, 13, and 15, APP DISP)

Rigid Formats 3, 13, and 15 provide for a normal mode analysis of undamped systems with symmetric matrices. Rigid Format 3 is for use with elastic, linear structural models. Rigid Format 13 allows the use of differential stiffness effects. The applied loads are assumed to move with their points of application and they remain fixed in magnitude and direction. Rigid Format 13 adds the differential stiffness matrix to the original stiffness matrix in proportion to a user-specified increment for the deflections due to the preload plus incremental load which is the total load applied to the model. Rigid Format 15 computes normal modes for models utilizing cyclic symmetry. Additionally, normal modes calculations are included in the Rigid Formats for Complex Eigenvalue Transient Response and Modal Flutter analyses summarized in the next Section.

Rigid Formats 3, 13, and 15 generate both mass and stiffness matrices and offer a choice of methods for eigenvalue extraction. If only a limited number of mode shapes are required within a user specified range of frequencies, then the FEER, Inverse Power or Determinant method would be the appropriate choices. The Givens method of tridiagonalization is available and is recommended if all or a large proportion of the natural frequencies and mode shapes are desired. A Guyan reduction, which is available in all Rigid Formats for eliminating specified degrees of freedom, is recommended for reducing the size of the matrices to be used by the Givens method. (Massless degrees of freedom must be eliminated for this method.)

The available output of results includes the eigenvalues and natural frequencies, mode shape deflections, modal forces and stresses for selected elements, modal reaction forces, modal mass, and plots of the structural model for each mode shape.

The detailed theoretical basis for these calculations is presented in the Theoretical Manual, Section 10. Section 19 of the Guide describes how to apply these three normal modes analysis Rigid Formats.

## COMPLEX EIGENVALUE ANALYSIS (RIGID FORMATS 7 and 10, APP DISP)

### 4.5 COMPLEX EIGENVALUE ANALYSIS (RIGID FORMATS 7 AND 10, APP DISP)

Rigid Formats 7 and 10 offer the user a capability to compute complex eigenvalues and vectors of non-conservative systems. These Rigid Formats provide for an analysis of systems which include user-specified input of real or complex mass, damping and stiffness matrices or matrix transfer function equations. The assembled matrices may be real or complex, symmetric or nonsymmetric, singular or nonsingular.

The two formulations provided are the direct formulation of Rigid Format 7 and the modal formulation of Rigid Format 10. The direct formulation provides for the most general description of a model which also includes program generated viscous and structural damping. The unknowns are the degrees of freedom related to grid points, scalar points, and any special extra points which may be used to specify non-structural quantities as are encountered in control system, aerodynamic, or hydrodynamic modeling.

The modal approach, in contrast, employs the free vibration modes of the undamped model as independent degrees of freedom to be assembled with the user-specified direct input matrices and extra point control parameters. Proportional viscous damping on the modal coordinates is included.

The selection of approach would depend on the particular problem to be solved and the number of roots to be extracted. The direct approach offers the greatest flexibility if only a few roots are desired. If many roots are to be extracted, the modal approach may be more economical. A summary of features comparing direct versus modal approaches for the dynamics Rigid Formats is presented in Table 1 to help the user select the Rigid Format best suited to his needs.

The available output includes frequencies and mode shape displacements, element forces and stresses, and support reactions. These may be printed in either SORT1 or SORT2 in either real/imaginary or magnitude/phase angle format. SORT1 prints all the requested output for each frequency. SORT2 prints each component of output for all frequencies. The theoretical basis for these Rigid Formats is presented in the Theoretical Manual, Section 10, and their use is presented in Section 19 of the Guide.

## DYNAMIC RESPONSE ANALYSIS (RIGID FORMATS 8, 9, 11 and 12, APP DISP)

### 4.6 DYNAMIC RESPONSE ANALYSIS (RIGID FORMATS 8, 9, 11 and 12, APP DISP)

The NASTRAN dynamic analysis Rigid Formats provide a maximum amount of flexibility and capability. Rigid Formats 8 and 11 offer Frequency and Random Response capability and Rigid Formats 9 and 12 offer Transient Analysis capability. Rigid Formats 8 and 9 use a direct approach; the other two use a modal approach. Table 1 summarizes the various options available to help the user select the Rigid Format best suited to his particular problem.

These capabilities can be used to solve problems with thousands of degrees of freedom with many time steps, or many frequencies and mode shapes. Provision has been made to allow many types of special modeling techniques. Care should be taken, however, to avoid the dynamic analysis of models that may be unnecessarily large because of the lengthy (and expensive) computing times required for solution. Every effort should be made to reduce the size of the problem either by careful design of the original model or by using the Guyan method to reduce the total degrees of freedom. The user should pay special attention to the selection of the most economical method for solving his particular problem.

The modal approach for dynamic analyses differs from the direct approach in that it uses the undamped mode shapes as independent degrees of freedom replacing the original model. In either approach, special extra points may be added for special modeling purposes. The input loads for the modal approach are transformed to the modal coordinates, and the resulting modal displacements are transformed back to the physical displacements for output purposes.

The choice of direct or modal approach is dependent on the specific problem. The direct approach solves a more general problem and does not require the extra steps of extracting the normal modes and of performing the transformations to form modal coordinates. For transient analysis, however, if many time steps are required, the direct formulation may be inefficient compared with the modal approach.

Also available with the modal approach (Rigid Formats 11 and 12) is a mode acceleration method of improving the solution accuracy. This procedure replaces the unconstrained rigid body accelerations with equivalent inertial and damping forces. The augmented loading is then solved statically to obtain improved element forces and stresses. The user is cautioned, however, that this method is costly and should be used selectively.

## ENGINEERING ANALYSES WITH NASTRAN

The Frequency and Random Response analysis of Rigid Formats 8 and 11 can be used to analyze the steady state response of systems due to sinusoidally varying loads at specified frequencies. The model may include direct input matrices and transfer functions. The assembled matrices may be non-symmetric, real or complex, and singular or nonsingular. Loads must be input on specific degrees of freedom and may have phase angles, time lags, and frequency dependent magnitudes. The output may be sorted by frequency (SORT1) or by component for all frequencies (SORT2) and printed in either a real/imaginary or a magnitude/phase angle format. Curve plotting of these results is also available for each output component or a function of frequency.

The Random Response analysis is treated as a data reduction procedure that is applied to the results of a Frequency Response analysis. The user inputs a power spectral density function, which is assumed to be stationary with respect to time, and the program computes the power spectral density, mean deviation and autocorrelation function for the response of the selected output components. The output from the Random Analysis must be selected one component at a time, not via the Case Control options, but via the control cards of the X-Y plot package. The random output will be real numbers automatically printed and may be plotted versus frequency if so requested.

The Transient Analyses (Rigid Formats 9 and 12) perform a step-by-step integration of the structural response in a time domain. The user provides the initial conditions, time step requirements, and a time varying load. The available output for specified integration time intervals includes displacements, velocities, accelerations, forces, and stresses for selected elements and support reactions.

Some special features available to Transient Analysis include the capacity to incorporate user-specified direct input matrices, nonsymmetric control function equations, and a limited nonlinear analysis capability. The nonlinear capability is available through displacement and velocity dependent load components applied to specific degrees of freedom. For purposes of economy, the user may change the integration time step. However, for each time step change, the coefficient matrices must be reassembled.

The theoretical basis for these analyses is presented in the Theoretical Manual, Section 9 through 12 and their use is described in Section 19 of the Guide.

## LINEAR STATIC HEAT TRANSFER ANALYSIS (RIGID FORMAT 1, APP HEAT)

### 4.7 LINEAR STATIC HEAT TRANSFER ANALYSIS (RIGID FORMAT 1, APP HEAT)

The linear heat transfer formulation is analogous to the structural formulation with temperatures replacing deflections as the unknowns. Rigid Format 1 is available for determining steady-state temperatures with no radiation effects. The same modeling features for specifying grid point geometry, element connectivity and material properties are provided. In addition, special features are available for the specification of fixed temperature, convection, and heat flux boundary conditions. The available output consists of resultant grid point temperatures throughout the model. This capability is described in detail in Section 22.

## NONLINEAR STATIC HEAT TRANSFER ANALYSIS (RIGID FORMAT 3, APP HEAT)

### 4.8 NONLINEAR STATIC HEAT TRANSFER ANALYSIS (RIGID FORMAT 3, APP HEAT)

Rigid Format 3, APPROACH HEAT, which provides all the features of Rigid Format 1, also treats heat transfer analyses with temperature dependent conductivities of the elements and nonlinear radiation exchange. The solution of thermal equilibrium is obtained using an iterative technique that is user controlled. Section 22 describes in detail how to apply this capability.

## TRANSIENT HEAT TRANSFER ANALYSIS (RIGID FORMAT 9, APP HEAT)

### 4.9 TRANSIENT HEAT TRANSFER ANALYSIS (RIGID FORMAT 9, APP HEAT)

Rigid Format 9, APPROACH HEAT, provides the capability of time domain analysis for models that include linear conduction, film heat transfer, nonlinear radiation, and any special effects modeled with NASTRAN nonlinear elements. User controls for integration procedures and options for linearizing radiation effects are provided. More detail on how to apply this capability is presented in Section 22.

## AERODYNAMIC FLUTTER ANALYSIS (RIGID FORMAT 10, APP AERØ)

### 4.10 AERODYNAMIC FLUTTER ANALYSIS (RIGID FORMAT 10, APP AERØ)

Rigid Format 10, APPROACH AERØ, provides the capability for modal flutter analysis for stability studies of aeroelastic systems with a minimum number of degrees of freedom. This Rigid Format includes structural mode calculations, aerodynamic matrix calculations, and transformation of the aerodynamic matrix to modal coordinates. The flutter stability analysis is performed using one of three available user selected methods: the K-method, the KE-method, and the PK-method. Solutions may be obtained for subsonic and supersonic flow conditions. How to access this capability is described in Section 21.



## AERODYNAMIC RESPONSE ANALYSIS (RIGID FORMAT 11, APP AERØ)

### 4.11 AERODYNAMIC RESPONSE ANALYSIS (RIGID FORMAT 11, APP AERØ)

Rigid Format 11, APPROACH AERØ, provides the capability to compute responses of an aeroelastic system due to applied loads and gusts. This Rigid Format may be used to solve frequency response, random response, and transient response problems. Transient analyses are performed using a Fourier transform method. The structural model is reduced to normal mode format prior to coupling with the aerodynamic matrix. This Rigid Format may be used for both subsonic and supersonic flow conditions. Details are presented to access this Rigid Format in Section 21.

## CORRELATION OF ANALYSIS VERSUS MODEL CAPABILITIES

### 4.12 CORRELATION OF ANALYSIS VERSUS MODEL CAPABILITIES

A summary of NASTRAN modeling options versus Rigid Format application is presented in Table 2. Modeling options available in NASTRAN were introduced earlier in Section 3; the Rigid Formats are introduced here in Section 4, and the relationships between the two are summarized in the table.

ENGINEERING ANALYSES WITH NASTRAN

Table 1. Summary of Analysis Options for Dynamic Rigid Formats

OPTIONS	RIGID FORMAT NUMBER, APP DISP					
	DIRECT			MODAL		
	Complex Eigenvalue 7	Frequency Response 8	Transient 9	Complex Eigenvalue 10	Frequency Response 11	Transient 12
Proportional Structural Damping	1	1				
Proportional Viscous Damping			1	2	2	2
Damping Elements	1	1	1			
Real Direct Input Matrices or Transfer Functions	3	3	3	3	3	3
Complex Direct Input Matrices	3	3		3	3	
Non-linear Functions			3			4
Initial Conditions			3			4
Loads		3	3		3	3

Optional input constraints:

- (1) Applied to structure only
- (2) Applied to modal coordinates only
- (3) Applied to structure or extra points
- (4) Applied to extra points only

CORRELATION OF ANALYSIS VERSUS MODEL CAPABILITIES

Table 2. Summary of Modeling Options Versus Rigid Format

MODELING OPTIONS	DISP															HEAT			AERO	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	3	9	10	11
<b>STRUCTURES/NONSTRUCTURES</b>																				
1,2,3D Structures	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Substructures	•	•	•					•	•											
Cyclic Structures														•	•					
Axisymmetric Structures	•	•	•			•	•	•	•	•	•					•	•	•		
Aerodynamic Modeling																			•	•
Acoustic Modeling			•					•	•	•	•	•								
Hydroelastic Modeling							•	•	•											
<b>NON-LINEARITIES</b>																				
Large Deflection Modeling				•	•									•						
Non-linear Materials						•											•			
<b>HEAT TRANSFER</b>																				
Conduction & Convection																•	•	•		
Radiation																	•	•		
<b>LOADS</b>																				
Static Loads	•	•		•	•	•		•	•		•	•	•	•		•	•	•		•
Frequency Dependent Loads								•			•									•
Time Dependent Loads									•			•						•		•
Non-Linear Loads									•			•						•		
<b>CONSTRAINTS</b>																				
Guyan Reduction	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•
Multi-Point Constraints	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Single Point Constraints	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Element Deformation	•	•		•	•	•							•	•						
Rigid Elements	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Free Body Supports		•	•							•	•	•				•			•	•

## 5. INTRODUCTION TO THE NASTRAN SYSTEM

### 5.1 PROGRAM DESIGN CRITERIA

The NASTRAN program has been designed according to two classes of criteria. The first class related to functional requirements for the solution of an extremely wide range of large and complex problems in structural analysis with high accuracy and computational efficiency. These criteria are achieved by developing and incorporating the most advanced mathematical models and computational algorithms that have been proven in practice. In particular, they are achieved by providing such features as the bandwidth-with-active-column technique in matrix decomposition; packing routines to take maximum advantage of matrix sparsity so as to conserve input/output time; highly stable and efficient algorithms for the solution of problems in eigenvalue analysis and transient response; and an elegant approach to modeling the effects of control systems and other nonstructural components.

The second class of criteria relates to the operational and organizational aspects of the program. These aspects are somewhat divorced from structural analysis itself; yet they are of equal importance in determining the usefulness and quality of the program. Chief among these criteria are:

1. Simplicity of program input deck preparation.
2. Minimization of chances for human error in problem preparation.
3. Minimization of need for manual intervention during program execution.
4. Ease of program modification and extension to new functional capability.
5. Ease of program extension to new computer configurations and operation systems, and generality in ability to operate efficiently under a wide set of configuration capabilities.
6. Capability for step-by-step problem solution, without penalty of repeated problem set up.
7. Capability for problem restart following unplanned interruptions or problem preparation error.
8. Minimization of system overhead, in the three vital areas:
  - a. Diversion of core storage from functional use in problem solution.
  - b. Diversion of auxiliary storage units from functional to system usage.
  - c. System housekeeping time for performing executive functions that do not directly further problem solution.

## INTRODUCTION TO THE NASTRAN SYSTEM

To achieve a program design to meet these criteria, NASTRAN was developed as a modular system with its own executive control capability. Specific attention was given to opening the program to offer maximum user control over its operations. These design objectives are described next, followed by an overview of the computer system requirements imposed by the program and a preview of how the NASTRAN data deck is organized.

### 5.1.1 Modular Design and Executive Control

The criteria stated above have been achieved in NASTRAN by using modular separation of functional capabilities in designing the software system. Each module is independent of all other modules in the sense that modification of a module or addition of a new module will not in general require modification of other modules.

Furthermore, control of module executions is performed by an efficient, problem-independent Executive System. The concepts of functional modules and an Executive System providing control are illustrated by the software constraints specified for module development and operation.

The restrictions on modules are as follows:

1. Modules may interface with other modules only through auxiliary storage files that contain data blocks.
2. Since the availability of the auxiliary files required for the execution of a module depends on the execution of other modules, no module can specify or allocate files for its input or output data. All auxiliary storage allocation is reserved as an executive function.
3. Modules operate as independent subprograms and may not call or be called by other modules. They may be entered only from the executive routine.
4. Modules may interface with the executive routine through a parameter table that is maintained by the executive routine. User-specified options and parameters are communicated to modules in this way. The major line of communication is one-way, from user to executive routine to module. However, in addition, an appreciable two-way communication from module back to executive routine (and, therefore, to other modules) is permitted via the parameter table.

## PROGRAM DESIGN CRITERIA

No other constraints, except those imposed by the resident compilers and operating systems, are required for functional modules.

The essential functions of the executive system are:

1. To establish and control the sequence of module executions according to options specified by the user.
2. To establish and communicate values of parameters for each module.
3. To allocate files for all data blocks generated during program execution and perform input/output to auxiliary files for each module.
4. To maintain a full restart capability for restoring a program execution after either a scheduled or unscheduled interruption.

Each of these functions is essentially independent of any particular feature of structural analysis and applies to the operational control of any complex multimodule, multifile application program. The Executive System is open-ended in the sense that it can accommodate an essentially unlimited number of functional modules, files, and parameters. Modification of the executive system necessary for modification or extension of functional modules is restricted to changes in entries in control tables stored within the executive routine.

### 5.1.2 Design for User Control

The needs of the structural analyst have also been considered in all aspects of the design of the program. The first thing to be remembered is that, in view of the wide range of possible applications of the program, it is not known exactly what these needs may be. For this reason a high degree of flexibility and generality has been incorporated into certain areas of the program. For example, in addition to the usual list of structural elements that refer to specific types of construction, the user is provided with more general elements that may be used to construct any type of special element, to represent part of a structure by deflection influence coefficients, or to represent part of a structure by its vibration modes. For the more conventional types of structural analysis, the user is presented with a large number of convenience features, including plotting routines, which are definite necessities for analyzing large problems.

A major difficulty that a user faces in the solution of large problems is the avoidance of errors in the preparation of input data. Card formats and card ordering are made as simple and

## INTRODUCTION TO THE NASTRAN SYSTEM

flexible as possible in NASTRAN in order to avoid errors caused by trivial violations of format rules. A number of aids for the detection of legal but incorrect data are also provided.

The problems that can be solved by NASTRAN include the following general classes:

1. Static Structural Problems
2. Elastic Stability Problems
3. Dynamic Structural Problems
4. General Matrix Problems
5. Heat Transfer Problems
6. Aeroelasticity Problems

Each general problem class is further subdivided into case types which differ with regard to the type of information desired, the environmental factors considered, or the method of analysis. The mathematical computations required to solve problems are performed by the subprogram units called functional modules. Each case type requires a distinct sequence of functional module calls that are scheduled by the Executive System.

General methods of problem solution for all classes listed above except general matrix problems are established internally to NASTRAN. This is accomplished with coded sequences of macro instructions, called DMAP (for Direct Matrix Abstraction Program) commands, which are stored in the Executive System. Each particular sequence is called a Rigid Format and is requested by the user for the particular analysis to be performed (statics, elastic stability, dynamics, etc.).

Each Rigid Format consists of two parts. The first is a sequence of instructions (including instructions for executive operations as well as for functional module operations) that is stored in tables maintained by the executive system. The second part is a set of restart tables that automatically modify the sequence of instructions to account for any changes in the input data when a restart is made after partial or complete execution of a problem. The restart tables can accommodate a change of Rigid Format such as occurs, for example, when vibration modes are requested for a structure that was previously analyzed statically. The restart tables are, as can be imagined, quite extensive, and their generation constitutes a significant part of the effort expended in developing a Rigid Format. They are, however, one of the more important cost-saving features of NASTRAN.

It is also possible for the user to modify a Rigid Format via an ALTER feature, which is described in Section 2.2 of the User's Manual. Typical uses of the ALTER feature are to schedule



## PROGRAM DESIGN CRITERIA

an exit at an intermediate point in a solution for the purpose of checking intermediate output, to schedule the printing of a table or a matrix for diagnostic purposes, and to add or delete a functional module from the sequence of operating instructions.

A flexible procedure is provided for the solution of general matrix problems. All of the matrix operations (such as addition, multiplication, triangular decomposition, and eigenvalue extraction) used in the program can be directly addressed by the user with DMAP. The user constructs a chain of DMAP instructions in order to effect the solution of general matrix problems.

The rules for generating a DMAP sequence are explained in Section 5 of the User's Manual. The DMAP sequence itself consists of a series of statements consisting of executive operation instructions and functional module calls. Each statement contains the name of the instruction (or functional module), the names of the input data blocks, the names of the output data blocks, and the names and values of parameters. Typical examples of parameter usage are to indicate whether an operation is to be performed with single- or double-precision arithmetic, which mathematical method will be used (when there are options), or the desired format of the output.

The names of some of the executive operations are BEGIN, CHPNT (used when it is desired to copy data blocks onto the Problem Tape in case an unscheduled restart is necessary), FILE (used to save an intermediate data block), REPT (used to provide looping capability), PURGE (used to prevent storage of data blocks), and END.

The functional modules belong to one of the following categories: structural modules, matrix operations, utility modules, and user modules. The structural modules are the main subprograms of NASTRAN. Some examples of structural modules, taken from dynamic analysis, are: READ (Real Eigenvalue Analysis), GKAM (Modal Dynamic Matrix Assembler), TRD (Transient Response, Dynamic), and DDR (Dynamic Data Recovery). Typical matrix operations provided are: add, multiply, transpose, etc. The utility modules mainly provide capability for formatting output data. The user modules are dummy modules that provide the user with the ability to write new functional capability that will automatically be recognized by the Executive System.

The usual methods of output for NASTRAN are the operating system print or punch files and the NASTRAN plot tapes. Procedures for normal output selection are described in Section 2.3 of the User's Manual. The printing of tables or matrices generated by NASTRAN is controlled by a group of utility modules described in Section 5.3 of the User's Manual. In many cases, it is desirable to save matrices and tables for use in restart operations. When using Rigid Formats,

## INTRODUCTION TO THE NASTRAN SYSTEM

it is possible to save preselected tables and matrices by using the checkpoint option described in Section 2.2 of the User's Manual. Checkpointed files are written on the New Problem Tape. It is also possible for the user to save selected matrices on tape by inserting one of the user modules described in Section 5.3 of the User's Manual into the DMAP sequence by means of the ALTER option.

The usual method of input for NASTRAN is the operating system card reader. When performing restarts, the New Problem Tape from a previous run is redesignated as the Old Problem Tape and used as an additional source of input. Tapes that have been prepared with user modules on previous runs can also be used as additional input sources by inserting one of the input user modules into the DMAP sequence by means of the ALTER option.

## PROGRAM SYSTEM REQUIREMENTS

### 5.2 PROGRAM SYSTEM REQUIREMENTS

NASTRAN is a very large, FORTRAN computer program. It consists of more than 1600 sub-routines and over 200 individual overlay segments. The program is designed for batch mode operation on each of three computer configurations: IBM System 360/370 series, CDC 6000/CYBER series, and UNIVAC 1108/1110 series computers.

Two key concepts in the structure of NASTRAN are the open core and file concepts. All data used or created in NASTRAN calculations are stored in an area of computer memory which begins where program instructions end and terminates where the user has specified the limit of memory resources for the particular job. This area of memory is called "open core." Data are only temporarily stored in open core. While the data are not actually needed for computations, they are stored on either input, output, or scratch files assigned to the particular module. Thus, the file is the primary source of data storage, and FORTRAN file requirements are a major system resource requirement of NASTRAN. Typical NASTRAN runs require as many as 50 FORTRAN files for execution.

The open core concept is described in detail with an example in Section 5.2.4. NASTRAN file usage is described in Section 5.2.5. Additional information about NASTRAN and its characteristics peculiar to installation on different computers is presented in Sections 5.2.1 through 5.2.3.

#### 5.2.1 NASTRAN Computers

Although NASTRAN is a FORTRAN-oriented system, considerable effort was required to develop programming and word-handling techniques applicable to three separate computer configurations. These computers exhibit wide differences in their binary word sizes and integer representation methods. The current computer configurations for NASTRAN and their significant differences follow:

1. IBM System 360/370 Series  
Word Size - 32 Bits  
Character Capacity - 8 bits/character and 4 characters/word (character  $\equiv$  byte)  
Integer Representation - Twos complement for negative integers
2. UNIVAC 1108/1110  
Word Size - 36 Bits

## INTRODUCTION TO THE NASTRAN SYSTEM

Character Capacity - 6 bits/character and 6 characters/word

Integer Representation - Ones complement for negative integers

### 3. CDC 6000/CYBER

Word Size - 60 Bits

Character Capacity - 6 bits/character and 10 characters/word

Integer Representation - Ones complement for negative integers

#### 5.2.2 Alphanumeric Data

Data stored within a computer as binary-coded-decimal (BCD) characters must be represented by the proper hardware-defined bit codes. These character codes (and in the case of the IBM System/360, the number of bits representing the code) vary among the NASTRAN computer types. Although the number of characters-per-word could have been obtained from the SYSTEM table, various data blocks and buffers within NASTRAN required firm entry sizes, regardless of computer type, to facilitate indexing. For these reasons, the minimum number of characters-per-word (4) among the three computer types was chosen as a program design standard. Computer types with a word capacity of greater than four characters will have the unused low-order character positions filled with BCD blanks.

#### 5.2.3 Word Packing

Standard FORTRAN compilers do not provide the capability for storing or retrieving data that occupies less than a full computer word. Through the Machine Word Functions (MAPFNS) routine, some limited word packing (not to be confused with matrix packing) is performed within the Executive System and a few utility subroutines. Packing provides an efficient use of memory space at the expense of the additional operating time needed to combine or separate the elements of the packed words. The Machine Word Function ORF is generally used for combining elements, while ANDF with a suitable mask is used for separating them.

#### 5.2.4 The Open Core Concept

The design philosophy of the NASTRAN system dictated a completely open-ended design whenever possible. NASTRAN was to have the flexibility to operate on a second-generation machine with a 32K core (such as the now unsupported IBM 7094/7040 DCS) as well as the largest of the IBM S/360 series of computers, and take complete advantage of the additional core storage without major

## PROGRAM SYSTEM REQUIREMENTS

program changes. The use of a fixed dimension for large arrays was rejected, since this automatically restricted the size of a problem that could be solved. Instead, modules were programmed to allocate space as required and to use spill logic to transfer data to scratch files when complete core allocation is impossible. In this manner, a problem might cause spill logic to be used on a computer with limited core storage, but not on a computer with a large core storage capacity.

### 5.2.4.1 Definition of Open Core

The definition of open core in NASTRAN is: a contiguous block of working storage defined by a labeled common block whose length is a variable determined by the NASTRAN executive function, CØRSZ. The implementation of this definition by the module writer consists of the originating of a labeled common block at the end of his overlay segment. This labeled common block contains a dimensioned variable of length 1. CØRSZ returns the number of words of core available between his open core origin and the end of core. The module writer can now write his program as if he had dimensioned his array by that number. In actuality, he is extending beyond the area reserved for the array into an area reserved for the job but not currently used by the segment. When implementing this concept, care must be taken to assure that the system does not use this area.

### 5.2.4.2 Example of an Application of Open Core

Figure 1 demonstrates the use of open core by two subroutines, A and B. By some means, which are machine dependent and are discussed in Section 5, an end point is established for open core. The length of open core is then the difference between this end point and the labeled common block. In the example shown, subroutine A will have more open core available to it than B does.

### 5.2.5 NASTRAN Input and Output Files

The particular (IBM S/360, UNIVAC 1100, CDC 6000) operating system input and output files provide the required data connection between NASTRAN, the input data decks, and the printed output. Utility subroutines XRCARD and RCARD convert special NASTRAN input card formats to standard FORTRAN data words easily handled by all NASTRAN input processors. Printed output is generated through FORTRAN-formatted write statements. All internal data block input/output is handled by GINØ, the system of NASTRAN general purpose input/output routines. GINØ provides the required manipulation

## INTRODUCTION TO THE NASTRAN SYSTEM

to tailor the variable-length logical data records needed by most NASTRAN modules to fixed-length records available on all direct access mass storage hardware.

### 5.2.5.1 Use of the Operating System Input File

The system input file is read only by the following routines within the NASTRAN Preface:

1. SEMINT reads the first card and processes it using utility XRCARD if it is the NASTRAN card.
2. The Executive Control Deck containing free-field cards is read and processed by XCSA using the XRCARD utility.
3. The Case Control Deck containing free-field cards is read and processed by IFP1 using the XRCARD utility.
4. The Bulk Data Deck containing fixed-field cards is read by XSORT. This data is subsequently processed by IFP using the RCARD utility.

These card conversion utilities (XRCARD and RCARD) provide, respectively, all the free-field and fixed-field data card processing required by NASTRAN.

### 5.2.5.2 Use of the Subroutine XRCARD

XRCARD interprets NASTRAN free-field data cards and processes the fields into a sequential buffer that can be easily handled by subsequent modules. Free-field data consist of series of data items separated by suitable delimiters and punched in non-specific card columns. Data items may include alphanumeric, integer, and various types of real variables. Field delimiters may include the comma, slash, parenthesis, and blanks. For details regarding data and delimiter usage and the format of the sequential output buffer, see the XRCARD subroutine description in the Programmer's Manual, Section 3.4.19.

### 5.2.5.3 Use of the Subroutine RCARD

RCARD interprets NASTRAN fixed-field data cards and processes the fields into a sequential buffer that can be easily handled by subsequent modules. Fixed-field data consist of data items punched within specific card fields. Each eighty-column card is divided into an eight-column ID field (for the card mnemonic) followed by either eight eight-column data fields or four sixteen-column data fields. A special character (asterisk or plus) within the ID field determines

## PROGRAM SYSTEM REQUIREMENTS

when the card is to be interpreted as containing sixteen-column fields. The last eight columns of the card are for continuation mnemonics used by XSDRT and are not processed by RCARD. The data item within the ID field must be alphanumeric. The data items within all other fields may include alphanumeric, integer, and various types of real variables. For details regarding data and the format of the sequential output buffer, see the RCARD subroutine description in the Programmer's Manual, Section 3.4.20.

### 5.2.5.4 Use of the Operating System Output File

Although NASTRAN printed output is formed and placed onto the system output file through use of standard FORTRAN-formatted write statements, two basic NASTRAN design concepts prohibit every operating module from generating printed output. First, since the FORTRAN I/O package for output generation occupies a sizable block of computer memory, this package is generally positioned by loader directives within specific output-oriented segments, rather than within the root segment of the overlay, to reduce the total memory requirement. Second, because many functional modules generate the same or similar diagnostic and information messages, a NASTRAN message writer (MSGWRT) was developed to centralize message text and thus prevent duplications within many separate modules.

For the reasons previously discussed, NASTRAN output generation is restricted to a specific class of modules which can reside within an output-oriented segment below the link root segment. These segments contain the output-producing modules such as the Output File Processor (OFP), the Message Writer (MSGWRT), and the various table and matrix printers (TABPT, MATPRT, etc.) along with the output titling (PAGE) and necessary FORTRAN I/O packages.

### 5.2.5.5 GINØ

GINØ is a collection of subroutines which provide for all input and output operations within NASTRAN except reading data from the resident system input file and writing data on the resident system output and punch files. These latter operations are accomplished through FORTRAN-formatted read/write statements. NASTRAN performs input/output operations by making the following calls to GINØ entry points:

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### 1. OPEN

OPEN initiates activity for a file (unless the data block assigned to the file is purged, in which case an alternate return is given). A working storage area (GINØ buffer), for use by GINØ, is assigned (allocated) by the calling program, thus providing optimum allocation of storage by the calling program. This working storage area is reserved for use by GINØ until activity on the file is terminated by a call to CLOSE (see paragraph 4, below). On each of the NASTRAN computers, the working storage area allocated by the calling program is separate from the actual physical I/O buffer.

### 2. WRITE

WRITE writes a specified (by the calling program) number of words on a file. The block of words to be written may comprise an entire logical record or portion of a logical record.

### 3. READ

READ returns to the calling program a specified (by the calling program) number of words from the logical record at which the file is currently positioned. READ may be used to transmit an entire logical record or portion of a logical record.

### 4. CLOSE

CLOSE terminates activity for a file. The working storage area assigned at OPEN is released. The file is repositioned to the load point is requested.

### 5. REWIND

REWIND repositions the requested file to the load point. The file must be "open," i.e., a REWIND operation is requested subsequent to a call to OPEN and prior to a call to CLOSE.

### 6. FWDREC

RWDREC repositions the requested file one logical record forward.

### 7. BCKREC

BCKREC repositions the requested file one logical record backwards.

### 8. SKPFIL

SKPFIL repositions the requested file forward or backward N logical files, where N is specified by the calling program.



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### 9. EOF

EOF writes a logical end-of-file on the requested file.

The basic unit of I/O in NASTRAN is a logical record. The length of a logical record is completely variable and may range from one word to an arbitrarily large number of words. For NASTRAN matrix data blocks, the convention was adopted that each column of the matrix would comprise one logical record. For NASTRAN data blocks containing tables, no rigid convention exists. Typically, each logical record contains one table of a specific type.

The logical record concept provides greatest ease in programming. However, since these records must be stored on a physical device such as a drum, disk, or tape, the characteristics of the device must be taken into consideration. The bulk of NASTRAN data is stored on drums or disks. For both these devices, the common unit of organization is a track, which stores a fixed number of words. Thus, there is a conflict between the variable-length GINØ records and the fixed-length tracks.

This conflict is resolved by blocking. GINØ acts as the interface between the device and the NASTRAN program. Using this technique, the program itself need not be concerned with device considerations (which would create machine-dependent code). GINØ has been parameterized so that different devices may be easily accommodated.

Basically, blocking provides for the reading and writing of fixed-length blocks. The length of a block is a function of the device. It may be one track, one-half track, or other integral division of a track (but never more than one track). Because of the relatively large time to access a given position on a track (due to the rotational speed of the device and/or mechanical movement of the head to the track), a block size equal to one full track is the most desirable. However, limitations in the amount of storage available to hold the blocks in core is a second consideration.

Since the logical record lengths are variable but the length of records physically read or written is fixed, logic must be provided to accommodate this situation. This logic is provided in the GINØ routine, which allows for the following cases:

1. Multiple logical records per block
2. Multiple blocks per logical record

## INTRODUCTION TO THE NASTRAN SYSTEM

The method by which physical input and output of blocks is accomplished by GINØ is machine dependent. On the IBM S/360, BSAM macros are used; on the UNIVAC 1108, NTRAN is used; on the CDC 6600, NØS macros are used. These implementation differences are transparent to the NASTRAN applications programmer (functional module writer). The systems programmer who is interested in implementation details on the various machines is referred to Section 5 of the Programmer's Manual.

The names of files input as arguments to the GINØ routines listed above may be alphabetic (BCD, of the form 4HXXXX) or integer.

A GINØ file name is BCD if the file contains permanent executive tables or data blocks. A list of these files for a particular NASTRAN run resides in the permanent portion of the FIST executive table. The following list presents all current executive files with their BCD file names:

<u>File</u>	<u>BCD File Name</u>
Data Pool File	PØØL
New Problem Tape	NPTP
Old Problem Tape	ØPTP
BCD Plot Tape	PLT1
Binary Plot Tape	PLT2
User's Master File	UMF
New User's Master File	NUMF
User Input File	INPT
User Input Files	INP1 - INP9

Functional modules should not access these permanent executive files. Functional modules access the files on which their input, output, and scratch data blocks reside by internal integer GINØ file names. Prior to calling a functional module, the link driver routine, XSEMI, calls subroutine GNFIST (GNFIST is called exclusively by XSEMI) to generate the FIST executive table. For each input, output, or scratch data block required for operation of a module (this information being contained in the ØSCAR entry), GNFIST searches the FIAT to find the data block. If the data block is in the FIAT and a file has been assigned to it, an internal GINØ file number denoting the data block and a pointer (index) to the entry in the FIAT is placed in the FIST. The following convention is used for internal GINØ file numbers: input data blocks -- 100 + position in the

## PROGRAM SYSTEM REQUIREMENTS

ØSCAR entry; output data blocks -- 200 + position in the ØSCAR entry; scratch data blocks -- 301 through 300 + n, where n = number of scratch data blocks as defined in the MPL. (The position in the ØSCAR entry is the position in the DMAP instruction). If the data block is in the FIAT and is purged, no entry is placed in the FIST. For example, consider the following DMAP calling sequence for functional module XYZ:

```
XYZ      A,B,C/D,E,F,G/V,N,PARM1/V,N,PARM2 $
```

The data blocks input to the module are A, B, and C; the data blocks output from the module are D, E, F, and G; the module's parameters are PARM1 and PARM2. Note that internal scratch files are not mentioned in the DMAP calling sequence. The number of scratch files for a module is defined in the Module Property List (MPL) executive table (see Section 2.4) and is communicated to the Executive System via the ØSCAR. Details on the syntactical rules of DMA<sup>P</sup> are given in Section 5 of the User's Manual.

In order to read the input data block B, the GINØ file number interval to XYZ is 102; in order to write data block D, the GINØ file number is 201. The third of, say, five scratch data blocks is referenced by XYZ through the GINØ file number 303.

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```

SUBROUTINE A
COMMON /BLANK/ XX
COMMON /AX/ Z(1)
INTEGER CORSZ
NZ = CORSZ(Z(1),XX)
DO 10 I = 1, NZ
10 Z(I) = I
RETURN
END
    
```

```

SUBROUTINE B
COMMON /BLANK/ XX
COMMON /BX/ Z(1)
INTEGER CORSZ
NZ = CORSZ(Z(1),XX)
DO 10 I = 1, NZ
10 Z(I) = I
:
RETURN
END
    
```

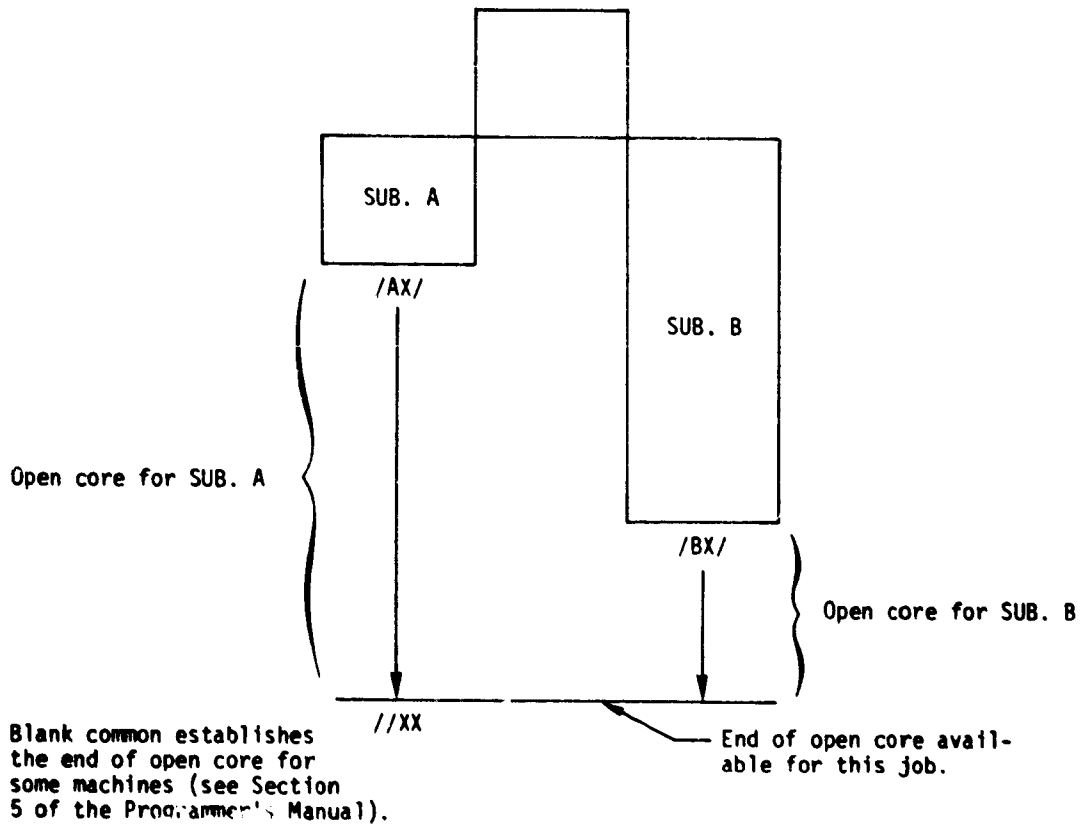


Figure 1. An Example of the Use of Open Core.

## NASTRAN DATA DECK ORGANIZATION

### 5.3 NASTRAN DATA DECK ORGANIZATION

NASTRAN is designed for batch mode operation. As such, job submittal takes the form of a card deck or card images on file submitted as a file. The input deck begins with the required resident operating system control cards. The type and number of these cards will vary with the installation. Instructions for the preparation of these control cards are presented in Section 11. Also, additional details regarding system control cards should be obtained from the programming staff at each installation.

The operating system control cards are followed by the NASTRAN Data Deck, shown in Figure 1, which is constructed in the following order (depending on the particular job requirements):

1. The NASTRAN Card
2. The Executive Control Deck
3. The Substructure Control Deck
4. The Case Control Deck
5. The Bulk Data Deck
6. The INPUT Module Data Card(s)

#### 5.3.1 The NASTRAN Card

The NASTRAN card is used to change the default values for certain operational parameters, such as buffer size and machine model number. The NASTRAN card is optional, but if present, it must be the first card of the NASTRAN Data Deck. The NASTRAN card is a free-field card (similar to cards in the Executive Control Deck) Its format is as follows:

NASTRAN keyword<sub>1</sub> = value, keyword<sub>2</sub> = value, ...

The most frequently used keywords are as follows:

1. **BUFSIZE** - Defines the number of words in a GINØ buffer. Usually this value is standardized at any particular installation. However, the desired value may be different from the default value of 1803 (IBM), 1183 (CDC), and 1795 (UNIVAC). In any event, related runs, such as restarts and User Master File runs, must use the same BUFSIZE for all parts of the run
2. **CØNFIG** - Defines the model number of the configuration for use in timing equations for matrix operations. Entries exist for the following configurations:

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<u>MACHINE</u>	<u>CONFIG.</u>	<u>MODEL NO.</u>
IBM 360	0 (default)	91, 95
	3	50
	4	65
	5	75
	6	85
	7	195
	IBM 370 (no default)	9
10		165
11		145
12		158
13		168
CDC 6000 (no default)	6	6400/6500
	16	6600
CDC CYBER 170	0 (default)	175
	12	174
	14	173
	15	176
UNIVAC 1100	0 (default)	1110
	14	1108

The machine type is automatically determined by NASTRAN. If the model number is the default, the CONFIG keyword is not needed on the NASTRAN card. It is important to indicate the proper configuration; otherwise, all time-dependent matrix decisions will be incorrect.

3. **MODCOM(i)** - Defines a nine-word array for module communications. Currently, only MODCOM(1) is supported. If MODCOM(1) = 1, diagnostic statistics from subroutine SDCOMP are printed; if -1, time and core estimates for module SDCMPS are made without doing the decomposition.
4. **HICORE** - Defines the amount of open core available to the user on the UNIVAC 1100 series machines. The user area default is nominally 65K decimal words. The ability to increase this value may be installation limited.
5. **TRACKS** - Establishes the format for the number of tracks (7 or 9) required for the NASTRAN permanent plot file which will be copied to tape. This parameter is not required if a physical plot tape is used, since system control cards define the tracks. The parameters TRACKS = 7, FILES = PLT2 cause plot data to be written to a disk file formatted for a plotter that reads 7-track tapes.
6. **FILES** - Establishes NASTRAN permanent files as being disk files rather than tape files. The FILES are POOL, @PTP, NPTP, UMF, NUMF, PLT1, PLT2, INPT, INP1, INP2, ... INP9. Multiple file names must be enclosed with parentheses such as FILES = (UMF,NPTP). The

## NASTRAN DATA DECK ORGANIZATION

FILES parameter(s) must be last on the NASTRAN card. Note the plot files, PLT1 and PLT2, cannot be copied from disk to tape on the UNIVAC, therefore, a physical tape must be assigned prior to job execution if plotting from disk is not available.

7. STST - Defines the singularity tolerance in EMG and SMA1. The default value is .01. Singularities are written to GPST or (if altered into the Rigid Format) GPSPC. If module GPSPC is used, it may, on option, automatically constrain the strongest singularity (weakest stiffness) combination.

Additional information for all NASTRAN card options is given in Section 6.3 of the Programmer's Manual.

### 5.3.2 Function of the Executive Control Deck

The first purpose of executive control is to provide a level of regulation for the many options within NASTRAN. At this level the executive distinguishes between the broad approaches to problem solution, e.g., between a matrix abstraction approach by the analyst or a Rigid Format approach according to problem class. Also at this level, the executive distinguishes between several operational modes, e.g., a first attempt, a continuation, or a modification. Certain other functions of a general nature are convenient to include with the executive control such as problem identification, selection of a level of diagnostics, and the estimation of solution time.

The Executive Control Deck includes cards which describe the nature and type of the solution to be performed. These include an identification of the problem, an estimated time for solution of the problem, a selection of an approach to the solution of the problem, a restart deck from a previous run if the solution is to be restarted, an indication of any special diagnostic printout to be made, and a specification of whether execution of the problem is to be completed in a single run, or whether execution will be stopped (checkpointed) at some intermediate step.

Each of the cards comprising the Executive Control Deck is read and analyzed. Depending on the card, information is either stored in various executive tables maintained in core storage or written in a control table on the New Problem Tape for further processing during a later phase of the Preface.

The Executive Control Deck is described in detail with examples in Section 6.

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### 5.3.3 Function of the Substructure Control Deck

The user places commands needed to control the execution of NASTRAN for automated multi-stage substructuring analyses via the Substructure Control Deck. These commands are automatically translated into DMAP alter packages which are then automatically inserted into the Executive Control Deck.

The Substructure Control Deck is an optional deck. It is used only when the substructuring system has been requested through the APPROACH card in the Executive Control Deck. Further details and examples for the Substructure Control Deck are found in Sections 7 and 20.

### 5.3.4 Function of the Case Control Deck

When the Rigid Format solution route is selected, further details of control are provided by the Case Control portion of the executive. In effect, the analyst can manipulate his problem by means of entries he inserts in the Case Control Deck. Fundamental to the method of control in this section is the notion of sets. Boundary conditions, loading cases, and output selections are identified by set numbers and selected accordingly. The analyst can make choices amongst the sets of data representing different physical situations which are allowed to be assembled in the bulk data portion of the problem input. Here also the analyst can regulate his output.

The Case Control Deck includes cards that indicate the following options: selection of specific sets of data from the Bulk Data Deck (i.e., from the data deck that describes the modeling details and parameters of a problem), selection of printed or punched output, definition of subcases, and the definition of plots to be made.

The information defining data set selection, output format selection, and subcase definition is read from the Case Control Deck and written into a case control data block. Information defining plot requests is written into a plot control data block.

If the problem is a restart, a comparison with the case control data block from the previous run (stored on the Old Problem Tape) is made. Differences are noted in an executive restart table.

### 5.3.5 Function of the Bulk Data Deck

In NASTRAN the input supplied to the mathematical operations performed in functional modules is provided in the form of previously organized data blocks. Data blocks derive from two sources: those that derive from the bulk input data and those that are generated as output from previous



## NASTRAN DATA DECK ORGANIZATION

functional modules. Those that derive from the bulk data are organized into data blocks by the IFP routine, but prior to the execution of IFP, XSORT sorts the bulk data. Operation of the XSORT routine is influenced by the type of run. If the run is a cold start (that is, an initial submittal for a given job), the bulk data is read from the system input unit or the User's Master File, is sorted, and is written on magnetic files in preparation for problem execution. If the analyst wants to provide for a future restart, the SORT routine prepares a file on the New Problem Tape which contains the sorted bulk data. If the run is a restart, the bulk data are copied from the Old Problem Tape with the addition of any changes from the system input unit.

An echo of the unsorted bulk data is given if requested. Similarly, printing of the sorted bulk data may be suppressed on request.

Since the collating sequence of alphanumeric characters varies from computer to computer, the sort routine converts all characters to an internal code prior to sorting. Following the sort, the characters are reconverted. In this way, the collating sequence is made computer independent.

The algorithm used by the sort routine is biased toward the case where the data is in sort or nearly in sort. Consequently, Bulk Data Decks which are nearly in sort will be processed efficiently by the routine.

### 5.3.6 INPUT Module Data

NASTRAN provides the capability to automatically generate bulk data cards for a number of selected test problems. This capability is fully described in the User's Manual, Section 2.6. The capability is accessed by using a DMAP alter package in the Executive Control Deck and by placing specially formatted data cards following the Bulk Data Deck, as shown in Figure 1.

### 5.3.7 NASTRAN Character Set

Except for the IBM 360/370 series, all NASTRAN data cards must be punched using the character set shown in Table 1, below. The EBCDIC character set may be used on the IBM 360/370 series. Any EBCDIC characters are automatically translated into the character set shown in the table below. The EBCDIC character card punch configurations are shown in parenthesis for the five characters that differ from the standard character set.

# INTRODUCTION TO THE NASTRAN SYSTEM

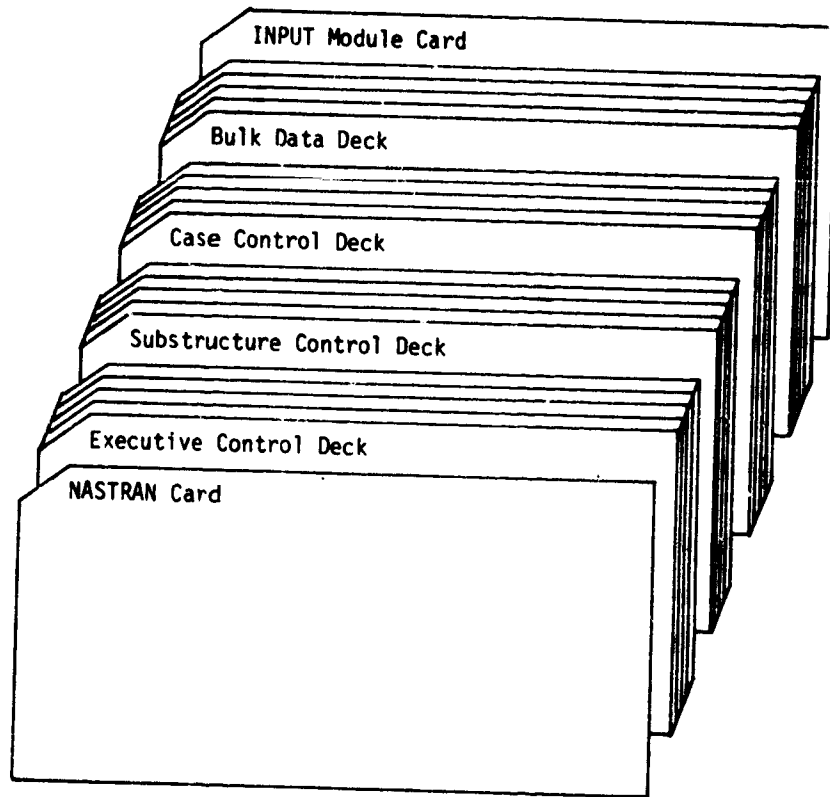


Figure 1. General construction of NASTRAN data deck.

# NASTRAN DATA DECK ORGANIZATION

Table 1. NASTRAN Character Set.

Character	Card Punch(s)	Character	Card Punch(s)	EBCDIC Punch(s)
blank	blank	N	11-5	
0	0	⊙	11-6	
1	1	P	11-7	
2	2	Q	11-8	
3	3	R	11-9	
4	4	S	0-2	
5	5	T	0-3	
6	6	U	0-4	
7	7	V	0-5	
8	8	W	0-6	
9	9	X	0-7	
A	12-1	Y	0-8	
B	12-2	Z	0-9	
C	12-3	\$	11-3-8	
D	12-4	/	0-1	
E	12-5	+	12	(12-6-8)*
F	12-6	-	11	
G	12-7	(	0-4-8	(12-5-8)*
H	12-8	)	12-4-8	(11-5-8)*
I	12-9	'	4-8	( 5-8 )*
J	11-1	=	3-8	( 6-8 )*
K	11-2	,	0-3-8	
L	11-3	.	12-3-8	
M	11-4	*	11-4-8	

\*IBM 360/370 only.

## 6. EXECUTIVE CONTROL DESCRIPTION

### 6.1 INTRODUCTION

The Executive Control Deck serves to identify the job and the type of solution to be performed. It also declares the general conditions under which the job is to be executed, such as, maximum time allowed, type of system diagnostics desired, restart conditions, and whether or not the job is to be checkpointed.

If the job is to be executed with one of NASTRAN's standard Rigid Formats, the number of that Rigid Format is declared. Any alterations to the Rigid Format that may be desired would also be part of the Executive Control Deck. These alterations would be specified as a set of DMAP instructions to be inserted into the Rigid Format sequence (User's Manual, Section 3).

If Direct Matrix Abstraction (User's Guide, Section 15; and User's Manual, Section 5) is used, the complete DMAP sequence must appear in the Executive Control Deck. These DMAP instructions allow the user to specify his own sequence of matrix operations independent of the standard sequences provided by the Rigid Formats.

The organization of the NASTRAN input deck is described next along with the card format in Section 6.2. The Executive Control options are described in Section 6.3 and summarized in Table 1. Examples are also provided in Section 6.4.

## EXECUTIVE CONTROL DESCRIPTION

Table 1. Executive Control Options

The following Executive Control cards are mandatory:

1. APP - selects a Rigid Format approach or a user provided Direct Matrix Abstraction Program (DMAP).
2. CEND - defines the end of the Executive Control deck.
3. ID - defines the beginning of the Executive Control deck.
4. TIME - defines the maximum time in minutes allotted to the execution of the NASTRAN program.

The following Executive Control cards are required under certain circumstances:

1. BEGIN\$ - defines the beginning of user provided DMAP statements.
2. END\$ - defines the end of user provided DMAP statements.
3. ENDALTER - defines the end of user provided changes to a Rigid Format.
4. RESTART - defines the beginning of a restart dictionary.
5. SOL - selects the solution number of a Rigid Format.
6. UMF - selects a data deck from a User Master File.
7. UMFEDIT - controls execution of a UMF editor.

The following Executive Control cards are optional:

1. ALTER - defines the Rigid Format statement(s) at which the user makes alterations.
2. CHKPNT - requests the execution to be checkpointed.
3. DIAG - requests diagnostic output to be provided or operations to be effected.
4. NUMF - requests a User Master File to be created.
5. \$ - defines a non-executable comment.

## INPUT SEQUENCE AND FORMAT

### 6.2 INPUT SEQUENCE AND FORMAT

The sequence of input cards for execution of a NASTRAN run, see Figure 1, begins with the required resident operating system control cards. The type and number of these cards varies with the conventions used at each computer installation. See the programming staff at that installation for instruction in the preparation of these control cards. Typical examples of the operating system control cards used by NASTRAN are illustrated in Section 11 for all three computer systems on which NASTRAN is maintained (Programmer's Manual, Section 5).

These operating system control cards are followed by the NASTRAN Data Deck which consists of four sections:

1. Executive Control Deck (described here).
2. Substructure Control Deck (Optional, Section 7).
3. Case Control Deck (Section 8).
4. Bulk Data Deck (Section 9).

The Executive Control Cards are summarized in Table 1 and illustrated with examples in Section 6.4. They may occur in any sequence with only the following exceptions:

#### NASTRAN

This is an optional card and is described in Section 5 of the Guide and Section 2 of the User's Manual.

#### ID A1,A2

This is the first card of the Executive Control Deck. It may be preceded only by the NASTRAN card, if used, and the operating system control cards.

#### CEND

This card is the last card of the Executive Control Deck and is followed by the Case Control Deck or the Substructure Control Deck.

The Executive Control Card format is free field. The name of the operation (e.g., CHPNT, TIME, CEND, etc.) may begin in any card column and is followed by the operand. The operand must be separated from the name by one or more blanks. The fields of the operand are separated by commas and may be integers or alphanumeric. The first character of an alphanumeric field must be alphabetic, followed by up to 7 additional alphanumeric characters. If desired, blanks may be placed adjacent to separating commas for legibility. If a card ends with a comma, a continuation card will be expected. Comment cards (\$) in column 1 may be inserted anywhere in the deck following the ID card. The individual options are described next.

## EXECUTIVE CONTROL OPTIONS

### 6.3 EXECUTIVE CONTROL OPTIONS

The Executive Control options are summarized in Table 1. Note that the DMAP options, which are included as part of the Executive Control Deck on input to NASTRAN, are not summarized here. Instead, see Section 15 of this Guide for examples, and Section 5 of the User's Manual for full detail on the individual DMAP instructions. The full explanation and examples for each of the Executive Control options and the operands A1 and K1 is found in Section 2.2 of the User's Manual.

#### 6.3.1 Use of Executive Control Cards

As already noted in Section 6.2, the NASTRAN card, when used, is always the first card in the input stream following the operating system control cards. Otherwise, the ID card is the first card and CEND is the last card of the Executive Control Deck.

If a restart run is being made, the restart dictionary punched from the preceding run must be included. The RESTART card is the first card of the dictionary which contains the user problem identifiers provided for the run being checkpointed. The last card contains the comment \$ END OF CHECKPOINT DICTIONARY. The information on the RESTART card is used by NASTRAN to check that the correct restart tape (Old Problem Tape) has been provided. If a new Rigid Format execution is to be made with the same model from a previous run, a restart with Rigid Format switch could save processing time by not requiring the regeneration of matrices saved from the earlier run. If desired, the restart dictionary may also be modified to alter the reentry point used for the current problem (see User's Manual, Section 3.1.3, for detail).

If DIAGNOSTICS are desired, the "sense switches" K must be specified. See the list of options in Section 2.2.1. If long runs are being made with the user monitoring the operator's console, a status report can be requested by inputting DIAG 5,6 to get BEGIN and END times for each functional module printed on the operator's console. Most of the options, however, are designed for use in program development and debugging of NASTRAN. Use of DMAP print utilities (Section 15 of the User's Guide), and NASTRAN's plot capabilities (Section 4 of the User's Manual) are suggested for obtaining detailed information which would be helpful in finding errors in a structural model.

If a CHKPNT is requested (A1 = YES), a New Problem Tape must be provided (Section 11 of the User's Guide).

## EXECUTIVE CONTROL DESCRIPTION

To modify a Rigid Format sequence, use the ALTER card to add the desired DMAP instructions. The sequence numbers of the Rigid Formats are provided in the User's Manual, Section 3. More than one alter package may be used; however, the last package must terminate with ENDALTER. See Section 15 of the Guide for examples of typical packages.

To be assured that a checkpoint is taken before the operating system terminates a job for insufficient time, set the TIME operand K to less than the time limit specified on the operating system run, job, or job step control card. That way NASTRAN will provide a normal exit, and the punching of the checkpoint dictionary can be completed.

If the UMFEDIT editing feature is to be used, the appropriate input (UMF) and output (NUMF) tapes must be mounted (User's Manual, Section 2.5; and User's Guide, Section 11).

If the approach being used is APP DMAP, the desired DMAP instructions must be initiated with BEGIN\$ or XDMAP\$ (User's Manual, Section 5.2) and terminated with END\$. Note that any alphanumeric commentary (except \$) may be inserted between BEGIN and the dollar sign (\$).



## EXAMPLES OF EXECUTIVE CONTROL DECKS

### 6.4 EXAMPLES OF EXECUTIVE CONTROL DECKS

The following are examples of commonly employed Executive Control Deck arrangements. Additional examples can be found in Sections 18-26.

#### 6.4.1 Example 1 - Cold Start, No Checkpoint

Card No.

1	ID	MYNAME, BRIDGE23
2	APP	DISP
3	SOL	2,0
4	TIME	5
5	DIAG	1,2
6	CEND	

- Notes:
2. Execute a displacement approach.
  3. Use the unmodified (K2=0), Rigid Format 2 - Static analysis with inertia relief.
  5. Request core memory dump if a nonpreface fatal message is generated, and print File Allocation Table (FIAT) (Programmer's Manual, Section 2.4.1) following each call to the File Allocator.

#### 6.4.2 Example 2 - Cold Start, Checkpoint, Modified System Parameters

Card No.

1	NASTRAN	BUFSIZE=878
2	ID	PERS@NZZ, SPACECFT
3	CHKPNT	YES
4	APP	DISP
5	SOL	1,3
6	TIME	15
7	CEND	

- Notes:
1. Requests a change in GIN@ buffer size for NASTRAN's own read/write routine.
  2. Requests a checkpoint tape be written (New Problem Tape).
  3. Remove instructions for loop control which process additional sets of constraints (K2=3), Rigid Format 1 - Static Analysis.

## EXECUTIVE CONTROL DESCRIPTION

### 6.4.3 Example 3 - Restart, Checkpoint, Rigid Format Switch

#### Card No.

```
1  NASTRAN  BUFFSIZE=878
2  ID      PERSONZZ, CASEB
3  RESTART  PERSONZZ,SPACECFT,2/21/72, 3353,
4      1,   XVPS, FLAG=0, REEL=1, FILE=6
5      2,   REENTER AT DMAP SEQUENCE NUMBER 7
6      3,   GPL, FLAG=0, REEL=1  FILE=7
      .
7  $ END OF CHECKPOINT DICTIONARY
8  APP      DISP
9  SOL      3,3
10 TIME     10
11 CHPNT    YES
12 CEND
```

- Notes:
1. The same NASTRAN card is used to retain system parameters of the original cold start run.
  2. New ID parameters specified to help identify the restart dictionary to be punched by this run.
  3. The first card of the restart dictionary punched by the previous run in which the CHPNT option was selected. Date and time of execution is added to the checkpointed run ID to prevent inadvertent restart from the wrong tape. (See User's Manual, Section 2.2.1, for explanation of cards to follow.)
  - 4-7. The restart dictionary identifying the data stored on the restart tape (Old Problem Tape) which was created as the New Problem Tape on the previous run.
  9. Requests a switch to a normal modes analysis (Rigid Format 3), and removes the looping instructions for processing additional sets of constraints (K2=3).
  11. Requests a new checkpoint tape be written, a New Problem Tape for this run.

### 6.4.4 Example 4 - Restart, No Checkpoint, Altered Rigid Format

#### Card No.

```
1  ID      PERSONYY,PROJECTY
2  RESTART  PERSONZZ,SPACECRAFT, 3/1/73, 5351,
3      1,   XVPS, FLAGS=0, REEL=1, FILE=6
```

## EXAMPLES OF EXECUTIVE CONTROL DECKS

### Card No.

```
4      2,    REENTER AT DMAP SEQUENCE NUMBER 7
5      3,    GPL, FLAGS=0, REEL=1, FILE=7
        .
6      $ END OF CHECKPOINT DICTIONARY
7      CHPNT  NØ
8      APP    DISP
9      SOL    3,3
10     TIME   15
11     ALTER  35
12     MATPRN KGGX,...// $
13     TABPT  GPST,...// $
14     ENDALTER
15     CEND
```

- Notes:
7. CHPNT card is optional here since NØ is the default.
  11. Beginning of ALTER package for inserting DMAP instructions after Rigid Format 3 sequence number 35.
  12. Request printout of stiffness matrix KGGX (User's Manual, Section 5.3.2; Programmer's Manual, Section 2.2.1 and 2.3.9.1).
  13. Request printout of Grid Point Singularity Table GPST (User's Manual, Section 5.3.2; Programmer's Manual, Sections 2.2.1 and 2.3.9.3).
  14. ENDALTER concludes the alter package.

## 7. SUBSTRUCTURE CONTROL DESCRIPTION

### 7.1 INTRODUCTION

The Substructure Control Deck (User's Manual, Section 2.7) is an optional deck in the NASTRAN input data stream. Its presence involves the use of the automated multi-stage substructuring system with modal synthesis. When this deck is used, it is always placed immediately following the Executive Control Deck.

Use of the Substructure Control Deck also requires using either of the following three forms of the APPROACH card in the Executive Control Deck:

APP DISP, SUBS

APP DISP, SUBS, 1

APP DMAP, SUBS

The APP DISP, SUBS Executive Control command causes NASTRAN to automatically create ALTERs to the displacement approach Rigid Format specified. The APP DISP, SUBS, 1 command indicates NASTRAN is not to automatically create the ALTERs. In this case, the user will provide an ALTER package for the substructure operation to be performed. This package is placed directly in the Executive Control Deck input stream. The APP DMAP, SUBS command indicates that a user supplied DMAP sequence for substructuring operations will be provided in the Executive Control Deck independent of any specified Rigid Format. These Executive Control commands, their use and control over the substructuring system, are fully explained later in Section 20.

## INPUT SEQUENCE AND FORMAT

### 7.2 INPUT SEQUENCE AND FORMAT

The Substructure Control Deck is input immediately following the last card (CEND) of the Executive Control Deck (User's Guide, Section 6). The first card of the Substructure Control Deck must be SUBSTRUCTURE PHASE $i$ , where  $i = 1, 2, \text{ or } 3$ , according to the phase of execution being performed. The last card must be ENDSUBS.

The Substructure Control cards are free format. Blanks are used to separate the control words. The equal sign (=) is used in an assignment statement. A comma (,) as the last entry on a physical card signals that a continuation card will be used. Comment cards, signalled by a dollar sign (\$) in card column one, can be inserted anywhere in the Substructure Control Deck and thus may contain any alphanumeric characters the user desires. Only the first four characters of each control word need be used so long as that option is uniquely identified. A summary of Substructure Control cards is given in Table 1. Typical examples of their use are given in Section 7.4 and additional examples which are related to actual problems can be found in Section 20.

The input sequence of Substructure Control cards is critical to successful execution. All substructure commands except SUBSTRUCTURE, ENDSUBS, and S0F cause DMAP alters to be generated. These alter packages are built by NASTRAN as the Substructure Control Deck commands are encountered. NASTRAN then executes the analysis specified in the same sequence as these DMAP alters are generated. By convention, the S0F command and its subcommand PASSWORD are placed before other executable commands. The user should also note that the order of subcommands following a given command is not critical.

The function of each Substructure Control command is described in Section 20 of this Guide, and in Sections 1.10.2 and 2.7 of the User's Manual. The DMAP alters automatically generated from each substructuring command are presented in Section 5.9 of the User's Manual. A description of how the user may interface with these NASTRAN-generated substructuring DMAP alters is presented in Section 2.7.2 of the User's Manual where the reader will learn what restrictions are imposed by this procedure on other user-supplied DMAP alters for the Executive Control Deck.

The relationship between the Substructure Control Deck and the Executive Control Deck was given in Section 7.1. This relationship and others among the Substructure Control Deck, the Case Control Deck, and the Bulk Data Deck are fully developed with examples in Section 20.

## SUBSTRUCTURE CONTROL DESCRIPTION

Table 1. Summary of Substructure Commands.

### A. Phase and Mode Control

# SUBSTRUCTURE	- Defines execution phase (1, 2, or 3)
NAME*	- Specifies Phase 1 or Phase 3 substructure name (not used in Phase 2)
SAVEPLOT	- Requests plot data be saved in Phase 1
OPTIONS	- Defines matrix options (K, B, K4, M, P, or PA)
RUN	- Limits mode of execution (DRY, G, DRYG, STEP)
# ENDSUBS	- Terminates Substructure Control Deck

### B. SOF Controls

# SOF	- Assigns physical file for storage of the SOF
PASSWORD*	- Protects and ensures access to correct file
SOFOUT or SOFIN	- Copies SOF data to or from an external file
POSITION	- Specifies initial position of input file
NAMES	- Specifies substructure name used for input
ITEMS	- Specifies data items to be copied in or out
SOFPRINT	- Prints selected items from the SOF
DUMP	- Dumps entire SOF to a backup file
RESTORE	- Restores entire SOF from a previous DUMP operation
CHECK	- Checks contents of external file created by SOFOUT
DELETE	- Deletes out selected groups of items from the SOF
EDIT	- Edits out selected groups of items from the SOF
DESTROY	- Destroys <u>all</u> data for a named substructure and <u>all</u> the substructures of which it <u>is</u> a component

### C. Substructure Operations

COMBINE	- Combines sets of substructures
NAME*	- Names the resulting substructure
TOLERANCE*	- Limits distance between automatically connected grids
CONNECT	- Defines sets for manually connected grids and releases
OUTPUT	- Specifies optional output results
COMPONENT	- Identifies component substructure for special processing
TRANSFORM	- Defines transformations for named component substructures
SYMTRANSFORM	- Specifies symmetry transformation
SEARCH	- Limits search for automatic connects
EQUIV	- Creates a new equivalent substructure
PREFIX*	- Prefix to rename equivalenced lower level substructures

# Mandatory Control Cards

\* Required Subcommand

## INPUT SEQUENCE AND FORMAT

Table 1 Summary of Substructure Commands (continued).

### C. Substructure Operations (continued)

<b>REDUCE</b>	- Reduces substructure matrices
<b>NAME*</b>	- Names the resulting substructure
<b>BBOUNDARY*</b>	- Defines set of retained degrees of freedom
<b>RSAVE</b>	- Indicates the decomposition product of the interior point stiffness matrix is to be saved on the SØF
<b>OUTPUT</b>	- Specifies optional output requests
<b>MREDUCE</b>	- Reduces substructure matrices using a normal modes transformation
<b>NAME*</b>	- Names the resulting substructure
<b>BBOUNDARY*</b>	- Defines set of retained degrees of freedom
<b>FIXED</b>	- Defines set of constrained degrees of freedom for modes calculation
<b>RNAME</b>	- Specifies basic substructure to define reference point for inertia relief shapes
<b>RGRID</b>	- Specifies grid point in the basic substructure to define reference point for inertia relief shapes. Defaults to origin of basic substructure coordinate system
<b>METHOD</b>	- Identifies EIGR Bulk Data card
<b>RANGE</b>	- Identifies frequency range for retained modal coordinates
<b>NMAX</b>	- Identifies number of lowest frequency modes for retained modal coordinates
<b>ØLDMØDES</b>	- Flag to identify rerunning problem with previously computed modal data
<b>ØLDBØUND</b>	- Flag to identify rerunning problem with previously defined boundary set
<b>USERMØDES</b>	- Flag to indicate modal data have been input on bulk data
<b>OUTPUT</b>	- Specifies optional output requests
<b>RSAVE</b>	- Indicates the decomposition product of the interior point stiffness matrix is to be stored on the SØF
<b>CREDUCE</b>	- Reduces substructure matrices using a complex modes transformation
<b>NAME*</b>	- Names the resulting substructure
<b>BBOUNDARY*</b>	- Defines set of retained degrees of freedom
<b>FIXED</b>	- Defines set of constrained degrees of freedom for modes calculation
<b>METHOD</b>	- Identifies EIGC Bulk Data card
<b>RANGE</b>	- Identifies frequency range of imaginary part of the root for retained modal coordinates
<b>NMAX</b>	- Identifies number of lowest frequency modes for retained modal coordinates
<b>ØLDMØDES</b>	- Flag to identify rerunning problem with previously computed modal data
<b>GPARAM</b>	- Specifies structural damping parameter
<b>OUTPUT</b>	- Specifies optional output requests
<b>RSAVE</b>	- Indicates the decomposition product of the interior point stiffness matrix is to be stored on the SØF

\* Required Subcommand

## SUBSTRUCTURE CONTROL DESCRIPTION

Table 1. Summary of Substructure Commands (continued).

### C. Substructure Operations (continued)

MRECOVER	- Recovers mode shape data from an MREDUCE or CREDUCE operation
SAVE	- Stores modal data on SØF
PRINT	- Stores modal data and prints data requested
SØLVE	- Initiates substructure solution (statics, normal modes, frequency response, or transient analysis)
RECOVER	- Recovers Phase 2 solution data
SAVE	- Stores solution data on SØF
PRINT	- Stores solution and prints data requested
BRECOVER	- Basic substructure data recovery, Phase 3
PLØT	- Initiates substructure undeformed plots



## EXAMPLES OF SUBSTRUCTURE CONTROL DECKS

### 7.3 EXAMPLES OF SUBSTRUCTURE CONTROL DECKS

The following are examples of Substructure Control Decks. Additional examples are found in Section 20 of this Guide and in Section 1.10.2 of the User's Manual as they apply to specific problems. The notes are intended to highlight the specific intent of the particular card illustrated.

#### 7.3.1 Example 1 - Phase 1, Create Substructure WING

Card No.

```
1  SUBSTRUCTURE PHASE1
2  SØF(1) = SØF1, 1000, NEW    $   (CDC)
   or SØF(1) = FT02,,NEW      $   (IBM)
   or SØF(1) = INP1, 1000, NEW $   (UNIVAC)
3  PASSWORD = PRØJECTX
4  NAME = WING
5  SAVEPLØT = 1
6  SØFPRINT TØC
7  ENDSUBS
```

- Notes:
2. This deck is the first substructure execution for Project X. It introduces and, hence, initializes the SØF. Three versions of this card are shown, one for each of the NASTRAN computers. Refer to Section 2.7 of User's Manual for further details and instructions on the use of the SØF command. Note that for the life of this SØF file, this is the only time the "NEW" parameter is used.
  3. Assigns the password PRØJECTX to this SØF. This password must always be used in later executions to gain access to the SØF.
  4. Assigns the name WING to all matrices and tables created by this NASTRAN execution which is to generate a basic phase 1 model.
  5. Requests data be saved for undeformed plotting of this structure. To define these data, the following cards must appear at the end of the Case Control Deck:

```
ØUTPUT(PLØT)
SET 1 = (any valid set definition)
```

Note that only one set may be saved for a given Phase 1 substructure.

6. Requests a print of the substructure operating file (SØF) table of contents.

## SUBSTRUCTURE CONTROL DESCRIPTION

### 7.3.2 Example 2 - Phase 2, Operations on Substructure WING

#### Card No.

```
1  SUBSTRUCTURE PHASE2
2  SØF(1) = SØF1, 1000
3  PASSWØRD = PRØJECTX
4  SØFPRINT TØC
5  REDUCE WING
6      NAME = WINGR
7      BØUNDARY = 10
8  MREDUCE WINGR
9      NAME = MRWING
10     BØUNDARY = 20
11     FIXED = 30
12     METHØD = 40
13     NMAX = 5
14     ØUTPUT = 1, 10
15  SØLVE MRWING
16  RECØVER MRWING
17     PRINT MRWING
18     DISP = ALL
19  ENDSUBS
```

- Notes:
- 5-7. Requests a Guyan reduction for the matrices associated with substructure WING. The new model will be named WINGR and will have degrees of freedom identified by boundary set 10 specified on BØYC and BØYSi Bulk Data cards. The other degrees of freedom from WING not referenced on these cards will be eliminated or reduced out.
  - 8-14. Requests a normal mode reduction using the matrices associated with WINGR. The new model will be named MRWING. It will contain physical coordinate degrees of freedom defined by boundary set 20, and will have 5 (NMAX) additional modal coordinates computed using the eigenvalue extraction method with set ID 40 identified by the EIGR card. When the modes are computed, degrees of freedom specified by boundary set 30 (FIXED) will be constrained to zero displacement. Diagnostic and summary ØUTPUT is requested.
  - 15. Requests a solution for model MRWING using the appropriate DMAP sequence specified on the Rigid Format used, i.e., normal modes for RF 3, frequency response for RF 8, etc.
  - 16. Requests the process be initiated for recovery of data from the solution obtained for MRWING.

EXAMPLES OF SUBSTRUCTURE CONTROL DECKS

17,18. Requests the displacements be printed for all degrees of freedom from the solution to MRWING.

## 8. CASE CONTROL DESCRIPTION

### 8.1 INTRODUCTION

The Case Control Deck is used to provide titling information, to select sets of data from the Bulk Data Deck, to generate the subcase structure, and to make output requests for printing, punching, and/or plotting.

The Case Control data are placed on a file which is read by the NASTRAN functional modules. This information is used by a module to control its processing and to select the specific data on which it is to operate. The sequence in which these functional modules themselves are called is controlled by user input to the NASTRAN Executive Control Deck (User's Guide, Section 6). The Case Control options (User's Manual, Section 2.3) are listed in Table 1. Typical examples of their use are given in Section 8.4. Additional examples related to actual problems can be found in Sections 18 through 26.

## INPUT SEQUENCE AND FORMAT

### 8.2 INPUT SEQUENCE AND FORMAT

The Case Control Deck is input immediately following the last card (CEND) of the Executive Control Deck (User's Guide, Section 6) or, when present, the last card (ENDSUBS) of the Sub-structure Control Deck (User's Guide, Section 7). It terminates with the BEGIN BULK card which initiates the input of the Bulk Data Deck. This card and the ENDDATA card, which signals the end of Bulk Data, must always be used even if there are no Bulk Data cards.

The Case Control card is free format. Blanks are used to separate the control words. The equal sign (=) is used in an assignment statement. A comma (,) at the end of a physical card signals that a continuation card will be used. Comment cards, signalled by a dollar sign (\$) in card column one, can be inserted anywhere in the Case Control Deck and thus may contain any alphanumeric characters the user desires. Only the first four characters of each control word need be used so long as that option is uniquely identified.

The input sequence of Case Control cards is arbitrary with the exceptions of the locations of SUBCASE, SJBCOM, etc.; @OUTPUT(PLØT) and @UTPLØT(XYPLØT) commands; and the set of plot commands. The effects of Case Control card order is discussed in Section 2.3 of the User's Manual.

## CASE CONTROL OPTIONS

### 8.3 CASE CONTROL OPTIONS

The Case Control options are listed in Table 1. These options are divided into functional groups for Bulk Data selection, output selection, and subcase specification as described below. A brief summary of the subcase specification options is presented in Table 2. Examples, with explanations, are presented in Section 8.4. Additional examples as they apply to specific problems can be found in Sections 18 through 26. Refer to the discussion of each available Rigid Format (User's Manual, Section 3) for a detailed description of the applicable Case Control options.

#### 8.3.1 Bulk Data Selection

In general, element connectivities, element properties, gridpoint coordinates, and related geometry data used to describe a structural model are not selected from Bulk Data by Case Control. All of these data that are found in the Bulk Data Deck are used in defining the model. However, Case Control is used to select from Bulk Data by specification of the appropriate set identifiers, those load sets, constraint sets, temperature data, direct input matrix data, and method of analysis which are to be used in solving a particular problem. The concept of Case Control allows the user to analyze one model under many different loading and constraint conditions all in one run. Each unique combination of conditions is identified in Case Control as a separate subcase within that one run.

Additional control, it should be noted, is provided directly in Bulk Data via the PARAM card (User's Manual, Section 3.1). Each Rigid Format (User's Manual, Section 3) allows for selected parameters to be specified on this card. These parameters may be used in directing NASTRAN to perform additional processing and to provide for additional output.

#### 8.3.2 Output Selection (User's Manual, Section 2.3)

The Case Control options for control of NASTRAN output allow the user to select the results he wishes to have printed, punched, or plotted. General structural analyses, as performed by NASTRAN, can produce such overwhelming volumes of computer printout that this selective feature is one of the most important functions of the Case Control Deck. A full description of the specialized output available is presented at the conclusion of the discussion of each Rigid Format (User's Manual, Section 3).

## CASE CONTROL DESCRIPTION

Certain categories of NASTRAN output are automatically provided (User's Manual, Section 3.1). The automatic output includes the NASTRAN title page, echo of the Executive Control, Case Control, and sorted Bulk Data Decks, DMAP sequence listing on restarts and the Checkpoint Dictionary when a checkpoint has been requested. Additional output can be requested for diagnostic purposes, e.g., see Executive Control DIAG card (User's Manual, Section 2) and DMAP alters (User's Guide, Section 15).

The specific output which may be requested through Case Control can be divided into categories as follows:

1. Output Control - provide for titles, organization, pagination and mode of output.
2. Output Amounts - provide for definition of sets and intervals to limit volume of output.
3. Output Categories - provide for selection of data types to be output.

These requests may be applied for all subcases or selectively to individual subcases to further limit the volume of desired output. Within a subcase, the user also has the option to suppress output which had been requested above the subcase level. The output requests for specific types of data provide the parameters (User's Manual Section 2.3) with which the user may select special sorting of the output, e.g., printed or punched. The user should refer to the explanations of the Case Control examples in Section 8.4 where certain idiosyncrasies in the use of the output options are described.

The output available from a Random Response Analysis, Rigid Formats 8 and 11 should be especially noted. Unlike the results from other available analyses, the printout of the power spectral density and autocorrelation functions is available only through the plotting control options provided for @OUTPUT(XY@UT) (User's Manual, Sections 10.4 and 19.7).

Plotting requests, which always appear after the last subcase, are sufficiently specialized that separate sections (User's Guide, Sections 10.3 through 10.5) are devoted to a discussion of the four forms of plotting available in NASTRAN. These forms are:

1. Structural - illustrates the actual model in an undeformed and/or in a deformed state (User's Manual, Section 4.2).
2. X-Y Plot - provides curve plotting of selected response data in functional form (User's Manual, Section 4.3).

## CASE CONTROL OPTIONS

3. Matrix Plot - provides a topographical display of matrix coefficients in graphical form (User's Manual, Section 5.3.2, "SEEMAT").
4. Contour Plots - displays stress and displacement contours (User's Manual, Section 4.2).

### 8.3.3 Subcase Specification (User's Manual, Section 2.3)

In general, separate subcases are used to define unique combinations of loadings and constraint sets. Subcases also are used to control output requests, to identify the method of analysis, to change integration time intervals and/or to specify unique sets of direct input matrices. Furthermore, separate subcases are used to control symmetry and anti-symmetry conditions including superposition of the corresponding solutions. Guidelines for subcase requirements according to each of the available Rigid Formats can be found in the "Case Control Deck and Parameters" subsection of the User's Manual starting with Section 3.2. The following summarizes these requirements as they apply to the different classes of analysis:

1. Static Analyses, Rigid Formats 1 and 2
  - Separate subcases for each unique combination of loadings and constraint sets.
  - Loading conditions, selected from Bulk Data with LOAD, DEFORM, or TEMPERATURE (LOAD) cards, which are associated with the same sets of constraints should be called for in contiguous subcases to avoid unnecessary computations. The SPC constraint sets may include gridpoint displacements as a loading condition which will be superimposed on any other loading selected in that subcase.
2. Static Analysis with Differential Stiffness, Rigid Format 4
  - Case Control must contain only two subcases. The loading and constraint sets must be specified above the subcase level. The first subcase is used to specify the output requests that apply only to the linear solution. The second subcase is used to specify output requests for the nonlinear solution.
3. Buckling Analysis, Rigid Format 5
  - Same as #2 above except that the second subcase contains the METHOD card selecting the EIGB card from Bulk Data which defines the method of eigenvalue extraction.
4. Piecewise Linear Analysis, Rigid Format 6
  - Case Control must contain one and only one subcase.
  - The PLCDEF card which must be used to select the sequence of loading factors to be applied.
5. Normal Modes Analysis, Rigid Format 3
  - Multiple subcases are used only to control output requests.
  - The METHOD card must be used to select the EIGR card from Bulk Data.



## CASE CONTROL DESCRIPTION

6. Direct Complex Eigenvalue Analysis, Rigid Format 7
  - At least one subcase must be defined for each unique set of direct input matrices (K2PP, M2PP, B2PP).
  - The CMETHOD card must be used to select the EIGC card from Bulk Data for each set of direct input matrices.
  - Multiple subcases for each set of direct input matrices are used only for output control.
7. Direct Frequency and Random Response, Rigid Format 8
  - At least one subcase must be defined for each unique set of direct input matrices (K2PP, M2PP, B2PP) or frequencies and only one FREQUENCY card and one DFREQUENCY card can be used for each such set.
  - Consecutive subcases for each set of direct input matrices or frequencies are used to define the loading conditions - one subcase for each dynamic loading condition selected from Bulk Data by the DLOAD card.
  - Constraints must be specified directly in Bulk Data (GRID or GRDSET) or selected above the subcase level. Grid point displacements specified with these constraint sets will be ignored.
  - Output from a Random Response Analysis may be selected only with the XYOUT options (User's Guide, Section 10.4)
8. Direct Transient Response, Rigid Format 9
  - One subcase must be defined for each dynamic loading condition selected from Bulk Data by the DLOAD card.
  - Constraints must be specified directly in Bulk Data (GRID or GRIDSET) or specified above the subcase level. Grid point displacements specified with these constraint sets will be ignored.
9. Modal Complex Eigenvalue, Frequency and Random Response, and Transient Response Analyses, Rigid Formats 10, 11 and 12
  - METHOD must appear above the subcase level to select the method of eigenvalue extraction.
  - Constraints must be specified directly in Bulk Data (GRID or GRDSET) or specified above the subcase level. Grid point displacements specified with these constraint sets will be ignored.
10. Normal Modes with Differential Stiffness, Rigid Format 13
  - The Case Control Deck must contain three subcases.
  - The first subcase is used for output selection for the linear case and to define static loading condition with a LOAD, TEMPERATURE(LOAD), or DEFORM selection, unless all loading is specified by grid point displacements on SPC cards.
  - DSCOEFFICIENT must appear in the second subcase, either to select a DSFACT set from the Bulk Data Deck, or to explicitly select the default value of unity.
  - METHOD must appear above the subcase level to select an EIGR bulk data card.
  - The static differential stiffness solution is output from the second subcase. The eigenvector solution is output from the third subcase.
  - An SPC set must be selected above the subcase level unless all constraints are specified on GRID cards.

## CASE CONTROL OPTIONS

11. Static Analysis Using Cyclic Symmetry, Rigid Format 14
  - A separate group of subcases must be defined for each symmetric segment. For dihedral symmetry, a separate group of subcases are defined for each half.
  - The different loading conditions are defined within each group of subcases. The loads on each symmetric segment and the selected output requests may be independent. The number of loading cases is specified on the PARAM card NLØAD.
  - The SPC and MPC requests must appear above the subcase level and may not be changed.
  - An alternate loading method is to define a separate group of subcases for each harmonic index, k. The parameter CYCIØ is included and the load components for each index are defined directly within each group for the various loading conditions.
12. Normal Modes Analysis Using Cyclic Symmetry, Rigid Format 15
  - METHODØ must be used to select an EIGR card that exists in the Bulk Data Deck.
  - An SPC set must be selected unless the model is a free body or all constraints are specified on GRID cards, Scalar Connection cards or with General Elements.
  - Multiple subcases are used only to control output requests. A single subcase is sufficient if the same output is desired for all modes. If multiple subcases are present, the output requests will be honored in succession for increasing mode numbers. MØDES may be used to repeat subcases in order to make the same output requests for several consecutive modes.
13. Static Heat Transfer Analysis, Rigid Format 1, APP HEAT
  - A separate subcase must be defined for each unique combination of constraints and static loads.
  - A static loading condition must be defined for (not necessarily within) each subcase with a LØAD selection, unless all loading is specified with grid point temperatures on SPC cards.
  - An SPC set must be selected for (not necessarily within) each subcase, unless all constraints are specified on GRID cards or Scalar Connection cards.
  - Loading conditions associated with the same sets of constraints should be in contiguous subcases, in order to avoid unnecessary looping.
  - REPCASE may be used to repeat subcases in order to allow multiple sets of the same output item.
14. Nonlinear Static Heat Transfer Analysis, Rigid Format 3, APP HEAT
  - A single subcase must be defined with a single loading condition (LØAD) and a single constraint condition (SPC).
  - An estimated temperature distribution vector must be defined on TEMP cards and selected with a TEMP(MATERIAL) request. Temperatures for constrained components are taken from these TEMP cards and entries on SPC cards are ignored.

## CASE CONTRGL DESCRIPTION

15. Transient Heat Transfer Analysis, Rigid Format 9, APP HEAT
  - A single subcase must be defined with a single constraint condition.
  - DL0AD and/or NONLINEAR must be used to define a single time-dependent loading condition. The static load cards (QVECT, QV0L, QHBDY, QBDY1, and QBDY2) can be used to define a dynamic load by using these cards with, or instead of, the DAREA cards. The set identification number on the static load cards (Field 2) is used in the same manner as the set identification number on the DAREA cards (Field 2).
  - TSTEP must be used to select the time-step intervals to be used for integration and output.
  - If nonzero initial conditions are desired, IC must be used to select a TEMP set in the Bulk Data Deck.
  - An estimated temperature distribution vector must be defined on TEMP cards and selected with a TEMP(MATERIAL) request if radiation effects are included.
16. Modal Flutter Analysis, Rigid Format 10, APP AER0
  - Only one subcase is allowed.
  - Desired direct input matrices for stiffness  $[K_{pp}^2]$ , mass  $[M_{pp}^2]$ , and damping  $[B_{pp}^2]$  must be selected via the keywords K2PP, M2PP, or B2PP.
  - CMETH0D must be used to select an EIGC card from the Bulk Data Deck.
  - FMETH0D must be used to select a FLITTER card from the Bulk Data Deck.
  - METH0D must be used to select an EIGR card that exists in the Bulk Data Deck.
  - SDAMPING must be used to select a TABDMP1 table if structural damping is desired.
17. Modal Aeroelastic Response, Rigid Format 11, APP AER0
  - METH0D must appear above the subcase level to select eigenvalue extraction method.
  - At least one subcase must be defined for each unique set of direct input matrices (K2PP, M2PP, B2PP) or frequencies.
  - Consecutive subcases for each set of direct input matrices or frequencies are used to define the loading condition - one subcase for each dynamic loading condition.
  - Constraints must be defined above the subcase level
  - DL0AD must be used to define a frequency-dependent loading condition for each subcase. If transient loads are selected, a Fourier Transform is used to compute frequency-dependent loads. All loads in one run must be of the same type.
  - FREQUENCY must be used to select one, and only one, FREQ, FREQ1, or FREQ2 card from the Bulk Data Deck. If TL0ADs are selected, a TSTEP must be selected.
  - 0FREQUENCY(0TIME) may be used above the subcase level or within each subcase to select a subset of the solution frequencies (times) for output requests. The default is to use all solution frequencies (times).
  - If Random Response calculations are desired, RAND0M must be used to select RANDPS and RANDT1 cards from the Bulk Data Deck. Only one 0FREQUENCY and FREQUENCY card can be used for each set of direct input matrices.

## CASE CONTROL OPTIONS

Table 1. Case Control Options

### BULK DATA SELECTION

<u>Loads:</u> DEFORM DL0AD DSC0EFFICIENT L0AD NONLINEAR PLC0EFFICIENT	<u>Constraints:</u> AXISYMMETRIC MPC SPC	<u>Direct Input Matrices:</u> B2PP K2PP M2PP TFL	<u>Dynamic Analyses Conditions:</u> CMETH0D FREQUENCY IC METH0D RAND0M SDAMPING TSTEP	<u>Thermal Fields:</u> TEMPERATURE TEMPERATURE(L0AD) TEMPERATURE(MATERIAL)
				<u>Aeroelasticity:</u> FMETH0D GUST

### OUTPUT SELECTION

<u>Output Control:</u> ECH0 LABEL LINE MAXLINES 0UTPUT 0UTPUT(PL0T) 0UTPUT(XY0UT) 0UTPUT(XYPL0T) SUBTITLE TITLE	<u>Specific Output Amounts:</u> HARMONICS M0DES 0FREQUENCY SET	<u>S0LUTION Set Response:</u> NLL0AD SACCELERATION SDISPLACEMENT SVECTOR SVELOCITY	<u>Stress, Force, Degree-of-Freedom Response:</u> ACCELERATION DISPLACEMENT ELFORCE ELSTRESS ESE FORCE GPFORCE MPCFORCE NCHECK 0L0AD PRESSURE SPCFORCES STRESS THERMAL VECTOR VELOCITY	<u>Aeroelasticity:</u> AER0F
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### SUBCASE SPECIFICATION

<u>General Case:</u> SUBCASE REPCASE SUBC0M	<u>Symmetric Case:</u> SYM SYMC0M	<u>Combination Coefficients</u> General: SUBSEQ	<u>Symmetric:</u> SYMSEQ
--	---	---	-----------------------------

## CASE CONTROL DESCRIPTION

Table 2. Case Control - Subcase Specification

SUBCASE	Defines the beginning of a subcase that is terminated by the next subcase delimiters encountered.
SUBCOM	Defines a combination of two or more immediately preceding subcases in static or inertia relief problems only. Output requests above the subcase level are used.
SUBSEQ	Must appear in a subcase defined by SUBCOM to give the coefficients for making the linear combination of the preceding subcases. The first coefficient applies to the first subcase, the second to the next subcase, etc., for all subcases except combination subcases.
SYM	Defines a subcase in static or inertia relief problems for which only output requests within the subcase will be honored. Primarily for use with symmetry problems where the individual parts of the solution may not be of interest.
SYCOM	Defines a combination of two or more immediately preceding SYM subcases in static or inertia relief problems only. Output requests above the subcase level are used.
SYMESEQ	May appear in a subcase defined by SYCOM to give the coefficient, one for each subcase, for making the linear combination of the preceding SYM subcases. A default value of 1.0 is used if no SYMESEQ card appears, otherwise, a coefficient must be specified for all subcases except combination subcases.
REPCASE	Defines a subcase in static or inertia relief problems only that is used to make additional output requests for the previous real subcase. This card is required because multiple output requests for the same item are not permitted in the same subcase.
MODES	Repeats the subcase in which it appears MODES times for eigenvalue problems. Used to repeat the same output request for several consecutive modes.

## EXAMPLES OF CASE CONTROL DECKS

### 8.4 EXAMPLES OF CASE CONTROL DECKS

The following are examples of commonly employed Case Control Deck arrangements. Additional examples can be found in Sections 18 through 26, as they apply to specific problems. The notes that are provided are intended to highlight the particular intent of the current example.

Details already explained in preceding examples are not repeated.

#### 8.4.1 Example 1 - Multiple Static Loadings

##### Card No.

```
1  TITLE = STATIC ANALYSIS OF DOOR FRAME
2  SUBTITLE = CLOSED POSITION
3  OUTPUT
4  DISPLACEMENTS = ALL
5  MPC = 3
6  SPC = 15
7  SET 1 = 256 THRU 289
8  SET 5 = 15 THRU 20, 23, 25, 101 THRU 123
9  SUBCASE 1
10 LABEL = DECOMPRESSION
11 LOAD = 561
12 LOAD = 1
13 SUBCASE 2
14 LABEL = REENTRY THERMAL
15 TEMPERATURE (LOAD) = 761
16 STRESS = ALL
17 SUBCASE 3
18 LABEL = IMPACT
19 SPC = 25
20 LOAD = 1061
21 STRESS = 5
22 BEGIN BULK
```

## CASE CONTROL DESCRIPTION

### Notes:

- 1-2. Identified basic problem and special conditions
- 3-4. Overall output request for all gridpoint displacements
5. Selects multipoint constraint set from Bulk Data Deck
6. Selects single point constraint set from Bulk Data Deck
- 9-10. Defines sets of grid points and elements for selective output to be specified later
- 11-14. First load subcase, label information, loading selected from Bulk Data and special output request for applied loads on grid point set #1.
- 15-18. Second load subcase, label information, thermal load set selection and special output request for stresses for all elements.
- 19-21. Third load subcase, label information, change in single point constraint set, load selection and limited stress output for elements defined by set #5.
22. Signals beginning of Bulk Data Deck to follow

### 8.4.2 Example 2 - Linear Combination of Subcases

#### Card No.

```
1  TITLE - BUILDING ASG637-111-PG
2  $ SET 1 GROUND FLOOR AND FIRST FLOOR BEAMS
3      SET = 1 THRU 25, 51 THRU 75,
4          101 THRU 125, 151 THRU 175
5  $ SET 2 SUPPORT GRID POINTS
6      SET 2 = 1 THRU 26
7      DISPLACEMENTS = ALL
8      ELFORCE = 1
9      LOAD = ALL
10     SPCFORCE = 2
11  SUBCASE 10
12     ELFORCE = NONE
13     DEFORM = 10
14     SPC = 10
15  SUBCASE 20
16     ELFORCE = NONE
```

## EXAMPLES OF CASE CONTROL DECKS

### Card No.

17           SPC = 20  
18           SUBCOM 31  
19           LABEL = PRETENSION PLUS TWICE SUPPORT SETTLEMENT  
20           SUBSEQ = 1.0, 2.0  
21           SUBCOM 32  
22           LABEL = PRETENSION MINUS TWICE SUPPORT SETTLEMENT  
23           SUBSEQ = 1.0, -2.0  
24           BEGIN BULK

- Notes:
- 4,7. Comment card to facilitate interpretation of set definition.
  - 12. Output request for support reactions on single point constraints and printout of gridpoint loading vector.
  - 13-15. First subcase, element deformation loading, suppression of element force output request above subcase level, and selection of single point constraint set.
  - 17-19. Second subcase, enforced displacements at support specified by single point constraint set and suppression of element force output. A null load vector will be output due to absence of direct applied gridpoint loads.
  - 20-22. Combination subcase adding two previous subcases, label information and coefficients for combination with output for displacements, element forces, reactions and applied loads.
  - 23-25. Combination subcase taking subcase 10 and subtraction twice subcase 20. Same output with new label.

Special note should be made of the fact that NASTRAN applies the combination coefficients to the element stress and force results before they are corrected for the DEFORM or TEMP(LOAD) loading effects. These corrective effects are not multiplied by the combination coefficient when they are added to the combination loading results.

### 8.4.3 Example 3 - Statics Problem with Symmetry

#### Card No.

1           TITLE = GROUND LEVEL STORAGE TANK  
2           SUBTITLE = NON-SYMMETRIC LOADS  
3           SET 1 = 1, 11, 21, 31, 51  
4           SET 2 = THRU 10, 101 THRU 110



## CASE CONTROL DESCRIPTION

### Card No.

5        DISPLACEMENTS = ALL  
6        ELSTRESS = 2  
7        LOADS = 1  
8        SYM 1  
9        SPC = 11  
10       LOAD = 21  
11       SYM 2  
12       SPC = 12  
13       LOAD = 22  
14       SYMCOM 3  
15       SYMCOM 4  
16       SYMSEQ 1.0, -1.0  
17       BEGIN BULK

Notes: 10-15. Definition of symmetric and anti-symmetric loads and support conditions.  
16. Symmetric summation of subcases 1 and 2.  
17-18. Anti-symmetric combination of subcases 1 and 2. The output selected will be printed for all four subcases.

### 8.4.4 Example 4 - Use of REPCASE in Static Analysis

#### Card No.

1        TITLE = FRAMING FOR BLDG 673-7A  
2        SUBTITLE = HEAVY EQUIPMENT LOADING  
3        SET 1 = 1 THRU 10, 101 THRU 110, 201 THRU 210  
4        SET 2 = 21 THRU 30, 121 THRU 130, 221 THRU 230  
5        SET 3 = 41 THRU 100 EXCEPT 55, 57, 59, 61, 65, 72, 78, 95  
6        SUBCASE 1  
7        LOAD = 10  
8        SPC = 11  
9        DISP = ALL  
10       ELFORCE = 1

## EXAMPLES OF CASE CONTROL DECKS

### Card No.

11 REPCASE 2  
12 ELFORCE = 2  
13 REPCASE 3  
14 ELFORCE = 13  
15 BEGIN BULK

Notes: 8-11. Specifies load and support conditions to be analyzed and requests output for displacements at all grid points and element forces for the elements in set #1.  
12-15. Specified two subcases for output control for printing element forces for sets #2 and #3.

### 8.4.5 Example 5 - Use of MODES and PUNCH Output Options

#### Card No.

1 TITLE = @XTANK SUPPORT SYSTEM WITH CONSTRAINED MODES  
2 LINE = 40  
3 METHOD = 2  
4 SPC = 10  
5 SUBCASE 1  
6 DISP(PUNCH) = ALL  
7 STRESS = ALL  
8 MODES = 2  
9 SUBCASE 3  
10 DISP = ALL  
11 BEGIN BULK

Notes: 4. Specified 40 lines maximum per page of printout.  
5. Selects EIGR card from Bulk Data for specification of method for eigenvalue extraction.  
7-10. Specified displacements be punched and element stresses be printed for the first two modes.  
11-12. Specified displacements be printed for all remaining modes.

## CASE CONTROL DESCRIPTION

### 8.4.6 Example 6 - Use of SORT2 Output Option

#### Card No.

```
1  TITLE = TRANSIENT ANALYSIS OF AXLE
2  SUBTITLE = TRAVELLING WAVE
3      TSTEP = 9
4      IC = 9
5  SET 1 = 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
6  OUTPUT
7      DISP(SORT2) = 1
8      VEL(SORT2) = 1
9  BEGIN BULK
```

- Notes:
- 5. Selects timestep definition from Bulk Data.
  - 6. Selects initial conditions from Bulk Data.
  - 8-10. Specifies output requests for displacements and velocities for all output time steps (SORT2) at each grid point selected by set #1. The excitation is produced by initial conditions only.

Special note should be taken that there is only one subcase here and, therefore, it need not be explicitly defined.

### 8.4.7 Example 7 - Use of XYOUT with Frequency and Random Response

#### Card No.

```
1  TITLE = DIRECT RANDOM RESPONSE TO PSD102-A
2  SUBTITLE = CABINET 5A
3      SPC = 11
4      DLOAD = 102
5      FREQ = 101
6      RANDOM = 2
7  OUTPUT
8      SET 1 = 1 THRU 10, 101 THRU 110, 120, 130, 150
9      SET 2 = 0.1, 0.3, 0.6, 1.2, 1.8, 2.4, 3.0
10     OFREQ = 2
```

## EXAMPLES OF CASE CONTROL DECKS

### Card No.

11 ACCEL(SORT2,PHASE) = 1  
12 SUBCASE 15  
13 LABEL = DAMPING SOURCE TOP  
14 B2PP = TIEDAMP  
15 OUTPUT(XYOUT)  
16 TCURVE = PSD FOR TOP DAMPING  
17 XYPRINT ACCE PSD( 15/1(T1)/1(T2)/101(R3))  
18 BEGIN BULK

- Notes:
- 5-8. Specifies environment for the analysis including support conditions, frequency dependent dynamic load, the set of frequencies for solution and the power spectral density function.
  - 12. Specifies frequency set #2 for outputting results.
  - 13. Requests the acceleration for all output frequencies for each grid point of set #1 in magnitude/phase angle format.
  - 16. Specifies the direct input damping matrix.
  - 19. Requests output from the Random Response analysis consisting of the power spectral density function for the first subcase (#15) at gridpoint 1 (X-acceleration), gridpoint 1 (Y-acceleration) and gridpoint 101 (Z-angular acceleration).

## 9. BULK DATA DESCRIPTION

### 9.1 INTRODUCTION

The primary NASTRAN input medium for definition of the data required for a structural analysis is the Bulk Data Deck. The cards in this deck are used to define the structural model and the various other sets of data used to specify the environment to which the model is subjected for analysis. Also, Bulk Data cards may be used to specify the parameters and limits required to control the analysis. A brief summary of the available options are presented in Table 1. An alphabetically ordered, detailed description of all Bulk Data cards is found in the User's Manual, Section 2.4.

In general, all the data submitted describing the physical properties of the model are used directly by NASTRAN. Those data used to specify conditions of the environment such as constraints, temperatures, and loadings must be selected via Case Control options if they are to be applied to the model. Methods of analysis, including the associated data and limits must also be selected from Bulk Data via the Case Control options. Because these last two categories of information are fully under the control of the user, the Bulk Data Deck may include several sets of these data at once. The "subcase" structure of the Case Control deck provides the user with the facility to define each unique combination of these data as separate subcases to be analyzed since more than one subcase may be solved in a single run with NASTRAN.

For large problems, the Bulk Data Deck may consist of several thousand cards. In order to minimize the handling of large numbers of cards, provision has been made in NASTRAN to alphabetically sort and store the Bulk Data on a checkpoint tape and/or on a User's Master File tape (Section 9.4). Data can then be added or selectively deleted during subsequent runs.

The Bulk Data Deck may be submitted with the cards in any order as a sort is performed prior to the execution of an analysis. It should be noted that the machine time to perform this sort is minimized for a deck that is already sorted. The sort time for a badly sorted deck will become significant for large decks. The user may obtain a printed copy of the unsorted and/or the sorted bulk data by selection in the Case Control Deck (User's Manual, Section 2.3, ECHO). A sorted listing is necessary in order to make modifications during a subsequent execution from a checkpoint/restart. This listing is automatically provided as an echo of the Bulk Data Deck unless specifically suppressed by the user.

## BULK DATA DESCRIPTION

Input data preparation for large finite elements models is very often the largest single cost in an analysis, as well as a major source of error. Automated data generation is one means for reducing both cost and input error through the use of design oriented models that cover more of the structure than a single finite element. NASTRAN provides a specialized utility module, called INPUT, to create the majority of Bulk Data cards required for seven selected kinds of problems. This automated data generation is described in Section 9.5.

To examine the use of Bulk Data Cards, refer to the Demonstration Problem Manual which contains an extensive index to problems illustrating application of each Bulk Data Card option.

## PROBLEM DEFINITION

### 9.2 PROBLEM DEFINITION

NASTRAN embodies a lumped element approach, wherein the distributed physical properties of a structure are represented by a model consisting of a finite number of idealized sub-structures or elements that are interconnected at a finite number of grid points, to which loads are applied. All input and output data pertain to this idealized structural model.

The grid point definition forms the basic framework for the structural model. All other parts of the structural model are referenced either directly or indirectly to the grid points.

Three general types of grid points are used in defining the structural model. They are:

1. Geometric grid point - A point in three-dimensional space at which three components of translation and three components of rotation are defined. The coordinates of each grid point are specified by the user.
2. Scalar point - A point in vector space to which one degree of freedom is assigned. Scalar points can be coupled to geometric grid points by means of scalar elements and by constraint relationships.
3. For axisymmetric analyses, the geometric grid point becomes a ring--a point in space rotated about the structural axis of symmetry.

The structural element is a convenient means for specifying many of the properties of the structure, including material properties, mass distribution and some types of applied loads. In static analysis by the displacement method, stiffness properties are input by means of structural elements, scalar stiffness elements, or stiffness matrices. Mass properties (used in the generation of gravity and inertia loads) are input either as properties of structural elements or as properties of grid points. In dynamic analysis, mass, damping, and stiffness properties may be input either as the properties of structural elements or as the properties of grid points (direct input matrices).

Structural elements are defined on connection cards by referencing grid points. In a few cases, all of the information required to generate the structural matrices for the element is given on the connection card. In most cases the connection card refers to a property card, on which the cross-sectional properties of the element are given. The property card in turn refers to a material card which gives the material properties. If some of the material properties are stress-dependent or temperature-dependent, a further reference is made to tables for this information.

## BULK DATA DESCRIPTION

Various kinds of constraints can be applied to the grid points. Single-point constraints are used to specify boundary conditions, including enforced displacements of grid points. Multipoint constraints are used to specify a linear relationship among selected degrees of freedom, including the definition of infinitely rigid elements. Additionally, rigid elements are available for automatic generation of multipoint constraint equations. Omitted points are used to partition matrices and to reduce the number of degrees of freedom used in the analysis. Free-body supports are used to remove stress-free motions in static analysis and to evaluate the free-body inertia properties of the structural model.

Static loads may be applied to the structural model by concentrated loads at grid points, pressure loads on surfaces, or indirectly, by means of the mass and thermal expansion properties of structural elements and enforced deformations of one-dimensional structural elements. Due to the great variety of possible sources for dynamic loading, general functional and tabular forms of loads are provided to the user in dynamic analysis.

General procedures for defining structural models are described in the User's Manual, Section 1. Some useful and specific ideas for modeling using NASTRAN are presented in Sections 18, 19 and 21-26. The user is encouraged to become familiar with the many suggestions and guidelines presented in these sections. They include how to use the special coordinate systems, how to number grid points to avoid inefficient processing, what elements can be used for which purpose, how to load and support a structure, and how to exploit the unusual modeling features of NASTRAN. Additional technical detail, of course, can be found throughout the Theoretical Manual.

NASTRAN provides features for automatic Bulk Data generation. A description of the capability is found in Section 9.5.



## OPTIONS AND FORMAT

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### 9.3 OPTIONS AND FORMAT

There are nearly two hundred Bulk Data options currently available in NASTRAN. Because there are so many and varied alternatives, these options are summarized in the following Table 1, where they are organized according to data types for easy reference by the user. A scan of these options will provide the user with an overview of his alternatives for model specification, for load definition and for control of the execution. In the User's Manual, Section 2, each option is listed in alphabetical sort by Bulk Data Card mnemonic. Here, the user will find the full description of the input card format, the applicable restrictions, and the references to other Bulk Data Cards required to complete the input. Here also, the user will find which Case Control option must be used, if any, to selectively apply these data to the problem at hand.

Each category of data found in Table 1 includes references to the standard NASTRAN manuals for the related theory and application of the input shown. The order of the categories was selected to follow a natural sequence for model development. As such, a user may use these tables as a checklist to be assured that he has considered every aspect of his input.

It should be noted that some options appear in more than one category. This is done to help avoid overlooking an option that may serve several purposes.

Specific procedures and the formats for Bulk Data input are clearly spelled out in the User's Manual, Section 2.4. Examples of many of the Bulk Data options can be found throughout this User's Guide where actual problems for each of the standard and special analysis capabilities of NASTRAN are illustrated and explained.

To summarize, each Bulk Data Card is divided into ten fields; each eight columns wide. The first field contains either the card mnemonic or the continuation code from the preceding card if more than one card is required for definition of the data. These continuation codes must be unique in order to facilitate the sorting of the Bulk Data Deck. The last seven columns (74-80) of field 10 on each card are used only for specification of that unique continuation code. The card mnemonic always starts in card column 1. The continuation code from the preceding card starts in card column 2 with a + in card column 1. Each of the remaining data entries to be supplied may be placed without imbedded blanks anywhere within the appropriate field. These entries may be integer, real, or alphanumeric data.

## BULK DATA DESCRIPTION

However, occasionally more than eight-card columns are required for the user to specify his data with sufficient accuracy. In these situations, each Bulk Data Card may be expanded to cover two separate cards with 16-column fields for the data entries (fields 2-9). When this arrangement is used, an \* must appear following the card mnemonic and/or in card column 1 of the continuation card.

The type of data to be expected in each field is checked by NASTRAN on input, and a message is issued in the event of an error. To help detect possible modeling errors, NASTRAN also performs many other checks as the input data is used by the program.

## USER MASTER FILE

### 9.4 USER MASTER FILE

NASTRAN provides the User's Master File (UMF) capability to assist the user in handling large (several boxes of cards) Bulk Data Decks which are often typical for NASTRAN problems. This capability is completely described with examples in the User's Manual, Section 2.5. The capability is briefly summarized here.

Prior to the first run of NASTRAN for a new model, the entire Bulk Data Deck may be submitted to create a User's Master File. On a subsequent run, the user may create either a User's Master File or a Standard checkpoint to a tape called the New Problem Tape (NPTP) on which will be stored the Bulk Data Deck in sorted order. Any other subsequent runs can then be made with the old problem tape as a source for that data deck. When a run is a restart from a checkpoint, the old checkpoint tape, now called the Old Problem Tape (OPTP), must be provided. Any Bulk Data cards submitted with the restart run will be added to the old Bulk Data Deck for access during processing. If a checkpoint for this run is requested, another New Problem Tape will be written on which will be stored the new, augmented Bulk Data Deck. The UMF and OPTP may not be used at the same time, since the bulk data would be duplicated.

Thus, a user can add Bulk Data cards with each subsequent run, and he can also delete cards by inserting Bulk Data cards with a / in column one, followed by one or two of the sequence numbers assigned to each card of the sorted Bulk Data Deck from the previous run. All cards in the range of these sequence numbers will be deleted. If only one number is input, only that Bulk Data card is removed. These features are also available for editing and updating the User's Master File.

## AUTOMATED DATA GENERATION

### 9.5 AUTOMATED DATA GENERATION

#### 9.5.1 Utility Module INPUT Usage

NASTRAN provides a special utility module, INPUT, for creating the majority of Bulk Data cards for seven selected kinds of problems. This capability is fully described in Section 2.6 of the User's Manual, where examples of its use are found. A summary of the key INPUT features is provided here:

1. INPUT allows the user of NASTRAN to generate the majority of the bulk data cards for a number of selected test problems without having to actually input the physical cards into the Bulk Data Deck.
2. The test problems for which partial data are generated by INPUT are:
  - a. N x N Laplace Network from scalar elements
  - b. W x L Rectangular Frame from BAR elements or RBD elements
  - c. W x L Rectangular Array of QUAD1 elements
  - d. W x L Rectangular Array of TRIA1 elements
  - e. N - segment string from scalar elements
  - f. N - cell beam made from BAR elements
  - g. N - scalar point full matrix with optional unit loading
  - h. N - spoke wheel made from BAR elements

## BULK DATA DESCRIPTION

Table 1. Bulk Data Options

### A. Spatial Geometry

#### Axisymmetric Approach (UM 1.3.7, 1.7.1, TM 4.1, 5.9)

AXIC	Required to define existence of conical shell problem
AXIF	Required to define existence of fluid coordinate system, includes default parameters
AXSL0T	Required to define existence of acoustic slot analysis, includes default parameters.
POINTAX	Location on shell ring (conical shell) at which loads can be applied and displacements are requested.
RINGAX	Ring for conical shell.
SECTAX	Sector of a conical shell.

#### Coordinate Systems (UM 1.2.2, TM 3.4.1)

BAROR	Simple beam orientation and property default for CBAR.
CORDIC	Cylindrical coordinate system by reference to (i=1, three grid points, and i=2, coordinates of three points).
CORDIR	Rectangular coordinate system by reference to (i=1, three grid points, and i=2, coordinates of three points).
CORDIS	Spherical coordinate system by reference to (i=1, three grid points, and i=2, coordinates of three points).
GTRAN	Redefines output coordinate system displacement sets for substructuring.
TRANS	Transformation of basic coordinate systems for substructuring.

#### Fluid Points (UM 1.7.1, TM 16.1.1)

FREEPT	Fluid surface points for recovery of displacements.
FSLIST	Declares fluid points (RINGFL) which lie on free surface boundary.
GRIDB	Grid location on RINGFL for structure boundary.
GRIDF	Scalar degree of freedom for acoustic analysis of a fluid.
GRIDS	Scalar degree of freedom on acoustic slots.
PRESPT	Pressure points for data recovery in fluid analyses.
RINGFL	Circle (fluid point) in fluid model.
SLBOY	List of slot points (GRIDS) on interface between fluid and radial slots.

## AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

### A. Spatial Geometry (cont'd)

#### Grid Points (UM 1.1, 1.2, TM 3.1)

GRID	Grid point location, direction of displacement and constraints.
GRIDB	Alternate GRID definition for hydroelastic analysis.
GRDSET	Default options for all GRID cards.
SEQGP	Grid and scalar point number resequencing.

#### Scalar Points (UM 1.1, TM 3.1, 14.2)

EP@INT	Extra points defined for dynamics.
SEQEP	Extra point number resequencing.
GRIDF	Scalar degree of freedom for acoustic fluid analysis.
GRIDS	Scalar degree of freedom on acoustic slot boundary.
SP@INT	Scalar points defined.
SEQGP	Grid and scalar point number resequencing.

#### Aerodynamics (UM 1.11, TM 17.0)

AEFACT	Aerodynamic Spanwise Divisions.
AER@	Aerodynamic Physical Data.

### B. Element and Properties

#### Axisymmetric (UM 1.3.7, 1.7.1, TM 4.1, 5.9)

AXIC	Required to define existence of conical shell problems.
CC@NEAX	Conical shell element connection.
PC@NEAX	Conical shell property.
CT@DRG	Toroidal ring element condition.
PT@DRG	Toroidal ring property.
CTRAPRG	Trapezoidal ring element connection and property - axisymmetric response.
CTRIARG	Triangular ring element connection and property - axisymmetric response.
DMIAX	Direct matrix input for axisymmetric problems.
CTRAPAX	Trapezoidal ring element connection and property - nonaxisymmetric response.
CTRIAAX	Triangular ring element connection and property - nonaxisymmetric response.

## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### B. Element and Properties (cont'd)

#### Dummy (UM 1.3.1, TM 5.1)

ADUMi	Attributes for DCUMi AND PDUMi dummy elements (for user-defined element types i=i thru 9).
CDUMi	Dummy element connection.
PDUMi	Dummy element property.
PLØTEL	Dummy element definition (for plotting only).

#### Fluid (UM 1.7.1, TM 16.1.4)

AXIF	Required to define existence of fluid analysis and default parameters.
AXSLØT	Required to define existence of axisymmetric slot analysis and default parameters.
CAXFi	Fluid element connection i=2, 3 or 4 fluid points in an acoustic slot analysis.
CFLUIDi	Fluid element connection for axisymmetric fluid (for user-defined fluid points i=2, 3 or 4).
CSLØTi	Slot element connecting i=3 or i=4 GRIDS points for evenly spaced radial slots.

#### General (UM 1.3.1, TM 5.7)

CNGRNT	Indicates identical elements to another specified primary element.
GENEL	General element in terms of its transformation matrices.
CØNMi	Concentrated mass element connection (i=1 for mass matrix, or i=2 for offset mass inertia properties).

#### Line (UM 1.3.2, TM 5.2)

CBAR	Simple beam element connection.
PBAR	Simple beam property.
BARØR	Simple beam orientation default for CBAR.
CØNRØD	Rod element property and connection.
CRØD	Rod tension-compression-torsion element connection.
PRØD	Rod element property.
CTUBE	Tube tension-compression-torsion element connection.
PTUBE	Tube element property.
CVISC	Viscous damping connection, extensional and rotational.
PVISC	Viscous damper property, extensional and rotational.

AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

B. Element and Properties (cont'd)

Plate (UM 1.3.5, TM 5.8)

CQDMEM	Quadrilateral membrane element connection.
PQDMEM	Quadrilateral membrane element property.
CQDPLT	Quadrilateral bending element connection.
PQDPLT	Quadrilateral bending element property.
CQUADI	Quadrilateral membrane and bending element connection (i=1 for general and i=2 for homogeneous behavior).
PQUADI	Quadrilateral membrane and bending element property (i=1 for general and i=2 for homogeneous properties).
CSHEAR	Shear panel element connection.
PSHEAR	Shear panel property.
CTRBSC	Basic triangular bending element connection.
PTRBSC	Basic triangular bending element property.
CTRPLT1	Higher order triangular plate element connection.
PTRPLT1	Higher order triangular plate element property.
CTRIA1	Triangular membrane and bending element connection (i=1 for general and i=2 for homogeneous behavior).
PTRIA1	Triangular membrane and bending element property (i=1 for general and i=2 for homogeneous properties).
CTRMEM	Triangular membrane element connection.
PTRMEM	Triangular membrane element property.
CTRIM6	Higher order triangular membrane element connection.
PTRIM6	Higher order triangular membrane element property.
CTRPLT	Triangular bending element (TRPLT) connection.
PTRPLT	Triangular bending element (TRPLT) property.
CTWIST	Twist panel element connection.
PTWIST	Twist panel property.



## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### B. Element and Properties (cont'd)

#### Rigid Connectors (UM 1.4.2, TM 3.5.1)

MPC	Equations of constraint which may be used to simulate a rigid element.
MPCS	Multipoint constraints for substructuring.
MPCADD	Union of multipoint constraint sets defined by MPC cards.
CONCT	Substructuring connectivities
CONCT1	Substructuring connectivities
CRIGDR	Rigid rod element.
CRIGD1	Rigid element for 6 DOF.
CRIGD2	Rigid element for selected DOF.
CRIGD3	General rigid element.
CYJ@IN	Connectivities for cyclic symmetry models.
RELES	Releases rigid connections for substructuring.

#### Scalar (UM 1.3.8, TM 5.6)

CDAMP1	Scalar viscous damper connection (i=2 or 4 without reference to property).
PDAMP	Scalar viscous damper property.
CELAS1	Scalar spring connection (i=2 or 4 without reference to property).
PELAS	Scalar spring property.
CMASS1	Scalar mass connection (i=2 or 4 without reference to property).
PMASS	Scalar mass property.
CONM1	Concentrated mass element connection (i=1 for mass matrix, or i=2 for offset mass inertia properties).
CVISC	Viscous damping connection, extensional and rotational.
PVISC	Viscous damper property, extensional and rotational.

#### Solid (UM 1.3.9, TM 5.12)

CHEXA1	Hexahedron constant strain element connection (i=1 uses 5 tetrahedra, i=2 uses 10 overlapping tetrahedra).
CINEX1	Isoparametric solid hexahedron element connections (i=1 for linear, i=2 for quadratic, and i=3 for cubic functions).

## AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

### B. Element and Properties (cont'd)

#### Solid (cont'd)

PIHEX Isoparametric solid hexahedron element property.  
CTETRA Tetrahedron constant strain element connection.  
CWEDGE Wedge constant strain element connection.

#### Surface Heat (UM 1.8.3, TM 8.3)

CHBDY Heat convection boundary for steady-state heat condition.

### C. Materials

#### Anisotropic (UM 1.3.1, TM 4.2)

MAT2 Anisotropic material properties.  
MATT2 Temperature-dependent table references for MAT2 properties.  
MAT3 Orthotropic material properties.  
MATT3 Temperature-dependent table references for MAT3 properties.  
MAT5 Anisotropic thermal material properties.  
MATT5 Temperature-dependent table references for thermal conductivity matrix (MAT5).

#### Fluid (UM 1.7, TM 16.1.1)

AXIF Defines default parameters and existence of fluid analysis.  
AXSLOT Default parameters and the existence of axisymmetric slot analysis.  
BDYLIST Fluid mass density at fluid boundary.  
CFLUID1 Fluid mass density and bulk modulus.  
CSLOT1 Slot fluid element mass density and bulk modulus.  
FSLIST Fluid mass density at free surface.  
SLBDY Fluid mass density at boundary between axisymmetric fluid and evenly spaced radial slots.

#### Isotropic (UM 1.3.1, TM 4.2)

MAT1 Isotropic material properties.  
MATT1 Temperature-dependent table references for MAT1 properties.  
MATT4 Temperature-dependent table reference for thermal conductivity or convective film coefficient (MAT4).

## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### C. Materials (cont'd)

#### Stress Dependent (UM 1.3.1, TM 3.8.1)

MATS1        Stress-dependent table references for MAT1 properties.  
TABLES1     Tabular stress-strain function referenced by MATS1.

#### Temperature Dependent (UM 1.8.3)

MATTi        Table references for MATi type material and thermal properties (i=1, 4 for isotropic, i=2, 3, 5 for anisotropic).  
TABLEMi     Tabular function for generating material properties and parameter data (i=1 thru 4 for specific algorithm)  
TEMP         Grid point temperature field.  
TEMPD        Grid point temperature field default.  
TEMPAX       Temperature sets for conical shell problem.  
TEMPPi       Plate element temperature field (i=1 includes gradient, i=2 includes thermal moments, and i=3 includes tabular description over cross section).  
TEMPRB       Temperature field for line elements.

### D. Constraints and Partitioning

#### Fluid Boundary (UM 1.7.2, TM 16.1.3)

BDYLIST     Defines boundary (RINGFL points) between fluid and structure.  
FLSYM        Axisymmetric symmetry control.  
FSLIST       Required to define fluid points which lie on free surface.  
SLBDY        List of slot points (GRIDS) between fluid and radial slots.

#### Heat Boundary (UM 1.8.3, TM 8.3)

CHBDY       Heat convection boundary element for steady-state heat condition.

#### Multipoint Constraints (UM 1.4.2, TM 3.5.1)

MPC          Defines linearly dependent constraint relations between displacements.  
MPCADD       Union of multipoint constraint sets defined by MPC cards.  
MPCAX        Required to define MPC-type relations for conical shell coordinates.

AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

D. Constraints and Partitioning (cont'd)

Partitioning (UM 1.4.4, TM 3.5.3)

ASET	Defines independent degrees of freedom to be placed in analysis set.
ASET1	Defines independent degrees of freedom to be placed in analyses set.
BDYC	Defines boundary sets with substructuring
BDYS1	Defines boundary sets with substructuring.
OMIT	Defines degrees of freedom omitted from analysis set (reduces independent degrees of freedom).
OMIT1	Defines degrees of freedom omitted from analysis set (reduces independent degrees of freedom).
OMITAX	Omitted conical shell degrees of freedom.

Rigid Body Motion Constraints (UM 1.4.3, TM 3.5.5)

SUPAX	Conical shell fictitious supports for determinate reactions for free body analysis.
SUPPORT	Fictitious supports for determinate reactions applied to free body analysis.

Single-Point Constraints (UM 1.4.1, TM 3.5.2)

GRID	Grid point location, direction of displacement and constraints.
GRIDB	Grid location on RINGFL for fluid boundary and constraints.
GRDSET	Default options for all GRID cards.
SPC	Defines single-point constraints and enforced displacements.
SPC1	Defines sets of single-point constraints.
SPCADD	Union of singular point constraint sets defined by SPC and SPC1 cards.
SPCAX	Defines single-point constraints for conical shell coordinates.
SPCS	Defines single-point constraints with substructuring.
SPCS1	Defines single-point constraints with substructuring.
SPCD	Defines enforced displacements.
SPCSD	Defines enforced displacements with substructuring.

## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### E. Loads

#### Combinations (UM 1.5.1, TM 11.1)

DLBAD	Linear combination of dynamic load sets.
LOAD	Linear combination of static load sets (except temperature and displacement loads).
LOADC	Linear combination of load sets with substructuring.

#### Dynamic (UM 1.52, 1.53, TM 11.1, 12.1)

DAREA	Dynamic load scale factor and grid point location.
DELAY	Dynamic load function time delay and grid point location.
DLBAD	Linear combination of dynamic load sets.
DPHASE	Dynamic load function phase lead term $\theta$ (theta).
NONLIN1	Nonlinear displacement dependent transient forcing functions (i=1 thru 4 defines function type).
PRESPT	Fluid pressure point locations for output and control devices.
RANDPS	Frequency dependent self and cross-power spectral density factors of load sets.
RANDT1	Autocorrelation function time lag for random analysis.
TABRND1	Tabular function of power spectral density versus frequency for random analysis.
RLBAD1	Frequency dependent dynamic loads for frequency response (i=1, 2 defines function type).
TABLED1	Tabular function for generating frequency or time-dependent loads (i=1 thru 4 for specific algorithm).
TLBAD1	Time-dependent dynamic load for transient response (i=1, 2 for function type).
TSTEP	Time step intervals for solution and output in transient analysis.
DAREAS	Dynamic load scale factor with substructuring.
DELAYS	Dynamic load function time delay with substructuring.
DPHASES	Dynamic load function phase lead term with substructuring.

## AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

### E. Loads (cont'd)

#### Heat Transfer (UM 1.5, TM 8.0)

QHBDY	Thermal load at boundary for steady-state heat conduction.
QBDY1	Uniform heat flux into HBDY elements.
QBDY2	Distributed heat flux into HBDY elements.
QVECT	Vector heat flux into HBDY elements.
QVOL	Heat flux per volume generated by elements.
PLBAD3	Uniform static pressure on surface of hexahedron element.
TEMP	Grid point temperature field.
TEMPD	Grid point temperature field default.
TEMPAX	Temperature sets for conical shell problem.
TEMPP1	Plate element temperature field (only average temperature used for heat transfer analysis).
TEMPRB	Temperature field for line elements (only average grid point temperature used for heat transfer analysis).

#### Static (UM 1.5.1, TM 3.6)

DEFORM	Enforced axial deformation for line elements.
DSFACT	Defines scale factors for loads and stiffness matrices in differential stiffness analysis.
FORCE	Force load specified at grid point by vector.
FORCE1	Force load specified at grid point (i=1, two grid points, or i=2, four grid points)
FORCEAX	Force loading on an axisymmetric ring.
GRAV	Gravity vector definition (uses mass matrix).
LOAD	Linear combination of static load sets (not including thermal or deformation loadings).
MOMAX	Moment specified on an axisymmetric ring.
MOMENT1	Moment specified at grid point (i=1, two grid points, or i=2, four grid points)
PLFACT	Defines scale factors for load increments in piecewise linear analysis.
PLBAD	Defines a static pressure load on an area.
PLBAD2	Defines a pressure load applied to two-dimensional (plate) elements.
PLBAD3	Uniform static pressure on surface of hexahedron element.

## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### E. Loads (cont'd)

#### Static (cont'd)

PPOINTAX	Defines location on axisymmetric conical shell ring (RINGAX) at which loads may be applied.
PRESAX	Defines pressure loading of conical shell element.
RFORCE	Static loading condition due to centrifugal force field.
SLPAD	Defines static loads on scalar points.
TEMP	Grid point temperature field.
TEMPD	Grid point temperature field default.
TEMPAX	Temperature sets for conical shell problems.
TEMPI	Plate element temperature field (i=1 includes gradient, i=2 includes thermal moment, and i=3 includes tabular description of temperature over cross section).
TEMPRB	Temperature field for line elements including gradient.

### F. Methods

#### Buckling (TM 10.3, 10.4)

EIGB Required data for eigenvalue extraction for buckling analysis.

#### Control Systems (TM 1.4.2)

TF Dynamic transfer function as equation or direct matrix input.

#### Differential Stiffness (TM 7.1)

DSFACT Define scale factors for applied loads and stiffness matrices in differential stiffness approach.

#### Eigenvalue (TM 10.0)

EIGC Data required to perform complex eigenvalue analysis.

EIGP Defines poles used in complex eigenvalue analysis.

EIGR Data required to perform real eigenvalue analysis.

TABDMP1 Tabular function of structural damping versus frequency for modal formulations only.

#### Frequency Response (TM 12.1)

FREQ Set of frequencies used in frequency response analysis.

FREQ1 Set of frequencies specified by starting frequency, increment, and number of increments desired.

FREQ2 Set of frequencies specified by starting frequency, final frequency, and number of logarithmic increments desired.

## AUTOMATED DATA GENERATION

Table 1. Bulk Data Options (cont'd)

### F. Methods (cont'd)

#### Frequency Response (cont'd)

TABDMP1 Tabular function of structural damping versus frequency for modal formulations only.

#### Hydroelastic (UM 1.7, TM 16.1, 16.2)

FREEPT Location of fluid free surface points for displacement recovery.

AXSLØT Required to define existence of axisymmetric slot analysis and default parameters.

#### Piecewise Linear (TM 3.8)

PLFACT Required to define scale factors for load increments in piecewise linear analysis.

#### Random Response (TM 12.2)

RANDPS Frequency dependent self and cross-power spectral density factors of load sets.

RANDT1 Autocorrelation function time lag for random analysis.

TABRND1 Tabular function of power spectral density versus frequency for random analysis.

#### Transient Response (UM 1.6, TM 11.0)

TABDMP1 Tabular function of power spectral density versus frequency and modal formulations only.

TIC Initial conditions for both displacement and velocity for direct formulations only.

TSTEP Time step intervals used in transient analysis solution.

TICS Initial conditions for both displacement and velocity for substructuring (RF 8 and 9 only).

#### Aerodynamics (UM 1.11, TM 17.0)

FLUTTER Aerodynamic Flutter Data.

MKAERØi Mach Number - Frequency Tables.

FLFACT Aerodynamic Physical Data.

### G. Miscellaneous

#### Comment (UM 2.4.2)

\$ For inserting commentary material into unsorted echo deck.

#### Delete (UM 2.4.2)

For removing cards from either Old Problem Tape or the User's Master File.



## BULK DATA DESCRIPTION

Table 1. Bulk Data Options (cont'd)

### G. Miscellaneous (cont'd)

#### Direct Matrix Input

CONMI	Concentrated mass element connection (i=1 for mass matrix, i=2 for offset mass inertia properties).
DMI	User-defined direct matrix input, real or complex (general).
DMIG	User-defined direct structural matrix input, real or complex at grid points.
DMIAX	Axisymmetric related user-defined direct matrix input (fluid or structural).
TF	Direct matrix input for dynamic transfer function.

#### Output Control

FREEPT	Location of free surface fluid points for displacement recovery.
PLØTEL	Dummy element definition for plotting purposes only.
POINTAX	Defines location on axisymmetric conical shell ring (RINGAX) for recovery of displacements.
PRESPT	Pressure point on RINGFL for pressure data recovery in fluid.
TSTEP	Time step intervals for which solutions and output quantities to transient analysis are desired.

#### Parameters (UM 3.1.5)

PARAM	Specifies parameter values used in DMAP sequences (including rigid formats).
-------	--

#### Resequencing (UM 1.2.2)

SEQEP	Resequences extra point numbering to optimize bandwidth.
SEQGP	Resequences grid and scalar point numbering to optimize bandwidth.

#### Tabular Input (UM 1.8.3)

DTI	Input table data blocks directly.
TABDMP1	Tabular function of structural damping versus frequency.
TABLED1	Tabular function for generating frequency or time-dependent loads (user prescribes i=1 thru 4 for specific algorithm).
TABLEM1	Tabular function for temperature-dependent material properties and parametric data (user prescribes i=1 thru 4 for specific algorithm).
TABLES1	Tabular stress-strain function referenced by MATS1 card.
TABRND1	Tabular function of power spectral density versus frequency.

## 10. PRINTING AND PLOTTING FEATURES

### 10.1 INTRODUCTION

The possible options for printing and/or plotting the results obtained with NASTRAN are many and varied. In most cases the labeling of this output is self-explanatory, or it is deductively obvious. In spite of the wide variety of possible output, certain uniformity has been provided to expedite its interpretation. This section, therefore, illustrates only the characteristic sets of output and some of the less obvious interpretations, where necessary.

The types of NASTRAN printed output may be subdivided into five general categories: (1) input echo, (2) error messages, (3) substructure control requests, (4) case control requests and (5) miscellaneous. The last category itself may be segregated into special output requests controlled other than from case control and automatic output. The location of this output will vary with the sequence of operations performed by NASTRAN, and some will vary with the particular computer system being used. Each of these output categories will be discussed in the sections that follow.

## INPUT DATA ECHO AND DIAGNOSIS

### 10.2 INPUT DATA ECHO AND DIAGNOSIS

The input data to NASTRAN undergoes extensive checking, rearranging, and numerical processing in the initial phases of execution. The Executive Control Deck, the Substructure Control Deck, the Case Control Deck, the Bulk Data Deck, and the DMAP sequence are processed in five phases, each phase having its own procedure for processing and diagnosis.

The Executive Control Deck is printed as shown in Figure 1 on every execution of NASTRAN, exactly as it is input on cards, except when approach DMAP is used. In this case, the DMAP deck is echoed later. Diagnostic messages, if any, follow the printout of each data card.

The Substructure Control Deck printout (if substructuring is used) is shown in Figure 2. The deck is reproduced exactly as input, and diagnostic messages, if any, follow the printout of each data card. An echo of the automatically generated DMAP alters may be requested by DIAG 23 in the Executive Control Deck. This echo will follow immediately and precede the Case Control Deck echo described next.

The Case Control Deck printout is shown in Figure 3. All input cards are printed with no modifications. The diagnostic messages deal primarily with proper data format. In certain levels of NASTRAN, a complete list of all legal case control requests are printed if the user misspells a request. The plot control cards, a subset of the Case Control Deck, are processed in a similar manner.

The Bulk Data Deck may be printed in two forms, depending on the ECHO option selected. The unsorted bulk data echo option (Figure 4) is an unprocessed printout of the input Bulk Data Deck. On a restart from a previous run, only the new cards and deletion cards are printed along with a sorted echo of the modified Bulk Data Deck, including these new cards that were added.

The default printout is a sorted echo (Figure 5) of all the bulk data cards to be used in the computer run. They are arranged in alphabetical and numerical order. All entries in fields 2-9 are shifted and left-justified by NASTRAN for proper alignment to facilitate the sorting. The continuation cards are printed following the parent card. No comment cards are printed in the sorted echo. Each card is assigned a sequence number on the left-hand side to allow for modification of the Bulk Data Deck on restart from a checkpoint.

The diagnostics are printed with the sorted bulk data echo. If errors occurred in the data format, the card containing the error is identified as shown in Figure 5. For some errors it is

## PRINTING AND PLOTTING FEATURES

printed again, and the specific data field containing the error is underlined. The Bulk Data Deck is processed one card at a time, and errors occurring from a combination of different data cards may not be detected at the same time.

Following the bulk data echo is the DMAP compiler source listing (UM 3.2 to 3.20) if requested by DIAG 14 in the Executive Control Deck. In normal structural analyses, this is a listing of the Rigid Format selected in the Executive Control Deck. This listing will include any user-supplied DMAP alters and alters created by NASTRAN for automated substructuring, if used (see Figure 6). Section 3 of the User's Manual describes the Rigid Formats, and Section 5 of the User's Manual describes the details of the DMAP language.

A special procedure is used on a restart from a previous run. The DMAP operations to be executed on restart are identified with an asterisk (\*). Immediately preceding the DMAP listing is a summary of modified bulk data cards by data card name. Also, the types of data which are to be modified are marked with a dollar sign (\$). Only those users who are interested in the mathematical operations performed during a restart need to be concerned with these details.

## USER-REQUESTED DIAGNOSTIC MESSAGES

### 10.3 USER-REQUESTED DIAGNOSTIC MESSAGES

The DIAG card in the Executive Control Deck is a convenient tool for printing information on the status of a NASTRAN run. More than thirty diagnostic requests are available. For example, the DIAG card is used to print matrix trailers, the contents of certain arrays and tables, DMAP statements, etc. The method of requesting this type of print is illustrated in Figure 1 where eight DIAG numbers are specified. The information obtained in an unsuccessful run may be used to locate an area where there may be a program error or an engineering modeling error. A few of the more common requests are discussed and illustrated below.

DIAG 8 prints the trailers of matrix and table data blocks. The six words describe the dimensions, form, type and density of a matrix, but may not contain relevant information for a table. Shown below is an example and a description of each item in a matrix trailer.

```
*** DIAG 8 MESSAGE -- TRAILER FOR DATA BLOCK SCRATCH4 = 9 8 6 1 4 4861

MATRIX NAME           = SCRATCH4
NO. OF COLUMNS       = 9
NO. OF ROWS          = 8
MATRIX FORM           = 6
MATRIX TYPE           = 1
MAXIMUM NO. OF TERMS IN ANY COLUMN = 4
MATRIX DENSITY        = .4861 (= 48.61%)
```

A complete discussion of data block trailers, including definitions of matrix form and type is presented in the Programmer's Manual, Section 2.2.

DIAG 13 prints in the dayfile the current length of open core each time the calculation routine is called throughout the NASTRAN execution. The length is given in both octal and decimal numbers. An example is shown in Figure 7.

DIAG 14 prints the DMAP statements for the Rigid Format selected. The beginning of the Rigid Format 1 listing is presented in Figure 6.

DIAG 15 displays in the dayfile the GIN# open and close operations for subroutines, data blocks, and scratch files. The numbers from 0 to 3 shown to the right of the open and close statements in Figure 7 are the codes which indicate file conditions (read, write, rewind, end

## PRINTING AND PLOTTING FEATURES

of file). The codes are described in Section 3.4 of the Programmer's Manual.

\* DIAG 19 prints data used by NASTRAN to determine which of three methods will be most efficient for matrix multiply and add or triple multiply (see Figure 8).

DIAG 21 provides a table showing the vector sets to which each degree of freedom of grid, scalar, and extra points belong. Such a table is illustrated in Figure 9.

DIAG 22 provides as many as five tables showing the assignment of degrees of freedom of grid, scalar, and extra points to Analysis, Omit, SPC, and MPC sets. One type of table is shown in Figure 10.

DIAG 23 prints a listing of the DMAP alters generated during an automated multistage substructuring run. The first part of a typical listing is shown in Figure 11.

## ERROR AND WARNING MESSAGES

### 10.4 ERROR AND WARNING MESSAGES

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The NASTRAN system will automatically print out messages to the user for several reasons: user information messages, user warning and fatal messages, and system error messages. Most of these messages are listed with a brief description in Section 6 of the User's Manual. Each message is given a number and may refer to a specific data item, mathematical operation, or internal operation. Fatal messages will cause the program to exit.

Of specific user interest are the user information messages which provide data regarding the performance of a particular job. User information messages 3023 through 3028 provide data on the matrix decomposition. These include such data as the semi-bandwidth (B), the active columns (C), the number of columns held in core (R), and the estimated CPU running time in seconds. Message number 3035 prints out the error ratio for a solution. Message number 2073 prints the method selected for a matrix multiply operation. These messages aid the user in detecting problems with running time and accuracy.

Another type of message is the warning of gridpoint singularities (Figure 12) which provides useful information. This printout lists the grid points which have a possible singularity in the stiffness matrix. The number of singularities and the specific unconstrained degrees of freedom (gridpoint displacements or rotations) are listed in the order that they are detected. This is only a warning message and may not be significant in certain special cases.

## CASE CONTROL DECK OUTPUT CONTROL

### 10.5 CASE CONTROL DECK OUTPUT CONTROL

The output data processing for presentation of results is performed by NASTRAN with a single, general purpose routine which prints titles, labels, column headings, and the numerical results. It is therefore obvious that many types of data will share similar formats and have the same general appearance.

The Case Control input contains specifications for the type and contents of printout (UG 8). Each output request defines a physical type of variable and specifies a set of points or elements to which the request applies. Options are available to print out the results of a dynamic analysis in either of two types of sort. The default option, SORT1, will print the results for all points or elements for each time step or frequency (Figure 13). SORT2 will print the results for each point or element for all time steps or frequencies (Figure 14).

In certain dynamic problems (Figure 13) for Complex Eigenvalues or Frequency Response, the output consists of complex numbers. The user has the option of specifying that the output be printed in a real/imaginary format or in a magnitude/phase angle format. Each pair of numbers is written with the real value or magnitude directly above the imaginary value or phase angle. (Note: The phase angles are in degrees.)

The most common format of printed output relates to the grid, scalar, or extra points (Figure 13). The following quantities are printed in this format:

DISPLACEMENT	ACCELERATION
LOAD	VECTOR
SPCFORCE	PRESSURE
VELOCITY	THERMAL

In dynamic analysis, the following types of output are available as SOLUTION set output (Figure 14):

SDISPLACEMENT	SACCELERATION
SVELOCITY	NLOAD

This output provides the results only for the degrees of freedom used in the solution of the dynamic problem. If a direct formulation is used, the quantities printed relate to the motion of



## PRINTING AND PLOTTING FEATURES

the grid, scalar, or extra points remaining after the constraints and matrix reductions have been applied. If a modal formulation is used, the output describes the motion of the modal coordinates and any user-supplied extra points. The NLLDAD output request provides the nonlinear displacement or velocity-dependent loads generated only for the transient analysis.

Note that grid, scalar, and extra points, as well as modal coordinates, may be intermingled in the output. The points with only one degree of freedom are printed in a special format. The "ID" = N number is printed only for the first point in a sequential set of up to six such points. The results for the second and succeeding points are printed on the same line with the first. If more than six points occur in a numerical sequence, the seventh "ID" will be printed so as to identify the second line of printout, and so on for every succeeding set of six such points.

In the general gridpoint output, the values given for T1, T2, and T3 correspond to the three translations, and R1, R2, and R3 correspond to the three rotations of that grid point. The orientation of these displacement components is defined by the output displacement coordinate system, which is either the NASTRAN "basic" rectangular system or a special coordinate system that is specified by the user for that grid point. If a rectangular system is used, the T1, T2, T3 and R1, R2, R3 directions correspond to the X,Y,Z ( $T1 = u_r$  (radial),  $T2 = u_\theta$  (circumferential), and  $T3 = u_z$  (axial)). The rotations R1, R2, and R3 are given in units of radians and are defined as vectors with the same directions as the translations.

The formats of the element forces and stresses are not as uniform as the output formats for gridpoint data. Each element type has a particular set of output quantities which is printed in a self-explanatory format. These formats may vary with the type of analysis. Element force output, in general, is the self-equilibrating internal load system for that element in units of force (moment), or force (moment) per length. Element stress output, in general, consists of direct stresses at a particular point in the element. Both these sets of element output quantities are defined in the local element coordinate system. Section 2 of the User's Manual lists the output quantities available for each element. Examples of these printouts are given in Figures 15 and 16. The first example is a typical element stress output; the second is a more elaborate printout of stresses occurring in the harmonic analysis of an axisymmetric conical shell element. As with the grid point data printout for dynamic analyses, these values may be real or complex, and may be requested in either SORT1 or SORT2 format.

CASE CONTROL DECK OUTPUT CONTROL

Table 1. Output Request Codes for Combine and Reduce Operations.

COMBINE		MREDUCE	
Code	Output	Code	Output
2	SØF table of contents	1	Current problem summary
3	CØNCT1 bulk data summary	2	Boundary set summary
4	CØNCT bulk data summary	3	Summary of grid point ID numbers in each boundary set
6	GTRAN bulk data summary	4	The EQSS item for the structure being reduced
7	TRANS bulk data summary	5	The EQSS item
9	RELES bulk data summary	6	The BGSS item
11	Summary of automatically generated connections	7	The CSTM item
12	Complete connectivity map of final combined pseudostructure	8	The PLTS item
13	The EQSS item	9	The LØDS item
14	The BGSS item	10	Modal DØF set summary
15	The CSTM item	11	Fixed set summary
16	The PLTS item	12	Summary of grid point ID numbers in each fixed set
17	The LØDS item		
REJUICE		CREDUCE	
Code	Output	Code	Output
1	Current problem summary	1	Current problem summary
2	Boundary set summary	2	Boundary set summary
3	Summary of grid point ID numbers in each boundary set	3	Summary of grid point ID numbers in each boundary set
4	The EQSS item for the structure being reduced	4	The EQSS item for the structure being reduced
5	The EQSS item	5	The EQSS item
6	The BGSS item	6	The BGSS item
7	The CSTM item	7	The CSTM item
8	The PLTS item	8	The PLTS item
9	The LØDS item	9	The LØDS item
		10	Modal DØF set summary
		11	Fixed set summary
		12	Summary of grid point ID numbers in each fixed set

## PRINTING AND PLOTTING FEATURES

Table 2. Summary for Structural Plotting Options.

PLOTID	Optional to give plot identification, must precede OUTPUT(PLOT)
SET i	Required and specifies sets of elements for plotting (UM 4.2 for options)
PLOTTER	Optional to specify plotter name and MODEL names (UM 4.1) if other than SC 4020 (UM 4.2 for options)
PROJECTION	Optional to specify type if other than ORTHOGRAPHIC (TM 13.)
AXES ( VIEW )	Optional to define observer's coordinate system and to position the figure (UM 4.2)
MAXIMUM DEFORMATION	Required to specify scale for plotting deformed structure and must precede FIND card (UM 4.2)
SCALE	Required to specify scale of plotted object, may be replaced by FIND card (UM 4.2)
ORIGIN	Required to define origin of plotted object relative to lower left-hand corner of paper, may be replaced by FIND card (UM 4.2)
VANTAGE POINT	Required to specify location of observer with respect to structural model for either perspective or stereoscopic projections only, may be replaced by FIND card (UM 4.2, TM 13.)
PROJECTION PLANE SEPARATION	Required to specify R-direction separation of the observer and the projection plane for perspective or stereoscopic projections only, may be replaced by FIND card (UM 4.2, TM 13.)
OCULAR SEPARATION	Optional to specify S-coordinate separation of the two vantage points of other than 2.756 inches in the stereoscopic projections only (UM 4.2)
CAMERA	Optional to specify type of film and/or paper and number of blank frames on microfilm plotters only (UM 4.2)

CASE CONTROL DECK OUTPUT CONTROL

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N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

IO       MASTRAN.SAMPLE  
APP     DISPLACEMENT  
SOL     1,0  
CHKPNT YES  
TIME    5  
DIAG    0,11,13,14,15,19,21,22  
CEMD

Figure 1. Example of the NASTRAN Executive Control Deck Echo.

PRINTING AND PLOTTING FEATURES

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N A S T R A N S U B S T R U C T U R E D E C K E C H O

```
SUBSTRUCTURE PHASE2
PASSWORD = H0LSYN
SOF(1) = 30F1.500 $ CDC
OPTIONS M,M,P
SOPRINT TOC
MREDUCE ABASIC
NAME M1
BOUNDARY 5
FIXED 5
METHOD 9
OUTPUT 1.5,6,9,10
SOPRINT TOC
MREDUCE ABASIC
NAME M1
BOUNDARY 4
FIXED 4
METHOD 9
OUTPUT 1.5,6,9,10
SOPRINT TOC
COMBINE MAMB
NAME MCOM9
TOLERANCE 0.001
OUTPUT 2,7,12
COMPONENT M8
TRANSFORM 40
SOPRINT TOC
MREDUCE MCOM9
NAME RTPUSS
BOUNDARY 42
FIXED 9
METHOD 90
MMAX 14
OUTPUT 1.5,6,9,10
```

Figure 2. Example of the NASTRAN Substructure Control Deck Echo.

CASE CONTROL DECK OUTPUT CONTROL

STATIC ANALYSIS OF A THREE-PANEL TRUSS  
 OUTPUT REQUEST FOR ALL QUANTITIES

C A S E C O N T R O L D E C K E C H O

CARD  
 COUNT  
 1 TITLE = STATIC ANALYSIS OF A THREE-PANEL TRUSS  
 2 SUBTITLE = OUTPUT REQUEST FOR ALL QUANTITIES  
 3 LINE = 38  
 4 ECHO = BOTH  
 5 SPC = 1  
 6 OUTPUT  
 7 DISPLACEMENT = ALL  
 8 SPECFORCE = ALL  
 9 FORCE = ALL  
 10 STRESS = ALL  
 11 GPFORCE = ALL  
 12 ESE = ALL  
 13 OLLOAD = ALL  
 14 SUBCASE 1  
 15 LABEL = 240-LB LOAD AT GRID POINT 4  
 16 LOAD = 1  
 17 SUBCASE 2  
 18 LABEL = 120-LB LOAD AT GRID POINT 2  
 19 LOAD = 2  
 20 BEGIN BULK

\*\*\* DIAG B MESSAGE --- TRAILER FOR DATA BLOCK CASECC \* 2 2 200 0 0

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Figure 3. Example of the NASTRAN Case Control Deck Echo.

PRINTING AND PLOTTING FEATURES

```

INPUT BULK DATA DECK ECHO
* 1 .. 2 .. 3 .. 4 .. 5 .. 6 .. 7 .. 8 .. 9 .. 10 .
$ DEFINE GRID POINT LOCATIONS
GRID 1 0.0 0.0 0.0
GRID 2 180.0 0.0 0.0
GRID 3 180.0 240.0 0.0
GRID 4 360.0 0.0 0.0
GRID 5 360.0 240.0 0.0
GRID 6 540.0 0.0 0.0
GNDSET
$ SPECIFY GRID POINT CONNECTIVITIES
CKOD 1 1 1 2
CKOD 2 2 1 3
CKOD 3 3 2 3
CKOD 4 1 2 4
CKOD 5 1 3 4
CKOD 6 3 3 5
CKOD 7 3 4 5
CKOD 8 2 5 6
CKOD 9 1 4 6
$ DEFINE LOADING CONDITIONS
FORCE 1 4 240.0 0.0 -1.0 0.0
FORCE 2 2 120.0 0.0 -1.0 0.0
$ DEFINE ELEMENT PROPERTIES
PROD 1 100 7.97
PROD 2 100 21.16
PROD 3 100 11.77
$ PROVIDE MATERIAL SPECIFICATIONS
MAT1 100 30.0+7 0.3 4.28
+MRGNS 20.0+4 15.0+4 12.0+4
$ DEFINE BOUNDARY CONDITIONS
SPC 1 1 12 0.0 6 2 0.0
$ REQUEST ADDITIONAL OUTPUT
PARAM GRDPNT 0
PARAM IRIS 1
ENDDATA

TOTAL COUNT= 54
    
```

\*\*\* USER INFORMATION MESSAGE 207, BULK DATA NOT SORTED, SMOPT WILL BE CHANGED TO DECK.

Figure 4. Example of the NASTRAN Input Data Deck Echo - Unsorted.

CASE CONTROL DECK OUTPUT CONTROL

THREE ELEMENT BEAM OF LENGTH 3.0  
EACH ELEMENT HAS LENGTH 1.0

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CARD COUNT	1	2	3	4	5	6	7	8	9	10
1-	BAR0	1	1	1	1	1	1	1	1	1
2-	CMAP	2	2	2	2	2	2	2	2	2
3-	CMAP	3	3	3	3	3	3	3	3	3
4-	CMAP	4	4	4	4	4	4	4	4	4
5-	COMM2	10	10	10	10	10	10	10	10	10
6-	EC1	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
7-	EC2	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
8-	EC3	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
9-	EC4	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
10-	EC1	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
11-	EC2	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
12-	EC3	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
13-	EC4	2.0E-6	0.	0.	0.	0.	0.	0.	0.	0.
14-	FORCE	11	11	11	11	11	11	11	11	11
15-	FORCE	12	12	12	12	12	12	12	12	12
16-	FORCE	41	41	41	41	41	41	41	41	41
17-	FORCE	42	42	42	42	42	42	42	42	42
18-	FORCE	104	104	104	104	104	104	104	104	104
19-	FORCE	104	104	104	104	104	104	104	104	104
20-	FORCE	104	104	104	104	104	104	104	104	104
21-	GRID	1	1	1	1	1	1	1	1	1
22-	GRID	2	2	2	2	2	2	2	2	2
23-	GRID	3	3	3	3	3	3	3	3	3
24-	GRID	4	4	4	4	4	4	4	4	4
25-	MAT1	1	1	1	1	1	1	1	1	1
26-	PARAM	ATMASS	1.0E7	1.0E7	1.0E7	1.0E7	1.0E7	1.0E7	1.0E7	1.0E7
27-	PARAM	25.	25.	25.	25.	25.	25.	25.	25.	25.
	PARAM	1	1	1	1	1	1	1	1	1
	ENDDATA									

\*\*\* USEN FATAL MESSAGE 315, FORMAT ERROR ON BULK DATA CARD FORCE 42 2.0E-5 SORTED CARD COUNT 16

Figure 5. Example of the NASTRAN Input Data Deck Echo - Sorted.



LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```

OPTIONS IN EFFECT: GO      ERR=2  NOLIST  NNODECK  MOREF  NONSCAR
1 BEGIN  NO.1 STATIC ANALYSIS - SERIES P $
2 FILE   GTP2=SAVE/ESTI=SAVE $
3 FILE   UG=APPEND/PGG=APPEND/UGV=APPEND/GH=SAVE/KNN=SAVE $
4 GP1    GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPD,SIL/V,N,LUSET1/ V,N,
        NOGPOT/V,N,ALWAYS=-1 $
5 SAVE   LUSET $
6 CHKPNT GPL,EQEXIN,GPDT,CSTM,BGPD,SIL $
7 GP2    GEOM2,EQEXIN/ECT $
8 CHKPNT ECT $
9 PARAM  PCB//C,N,PRES/C,N/C,N/C,N/V,N,NOPCDB $
10 PURGE PLTSETX,PLTPAR,GPSETS,ELSETS/NOPCDB $
11 CCND  PL,NOPCDB $
12 PLTSET PCB,EQEXIN,ECT/PLTSETX,PLTPAR,GPSETS,ELSETS/V,N,NSIL/ V,N,
        JUMPLOT=-1 $
13 SAVE  NSIL,JUMPLOT $
14 PRMSG  PLTSETX// $
15 PARAM  /C,N,MPY/V,N,PLTLG/C,N,1/C,N,1 $
16 PARAM  /C,N,MPY/V,N,PFIL/C,N,0/C,N,0 $
  
```

Figure 6. Partial Listing of NASTRAN DMAP Statements for Rigid Format 1.

CASE CONTROL DECK OUTPUT CONTROL

```

09.34.16. 7.0 2.405 END IFF
09.34.16. 7.0 2.410 XGPI DECIMAL= 42049
09.34.16.CORE OCTAL=122101 DECIMAL= 42046
09.34.16.CORE OCTAL=122076
09.34.16. OPEN NPTP 0
09.34.17. OPEN SCATCHI 1
09.34.17. CLOSE SCATCHI 1
09.34.17. CLOSE NPTP 1
09.34.17. OPEN IFFFILE 0
09.34.17. CLOSE IFFFILE 1
09.34.17. OPEN SL4ATCHI 0
09.34.17. CLOSE SL4ATCHI 0
09.34.17. OCTAL=122076 DECIMAL= 42045
09.34.19. CLOSE SCATCHI 1
09.34.19. OPEN SCATCHI 1
09.34.19. CLOSE SCATCHI 3
09.34.19. OPEN POOL 3
09.34.19. CLOSE POOL 1
09.34.20. OPEN NPTP 0
09.34.20. CLOSE NPTP 2
09.34.20. OPEN NPTP 3
09.34.20. CLOSE NPTP 2
09.34.21. OPEN XPTU 1
09.34.21. CLOSE XPTU 1
09.34.21. OPEN POOL 2
09.34.21. CLOSE POOL 2
09.34.21. CORE OCTAL=130022 DECIMAL= 48145
09.34.21. 12.0 10.340 SEMI END
09.34.21. OPEN POOL 2
09.34.21. CLOSE POOL 2
09.34.21. CORE OCTAL=152704 DECIMAL= 54724
09.34.21. 12.0 11.075 CORE LEFT 28600
09.34.21. 12.0 11.075 LINK BEGN NS02
09.34.21. OPEN
09.34.21. CLOSE
09.34.22. LINK2,MSADATA,OUTPUT,PUNCH.
09.34.27. CLOSE GEOM1 1
09.34.27.CORE OCTAL=142632 DECIMAL= 50586 2
09.34.27. OPEN POOL
09.34.27.
09.34.27. M A S T R A M E X E C U T I O N ==
09.34.27. ELAPSED CPU
09.34.27. SECUMOS SECUMOS MODU-STATUS
09.34.27. LINK END ---
09.34.27. 0.0 0.000 LINK END ---
09.34.27.CORE OCTAL=125750 DECIMAL= 44008 2
09.34.27. CLOSE POOL
09.34.28. 1.0 .005 MSFA

```

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OF QUALITY

Figure 7. Portion of a Dayfile Illustrating DIAG 13 (Core Length) and DIAG 15 (Open-Close).

PRINTING AND PLOTTING FEATURES

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000USER INFORMATION MESSAGE 3023---PARAMETERS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK SCRATCH3 ( N = 24 )
TIME ESTIMATE = 1 C AVG = 5 PC AVG = 0 SPILL GROUPS = 0 S AVG = 1
ADDITIONAL CPNE = -27025 C MAX = 9 PCMAX = 0 PC GROUPS = 0 PREFACE LOOPS = 1
METHOD 3 T 0NR PASSES = 10EST. TIME = .0
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPY3 = .2 SECONDS.
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPYAD - (AT0R)0A + E = .1 SECONDS.
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPYAD - AT0(R0A) + F = .1 SECONDS.
METHOD 1 NT,0NR PASSES = 10EST. TIME = .0
METHOD 3 T 0NR PASSES = 10EST. TIME = .0
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPY3 = .P SECONDS.
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPYAD - (AT0R)0A + E = .2 SECONDS.
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPYAD - AT0(R0A) + E = .2 SECONDS.
METHOD 1 NT,0NR PASSES = 10EST. TIME = .1
METHOD 3 T 0NR PASSES = 10EST. TIME = .1
000 USER INFORMATION MESSAGE 6525, TRIPLE MULTIPLY TIME ESTIMATE FOR MPYAD - (AT0R)0A + E = .0 SECONDS.
METHOD 3 T 0NR PASSES = 10EST. TIME = .0

```

Figure 8. Example of the Output from DIAG 19 - MPYAD Method Selection.

STATIC ANALYSIS OF A THREE-PANEL TRUSS  
OUTPUT REQUEST FOR ALL QUANTITIES

CASE CONTROL DECK OUTPUT CONTROL

INT	DOF	EXT	GP.	DOF	SH	SG	L	A	F	M	G	R	O	S	M
1	1	1	1	1	•										
2	1	2	1	2	•										
3	1	3	1	3	•										
4	1	4	1	4	•										
5	1	5	1	5	•										
6	1	6	1	6	•										
7	2	1	2	1	•										
8	2	2	2	2	•										
9	2	3	2	3	•										
10	2	4	2	4	•										
11	2	5	2	5	•										
12	2	6	2	6	•										
13	3	1	3	1	•										
14	3	2	3	2	•										
15	3	3	3	3	•										
16	3	4	3	4	•										
17	3	5	3	5	•										
18	3	6	3	6	•										
19	4	1	4	1	•										
20	4	2	4	2	•										
21	4	3	4	3	•										
22	4	4	4	4	•										
23	4	5	4	5	•										
24	4	6	4	6	•										
25	5	1	5	1	•										
26	5	2	5	2	•										
27	5	3	5	3	•										
28	5	4	5	4	•										
29	5	5	5	5	•										
30	5	6	5	6	•										
31	6	1	6	1	•										
32	6	2	6	2	•										
33	6	3	6	3	•										
34	6	4	6	4	•										
35	6	5	6	5	•										
36	6	6	6	6	•										
----- COLUMN TOTALS -----					3	24	9	9	9	9	36	36	0	27	0

\*\*\* USER INFORMATION MESSAGE 2119, SUBROUTINE GP4PRT - DIAG 22 SET DISP SETS VS. DOF FOLLOWS.

Figure 9. Example of the Output Table Provided by DIAG 21.

PRINTING AND PLOTTING FEATURES

STATIC ANALYSIS OF A THREE-PANEL TRUSS  
 OUTPUT REQUEST FOR ALL QUANTITIES

		SPC DISPLACEMENT SET									
		-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-
10		1-1	1-2	1-3	1-4	1-5	1-6	2-3	2-4	2-5	2-6
110		3-3	3-4	3-5	3-6	4-3	4-4	4-5	4-6	5-3	5-4
210		5-5	7-6	6-2	6-3	6-4	6-5	6-6			

Figure 10. Example of the Output Provided by DIAG 22.

CASE CONTROL DECK OUTPUT CONTROL

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NASTRAN SUBSTRUCTURE DECK ECHO

```

ALTER DECK ECHO
1 ALTR
2 PARM
3 LABEL
4 SPUT
5
6 MRED1
7
8 CMD
9 SOST
10
11 CMD
12 EQUV
13 EQUV
14 CMD
15 SCE1
16 LABEL
17 READ
18
19 OFP
20 EQUV
21 CMD
22 UMRG:
23 LABEL
24 MRED2
25
26 LABEL
27 CMD
28 SPUT
29
30 MRED1

//ADD//DRY/1 /0 $
LBSRG $
//DRY//TOC //SDFP/0 /0 //0 //0 //0 //
CASFC,GEOM,DYNAMICS,CSTM/USETR,EEDR,EOST,DMR//BASIS //
S,N,DRY/3 /S,N,NDFIX/S,N,SMIP//REAL $
LPM23 /DRY $
/K2 /M2 /P2 // /S,N,DRY//BASIS //KMTX//PMTY//
PVEC//ORNTX//K4M $
LPM23 /SKIP $
K2 /KFFX/MCFIX $
M2 /MFFX/MFFIX $
LPM13 /NDFIX $
USETR,K2 /P2 // /KFFX,KFSX,KSSX,MFFX // $
LPM13 //
KFFX,MFFX // /EEDR,USETR,/LAMP,PMIR,MIR,DEIGR//MDECO//
NFIGVS $
LAMP,DEIGR// $
PMIP,PMIS/NDFIX $
LPM23 /NDFIX $
USETR,PMIR,/PMIS//NO//P//SO $
LPM23 $
CASECC,LAMP,PMIS,EOST,USETR,K2 /M2 // /S,N,DRY//PVEC $
OSH/M1 /M1 // /P1 /P01 /3 // /S,N,DRY//PVEC $
LPM23 $
FINIS,DRY $
//DRY//TOC //SDFP/0 /0 //0 //0 //0 //0 //
CASFC,GEOM,DYNAMICS,CSTM/USETR,EEDR,EOST,DMR//BASIS //

```

Figure 11. A Partial Listing of DMAP Alters Generated During Automated Multi-Stage Substructuring (Obtained from DIAG 23).

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POINT ID.	TYPE	SINGULARITY ORDER	GRID POINT ID	STONGEST COMBINATION	SINGULARITY ORDER	WEAKER COMBINATION	SPC	MPC	NEAREST COMBINATION
1	6	1	3	3	1				
2	6	1	3	3	1				
3	6	1	3	3	1				
4	6	1	3	3	1				
5	6	1	3	3	1				
6	6	1	3	3	1				
7	6	1	3	3	1				
8	6	1	3	3	1				
9	6	1	3	3	1				
10	6	1	3	3	1				
11	6	1	3	3	1				

10.5-16

Figure 12. Example of a Grid Point Singularity Table.

CASE CONTROL DECK OUTPUT CONTROL

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SUBCASE 1

DISPLACEMENT APPROXIMATE, DIGID FORMAT 11  
 FREQUENCY = 2.000000E+01

C O M P L E X A C C E L E R A T I O N V E C T O R  
 (MAGNITUDE/PHASE)

POINT NO.	TYPE	T1	T2	T3	R1	R2	R3
1	G	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	G	0.0	0.0	1.671510E+02	0.0	1.637622E+02	0.0
		0.0	0.0	203.4311	0.0	23.4277	0.0
3	G	0.0	0.0	6.417696E+02	0.0	3.076057E+02	0.0
		0.0	0.0	203.4246	0.0	23.4179	0.0
4	G	0.0	0.0	1.385247E+03	0.0	4.329512E+02	0.0
		0.0	0.0	203.4186	0.0	23.4100	0.0
5	G	0.0	0.0	2.367595E+03	0.0	5.418274E+02	0.0
		0.0	0.0	203.4141	0.0	23.4061	0.0
6	G	0.0	0.0	3.542418E+03	0.0	6.355032E+02	0.0
		0.0	0.0	203.4115	0.0	23.4073	0.0
7	G	0.0	0.0	4.894042E+03	0.0	7.133312E+02	0.0
		0.0	0.0	203.4110	0.0	23.4126	0.0
8	G	0.0	0.0	6.383551E+03	0.0	7.725722E+02	0.0
		0.0	0.0	203.4122	0.0	23.4198	0.0
9	G	0.0	0.0	7.971708E+03	0.0	8.116790E+02	0.0
		0.0	0.0	203.4144	0.0	23.4263	0.0
10	G	0.0	0.0	9.616751E+03	0.0	8.302117E+02	0.0
		0.0	0.0	203.4168	0.0	23.4301	0.0
11	C	0.0	0.0	1.129323E+04	0.0	8.347499E+02	0.0
		0.0	0.0	203.4189	0.0	23.4312	0.0

Figure 13. Example of Complex Vector Output in SPRT1 Format.



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DISPLACEMENT APPROACH, RIGID FORMAT 9  
POINT-ID = 10

TIME	TYPE	Y1	Y2	Y3	R1	R2	R3
0.0	E	1.000000E+01					
1.000000E-01	E	5.216204E+00					
2.000000E-01	E	-3.335933E+00					
3.000000E-01	E	-8.985948E+00					
4.000000E-01	E	-6.820184E+00					
5.000000E-01	E	1.277930E+00					
6.000000E-01	E	8.264471E+00					
7.000000E-01	E	8.062300E+00					
8.000000E-01	E	8.474603E-01					
9.000000E-01	E	-7.104609E+00					
1.000000E+00	E	-9.137197E+00					
1.020000E+00	E	-8.514564E+00					
1.100000E+00	E	-2.773559E+00					
1.200000E+00	E	6.206277E+00					
1.300000E+00	E	9.532409E+00					
1.400000E+00	E	4.173374E+00					
1.500000E+00	E	-4.987663E+00					
1.600000E+00	E	-9.604847E+00					
1.700000E+00	E	-5.471220E+00					
1.800000E+00	E	3.647029E+00					
1.900000E+00	E	9.442608E+00					
2.000000E+00	E	6.635385E+00					

V E L O C I T Y V E C T O R (SOLUTION SET)

Figure 14. Example of Solution Set Vector Output in SPRINT2 Format.

DISPLACEMENT APPROACH, RIGID FORMAT 12  
ELEMENT-10 -

TIME	SA1		SA2		SA3		SA4		AXIAL-STRESS		SA-MAX		SA-MIN		M.S.-T	
	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16
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
1.38000E-03	-3.173043E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.173043E+03	-4.765597E+03	-1.0E+00	-1.0E+00	-1.0E+00
2.776000E-03	-1.637746E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.637746E+04	-1.631670E+04	-1.0E+00	-1.0E+00	-1.0E+00
4.144000E-03	-3.162134E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.162134E+04	-2.572238E+04	-1.0E+00	-1.0E+00	-1.0E+00
5.552000E-03	-2.734461E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.734461E+04	-2.224265E+04	-1.0E+00	-1.0E+00	-1.0E+00
6.940000E-03	-2.709755E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.299755E+03	-2.820375E+03	-1.0E+00	-1.0E+00	-1.0E+00
8.328000E-03	2.873686E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.873686E+04	0.0	0.0	-1.0E+00	-1.0E+00	-1.0E+00
9.716000E-03	5.893338E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.893338E+04	0.0	0.0	-1.0E+00	-1.0E+00	-1.0E+00
1.110400E-02	7.490571E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.490571E+04	0.0	0.0	-1.0E+00	-1.0E+00	-1.0E+00
1.249200E-02	5.625293E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.625293E+04	0.0	0.0	-1.0E+00	-1.0E+00	-1.0E+00
1.388000E-02	8.470672E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.470672E+03	0.0	0.0	-9.0E-01	-9.0E-01	-9.0E-01
1.526800E-02	-4.415245E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4.415245E+04	-3.752571E+04	-1.0E+00	-1.0E+00	-1.0E+00
1.665600E-02	-8.695184E+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-8.695184E+04	-7.496687E+04	-1.0E+00	-1.0E+00	-1.0E+00
1.804400E-02	-1.037364E+05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.037364E+05	-1.037364E+05	-1.0E+00	-1.0E+00	-1.0E+00

10.5-19

Figure 15. Example of Element Stress Output in S8RT2 Format.

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CONCRETE ELEMENTS

ELEMENT ID = 10 POINT ANGLE = 90.0000

STRESS IN X Y Z DIRECTION SHELL ELEMENTS (CUMEX)

TIME	FIBER DISTANCE	STRESS NORMAL-V	STRESS NORMAL-U	STRESS SHEAR-UV	PRINCIPAL ANGLE	PRINCIPAL STRESS MAJOR	PRINCIPAL STRESS MINOR	MAXIMUM SHEAR
0.0	0.0	0.0	0.0	0.0	0.0000	0.0	0.0	0.0
1.000000E-03	0.0	-2.29370E-04	-2.548852E-05	-4.774257E-05	-77.8527	-1.440206E-05	-2.400024E-04	1.125094E-04
2.000000E-03	0.0	-5.176778E-04	-4.275067E-05	-1.196061E-04	-45.1017	-7.450319E-05	-2.310592E-04	1.055740E-04
3.000000E-03	0.0	-6.460272E-04	-1.042400E-04	-1.579912E-04	-76.0531	-1.453511E-05	-5.440990E-04	2.690027E-04
4.000000E-03	0.0	-6.735065E-04	-1.178625E-04	-1.100774E-04	99.5045	-6.612039E-05	-5.261906E-04	2.400501E-04
	0.0	-5.406046E-04	-2.947502E-04	-1.309925E-04	-74.0024	-6.530924E-05	-6.048026E-04	3.122504E-04
	0.0	-6.050174E-04	-3.140837E-04	-2.657506E-04	76.0665	-9.460739E-05	-6.947637E-04	3.510787E-04
	0.0	-5.406046E-04	-2.947502E-04	-1.309925E-04	-66.6194	-2.305557E-04	-6.070892E-04	1.050606E-04
	0.0	-6.050174E-04	-3.140837E-04	-2.657506E-04	58.5133	-1.390649E-04	-7.606568E-04	3.207054E-04

Figure 16. Example of Stress Output for Axisymmetric Conical Shell Elements.

ORIGINAL COPY IS  
PROPERTY

SUBSTRUCTURE 2, RUN 2, PHASE 1, RF 2

SUBSTRUCTURE OPERATING FILE TABLE OF CONTENTS

SUBSTRUCTURE NO.	NAME	TYPE	SS	PS	LL	CS	HL	E	B	O	G	S	O	L	H	V	O	P	U	H	U	O	S	P	L	L	G	P	L	K	S	P	M
1	ABASIC	5	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
2	BRASIC	4	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	

SIZE OF ITEM IS GIVEN IN POWERS OF TEN (0 INDICATES DATA IS STORED IN PRIMARY)

000 UNUSED SPACE ON SDF • 674708 WORDS.  
 OR • 464 BLOCKS.  
 OR • 96 PERCENT.  
 000 HIGHEST BLOCK USED • 16

ORIGINAL PAGE IS  
 OF POOR QUALITY

IS  
 QUALITY

Figure 17. Example of an SDF Table of Contents After Two Phase 1 Runs.

PRINTING AND PLOTTING FEATURES

TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
 NASTRAN DECOMPOSITION PROFILE NO. 2-3-3

MODAL REDUCE, COMBINED MODAL RECOVERY, RUN 3, PHASE 2, RE 3

S U R S T R U C T U R E O P E R A T I N G F I L E T A B L E O F C O N T E N T S

SUBSTRUCTURE NO.	NAME	TYPE	SS	PS	LL	CS	HL	F	B	C	L	P	K	M	H	U	P	O	S	V	D	A	L	O	F	L	G	P	L	K	S	P	M
1	ABASIC	B	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
2	RBASIC	B	0	0	0	0	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
3	M6	M	0	0	1	4	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
4	P3	M	0	0	2	3	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
5	MCOMB	C	0	0	3	0	6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
6	RTRUSS	M	0	0	1	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	

SIZE OF ITEM IS GIVEN IN POWERS OF TEN (0 INDICATES DATA IS STORED IN PRIMARY)

\*\*\* UNUSED SPACE ON SDP = 477196 WORDS.  
 09 = 419 BLOCKS.  
 00 = 07 PERCENT.  
 \*\*\* HIGHEST BLOCK USED = 62

Figure 18. SPF Table of Contents at the End of Phase 2 Runs.

CASE CONTROL DECK OUTPUT CONTROL

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DATE 11/30/78

NOVEMBER 24, 1978

TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
 NASTRAN DEMONSTRATION PROBLEM NO. 2-3-1

MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 3, PHASE 2, PF 3

S U M M A R Y O F C U R R E N T P R O B L E M

NAME OF PSEUDOSTRUCTURE TO BE REDUCED . . . . . ABASIC 5  
 BOUNDARY SET IDENTIFICATION NUMBER . . . . . 5  
 RIGID BODY POINT IDENTIFICATION NUMBER . . . . .  
 OLDROUND FLAG SET . . . . . NO  
 FREE BODY CODES TO BE CALCULATED . . . . . NO  
 SAVE REDUCTION PRODUCTS . . . . . NO  
 MAXIMUM NUMBER OF FREQUENCIES TO BE USED . . . . . ALL  
 NAMES OF COMPONENT SUBSTRUCTURES CONTAINED IN ABASIC  
 ABASIC  
 NAME GIVEN TO RESULTANT PSEUDOSTRUCTURE MA . . . . .  
 FIXED SET IDENTIFICATION NUMBER . . . . .  
 RIGID BODY SUBSTRUCTURE NAME . . . . .  
 OLDROUND FLAG SET . . . . . NO  
 USER MODES FLAG SET . . . . . NO  
 EIGENVALUE EXTRACTION METHOD . . . . .  
 GAPVAL VALUE . . . . . 0.  
 RANGE OF FREQUENCIES TO BE USED . . . . . ALL

\*\*\* USER INFORMATION MESSAGE 2010: GIVENS TIME ESTIMATE IS 1 SECONDS.  
 PROBLEM SIZE IS 24, SPILL WILL OCCUR FOR THIS CORE AT A PROBLEM SIZE OF 307 .

\*\*\*USER INFORMATION MESSAGE 3023---PARAMETERS FOR SYMPETRIC DECOMPOSITION OF DATA BLOCK MFFH ( N = 24 )  
 TIME ESTIMATE 1 C AVG = 1 PC AVG = 0 SPILL GROUPS = 0 S AVG = 1  
 ADDITIONAL CODE = -407P0 C MAX = 1 PC MAX = 0 PC GROUPS = 0 PREFACE L-JUMPS = 1  
 METHOD 2 NT,NBR PASSES = 1,EST. TIME = .1  
 METHOD 1 T,NBR PASSES = 1,EST. TIME = .1  
 METHOD 1 NT,NBR PASSES = 1,EST. TIME = .0  
 METHOD 1 NT,NBR PASSES = 1,EST. TIME = .0  
 METHOD 3 T,NBR PASSES = 1,EST. TIME = .0

Figure 19. Example of the Summary of Current Problem Table for a Reduce Operation.

PRINTING AND PLOTTING FEATURES

TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
 MASTRAN DEMONSTRATION PROBLEM NO. 2-3-3

NOVEMBER 24, 1978 MASTRAN 11/30/78 PAGE 62  
 MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 3, PHASE 2, RF 3

GRID POINT ID	INTERNAL POINT ID	COMPONENT DOF	GRID POINT ID	INTERNAL POINT ID	COMPONENT DOF	INTERNAL POINT ID	COMPONENT DOF
101	5	1	102	6	1	103	7
104	8	1	105	9	1	106	10
107	11	1	108	12	1	109	13
110	14	1	111	15	1	112	16
113	17	1	114	18	1	115	19
116	20	1	117	21	1	119	22

Figure 20. Example of the EQSS Item for a Reduced Pseudostructure.

TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
 MASTRAN DEMONSTRATION PROBLEM NO. 2-3-3

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MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 3, PHASE 2, RF 3

INTERNAL POINT ID	INTERNAL SIL ID	COMPONENT DOF	INTERNAL POINT ID	INTERNAL SIL ID	COMPONENT DOF	INTERNAL POINT ID	INTERNAL SIL ID	COMPONENT DOF
1	1	12	2	3	17	3	5	12
4	7	7	5	8	1	6	9	1
7	10	1	8	11	1	9	12	1
10	13	1	11	14	1	12	15	1
13	16	1	14	17	1	15	16	1
16	19	1	17	20	1	18	21	1
19	22	1	20	23	1	21	24	1
22	25	1						

Figure 21. Example of the EQSS Item - Scalar Index List for a Reduced Pseudostructure.

CASE CONTROL DECK OUTPUT CONTROL

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TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS

NASTRAN DEMONSTRATION PROBLEM NO. 7-3-3

MODAL REDUCE. COMBINE. MODAL RECOVERY, PUP 3, PHASE 2, PF 3

INTERNAL POINT ID	BESS ITEM FOR SUBSTRUCTURE			TRUSS ELEMENTS		
	CSTM ID NO.	X1	X2	X1	X2	X3
1	0	0	0	-0.307700E+02	0	0
2	0	0	0	0	0	0
3	0	0	0	0.300000E+02	0	0
4	0	0	0	0	0	0
5	-1	0	0	0	0	0
6	-1	0	0	0	0	0
7	-1	0	0	0	0	0
8	-1	0	0	0	0	0
9	-1	0	0	0	0	0
10	-1	0	0	0	0	0
11	-1	0	0	0	0	0
12	-1	0	0	0	0	0
13	-1	0	0	0	0	0
14	-1	0	0	0	0	0
15	-1	0	0	0	0	0
16	-1	0	0	0	0	0
17	-1	0	0	0	0	0
18	-1	0	0	0	0	0
19	-1	0	0	0	0	0
20	-1	0	0	0	0	0
21	-1	0	0	0	0	0
22	-1	0	0	0	0	0

Figure 22. Example of the BESS Item for a Reduced Pseudostructure.



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TOUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS      MFCV4450 24, 1970      FASTPAN 11/30/70      PAGE 65  
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MODAL REDUCE, COMBINE, MODAL RECOVERY, JUN 3, PHASE 2, RF 3

COMPONENT NAME	NUMBER OF LOAD SETS	LOADS ITEM FOR SUBSTRUCTURE	IDENTIFICATION NUMBERS
ARASIC	1	980	
PA		NO LOAD SETS FOR THIS COMPONENT.	
BRASIC	1	980	
MB		NO LOAD SETS FOR THIS COMPONENT.	
PTPUSS		NO LOAD SETS FOR THIS COMPONENT.	

Figure 23. Example of the L90S Item for a Reduced Pseudostructure.

MODAL REDUC. CONTIN. MODAL RECOVERY, RUN 3, PHASE 2, OF 3

MODAL DOF SUMMARY FOR REDUCED SUPERSTRUCTURE TRUSS

USAGE CODES ARE 0 - PIGGY-BODY POINT  
 1 - INCLUDED IN MODAL SET  
 2 - EXCLUDED FROM MODAL SET BECAUSE OF NON-PARTICIPATION  
 3 - EXCLUDED FROM MODAL SET BECAUSE OF RANGE OF RAY

MODE NUMBER	CYCLES	USAGE CODE	SPIN POINT ID	SIL
1	3.595778E+00	1	101	8
2	1.756351E+01	1	102	9
3	2.49219E+01	1	103	10
4	3.950692E+01	1	104	11
5	6.109854E+01	1	105	12
6	8.926014E+01	1	106	13
7	8.645307E+01	1	107	14
8	9.449753E+01	1	108	15
9	1.117643E+02	1	109	16
10	1.233484E+02	1	110	17
11	1.275543E+02	1	111	18
12	1.303587E+02	1	112	19
13	1.349217E+02	1	113	20
14	1.436055E+02	1	114	21
15	1.620193E+02	1	115	22
16	1.803218E+02	1	116	23
17	2.007017E+02	1	117	24
18	2.04566E+02	1	118	25
19	2.739852E+02	3		
20	4.087724E+02	3		

Figure 24. Example of the Modal DOF Summary for a Reduced Pseudostructure.

PRINTING AND PLOTTING FEATURES

MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 3, PHASE 2, KF 3

INTERNAL POINT NO	INTERNAL DOF NO	DEGREES OF FREEDOM	SUMMARY OF PSEUDOSTRUCTURE CONNECTIVITIES
1	1	12	MA MB ANASIC 1 1
2	3	12	ANASIC 2
3	5	12	ANASIC 3
4	7	1	MA 101
5	8	1	MA 102
6	9	1	MA 103
7	10	1	MA 104
8	11	1	PA 105
9	12	1	PA 106
10	13	1	MA 107
11	14	12	ANASIC 51 BBASIC 1
12	16	12	ANASIC 52 BBASIC 2

Figure 25. Example of Grid Point Connectivity Output for a COMBINE Operation.

ABASIC

COMPONENT

D I S P L A C E M E N T V E C T O R

POINT ID.	TYP	T1	T2	T3	P1	P2	P3
1	G	1.246043E-02	6.534183E-02	0.0	0.0	0.0	0.0
2	G	-3.627093E-15	6.535092E-02	0.0	0.0	0.0	0.0
3	G	-1.246043E-02	6.534183E-02	0.0	0.0	0.0	0.0
11	G	1.430501E-02	8.759338E-02	0.0	0.0	0.0	0.0
12	G	-4.131227E-15	8.759338E-02	0.0	0.0	0.0	0.0
13	G	-1.430501E-02	8.759338E-02	0.0	0.0	0.0	0.0
21	G	1.526662E-02	1.099199E-01	0.0	0.0	0.0	0.0
22	G	-4.660177E-15	1.099199E-01	0.0	0.0	0.0	0.0
23	G	-1.526662E-02	1.099199E-01	0.0	0.0	0.0	0.0
31	G	1.566840E-02	1.318757E-01	0.0	0.0	0.0	0.0
32	G	-4.836731E-15	1.318757E-01	0.0	0.0	0.0	0.0
33	G	-1.566840E-02	1.318757E-01	0.0	0.0	0.0	0.0
41	G	1.576652E-02	1.532938E-01	0.0	0.0	0.0	0.0
42	G	-4.893382E-15	1.532938E-01	0.0	0.0	0.0	0.0
43	G	-1.576652E-02	1.532938E-01	0.0	0.0	0.0	0.0

CASE CONTROL DECK OUTPUT CONTROL

Figure 26. Example of Displacement Vector Output Requested Under a PRINT Subcommand.

TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
 NASTRAN DEMONSTRATION PROBLEM NO. 2-3-4  
 SOLVE AND RECOVERY, RUN 4, PHASE 2, RE 0  
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MODAL COORDINATE ENERGIES FOR SUBSTRUCTURE MA

TIME = 2.400000E-01

GRID	TYPE	MODE	FREQUENCY	KINETIC	KE/TOTAL	POTENTIAL	PE/TOTAL
101	IN-MODE	1	1.378449E+01	1.132131E-02	.0014	2.983574E-01	.9993
102	IN-MODE	2	5.716136E+01	7.594774E-03	.0011	1.782210E-04	.0076
103	IN-MODE	3	6.452175E+01	-6.126766E-27	-.0003	3.165714E-28	.0000
104	IN-MODE	4	9.687956E+01	4.285096E-34	.0001	7.094307E-06	.0000
105	IN-MODE	5	1.234085E+02	7.420290E-05	.0000	1.683274E-06	.0000
106	IN-MODE	6	1.480454E+02	3.292543E-06	.0000	5.151932E-09	.0000
107	IN-MODE	7	1.514840E+02	4.221955E-30	.0000	6.413725E-30	.0000
TOTAL ENERGY FOR THIS VECTOR					1.7000	2.982652E-01	1.0000

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ORIGINAL PAGE IS  
 OF POOR QUALITY

Figure 27. Example of Energy Output Requested Under a PRINT Subcommand.

OUTPUT FROM GRID POINT WEIGHT GENERATOR  
REFERENCE POINT = 0

```

***
* 2.312069E+00 -1.047336E-16 0. 1.256035E-15 1.073122E+01 -1.594735E+00 *
* 2.094672E-17 2.312069E+00 0. -1.073122E+01 -8.37688E-17 2.332196E+01 *
* 0. 0. 2.312069E+00 1.594735E+00 -2.332196E+01 0. *
* 1.080229E-15 -1.073122E+01 1.594735E+00 6.241736E+01 -1.610790E+01 -1.080476E+02 *
* 1.073122E+01 4.199244E-16 -2.332196E+01 -1.610790E+01 2.962841E+02 -7.379832E+00 *
* -1.594735E+00 2.332196E+01 0. -1.080426E+02 -7.379832E+00 2.377293E+02 *
***

```

```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION
***
* 1.000000E+00 0. 0. *
* 0. 1.000000E+00 0. *
* 0. 0. 1.000000E+00 *
***

```

```

DIRECTION      MASS      X-C.G.      Y-C.G.      Z-C.G.
MASS AXIS SYSTEM (S)  2.312069E+00  5.435313E-16  6.897430E-01  4.641393E+00
X      2.312069E+00  1.008705E+01 -3.623092E-17  4.641393E+00
Y      2.312069E+00  1.008705E+01  6.897430E-01  0.
Z

```

```

(I(S) - INERTIAS PFLATIVED TN C.G.
***
* 1.150999E+01 2.171737E-02 -2.037070E-01 *
* 2.171737E-02 1.121044E+01 -2.196100E-02 *
* -2.037070E-01 -2.196100E-02 1.379537E+00 *
***
(I(O) - PRINCIPLE INERTIAS
***
* 1.375392E+00 1.151530E+01 *
* 1.120888E+01 *
O - TRANSFORMATION MATRIX -- I(O) = O*(I(S))
***
* -2.010102E-02 9.971652E-01 7.250850E-02 *
* -2.188090E-03 7.247010E-02 -9.973675E-01 *
* -9.979958E-01 -2.020676E-02 7.249831E-04 *
***

```

Figure 28. Weight and Balance Output.

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OF POOR QUALITY

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\*\*\* WOLY 2 \*\*\*

COLUMN	POINT	WOLY	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE
1 (											
7 T2		7-T2)									
7 R3	7 R3	-7.45058E-09		8 T2	-2.91038E-11		8 R3	-3.35276E-08		9 T2	-3.63798E-11
9 R3	10 T2	-7.27596E-11		10 R3	-1.86263E-08		11 T2	7.77596E-11		11 R3	-7.45058E-09
	9 R3	-3.35276E-08									

Figure 29. Example of Residual Load Vector Output.

MATRIX PHIA (GIND NAME 101) IS A REAL 30 ROW RECTANG MATRIX.

COLUMN	1	ROWS	1	THRU	30	5	COLUMN X	30	ROW	RECTANG	MATRIX.
COLUMN 1	1.00000E+00	1.00000E+00	1.33648E+00	2.04439E-32	2.56715E+00	3.02270E-32	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00
COLUMN 2	1.00000E+00	1.00000E+00	1.33648E+00	2.04439E-32	2.56715E+00	3.02270E-32	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00
COLUMN 3	1.00000E+00	1.00000E+00	1.33648E+00	2.04439E-32	2.56715E+00	3.02270E-32	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00
COLUMN 4	1.00000E+00	1.00000E+00	1.33648E+00	2.04439E-32	2.56715E+00	3.02270E-32	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00
COLUMN 5	1.00000E+00	1.00000E+00	1.33648E+00	2.04439E-32	2.56715E+00	3.02270E-32	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00	3.69898E+00

THE NUMBER OF NON-ZERO WORDS IN THE LARGEST RECORD \* 30  
 THE DENSITY OF THIS MATRIX IS 100.00 PERCENT.

Figure 30. Matrix PHIA Printed by DMAP Module MATPRN.



PRINTING AND PLOTTING FEATURES

MODAL REDUCE, COMPARE, MODAL RECOVERY, RUN 3, PHASE 2, PF 3

E I G E N V A L U E A N A L Y S I S S U M M A R Y (GIVEN'S METHOD)

NUMBER OF EIGENVALUES EXTRACTED . . . . .	24
NUMBER OF EIGENVECTORS COMPUTED . . . . .	7
NUMBER OF EIGENVALUE CONVERGENCE FAILURES . . . . .	0
NUMBER OF EIGENVECTOR CONVERGENCE FAILURES . . . . .	0
REASON FOR TERMINATION . . . . .	1
LARGEST OFF-DIAGONAL MODAL MASS TERM . . . . .	0.
MODE PAIR . . . . .	0
NUMBER OF OFF-DIAGONAL MODAL MASS TERMS FAILING CRITERION . . . . .	0

Figure 31. Example of the Eigenvalue Analysis Summary Table.

CASE CONTROL DECK OUTPUT CONTROL

MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 3, PHASE 2, RF 3

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIAN FREQUENCY	CYCLIC FREQUENCY	GENERALIZED MASS	GENERALIZED STIFFNESS
1	24	7.501816E+03	4.661303E+01	1.378490E+01	3.012400E-01	2.260597E+03
2	23	1.074214E+05	3.277921E+02	5.215334E+01	5.193695E-01	5.536172E+04
3	22	1.643717E+05	5.054272E+02	6.522575E+01	3.715326E-01	5.449442E+04
4	21	3.705307E+05	6.087124E+02	9.647954E+01	4.161164E-01	1.541840E+05
5	20	6.012425E+05	7.753983E+02	1.234095E+02	4.294454E-01	2.550364E+05
6	19	8.654991E+05	9.303221E+02	1.540254E+02	3.484948E-01	3.189319E+05
7	18	9.053277E+05	9.518220E+02	1.521440E+02	1.392124E-01	1.252103E+05
8	17	1.353059E+06	1.163210E+03	1.851307E+02	0.0	0.0
9	16	1.612736E+06	1.269935E+03	2.021165E+02	0.0	0.0
10	15	1.836006E+06	1.354993E+03	2.156534E+02	0.0	0.0
11	14	2.027652E+06	1.423957E+03	2.266228E+02	0.0	0.0
12	13	2.029494E+06	1.424601E+03	2.257323E+02	0.0	0.0
13	12	2.445966E+06	1.576378E+03	2.508834E+02	0.0	0.0
14	11	2.751795E+06	1.658455E+03	2.640169E+02	0.0	0.0
15	10	3.458823E+06	1.859791E+03	2.959950E+02	0.0	0.0
16	9	3.562177E+06	1.687373E+03	3.003848E+02	0.0	0.0
17	8	3.621002E+06	1.902693E+03	3.024548E+02	0.0	0.0
18	7	4.263820E+06	2.064660E+03	3.286088E+02	0.0	0.0
19	6	4.466223E+06	2.113344E+03	3.363491E+02	0.0	0.0
20	5	4.511780E+06	2.124095E+03	3.390602E+02	0.0	0.0
21	4	4.771722E+06	2.144277E+03	3.476624E+02	0.0	0.0
22	3	5.303790E+06	2.302596E+03	3.665332E+02	0.0	0.0
23	2	5.612925E+06	2.369161E+03	3.770637E+02	0.0	0.0
24	1	7.754982E+06	2.784777E+03	4.432110E+02	0.0	0.0

Figure 32. Example of the Real Eigenvalue Output Table.

PRINTING AND PLOTTING FEATURES

SPHERICAL SHELL WITH PRESSURE LOADING, NO MOMENTS ON BOUNDARY  
NASTRAN DEMONSTRATION PROBLEM NO. 1-2-1

MESSAGES FROM THE PLOT MODULE

P L O T T E R   D A T A

THE FOLLOWING PLOTS ARE FOR AN SC-4020 PLOTTER

AN END-OF-FILE MARK FOLLOWS THE LAST PLOT

PAPER SIZE = 7.5 X 7.5, PAPER TYPE = VELLUM

E N G I N E E R I N G   D A T A

ORTHOGONAL PROJECTION  
ROTATIONS (DEGREES) - GAMMA = 20.00, BETA = 30.00, ALPHA = 0.00, AXES = +X,+Y,+Z, SYMMETRIC  
SCALE (OBJECT-TO-PLOT SIZE) = 8.351734E-02  
ORIGIN    1    X0 = -8.679378E-01, Y0 = 1.540936E+00 (INCHES)

Figure 33. Plot Data Summary for One Plot.

CASE CONTROL DECK OUTPUT CONTROL

C A S E C O N T R O L D E C K E C H O

CARD COUNT

1 TITLE = SPHERICAL SHELL WITH PRESSURE LOADING, NO MOMENTS ON BOUNDARY  
 2 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-2-1  
 3 LOAD = 1  
 4 SPC = 2  
 5  
 6 DISP = ALL  
 7 SPCF = ALL  
 8 STRESS = ALL  
 9 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 1-2-1  
 10 OUTPUT(PLOT)  
 11 PLOTTER SC  
 12 MAXIMUM DEFORMATION 6.0  
 13 \$ ALL ELEMENTS  
 14 SET 1 = ELEMENTS TRIA2  
 15 \$ PLOT1 - EDGES AND CENTERLINE  
 16 SET 2 = PLOT1  
 17 \$  
 18 VIEW 20.0, 30.0, 0.0  
 19 FIND SCALE ORIGIN 1 SET 1  
 20 PTITLE = UNDEFORMED SECTION TRIA2 ELEMENTS  
 21 PLOT LABEL(BOTH), SYMBOLS 6  
 22 PTITLE = SECTION TRIA2 ELEMENTS WITH UNDERLAY  
 23 PLOT STATIC DEFORMATION 0.1, SET 1, ORIGIN 1, SHAPE, LABELS  
 24 \$  
 25 PERSPECTIVE PROJECTION  
 26 \$  
 27 MAXIMUM DEFORMATION 6.0  
 28 FIND SCALE, SET 2, ORIGIN 1000  
 29 PTITLE = SECTION PLOT1 ELEMENTS (PERSPECTIVE PROJECTION)  
 30 PLOT SET 2, ORIGIN 1000, LABELS  
 31 PTITLE = FULL MODEL (VIA SYMMETRY) TRIA2 ELEMENTS - PERSPECTIVE  
 32 PLOT SET 1, ORIGIN 1000, SYMBOLS 9, SHAPE, SYMMETRY X,  
 33 SET 1, ORIGIN 1000 SYMBOLS 9 SHAPE SYMMETRY Y,  
 34 SET 1, ORIGIN 1000 SYMBOLS 9 SHAPE SYMMETRY Y,  
 35 \$  
 36 \$  
 37 \$  
 38 \$

Figure 34. Example of a Structural Plot Packet in the Case Control Deck.

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AERDELASTIC FLUTTER ANALYSIS OF A FIFTEEN DEGREE SWEEP WING      NOVEMBER 27, 1978      NASTKAN 11/30/76      PAGE 2  
 NASTRAN DEMONSTRATION PROBLEM NO. 10-2-1

K VALUES .200(0) .167(0) .143(1) .125(2) .111(3) .100(4)

C A S C    C O N T R O L    D E C K    E C H O

CARD  
 COUNT

1    TITLE = AERDELASTIC FLUTTER ANALYSIS OF A FIFTEEN DEGREE SWEEP WING  
 2    SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 10-2-1  
 3    LABEL = K VALUES .200(0) .167(0) .143(1) .125(2) .111(3) .100(4)  
 4    ECHO = BOTH  
 5    SPC=1  
 6    METHOD=10  
 7    CYC=20  
 8    PMETHOD=30  
 9    OUTPUT(XYOUT)  
 10    XTITLE = VELOCITY  
 11    YTITLE = DAMPING (G)  
 12    YBTITLE = FREQUENCY (F)  
 13    TCURVE = V-G AND V-F DATA POINTS  
 14    CURVELINESYMBOL=-1  
 15    XYPAPERPLOT VG / 1(G,F) 2(G,F) 3(G,F) 4(G,F) 5(G,F) 6(G,F)  
 16    BEGIN SULK

Figure 35. Example of an XY Plot Packet in the Case Control Deck.

CASE CONTROL DECK OUTPUT CONTROL

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FREQUENCY RESPONSE AND RANDOM ANALYSIS OF A 10 CELL BEAM  
 NASTRAN DEMONSTRATION PROBLEM NO. 11-1-1

X Y - O U T P U T S U M M A R Y

ROOT MEAN SQUARE VALUE = 3.742491E+02  
 FREQUENCY OF ZERO CROSSINGS (IN ZERO) = 5.003758E+01  
 POWER-SPECTRAL-DENSITY-FUNCTION (PSDF)  
 DISPLACEMENT CURVE (OF 2)

XY-PAIRS BETWEEN HMIN AND HMAX WILL BE PRINTED  
 XY-PAIRS WITHIN FRAME LIMITS WILL BE PLOTTED  
 PLOTTER SPECIFIED IS SC 4020  
 PENSIZE = 1

THIS IS CURVE 1 OF WHOLE FRAME 1

CURVE TITLE = POWER SPECTRAL DENSITY OF POINT 6 DISPLACEMENT  
 X-AXIS TITLE = FREQUENCY (HERTZ)  
 Y-AXIS TITLE = S

THE FOLLOWING INFORMATION IS FOR THE ABOVE DEFINED CURVE ONLY.

WITHIN THE FRAME X-LIMITS ( X = 0. TO X = 2.000000E+02 )  
 THE SMALLEST Y-VALUE = 0. AT X = 1.050000E+02  
 THE LARGEST Y-VALUE = 2.797422E+04 AT X = 5.000000E+01

WITHIN THE X-LIMITS OF ALL DATA ( X = 0. TO X = 2.000000E+02 )  
 THE SMALLEST Y-VALUE = 0. AT X = 1.050000E+02  
 THE LARGEST Y-VALUE = 2.797422E+04 AT X = 5.000000E+01

E N D O F S U M M A R Y

P R I N T E D D A T A F O R T H I S C U R V E F O L L O W S

Figure 36. Example of the XY Output Summary Table for One Curve.

PRINTING AND PLOTTING FEATURES

FREQUENCY RESPONSE AND RANDOM ANALYSIS OF A 10 CELL BEAM  
 NASTRAN DEMONSTRATION PROBLEM NO. 11-1-1  
 NOVEMBER 27, 1978 NASTRAN 11.7.78 PAGE 103

DISPLACEMENT	CURVE	ID	6	COMPONENT	5	WHOLE FRAME	Y-VALUE	CARD NUMBER
			PRINT NUMBER		X-VALUE			
		1		0.	0.		6.019458E-01	
		2		5.000000E+00	6.122720E-01		6.122720E-01	
		3		1.000000E+01	6.451568E-01		6.451568E-01	
		4		1.500000E+01	7.071608E-01		7.071608E-01	
		5		2.000000E+01	8.127417E-01		8.127417E-01	
		6		2.500000E+01	9.931214E-01		9.931214E-01	
		7		3.000000E+01	1.322450E+00		1.322450E+00	
		8		3.500000E+01	2.012493E+00		2.012493E+00	
		9		4.000000E+01	3.900316E+00		3.900316E+00	
		10		4.500000E+01	1.366280E+01		1.366280E+01	
		11		5.000000E+01	2.797422E+04		2.797422E+04	
		12		5.500000E+01	9.381165E+00		9.381165E+00	
		13		6.000000E+01	2.077693E+00		2.077693E+00	
		14		6.500000E+01	8.127417E-01		8.127417E-01	
		15		7.000000E+01	4.034295E-01		4.034295E-01	
		16		7.500000E+01	2.296375E-01		2.296375E-01	
		17		8.000000E+01	1.431178E-01		1.431178E-01	
		18		8.500000E+01	9.533566E-02		9.533566E-02	
		19		9.000000E+01	6.600560E-02		6.600560E-02	
		20		9.500000E+01	4.899345E-02		4.899345E-02	
		21		1.000000E+02	3.717110E-02		3.717110E-02	
		22		1.050000E+02	0.		0.	
		23		1.100000E+02	0.		0.	
		24		1.150000E+02	0.		0.	
		25		1.200000E+02	0.		0.	
		26		1.250000E+02	0.		0.	
		27		1.300000E+02	0.		0.	
		28		1.350000E+02	0.		0.	
		29		1.400000E+02	0.		0.	
		30		1.450000E+02	0.		0.	
		31		1.500000E+02	0.		0.	
		32		1.550000E+02	0.		0.	
		33		1.600000E+02	0.		0.	
		34		1.650000E+02	0.		0.	
		35		1.700000E+02	0.		0.	
		36		1.750000E+02	0.		0.	
		37		1.800000E+02	0.		0.	
		38		1.850000E+02	0.		0.	

Figure 37. Example of a Table of XY Pairs Scheduled for Plotting.

## SUBSTRUCTURE CONTROL DECK OUTPUT CONTROL

### 10.6 SUBSTRUCTURE CONTROL DECK OUTPUT CONTROL

NASTRAN provides the automated substructuring user with facilities to print useful summaries of substructuring bookkeeping information, the status and contents of the substructuring data base file (SØF), descriptions of the results of Substructure Control Deck commands, as well as the normal engineering information of analysis results such as displacements, velocities, accelerations, forces of constraint, and applied loads.

Structural analysis results at the basic substructure level, including element forces and stresses, grid point force summaries, omitted degrees of freedom displacements, etc., are not printed using Substructure Control Deck commands. These data are requested using Case Control Deck output requests in Phase 3 substructuring runs. The automated substructuring system is completely described in Section 20, including the relationships between Case Control and Substructure Control Deck output requests. Summaries of the output requests available in the Substructure Control Deck are provided in this section.

There are three major print request commands and a plot request command included in the Substructure Control Deck. Each is described in the following sections and in detail in the User's Manual, Section 2.7.

#### 10.6.1 SØFPRINT Command

The SØFPRINT command provides a means of determining the status of the Substructure Operating File (SØF) at any stage of an analysis. The command is often used to obtain the table of contents of the SØF which includes a list of all substructures, how the substructures are related, how much storage space is being used and remains available, and which substructure items exist. The form of the command is simply:

SØFPRINT TØC

Examples of SØFPRINT TØC printed output are shown in Figures 17 and 18.

The SØFPRINT command also may be used to request print of individual substructure items or matrices, such as a stiffness matrix or load.

All options for using the SØFPRINT command are described in the User's Manual, Section 2.7.



## PRINTING AND PLOTTING FEATURES

### 10.6.2 OUTPUT Subcommand

The subcommand `OUTPUT` is used with substructuring operation commands `COMBINE`, `REDUCE`, `MREDUCE`, and `CREDUCE`. `OUTPUT` requests specific information relating to the operation being performed. The command is used as shown below:

```
OUTPUT 1,2,6,...,17
```

Each integer requests a particular item relating to the operation. A complete summary of the options available for `OUTPUT` under each command is presented in Table 1. Use of `OUTPUT` is illustrated in Figure 2, and examples of the resulting print are presented in Figures 19 through 25.

### 10.6.3 PRINT Subcommand

`PRINT "name"` is used as a subcommand of `RECOVER` or `MRECOVER` where "name" is any substructure. The `PRINT` subcommand is followed by case control type commands such as `DISP`, `SPCF`, `PLoad`. These commands are merged with any similar Case Control Deck commands to create a complete print request for the named substructure. For these cases the Substructure Control Deck commands override any identical Case Control Deck commands. Note that no output will be printed unless these specific requests (`DISP`, `SPCF`, `PLoad`) appear in either the Substructure Control or Case Control Decks.

`ENERGY` is a subcommand to `PRINT` in substructure control, but it is not available as a Case Control command. `ENERGY` is used to print relative modal coordinate contributions to analytical solutions. The `ENERGY` command only applies to substructures used in modal reduce (`MREDUCE`) operations.

For specific details of using `PRINT` and associated commands, refer to descriptions of the `RECOVER` and `MRECOVER` commands in section 2.7 of the User's Manual. Output generated by displacement and energy requests in substructuring is illustrated in Figures 26 and 27.

### 10.6.4 PLOT Command

Structural plots of undeformed structures are requested in Phase 2 substructuring runs using the command:

```
PLOT name
```

where name is any substructure (from a basic model to the completely assembled model). Any number of these commands may appear in the Substructure Control Deck. Undeformed structural plots will be

#### SUBSTRUCTURE CONTROL DECK OUTPUT CONTROL

generated using Case Control Deck structural plot commands. The entire sequence of Case Control commands will be executed for each Substructure Control Deck command. Refer to Section 20 of the User's Guide and Section 4 of the User's Manual for more details on substructures and plotting.

## MISCELLANEOUS PRINTOUT

### 10.7 MISCELLANEOUS PRINTOUT

Along with the standard output options, certain results are printed automatically or may be selectively requested independent of the Case Control options. Those quantities which are selected by the user are described below, followed by a description of the results which are output automatically.

#### 10.7.1 Parameter-Controlled Output

Specialized output may be requested via the PARAM Bulk Data Card (User's Manual, Section 3.1). These options include:

GRDPNT - requests the weight and balance results (Figure 28). The output quantities for the user-specified grid points are:

1. Reference points.
2. Rigid body mass matrix ( $M_0$ ) relative to the reference point in the basic coordinate system.
3. Transformation matrix (S) from basic coordinate system to principal mass axes.
4. Principal masses and associated centers of gravity.
5. Inertia matrix  $I(S)$  about the center of gravity relative to the principal mass axes.
6. Inertia matrix  $I(Q)$  about the center of gravity relative to the principal inertia axes.
7. Transformation matrix (Q) such that  $[I(Q)] = [Q]^T [I(S)] [Q]$ .

The generality of this output is necessary due to the potential problems of the user's inputting directional masses and general inertia terms. The effects of scalar points are ignored, but all other mass effects are included.

IRES - requests the printout of the static analysis residual load vector (Figure 29). This will produce a printout of the error occurring at each solution degree of freedom for each static load vector. The form of the data is in general matrix output format printed by the DMAP module MATGPR (User's Manual, Section 5.3).

#### 10.7.2 DMAP-Controlled Output

An Output Utility Module's (User's Manual, Section 5.3) printout is controlled by including DMAP modules MATPRN, MATGPR, and/or TABPT in the DMAP alters to a Rigid Format or in the user-

## PRINTING AND PLOTTING FEATURES

specified DMAP program. The MATGPR module, which prints results with gridpoint references, and MATPRN module, which prints results using the internal numbering sequence, are highly recommended for finding difficult errors in a matrix formulation, but the volume of printout precludes their use in routine debugging of large problems. Examples of the printout format are given in Figures 29 and 30. The TABPT module prints the internal NASTRAN table data specified in the DMAP instructions. The use of these modules requires some knowledge of the DMAP language (User's Manual, Section 5), and requires an understanding of the NASTRAN data block contents (Programmer's Manual, Section 2).

### 10.7.3 Automatic Output

Diagnostic printout which may be augmented with the Executive Control DIAG card (User's Guide, Section 1, and User's Manual, Section 2.2) is a convenient tool for the experienced NASTRAN user to analyze the execution of a problem. A description of all possible outputs is beyond the scope of this Guide. Also, an understanding of some of the available printout requires a knowledge of the NASTRAN program.

Some of this diagnostic output is automatic. This printout occurs in different locations, depending on the particular computer system being used. The standard output consists of the BEGIN and END times for every functional module and some of the major subroutines.

When a user requests a checkpoint be taken, the RESTART data is automatically printed. This data is written as it is created and is a duplicate of the checkpoint dictionary cards punched at the end of each run. If the restart deck is lost, the cards may be punched manually from this printout.

Every time an eigenvalue extraction routine is executed, the Eigenvalue Summary Tables are automatically printed. This occurs in normal modes, buckling, and complex eigenvalue analyses. The output shown in Figure 31 and 32 includes the eigenvalue routine diagnostics and the eigenvalues, frequencies, generalized (modal) mass, and generalized (modal) stiffness for each solution root. Refer to the Rigid Format descriptions (User's Manual, Section 3) for a definition of the contents printed for each Rigid Format.

Each time a plot output request is made, a Plot Summary Table is automatically printed for both the structure (Figure 33) or plot (Figure 36) operations. Each plot produces a page of output containing data in the scale factors, origins, sets, labels, and/or curve maximums and minimums.

## STRUCTURAL AND CONTOUR PLOTTING

### 10.8 STRUCTURAL AND CONTOUR PLOTTING

#### 10.8.1 Structural Plotting

The structure plot control options, as summarized in Table 2, are described in detail in Section 4 of the User's Manual. Illustrative examples of their use are presented in Sections 18 and 19 of this Guide. The following describes the actual results and contains recommendations for general usage.

1. The undeformed plots are generated near the beginning of the NASTRAN execution. These plots provide visual verification of the geometry and element connectivities of a model. For large complex problems, it is recommended that several plots be made using different sets of elements, view angles, and labeling options in various combinations. The user may then select the best views of his structure for plotting the results of subsequent runs.
2. Use of the FIND option is recommended to automatically calculate the origin and scaling factors used for plotting each section of a structure. Figure 33 illustrates the plot data summary printed out for each plot requested. If the user specified his own data, it is possible that some points will not be included in the plot. This also occurs frequently when a different set of structural elements is plotted with the origin and scale of a previously plotted structure. The FIND card should be used before each PLOT command, unless the structure and view data are unchanged. Another problem occurs when a deformed structure is plotted and the MAXIMUM DEFORMATION card is missing. Without it, the scale is chosen to place the extreme limits of the structure at the edge of the plot. Large deformations at these points, therefore, might not get plotted.
3. The use of symmetry perspective and stereo projections, and user-defined scales and origins is not recommended for the inexperienced user. These options are best approached in an experimental mode by using small test examples. Figure 34 shows part of a large structure plot packet in a Case Control Deck. It illustrates the use of many of the plotting options.
4. Quite frequently some of the plotter choices available in NASTRAN are not compatible with a certain installation hardware or may be inefficient for some plotters. Plot tape conversion programs are commonly available to remedy these situations. They require only an additional tape set-up and an extra job step in the job control deck.

## PRINTING AND PLOTTING FEATURES

### 10.8.2 Contour Plotting

Contour plots may be obtained by requesting them on PLOT cards and by including a separate CONTOUR card in the structure plot packet. Nine types of stress and four types of displacement contour plots may be selected. The parameters on the CONTOUR card are discussed in Section 4.2 of the User's Manual. In a normal NASTRAN run, these plots are available following the solution of the structure. In a substructuring run, they are available only in Phase 3 runs, where the basic structural relations between points and elements are recovered and the solution data for each substructure is known (User's Guide, Section 20).

## XY PLOTTING AND PRINTING

### 10.9 XY PLOTTING AND PRINTING

The XYPLØT options (User's Manual, Section 4.3) are used for a variety of purposes in dynamic analysis, especially to produce curve plots of selected variables versus time or frequency. Options are also available to print out selected components of the results versus time or frequency, or to print out the peak values only. Also, the printer itself may be used as a plotter when quick qualitative results are desired. The printed characters are placed in locations on the printout to represent one or more curves at a time. Figure 35 shows the XY request packet in a Case Control Deck. Figure 36 illustrates a typical XY Output Summary table, one of which is printed for each curve. When the XYPRINT command is used, a table of XY pairs is printed immediately following the summary table (Figure 37). This represents the data which will be plotted to fill the current request.

The command cards to produce XYPLØT printout or plots are described in Section 4.3 of the User's Manual. The following discussion is concerned with aiding the user in interpreting his output and avoiding problems.

1. Quite frequently the user cannot anticipate the critical points and elements for which plots are desired. Plotting a number of points and elements may be inefficient and confusing. A common procedure is to checkpoint the solution run and printout much of the data. From these data, the critical points and elements and the plot scales may be selected, and a restart can be made for plotting only.
2. The automatic selection of scales in the XYPLØT option was designed for the general case and may be undesirable for a specific user problem. For instance, quantities which are to be compared should be plotted with the same scale with perhaps more than one curve plotted per page. But, the plotter automatically sizes each plot to reach the upper and lower limits of the plot region specified. The procedure suggested above should help avoid this problem.
3. The automatic labeling of the plots includes the point or element identification number and plot sequence number. This sequence number corresponds to the order in which the plots were created. A separate and unique TCURVE title for each frame should be input for every plot. Later, this title will be very useful when the user attempts to recall what he had intended to have shown in each plot.

#### PRINTING AND PLOTTING FEATURES

4. The number of options available in the XYPLØT control package is usually overwhelming to the beginner. It is suggested that, at first, single plots to be placed on single frames and that most of the defaults be used. If a checkpoint has been taken, the options may be selectively and economically experimented with, using the restart feature of NASTRAN.



## MATRIX TOPOLOGY

### 10.10 MATRIX TOPOLOGY

NASTRAN provides a special capability to print or plot the topology of any matrix. This capability requires the user to insert a DMAP alter packet with the SEEMAT instruction (User's Manual, Section 5.3) which identifies the matrix data block and selects the output options. Whether printed or plotted, the SEEMAT output will show the nonzero matrix elements positioned pictorially by row and column within the outlines of the matrix. SEEMAT identifies each degree of freedom which, for large matrices, will produce a large volume of output.

## 11. SYSTEM CONTROL CARD DECKS

### 11.1 INTRODUCTION

This section is designed to orient a new user of NASTRAN to the basic requirements for operating NASTRAN on any of the standard computer systems listed in Table 1.

Table 1. Standard Computer Systems for NASTRAN

Section	Computer System
11.2	IBM 360/370 (BS) (PM 5.3)
11.3	UNIVAC 1108/1110 (Exec 8) (PM 5.4)
11.4	CDC 6000/CYBER (NBS, NBS/BE) (PM 5.5)

Though a vast majority of the NASTRAN subroutines are written in a subset of FORTRAN to be compilable with all three systems, certain utilities have been written in Assembly language to facilitate interfacing the NASTRAN Executive System with the resident operating system software.

NASTRAN consists of approximately 1600 subroutines of source code and is divided into 15 functional links (Programmer's Manual, Section 5). When the NASTRAN program is actually installed at the user's location, the local usage conventions must be considered in order to determine the most advantageous means of making NASTRAN accessible to the user. At certain installations, where NASTRAN is heavily used, it may be made available as a system resident program. Alternatively, the program may be stored off-line, but in load module form so that it can be readily loaded into the system when required. It should be noted that NASTRAN is designed to dynamically allocate core so that at execution time, all the core memory that can be made available will be used. Whenever practicable, the maximum core available should be used to achieve minimum run times. For further discussion of core requirements, see Section 14.

Each of the following sections will summarize the rudiments of the system control cards required to operate NASTRAN on each of the three computer systems. Examples are provided for many of the typical situations encountered, including usage of checkpoint tapes, user tapes, plot tapes, and substructure operating files. Not all conditions can be covered in this Guide. However, sufficient examples are given to indicate what questions to ask of the resident systems personnel in the event more complex arrangements are desired.

## NASTRAN ON THE IBM SYSTEM 360/370 (DS)

### 11.2 NASTRAN ON THE IBM SYSTEM 360/370 (DS)

#### 11.2.1 Deck Organization Summary

This section describes how the NASTRAN input deck (including control cards) must be set up for operation on the IBM 360/370 hardware (Programmer's Manual, Section 5.3). The overall organization of the deck is shown in the table below. Each item in the table is described in Section 11.2.2. Many examples of common deck set-ups are presented in Section 11.2.3. All system control cards have two slashes (//) punched in columns 1 and 2.

Table 1. Organization of the Input Deck

1	JOB card
2	NASTRAN instream procedure
3	EXEC card
4	Control cards for optional files
5	NASTRAN data deck
6	/*

#### 11.2.2 Descriptions of the Input Deck

##### 11.2.2.1 JOB Card

The JOB card identifies the job and furnishes parameters necessary for scheduling and accounting purposes. It is installation-dependent; therefore, check with cognizant personnel at your installation for the proper usage.

##### 11.2.2.2 NASTRAN Instream Procedure

The NASTRAN instream procedure is a deck of about 100 control cards which are required to execute NASTRAN. These cards must be included in every run. However, some installations may have these cards permanently stored in the system (cataloged). In this case, the instream procedure deck may be left out of the input deck.

A listing of the NASTRAN instream procedures is given in Table 2, followed by descriptions of the numbered items.

SYSTEM CONTROL CARD DECKS

Table 2. Basic Job Control Language (JCL) for NASTRAN Runs.

```

1. //NASTRAN PROC NAME='XLJLR.NSTNLMOD.L1750.LOAD'.
//      PUNITS=CYL,P1=1,P2=1,
//      SUNITS=CYL,S1=3,S2=1,
//      TUNITS=CYL,T1=3,T2=1,
//      DENPLT=1
//-----
//*---
//*---          *****
//*---          *   PROCEDURE   N A S T R A N   *
//*---          *****
//*---
//-----
2. //NS      EXEC PGM=NASTRAN,REGION=410K,PARM='CORE=(STAT,64K)'
3. //FT01F001 DD UNIT=SYSDA,SPACE=(CYL,(5,1)),
//      DCB=(RECFM=FB,LRECL=80,BLKSIZE=7280,BUFNO=1)
4. //FT04F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3429)
5. //FT05F001 DD DDNAME=SYSIN
6. //FT06F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3429)
7. //FT07F001 DD SYSOUT=B
8. //FT14F001 DD DDNAME=PLT2          * FORTRAN PLOT REF
9. //INP1     DD DSN=NULLFILE        EXTRA
10. //INP2     DD DSN=NULLFILE        INPUT
11. //INP3     DD DSN=NULLFILE        AND
12. //INP4     DD DSN=NULLFILE        OUTPUT
13. //INP5     DD DSN=NULLFILE        UNITS
14. //INP6     DD DSN=NULLFILE        FOR
15. //INP7     DD DSN=NULLFILE        MATRIX
16. //INP8     DD DSN=NULLFILE        STORAGE
17. //INP9     DD DSN=NULLFILE        AND
18. //INPT     DD DSN=NULLFILE        RETRIEVAL
//
//* FOLLOWING FIVE CARDS DEFINE THE EXECUTIVE FILES.
//* EXCEPT FOR THE NPTP AND POOL, THESE FILES ARE DEFINED TO BE NULL
//* AND NO EXTERNAL USE CAN BE MADE OF THESE DATA SETS UNLESS PROC
//* OVERRIDE CARDS ARE SUPPLIED---SPECIFY UNIT, DSN, VOL-SER-NO.
//* FURTHERMORE ANY OVERRIDES MUST APPEAR IN THE SAME ORDER AS
//* THOSE BEING OVERRIDDEN. I.E., ALPHABETICAL.
//
19. //NPTP     DD UNIT=SYSDA,SPACE=(LPUNITS,(LP1,LP2)),DISP=(,PASS)
20. //OPTP     DD DSN=NULLFILE,LABEL=(,NL),DISP=OLD
21. //PLT2     DD DSN=NULLFILE
22. //POOL     DD UNIT=SYSDA,SPACE=(LPUNITS,(LP1,LP2))
23. //UMF      DD DSN=XLJLR.UMF.BULK.L1750.DATA,DISP=SHR
//
//* **** EXAMPLE TAPE OVERRIDE CARDS FOR EXECUTIVE FILE DD'S ****
//* **** QUESTIONS(?) MUST BE REPLACED WITH APPROPRIATE NAME ****
//
//* //NS.NPTP DD UNIT=2400,VOL=SER=?,DSN=?,DISP=(NEW,KEEP),
//* //      LABEL=(1,BLP)
//* //NS.OPTP DD UNIT=2400,VOL=SER=?,DSN=?,DISP=OLD,
//* //      LABEL=(1,BLP)

```

NASTRAN ON THE IBM SYSTEM 360/370 (DS)

Table 2. Basic Job Control Language (JCL) for NASTRAN Runs (Continued)

```

//*
//*
//* ***** PRIMARY SCRATCH DATA SETS *****
//*
24. //PRI01 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
25. //PRI02 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
26. //PRI03 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
27. //PRI04 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
28. //PRI05 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
29. //PRI06 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
30. //PRI07 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
31. //PRI08 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
32. //PRI09 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
33. //PRI10 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
34. //PRI11 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
35. //PRI12 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
36. //PRI13 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
37. //PRI14 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
38. //PRI15 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
39. //PRI16 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
40. //PRI17 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
41. //PRI18 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
42. //PRI19 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
43. //PRI20 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
44. //PRI21 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
45. //PRI22 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
46. //PRI23 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
47. //PRI24 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
48. //PRI25 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
49. //PRI26 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
50. //PRI27 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
51. //PRI28 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
52. //PRI29 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
53. //PRI30 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
54. //PRI31 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
55. //PRI32 DD UNIT=SYSDA,SPACE=(6PUNITS,(6P1,6P2))
//*
//* ***** SECONDARY SCRATCH DATA SETS *****
//*
56. //SEC01 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
57. //SEC02 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
58. //SEC03 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
59. //SEC04 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
60. //SEC05 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
61. //SEC06 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
62. //SEC07 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
63. //SEC08 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
64. //SEC09 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
65. //SEC10 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
66. //SEC11 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
67. //SEC12 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
68. //SEC13 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
69. //SEC14 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
70. //SEC15 DD UNIT=SYSDA,SPACE=(6SUNITS,(6S1,6S2))
71. //SNAPSHOT DD SYSOUT=A,DCB=(RECFM=VBA,LAECL=125,MLKSIZE=002)
72. //STEPL10 DD DSN=6NAME,DISP=SMR
73. //SYSUDUMP DD SYSOUT=A

```

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SYSTEM CONTROL CARD DECKS

Table 2. Basic Job Control Language (JCL) for NASTRAN Runs (Continued)

```

//*
//* ***** TERTIARY SCRATCH DATA SETS *****
//*
74. //TER01 DD UNIT=SYSDA,SPACE=(&TUNITS,(&T1,&T2))
75. //TER02 DD UNIT=SYSDA,SPACE=(&TUNITS,(&T1,&T2))
76. //TER03 DD UNIT=SYSDA,SPACE=(&TUNITS,(&T1,&T2))
77. //TER04 DD UNIT=SYSDA,SPACE=(&TUNITS,(&T1,&T2))
78. //XPTD DD UNIT=SYSDA,SPACE=(&PUNITS,(&P1,&P2))
//-----
//----- END OF PROCEDURE -----
//-----
79. // PEND

```

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Item

Description

1. The PROC card defines the name of the instream procedure and sets default values for the symbolic parameters.

<u>SYMBOLIC PARAMETER</u>	<u>DEFAULT VALUE</u>	<u>DESCRIPTION</u>
R	400K	Defines region size.
T	10	Defines CPU limit (minutes).
DENPLI	1	Defines the density of the plot tape (556 bpi)
NAME	XLJLR.NSTNLMOØ. L1750.LØAD	Defines the data set name of the executable.
PUNITS	CYL	Defines the space allocation units for the primary files.
P1	1	Defines the initial space allocation for the primary files.
P2	1	Defines the increment space allocation for the primary files.
SUNITS	CYL	Defines the space allocation units for the secondary files.
S1	3	Defines the initial space allocation for the secondary files.
S2	1	Defines the increment space allocation for the secondary files.
TUNITS	CYL	Defines the space allocation units for the tertiary files.
T1	3	Defines the initial space allocation for tertiary files.
T2	1	Defines the increment space allocation for tertiary files.

2. The EXEC card defines the name of the program to be executed, NASTRAN, the region size in which NASTRAN is to be executed, and the default PARM.
3. The FTØ1FØØ1 DD card defines the data set to be used as intermediate storage for NASTRAN input. BCD or EBCDIC card images are read and converted to BCD card images and written on Unit 1, then NASTRAN reads its input from Unit 1.
4. The FTØ4FØØ1 DD card defines the data set that will contain the run log. The NASTRAN run log contains internal timing for NASTRAN and a trace of the modules that are executed in an execution. It is usually assigned to a printer (SYSØUT=A); however, it may be assigned to any device or set to dummy and thereby deleted as desired.
5. The FTØ5FØØ1 DD card is deferred by the use of the DDNAME=SYSIN parameter and will be discussed in the examples that follow.

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6. The FT06F001 DD card defines the printed output from the NASTRAN run. This printed output is written in BCD. As with FT04F001, it can be modified at execution time by the user as desired.
7. The FT07F001 DD card defines the punched output from NASTRAN executions. It can be modified as desired.
8. The FT14F001 DD card is deferred by the use of DDNAME=PLT2 (see Item 23).
- 9 thru 18. These DD cards define data sets to be used as user tapes through the use of INPUT2 and OUTPUT2 routines. All have the parameter DSN=NULLFILE which restricts the operating system from allocating them unless they are supplied as override JCL.
19. The NPTP DD card is used to describe the new problem tape (checkpoint tape) to be used by NASTRAN. It is set up as a temporary file and should be overridden if it is to be saved for later use.
20. The @PTP card defines the old problem tape (previous checkpoint tape) for the NASTRAN run. It must exist prior to the NASTRAN run in which it is used, and in this procedure DSN=NULLFILE must be overridden before the @PTP could be used to retrieve data.
21. The PLT2 DD card defines the output data set containing the SC4020, CALCOMP or NASTPLT plotting data.
22. The PDDL DD cards define the data set to be used as the Data Pool file. It is always present and refers to temporary scratch disk.
23. The UMF DD card defines the data set that contains the User Master File data to be input to NASTRAN. It must be specified if it is needed.
- 24 thru 55. These DD cards define the primary units to be used by NASTRAN as temporary working files. (Note, each DD card must reference only one unit.)
- 56 thru 70. These DD cards define the secondary units to be used by NASTRAN as temporary working files. (Note, each DD card must reference only one unit.)
71. The SNAPSHOT DD card defines the data set that contains the diagnostic dump if NASTRAN takes a user abort. It is assigned to the printer.
72. The STEPLIB card defines the data set name and the location of the executable.
73. The SYSUDUMP DD card defines the data set that contains the diagnostic dump if NASTRAN takes a system abort. It is assigned to a printer.



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- 74 thru 77. These DD cards define the tertiary units to be used by NASTRAN as temporary working files. (Note, each DD card must reference only one unit.)
78. The XPTD DD card defines the temporary data set that is to contain the checkpoint dictionary during CHECKPOINT runs in a GIN compatible format (NOT BCD card images).
79. The PEND card signifies the end of an instream procedure. It should be removed before the JCL is placed on the PROCLIB.

The following restriction should be noted: Plot tapes must be 7-track tapes when plotting for a Stromberg-Carlson plotter; any remaining tapes (problem tapes, UMF, PLT2 tape for the CALCOMP plotter, or the General Purpose Plotter, etc.) may be 7- or 9-track as the user desires.

The NASTRAN execution deck setup is presented as an instream procedure such that it may be verified before addition to the installation procedure library (PROCLIB) to permit easy recall and reuse.

The procedure provided is intended for use on an IBM 360 computer operating under OS. It should be reviewed for each installation prior to actual use. Among the items that may necessitate modification of the procedure are the following:

1. Any modification to the standard IBM OS operating system could make modification of the PROC necessary. For example, all SYSOUT=A and SYSOUT=B data sets are provided with DCB information and space allocation. If a particular installation is using HASP (Houston Automatic Spooling System), it becomes necessary to remove the DCB parameters and the space allocation is no longer needed. Similar modifications will be necessary when running under ASP (Auxiliary Support Processor) or related systems.
2. The procedure as provided has temporary scratch file space sufficient for small to medium size problems. Medium to large problems will require the initial space allocation for primary and secondary files to be doubled (PI=2, SI=6), while very large problems often tax the resources of the computer and must be dealt with on an individual basis.
3. If the number of DD statements in the procedure is too great, it may be reduced (at some cost in performance) as follows with the most expendable data sets listed first:

## SYSTEM CONTROL CARD DECKS

- a. INPT,INP1,INP2,---,INP9,BPTP,UMF,PLT2(and FT14FO01). The data sets are not used by NASTRAN unless requested by the user through his data.
- b. TER01,TER02,---. Tertiary files may be eliminated if careful thought is given to the selection of the space allocation parameters P1 and S1.
- c. The secondary files (SEC01,SEC02,---,SEC15) may be cut back to a single one (SEC01) as long as enough space is pre-allocated for the primary files (PRI01,PRI02,---) to run the problem. It is recommended that at least four or five secondary files be retained, however.

### 11.2.2.3 EXEC Card

The EXEC card actually causes NASTRAN to execute. The format is:

```
//name EXEC NASTRAN
```

where "name" is an alphanumeric name of up to 8 characters, the first of which must be alphabetic. "Name" is optional. If used, it should begin in column 3.

There must be at least one blank space preceding the word EXEC, and at least one blank space between EXEC and NASTRAN.

**NOTE:** For some unusual problems, it may be necessary to specify parameters on this card. These parameters are described in Section 11.2.2.2.

11.2.2.4 Control Cards for Optional Tape and Disk Files

No tapes are required to run NASTRAN. However, a variety of options are available to the user which require the definition of tapes and/or their disk file equivalents in the system control card deck. These additional files fall into two categories: 1) NASTRAN permanent files (see Table 3) which are referenced in the procedure deck (Section 11.2.2.2), and 2) Other FORTRAN units not covered in the procedure deck. For additional information on how NASTRAN manages input/output in the IBM system, see Section 5.3.2 in the NASTRAN Programmer's Manual.

Table 3. NASTRAN Permanent Files

File Name	Purpose
INP1 (i=1,2,...,9,T)	User tapes referenced by DMAP utility modules INPUTT1 and OUTPUT1 (UG 15, UM 5.3.2)
NPTP	New problem tape for checkpointing
OPTP	Old problem tape for restarting
PLT2	Plot tape for SC4020, Calcomp, or NASTRAN General Purpose Plotter (assigned FORTRAN Unit 14)
UMF	User's Master File

Note that the file names in Table 3 are in the same order (alphabetical) as they appear in the procedure deck (Section 11.2.2.2). In order to successfully override the procedure deck specifications, the defining cards must appear in the same order after the // EXEC NASTRAN card.

In addition, the user may wish to use any of the remaining FORTRAN units not referenced in the procedure deck. These are needed when using the INPUTT2 and/or OUTPUT2 DMAP utilities (User's Guide, Section 15; User's Manual, Section 5.3.2) and when running substructuring problems (User's Guide, Section 7; User's Manual, Section 2.7). The FORTRAN units available for use are FT02F001, FT03F001, FT08F001-FT13F001, and FT15F001-FT23F001. Control cards defining these units must appear after the aforementioned set of procedure deck override cards.

Generally, NASTRAN permanent files (except for the plot tape PLT2) may be located on user-assigned disk packs instead of on tape. If the user wishes to store any such file on disk, he must specify FILES=xxx (xxx=INP, ...,UMF) on the NASTRAN card (User's Guide, Section 6).

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### 11.2.2.5 NASTRAN Data Deck

The NASTRAN data deck must be preceded by the following card:

```
//NS.SYSIN DD *
```

There must be at least one blank space on either side of "DD."

### 11.2.2.6 /\* Card

The data deck must be followed by one delimiter card with "/" punched in columns 1 and 2.

### 11.2.3 Examples

This section presents a number of examples which illustrate the deck of control cards needed to successfully execute NASTRAN for a variety of problems. These examples are annotated. However, because of the volume of the text, notations made for a given example are not repeated on subsequent examples. Therefore, if a card in some example is not understood, it will be necessary to refer to an earlier example where the card is annotated. The examples are organized as shown in Table 4. Table 5 identifies the key features of each example.

#### 11.2.3.1 Example 1 - Standard

1. //NASTRAN JOB-----
2. Instream Procedure Deck
3. // EXEC NASTRAN
4. //NS.SYSIN DD \*
5. NASTRAN Input Deck
6. /\*

- Notes:
1. See Section 11.2.2.1.
  2. See Section 11.2.2.2.
  3. See Section 11.2.2.3.
  4. Identifies the following cards as NASTRAN input data.
  5. See Section 11.2.2.5.
  6. See Section 11.2.2.6.

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Table 4. Organization of the Examples.

Example	Description
1-2	Non-restart runs
3-4	Restart runs
5-6	Runs using Substructure Operating Files
7-8	Runs performing data transmission to/from other programs
9-10	Runs using the User's Master File

Table 5. NASTRAN Key Features in Control Card Examples.

Feature	Example Number									
	1	2	3	4	5	6	7	8	9	10
Plot		X	X							
Checkpoint			X							
Restart				X	X					
Substructuring					X	X				
Data Transmission							X	X		
User's Master File									X	X
INP1, ..., INP9, INPT							X			
NPTP			X		X					
0PTP				X						
PLT2		X	X							
UMF									X	X
FTxxFO01					X	X		X		

## SYSTEM CONTROL CARD DECKS

### 11.2.3.2 Example 2 - Standard, with Plotting

```
1. // EXEC NASTRAN
2. //NS.PLT2 DD UNIT=2400,LABEL=(,NL),DSN=PLT360,
   //      DCB=(BLKSIZE=2400,RECFM=U,BUFNO=1),
   //      DISP=(NEW,KEEP)
3. //NS.SYSIN DD *
```

Notes: 2. Defines the plot tape. The PLT2 DD card in the procedure deck is overridden. If the NASTRAN General Purpose Plotter is used, the DCB parameters should be as follows:

```
DCB=(BLKSIZE=3000,RECFM=F,BUFNO=1)
```

### 11.2.3.3 Example 3 - Very Large Model, with Checkpoint and Plotting

```
1. // EXEC NASTRAN,R=600K,T=200,P1=5,P2=5,S1=10,
   //      S2=10,T1=10,T2=10
2. //NS.NPTP DD UNIT=2400,LABEL=(,NL),DSN=NPTP360,
   //      DISP=(NEW,KEEP)
3. //NS.PLT2 DD UNIT=2400,LABEL=(,NL),DSN=PLT360,
   //      DCB=(BLKSIZE=2400,RECFM=U,BUFNO=1),
   //      DISP=(NEW,KEEP)
4. //NS.SYSIN DD *
```

Notes: 1. Procedure deck parameters are redefined to provide larger region size, longer execution time, and more scratch file space (Section 11.2.2.2).

2. Overrides NPTP DD card. DCB parameters are internally generated.

3. Overrides PLT2 DD card. Notice that NPTP and PLT2 cards are placed in same order as in procedure deck (Table 2).

### 11.2.3.4 Example 4 - Restart

```
1. // EXEC NASTRAN
2. //NS.NPTP DD UNIT=2400, VOL=SER=xxxxxx,
   LABEL=(,NL),DSN=NPTP360,DISP=OLD
3. //NS.SYSIN DD *
```

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Notes: 2. Overrides @PPTP DD card in procedure deck. NASTRAN buffer size must be same as in run which generated @PPTP.xxxxxx is installation assigned.

### 11.2.3.5 Example 5 - Substructuring, Initial S@F Creation, Checkpoint

```
1. // EXEC NASTRAN
2. //NS.NPTP DD UNIT=2400,LABEL=(,NL),DSN=NPTP360
   // DISP=(NEW,KEEP)
3. //NS.FT02FO01 DD UNIT=2314,VOL=SER=xxxxxx,
   // DSN=S@F1,SPACE=(TRK,(500)),
   // DCB=BUFNO=1,DISP=(NEW,KEEP)
4. //NS.SYSIN DD *
   :
5. S@F(1)=FT02,,NEW
```

Notes: 3. Allocates FORTRAN Unit number 2 on a disk pack for use as a new S@F. xxxxx is installation assigned. This card is placed after the NPTP override card.

5. References FORTRAN Unit number 2 in the Substructure Control Deck. Size of S@F is defined in SPACE field on JCL card.

### 11.2.3.6 Example 6 - Substructuring, Multiple S@F's

```
1. // EXEC NASTRAN
2. //NS.FT02FO01 DD UNIT=2314,VOL=SER=xxxxxx,
   // DSN=S@F1,DISP=OLD
3. //NS.FT03FO01 DD UNIT=3314,VOL=SER=xxxxxx,
   // DSN=S@F2,SPACE=(TRK,(1000)),
   // DCB=BUFNO=1,DISP=(NEW,KEEP)
4. //NS.SYSIN DD *
   :
5. S@F(1)=FT02
6. S@F(2)=FT03
```

Notes: 2. JCL for S@F created in previous run. NASTRAN buffer size must be the same

3. Allocates FORTRAN Unit number 3 on a disk pack for use as extended S@F space.

5. References FORTRAN Unit number 2 in the Substructure Control Deck.

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- References FORTRAN Unit number 3 in the Substructure Control Deck. New parameter is not needed for SPF extensions (in fact, must not appear).

### 11.2.3.7 Example 7 - User Tape Input

- // EXEC NASTRAN
- //NS.INPT DD UNIT=2400,VOL=SER=xxxxxx,LABEL=(,NL),  
// DSN=INPT360,DISP=OLD
- //NS.SYSIN DD \*

Notes: 2. Overrides INPT DD card in procedure deck. File is used as input to INPUT1 module (UM 5.3.2). Could also be an old tape attached for output via OUTPUT1 module (UM 5.3.2). Other file names that can be used are INP1(i=1.9).

### 11.2.3.8 Example 8 - User Tape Output

- // EXEC NASTRAN
- //NS.FT19F001 DD UNIT=2400,VOL=SER=xxxxxx,LABEL=(,NL),  
// DSN=USER360,DCB=(BLKSIZE=8190,RECFM=VS),  
// DISP=(NEW,KEEP)
- //NS.SYSIN DD \*

Notes: 2. Definition of additional FORTRAN unit to be used by OUTPUT2 module (UM 5.3.2). The number 19 will appear in the appropriate location in the OUTPUT2 DMAP statement.

### 11.2.3.9 Example 9 - Demo Driver Decks and UMF Tape

- // EXEC NASTRAN
- //NS.UMF DD UNIT=2400,VOL=SER=xxxxxx,LABEL=(,BLP),  
// DSN=UMF,DCB=DEN=2,DISP=OLD
- //NS.SYSIN DD UNIT=2314,VOL=SER=xxxxxx,  
// DSN=XLJLR.UMF.DRIVER.L1750.DATA(D10120),  
// DCB=BUFNO=1,DISP=SHR  
/\*

Notes: 2. Overrides the UMF DD card to reference the UMF tape.  
3. Overrides the SYSIN DD card to reference the Driver Deck file. Demo problem D10120 (member name) is used as an example. Notice that no instream bulk data cards are required.



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### 11.2.3.10 Example 10 - UMF File on Disk

```
1. // EXEC NASTRAN
2. //NS.UMF DD UNIT=2314,VOL=SER=xxxxxx,
   // DSN=XLJLR.UMF.BULK.L1750.DATA,DISP=SHR
3. //NS.SYSIN DD *
4. NASTRAN FILES=UMF
5. {NASTRAN Executive Control and Case Control decks.}
6. BEGIN BULK
7. ENDDATA
8. /*
```

- Notes:
2. Overrides the UMF DD card to reference UMF disk file.
  4. Required to signal to NASTRAN that UMF resides on disk.
  - 5 thru 7. Executive Control deck, Case Control deck, BEGIN BULK card, and ENDDATA card are required, but no Bulk Data deck is required. Reference must be made to UMF deck in Executive Control.

## NASTRAN ON THE UNIVAC 1108/1110 (EXEC 8)

### 11.3 NASTRAN ON THE UNIVAC 1108/1110 (EXEC 8)

#### 11.3.1 Deck Organization Summary

This section describes how the NASTRAN input deck (including control cards) must be set up for operation on the UNIVAC hardware (Programmer's Manual, Section 5.4). The overall organization of the deck is shown in the table below. Each item in the table is described in Section 11.3.2 in the following text. Section 11.3.3 explains the procedure to catalog NASTRAN. Many examples of common deck set-ups are presented in Section 11.3.4.

Table 1. Organization of the Input Deck

1	RUN card
2	QUAL card
3	Control cards for tapes
4	Control cards for heading and Link 1
5	NASTRAN data deck
6	Control card for Links 2-99
7	FIN card

Throughout this section, the NASTRAN program is assumed to be cataloged on FASTRAND. If NASTRAN is stored on tape instead, it will be necessary to catalog it. Section 11.3.3 explains this procedure.

Many control cards are exemplified in this section. In all cases, they begin with the symbol "@". This symbol (a 7/8 multi-punch) must be punched in column one of the control card. An alphanumeric string of characters always immediately follows this symbol, beginning in card column two.

#### 11.3.2 Descriptions of the Input Deck

##### 11.3.2.1 RUN Card

The RUN card identifies the run and furnishes parameters necessary for scheduling and accounting purposes. It is installation-dependent; therefore, check with cognizant personnel at your installation for the proper usage.

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### 11.3.2.2 QUAL Card

The QUAL card is used to qualify for NASTRAN the file names which are referenced downstream in the input deck. The format is:

@QUAL   qualifier

Replace "qualifier" with the proper alphanumeric string in use at your installation. This string should be preceded by at least one blank space.

### 11.3.2.3 Control Cards for Tapes

No tapes are required to run NASTRAN. However, if the user wishes to checkpoint, restart, plot or have access to user tapes, etc., tapes are needed. The tape units which may be used have been assigned by the system utility routine NTAB\$ (Programmer's Manual, Section 5.4.2) as follows:

<u>F0RTRAN</u> <u>Unit</u> <u>No. (s)</u>	<u>External Name</u>
1-7	Standard units assigned for operations
8	@PTP - Old Problem Tape used for restart
9	NPTP - New Problem Tape used for checkpointing
10	UMF - User Master File used for input
11	NUMF - New User Master File used for output
13	PLT2 - Plot tape for SC4020, CALCOMP, or NASTPLT Plots
14	INPT - User tapes for input and/or output
15-23	INP1 (1-9) - Available for user tapes
24-39	24-39 - Available as UT1-UT5 user tapes

These units will be dynamically assigned by NASTRAN for internal use unless they have been previously assigned by user-supplied assign cards. The user supplied tape control cards must reference the external name as shown in the following examples:

@ASG,T   PLT2,T,tapeno   or   @ASG,T   25,T,tapeno

Note that "tapeno" must be replaced with the reel number of the tape to be used; and one or more blank spaces must follow "@ASG,T."

When executing on the UNIVAC 1108/1110, the external names INPT and INP1 can be assigned as user tapes and referenced via the companion DMAP utilities (User's Manual, Section 5.3.2) INPUT1

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and @OUTPUT1. These same FORTRAN unit numbers (14-23) plus units 24-29 may be referenced directly as user tapes via the companion DMAP utilities (User's Manual, Section 5.3.2) INPUTT2 and @OUTPUT2. The user must, however, take care that the FORTRAN unit number referenced by INPUTT1 and/or @OUTPUT not also be referenced by INPUTT2 and/or @OUTPUT2 in the same NASTRAN run.

### 11.3.2.4 Link 1 Card

Two cards are required to suppress the system heading on each page of output and to initiate the execution of Link 1.

```
@HDG,N
@XQT *NASTRAN.LINK1
```

### 11.3.2.5 The NASTRAN Data Deck

This is the standard NASTRAN data input consisting of the Executive Control Deck, the Sub-structure Control Deck (optional), the Case Control Deck, and the Bulk Data Deck. (See Sections 6, 7, 8, and 9 of this guide for details.)

### 11.3.2.6 Other Links

A control card adds about 1400 link execution cards to the run stream from a NASTRAN program file. These cards are required to execute Links 2 through 15 and 99 of NASTRAN. The format is:

```
@ADD *NASTRAN.NASTRAN
```

One or more blank spaces must follow "@ADD". Omitting this card will cause NASTRAN to exit after executing Link 1 and serve as an economical input data check.

### 11.3.2.7 The FIN Card

The FIN card indicates the end of the input deck. The format is:

```
@FIN
```

## 11.3.3 Cataloging the NASTRAN Program

If NASTRAN is stored on tape at your installation, it will be necessary to copy it to NASTRAN before it can be executed. To perform this task, the following cards should replace the QUAL card (item 2) in the input deck:

```
@DELETE,C NASTRAN
@DELETE,C NASTRAN.NASTRAN
@ASG,UPR NASTRAN,F//PDS/20
```

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```
@ASG,T      ABSTAP,T,xxxxxR*
@COPY,G     ABSTAP.,NASTRAN.
@FREE       ABSTAP.
```

\*Replace "xxxxx" with the serial number of the tape.

### 11.3.4 Examples

This section presents a number of examples which illustrate the deck of control cards needed to successfully execute NASTRAN for a variety of problems. These examples are annotated. However, because of the volume of the text, notations made for a given example are not repeated on subsequent examples. Therefore, if a card in some example is not understood, it will be necessary to refer to an earlier example where the card is annotated. The examples are organized as shown in Table 2. Table 3 identifies the key features of each example.

#### 11.3.4.1 Example 1 - Options = none

```
1      @RUN      - - -
2      @QUAL     qualifier
3      @HDG,N
4      @XQT      *NASTRAN.LINK1
          (NASTRAN DATA DECK)
5      @ADD      *NASTRAN.NASTRAN
6      @FIN
```

- Notes:
1. Installation-dependent RUN card.
  2. Replace "qualifier" with the proper alphanumeric string in use at your installation.
  3. Suppress system heading on output pages.
  4. Add control card to initiate execution.
  5. Add control cards needed for NASTRAN execution.
  6. Terminates run.

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Table 2. Organization of the Examples.

Example	Description
1-4	Non-restart runs
5-8	Restart runs
9-14	Runs using the User's Master File
15-17	Runs performing data transmission to/from other programs
18-19	Substructuring runs

Table 3. NASTRAN Key Features in Control Card Examples.

Feature	Example Number																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Restart					X	X	X	X											
Checkpoint			X	X			X	X					X	X					
Plot		X		X		X		X				X		X					
User's Master File									X	X	X	X	X	X					
Data Transmission															X	X	X		
Substructuring																		X	X
User Tapes															X	X	X	X	X
NPTP			X	X			X	X					X	X					
NUMF									X	X									
@PTP					X	X	X	X											
PLT2		X		X		X		X				X		X					
UMF										X	X	X	X	X					

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### 11.3.4.2 Example 2 - Options = plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    PLT2,T,xxxxxW
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card defines the plot tape. Replace "xxxxx" with the reel number of the tape.

### 11.3.4.3 Example 3 - Options = checkpoint

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card defines the New Problem Tape (or checkpoint tape). Replace "xxxxx" with the reel number of the tape.

### 11.3.4.4 Example 4 - Options = checkpoint, plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @ASG,T    PLT2,T,yyyyyW
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```

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11.3.4.5 Example 5 - Options = restart

```
1   @RUN      . - - -
2   @QUAL     qualifier
3   @ASG,T    @PTP,T,xxxxxR
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card defines the Old Problem Tape (or restart tape).  
Replace "xxxxx" with the reel number of the tape.

11.3.4.6 Example 6 - Options = restart, plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    @PTP,T,xxxxxR
4   @ASG,T    PLT2,T,yyyyyW
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```

11.3.4.7 Example 7 - Options = restart, checkpoint

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @ASG,T    @PTP,T,yyyyyR
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```



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### 11.3.4.8 Example 8 - Options = restart, checkpoint, plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @ASG,T    @PTP,T,yyyyyR
5   @ASG,T    PLT2,T,zzzzzW
6   @XQT      *NASTRAN.LINK1
7   (NASTRAN Data Deck)
8   @ADD      *NASTRAN.NASTRAN
9   @FIN
```

### 11.3.4.9 Example 9 - Options = create a UMF

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NUMF,T,xxxxxW
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card identifies the tape for the New User's Master File.  
Replace "xxxxx" with the serial number of the tape.

### 11.3.4.10 Example 10 - Options = edit the old UMF and create a new UMF

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NUMF,T,xxxxxW
4   @ASG,T    UMF,T,yyyyyR
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```

Notes: 3. This card identifies the tape for the User's Master File.  
Replace "xxxxx" with the serial number of the tape.

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11.3.4.11 Example 11 - Options = UMF

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    UMF,T,xxxxxR
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

11.3.4.12 Example 12 - Options = UMF, plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    PLT2,T,xxxxxW
4   @ASG,T    UMF,T,xxxxxR
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```

11.3.4.13 Example 13 - Options = UMF, checkpoint

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @ASG,T    UMF,T,xxxxxR
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN
```

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### 11.3.4.14 - Example 14 - Options = UMF, checkpoint, plot

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    NPTP,T,xxxxxW
4   @ASG,T    PLT2,T,yyyyyW
5   @ASG,T    UMF,T,zzzzzR
6   @XQT      *NASTRAN.LINK1
7   (NASTRAN Data Deck)
8   @ADD      *NASTRAN.NASTRAN
9   @FIN
```

### 11.3.4.15 Example 15 - Options = user tape input

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    INPT,T,xxxxxR
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card identifies the user's input tape. Replace "xxxxx" with the serial number of the tape. More than one user input tape may be used in a given job. Additional tape names are INP<sub>i</sub>, i=1,9.

### 11.3.4.16 Example 16 - Options = user tape output

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    INP1,T,xxxxxW
4   @XQT      *NASTRAN.LINK1
5   (NASTRAN Data Deck)
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

NASTRAN ON THE UNIVAC 1108/1110 (EXEC 8)

Notes: 3. This card identifies the user's output tape. Replace "xxxxx" with the serial number of the tape. More than one user output tape may be used in a given job. Additional tape names are INP<sub>i</sub>, i=1,9.

11.3.4.17 Example 17 - Options = user tape input and output

```

1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    INP3,T,xxxxxW
4   @ASG,T    INP7,T,yyyyyR
5   @XQT      *NASTRAN.LINK1
6   (NASTRAN Data Deck)
7   @ADD      *NASTRAN.NASTRAN
8   @FIN

```

11.3.4.18 Example 18 - Options = new SØF on disk

```

1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,U    INP1,F///1000
4   @XQT      *NASTRAN.LINK1
5   NASTRAN   FILES=INP1
   .         (other NASTRAN data cards)
   .
6   SØF(1) = INP1,400,NEW
   .         (other NASTRAN data cards)
   .
7   @ADD      *NASTRAN.NASTRAN
8   @FIN

```

Notes: 3. The card identifies the file to be used as the SØF. Allowable names for the SØF files are INPT and INP<sub>i</sub>, i=1,9.

5. The specification required because INP1 resides on disk.

6. SØF declaration in the Substructure Control Deck.

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### 11.3.4.19 Example 19 - Options = old SØF on tape

```
1   @RUN      - - -
2   @QUAL     qualifier
3   @ASG,T    INPT,T,xxxxR
4   @XQT      *NASTRAN.LINK1
      .       (NASTRAN data cards)
      .
5   SØF(1)=INPT,250
      .       (other NASTRAN data cards)
      .
6   @ADD      *NASTRAN.NASTRAN
7   @FIN
```

Notes: 3. This card identifies the user's SØF. Replace "xxxxx" with the serial number of the tape. Additional SØF's (up to 10) are similarly defined.

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### 11.4 NASTRAN ON THE CDC 6000/CYBER (NOS AND NOS/BE)

#### 11.4.1 Organization of the Input Deck

This section describes the organization of the NASTRAN input deck. Table 1 lists the items appearing in the overall deck setup.

Table 1. Organization of the Input Deck

1	JOB description cards
2	Control cards to load NASTRAN
3	Optional tape setup cards
4	Execution procedure cards
5	NASTRAN data deck
6	EOR and EOF cards

Each item in the table is described in Section 11.4.2. Several examples of common deck setups are presented in Section 11.4.3. For more information concerning NASTRAN on the CDC 6000/CYBER, see Section 5.5 in the NASTRAN Programmer's Manual.

#### 11.4.2 Descriptions of the Input Deck

##### 11.4.2.1 JOB Description Cards

These cards vary according to installation and whether or not a terminal is being used. A key card is the JOB card. It contains limits on core size, CPU time, I/O time, tapes, and priorities.

##### 11.4.2.2 Control Cards to Load NASTRAN

NASTRAN operates as 15 separate programs, or links, under the NOS and NOS/BE operating systems. These 15 files may be stored on tape, on the system permanent files, or on private disk packs. These options may vary considerably from site to site.

If NASTRAN exists on system or private disk files, an ATTACH card is used for each link. If it is stored on tape, the links must be copied separately onto random access devices.

## SYSTEM CONTROL CARD DECKS

Various methods are used to accomplish the latter, depending on the installation. Consult the systems programmer or NASTRAN representative for assistance in this case.

If the user has a foreknowledge of which NASTRAN links are actually needed for a given execution, he can save time and expense by attaching or copying from tape only the required links.

### 11.4.2.3 Optional Tape Setup Cards

No tapes are required to run NASTRAN. However, if the user wishes to checkpoint, restart, plot, run substructuring, or have access to user tapes, etc., tapes, or their disk equivalents, are required. The user should refer to the Programmer's Manual, Section 5.5.2 and 5.5.4 as well as his local systems personnel for additional detail concerning the procedures for assigning tapes for use by NASTRAN. The tapes which are available to the user are as follows:

<u>File Name</u>	<u>Purpose</u>
INP1 (i=T,1,2,...,9)	User tapes referenced by DMAP utility modules INPUT1 and OUTPUT1 (UG 15, UM 5.3.2)
UT1 (i=1,...,5)	User tapes referenced by DMAP utility modules INPUT2 and OUTPUT2 (UG 15, UM 5.3.2)
NPTP	New Problem Tape for checkpointing
OPTP	Old Problem Tape for restarting
UMF	User Master File
PLT2	Plot tape for NASTRAN General Purpose Plotter, SC4020, Calcomp, or DDBO plots

The user must reference these file names in his job control deck if they are to be used on a NASTRAN run. The user tapes INP1 and UT1 are accessed via the DMAP parameter P2 (UM 5.3.2) corresponding to the specified file name.

Substructure runs require (1 to 10) Substructure Operating Files. These also must be defined by control cards unless they are being used only for scratch purposes within the run. The logical file names must be 4 letters in length, and must match the names on the SBF cards in the Substructure Control Deck (User's Guide, Section 7).

Typical formats of the tape/disk control cards are:

```
REQUEST,OPTP,HI.4363,R0L  
REQUEST,PLT2,HI.(SAVE,RING,NL) )-tape  
ATTACH(SBF1,OLDSBF,ID=xxx) )-disk
```

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These requests also vary with the local operating system.

### 11.4.2.4 Execution Procedure Cards

Due to differences in link switching, the execution procedure differs between the NØS and NØS/BE operating systems. NØS, at most, requires only RFL, REDUCE, and execution command cards, as follows:

```
RFL(220000)
REDUCE(-)
LINK1,INPUT.
```

Under NØS/BE, the deck setup reads in a CYBER Control Language procedure file, and transfers control to it (see Section 11.4.3).

### 11.4.2.5 NASTRAN Data Deck

This is the standard NASTRAN data input consisting of the Executive Control Deck (User's Guide, Section 6), the Substructure Control Deck (User's Guide, Section 7), the Case Control Deck (User's Guide, Section 8), and the Bulk Data Deck (User's Guide, Section 9).

### 11.4.2.6 EØR and EØF Cards

An EØR card (7-8-9 multi-punch in column 1) separates all input records from each other and from the system control cards. An EØF card (6-7-8-9 multi-punch in column 1) terminates the entire deck.

### 11.4.3 Examples

The following examples show control card setups for using NASTRAN under the NØS and NØS/BE operating systems. Accounting, tape results and plot library control cards may vary at different installations. The first nine deck setups illustrate usage on NØS. Example 10 illustrates the additional task that needs to be performed when executing under NØS/BE. Table 2 identifies the key features of each example.



## SYSTEM CONTROL CARD DECKS

Table 2. Key Features of Examples.

Feature	Example Number									
	1	2	3	4	5	6	7	8	9	10
Plot		X								
Checkpoint		X		X				X		
Restart			X	X				X		
Substructuring					X	X				
User's Master File							X	X		
Data Transformation									X	
NØS/BE										X

### 11.4.3.1 Example 1 - Simple Load and Execute (NØS)

```

1.  NASTRAN,T500.
    USER,-----
    CHARGE,-----
    DELIVER,-----
    *---DUMP NASTRAN FROM TAPE TO DISC
2.  REQUEST(TAPE,NT,D=PE,LB=KU)NASTØ1
3.  REWIND,TAPE.
4.  COPYBF,TAPE,LINK1.
5.  COPYBF,TAPE,LINK2.
6.  COPYBF,TAPE,LINK3.
7.  COPYBF,TAPE,LINK4.
8.  COPYBF,TAPE,LINK5.
9.  COPYBF,TAPE,LINK6.
10. COPYBF,TAPE,LINK7.
11. COPYBF,TAPE,LINK8.
12. COPYBF,TAPE,LINK9.
13. COPYBF,TAPE,LINK10.
14. COPYBF,TAPE,LINK11.
15. COPYBF,TAPE,LINK12.
16. COPYBF,TAPE,LINK13.
17. COPYBF,TAPE,LINK14.
18. COPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *---EXECUTE NASTRAN
20. RFL(220000)
21. REDUCE(-)
22. LINK1,INPUT.
23. /EØR
24.     (NASTRAN INPUT DATA)
25. /EØF

```

- Notes:
1. Job cards, installation dependent.
  2. Tape containing 15 NASTRAN link files is attached.
  3. Make sure tape is rewound.

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- 4-18. Copy tape to 15 individual temporary disk files.
19. Free tape drive for other jobs.
20. Set maximum field length for NASTRAN execution.
21. Allows NASTRAN to dynamically alter field length.
22. Execute NASTRAN link 1. Other links will be dynamically executed.
23. End-of-record (7-8-9 multi-punch in column 1). Separates system control cards from NASTRAN input deck.
24. NASTRAN input data, consisting of the Executive Control Deck (UG 6), the Substructure Control Deck (UG 7), the Case Control Deck (UG 9), and the Bulk Data Deck (UG 9).
25. End-of-file (6-7-8-9 multi-punch in column 1). Job Terminator.

### 11.4.3.2 Example 2 - Checkpoint and Plot

```
1.  NASTRAN,T500.  
    USER,-----  
    CHARGE,-----  
    DELIVER,-----  
    *--DUMP NASTRAN FROM TAPE TO DISC  
2.  REQUEST(TAPE,NT,D=PE,LB=KU)NAST01  
3.  REWIND,TAPE.  
4.  COPYBF,TAPE,LINK1.  
5.  COPYBF,TAPE,LINK2.  
6.  COPYBF,TAPE,LINK3.  
7.  COPYBF,TAPE,LINK4.  
8.  COPYBF,TAPE,LINK5.  
9.  COPYBF,TAPE,LINK6.  
10. COPYBF,TAPE,LINK7.  
11. COPYBF,TAPE,LINK8.  
12. COPYBF,TAPE,LINK9.  
13. COPYBF,TAPE,LINK10.  
14. COPYBF,TAPE,LINK11.  
15. COPYBF,TAPE,LINK12.  
16. COPYBF,TAPE,LINK13.  
17. COPYBF,TAPE,LINK14.  
18. COPYBF,TAPE,LINK15.  
19. RETURN,TAPE.  
    *--TAPE SETUP  
20. REQUEST(NPTP,NT,D=PE)SAVE  
21. REQUEST(PLT2,MT,HI)SAVE  
22. RFL(220000)  
23. REDUCE(-)  
24. LINK1,INPUT.  
25. /EOR  
26. (NASTRAN INPUT DATA)  
27. /EOF
```

Notes: 20. Attach NPTP for checkpointing.

21. Attach 7-track PL12 for plotting using the SC4020, Calcomp, DD80, or NASTRAN plotters.

## SYSTEM CONTROL CARD DECKS

### 11.4.3.3 Example 3 - Static Analysis Restart

```

1.  NASTRAN,T500.
    USER,-----
    CHARGE,-----
    DELIVER,-----
    *--ATTACH NASTRAN FILES NEEDED FOR STATICS
2.  ATTACH(LINK1,NASTLINK1,ID=LRC)
3.  ATTACH(LINK2,NASTLINK2,ID=LRC)
4.  ATTACH(LINK4,NASTLINK4,ID=LRC)
5.  ATTACH(LINK5,NASTLINK5,ID=LRC)
6.  ATTACH(LINK8,NASTLINK8,ID=LRC)
7.  ATTACH(LINK12,NASTLINK12,ID=LRC)
8.  ATTACH(LINK13,NASTLINK13,ID=LRC)
9.  ATTACH(LINK14,NASTLINK14,ID=LRC)
    *--TAPE SETUP
10. REQUEST(@PTP,NT,D=PE)VSN=xxxxxx
11. RFL(220000)
12. REDUCE(-)
13. LINK1,INPUT.
14. /EOR
15.     (NASTRAN INPUT DATA)
16. /EOF

```

Notes: 2-9. Links needed for static analysis attached. Reside on disk.  
 10. Attach @PTP for restart. xxxxxx is installation assigned.

### 11.4.3.4 Example 4 - Restart j Checkpoint Using Disk

```

1.  NASTRAN,T500.
    USER,-----
    CHARGE,-----
    DELIVER,-----
    *--DUMP NASTRAN FROM TAPE TO DISC
2.  REQUEST(TAPE,NT,D=PE,LB=KU)NASTC1
3.  REWIND,TAPE.
4.  COPYBF,TAPE,LINK1.
5.  COPYBF,TAPE,LINK2.
6.  COPYBF,TAPE,LINK3.
7.  COPYBF,TAPE,LINK4.
8.  COPYBF,TAPE,LINK5.
9.  COPYBF,TAPE,LINK6.
10. COPYBF,TAPE,LINK7.
11. COPYBF,TAPE,LINK8.
12. COPYBF,TAPE,LINK9.
13. COPYBF,TAPE,LINK10.
14. COPYBF,TAPE,LINK11.
15. COPYBF,TAPE,LINK12.
16. COPYBF,TAPE,LINK13.
17. COPYBF,TAPE,LINK14.
18. COPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--TAPE/DISK SETUP
20. REQUEST(@PTP,NT,D=PE)VSN=xxxxxx
21. REQUEST(NPTP,*PF)
22. RFL(220000)
23. REDUCE(-)
24. LINK1,INPUT.
    *--CATALOG NEW FILE

```

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```
25. CATALOG(NPTP,NEWPTAP, ID=LRC,RP=30)
26. /EOR
27. NASTRAN FILES = NPTP
    (NASTRAN INPUT DATA)
28. (REMAINING NASTRAN INPUT)
29. /EOF
```

- Notes: 21. Request NPTP as a permanent file to be subsequently cataloged.  
25. Catalog NPTP.  
27. NASTRAN card must have FILES=NPTP, as NPTP will reside on disk.

11.4.3.5 Example 5 - Substructuring, Initiate SDF

```
1. NASTRAN,T500.
   USER,-----
   CHARGE,-----
   DELIVER,-----
   *--ATTACH NASTRAN
2. ATTACH(LINK1,NASTLINK1, ID=LRC)
3. ATTACH(LINK2,NASTLINK2, ID=LRC)
4. ATTACH(LINK3,NASTLINK3, ID=LRC)
5. ATTACH(LINK4,NASTLINK4, ID=LRC)
6. ATTACH(LINK5,NASTLINK5, ID=LRC)
7. ATTACH(LINK6,NASTLINK6, ID=LRC)
8. ATTACH(LINK7,NASTLINK7, ID=LRC)
9. ATTACH(LINK8,NASTLINK8, ID=LRC)
10. ATTACH(LINK9,NASTLINK9, ID=LRC)
11. ATTACH(LINK10,NASTLINK10, ID=LRC)
12. ATTACH(LINK11,NASTLINK11, ID=LRC)
13. ATTACH(LINK12,NASTLINK12, ID=LRC)
14. ATTACH(LINK13,NASTLINK13, ID=LRC)
15. ATTACH(LINK14,NASTLINK14, ID=LRC)
16. ATTACH(LINK15,NASTLINK15, ID=LRC)
   *--SDF SETUP
17. REQUEST(SDF1,*PF)
   *--EXECUTE NASTRAN
18. RFL(220000)
19. REDUCE(-)
20. LINK1,INPUT.
   *--SDF CATALOG
21. CATALOG(SDF1,NASTSDF1, ID=LRC,RP=30)
22. /EOR
23. (NASTRAN INPUT)
24. SDF(1)=SDF1,500,NEW
25. (REMAINING NASTRAN INPUT)
26. /EOF
```

- Notes: 2-16. Nastran resides on permanent files.  
17. Request SDF1 for future catalog.  
21. Catalog SDF1.  
24. SDF card in Substructure Control Deck must reference logical file name in Job Control Deck (UG 7). NEW must appear on card.

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### 11.4.3.6 Example 6 - Substructuring, Extend S0F

```

1.  NASTRAN,T500.
    USER, -----
    CHARGE, -----
    DELIVER, -----
    *--DUMP NASTRAN FROM TAPE TO DISC
2.  REQUEST(TAPE,NT,D=PE,LB=KU)NAST01
3.  REWIND,TAPE.
4.  COPYBF,TAPE,LINK1.
5.  COPYBF,TAPE,LINK2.
6.  COPYBF,TAPE,LINK3.
7.  COPYBF,TAPE,LINK4.
8.  COPYBF,TAPE,LINK5.
9.  COPYBF,TAPE,LINK6.
10. COPYBF,TAPE,LINK7.
11. COPYBF,TAPE,LINK8.
12. COPYBF,TAPE,LINK9.
13. COPYBF,TAPE,LINK10.
14. COPYBF,TAPE,LINK11.
15. COPYBF,TAPE,LINK12.
16. COPYBF,TAPE,LINK13.
17. COPYBF,TAPE,LINK14.
18. COPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--S0F SETUP
20. ATTACH(S0F1,NASTS0F1,ID=LRC)
21. RFL(220000)
22. REDUCE(-)
23. LINK1,INPUT.
    *--S0F EXTEND
24. EXTEND(S0F1)
25. /E0R
26. (NASTRAN INPUT)
27. S0F(1)=S0F1,500
28. (REMAINING NASTRAN INPUT)
29. /E0F

```

- Notes: 20. Attach permanent file containing old S0F.  
 24. Extend S0F to save newly written data.  
 27. S0F declaration in Substructure Control Deck.

### 11.4.3.7 Example 7 - UMF Run

```

1.  NASTRAN,T500.
    USER, -----
    CHARGE, -----
    DELIVER, -----
    *--DUMP NASTRAN FROM TAPE TO DISC
2.  REQUEST(TAPE,NT,D=PE,LB=KU)NAST01
3.  REWIND,TAPE.
4.  COPYBF,TAPE,LINK1.
5.  COPYBF,TAPE,LINK2.
6.  COPYBF,TAPE,LINK3.
7.  COPYBF,TAPE,LINK4.
8.  COPYBF,TAPE,LINK5.
9.  COPYBF,TAPE,LINK6.
10. COPYBF,TAPE,LINK7.

```

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```

11. COPYBF,TAPE,LINK8.
12. COPYBF,TAPE,LINK9.
13. COPYBF,TAPE,LINK10.
14. COPYBF,TAPE,LINK11.
15. COPYBF,TAPE,LINK12.
16. COPYBF,TAPE,LINK13.
17. COPYBF,TAPE,LINK14.
18. COPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--SET UP UMF TAPE
20. REQUEST(UMF,NT,D=PE)VSN=xxxxxx
    *--EXECUTE NASTRAN
21. RFL(220000)
22. REDUCE(-)
23. LINK1,INPUT.
24. /EOR
25. (NASTRAN INPUT DATA)
26. /EOF

```

Notes: 20. UMF tape set up. Reference is made to it in the Executive Control Deck of the NASTRAN input (UG 6).

11.4.3.8 Example 8 - Executive Demonstration Problems 1-1-1 and 1-1-1A.

These problems test Statistics Rigid Format #1 and the restart code, and use the User Master File to obtain bulk data. Note that the PUNCH file, which contains restart table data, must be PACKED to eliminate record marks (7-8-9 cards) within the file.

```

1. NASTRAN,T500.
   UMF,-----
   CHARGE,-----
2. REQUEST(TAPE,NT,D=PE,LB=KU)NAST01
3. REWIND,TAPE
4. COPYBF,TAPE,LINK1.
5. COPYBF,TAPE,LINK2.
6. COPYBF,TAPE,LINK3.
7. COPYBF,TAPE,LINK4.
8. COPYBF,TAPE,LINK5.
9. COPYBF,TAPE,LINK6.
10. COPYBF,TAPE,LINK7.
11. COPYBF,TAPE,LINK8.
12. COPYBF,TAPE,LINK9.
13. COPYBF,TAPE,LINK10.
14. COPYBF,TAPE,LINK11.
15. COPYBF,TAPE,LINK12.
16. COPYBF,TAPE,LINK13.
17. COPYBF,TAPE,LINK14.
18. COPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--GET THE UMF AND DRIVER DECKS
20. REQUEST(TAPE,NT,D=PE,LB=KU)NAST03
21. COPYBF,TAPE,UMF.
22. COPYBF,TAPE,LOADPL.
23. REWIND,UMF.
24. RETURN,TAPE.
    *--UPDATE A DRIVER DECK AND EXECUTE
25. UPDATE,Q,C=NASDATA.
26. RFL(220000)

```

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```

27. REDUCE(-)
28. LINK1,NASDATA.
29. REDUCE
    *--PROCESS FILES FOR RESTART
30. REWIND,NPTP,PUNCH,UMF.
31. PACK,PUNCH.
32. RETURN,ØØL.
33. RENAME,ØPTP=NPTP.
    *--UPDATE SECOND DRIVER DECK AND EXECUTE
34. UPDATE,Q,C=NASDATA.
35. RFL(220000)
36. REDUCE(-)
37. LINK1,NASDATA.
38. /EØR
39. *C DDC1011
40. /EØR
41. *C DDC1011A
42. *I DDC1011A.3
43. *READ PUNCH
44. /EØF

```

- Notes:
20. Attach tape containing UMF and UMF Driver Decks.
  21. Copy UMF to permanent file.
  22. Copy UMF Driver Decks to ØLDPL for CDC UPDATE utility.
  25. Obtain driver deck for input into NASTRAN.
  28. NASTRAN execution. Input found on file NASDATA, generated by update.
  29. Turn over control of field length to system.
  31. Pack punch file containing checkpoint dictionary.
  32. Scratch previous NASTRAN PØØL file.
  33. Old NPTP is now new ØPTP.
  34. Obtain follow-up driver deck for input into NASTRAN.
  37. Execute NASTRAN a second time.
  39. UPDATE command to place driver deck DDC1011 onto UPDATE compile file.
  - 42-43. Checkpoint dictionary residing on file PUNCH is inserted into driver deck DDC1011A for restart purposes.

### 11.4.3.9 Example 9 - Data Transmission

```

1. NASTRAN,T500.
   USER,-----
   CHARGE,-----
   DELIVER.-----
   *--DUMP NASTRAN FROM TAPE TO DISC
2. REQUEST(TAPE,NT,D=PE,LB=KU)NAST-1
3. REWIND,TAPE.
4. COPYBF,TAPE,LINK1.
5. COPYBF,TAPE,LINK2.

```

NASTRAN ON THE CDC 6000/CYBER (NØS AND NØS/BE)

```

6.  CØPYBF,TAPE,LINK3.
7.  CØPYBF,TAPE,LINK4.
8.  CØPYBF,TAPE,LINK5.
9.  CØPYBF,TAPE,LINK6.
10. CØPYBF,TAPE,LINK7.
11. CØPYBF,TAPE,LINK8.
12. CØPYBF,TAPE,LINK9.
13. CØPYBF,TAPE,LINK10.
14. CØPYBF,TAPE,LINK11.
15. CØPYBF,TAPE,LINK12.
16. CØPYBF,TAPE,LINK13.
17. CØPYBF,TAPE,LINK14.
18. CØPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--USER TAPE SETUP
20. REQUEST(INPT,NT,D=PE)/SN,xxxxxx
21. REQUEST(UT5,NT,D=PE)SAVE
    *--EXECUTE NASTRAN
22. RFL(220000)
23. REDUCE(-)
24. LINK1,INPUT.
25. /EØR
26. (NASTRAN INPUT DATA)
27. /EØF

```

Notes: 20. Requests user tape to be read by DMAP utility INPUTT1 (UM 5.3.2)

21. Requests user tape to be written on by DMAP utility OUTPUT2 (UM 5.3.2). FØRTRAN unit 15 is implied.

11.4.3.10 Example 10 - Execution under NØS/BE

```

1.  NASTRAN,T500.
    USER, --- ----
    CHARGE, -----
2.  REQUEST(TAPE,NT,D=PE,LB=KU,F=SI)NASTØ1
3.  REWIND,TAPE.
4.  CØPYBF,TAPE,LINK1.
5.  CØPYBF,TAPE,LINK2.
6.  CØPYBF,TAPE,LINK3.
7.  CØPYBF,TAPE,LINK4.
8.  CØPYBF,TAPE,LINK5.
9.  CØPYBF,TAPE,LINK6.
10. CØPYBF,TAPE,LINK7.
11. CØPYBF,TAPE,LINK8.
12. CØPYBF,TAPE,LINK9.
13. CØPYBF,TAPE,LINK10.
14. CØPYBF,TAPE,LINK11.
15. CØPYBF,TAPE,LINK12.
16. CØPYBF,TAPE,LINK13.
17. CØPYBF,TAPE,LINK14.
18. CØPYBF,TAPE,LINK15.
19. RETURN,TAPE.
    *--READ AND EXECUTE NASTRAN PRØC.
20. CØPYCR,INPUT,NASTRAN
21. BEGIN,NASTRAN,NASTRAN.
22. /EØR
23. .PRØC,NASTRAN,RFL=200000,INPUT=,ØUTPUT=,PUNCH=.
24. #RFL,RFL.
25. LINK1,INPUT,ØUTPUT,PUNCH.

```



## SYSTEM CONTROL CARD DECKS

```
26. WHILE,RIG,EQ,0,REPEAT.  
27. BEGIN,NEXT,TAPE99.  
28. ENDW(REPEAT)  
29. REVERT.  
30. EXIT.  
31. REVERT(ABORT)  
32. /EOR  
33. NASTRAN SYSTEM(76)=1  
34. (NASTRAN INPUT DATA)  
35. /EOF
```

- Notes: 20. CYBER Control Language Procedure File (CCL Proc)  
is copied to file NASTRAN.
21. Transfer control to file NASTRAN.
- 23-31. CCL Proc.
33. SYSTEM(76) must be set equal to 1 on the NASTRAN card  
to inform NASTRAN of NOS/BE operating system.

## 12. NASTRAN INFORMATION SOURCES

### 12.1 NASTRAN NEWSLETTER

Periodically, the NASTRAN Newsletter is published to provide NASTRAN users with timely information on the development of new capability, Software Problem Reports (SPR), Documentation Error Reports (DER), and user's experiences. The Newsletter is free and may be subscribed to by writing COSMIC at the following address:

Computer Software Management  
and Information Center  
University of Georgia  
Suite 112, Barrow Hall  
Athens, Georgia 30603  
Telephone: (404) 542-3265

A blank form to be used in subscribing is shown in Figure 1. The information requested on this form is used by COSMIC to help them provide better service to all NASTRAN users.

NASTRAN INFORMATION SOURCES

01 01	LAST NAME	01 21	INITIALS	01 31	PREFIX	01 37	NO CHANGE
01 41	TELEPHONE NUMBER	01 56	JOB DESCRIPTION	01 71	JOB AREA		
02 01	COMPANY NAME						
03 01	COMPANY ADDRESS						
04 01	COMPANY ADDRESS						
05 01	CITY	05 21	STATE	05 31	ZIP CODE		
06 01	YRS.	06 06	MONTHS	06 11	FREQUENCY OF USE	06 21	CPU HOURS (OWN)
						06 31	CPU HOURS (DATA CENTERS)
		06 41	USERS	06 51	TYPE	06 61	CPU HOURS (COMPANY)
						06 71	S.S.B.
07 01	COMPUTER	07 12	MEMORY	07 21	COMPUTER	07 32	MEMORY
07 41	COMPUTER	07 52	MEMORY	07 61	COMPUTER	07 72	MEMORY

Figure 1. Application to receive NASTRAN Newsletter

NASTRAN NEWSLETTER

00 00	PLOTTER	00 11	PLOTTER	00 21	PLOTTER
00 30	LEVEL	00 41	LEVEL	00 51	LEVEL
RIGID FORMAT 00 01					
(insert 0 number 1-4)					
00 01	PRE-PROCESSOR	00 11	PURPOSE		
00 20			PURPOSE (Continued)		
10 01	POST-PROCESSOR	10 11	PURPOSE		
10 20			PURPOSE (Continued)		
11 01	F T A R	11 11	F T A R	11 21	F T A R
11 31	F T A R	11 41	F T A R	11 51	F T A R
11 61	F T A R	11 71	F T A R		

Figure 1 Application to receive NASTRAN Newsletter (cont'd).

NASTRAN INFORMATION SOURCES

12	01	IMPROVEMENT																		
12	21	IMPROVEMENT (Continued)																		
12	41	IMPROVEMENT (Continued)																		
12	61	IMPROVEMENT (Continued)																		
13	01	IMPROVEMENT (Continued)																		
13	21	IMPROVEMENT (Continued)																		
13	41	IMPROVEMENT (Continued)																		
13	61	IMPROVEMENT (Continued)																		
14	01	COMMENTS																		
14	21	COMMENTS (Continued)																		
14	41	COMMENTS (Continued)																		
14	61	COMMENTS (Continued)																		

Figure 1. Application to receive NASTRAN Newsletter (cont'd).

15	01	COMMENTS (Continued)
15	21	COMMENTS (Continued)
15	41	COMMENTS (Continued)
15	61	COMMENTS (Continued)
16	01	BENEFITS
16	21	BENEFITS (Continued)
16	41	BENEFITS (Continued)
16	61	BENEFITS (Continued)
17	01	BENEFITS (Continued)
17	21	BENEFITS (Continued)
17	41	BENEFITS (Continued)
17	61	BENEFITS (Continued)

Figure 1. Application to receive NASTRAN Newsletter (cont'd).

## SOFTWARE PROBLEM REPORT (SPR) LOG

### 12.2 SOFTWARE PROBLEM REPORT (SPR) LOG

Another service called the Software Problem Report (SPR) Log is also provided by COSMIC as part of their NASTRAN maintenance service. This log is available to all interested users by writing to COSMIC. The SPR Log is essentially a working document whose primary value lies in its currency. For this reason, it is continuously updated and published at frequent intervals.

The user is encouraged to submit SPRs to COSMIC as a service to all other users of NASTRAN. The recommended procedures for doing so are presented in Section 12.4.

## NASTRAN USER'S COLLOQUIUM

### 12.3 NASTRAN USER'S COLLOQUIUM

More formal reports on application and development of NASTRAN have been published by NASA following each NASTRAN User's Colloquium held at various NASA centers around the country. The Colloquium proceedings now available are entitled:

#### "NASTRAN: USER'S EXPERIENCES"

1. NASA TM X-2378, September, 1971
2. NASA TM X-2637, September, 1972
3. NASA TM X-2893, September, 1973
4. NASA TM X-3278, September, 1975
5. NASA TM X-3428, October, 1976

#### "SIXTH USER'S COLLOQUIUM"

6. NASA CP-2018, October, 1977

#### "SEVENTH USER'S COLLOQUIUM"

7. NASA CP-2062, October 1978

These proceedings may be obtained at modest cost from:

National Technical Information Service  
Springfield, Virginia 22151



## SPR SUBMITTAL

### 12.4 SPR SUBMITTAL

It is a goal that every NASTRAN run terminate with either correct results or a user-oriented message describing the difficulties encountered. Progress towards this goal is made by means of user-submitted materials describing software problems. Figure 1 shows the standard SPR submittal form.

The following guidelines are recommended so that each Software Problem Report (SPR) can be efficiently handled.

1. If you suspect an error, first try to determine if the error is already known. An SPR log is available through COSMIC which lists known errors. This log is indexed by module and often contains a suggested user avoidance procedure.
2. If the malfunction involves a computer-dependent termination, such as system abends on the IBM 360 or error modes on the CDC and UNIVAC computers, consult first with your own programming operations staff for possible job set-up errors.
3. Having decided that the problem is caused by an unknown malfunction in NASTRAN, and if you have programmers available, attempt to determine the cause by consulting them and the listings. The best error submittal is one which contains a run which exemplifies a stated error and contains a suggested program correction along with the statement, "We tried this fix and it worked," or even "We tried this and it didn't work."
4. Having exhausted your own resources, consider sending the run to COSMIC for further investigation. If you consider this approach, be sure that the run has as much diagnostic data as possible. In particular, be sure that DIAG's 1, 2, 3, 8, 13, 15, 16 (for inverse power problems), and 19 were on and that a dump was taken. Be sure to include an echo of all the input data and the Run Log (the day file (CDC), Log (UNIVAC), or FT04 (IBM)). If this data is not available, please rerun the job to obtain it. You should also take the time to describe the circumstances surrounding the run, i.e., "I changed this one card from when it ran before," etc. A complete NASTRAN data deck in card form should also be submitted, because later testing and other reruns may need

## NASTRAN INFORMATION SOURCES

to be made. If plots have been made, send copies of them. If user tapes are involved, dump them and send the dump. Be sure to give your name, address, phone number, and as precise a description of the difficulty as you can.

If you take the time to follow these guidelines, COSMIC will be able to respond to SPRs more quickly and more economically. The processing of SPRs can be delayed for extended periods when insufficient information is submitted to permit prompt identification and correction of the reported error.

SPR SUBMITTAL

Date: \_\_\_\_\_

Originator: \_\_\_\_\_

Organization: \_\_\_\_\_

Address: \_\_\_\_\_

\_\_\_\_\_

Phone No.: \_\_\_\_\_

NSMO Use

SPR No. : \_\_\_\_\_

Priority : \_\_\_\_\_

Date Rec'd. : \_\_\_\_\_

Date Assigned: \_\_\_\_\_

Materials Submitted:

- ( ) Output: \_\_\_\_\_ Runs
- ( ) Deck
- ( ) Plots
- ( ) Letter
- ( ) Dump
- ( ) Traceback
- ( ) Fix: \_\_\_\_\_
- ( ) Program Listing
- ( ) Link Map Listing
- ( ) Other: \_\_\_\_\_

Level: \_\_\_\_\_

Computer: \_\_\_\_\_

Rigid Format: \_\_, \_\_  Disp  Heat  Aero  
or  DMAP  Alters

Error Message: \_\_\_\_\_

Module: \_\_\_\_\_

Subroutine(s): \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Avoidance (if known): \_\_\_\_\_

\_\_\_\_\_

Estimate correction effort (if known): \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Description: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

NSMO Use

Level Fixed : \_\_\_\_\_

Test Problem : \_\_\_\_\_

Verified by NSMO : \_\_\_\_\_

Figure 1. NASTRAN Software Problem Report (SPR).

## DER SUBMITTAL

### 12.5 DER SUBMITTAL

It is also a goal of COSMIC to supply the user with complete and accurate documentation to facilitate the application and development of NASTRAN. Even though COSMIC carefully edits all documentation, errors of commission and errors of omission do occur. COSMIC recognizes, however, that it is the user who ultimately puts the documentation to its most severe test. Therefore, COSMIC welcomes all user reports of documentation errors. Valid errors will be reported to other users via the NASTRAN Newsletter.

A sample DER form is shown in Figure 1. The user is encouraged to submit this form to COSMIC along with a copy of the documentation page with annotations to indicate the error. If appropriate, also provide the specific text which would serve to correct that error. Some types of documentation errors may indicate the presence of software problems as well. If this is known, the user should consider submitting a supporting SPR following the procedures suggested in Section 12.4.

NASTRAN INFORMATION SOURCES

DER \_\_\_\_\_ SPR \_\_\_\_\_ NEW CAPABILITY \_\_\_\_\_

NASTRAN DOCUMENTATION ERROR REPORT (DER)

Originator: \_\_\_\_\_ Date: \_\_\_\_\_

Organization: \_\_\_\_\_ Phone No.: \_\_\_\_\_

- |        |                          |               |       |                |
|--------|--------------------------|---------------|-------|----------------|
| Manual | <input type="checkbox"/> | Theoretical   | _____ | } Page Numbers |
|        | <input type="checkbox"/> | User's        | _____ |                |
|        | <input type="checkbox"/> | Programmer's  | _____ |                |
|        | <input type="checkbox"/> | Demonstration | _____ |                |

Description of the Error and Corrections

(A copy of the page(s) in error with marked corrections should be attached.)

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Comments

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Editor Approval	NSMO Approval	MPSL Entry	Change Made	Editor Check	NSMO Verif.	Editor Verif.	MPSL Entry
_____	_____	_____	_____	_____	_____	_____	_____
Date	Date	Date	Date	Date	Date	Date	Date
_____	_____	_____	_____	_____	_____	_____	_____

Figure 1. NASTRAN Documentation Error Report (DER).

## 13. OPERATING PRINCIPLES OF NASTRAN

### 13.1 INTRODUCTION

To model a structure in NASTRAN requires a knowledge of the input and control options but little understanding of how the program itself works. However, a fundamental knowledge of the basic operating principals of the program will assist the user in fully using NASTRAN's capabilities. With the "black box" stigma of the program removed, the NASTRAN user is free to use many of the special purpose diagnostics and efficiency controls available to him. Understanding the operating principles also aids understanding processing failures, interpreting diagnostic output, and planning unusual analyses.

Presented in this section is an overview of NASTRAN as a computer software system. The overview includes a description of the major subdivisions of NASTRAN: the executive system, the functional modules, the input/output utilities, the matrix algebra utilities, and the data base file structures. Included here is a summary of standards and conventions used in NASTRAN code development to implement the theory of NASTRAN applications. The conventions described include the engineering notation used, the nested vector concept, the open core concept for data storage, formats used for matrices and tables, and fundamental concepts of the NASTRAN input/output (I/O) system. This section concludes with a discussion of the theory behind NASTRAN restart procedures.

In-depth treatment of the topics presented in this section are found in Sections 1 of the Theoretical and the Programmer's Manuals. Specific references to other material are also provided.

## PROGRAM DESIGN OVERVIEW

### 13.2 PROGRAM DESIGN OVERVIEW

An understanding of the NASTRAN program design can be facilitated by a knowledge of some of the design criteria which are related to computer science rather than structural analysis. Chief among these criteria are:

1. Simplicity of problem input deck preparation.
2. Minimization of chances for human error in problem preparation.
3. Minimization of need for manual intervention during program execution.
4. Capability for step by step problem solution, without penalty of repeated problem set up.
5. Capability for problem restart following unplanned interruptions or problem preparation error.
6. Minimization of system overhead in the three vital areas by:
  - a. Not diverting core storage from functional use in problem solution.
  - b. Not diverting auxiliary storage units from functional to system usage.
  - c. Not using system housekeeping time for performing executive functions that do not directly further problem solution.
7. Ease of program modification and extension to new functional capability.
8. Ease of program extension to new computer configurations and operating systems.
9. Maintain ability to operate efficiently under a wide set of computer configurations.

The design goals for NASTRAN are achieved through modular separation of program activities. The major functional subdivisions of NASTRAN are presented in Figure 1. They are:

1. The Executive System - It provides for overall control of the job. It allocates files, supervises the input process, generates the execution sequence. It acts as an interface between the program and the computer operating system.
2. System data and module parameters - These data are stored in small, core-held common blocks. These tables serve to define the status of the system and provide communication between the system and modules.

## OPERATING PRINCIPLES OF NASTRAN

3. **Functional Modules** - These are self-contained blocks of code designed to perform selected analytical functions such as element matrix generation or assembly with a minimum number of interface data blocks. To provide simplicity and convenience for updating and maintaining the system, the following restrictions are applied to functional modules:
  - a. Modules may interface with other modules only through auxiliary storage files, as opposed to passing information between each other while in core.
  - b. Since the availability and allocation of auxiliary files for module execution interact with the execution of other modules, no module can directly specify or allocate physical files. The auxiliary storage allocation is reserved as an Executive function.
  - c. Modules operate as independent subprograms, and may not call, or be called by, other modules. They may be entered only from the Executive System.
4. **GINØ (General Input/Output utilities)** - A comprehensive set of utility subroutines developed for manipulating data blocks. GINØ routines are always used to read or write data blocks for internal NASTRAN operations.
5. **Data Block** - A collection of unformatted tables and/or matrices used for writing to and reading from auxiliary storage. The contents and formats are defined by the routines creating them. Every NASTRAN file is made up of data blocks except for user-supplied files defined via the job control, all files are allocated temporarily.
6. **Matrix Utilities** - A set of mathematical subroutines provided for matrix decomposition, matrix multiply, matrix partitioning, eigenvalue analysis, etc.

These major subdivisions of NASTRAN and their relationships to each other are described in more detail in the following three sections.



PROGRAM DESIGN OVERVIEW

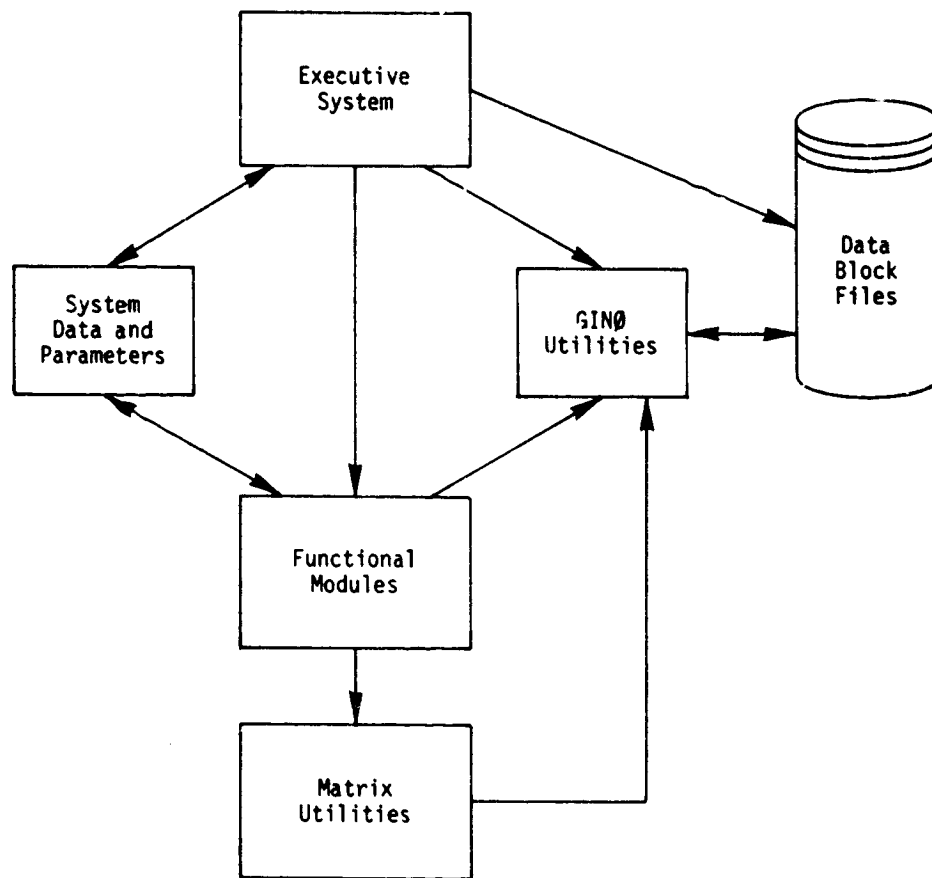


Figure 1. NASTRAN Program Subdivision.

## THE EXECUTIVE SYSTEM

### 13.3 THE EXECUTIVE SYSTEM

The essential functions of the Executive System are:

1. Establish and control the sequence of module executions according to options specified by the user.
2. Establish, protect, and communicate values of parameters for each module.
3. Allocate system files to all data blocks generated during program execution. A file is "allocated" to a data block, and a data block is "assigned" to a file.
4. Maintain a full restart capability for restoring a program execution after either a scheduled or unscheduled interruption.

The Executive System is open-ended in the sense that it can accommodate an essentially unlimited number of functional modules, files, and parameters. Modifications of the Executive System to accommodate changes or additions to functional modules are performed with changes to control data tables.

The Executive System controls the execution of NASTRAN in two phases: (1) the preface, in which a basic setup is performed; and (2) the execution of the DMAP program in which the modules are controlled. The key executive subroutines performing these steps are:

1. XCSA (Control Section Analysis) - Processes the Executive Control Data Deck and loads the DMAP code from the Rigid Format Tables.
2. GNFIAT (Generate FIAT) - Allocates the NASTRAN working files and assigns initial data block names to the File Allocation Table (FIAT).
3. XGPI (General Problem Initialization) - Processes the Direct Matrix Abstraction Program (DMAP) much like a compiler. Restart logic is also performed to identify the modules to be re-executed. The output is the Operational Sequence Control Array (@SCAR), which provides the information for executing the modules.
4. XSFA (Segment File Allocator) - Manages the data block to physical file relationships throughout the NASTRAN run. It reallocates files when new data blocks must be allocated and previously used data may be discarded to free the file to the system.

## OPERATING PRINCIPLES OF NASTRAN

5. XSEMI ( $i = 1, 2, \dots, M$ ) (Executive Sequence Monitor, Link  $i$ ) - The link-driven routines which control the calls to the functional modules. If a module resides in the  $i$ th link, the XSEMI routine requests the file and parameter allocations and directly calls the module. If the module resides on another link, the XSEMI routine returns to the overall control for loading another XSEMI routine. Each NASTRAN link is a major overlay segment of the program.

The general programming philosophy behind the Executive System routines is that reliability and efficiency are paramount concerns. It was also anticipated that few changes were to occur in the Executive System as the NASTRAN system grew, thus, few general rules were imposed on the Executive System code, resulting in a sophisticated, but difficult to modify, system.

In addition to the above specialized functions, the Executive System controls the input data card processing, and provides various other functions such as defining open core and clock time. For more information on the topics above, consult the NASTRAN Programmer's Manual Sections 1.2, 2.4, 2.2, and 4.1 through 4.20.

## FUNCTIONAL MODULES

### 13.4 FUNCTIONAL MODULES

A NASTRAN module consists of one or more subroutines which perform a single computational process. The size of a module may range from less than ten lines of code to many thousands of executable statements. Functional modules serve to manage or control a series of operations, which may be executed by other modules or matrix utilities, to accomplish an analytical objective. In general, functional modules are executed in the sequence specified by the NASTRAN Rigid Formats or by user DMAP instructions.

#### 13.4.1 Module Types

Four module types occur in NASTRAN, and each type is limited to a specific range of functions. These are:

1. Preface Modules - Executes under direct control of the Executive System during the problem initialization. Since these modules are not used by DMAP and their data block names are fixed, many of the normal NASTRAN coding restrictions do not apply. For example, preface modules may write on their own input files or on the reserved NASTRAN system files.
2. Executive Operation Modules - Perform logical DMAP operations such as JUMP, LOOP, and FILE declaration. Except for the checkpoint module, none of these modules perform any major calculations or I/O operations.
3. Utility Modules - Designed for general use with simple inputs and outputs. Utility functions range from performing print requests to complex matrix operations.
4. Analysis Oriented Modules - Provided for specific steps in the analysis of structures which are not easily defined with matrix algebra. Examples are the element table assembler (TA1) and the stress recovery routine (SDR2). Other modules are provided for more efficient processing of matrices than available with Utility Module DMAP steps. An example is module SSG2 which reduces the static load vectors using a series of matrix operations.

#### 13.4.2 Module Data Interfaces

Communication between modules is performed using data block files and parameters. The number

## OPERATING PRINCIPLES OF NASTRAN

of input files, output files, and parameters for every DMAP module are pre-defined in the block data program XMPLBD.

Input data block files are specified as file number 101, 102, 103 ... 100+N according to the DMAP calling sequence. These numbers are used in the calls to the GINØ utility subroutines for all file operations. Similarly, the output files are defined as 201, 202, 203 ... 200+n and the internal scratch files are labeled 301...300+N. Several of the GINØ system error messages reference these numbers. The user must refer to the Rigid Format description in the User's Manual to determine the actual data block in question.

Parameters are stored in the blank common block (COMMON /BLANK/ list). The types may be integer, real, complex, or BCD characters. Floating point numbers may be single or double precision. The type of each parameter is fixed in the module code and in the system tables. Modules may use the parameters as either input or output data.

### 13.4.3 Module Overlays and Open Core

Each module in NASTRAN generally is assigned separate overlay segments independent of the other modules. During execution only the module code and the required utility subroutines are loaded into core. Furthermore, a common block assigned by the module is loaded below the current code for use in an "open-core" storage space. Open core exists from this point to the maximum core space requested for the execution. All matrix and table data required for a given module operation are brought into open core for temporary storage. Results are moved from open core to data block files for access by other modules.

A typical NASTRAN overlay "tree" is illustrated in Figure 13.2. Shown are examples of modules which are divided into separate parts, consisting of a small "driver" routine which calls the major sections of code located near the bottom of core. This scheme allows the large and complex matrix utility routines to be used by more than one module in a link, yet still allows the largest possible open core space for each module.

Each module in NASTRAN performs its own open core allocations. The executive subroutine KØRSZ (core size) is used to determine the available length of core relative to a particular data location. The module allocates space for GINØ Input/Output buffers, along with all core-held variable length arrays. The modules are also responsible for their own spill processing. This occurs when a particular set of arrays do not fit in the available open core and must be processed a piece at a time using scratch files for the extra data.

## FUNCTIONAL MODULES

### 13.4.4 Module Restrictions

A number of general rules have been followed in the development of NASTRAN modules which provide efficiency, reliability, and ease of maintenance. Understanding these rules may aid in the use of the program. The general module design rules are:

1. Only GINØ utility routines (e.g., ØPEN, CLØSE, READ, WRITE, PACK) are used to access data blocks and scratch files.
2. Only substructure utilities (e.g., SØFØPEN) are used to access the automated substructure operation file (SØF).
3. No data is written on input data blocks. (Note, however, that a module may read output data blocks.)
4. Values of system parameters and arrays are not changed.
5. Utility routines are used whenever possible to avoid unnecessary code duplication. An example is the use of the MESSAGE routine which stores common error message print formats on a separate overlay.

For additional module coding restrictions and conventions, refer to Sections 1.3 through 1.5 of the NASTRAN Programmer's Manual. For discussions of the utility routines refer to Sections 1.7, 3.4, and 3.5 of the Programmer's Manual. For individual module descriptions refer to Section 4 of the Programmer's Manual.

# OPERATING PRINCIPLES OF NASTRAN

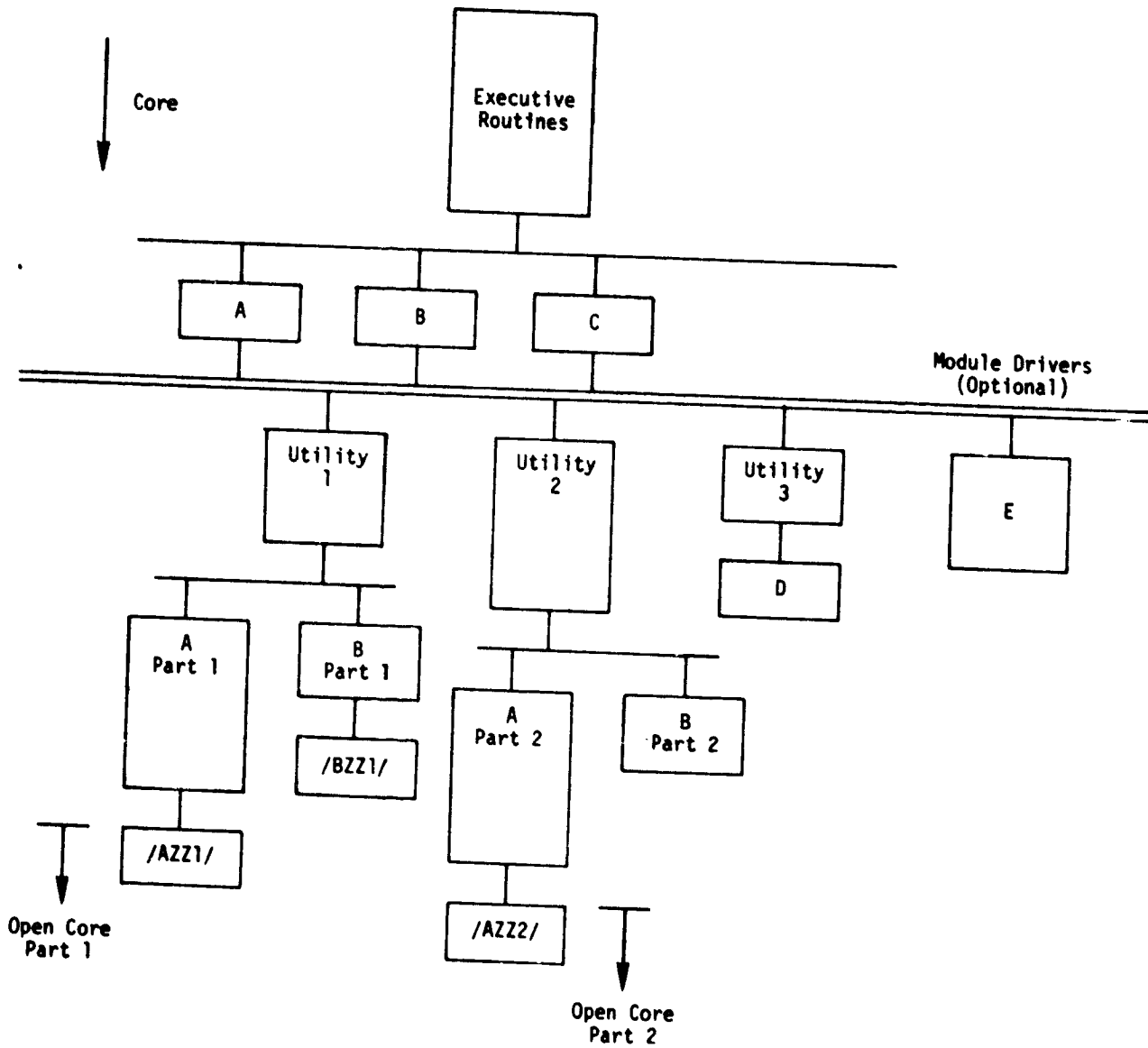


Figure 2. Illustration of NASTRAN Overlay System

## THE NASTRAN I/O SYSTEM

### 13.5 THE NASTRAN I/O SYSTEM

NASTRAN is primarily a file-oriented program, using mass storage devices for nearly all major data transfers. The four types of Input/Output systems provided in NASTRAN are the external user interfaces, the internal data blocks, the checkpoint/restart file, and the substructure data base. These are described individually below.

#### 13.5.1 External User Interfaces

Aside from the conventional input data file and output print files, NASTRAN may be used to read or write data on other user-supplied external files. These are summarized below;

1. Plot files are created for both structure plots (plots of the model geometry) and dynamic response curves (XY output plots). The format is dependent on the computer hardware and plotter hardware.
2. The punch file is used for several purposes. The restart dictionary data are automatically generated and stored on the punch file. The DMAP program may be punched if DIAG 17 is requested. All printout data may also be punched for post-processing by other programs.
3. User Files are machine-dependent file names that are requested by the user in his system job control cards. Modules using these files must be defined in a DMAP program. Modules INPUT1 and OUTPUT1 read and write data blocks in NASTRAN format. INPUT2 and OUTPUT2 read and write data blocks which are converted to FORTRAN format on the user files.
4. Substructure Operating Files (SOF) are direct access device files defined by the user for storing substructure data. A data base management system automatically provides the required NASTRAN I/O interface.

For more information on the external I/O interfaces of NASTRAN, see Section 5.0 of the NASTRAN Programmer's Manual for system interface descriptions versus computer type.

#### 13.5.2 NASTRAN Data Blocks

Data blocks in NASTRAN are treated as separate, self-contained files used for temporary data storage. The Executive System allocates the storage devices while the modules perform the calculations to generate data for storage in the data blocks.



## OPERATING PRINCIPLES OF NASTRAN

Each data block may be subdivided into an unlimited number of records. Each record may contain an unlimited number of words or may be completely null. In rare cases a data block may also contain several logical files, but this practice is discouraged. Detailed information on the data blocks used in the NASTRAN Rigid Formats is contained in Section 2.3 of the Programmer's Manual.

The most general form of data block is the table. Any format of data may be used with mixed integers, floating point number, and BCD characters. No data conversions are performed on tables.

A standardized packed matrix format is used for all NASTRAN data block matrices. Only non-zero terms and their packed identifiers are stored on the file. A set of matrix utility subroutines are used to read and write matrix terms. All NASTRAN matrices are stored by columns, i.e., each column is a separate logical record.

All NASTRAN data block names are stored in core-held tables which contain 6 words of so-called "trailer" information. The trailer data is used to identify the characteristics of files without actually performing any I/O operations. The trailers for matrix data blocks are particularly useful in that they contain the dimensions and density of the matrix. The input executive control card DIAG 8 will produce a printout of each trailer as the data block is created. The contents for matrices are:

WORD	DEFINITION
1	Internal Data Block Name
2	Number of Columns
3	Number of Rows
4	Type of Matrix (square, rectangular, etc.)
5	Type of Matrix Terms (single, double, etc.)
6	Maximum Number of Non-Zero Words in a Column
7	Matrix Density $\times 10^3$

For definitions of the types of matrices see the DMI (Direct Matrix Input) bulk data card description in Section 2.4 of the User's Manual.

### 13.5.3 Checkpoint Files

The NASTRAN checkpoint file is defined by the user on his machine-dependent job control input. A single operating system file is required, which may be on any of the available system permanent

## THE NASTRAN I/O SYSTEM

bulk storage devices, including multi-reel tapes. If a checkpoint is requested, the contents of the NPTP (New Problem TaPe) will include the current case control data, the sorted bulk data, all NASTRAN data blocks written via the DMAP request CHKPNT, and the parameter values at each checkpoint stop. Associated with the NPTP file is a checkpoint dictionary which is normally written on the punch file in card images. The restart dictionary contains descriptions of the data blocks and the XVPS (Executive Variable Parameter Save Table) stored on the NPTP file.

On restarts, the previously generated checkpoint file is assigned as the OPTP (Old Problem TaPe) file. The corresponding checkpoint dictionary is included in the Executive Control Deck and the program automatically proceeds with the restart process.

### 13.5.4 Substructure Operating Files

For automated multi-stage substructure analysis, the Substructure Operating File (SOF) is a single logical file used to store all data necessary for a complete multi-stage substructuring analysis. The SOF may actually reside on one to ten physical files. However, these physical files are chained together to form a single logical file for use in the analysis of larger problems.

Each physical file comprising the SOF must be a direct access disk file. These files are not processed with NASTRAN GIN operations, but treated as external user files. In a substructure analysis, NASTRAN stores data on the SOF which must be saved from run to run. Therefore, it is the user's responsibility to maintain the physical disk files comprising the SOF from one execution to the next. A complete description of how to use and maintain the SOF is presented in Section 20.12 of the User's Guide and Section 2.7 of the User's Manual.

## NASTRAN CHECKPOINT/RESTART LOGIC

### 13.6 NASTRAN CHECKPOINT/RESTART LOGIC

NASTRAN has a sophisticated checkpoint and restart capability. This capability allows the user to efficiently recover after either a scheduled or unscheduled interruption. Some situations applicable to the use of checkpoint/restart are listed below:

1. A run may abort due to insufficient time, a user data error, or insufficient core.
2. The user may request termination of his run at selected steps during the analysis for the purpose of examining intermediate results prior to continuing the run.
3. The user may wish to rerun only a portion of the analysis with limited data changes.

The overall design philosophy for restart is twofold. A restart selectively executes only the modules necessary to accomplish a user-input data change. The user is able to change any part of his problem including model data changes, additional cases, or more output requests. At the same time restarts are automatic as far as user interference is concerned. The user need only checkpoint his original run and submit changes to the original run on subsequent runs.

#### 13.6.1 Restart Types

In NASTRAN there are four general types of restarts. Unmodified Restart (UMR), Pseudo Modified Restart (PMR), Modified Restart (MR), and Rigid Format Switch (RFS). In Section 3 of the User's Manual, UMR's and PMR's are described together as Unmodified Restarts. These classifications are for descriptive and internal purposes. The user need not know anything about which type is which. The basic characteristics of each type will be described below.

An Unmodified Restart results when the user simply resubmits a problem with no data changes. It is used to continue a solution from the point of interruption. Presumably the problem aborted previously due to time expiring, or the user-requested early termination for the purpose of examining intermediate results prior to completing the solution. The restart dictionary (created while checkpointing) is processed, and the solution is started again at the last re-entry point (after the last successful checkpoint).

A Pseudo Modified Restart occurs when the user requests additional output from the program which simply requires the re-execution of an output module such as the Structure Plotter, the Grid Point Weight Generator, or the Stress Data Recovery module. The numerical solution is

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not effected by these modules; only new output is generated. Note that a PMR is the common case since printer output, plotter output, etc. is usually requested. A true UMR is rare. On a PMR, output modules are re-executed to display requested output, and then the problem is continued at the re-entry point.

A true Modified Restart occurs when some numerically significant data change. The modules which process these data must be re-executed. These modules are re-executed to regenerate their output data blocks based on the new data and the problem is continued at the re-entry point.

A Rigid Format Switch (RFS) is a special form of Modified Restart in which a problem changes from one solution type to another. One example would be: a user has solved for the static solution on Rigid Format 1 and now wants to find the normal modes by using Rigid Format 3. RFS may or may not require data changes. The key difference here is that the re-entry point cannot be used to determine the proper place to restart. For a RFS, NASTRAN examines the final modules on the new Rigid Format and lets the File Name Table chain the solution back to the proper restart point.

### 13.6.2 Restart Decision Process

To understand, in general, how the above types of restart are implemented, it is necessary to consider the Module Execution Decision Table (MEDT), which is associated with each Rigid Format. The Module Execution Decision Table has one entry for every DMAP instruction in the Rigid Format. A Card Name Table associates bits of the MEDT with selected bulk data card names, case control selections, and parameter names. The File Name Table associates bits of the MEDT with selected data block names. The following example illustrates the use of these tables in determining the effects of changing a bulk data card on a Modified Restart.

Suppose the FORCE bulk data card is to be changed when executing Rigid Format 1. DMAP modules BEGIN, FILE, FILE, GP3, SAVE, PARAM, PURGE, CHPNT, SSG1, CHPNT, EQUIV, etc., will be executed since the bit associated with loads is set for each of those modules.

Each part of the NASTRAN Preface contributes to processing the information for a restart. The XCSA module extracts and stores the Card Name Table, the File Name Table, the Module Execution Decision Table, the DMAP sequence, and the Rigid Format Switch bit if any. These are written in the XCSA Executive Control Table on the New Problem Tape for later use by module XGPI. IFPI compares the current CASECC (case control) data block with the one submitted on the previous run (a copy of CASECC is stored on the Old Problem Tape for this purpose).

## NASTRAN CHECKPOINT/RESTART LOGIC

Three types of changes are noted by IFP1:

1. Changes in data set selection such as Load set, SPC set, etc.;
2. The occurrence of output requests for printer, plotter, punch;
3. Changes in the looping structure of the problem.

XSORT analyzes bulk data card changes in a similar manner; setting the proper bits in the tables. XGPI then analyzes this information to decide which modules are to be executed. Input data blocks are then checked for RFS restarts to find if they are to be generated or available on the checkpoint tape. If the input data blocks are missing, the modules which generate them are flagged and the process continues until all module data requirements are satisfied.

### 13.6.3 Restart Rules

Some of the basic program rules followed in the restart decision process are:

1. The first choice of re-entry points is always the last entry in the checkpoint dictionary.
2. If a data block occurs more than once in the dictionary, the last entry before the re-entry point is always used.
3. On DMAP looping problems the program will restart either at the last entry for the last loop or at the first, depending on the changes. Restarts in the middle of a set of loops must be controlled by manually editing the dictionary.
4. User-supplied DMAP ALTER code is always executed. ALTER code defined in the checkpoint run is not saved and must be included in the restart if required.

## NASTRAN PROGRAMMING CONVENTIONS

### 13.7 NASTRAN PROGRAMMING CONVENTIONS

NASTRAN development encompassed a comprehensive set of rules for terminology, messages, and user controls. These have included the use of consistent mnemonics for the names of data program variables, and module/subroutines. These conventions have been useful both to the programmer and the engineer. A unique example, described below, is the use of vested degree of freedom sets for naming vectors, matrices, and their partitions. This nomenclature system is followed from the basic theoretical development, through the user data inputs, to the actual code. The reader is directed to Section 7.1 of the User's Manual for a comprehensive dictionary of terms which frequently occur in the use of NASTRAN.

This section describes some of the conventions particularly useful when running NASTRAN. Some of the particular diagnostics and notation systems are included along with error message rules and some methods for overriding the system.

#### 13.7.1 Diagnostic Outputs

The executive control card, DIAG, is particularly useful in diagnosing problems in NASTRAN. The format is:

DIAG  $n_1, n_2, n_3 \dots$

where each integer  $n$  produces a specific type of diagnostic output. Some sample diagnostics are given in the list below:

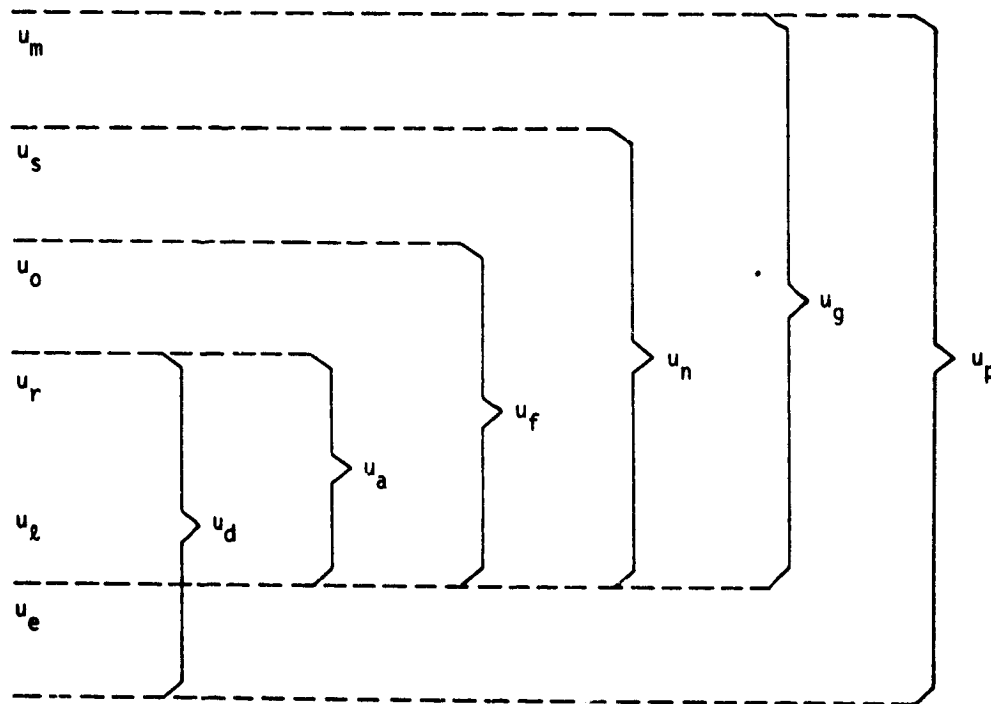
<u><math>n</math></u>	<u>Type of Output</u>
8	Prints matrix and table trailers when they are generated
13	Prints open core length
15	Trace open/close operations on data blocks
21,22	Print degree-of-freedom definitions for all points and all types of constraint sets
23	Print Automatically-generated DMAP ALTER data for substructure problems

The diagnostics referenced above are most commonly used and greatly assist the user in debugging NASTRAN problems. These and all other diagnostics are described in detail in Section 10.2 of the User's Guide.

## OPERATING PRINCIPLES OF NASTRAN

### 13.7.2 Matrix/Vector Degree of Freedom Sets

In NASTRAN, vectors and matrices share the same format. Each row or column corresponds to a single degree of freedom defined as a generalized displacement at a grid, scalar, or extra point. Each degree of freedom,  $u$ , belongs to one or more sets (e.g.,  $u_g$  and  $u_m$ ) as illustrated in the diagram below:



where the sets on the left-hand side are selected by the user as constraints either explicitly on SPC, MPC data or implicitly as subroutine degrees of freedom and left-hand displacement sets are defined in the list below:

- $u_m$  coordinates are eliminated as independent degrees of freedom by multi-point constraints
- $u_s$  coordinates are eliminated by single point constraints

## NASTRAN PROGRAMMING CONVENTIONS

- $u_o$  coordinates are omitted by structural matrix partitioning
- $u_r$  are coordinates to which determinate reactions are applied in static analysis
- $u_l$  are the remaining structural coordinates used in static analysis (points left over)
- $u_e$  are extra degrees of freedom introduced in dynamic analysis to describe control systems, etc.

In static analysis, we are concerned only with the grid point set,  $u_g$ , and its subsets. The application of constraints and partitioning to the stiffness matrix involves, essentially, the elimination of  $u_m$ ,  $u_s$ ,  $u_o$ , and  $u_g$  to form a stiffness matrix,  $k_{ll}$ , with coordinates defined by  $u_l$ .

The physical significances of these computations are explained in Section 3.5 of the Theoretical Manual. The concept of nested vector sets is extremely important in the theoretical development of NASTRAN. The reader may, in fact, find it useful at some point to memorize the relations defined above among the displacement sets.

Load vectors are identified with the same notation. Rectangular matrices are, whenever necessary to clarify the meaning of the symbol, distinguished by double subscripts referring to the vector sets associated with the rows and columns of the array.

In the NASTRAN DMAP, a standard set of names have been given to the various types of matrices. If  $x$  corresponds to the degree-of-freedom set or size, the following list explains the names:

- UxV - Matrix of displacement vectors
- Px - Matrix of load vectors
- Kxx - Stiffness matrix
- Mxx - Mass matrix
- Bxx - Damping matrix
- Gx - Transformation matrix for dependent coordinates, x
- Dx - Rigid body transformation
- Qx - Forces of constraint
- PHIx - Eigenvector matrix
- Uxx - Upper triangular decomposition factor
- Lxx - Lower triangular decomposition factor

For specific information on any data block, refer to Section 2 of the Programmer's Manual.



## OPERATING PRINCIPLES OF NASTRAN

In some cases, additional letters are added to the basic data blank name to denote a special form of the matrix data. The following list defines these key letters:

- Ø - Output data block
- D - Differential stiffness
- L and NL - linear and non-linear
- 1 or 2 - Denotes sort or output data.

### 13.7.3 Error Messages

NASTRAN provides a comprehensive system of error checking to facilitate recovery from error conditions. Section 6.1 of the User's Manual contains a list of all user and system message along with explanations when required. Some useful general comments on the error message system are listed below:

1. Warning Messages - Are issued when a logical discrepancy is encountered, which may be extraneous to the actual problem, and the program may proceed.
2. User Fatal Messages - Are always related to input data errors or serious structure modeling problems when no alternative path is possible. Insufficient time limits or core size may also cause these messages.
3. System Messages - Are intended to occur only when the program code is in error. However, these may occur due to user DMAP changes or after user warning messages have occurred, and the system cannot recover from the bad data.
4. Potentially Fatal Messages - Occur in the DMAP compilation and in substructure problems. These are serious, but not necessarily fatal, errors. Using DMAP, the user may specify these errors to be fatal with the XDMAP control card.

When the cause of a fatal error condition cannot be immediately determined, the user has several recourses. The user should survey the run output for automatically generated informative, warning, or other fatal messages which may help identify the source of the problem. The user should determine from the computer system "day file" which NASTRAN module was in execution at the time of the error. Then he should determine which calculations were being performed on what data. The user will find details of Rigid Format calculation steps in Section 3 of the User's Manual.

## NASTRAN PROGRAMMING CONVENTIONS

If the procedures outlined above do not uncover the source of the problem, the job should be re-run with requests for appropriate additional diagnostic output. This additional diagnostic output should be requested using the DIAG card in the Executive Control deck. Also, DMAP Afters could be included to obtain table and matrix printout of key information which would help identify the problem.

If rerunning the job and evaluation of the new data obtained do not identify the source of the problem, then the error should be reported to COSMIC. Refer to Section 12 of the User's Guide for those procedures.

## 14. ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

### 14.1 INTRODUCTION

An important aspect to using any finite element program is the task of estimating costs and resource requirements to determine feasibility of processing a particular structural model. Because small, simple models usually do not tax the capacity of the computer hardware and they usually do execute economically, the user may be unjustifiably tempted to linearly extrapolate the costs for processing much larger models. Depending on model size and configuration, the user may encounter serious problems with excessive execution times, job turnaround, file space, and overwhelming amounts of printout. The actual costs and resource requirements for a NASTRAN analysis are complex functions of matrix size, density, bandwidth, and available computer resources, and may increase dramatically with problem size and complexity.

Methods used for estimating cost and resource requirements for a NASTRAN analysis are presented in this section. Because detailed explanations of the algorithms and timing equations are given in the Theoretical and Programmer's Manuals, this section is oriented toward presenting more practical working procedures. Included is a summary of critical operations performed in each Rigid Format and timing parameters for estimating these critical steps. Simplified equations are included for estimating CPU time versus problem size and available computer core. Also, methods are presented for estimating other resource requirements, such as file space and tape requirements.

## METHODS FOR PREDICTING NASTRAN COST FACTORS

### 14.2 METHODS FOR PREDICTING NASTRAN COST FACTORS

Several methods are available to the user for predicting cost requirements of a particular structural model executing in a particular type of analysis. Estimates may be based upon experience, tests, and/or detailed examination of the computerized operations. The different methods are further explained in the following paragraphs.

#### 14.2.1 Past NASTRAN Experience

It should be noted that the NASTRAN program is designed to treat large models. However, the sizes of the resulting matrices may exceed the capacity of the more efficient in-core processing algorithms. Therefore, the NASTRAN matrix processing modules also include a necessary "spill" logic to provide for those conditions in which the required segments of matrix data cannot be held in core all at once and must be spilled to periphery storage devices. Thus, whenever this "spill" logic is invoked, there is usually a quantum jump in processing cost due to the extra data transfers to and from periphery storage. Estimating computer run times when spill will occur is a complex process. For this reason, using previous NASTRAN experience, described next, is highly recommended.

If previous NASTRAN models are similar to the problem in question, examination of the old runs will provide valuable insight into the costs of the different aspects of the analysis. A NASTRAN run log is recommended for cataloging pertinent data and costs of previous jobs. This log should include typical parameters such as number and type of elements, matrix sizes and densities, and matrix bandwidths, along with the corresponding execution times of key operations such as EMG, MPYAD, DECOMP, SDCOMP, FBS, and READ, etc. The start and stop time for each of these modules are given in the computer output, called the "Day File." The matrix size parameters may be obtained by including a DIAG 8 card in the Executive Control Deck. However, as mentioned previously, extrapolating run times is dangerous because the timing functions are complex. The run costs of some operations are proportional to the square of some, and to the cube of other size parameters. Also, when the size of the problem requires "spilling," i.e., becomes larger than can be conveniently handled in core, the cost of the additional multiple-pass operations may be several factors larger than those for the in-core run time.

#### 14.2.2 Testing for Cost with NASTRAN

In several critical matrix operations such as multiplication, decomposition, and forward-backward substitution, NASTRAN automatically estimates the CPU time before actually executing

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

the step. If the time limit given on the Executive Control card "TIME" will be exceeded, the program exits with a message containing that time estimate. The user may obtain the NASTRAN-calculated estimate at a small cost by submitting his job with a deliberately low limit on the TIME card. A similar procedure may be used in dynamic analysis when many time steps or frequencies are expected and the cost is known to be proportional to the number of solutions. The user may submit the job for only a small number of steps in order to obtain the actual run time per step and then extrapolating the solution time for the larger job. Note that this procedure will only approximate the cost for eigenvalue extractions using the inverse power method. It would not be valid for the Givens-Householder and Hessenberg methods of eigenvalue extraction.

### 14.2.3 Evaluation of the Computerized Algorithms

When the operational steps within the program and the size and form of the data to be processed are known, the resources required to process these data may be obtained by an analysis of the code algorithms. Fortunately, many of the major operations in NASTRAN have been analyzed for the purpose of automatically performing detailed internal estimates of the central processing time (CPU) in order to protect the user. These equations involve the size and properties of the input matrix data for each step, the available computer core, and the particular timing parameters for each computer. These equations, which are described in the Programmer's Manual, also may be used by the analyst to estimate the required resources and determine feasibility prior to the embarking on the lengthy tasks of preparing and checking the finite element model, its constraints, and the solution processing requirements. The following sections describe how to proceed with these estimating tasks.

## REQUIREMENTS FOR THE RIGID FORMATS

### 14.3 REQUIREMENTS FOR THE RIGID FORMATS

Each type of solution in NASTRAN, or Rigid Format, requires its own characteristic mixture of computer resources. Summarizing all of the calculation steps for each of the Rigid Formats is beyond the scope of this guide. For the interested user, the detailed steps taken for developing and processing of all matrix equations are presented in Section 3 of the User's Manual for every Rigid Format. Some of the specialized operations such as PLA3, PLA4 (Plastic Analysis) are not covered below and would require separate and detailed analysis of the program code.

For most purposes, the more costly operations in the Rigid Formats may be isolated to a few modules. These critical modules are named and the operations they perform are summarized in Table 1. The major calculation modules and subroutines used in each of the Rigid Formats and in the substructure operations are listed in Tables 2 and 3. In the analyses which could involve boundary set changes, nonlinear iterations, or time step changes, groups of operations would be repeated by looping through selected segments of these Rigid Formats. These groups of operations are denoted by underlining of the module names involved in that looping. Available procedures for predicting the running times for most of the operations are given in the subsequent sections.

The matrix size coefficients referenced in Tables 2 and 3 are:

- L: Static matrix size after all constraints and omitted degrees of freedom have been removed
- R: Rigid body support degrees of freedom
- D: Dynamic matrix size = L + extra points
- H: Modal dynamic size = no. of modes + extra points
- NL: Number of loads
- NF: Number of solution frequencies
- A<sub>i</sub>: Substructure matrix size, input to operation
- C: Contributing substructure matrix size
- B: Boundary size for output reduced matrices

#### 14.3.1 Static Condensation and Guyan Reduction

Matrix static condensation and the associated Guyan reduction procedure are provided in all NASTRAN Rigid Formats as a means of reducing the order of the solution matrices. This feature

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

is optional and is selected by use of OMIT or ASET data cards. Reasons for using this feature are presented in the User's Manual, Section 1.4.

The most costly processing steps for static condensation and Guyan reduction are described below. Equations and numerical coefficients to be used for computing CPU running times and core requirements are presented in later sections.

Three major steps are involved in static condensation, and a fourth step is used for Guyan reduction. These steps are:

- 1) SDCOMP (o x o) (Decompose  $K_{oo}$ )

$$[K_{oo}] = [L_{oo}][U_{oo}] \quad (1)$$

where the "o" degrees of freedom are either those unconstrained degrees of freedom specified on the OMIT data cards, or they are those not listed on ASET data cards.

- 2) FBS (o x a) (Solve for matrix  $G_o$ )

$$[L_{oo}][U_{oo}][G_o] = -[K_{oa}] \quad (2)$$

where the "a" degrees of freedom are either those unconstrained degrees of freedom specified on ASET data cards, or they are those associated with points.

- 3) MPYAD (a x o x a) (Solve for reduced stiffness matrix,  $K_{aa}$ )

$$[K_{aa}] = [\bar{K}_{aa}] + [K_{oa}]^T[G_o] \quad (3)$$

- 4) For other matrices (M, B, etc.), the steps for each type are (using the mass matrix as an example):

$$\text{MPYAD (o x o x a), } M_1 = [M_{oo}][G_o] + [M_{oa}] \quad (4)$$

$$\text{MPYAD (a x o x a), } M_2 = [M_{oa}]^T[G_o] + [\bar{M}_{aa}] \quad (5)$$

$$\text{MPYAD (a x o x a), } M_{aa} = [M_2] + [G_o]^T[M_1] \quad (6)$$

## REQUIREMENTS FOR THE RIGID FORMATS

### 14.3.2 Element Matrix Generation

The cost of generating matrix partitions of stiffness, mass, and damping coefficients for the finite elements in NASTRAN is associated primarily with CPU activity and is not significantly affected by core size or I/O transfers. Each of these element matrix partitions is generated in core-held arrays using individually designed algorithms and procedures appropriate to each element type. Because of the differences in algorithms and procedures, the cost of generating matrices for each element depends upon the element type, its configuration, and its properties. For instance, the cost of matrix calculation for the BAR element will increase when pin joints, grid point offsets, and local coordinate systems at the connected points are selected by the user.

Typical execution costs of NASTRAN for the most used element types are shown in Table 4 for various computer models. Note that the costs for some major element options are shown. For different models of computers from the same manufacturer, the costs will be nearly proportional to the outer loop factor, M, described later in Section 14.4. However, note that the element execution times are not proportional to M when comparing costs between manufacturers. This effect is caused by the differences in compilers and utility subroutine efficiencies.



## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

### 14.3.3 Determination of Open Core Size

The actual working core parameter,  $W$ , is dependent on the core allocated by the user, the space used by the necessary portion of NASTRAN, and the type of matrix data. In the sections which follow,  $W$  is defined as the number of matrix terms which may be placed in working core. If  $C$  is the number of core words available, the number of terms is:

$$W = C/p \quad (7)$$

where:

$$p = \begin{cases} 1, & \text{real single precision} \\ 2, & \text{real double precision or} \\ & \text{complex single precision} \\ 4, & \text{complex double precision} \end{cases}$$

For IBM and UNIVAC machines, double-precision arithmetic is normally required and is the default. For CDC hardware, only single precision is supported. For all machines, complex arithmetic is used in the solution and data recovery sections of Rigid Formats 7, 8, 10, and 11, and in the aeroelastic Rigid Formats only.

The exact number of words in open core may be obtained by including a DIAG 13 card in the Executive Control Deck. The requested printout will be included in the "day file" where the total space for open core available to the user is defined for each module. However, each module requires from two to six "buffers" for storing active input/output file data. The number of buffers depends upon the module, the input and output options, and upon the spill activity in large-order problems. The buffer size times the number of buffers required must be subtracted from the available core size to obtain the factor,  $C$ , which is the number of words of working core for storage of matrix data. The user must refer to the Programmer's Manual for explicit buffer requirements for a particular NASTRAN module, e.g., SDCOMP.

## REQUIREMENTS FOR THE RIGID FORMATS

Table 1. Definition of Critical Operations.

APD, AMG, FAI	- Aeroelastic data processing modules
COMPLEX MODES	- Extract general eigenvalues, eigenvectors
DDR1	- Dynamic Data Recovery - Recovers grid point displacements, etc.
DECOMP	- General decomposition for unsymmetric matrices
DSMG	- Differential Stiffness Matrix Generator, similar to EMG
EMG	- Element Matrix Generation
FBS	- Forward/Backward Substitution
MPYAD	- Matrix Multiply - Add
MODES	- Extract Normal Modes (READ module)
PLA3, PLA4	- Piecewise Linear calculation modules
RMG	- Radiation Matrix Generator
SDCOMP	- Symmetric Matrix Decomposition
SSGHT	- Heat transfer statics nonlinear solution generator

ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

Table 2. Critical Operations Versus Rigid Format.

RIGID FORMAT NO.	LOOP FACTORS	CRITICAL CALCULATIONS (NXM) - DENOTES MATRIX SIZE A, B - DENOTES LOOP	MAJOR OPTIONS
1	Constraints	EMG, <u>SDCOMP</u> (LxL), <u>FBS</u> (LxNL)	ØMIT - K
2		EMG, <u>SDCOMP</u> (LxL), <u>FBS</u> (LxR), <u>FBS</u> (LxNL)	ØMIT - K, M
3		EMG, <u>MØDES</u> (AxA)	ØMIT - K, M
4	Load Factors	EMG, <u>SDCOMP</u> (LxL), <u>FBS</u> (Lx1), <u>DSMG</u>	ØMIT - not recommended
5		EMG, <u>SDCOMP</u> (LxL), <u>FBS</u> (Lx1), <u>MØDES</u>	ØMIT - not recommended
6	Load Steps	EMG, <u>SDCOMP</u> (LxL), <u>FBS</u> (Lx1), <u>PLA3</u> , <u>PLA4</u>	ØMIT - not recommended
7		<u>COMPLEX MØDES</u> (DxD)	ØMIT - K, M, B, K4
8	Frequencies	<u>DECOMP</u> (DxD-COMPLEX), <u>FBS</u> (DxNL)	ØMIT - K, M, B, K4
9	Time Step Sizes, Time Steps	<u>DECOMP</u> (DxD), <u>MPYAD</u> (Dx1), <u>FBS</u> (Dx1)	ØMIT - K, M, B, K4
10		<u>MØDES</u> , <u>COMPLEX MØDES</u> (HxH)	ØMIT - K, M
11		<u>MØDES</u> , <u>MPYAD</u> (HxDxNE), <u>DDRT</u>	ØMIT - K, M DMI - Same as RFB (Hsize)
12		<u>MØDES</u> , <u>MPYAD</u> (HxDxNT), <u>DDRT</u>	ØMIT - K, M DMI - Same as RF9 (Hsize)

NOTE: Underlined groups involve looping.

REQUIREMENTS FOR THE RIGID FORMATS

Table 2. Critical Operations Versus Rigid Format (Cont'd).

RIGID FORMAT NO.	LOOP FACTORS	CRITICAL CALCULATIONS (Nxm) - DENOTES MATRIX SIZE A,B - DENOTES LOOP	MAJOR OPTIONS
13		EMG,SDCOMP (LxL), DIMG, M0DES	0MIT - K,KD,M
14	Cyclic Indices	EMG, MPYAD (2LxLxL), MPYAD (2LxLx2L), <u>DECOMP(2Lx2L)</u>	0MIT - K
15		EMG, MPYAD (2LxLxL), MPYAD (2LxLx2L), M0DES	0MIT - K,M
10(AERO)	AERO Factors	EMG, APD, EIGEN, AMG, <u>FAL, COMPLEX, EIGEN</u>	
11(AERO)		EMG, APD, EIGEN, AMG, <u>FAL, COMPLEX, EIGEN</u>	
1(HEAT)		SAME AS RFI	
3(HEAT)		EMG, RMG, <u>DECOMP(1xL)</u> , SSGHT	
9(HEAT)		RF9 + RMG	0MIT = K,B,R

ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

Table 3. Critical Substructure Operations.

Operation	Mathematical Description	Notes
<u>PHASE 1</u>		
	Same as selected Rigid Format without solution step	'RSAVE' avoids later DECOMP
<u>PHASE 2</u>		
COMBINE	$C = \sum H_i^T A_i H_i$	'AUT0' combine requires geometry search
REDUCE	$A \rightarrow B$ $(\theta = A - B)$	User selects matrices to be processed. B points are boundary dof.
MRREDUCE	Same as REDUCE plus mode extraction	8 points include boundary dof plus user-selected modal displacement dof
SOLVE	(See corresponding Rigid Format, g = substructure size)	
RECOVER	For Combined S.S.: MPYAD ( $A_0 \times C_i \times NL$ ) For Reduced S.S.: MPYAD ( $A \times B \times NL$ ) DECOMP ( $\theta \times \theta$ ), FBS ( $\theta \times NL$ )	
<u>PHASE 3</u>		
	Same as Phase 1 except restart is possible to avoid matrix reformulation costs.	

## ESTIMATING CPU TIME REQUIREMENTS

### 14.4 ESTIMATING CPU TIME REQUIREMENTS

In the following sections, numerical methods are given for estimating the central processing unit (CPU) time for the critical NASTRAN calculations. It must be noted that the given equations are based on average problem characteristics and have been determined from simplified code algorithms. Although the coefficients to be used in the equations have been determined empirically from actual hardware tests, their range of accuracy is limited by the range of the tests and the approximate nature of the equations.

The basic matrix timing coefficients for various computer hardware are given in Table 1. The three basic operations listed are:

#### M<sub>L</sub> - Tight Loop Multiply-Add

These values define the time for real arithmetic performed primarily in computer index registers.

#### M - Loose Loop Multiply-Add

These values define the time for real arithmetic performed by FORTRAN code with core data transfers.

#### P - Pack/Unpack for Matrix I/O

These values define the average CPU time to transfer one matrix term with row and column indices to or from a location in the file buffer.

Timing data given in Table 1 correspond to the default computer arithmetic precision selected by NASTRAN. All CDC system times are for single-precision operations. The timing data for the other machines correspond to double precision, the normal default. If a different precision is used in a key arithmetic operation, the coefficients should be adjusted accordingly.

The standard nomenclature used in NASTRAN timing calculations is given in Table 2. These terms are used in the basic timing procedures and equations which follow.

#### 14.4.1 Matrix Multiplication and Addition - MPYAD

Four separate methods are used by NASTRAN for multiplication of matrix data blocks. Three methods are used by the MPYAD module for computing the product of two matrices and adding a

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

third ( $A \cdot B \cdot C$ ). Additionally, the MPY3 module is provided for the specialized "triple multiply" operation ( $H^T A H$ ), frequently encountered in substructure analysis.

In the MPYAD module, the estimated running time for each of the three alternatives is calculated and the fastest method is selected by the program. The choice taken will depend on the relative sizes and densities of the input matrices and the amount of computer core available. Figure 1 provides approximate equations for the three MPYAD methods. Note that it is the time to multiply which predominates. The time to add is negligible by comparison. Large-order matrices with ranges in density of from 10 percent to 50 percent are assumed. For the more detailed equations, consult Section 3.5.12 of the NASTRAN Programmer's Manual.

### 14.4.2 Symmetric Triangular Decomposition (SDCOMP)

A sparse matrix Gaussian elimination method is used in NASTRAN for triangular decomposition of symmetric matrices. This method does not require so-called "banded matrices" to realize efficient processing. In effect, the method uses a variable length band, processing only the "active columns," in which non-zero terms occur. Full details on the computational algorithms are given in Section 4.7 of the Programmer's Manual. Also note that the rarely used "passive columns" effects are deleted in the method shown below.

Figure 2 illustrates the method used for calculating the "active column" size for each row of a matrix. The characters "X" signify non-zero, off-diagonal partitions of the input matrix. Typically, each X may represent six degrees of freedom or one grid point in the model. During the decomposition, the non-zero terms create additional terms in the rows below. The resulting region defined by the dashed lines will be completely populated in the resultant triangular factor. The number of active columns at each row is measured by counting the columns inside the dashed regions for that row. The algorithm described below may be used to calculate the CPU time for the in-core process. This is followed by a method for estimating the out-of-core execution time which involves "spill logic."

#### Symmetric Decomposition in Core

The steps used for calculating execution time are:

1. Calculate or estimate the active column factor  $C_i$  for each row  $i$ .

## ESTIMATING CPU TIME REQUIREMENTS

2. Calculate the maximum value  $C_{\max}$ , the average value  $C_{\text{avg}}$ , and the RMS value  $\bar{C}$ , where:

$$\bar{C}^2 = \frac{1}{N} \sum_i C_i^2 \quad (1)$$

$$C_{\text{avg}} = \frac{1}{N} \sum_i C_i \quad (2)$$

and  $N$  is the order of the matrix.

3. Determine if matrix spill logic is required. No spill occurs when the following condition is met:

$$W > \frac{1}{2} C_{\max} (C_{\max} + 3) \quad (3)$$

4. If no spill occurs, the timing equation is:

$$T = \frac{1}{2} M_x \bar{C}^2 N + P C_{\text{avg}} N \quad (4)$$

Note that the second term may usually be ignored.

Note that the example in Figure 2 shows a poorly banded matrix having a significant number of widely spaced coupling terms. However, examining the number of active columns listed down the right side of the figure, we observe that the actual value of  $\bar{C}$  is only about  $7D$ , where  $D$  is the number of active columns per partition  $X$ . By using the active column technique of decomposition, the running time would be comparable to a banded matrix with  $B = 7D$ .

### 14.4.3 Symmetric Decomposition with Spill

When the matrix decomposition process requires spill logic to compensate for limited core storage, scratch files are used for temporary out-of-core storage of results. The non-zero matrix terms shown in Figure 3 are subdivided into core-sized partitions, or "spill groups," which are spilled to and read back into core from these scratch files as necessary to finish the processing. Note that once a group is spilled, each row of that group is then treated separately and, as such, is read back in only if it is required for calculations involved in processing a subsequent group when it occupies core.



## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

The actual spill logic in the NASTRAN symmetric decomposition routines is very complex, and no single equation is adequate for estimating the resource requirements. A recommended procedure for large-order problems is to submit the job with a deliberately low estimate on the NASTRAN "TIME" card of the Executive Control Deck. The SDCOMP routine will perform the time and core requirement calculations, print the pertinent decomposition parameters, and exit due to the low user-specified time limit. However, this recommendation requires full development of the solution matrices, which may be expensive. Therefore, an approximate method is given below which will aid in preliminary estimation.

1. Horizontally subdivide the non-zero partitions of the matrix into spill groups which would fit in available core. Figure 3 illustrates the method using a banded matrix for simplicity. The number of rows for each spill group,  $S_i$ , is chosen such that:

$$\frac{S_i}{2} (2C_i - S_i) + 2C_i < W \quad (5)$$

where  $W$  is the total number of terms which may fit into core. The shaded area in Figure 3 corresponds to the available core space. Incidentally, note that  $S_i$  is less than  $C_i$  if spill logic is required.

2. For each row in a spill group, determine the number of groups below that spill group which are affected by that row. This determines the number of passes,  $N_{pi}$ , required for reading that row in from storage. Note that each row in a spill group may have to be treated separately. In the example, the first set of short rows in Group 1 will be processed with two passes, once when processing Group 2 and once when processing Group 3. The long rows forming the second part of Group 1 will require three passes since it affects three groups below, Groups 2, 3, and 4.
3. The additional CPU time required for the spill processing is approximately the following value:

$$T_s = \sum_i^N 2^P C_i N_{pi} \quad (6)$$

where  $P$  is the average coefficient of the pack and unpack time,  $C_i$  is the number of active columns for each row, and  $N_{pi}$  is the number of spill passes required to be performed on row  $i$ . Add  $T_s$  to the estimated time manually required for decomposition without spill logic.

## ESTIMATING CPU TIME REQUIREMENTS

### 14.4.4 Forward-Backward Substitution - FBS, GFBS

Forward-Backward Substitution is the second step of the general solution of simultaneous equations. It follows the decomposition of a matrix described above. The FBS module performs these operations for decomposed symmetric matrices, whereas the GFBS (General FBS) module is used when the decomposed matrix is nonsymmetric. Each is discussed separately below. The basic matrix equation of both the backward and the forward substitution steps is:

$$[U_{nn}][X_{np}] = [Y_{np}] \quad (7)$$

where  $[U]$  is the upper triangular matrix resulting from decomposition,  $[Y]$  is given, and  $[X]$  is to be determined as the matrix of  $P$  solution vectors, each  $n$  rows long.

For the symmetric code, the parameter  $C_{avg}$  for the average number of active columns is obtained from the same estimate used for symmetric decomposition. The FBS time is:

$$T_{FBS} = 2npM_l C_{avg} + P(2nC_{avg} + \frac{np}{2}) K_f \quad (8)$$

where  $K_f \sim np/W$ .  $K_f$  is the integer number of passes, where one "pass" is required for each core-held partition of the matrix  $Y$ .

For the unsymmetric code, the bandwidth  $B$ , the column size  $C$  of the upper triangular factors may be different from those of the lower factor ( $\bar{B}$  and  $\bar{C}$ ). Combining the two passes (the forward and backward substitution steps), we obtain the following equation:

$$T_{FBS} = npM_l(B + \bar{B} + C + \bar{C}) + nP(B + \bar{B} + \bar{C} + C + \frac{P}{2})K_f \quad (9)$$

where  $K_f \sim np/W$ .  $K_f$  is the integer number of passes where one pass is required for each core-held partition of matrix  $Y$ .

### 14.4.5 Mode Extraction (Module READ)

Four alternate methods of extracting normal modes are available in NASTRAN. Although the inputs and outputs from the calculation are nearly identical, the internal operations and the time and core requirements differ considerably. The methods of estimating the requirements for each of the four methods are described separately below:

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

- 1) Givens - Householder (GIV) with QR Transforms - This process requires a Cholesky decomposition of the mass (or differential stiffness) matrix. In most cases, the OMIT (or ASET) procedure must be used to remove massless components and may be used to reduce the matrix to core-held size, in which case the execution times for computing the manual modes of the resulting matrices are relatively short. However, note that the execution times to obtain these final reduced size matrices may be quite significant. When the size of the input dimension, N, becomes too large for the final matrices to fit in core (i.e.,  $(N(N+1)/2 > W)$ ), the execution time requirements increase significantly due to spill. The following calculation steps are performed for Givens eigenvalue extraction:

- a) Use SDCOMP on the mass matrix (order = N), perform an FBS to invert the triangular factor, and use MPYAD to pre- and post-multiply the stiffness matrix to obtain the dynamic matrix. Estimating equations for these steps have been given earlier (refer to Theoretical Manual, Section 9.2).
- b) Tridiagonalize the dynamic matrix with a CPU time for execution of approximately

$$T_{TD} = 4/3 M \cdot N^3 + 1/2 PNWK, \quad (10)$$

where 
$$K = \left\{ \left( 1/2 \frac{N(N+1)}{W} - 1 \right) \right\}, (K \geq 0) \quad (11)$$

and the term in brackets is rounded up.

- c) Inverse transform the resulting  $N_V$  eigenvectors to physical coordinates. This requires a CPU time ( $T_V$ ) of approximately

$$T_V = 3MN^3 N_V \quad (12)$$

- 2) Inverse Power with Shifts (INV) - In the inverse power method, the normal modes (eigenvectors) are obtained indirectly through an iteration process. The matrices are decomposed into triangular factors at "shift points," each of which may be used to extract several eigenvectors. Each eigenvector requires an approximate average of six FBS steps and six matrix multiplies with a single column right-hand matrix. For estimating the running time:

## ESTIMATING CPU TIME REQUIREMENTS

- a) Calculate the SDCOMP time,  $T_D$ , for decomposing the sum of the stiffness and mass matrix. Calculate the FBS and MPYAD time,  $T_{FM}$ , for a single column. See the other parts of this section for the appropriate estimating algorithms.
- b) The total time estimate,  $T$ , would then be approximated by the equation:

$$T = T_D(N_V/3) + 6T_{FM} \cdot N_V \quad (13)$$

where  $N_V$  is the expected number of eigenvectors to be extracted. Note that these estimates are obtained from experience with well-behaved systems. When closely grouped frequencies occur or a poor initial estimate of a region is chosen, more iterations may be required and/or extra start points may have to be considered. All of these will require an increase in the above estimate.

- 3) FEER Method - No accurate methods are currently available for estimating the running time for this method. However, tests indicate it is faster than the inverse power method.
- 4) Determinant Method (DET) - This method iterates to an eigenvalue by fitting curves through the matrix determinant at trial eigenvalues. Because of its inherent inefficiencies, the DET option is not recommended for general use. The only reason for its existence is for checking results from the other methods.

ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

Table 1. Timing Parameters for Typical Computers.

MAKE	IBM 360/			IBM 370/			CDC	CYBER	UNIVAC								
MODEL	50	65.7	75	85	91.5	155	158	165	168	195	6400	6600	173	175	176	1108	1110
CONFIG.	3	4	5	6	2	11	12	10	13	9	10	4	16	18	19	3	20
M <sub>1</sub>	100	20	12	2	0.9	25	9.5	1.8	1.7	0.3	15	5	8	2.7	1.2	14	
M	250	50	30	5	2.5	60	14	2.5	2.2	2.0	36	10	12	4.3	1.9	35	
P	500	160	100	50	36	145	60	30	20	36	110	53	65	27	7	60	

## ESTIMATING CPU TIME REQUIREMENTS

Table 2. Nomenclature for Timing Equations.

T	- CPU time
N	- Order of square matrix
$\bar{C}$	- RMS average of number of active columns
$C_{avg}$	- Simple average of number of active columns
W	- Effective core space (number of open core cards/number of words per matrix terms)
$M_t$	- Tight loop multiply time coefficient
M	- Loose loop multiply time coefficient
P	- Pack/Unpack coefficient for matrix I/O
B, $\bar{B}$	- Bandwidths for unsymmetric decomposition
n, m, p	- Matrix dimensions for MPYAD
K	- Number of passes for spill processing
$\rho_A, \rho_B$	- Density of matrices A and B

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

MATRIX PROBLEM:  $[A(m \times n)] \times [B(n \times p)] = [C]$

or

$$[A(n \times m)]^T \times [B(n \times p)] = [C]$$

METHOD 1 (Holds unpacked parts of band C in core)

$$T = M_L \rho_A mnp + P \rho_A mnk_1$$

where

$$k_1 \geq \frac{(m+n)p}{W}$$

$k_1$  is the integer number of passes in reading the A matrix.

METHOD 2 (Holds packed parts of A in core)

$$T = (M + M_L) \rho_A mnp + P(np + mp) K_2$$

where

$$K_2 \geq \frac{2\rho_A mn}{W}$$

$K_2$  is the integer number of passes in reading the B and C matrices.

METHOD 3 (Sparse B Matrix, Transpose Case Only)

$$T = M_L \rho_B mnp + P \rho_B (np + mp) K_2$$

Figure 1. Approximate Timing Equations for MPYAD.

# ESTIMATING CPU TIME REQUIREMENTS

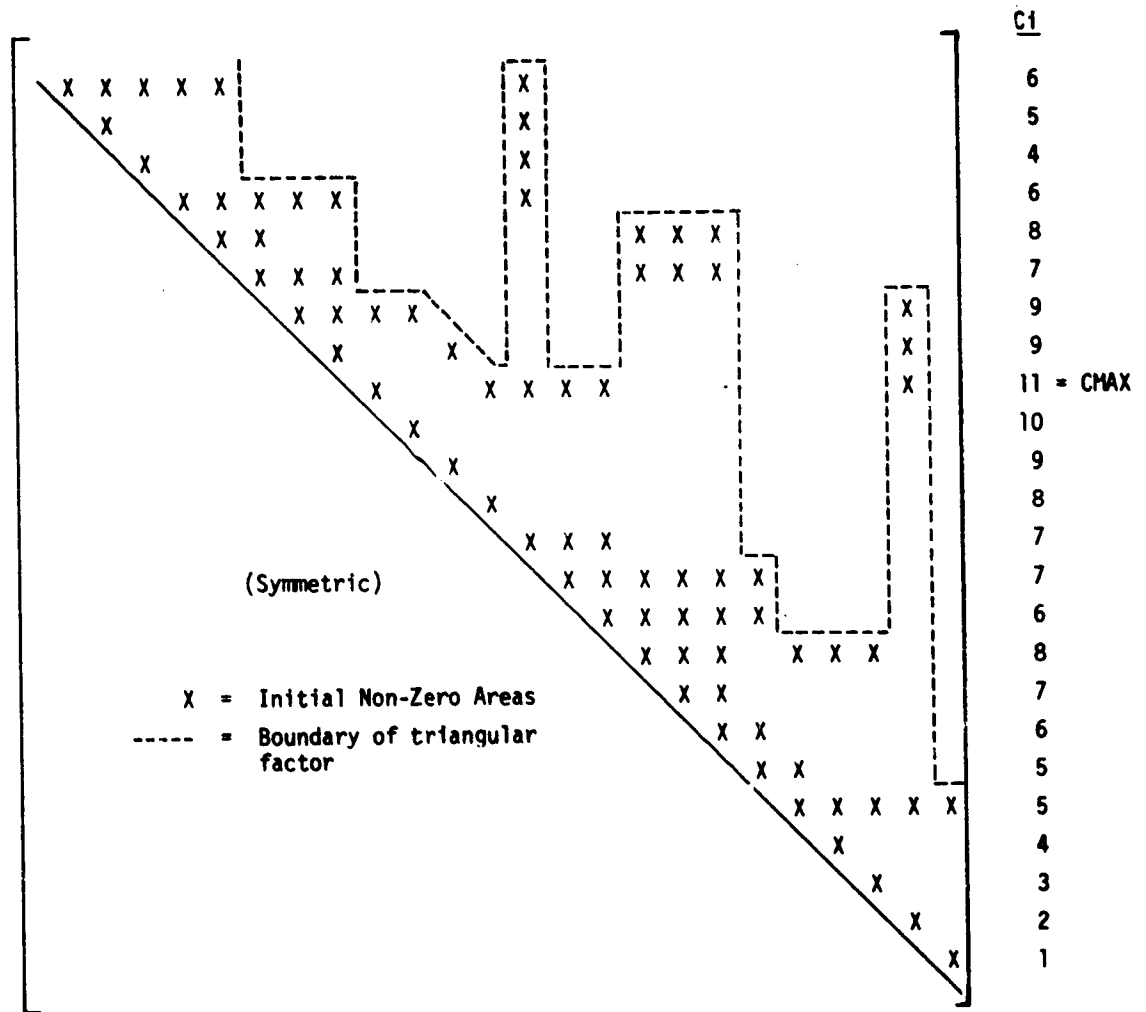


Figure 2. Region of Matrix Affected by Symmetric Decomposition.



ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

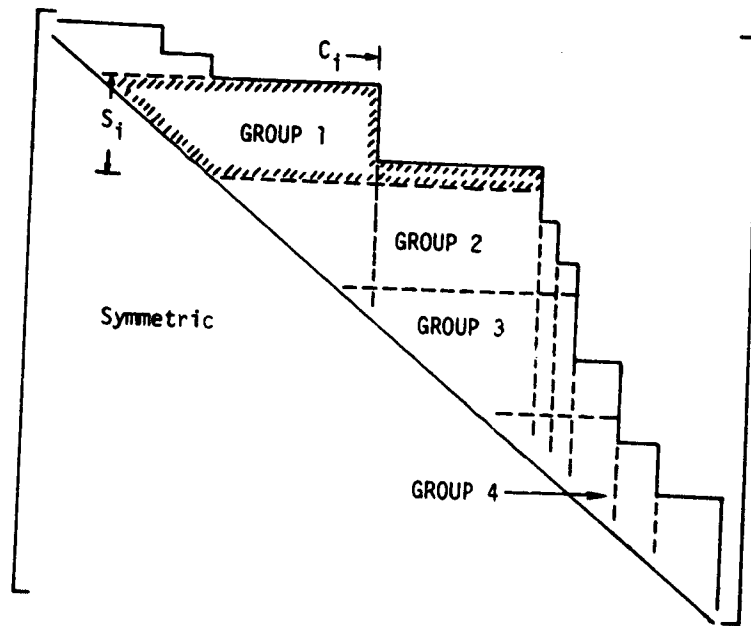


Figure 3. Subdividing Symmetric Upper Triangular Matrix Partition into "Spill Groups."

## ESTIMATING OTHER HARDWARE REQUIREMENTS

### 14.5 ESTIMATING OTHER HARDWARE REQUIREMENTS

In addition to the CPU time requirements previously derived, many other cost factors are involved in estimating the overall expense of a NASTRAN analysis. These factors range from the hardware costs of printing and plotting the results to the very significant costs of the engineering effort necessary to model the structure. Estimating the labor costs of performing an analysis is a major subject far beyond the scope of this guide. This section, therefore, deals only with other hardware factors which include I/O charges, tape mounts, and permanent file requirements. Because many of these items are highly dependent on the operating systems or installation facilities, additional information may be required by the user, which must be obtained from his local computing facility.

#### 14.5.1 Input/Output Data File Factors

In NASTRAN, most of the intermediate data storage is placed on scratch, bulk storage files which may be repeatedly accessed during the job execution. On most modern hardware, the actual cost for this process is billed in addition to the CPU costs, and defined as the local "I/O" cost.

Several different methods are used by the computer operating systems to charge the user for this I/O activity. Some of these are:

- 1) Charges for the total number of words or bits of data transferred through the I/O hardware.
- 2) Charges for the total file space requested and/or used by the program.
- 3) Charges for the number of calls to the peripheral processor (PP) routines which control the I/O operations.
- 4) Charge for the total actual clock time, which, on some systems may be the primary cost factor.

Many operating systems use a combination of the above factors in calculating system resource units or equivalent cost units for I/O activities. In NASTRAN, all of these activities tend to increase directly with model size, and their costs tend to be proportional to CPU costs. However, unlike the CPU charges, the user may modify the I/O costs by changing NASTRAN parameters or procedures. Some of his options are:

## ESTIMATING RESOURCE REQUIREMENTS FOR NASTRAN

- 1) If the system charges are primarily for I/O routine calls as in (3) above, the buffer size parameter, BUFSIZE, defined on the NASTRAN card, may be increased to increase the amount of data transferred in each I/O call, which reduces the number of calls required. See Section 2.1 of the User's Manual for details. However, note that the increased buffer space will correspondingly decrease the core space available for computation which, in turn, could affect the CPU cost.
- 2) If the system charges are primarily for the amount of data storage, as in (1) above, and the problem size is small, the BUFSIZE parameter may be decreased. This will reduce the space taken up by nearly empty blocks of data on the file and will give the program more useable core space.
- 3) On IBM hardware, the size and number of working files is controlled by the Job Control Deck. Although the standard NASTRAN setup is designed for efficiency in a normal analysis, the number and sizes of these files can be expanded or contracted for unusual cases. On other hardware, the number and size of the files are controlled by the program.
- 4) With very large structural matrices, the checkpoint file may become very large. In many cases, much of the data stored on this file will not be used in scheduled restarts. A suggested procedure is to run a small pilot model through the entire procedure and note which checkpoint files are necessary for the restart. The DMAP ALTER feature may be used to eliminate the unnecessary checkpoint instructions to reduce the size of the checkpoint file.

It should be noted that all of the above procedures are recommended only for the experienced NASTRAN user. Some experimentation with pilot runs may be necessary to check out and validate the particular combination of operating system changes and NASTRAN analysis modifications selected by the user.

### 14.5.2 Tape and Permanent File Requirements

The NASTRAN user may employ several options to archive data on bulk storage devices for subsequent jobs. These include using the checkpoint procedures or the OUTPUT1 modules which write user tapes. Since these user tapes generally contain only single matrices or block data, their size requirements are not crucial. However, some care may be necessary in the use of the

## ESTIMATING OTHER HARDWARE REQUIREMENTS

checkpoint procedures which are initiated with the Executive Control Deck CHKPØINT command. The ØUTPUTØ modules are called into service with DMAP alters input also via the Executive Control Deck.

The NASTRAN checkpoint/restart procedures may employ system permanent files, private disk packs, or physical tapes for the NPTP (New Problem Tape). The NPTP file is a single file which could easily exceed the space available on a single tape or disk pack. The user is cautioned to check with his computer center operations to obtain procedures for specifying multi-unit files for checkpoint runs on any large-order structural problems.

### 14.5.3 Substructure Operating File (SØF) Requirements

In the automated multi-stage substructure system (AMSS), a data base file system is used to store all data required for solving problems with substructuring. The Substructure Operating file (SØF) is a single random access data base which may reside on from one to ten system files. New files may be added to store the SØF as the data base grows, but the maximum size of each file must be specified on the run in which the file is first used. File size resources for each new substructure that is to be added to the data base are estimated based on the expected size of the corresponding NASTRAN data block to be stored. Each substructure will require storage of basic structural data including the stiffness matrix, with options for the mass, load, damping, and solution matrices. In addition, transformation matrix (HØRG) is required for each substructure which contributes to a higher level combination structure or to a reduced structure. The system automatically reports the space available on the SØF.

Several options are given in the system to maintain and control SØF file space. At each stage of the process, the space used currently and the unused space available are printed automatically. Additional files may be attached at any stage to provide more space for storage of the SØF. Finally, unused substructure data or data no longer required for subsequent operations may be deleted or edited from the files by the user in order to make that space available for future operations.

## 15. DIRECT MATRIX ABSTRACTION PROGRAM (DMAP)

### 15.1 DMAP OVERVIEW

DMAP is the "programming language" of NASTRAN which controls the execution logic and sequence of the NASTRAN program operations. Each DMAP instruction causes a block (module) of NASTRAN code to be executed, and each Rigid Format is simply a sequence of DMAP instructions permanently stored in NASTRAN. The user may code and execute a DMAP sequence in place of a Rigid Format. He may also make changes to the Rigid Formats through the use of ALTER and DMAP data. In either case, these instructions are always included in the Executive Control Deck (UG 6).

The format and detailed usage of the user-oriented DMAP instructions are described in Section 5 of the User's Manual. NASTRAN modules are described in Section 4 of the Programmer's Manual. The types of tasks which can be performed by NASTRAN using DMAP instructions fall into the following categories.

1. Executive, e.g., jump, checkpoint, equivalence files, exit (UM 5.3.4).
2. Utility, e.g., print or copy files, manipulate parameters (UM 5.3.2).
3. Matrix Arithmetic, e.g., add, multiply, transpose matrices (UM 5.3.1).
4. Structural, e.g., assemble tables, calculate element data (PM 4).

The first three categories are intended for general user applications. However, the structural oriented modules require specialized input tables and are intended for use in the Rigid Formats. In addition, several dummy modules have been implemented in NASTRAN for which the user may implement his own code (PM 6.7 and 6.12).

The next section presents a guide to the rules governing the use of DMAP instructions in NASTRAN. This is followed by a description with illustrative examples using each of the four categories of operations defined above.

## FUNDAMENTAL DMAP RULES

### 15.2 FUNDAMENTAL DMAP RULES

The DMAP code may be viewed as a program in which the variables are data blocks residing on I/O devices and simple parameters which remain in core. The DMAP module instructions are equivalent to subroutine calls in which the user selects the input and output variables and the subroutine performs a predefined operation. The general format for a module instruction is:

```
MODULE IN1, IN2, ... /OUT1, OUT2, ... /param 1/param 2/ .....$
```

where MODULE is the name of the operation, IN1, IN2, etc., are user-selected names of input data blocks, OUT1, OUT2, etc., are names of output data blocks, and param 1, param 2, are fields used for defining the parameters. As in a FORTRAN subroutine, the number of variables and their order in a module instruction are important.

The input and output data block names are chosen arbitrarily; their position in the instruction provides the instructions to the module. Guidelines for data block specification are:

1. Blank fields or two successive commas indicate a "purged" data block. The module specifications indicate where purged data blocks are legal.
2. Data blocks must reside on distinct files, i.e., the names are distinct and not equivalenced.
3. Input data blocks should be logically available as output from previous modules, as outputs from the preface, or as checkpointed data blocks on a restart run.

The parameter fields in the DMAP instructions may take several forms. Examples are listed below:

/(blank)/ or dropped from end - The module's default value is used.

/VAR/ or /V, N,VAR/ - VAR is a variable input parameter name.

/23.2/ or /C,N,23.2/ - An input constant, 23.2 is specified.

/VAR=16/ or /V,N,VAR=16/ - The variable VAR is given an input value if not previously set.

/V,S,LUSET/ - The output parameter LUSET is saved.

The types of constants used in the parameter fields are specified in the module descriptions and must be consistent. The types of constants used are integers, real numbers, complex numbers, and BCD flags.

## EXECUTIVE OPERATIONS

### 15.3 EXECUTIVE OPERATIONS

The formats for the Executive instructions are less restrictive than the functional modules. The input and output data block fields may be missing and parameters are specified with only the variable name. Executive Operations instructions or statements are divided into general categories as follows:

1. Declarative instructions FILE, BEGIN, and LABEL which aid the DMAP compiler and the file allocator.
2. Instructions CHKPNT, EQUIV, PURGE and SAVE which aid The NASTRAN executive system in allocating files, interfacing between functional modules and in restarting a problem.
3. Control instructions REPT, JUMP, COND, EXIT, and END which control the order in which DMAP instructions are executed.

The rules associated with the Executive Operations instructions are distinct for each instruction and are discussed individually in Section 5.7 of the User's Manual.

Some examples of executive module formats are:

BEGIN - Define start of DMAP  
LABEL LBL1 - Provide a label for jumps, etc.  
COND LBL2, PARAM - Conditional jump to label LBL2  
EQUIV DB1, DB2/PARAM - Equivalence two data blocks  
CHKPNT DB1, DB2, DB3 - Write data blocks on checkpoint file  
EXIT - Stop the program

The example that follows is most useful for those situations which call for controlling the partial execution of a Rigid Format. The subsequent sections present additional examples of execution operations.

DIRECT MATRIX ABSTRACTION PROGRAM (DMAP)

Example 1 - Partial Execution of Rigid Format 1

Alter Rigid Format 1 (Static Analysis) to stop execution after plotting the undeformed structure.

```

Card
No.
1      ID      EXAMPLE1,MODES
2      APP     DISP
3      SOL     1,0
4      TIME    2
5      ALTER   17 }
6      EXIT    $  }
7      ENDALTER
8      CEND
9      TITLE = DMAP EXAMPLE 1
10     PLOTID = MODEL DESIGN CHECK
11     OUTPUT (PLOT)
12     SET 1 ALL
13     FIND SET 1
14     PLOT
15     BEGIN BULK
    
```

BULK DATA FIELD

	1	2	3	4	5	6	7	8	9	10
16	CONROD	1	1	2	1	1.0				
17	CONROD	2	2	3	1	1.0				
18	GRID	1		0.0	0.0	0.0		123456		
19	GRID	2		1.0	1.0	0.0		3456		
20	GRID	3		2.0	0.0	0.0		123456		
21	MAT1	1	3.+7							
22	ENDDATA									

- NOTES ON CARDS:
2. Use displacement approach.
  3. Use Rigid Format 1.
  5. Insert the immediately following DMAP instruction(s) after Line 17 of the Rigid Format identified by the SOL card (UM 2.3.1).
  6. NASTRAN will execute the Rigid Format up to the point where it encounters "EXIT" where it will terminate.
  7. End of Rigid Format alters.



## UTILITY OPERATIONS

### 15.4 UTILITY OPERATIONS

The Utility Operation instruction (User's Manual 5.3.2) can be divided into general categories as follows:

1. Read and write of user tapes (e.g., INPUT, INPUT1, OUTPUT1)
2. Matrix and table printout (e.g., MATGPR, MATPRN, MATPRT, TABPRT, TABPT)
3. Manipulate parameters (e.g., PARAM, PRTPARM, SETVAL)
4. Display matrix topology (e.g., SEEMAT)
5. Generate partitioning vectors (e.g., VEC)

These utilities are particularly helpful for debugging a structural model as well as for checking out new routines developed by a user. Also, when external programs are to be used for data preparation for input to NASTRAN, or for post processing the results obtained from NASTRAN, these utilities facilitate the transmission of the data (User's Guide, Section 9). Examples of these utilities are presented below and in subsequent sections.

## DIRECT MATRIX ABSTRACTION PROGRAM (DMAP)

### Example 2 - Printout of Table Data

Alter Rigid Format 1 (Static Analysis) to print the grid point coordinates in the basic coordinate system.

Card No.		
1	ID	EXAMPLE2,BGPDT
2	APP	DISP
3	SOL	1,0
4	TIME	3
5	ALTER	5
6	TABPT	BGPDT,...//\$
7	ENDALTER	
8	CEND	
9	TITLE	= DMAP EXAMPLE 2
10	BEGIN BULK	

#### BULK DATA FIELD

	1	2	3	4	5	6	7	8	9	10
11	CONROD	1	1	2	1	1.				
12	CONROD	2	2	3	1	1.				
13	GRID	1		.0	.0	.0		123456		
14	GRID	2		1.	1.	0.		3456		
15	GRID	3		2.	0.	0.		123456		
16	MAT1	1	3.E+7							
17	ENDDATA									

- NOTES ON CARDS:
2. Use displacement approach.
  3. Use Rigid Format 1.
  5. Insert the immediately following DMAP instruction(s) after Line 5 of the Rigid Format identified by the SOL card.
  6. Print the Basic Grid Point Data Table (PM 2.3.3.5).
  7. End of Rigid Format alters.

## UTILITY OPERATIONS

### Example 3 - Write User Tape and Printout Intermediate Matrix

The following illustrates the writing of a user tape via FORTRAN for use in subsequent processing outside NASTRAN. The matrix data represents the mode shapes for the reduced set ( $u_a$ ) of dynamic degrees of freedom (Theoretical Manual, Section 9.3.1) computed with Rigid Format 3 (User's Manual 3.4.1).

<u>Card No.</u>	
1	ID EXAMPLE3,TEST2
2	APP DISP
3	TIME 10
4	SOL 3,1
5	ALTER 91
6	OUTPUT2 PHIA,.,.,./-1/11/C,N,TEST2 \$
7	OUTPUT2, .,.,./-9/11 \$
8	MATGPR GPL,USET,SIL,PHIA//C,N,FE/C,N,A \$
9	ENDALTER
10	CEND
11	TITLE = B0X3 FRAME
12	SPC = 12
13	METHOD = 3
14	DISP = ALL
15	PL0TID = MODE SHAPES WITHOUT EQUIPMENT
16	OUTPUT(PL0T)
17	SET 1 = ALL
18	VIEW 34., 30., 0.
19	MAXIMUM DEFORMATION 12.0
20	FIND SCALE
21	PL0T MODAL DEFORMATIONS 0, SET 1 SYMBOLS 2, SHAPE
22	BEGIN BULK
	⋮
23	ENDDATA

## DIRECT MATRIX ABSTRACTION PROGRAM (DMAP)

- NOTES ON CARDS:
4. Requests execution of Normal Modes Analysis.
  5. Insert following alter package following DMAP instruction 91, Rigid Format 3.
  6. Requests output via FORTRAN of the mode shapes for displacement set  $u_a$  to user tape on FORTRAN Unit 11 after rewinding and writing the NASTRAN label TEST2. (See UG 10 for FORTRAN unit assignments.)
  7. Writes final end of file (EOF) on the tape. Note that the first comma is required as a delimiter when the first field is blank.
  8. Requests printout of the same mode shape matrix for all modes generated (Number of modes is FE, Degrees of Freedom Set is A).
  9. Concludes the alter package.
  10. Concludes the Executive Control Deck.
  - 11-21. Case Control deck which specifies the constraint set, selects from Bulk Data the method of eigenvalues extraction, requests printing of the mode shapes for all grid points and directs the structural plotter package to plot all mode shapes underlaid by the undeformed plot of the model using all elements.
  - 22-23. Contain the Bulk Data Deck for the model which would include either OMIT or ASET data to reduce problem size via Guyan reduction to the desired displacement set  $u_a$ .

## MATRIX OPERATIONS

### 15.5 MATRIX OPERATIONS

The Matrix Operation instructions (User's Manual 5.3.1) include the basic functions of adding, multiplying, partitioning, merging, transposing and solving matrix equations with single and double precision, real or complex data. These DMAP instructions may be used to process any matrix data generated by NASTRAN or input to NASTRAN from outside sources via the user tape facilities.

#### Examples 4 - Processing with User Supplied Matrices

The following example illustrates a complete DMAP sequence for reading two matrices from user tape, adding them together and printing the results.

Card No.		
1	ID	EXAMPLE4,ADD
2	APP	DMAP
3	TIME	5
4	BEGIN	\$
5	INPUT2	/MTXA,MTXB,..,-1/15/*B9U* \$
6	ADD	MTXA,MTXB/MTXSUM/ \$
7	MATPRN	MTXA,MTXB,MTXSUM,..// \$
8	END	\$
9	CEND	
10	BEGIN BULK	
	:	
11	ENDDATA	

#### NOTES ON CARDS:

2. Defines DMAP approach.
4. Initiates input of user specified DMAP sequence.
5. Reads in two matrices (MTXA and MTXB) from user tape on FORTRAN Unit 15 which were written via FORTRAN by a program external to NASTRAN. (Note, this tape could also be written with NASTRAN using OUTPUT2 (UG 7.3.2.2) NASTRAN tape label B9U is used for positive identification.
6. Add the two matrices to form MTXSUM.
7. Printout all three matrices.
8. Terminates DMAP sequence.
9. Terminates Executive Control Deck.
- 10-11. Case Control Deck is empty except for initiation of the Bulk Data Deck which should contain at least one Bulk Data Card (e.g., DMI card with null data and the ENDDATA card required to terminate the NASTRAN input stream.

## STRUCTURAL OPERATIONS

### 15.6 STRUCTURAL OPERATIONS

The Structural Operation instructions (Programmer's Manual, Section 4) include all the basic functions for solving structural problems. These include processing of basic input data, generation and assembly of element and user specified stiffness, mass, damping and load matrices, execution of static and dynamic analyses and data recovery. The modules called by these DMAP instructions may in turn call the utility matrix operation subroutines as required to process the data.

The best examples of use of the Structural Operation DMAP instructions are the Rigid Formats themselves. A simple application is illustrated below. For more complex applications, see the Substructuring sample input in this Guide, Section 20. Additional examples are given in the User's Manual, Section 5.4.

#### Example 5 - Replace Program Generated Data with User Data

This example illustrates an alter to Rigid Format 3 (Normal Mode Analysis) so that a mass matrix input on DMIG Bulk Data cards is used in place of the NASTRAN generated mass matrix.

DIR / MATRIX ABSTRACTION PROGRAM (DMAP)

Card  
No.

1 ID EXAMPLE5,DMIG  
 2 APP DISP  
 3 TIME 2  
 4 SOL 3,0  
 5 ALTER 28,28  
 6 MTRXIN, MATPOOL,EQEXIN,SIL, /MFRMDMI/, /, /LUSET/NOMGG/O/O  
 7 ENDALTER  
 8 ALTER 30  
 9 EQUIV MFRMDMI,MGG/ \$  
 10 ENDALTER  
 11 CEND  
 12 TITLE = DMAP ALTER, EXAMPLE5  
 13 METHOD = 10  
 14 DISP = ALL  
 15 BEGIN BULK

BULK DATA FIELD

	1	2	3	4	5	6	7	8	9	10
16	CONROD	1	1	2	1	1.0				
17	CONROD	2	2	3	1	1.0				
18	DMIG	MFRMDMI	0	6	1	2				
19	DMIG	MFRMDMI	2	1		2	1	1.5+3		
20	DMIG	MFRMDMI	2	2		2	2	1.5+3		
21	EIGR	10	GIV				2			+EIG10
22	+EIG10	MAX								
23	GRID	1		0.0	0.0	0.0		123456		
24	GRID	2		1.0	1.0	0.0		3456		
25	GRID	3		2.0	0.0	0.0		123456		
26	MAT1	1								
27	ENDDATA		3.+7							

- NOTES ON CARDS:
2. Use displacement approach.
  3. Select Rigid Format.
  5. Replace line 28 of Rigid Format 3 (UM 3.4.1) with the following DMAP alter.
  6. Use the structural operation MTRXIN (PM 4.57) to replace SMA2 (PM ) and create the matrix MFRMDMI supplied by the user on DMIG Bulk Data cards. Sets flag NOMGG = 1 if that matrix is created, otherwise sets flag to -1.
  7. Conclude current alter package.
  8. Initiate another alter package to be inserted following line 30 of Rigid Format 3 (without replacing line 30).

## STRUCTURAL OPERATIONS

### NOTES ON CARDS (cont'd):

9. Equivalence user supplied matrix (MFR~~OM~~DMI) to the NASTRAN mass matrix (MGG). This user supplied matrix will now be used in all subsequent operations which reference MGG.
10. Concludes current DMAP alter package.
11. Concludes Executive Control Deck.
- 12-15. Case Control deck for extracting normal modes and specification of output requests.
- 18-20. Provides data for user supplied mass matrix referenced above by the name provided here (MFR~~OM~~DMI).

**SPECIAL NOTE:** The data set MATP~~OL~~ used as input for MTRXIN (Card No. 6) is generated during the NASTRAN preface operation (PM 2.3.2) and is not an output from a previously specified DMAP instruction.



## 16. NASTRAN EXTERNAL INTERFACES

### 16.1 INTRODUCTION

NASTRAN is a true general purpose computer program. As such, it may be used to perform a wide range of structural, structural with nonstructural interactions, and many other problems with physical phenomenon that can be defined in matrix equation format. Because of NASTRAN's versatility, requirements often exist for the transfer of data between NASTRAN and other computer programs or between different organizations, each using NASTRAN.

Data transfer to and from NASTRAN may be performed using the following:

1. Preprocessors for performing automatic data generation, data checking and updating, data conversion to NASTRAN format, grid point resequencing, partition vector generation, radiation view factor generation, etc.
2. NASTRAN output as input to postprocessors which perform data scanning, transient response data conversion to generate acceleration input, plot file editing, report generation, shock spectrum analyses, etc.
3. NASTRAN DMAP and Substructure Control Deck commands for transfer of substructuring data tables and matrices from NASTRAN to magnetic tape or disk and vice versa for back-up storage or as input to NASTRAN at other facilities, even if the computers are different.
4. Special NASTRAN Bulk Data Deck cards for direct matrix and table input to represent special purpose and unusual model requirements, load, or response phenomenon.
5. Special matrix and output data card punching capability.

The data transfer capabilities to and from NASTRAN listed above are described in this section.

## PRE- AND POSTPROCESSORS

### 16.2 PRE- AND POSTPROCESSORS

Computer programs which interface as pre- and postprocessors with NASTRAN are available from government sources. Such special purpose programs have been developed to perform automatic bulk data generation, grid point resequencing, radiation view factor generation, and other data generation or output scanning and reporting tasks.

COSMIC, NASA's Computer Software Management and Information Center, is a clearinghouse where government-sponsored and maintained software is transferred from government agencies to the industry. COSMIC is responsible for distributing NASTRAN and the many NASTRAN-related pre- and postprocessor programs that have been developed. To obtain a catalog of programs available through COSMIC, write or call:

COSMIC  
Suite 112, Barrow Hall  
University of Georgia  
Athens, Georgia 30602  
  
Director: Dr. Harold Hale  
Telephone: (404) 542-3265

## NASTRAN MODULES FOR DATA TRANSFER

### 16.3 NASTRAN MODULES FOR DATA TRANSFER

NASTRAN provides the capability for users to conveniently and easily transfer data from NASTRAN to user tapes or disk files. Access to this capability is provided through the seven DMAP modules listed below:

Module	Data Format	Operation
INPUT1	GINØ	Read
INPUT2	FØRTRAN	Read
ØUTPUT1	GINØ	Write
ØUTPUT2	FØRTRAN	Write
ØUTPUT3	"DMI" Card	Punch
TABPCH	"DTI" Card	Punch
EXIØ	User Selected	Read and Write

The user must code a DMAP sequence or use a Rigid Format alter to make use of these utilities, except for EXIØ. The Substructure Control Deck commands SØFØUT, SØFIN, RESTØRE, DUMP, and CHECK may be used to execute EXIØ. Each module and its use is explained in the sections that follow.

#### 16.3.1 NASTRAN GINØ Files

The most efficient way to transfer NASTRAN data blocks from one run to another on the same type of computer, is through the use of INPUT1 (Programmer's Manual, Section 4.98) and ØUTPUT1 (Programmer's Manual, Section 4.100). These modules use the NASTRAN read/write GINØ (General Input/Output) routines. Instructions and examples for using INPUT1 and ØUTPUT1 are presented in the User's Manual, Section 5.5.

#### 16.3.2 NASTRAN FØRTRAN Files

The NASTRAN utility modules INPUT2 (Programmer's Manual, Section 4.99) and ØUTPUT2 (Programmer's Manual, Section 4.101) provide a general capability for interfacing NASTRAN with

## NASTRAN EXTERNAL INTERFACES

other computer programs and pre- and postprocessors. These two utility programs read (or write) data blocks (tables or matrices) from tape or disk files using unformatted FORTRAN READ and WRITE statements. Instructions and examples for using INPUT2 and OUTPUT2 are presented in Section 5.5 of the User's Manual.

### 16.3.3 NASTRAN Punch Files

User's may create punched card records of NASTRAN matrices and tables using DMAP modules OUTPUT3 (Programmer's Manual, Section 4.102) and TABPCH (Programmer's Manual, Section 4.103). These records are useful for long-term storage of data in a physical format. Punched card files on magnetic tape are also a convenient way to transfer NASTRAN data between different types of computers. Note that if the data transfer is to be via magnetic tape, such data transfer from one make of machine to another will normally require assistance from computer support personnel at both machine sites.

OUTPUT3 and TABPCH generate punched card data in NASTRAN Bulk Data Deck card formats: DMI and DTI, respectively. These data card formats are presented in Section 2.4 of the User's Manual. Details regarding restrictions on their use are presented under "Remarks" for each bulk data card description.

Instructions for using OUTPUT3 and TABPCH, with examples, are presented in Section 5.5 of the User's Manual. Note that to use DMI or DTI data blocks, an appropriate DMAP sequence or alter package must be written.

### 16.3.4 NASTRAN S@F Files

NASTRAN provides special capability for transfer of substructuring data files between different types of computers. This capability is accessed using the S@F@UT(EXTERNAL) and S@F@IN(EXTERNAL) automated substructuring commands. More efficient operations are available if the data is to be transferred between computers of the same type. Use of these external transfer commands in the Substructure Control Deck automatically results in a DMAP call to module EXI@ (Programmer's Manual, Section 4.130). The external form of S@F@UT and S@F@IN cause unformatted data records on the Substructure Operating File to be converted to formatted records, similar to punch or print records. These records may be saved on magnetic tape and, as formatted records, they can easily be read into NASTRAN on a different type of computer. Detailed instructions for using the S@F@UT and S@F@IN commands are presented in Section 2.7 of the User's Manual.

## NASTRAN MODULES FOR DATA TRANSFER

When transferring substructure data with these commands, the user must consider tape standards and character sets of the two machines to be involved. For example, when creating a tape on a CDC computer for input to an IBM machine, the CDC user must request his output tape be in the EBCDIC character format. This request must be done using installation-dependent job control cards. The BCD character set would be specified if the input were to be either to CDC or to UNIVAC hardware. Note that external SDF files utilize a standard block size and should not be reblocked outside of NASTRAN.

## 17. INTRODUCTION TO NASTRAN APPLICATIONS

### 17.1 INTRODUCTIONS

In earlier sections of this manual general principles for modeling structures, controlling solutions, and operating in the NASTRAN environment are presented. The following sections contain more specific rules and guidelines particularized for the application of NASTRAN to each type of analysis. These discussions are augmented by annotated examples illustrating typical options. As a guide to identifying sections of interest to the reader, the paragraphs that follow outline how to plan for special applications of NASTRAN, and they summarize each in order of presentation in later sections.

These special applications are also discussed in order of decreasing frequency of useage and generality. The rules and guidelines presented in the first two sections, statics and dynamics, apply to the remaining special topics. Methods of analysis are presented in the latter sections because of their specialized nature and requirements for use by the experienced analysts utilizing the more sophisticated tools of NASTRAN.

## SUMMARY OF APPLICATIONS

### 17.2 SUMMARY OF APPLICATIONS

A brief summary of the applications capabilities of NASTRAN (and contents of the User's Guide sections which follow) is presented next.

#### 17.2.1 Static Analysis

Basic procedures for finite element structural analysis using NASTRAN are described in Section 18. Many of the topics are fundamental, so they also apply to the subsequent sections. The subjects include definition of elements, constraints, singularities, and non-linearities. Interpretation of the output is also described. Key data cards and case control options are included in the discussions. Six sample problems are presented along with card-by-card descriptions of the input data.

#### 17.2.2 Dynamic Analysis

Section 19 on dynamics examines the special modeling and analysis control options required for solutions in the time or frequency domain. Topics include identification and control of different dynamics analysis options, input options for mass and damping, and special options including use of transfer functions and non-linearities. Seven example problems are presented to illustrate some of the many modeling and solution alternatives.

#### 17.2.3 Substructuring and Modal Synthesis

The automated multi-stage substructuring system in NASTRAN (AMSS) provides an efficient approach to the analysis of large-order structural models. The AMSS capability allows a structure to be conceptually subdivided into smaller, more manageable substructures which are initially modeled and checked in separate NASTRAN runs. Substructures are then assembled to construct a system mode. Operations for reducing matrix sizes, combining substructures, invoking solution procedures, and recovering and editing data are controlled directly by the user with simple linguistic commands. Solutions are obtained using existing NASTRAN Rigid Formats. This capability is described in Section 20.

#### 17.2.4 Aeroelastic Analysis

NASTRAN structural models may be coupled with subsonic and supersonic aerodynamic models for aeroelastic flutter and gust response analysis. Structural grid points and aeroelastic degrees

## INTRODUCTION TO NASTRAN APPLICATIONS

of freedom are coupled by automated spline methods which may be used for axial bodies, fixed surfaces, and moveable surfaces. The options for aerodynamic coupling include strip theory, mach box method, piston theory, and the doublet lattice approach.

Section 21 of the User's Guide contains a description of NASTRAN aeroelastic analysis capability. A description of how to use the aeroelastic capability is presented in the User's Manual, Section 1.11.

### 17.2.5 Heat Transfer Analysis

NASTRAN heat transfer analysis capability may be used to determine temperatures and fluxes, or to determine temperature inputs for structural problems. Steady state and transient problems can be solved, including heat conduction (with variable conductivity for static analysis), film heat transfer, and non-linear (fourth power law) radiation. A useful feature of NASTRAN heat transfer is that the same model can be used for both the heat transfer and structural response analyses if the same finite elements are appropriate.

Instructions for using NASTRAN heat transfer capability are presented in Section 22.

### 17.2.6 Cyclic Symmetry Modeling

Cyclic symmetry formulations may be used for many structures such as pressure vessels, rotating mechanisms, and antennas for space communication. Each of these structures consists of several, virtually identical segments evenly spaced around an axis of symmetry. The advantage to the cyclic symmetry method is that only one of the identical segments need be modeled. A solution is obtained from a minimum set of matrix equations which are on the order of only one segment. Two basic approaches, rotational and dihedral symmetry are provided by this capability.

NASTRAN cyclic symmetry capabilities are fully described in Section 23.

### 17.2.7 Hydroelastic Analysis

The NASTRAN hydroelastic modeling option provides the capability for analysis of coupled axisymmetric fluid and nonsymmetric finite element systems. Small motion analyses yielding normal modes and dynamic responses may be performed. Fluid compressibility and gravity effects may be included. Basic input cards and a typical sample problem are described in Section 24.



## SUMMARY OF APPLICATIONS

### 17.2.8 Acoustic Cavity Analysis

The acoustic cavity analysis is designed to solve for resonant modes in slotted solid rocket engine cavities. The concepts of cyclic symmetry and axisymmetric elements are combined to obtain efficiency via reduced problem size. Required input and a sample problem are presented in Section 25.

### 17.2.9 Fully Stressed Design

The capability for fully stressed design provides a method in static analysis for optimizing structural properties for minimum size and/or uniform stress distributions. An iteration loop is provided to automatically update property data based upon internal stresses caused by several independent load cases. Convergence is achieved when all stresses or structural parameters reach their specified limits in at least one case. Input data and control parameters are described in Section 26. This section also includes a small comprehensive, example problem.

## PLANNING FOR SPECIAL APPLICATIONS

### 17.3 PLANNING FOR SPECIAL APPLICATIONS

A complete analysis project requires more effort than simply defining the finite element model, prescribing loads and constraints, and executing NASTRAN. A complete plan for a large analysis project often includes pre-processing steps for data preparation, a pilot model study, grid point resequencing, and an estimation of the execution costs. For the actual NASTRAN executions, checkpoint/restart steps might be deliberately scheduled and controlled with DMAP commands. NASTRAN post-processors for stress-scanning and external plotting may be used to edit output data for ease of analyst interpretation.

Because of the many available methods for solving a particular problem with NASTRAN, the user may find it difficult to select the optimum solution path. For this reason the user should familiarize himself with all of the special NASTRAN options. With this knowledge he may define an analysis approach meeting his own particular needs. The purpose of the detail descriptions of special NASTRAN applications presented in the following sections is to familiarize the reader with the basic capabilities and required input data.

Sections 18 and 19, Statics and Dynamics, apply to nearly every NASTRAN analysis. Unique data requirements and modeling restrictions for the special NASTRAN capabilities are presented in Sections 20 through 26.

Specific requirements for data card formats are given in the NASTRAN User's Manual. The theoretical approaches and their limitations are presented in the Theoretical Manual.

## 18. STATIC ANALYSIS

### 18.1 INTRODUCTION

The static analysis capability in NASTRAN is designed to solve for steady-state structural response to point loads, pressures, inertial loads, thermal loads, or enforced displacements. Rigid Format 1 addresses constrained structures and Rigid Format 2 treats free-body structures under uniform acceleration. Nonlinear static solutions using differential stiffness require Rigid Format 4, buckling is analyzed using Rigid Format 5, and plasticity analysis is processed with Rigid Format 6.

The purpose of this section is to define options for basic finite element modeling and methods for obtaining solutions. Topics are organized according to the sequence in which the typical analyst would approach the problem. Basic methods of simulating a structure using grid points and finite elements are followed by procedures for defining constraints and loading conditions. Thus, the methods used in NASTRAN for controlling the solution and selecting output requests are summarized. Special purpose options and the nonlinear analysis methods are briefly discussed, followed by several examples of static analysis input data decks.

## DEFINING THE STRUCTURAL MODEL

### 18.2 DEFINING THE STRUCTURAL MODEL

The idealized structural model in NASTRAN uses grid points (to which loads are applied and for which degrees of freedom are defined) and elements (which are connected at the points) as shown in Figure 1. Three general types of grid points are employed in static analysis:

1. Geometric Grid Point - A point in three-dimensional space at which three components of translation and three components of rotation are defined. The motions of the structure at these points are the displacement coordinates which represent the degrees of freedom for which a solution is obtained. The location of the point, the direction of the applied loads, and the orientation of the translations and rotations may be defined in terms of local coordinate systems. The user defines each grid point on a GRID bulk data card.
2. Scalar Point - A point to which only one degree of freedom is associated. These coordinates may represent actual displacements, displacement differences, or scalar quantities such as fluid pressure, electric current, voltage, or any other quantity required for a particular model. Such coordinates may be connected to one another and to grid points by means of constraint relationships or via scalar elements. The SPPOINT bulk data card is used to explicitly define scalar points.
3. Axisymmetric Rings - A point on the cross section of an axisymmetric structure, connected with axisymmetric elements. Displacement coordinates correspond to translation and rotation coefficients of a Fourier series describing deformation of the ring. RINGAX data cards define these points.

The structural element, be it a line, surface, or solid element, is a convenient parameterizing concept for specifying many properties of the structure, including its mechanical properties, material properties, mass distribution, and applied loads. In static analysis by the displacement method, stiffness properties are derived from the specified structural elements. Mass properties, used in the generation of gravity and inertia loads, may be specified either as properties of structural elements or as properties of grid points.

From a theoretical viewpoint, the formulation of a static structural problem for solution by the displacement method is completely described by the matrix equation

$$[K]\{u\} = \{P\} \quad (1)$$

STATIC ANALYSIS

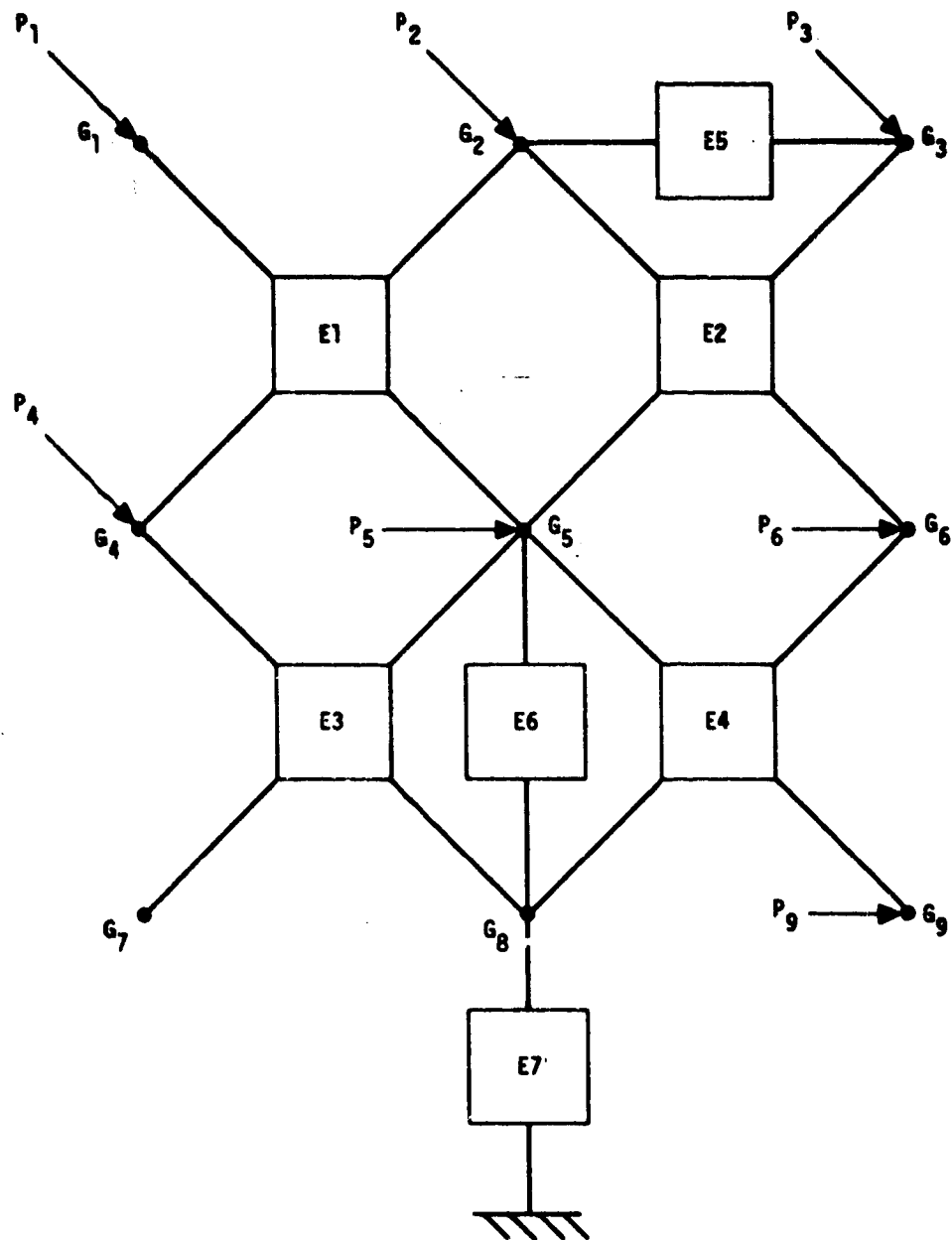


Figure 1. Topology of an idealized structural model.

## DEFINING THE STRUCTURAL MODEL

In static analysis, the stiffness matrix  $[K]$  is calculated for all degrees of freedom using the finite elements. It is then reduced in order by the application of various constraints on the solution vector  $\{u\}$ . In a parallel procedure, the load vectors  $\{P\}$  are generated from element and grid point load data and are modified also via the same constraint relationships used for  $\{u\}$ . After the solution to Equation 1 is obtained for the displacements,  $\{u\}$ , a data recovery process produces requested displacements, forces, and stresses for each specified loading condition. The available options to the NASTRAN user for defining a finite element model and analysis procedures are described below.

### 18.2.1 Finite Elements

NASTRAN provides a library of more than 60 different finite element formulations. These range from simple scalar springs which connect single degrees of freedom, to three-dimensional solid elements connecting up to 32 grid points. Table 1 in Section 9 of this User's Guide lists all the different element data cards by name. Theoretical development of each element is given in Section 5 of the Theoretical Manual. A description of each element is presented in Section 1.3 of the User's Manual, while the actual data card formats are described in Section 2.4 of the User's Manual. NASTRAN elements are defined by the user with the following data card types:

1. A connection card to define the grid or scalar points to be connected, the property number, and any necessary orientation data. The mnemonic for these Bulk Data cards contains the prefix C plus the element name. For example, the CBAR card defines the connections for the BAR element.
2. A property card to define the geometric data not implicitly given by the connected grid points and material identification numbers. Each property card is given a unique identification number which is referenced by any number of appropriate elements. The prefix P plus the element name is used to name the card, i.e., PBAR.
3. Material data cards to define elastic properties, mass density, thermal expansion data, and stress limits. The MAT $i$ , which  $i = 1, 2, \dots$ , define the material property data. Thermal and stress dependencies are defined by MATTi and MATSi data cards. Each material is given a unique identification number which may be referenced by any number of property cards.

## STATIC ANALYSIS

As in most general purpose programs, certain exceptions exist to the general rules. For instance, some elements do not require reference to an associated property card or to material data.

The selection of the grid point locations and element types is made by the user based upon his experience, the desired accuracy of solution, the cost of execution, and the engineering objectives for the entire analysis. The following guidelines are useful in defining the element models:

1. Select elements most suited to supporting the significant internal stresses. For instance, if bending stress is significant, plate elements would be indicated to support the out-of-plane applied loads.
2. The number of elements to be used for modeling a section of the structure is determined by the anticipated displacement and strain pattern. Each different element type approximates the true solution strain pattern with a particular function which may be a constant or a polynomial. The deviation between the actual strains and the approximated element strains determines the accuracy of solution.
3. Each type of element may not connect to all six degrees of freedom at a grid point. Any grid point displacement components which are not somehow "connected" by any attached elements must be constrained or they will cause matrix singularities.

### 18.2.2 Constraints and Boundary Conditions

Constraints are used in NASTRAN to specify known values and relationships for selected displacement coordinates. These constraints are used to specify fixed boundary conditions, to eliminate matrix singularities, to define rigid elements, and to support free body motion.

1. Single-point constraints define the displacement at individual displacement degrees of freedom. The data cards used are SPC, SPC1, SPCADD, SPCD, and the seventh field on the GRID card. The constraints on the GRID card are permanent. The SPC, SPC1, and SPCADD data are selected by Case Control cards and may be changed for different subcases. The SPCD data defines enforced displacements via load requests.
2. Multipoint constraints are defined by user-supplied coefficients relating two or more displacements. This option is applicable to many modeling situations such as rigid

## DEFINING THE STRUCTURAL MODEL

connections between two or more points, defining linkages and hinged joints and defining displacement differences as auxiliary degrees of freedom. The MPC and MPCADD Bulk Data cards are used to supply the input data. Note that:

- a. A dependent coordinate is generated for each data card. Since this coordinate is defined as dependent by the MPC equation, it may not be specified with any other constraint nor as a dependent coordinate in another MPC equation.
  - b. Since no checks on the validity of the equations are performed, erroneous answers may result if input errors are made. For example, if a rigid linkage is defined using wrong distances between grid points, the structural response will simulate a local attachment to ground.
3. Rigid elements are a special automatic form for MPC data generation. The constraint coefficients are calculated from the geometry of the referenced grid points connected via the rigid element specified on CRIGD1, CRIGD2, CRIGD3, and CRIGDR cards. Since each rigid element generates a set of MPC equations, a corresponding set of dependent coordinates is generated. As with the MPC data, no other constraints may be applied to those dependent coordinates.
  4. Rigid body supports are defined on a SUPORT card, and they are used to supply temporary, nonredundant constraints on free body motion. They are required for inertia relief analyses using Rigid Format 2, and they are recommended for use in modal analysis of free bodies.
  5. Matrix condensation, or Guyan reduction, is technically not a method of constraint, but it follows the same general path as the constraint sets described above. The data are supplied using OMIT, OMIT1, ASET, and ASET1 Bulk Data cards. The specified degrees of freedom for elimination by reduction are restricted to only unconstrained coordinates. Matrix condensation is generally not recommended for use in static analyses for reasons of efficiency. The exception to this is when using the automated substructuring capability described in Section 20.

Errors in constraint data are not automatically corrected by NASTRAN. Conflicting constraint data, when detected, are treated as fatal errors.



## STATIC ANALYSIS

Grid point singularity tests are performed to detect null columns in the stiffness matrix resulting from deficient constraints or element connectivities. A typical message contains:

1. The suspect grid point
2. The order of the singularity
3. The combinations of grid point components that cause the singularity, arranged in order of severity.

The grid point singularity testing is limited to one grid point at a time and does not detect coupled singularities, such as a free body. The numerical tolerance is conservative and may issue singularity messages for components having small relative stiffnesses. It may also ignore implicit constraints on the displacement components associated with multipoint constraints or rigid element data.

### 18.2.3 Loading Constraints

Static loads in NASTRAN fall into four general categories -- directly applied loads, enforced element strains, inertial loads, and enforced grid point displacements. Each category is summarized below:

1. Direct load options include concentrated forces and moments, pressures, and scalar loads. Data card names are FORCE, MOMENT, PLDAD, SLDAD, and their variations, listed earlier in Table 1 of Section 4. The load data on each card must belong to a load set. Different load sets may be combined into one set with a LOAD Bulk Data card. Only those load sets called out in the Case Control Deck are applied to the model as load vectors in the solution phase.
2. Enforced element strain options include temperature loads and enforced element deformations, e.g., caused by misfits in structural assembly. Only the ROD, TUBE, and BAR elements allow enforced deformations which are defined on the DEFORM card.

All elements may be subjected to thermal expansion. The grid point forces and moments computed to prevent expansion are applied as loads on the model. Temperature loads are requested separately from, and are combined with the other applied loads called out in the Case Control Deck.

The temperature field required to define these loadings obey the following priorities:

## DEFINING THE STRUCTURAL MODEL

- a. The default temperature for the entire structure is defined on a TEMPD card.
  - b. Grid point temperatures, defined on TEMP cards, override the default.
  - c. Element temperature fields containing gradients override the grid point data. Input data cards are TEMPRB, TEMPP1, TEMPP2. These data may also be used to define material coefficients for temperature-dependent materials.
3. Inertial loading options include gravity and centripetal forces. These loads, defined on GRAV and RFORCE data cards, are calculated directly from the structural mass matrix. These data are requested by use of the Case Control LOAD card.
  4. Enforced grid point displacements were discussed previously under Constraint Conditions in this section. The SPCD card is a special case in that it does not generate constraints and must be requested in a load set. Any component displacements defined on an SPCD card must be defined on SPC or SPC1 constraint data cards.

## STATIC ANALYSIS CONTROL DATA

### 18.3 STATIC ANALYSIS CONTROL DATA

The NASTRAN Executive Control, Case Control, and parameter input via the Bulk Data Deck provide control options for directing the basic computations. Complete descriptions of these data are given in Sections 2.2, 2.3, and for the PARAM Bulk Data card in Section 2.4 of the User's Manual. Some of the basic controls are given below.

#### 18.3.1 Executive Control Data

An Executive Control Deck example for static analysis is given below:

Card Input	<u>Comments</u>
ID STATICS, EXAMPLE	Identify job
APP DISP	Use displacement method
SØL 1,0	Select Rigid Format 1
TIME 5	Set internal time limit (CPU minutes)
CEND	End of deck

For more examples and other options on the above cards, see Section 6 of this guide. Other types of executive control cards define checkpoint/restart, request diagnostics, and provide DMAP input and alters.

#### 18.3.2 Case Control Deck

The NASTRAN Case Control Deck is used to define loading conditions, to select constraints, to control printed output, and to request plots. A basic Case Control Deck example for static analysis is given below:

## STATIC ANALYSIS

Card Input	<u>Comments</u>
TITLE = ANY CHARACTERS	Provide output page heading
SPC = 25	Select single-point constraint set
DISP = ALL	Request output - displacements
STRESS = ALL	Request output - element stresses
SUBCASE 11	Denote first case
LOAD = 5	Request first loading
LABEL = FIRST CASE LABEL	Provide output label
SUBCASE 25	Define second case
LOAD = 15	Request second loading
LABEL = SECOND CASE LABEL	Provide output label
BEGIN BULK	End of deck

Other useful examples of case control requests are given in Section 8 of this guide. The options are summarized in Table 5.

At the end of the Case Control Deck, the Plot Control Deck may be added for requesting plots showing the deformed and undeformed static model. The descriptions of the options are given in the User's Manual, Section 4. A basic example of a plot request for the undeformed structure is given below:

Card Input	<u>Comments</u>
OUTPUT (PLOT)	Required delimiter
SET 1 ALL	Use all elements for set to be plotted
FIND	Find scale and origin
PLOT	Plot - first set

### 18.3.3 Control Parameters

Parametric control data are specified on PARAM bulk data cards. The format is:

PARAM	NAME	VALUE
-------	------	-------

### STATIC ANALYSIS CONTROL DATA

A complete list of parameter options for all Rigid Formats is given on the bulk data card description for PARAM in the User's Manual, Section 2.4, and for each Rigid Format in the User's Manual, Section 3.

## OTHER STATIC SOLUTIONS

### 18.4 OTHER STATIC SOLUTIONS

The discussions above are primarily concerned with linear static analysis of user-defined structural configurations. Alternate analytical processes are available for special structural configurations and responses. These are summarized below.

#### 18.4.1 Property Optimization

NASTRAN includes a method of design optimization for linear static analysis (Rigid Format 1) based on automation of a relatively simple strategy known as "fully stressed design." According to this concept, the cross-sectional properties of each structural element are changed at each design iteration to produce a limit stress (zero margin of safety) somewhere within the element, on the assumption that the loads carried by the element are unaffected by changes in its cross-sectional properties. The assumption is strictly true only for statically determinate structures. In indeterminate structures of low redundancy, the assumption is not much in error, so that a few repetitions of the algorithm will produce a stress distribution throughout the structure which has very nearly a zero margin of safety in every element, i.e., a "fully stressed" design. In structures of high redundancy, the procedures will converge more slowly (if at all), and modifications of the basic strategy may be required to achieve convergence.

The physical quantities involved in the design algorithm are: properties, stresses, and stress limits. The properties may include thicknesses, cross-sectional areas, or moments of inertia. Most NASTRAN elements have several independent properties. They also have several types of stresses and several places where stresses can be evaluated. The stress limits include those for tension, compression, and shear.

#### 18.4.2 Cyclic Symmetry

Many structures, including pressure vessels, rotating machines, and antennas for space communications, are made up of virtually identical segments that are symmetrically arranged with respect to an axis. There are two types of cyclic symmetry: simple rotational symmetry, in which the segments do not have planes of reflective symmetry and the boundaries between segments may be generally doubly curved surfaces; and dihedral symmetry, in which each segment has a plane of reflective symmetry and the boundaries between segments are planar. In both cases, economic solutions for structural response are obtained by analyzing a subregion containing as few segments as possible.

## STATIC ANALYSIS

Principles of cyclic symmetry call for reducing the analysis region to the smallest repeated section of the structure. Neither accuracy nor generality are lost in the process, except that the treatment is limited to linear relationships between degrees of freedom. The use of cyclic symmetry allows the analyst to model only one of many identical segments resulting in a large saving of computer time for most applications. Details of the procedures for applying cyclic symmetry are described in Section 23 of this guide and Section 1.12 of the User's Manual. Static analysis with cyclic symmetry is performed using Rigid Format 14.

### 18.4.3 Nonlinear Static Solutions

NASTRAN provides for two types of static nonlinearities, differential stiffness and material plasticity. The geometric stiffness effects treated by Rigid Formats 4 and 5 provide the user with a second order approximation to the nonlinear effects of large deflections.

Rigid Format 4 computes the differential stiffness matrix by an iterative technique and treats the new matrix as a load correction. The internal loads are thus not linearly related to the applied load. The iterations are terminated when the user's criteria are met to obtain a solution.

In Rigid Format 5, the applied loads are assumed to move with their points of application and they remain fixed in magnitude and direction. The "differential stiffness" matrix is computed from the internal element loads resulting from the static solution or from the previous iteration. Rigid Format 5 combines the "differential stiffness" matrix with the original stiffness matrix to solve an eigenvalue problem and obtain the critical load factor that would produce buckling. This critical load factor, or the eigenvalue, multiplied by the preload vector, gives the critical loading at which the structure would become unstable or buckle. The eigenvector obtained is the mode shape in which the structure would buckle.

Rigid Format 6, on the other hand, is used for applications involving nonlinear materials. That is, the material properties are assumed to be stress dependent. The loading is applied in "piecewise linear" increments. After each increment, a new stiffness matrix is generated based on the current state of stress in each element. This new matrix is used to solve for a corresponding increment of displacement and stress. These increments are accumulated to produce the final nonlinear results. Since each increment in load requires a new solution, the user is faced with a compromise between accuracy, which requires small increments, and efficiency, which suggests using the largest possible increments. All static load options are allowed except for those due to temperature and enforced element displacements.

## STATIC ANALYSIS EXAMPLES

### 18.5 STATIC ANALYSIS EXAMPLES

This section illustrates the NASTRAN input data for simple static analysis. The application examples are extracted from input data used for problems discussed in the NASTRAN Demonstration Problem Manual. The user should refer to this manual for additional detail concerning the model and a discussion of the results. The specialized applications and the examples of how to use the DMAP commands, however, are not presented in the Demonstration Problem Manual.

#### 18.5.1 Rigid Format 1 - Shell with Symmetry Boundary Conditions

This problem demonstrates the finite element approach to the modeling of a uniform spherical shell. A spherical coordinate system is chosen to describe the location and displacement degrees of freedom at the grid points. Triangular plate elements are used to provide a nearly uniform pattern. Two symmetric boundaries are used to analyze the structure with a symmetric pressure load. Further modeling detail is given in the Demonstration Problem Manual, Section 1.2. The model and its loads are pictured below.

The analysis is carried out in two parts. First, the solution is obtained with roller supports which produce primarily a membrane behavior. The second solution is a restart which solves the same problem but with a clamped edge support which induces bending moments at the boundary.

##### 18.5.1.1 Input Cards - Unclamped Boundary and Symmetry Plots

<u>Card No.</u>	
0	NASTRAN FILES = (NPTP,PLT2)
1	ID DEM102, NASTRAN
2	DIAG 14
3	CHKPNT YES
4	TIME 5
5	APP DISPLACEMENT
6	SOL 1,1
7	CEND
8	TITLE - SPHERICAL SHELL WITH PRESSURE LOADING, NO MOMENTS ON BOUNDARY
9	SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-2-1
10	LOAD = 1
11	SPC = 2
12	OUTPUT
13	DISP = ALL
14	SPCF = ALL
15	STRESS = ALL
16	PLOT ID = NASTRAN DEMONSTRATION PROBLEM NO. 1-2-1
17	OUTPUT (PLOT)
18	PLOTTER SC
19	MAXIMUM DEFORMATION 6.0



## STATIC ANALYSIS

```

20 SET 1 INCLUDE ELEMENTS TRIA2
21 $ PLOTTEL - EDGES AND CENTERLINE
22 SET 2 INCLUDE, PLOTTEL
23 FIND SCALE ORIGIN 1
24 PTITLE UNDEFORMED STRUCTURE
25 PLOT LABELS SYMBOLS 6
26 PTITLE DEFORMED STRUCTURE
27 PLOT STATIC DEFORMATION 0,1, SET 1, ORIGIN 1, SHAPE, LABELS
28 PERSPECTIVE PROJECTION
29 FIND SCALE, ORIGIN 1000, SET 1, VANT POINT, REGION 0.3, 0.35, 0.1, 0.9, 0.8
30 PLOT SET 2, ORIGIN 1000, LABELS
31 PLOT SET 1, ORIGIN 1000, SYMBOLS 9, SHAPE,
32 SET 1, ORIGIN 1000 SYMBOLS 9 SHAPE SYMMETRY X,
33 SET 1, ORIGIN 1000 SYMBOLS 9 SHAPE SYMMETRY Y,
34 SET 1, ORIGIN 1000 SYMBOLS 9 SHAPE SYMMETRY XY
35 PLOT STATIC DEFORMATION 0,1,
36 SET 2, ORIGIN 1000, SHAPE,
37 SET 2, ORIGIN 1000, SHAPE, SYMMETRY X,
38 SET 2, ORIGIN 1000, SHAPE, SYMMETRY Y,
39 SET 2, ORIGIN 1000, SHAPE, SYMMETRY XY.
40 BEGIN BULK
  
```

	1	2	3	4	5	6	7	8	9	10
41	CORDS	2		.0	.0	.0	.0	.8	.1	+COR1
42	+COR1	1.	0.0	0.0						
43	CTRIA2	1	31	1	6	26	.0			
44	CTRIA2	34	31	24	25	23	.0			
45	GRDSET		2							
46	GRID	1		90.	7.	.0				
47	GRID	26	0	.0	.0	90.0	0			
48	MAT1	1	3.+6		.1666					
49	PLoad2	1	-1.0	1	2	3	4	5	6	
50	PLoad2	1	-1.0	31	32	33	34			
51	PLOTTEL	50	26	1		51	1	2		
52	PLOTTEL	68	13	17		69	17	20		
53	PTRIA2	31	1	3.						
54	SPC	1	26	12456	0.0					
55	SPC1	1	346	1	2	3	4	11	16	+SPC1-2
56	+SPC1-2	20	23							
57	SPC1	1	123456	5	10	15	19	22	24	+SPC1-1
58	+SPC1-1	25								
59	SPC1	2	2	10	15	19	22	24		
60	SPC1	2	345	1	2	3	4	11	16	+SPC2-1
61	+SPC2-1	20	23							
62	SPC1	2	2345	5	25					
63	SPC1	2	12456	26						
64	ENDDATA									

### 18.5.1.2 Notes on Data Cards

0. Requests NPTP and PLT2 be disk files rather than tape.
1. NASTRAN run identifier.
2. Requests Rigid Format printout.
3. Checkpoint is requested for restart with clamped boundary conditions.

## STATIC ANALYSIS EXAMPLES

4. Limits Execution time to five minutes. Local installation job card should provide a maximum time of more than five minutes to allow NASTRAN to exit normally and punch the checkpoint dictionary.
5. The displacement approach is selected.
6. Rigid Format 1 is to be executed without looping, which allows NASTRAN to purge files when they are no longer required.
7. End of NASTRAN Executive Control Deck.
10. Load condition 1 is the only loading. Note, since this implies only one subcase, no subcase delimiter is required.
11. Selects single-point constraint set 2 from Bulk Data for symmetry boundary conditions and unclamped supports.
- 12-15. Specifies output for all grid point displacements, support reactions and element stresses.
- 16-18. Identifies plot header frame label and Stromberg-Carlson plotter.
19. Specifies the maximum displacement to be plotted to a scale of 6 inches relative to the 90-inch radius of the sphere.
- 20-23. Specifies element sets, scaling factors, and origin for plotting.
24. Specifies plot title to appear on every plot frame generated.
25. Plot first set of elements (set 1), undeformed and orthographic projection.
27. Plot elements of set 1, deformed shape.
- 28-29. Calls for perspective plots and definition of plot parameters.
30. Perspective plot with PLØTEL only, undeformed.
- 31-34. Perspective plot of all triangular plate elements fully developed for symmetry, undeformed (UM 4.2.2.3).
- 35-39. Perspective plot of all PLØTEL fully developed for symmetry, deformed.
- 41-42. Defines orientation of spherical coordinate system.
- 43-44. Triangular element connectivities.
45. Sets default value 2 for the spherical coordinate system for output displacements at all grid points.
- 46-47. Grid point data in spherical coordinate system.
48. Material properties data.
- 49-50. Pressure load data.
- 51-52. Fictitious line elements for plot purposes.
53. Triangular element properties.
- 54-58. Single-point constraint set 1 including both clamped edge supports and symmetry boundary conditions. (Not selected in this run.)
- 59-63. Single-point constraint set 2 including unclamped edge supports and symmetry boundary conditions.
64. Signals the end of Bulk Data.

## STATIC ANALYSIS

Special note: The degrees of freedom constrained by the single-point constraint cards 54-63 are relative to a spherical coordinate system and not in the Basic X, Y, Z System.

### 1C.5.1.3 Input Cards - Restart with Clamped Boundary

```

Card
No.
0   NASTRAN FILES = @PTP
1   ID DEM102A, RESTART
2   TIME 5
3   APP DISPLACEMENT
4   SOL 1,1
5   RESTART DEM102, NASTRAN,02/04/76,36000,
6       1, XVPS , FLAGS = 0, REEL = 1, FILE = 54
7       2, REENTER AT DMAP SEQUENCE NUMBER 7
   :       :       :       :       :       :
105      98, REENTER AT DMAP SEQUENCE NUMBER 116
106      99, QG , FLAGS = 0, REEL = 1, FILE = 54
107      100, XVPS , FLAGS = 0, REEL = 1, FILE = 55
108      $ END @F CHECKPOINT DICTIONARY
109      CEND

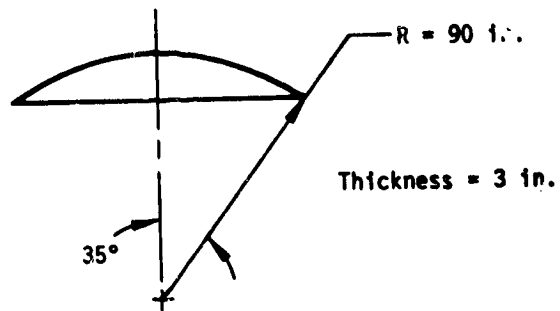
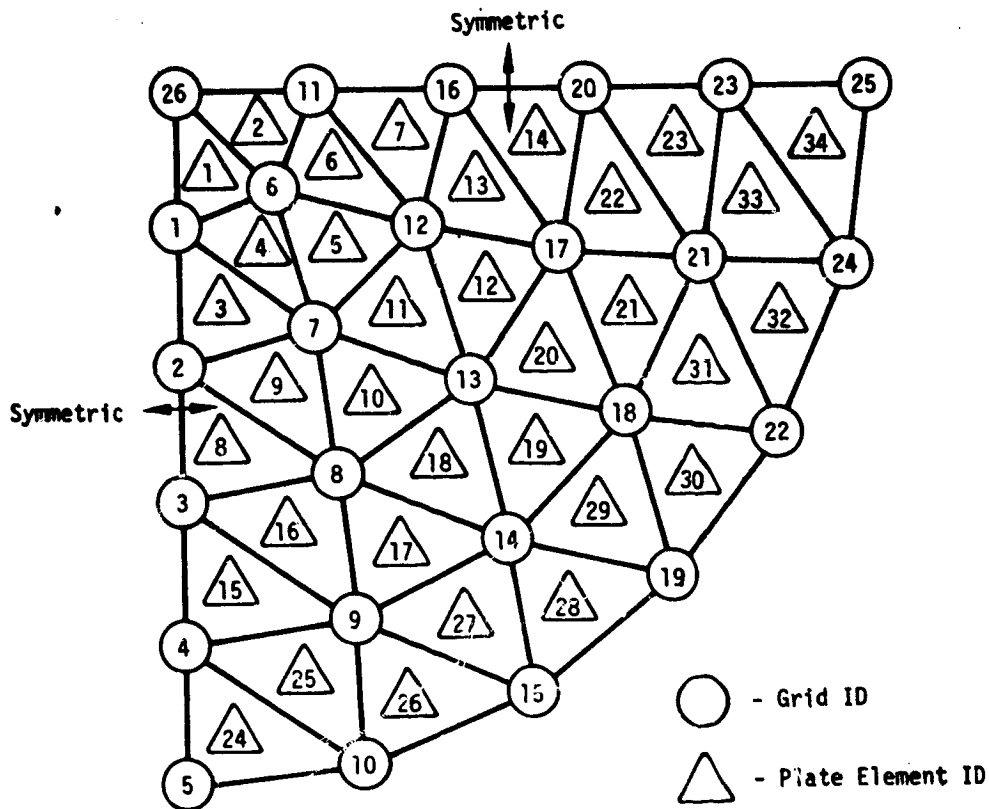
110     TITLE = SPHERICAL SHELL RESTART WITH CLAMPED BOUNDARY
111     SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-2A
112     ECHO = BOTH
113     LOAD = 1
114     SPC = 1
115     @OUTPUT
116     DISPLACEMENT = ALL
117     SPCFORCE = ALL
118     ELFORCE = ALL
119     STRESSES = ALL
120     BEGIN BULK
121     ENDDATA
    
```

### 18.5.1.4 Notes on Data Cards for Restart

- 5-108. Restart dictionary from previous run with unclamped boundary conditions.
- 112. Requests printout of both the current Bulk Data Deck as input (only one card in this case, ENDDATA) and the sorted printout of the full Bulk Data Deck kept from the previous checkpoint as modified by the current input.
- 113. Specifies the one pressure load condition.
- 114. Selects single-point constraint set 1 from Bulk Data for symmetry boundary conditions and clamped supports.

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OF QUALITY

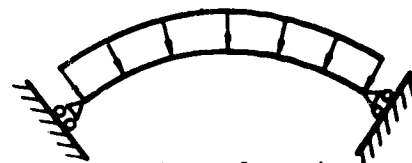
STATIC ANALYSIS EXAMPLES



Uniform Pressure  
Load 1 lb/in.<sup>2</sup>



Clamped Support  
(Problem 1-2-1A)



Membrane Support  
(Problem 1-2-1)

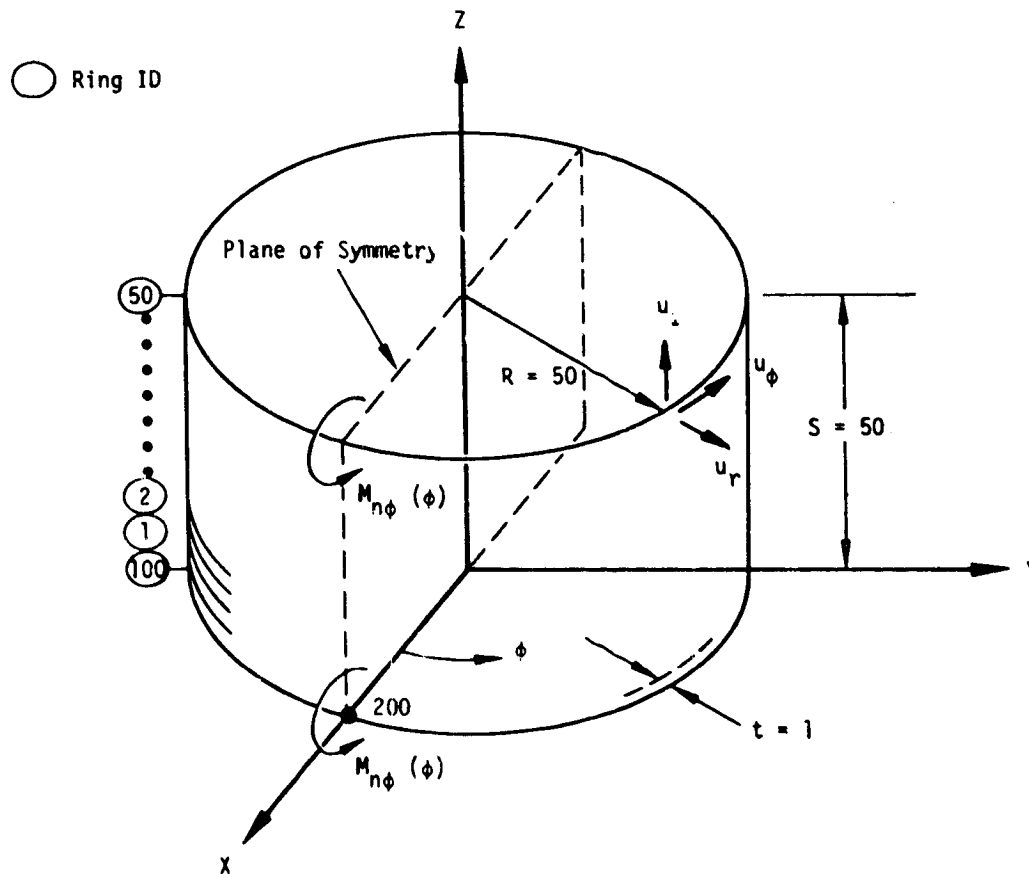
ORIGINAL PAGE IS  
OF POOR QUALITY

## STATIC ANALYSIS

### 18.5.2 Rigid Format 1 - Nonsymmetric Bending of a Cylinder

This problem illustrates the application of the conical shell element and its related special data. This element uses the Fourier components of displacement around an axisymmetric structure as the solution coordinates. The geometry of the structure is defined by rings instead of grid points. Its constraints must be defined by the particular Fourier harmonics, and the loads must be defined either with special data or in a harmonic form. This element is used only for statics and inertia relief analysis and may not be used in conjunction with any of the other structural elements.

The structure to be solved is a short, wide cylinder with a moderate thickness ratio. The applied loads and the output stresses are pure uncoupled harmonics. The basic purpose of this problem is to check the harmonic deflections, element stresses, and forces. Further modeling and loading detail is given in the Demonstration Problem Manual, Section 1.5. The model and its applied edge moment loading is pictured below.



## STATIC ANALYSIS EXAMPLES

### 18.5.2.1 Input Cards - Axisymmetric Model

```

Card
No.
1   ID DEM105, NASTRAN
2   DIAG 8
3   TIME 24
4   APP DISP
5   SOL 1,1
6   CEND

7   TITLE = NONSYMMETRIC BENDING OF A CYLINDER OF REVOLUTION
8   SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-5-1
9   LOAD = 15
10  AXISYM = COSINE
11  OUTPUT
12  SET 1 = 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 100, 200
13  SET 2 = 1, 6, 11, 16, 21, 26, 31, 36, 41, 46, 50
14  DISP = 1
15  FORCE = 2
16  HARMONICS = ALL
17  BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
18	AXIC	20								
19	CCONEAX	1	15	100	1					
20	CCONEAX	50	15	49	50					
21	MATI	15	91.0		.3	.5				
22	MOMAX	15	50	0	157.0796		2.0			
23	MOMAX	15	100	20	157.0796		-1.0			
24	PCONEAX	15	15	1.0	15	.0833333	15	1.0	.5	+PC
25	+PC	0.0	0.5	0.	90.	180.				
26	POINTAX	200	100							
27	RINGAX	1		50.0	1.0			4		
28	RINGAX	100		50.0	.0			1234		
29	ENDDATA									

### 18.5.2.2 Notes on Data Cards

- 10. Constrains the motions to be symmetric with respect to the X-Y plane.
- 14. Selects displacement output for rings specified in set 1, each harmonic will be output separately.
- 15. Selects element forces for all conical shell elements in set 2.
- 16. Output is to be printed for all harmonics of the applied load.
- 18. Required to define existence of an axisymmetric conical shell problem and specifies 20 harmonics to be used.
- 19-20. Conical shell element connectivities.
- 21. Specifies material properties.
- 22-23. Specifies edge moment loading for each harmonic.

## STATIC ANALYSIS

24-25. Conical shell properties.

26. Defines the ID and location of a point on a RINGAX at which the moment can be applied.

27-29. Specifies location of axisymmetric rings.

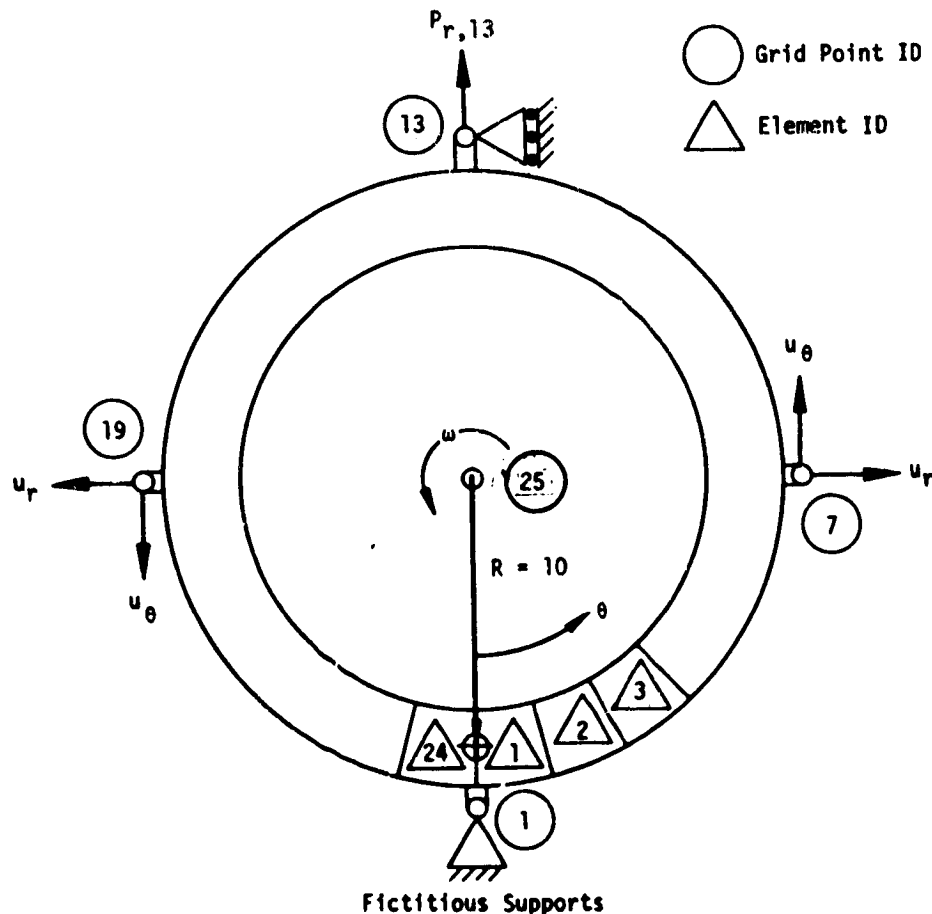
Special note: Point 200 in set 1 references the P@INTAX location and obtains the sum of all displacement harmonics. This same P@INTAX could be used to input a concentrated moment at point 200 and NASTRAN would evaluate the appropriate harmonic coefficients.

## STATIC ANALYSIS EXAMPLES

### 18.5.3 Rigid Format 2 - Free Body Ring

This problem illustrates the use of inertia relief analysis to solve a free-body problem. In inertia relief, the structure is under constant acceleration due to the applied loads; the reactions to the applied load are due to the masses of the structure. Fictitious, nonredundant support points must be provided to define a reference system attached to the body. The displacements of the body are measured relative to the supported coordinates.

The basic problem is illustrated below. The structure consists of a spinning ring with a constant radial load applied to one point. The rotational velocity creates centrifugal loads and the point load causes inertial reactions. The actual dynamic motion of the whole structure is a cyclic motion of the center point coinciding with the rotation of the ring. The displacements measured by the inertia relief analysis, however, will be the static motion relative to the support point displacements. The displacements are defined in a cylindrical coordinate system ( $u_1 = u_r$ ,  $u_2 = u_\phi$ ,  $u_3 = u_z$ ). See the Demonstration Problem Manual, Section 2.1 for further modeling details and a discussion of the theoretical solution.





## STATIC ANALYSIS

### 18.5.3.1 Input Cards - Inertial Relief

```

Card
No.
1  ID DEM201, NASTRAN
2  DIAG 8,14,21
3  TIME 5
4  APP DISPLACEMENT
5  SOL 2,1
6  CEND

7  TITLE = INERTIA RELIEF ANALYSIS OF A CIRCULAR RING
8  LABEL = CONCENTRATED AND CENTRIFUGAL LOADS
9  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-1-1
10 LOAD = 3
11 OUTPUT
12 DISP = ALL
13 LOAD = ALL
14 SPCFORCE = ALL
15 STRESSES = ALL
16 SET 1 = 1, 6, 7, 12, 13, 18, 19, 24
17 ELFORCE = 1
18 BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
19 BARØR			5							
20 CBAR	1			1	2	1.0	0.0	0.0	1	
21 +B1				-1.0	0.0	0.0	-1.0	0.0	1	+B1
22 CBAR	24			24	1				0.0	
23 +B24				-1.0	0.0	0.0	-1.0	0.0	1	+B24
24 CØRD:PC	2	0		0.0	10.0	0.0	-1.0	0.0	0.0	
25 +CØRD	0.	9.0		0.0	0.0	0.0	0.0	10.0	1.0	+CØRD
26 FORCE	1	13		2	100.0	1.0	.0	.0		
27 GRØSET		2					2			
28 GRID	1			11.0	0.0	0.0		345		
29 GRID	25	2		0.0	0.0	0.0				
30 LOAD	3	1.0		1.0	1			123456		
31 MAT1	1	1000.0		400.0		1.0	2			
32 +MAT1	100	200.		300.		.5				+MAT1
33 PARAM	GRØPNT	19								
34 PBAR	5	1		1000.0	10.	10.				
35 +P5	1.0	1.0		-1.0	-1.0					+P5
36 RFØRCE	2	25		2	.159155	0.0	0.0	1.0		
37 SUPØRT	1	2		1	1	13	2			
38 ENDDATA										

### 18.5.3.2 Notes on Data Cards

- 5. Selects Rigid Format 2 without looping instructions to allow removal of files not requested.
- 10. Load set selection required for Rigid Format 2.
- 11. Requests for all grid points, the output of non-zero components of load.
- 16-17. Requests element forces for all elements selected in set 1.

## STATIC ANALYSIS EXAMPLES

19. Specifies beam properties and orientation default. The orientation is defined in terms of the displacement coordinate system of the BAR origin grid points, which in this case are cylindrical systems.
- 20-23. BAR element connectivities and offset vectors.
- 24-25. Definition of cylindrical coordinate system.
26. Specifies a force applied at grid point 13 in coordinate system and single-point constraints.
- 28-29. Grid point definition.
30. Static load combination of load sets 1 and 2.
33. Sets a parameter to generate weight and balance information referenced to grid point 19.
- 34-35. BAR element properties.
36. Defines a centrifugal force field for load set 2.
37. Specifies fictitious supports for determinate reactions to be applied to constrain the free body motion.

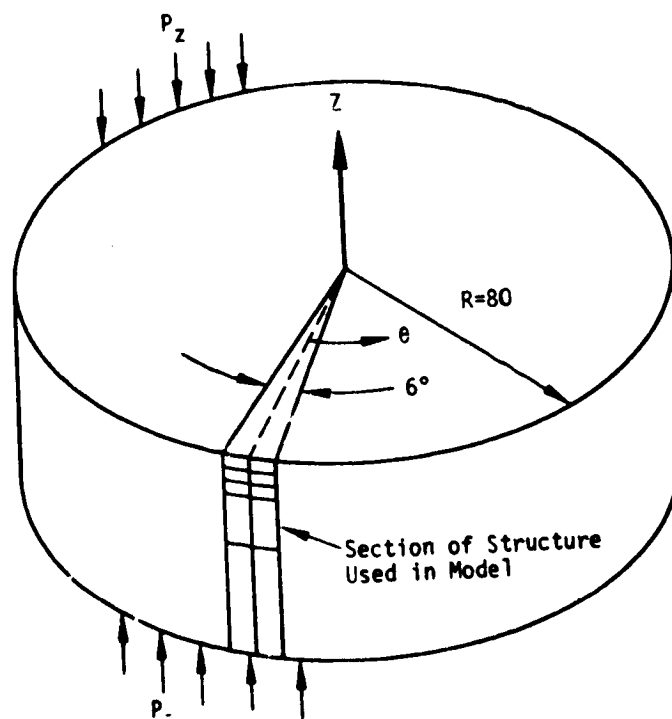
18.5.4 Rigid Format 5 - Symmetric Buckling of a Cylinder

This problem demonstrates the use of buckling analysis to extract the critical loads and the resulting displacements of a cylinder subjected to axial loading conditions. The buckling analysis Rigid Format solves the statics problem to obtain the internal loads in the elements. The internal loads define the differential stiffness matrix  $[K^d]$  which is proportional to the applied load. The load factors,  $\lambda_i$ , which cause buckling are defined by the equation:

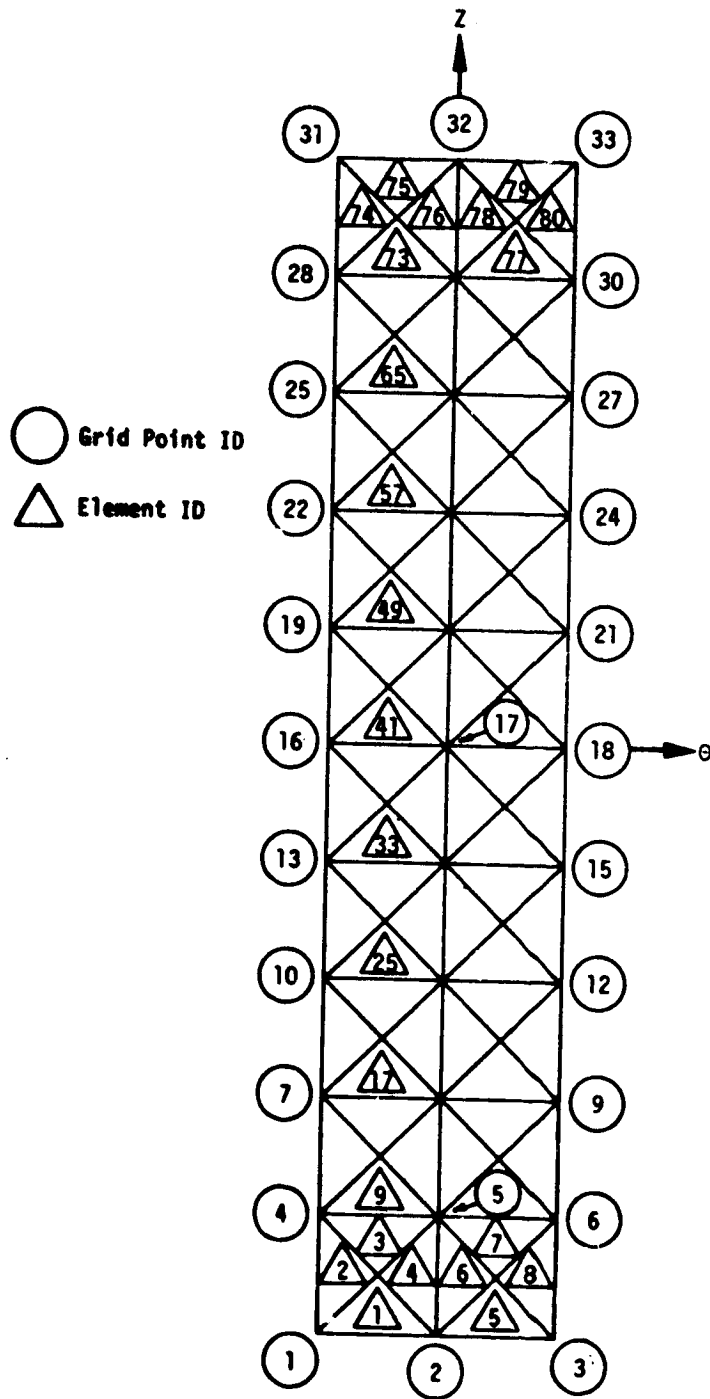
$$(\lambda_i [K^d] + [K])\{u_i\} = 0$$

where  $[K]$  is the linear stiffness matrix. This equation is solved by the real eigenvalue value methods for positive eigenvalues  $\lambda_i$ .  $\lambda_i$  is the multiplying factor, which when applied to the pre-load will produce buckling. More than one mode of buckling can be extracted if so desired.

The problem (illustrated below) consists of a short, large-radius cylinder under a purely axial compression load. A section of arc 6 degrees is used to model the axisymmetric motions of the whole cylinder. See the Demonstration Problem Manual, Section 5.1 for the theoretical solution.



STATIC ANALYSIS EXAMPLES



## STATIC ANALYSIS

### 18.5.4.1 Input Cards - With Structural Plotting

```

Card
No.
0  NASTRAN FILES = PLT2
1  ID DEM501, NASTRAN
2  DIAG 14
3  APP DISPLACEMENT
4  SOL 5,1
5  TIME 16
6  CEND

7  TITLE = SYMMETRIC BUCKLING OF A CYLINDER
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 5-1-1
9  SPC = 1
10 LOAD = 100
11 OUTPUT
12   SET 1 = 1 THRU 33
13   SET 2 = 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62,
14     66, 70, 74, 78
15   DISPLACEMENTS = 1
16   SPCFORCE = ALL
17   ELFORCE = 2
18   ELSTRESS = 2
19 SUBCASE 1
20 LABEL = STATICS SOLUTION
21   OUTPUT
22   LOAD = ALL
23 SUBCASE 2
24 LABEL = BUCKLING SOLUTION
25   METHOD = 300
26 $
27 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 5-1-1
28 OUTPUT(PL0T)
29   PLOTTER SC
30   SET 1 INCLUDE TRIA1
31 $
32   PERSPECTIVE PROJECTION
33   AXES Y, X, MZ
34   FIND SCALE, ORIGIN 1, VINTAGE POINT
35 PLOT LABELS, SYMBOLS 6.5
36 $
37   ORTHOGRAPHIC PROJECTION
38   MAXIMUM DEFORMATION 3.0
39   FIND SCALE, ORIGIN 2
40 PLOT STATIC DEFORMATION 0.1, ORIGIN 2, LABELS, SHAPE
41 PLOT MODAL DEFORMATION 2, RANGE 0.5, 3.0,
42   ORIGIN 2, VECTOR R, SYMBOLS 5,6
43   VIEW 0.0, 0.0, 0.0
44   FIND SCALE, ORIGIN 1
45 PLOT MODAL DEFORMATION 0.2, RANGE 0.0, 200.0, ORIGIN 1, SHAPE
46 BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
47	COR2C	100	0	25.0	.0	80.0	50.0	.0	80.0	+COR100
48	+COR100	25.0	0.0	0.0						
49	CTRIA1	1	200	1	2	51	.0			
50	CTRIA1	80	200	33	30	79	.0			
51	EIGB	300	DET	.10	2.5	4	4	0	1.5E-05	+EIGB300
52	+EIGB300	MAX								

### STATIC ANALYSIS EXAMPLES

	1	2	3	4	5	6	7	8	9	10
53	FORCE	1	1	100	1.0+3	0.0	0.0	0.5		
54	FORCE	1	33	100	1.0+3	0.0	0.0	-0.5		
55	GRDSET							462		
56	GRID	1	100	80.0	-3.0	-25.0	100			
57	GRID	79	100	80.0	1.5	22.5	100			
58	LOAD	100	1.0	1.897	1					
59	MAT1	400	1.+4		.0					
60	PARAM	IERS	1							
61	PTRIA1	200	400	2.5	400	1.302				+PTRIA1*
62	+PTRIA1*	1.510	0.0							
63	SEQGP	51	2.5	52	3.5	54	5.5	55	6.5	
64	SEQGP	75	26.5	76	27.5	78	29.5	79	30.5	
65	SPC	50038	17	3	.0					
66	SPC1	50037	1	1	2	3	31	32	33	
67	SPCADD	1	50037	50038						
68	ENDDATA									

#### 18.5.4.2 Notes on Data Cards

4. Selects Rigid Format 5 for buckling analysis.
- 9-10. Selects single-point constraint and preload sets from bulk data. Required to be specified above the subcase level.
19. Subcase delimiter for linear static analysis of preload condition.
23. Subcase delimiter for buckling analysis.
25. Selects method for real eigenvalue extraction from bulk data. Output will be that selected above the subcase level.
27. Specifies labeling information to identify plots.
- 28-29. Selects structural plotter package and Stromberg Carleson plotter.
30. Defines set of all triangular elements (TRIA1) to be plotted.
32. Calls for perspective projection.
33. Defines orientation of model relative to view axes.
34. Sets plotting parameters.
35. Plots undeformed model with element set 1.
37. Calls for orthographic projection.
38. Specifies the maximum displacement to be plotted to a scale of 3 units relative to the 80-unit radius of the cylinder model.
39. Sets plotting parameters.
40. Calls for a deformed structural plot of the static preload deformations, Subcase 1.
- 41-42. Calls for plotting of all buckling mode shapes within the eigenvalue range of 0.5 to 3.0 without showing the undeformed model.
- 43-44. Defines the view angle and defines plotting parameters.

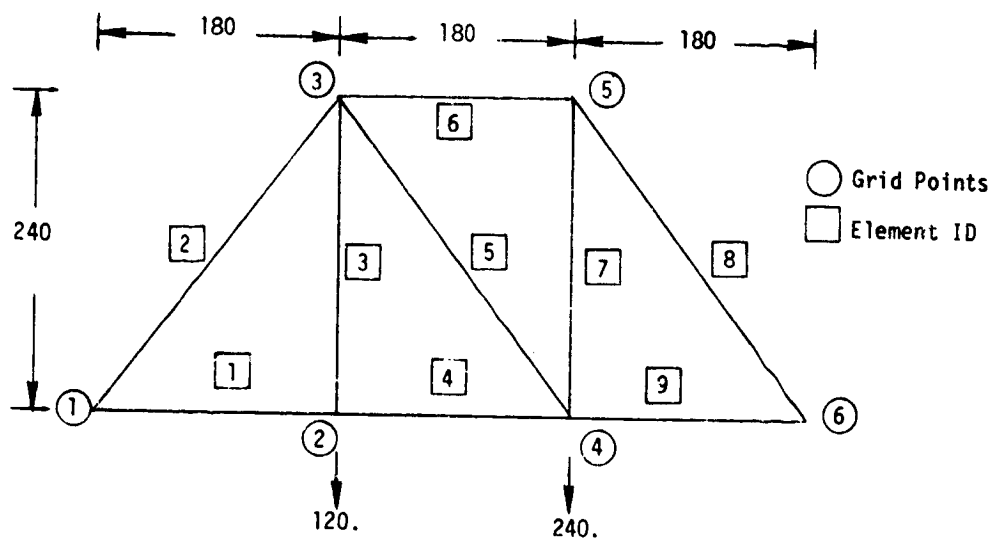
## STATIC ANALYSIS

- 45. Calls for plotting of all buckling mode shapes within the range of 0.0 to 200.0 superimposed on a plot of the undeformed model.
- 47-48. Defines a cylindrical coordinate system.
- 49-50. Specifies the triangular element connectivities.
- 51-52. Provides the parameters for the determinant method of real eigenvalue extraction.
- 53-54. Defines the forces to be applied.
- 55-57. Defines grid point locations and default single-point constraints.
  - 58. Scales the applied load set 1.
  - 60. Calls for printing of residual vectors after static solution.
- 61-62. Triangular element properties.
- 63-64. Grid point sequencing to improve banding of the stiffness and differential stiffness matrices.
- 65-66. Single-point constraint set definitions.
  - 67. Union of single-point constraint sets.

## STATIC ANALYSIS EXAMPLES

### 18.5.5 Rigid Format 6 - Piecewise Linear Analysis with Rod Elements

This problem, as shown below, illustrates elastic-plastic deformation of a three-panel truss subjected to concentrated grid point loads. Piecewise linear analysis involves loading the truss in increments and recalculating the material properties for each element as a function of the element stresses for the last load increment. The new stiffness matrix is used to solve for the change in the deflection caused by a new increment in load. The sum of all these increments represents the final solution (TM 3.8). This problem, though a "standard" verification problem, is not described in the Demonstration Problem Manual.



#### 18.5.5.1 Input Cards - Stress-Dependent Materials

Card No.	
1	ID NONLIN, TRUSS
2	DIAG 8
3	APP DISPLACEMENT
4	SOL 6,0
5	TIME 5
6	CEND



STATIC ANALYSIS

```

7 TITLE = PIECEWISE LINEAR ANALYSIS OF A THREE-PANEL TRUSS
8 LABEL = NASTRAN VERIFICATION PROBLEM
9 SPC = 1
10 LOAD = 1
11 PLCOEFFICIENT = 4
12 OUTPUT
13 SET 1 = 1, 2, 3, 4, 5, 6, THRU 10
14 DISPLACEMENT = 1
15 SPCFORCE = ALL
16 ELFORCE = 1
17 ELSTRESS = ALL
18 BLOAD = 1
19 $
20 PLOTID = NASTRAN VERIFICATION PROBLEM
21 OUTPUT(PLOT)
22 PLOTTER SC
23 CAMERA 3
24 VIEW 0.0, 0.0, 0.0
25 AXES Z, X, Y
26 MAXIMUM DEFORMATION 60.0
27 SET 1 INCLUDE R0D
28 FIND SCALE, ORIGIN 1, SET 1
29 PTITLE = THREE PANEL TRUSS
30 PLOT LABELS
31 PTITLE = DEFORMED SHAPE OVER UNDEFORMED SHAPE, EACH LOAD
32 PLOT STATIC DEFORMATION 0,1 THRU 3, MAXIMUM DEFORMATION 1.3, SHAPE, LABELS
33 BEGIN BULK
    BEGIN BULK
  
```

	1	2	3	4	5	6	7	8	9	10
34	CR0D	1	1	1	2					
35	CR0D	2	2	1	3					
36	CR0D	3	3	2	3					
37	CR0D	4	1	2	4					
38	CR0D	5	4	3	4					
39	CR0D	6	3	3	5					
40	CR0D	7	3	4	5					
41	CR0D	8	2	5	6					
42	CR0D	9	1	4	6					
43	F0RCE	1	2	0	120.0				-1.0	
44	F0RCE	1	4	0	240.0				-1.0	
45	GRID	1	0	.0	.0	.0	0	3456		
46	GRID	2	0	180.0	.0	.0	0	3456		
47	GRID	3	0	180.0	240.0	.0	0	3456		
48	GRID	4	0	360.0	.0	.0	0	3456		
49	GRID	5	0	360.0	.0	.0	0	3456		
50	GRID	6	0	540.0	.0	.0	0	3456		
51	MAT1	1	3.0+4		.3					*MAT1
52	*MAT1	16.99235344		11.814744801		1.E04				*MAT-1
53	MAT1	2	3.0+4		.3					
54	*MAT-1	18.82057716		100.0		200.0				
55	MATS1	2	1000							
56	PARAM	IRES	1							
57	PLFACT	4	1.0	2.0	2.5					
58	PR0D	1	1	7.97						
59	PR0D	2	1	21.16						
60	PR0D	3	1	11.77						
61	PR0D	4	2	7.97						
62	SPC	1	1	1	.0	1	2	.0		
63	SPC	1	6	2	.0					
64	TABLES1	1000								*1001
65	*1001	0.0		0.0		2.0911766-4		6.273525		*1002
66	*1002	4.1823532F-04		10.0		5.61167508E-4		11.0		*1003
67	*1003	1.0561495E-03		13.0					ENDT	
68	ENDDATA									

## STATIC ANALYSIS EXAMPLES

### 18.5.5.2 Notes on Data Cards

4. Selects Rigid Format 6 for piecewise linear analysis.
- 9-11. Only one subcase allowed (here it is implied by lack of subcase delimiter). Selects single-point constraint and load set from bulk data. Also selects PLFACT for increments to be applied to the load for each step of the analysis.
- 12-18. Specifies the desired printout of results. The results for elements with stress-dependent material properties will be printed out for each load increment, otherwise, only the cumulation stresses will be printed. All other selected output will be printed for the cumulation results at each load increment.
23. Requests three blank frames be skipped before plotting the next request.
30. Requests plot of undeformed structure for element set 1 (default to first defined set).
32. Requests plot of deformed shape superimposed on undeformed plot for load increments 1 through 3 and defines the same deformation factor for all load increments.
- 51-52. Specifies material properties which are not stress dependent. Uses a double precision continuation card format.
- 53-54. Specifies material properties which are stress dependent.
55. Specifies table reference for stress-dependent material property factors.
57. Provides for three load increments.
- 58-61. Element properties.
- 64-67. Tabular definition of stress-dependent properties using double precision continuation card format. The abscissa (X-entry) represents the strain (E) and the ordinate (Y-entry) represents the corresponding stress. At each load increment NASTRAN recomputes Young's Modulus (E) to be applied for the next load increment (TM 3.8.3). The algorithms used differ with element type (TM 3.8.4).

## 19. DYNAMIC ANALYSES

### 19.1 INTRODUCTION

This section summarizes the procedures used in dynamic analyses of structures with NASTRAN. Nine Rigid Formats are provided for dynamic analyses of structures, and they are listed here:

<u>Rigid Format No.</u>	<u>Description</u>
3	Normal Modes Analysis
7	Direct Complex Eigenvalue Analysis
8	Direct Frequency and Random Response Analysis
9	Direct Transient Response Analysis
10	Modal Complex Eigenvalue Analysis
11	Modal Frequency and Random Response
12	Modal Transient Response Analysis
13	Normal Modes Analysis with Differential Stiffness
15	Normal Modes Analysis using Cyclic Symmetry

NASTRAN dynamic analyses are separated into three basic types:

1. Eigenvalue Extraction
2. Frequency and Random Response
3. Transient Response

Furthermore, analysis solutions for each type are obtained using either a direct equation solution or a normal modes transformation of the structural equations before solution.

A flowchart for NASTRAN dynamic analyses is presented in Figure 1. The flowchart also includes the names of key NASTRAN modules utilized in dynamic analyses.

Of the two approaches to problem formulation, the direct method simply uses the displacements at selected grid points as dynamic degrees of freedom. The modes of structural vibration within a selected frequency range are used as degrees of freedom in the modal method. This approach results in a significant reduction in the number of degrees of freedom for solution, while maintaining response accuracy in the selected frequency range. However, an added step for eigenvalue extraction is introduced in the analysis.

## DYNAMIC ANALYSES

The flow diagram in Figure 1 is simplified to the extent that it shows only the major operations that are performed. Complete descriptions of the sequences of module calls for all Rigid Formats are contained in Section 3 of the NASTRAN User's Manual. The functions indicated in Figure 1 are described in subsections of the Theoretical Manual as follows:

- Section 9.2 - Real Eigenvalue Analysis, READ  
Complex Eigenvalue Analysis, CEAD
- Section 9.3 - Dynamic Pool Distributor, DPD  
Direct Dynamic Matrix Assembler, GKAD  
Modal Dynamic Matrix Assembler, GKAM
- Section 9.4 - Dynamic Data Recovery, DDR
- Section 11. - Transient Response Analysis, TRD
- Section 12. - Frequency Response Analysis, FRRD  
Random Analysis Module, RANDOM

The inputs to NASTRAN for structural dynamic analysis have been organized to provide ease of transition from static analysis input requirements described in Section 18. All elements, constraints, and scalar point modeling options are available in the dynamic analysis Rigid Formats. However, the following basic differences must be considered:

1. Longer running time results when the unreduced static model is used for a dynamic solution. Either the modal approach or the use of matrix condensation (ASET or OMIT data cards) with the direct approach is recommended to minimize the problem size.
2. Mass data are required.
3. Damping may be included using elements or proportionality factors.
4. Loads must be defined as functions of time or frequency.
5. Data appropriate to the method of solution for time steps, frequencies, and eigenvalue ranges are required, depending on the Rigid Format selected.

In addition to damping and mass modeling features provided for structural dynamic analysis, NASTRAN also provides general capabilities for modeling control systems, hydroelastic effects, and aeroelastic responses through the use of special elements and direct matrix input.

The following sections describe procedures and options used for various approaches to NASTRAN dynamic analysis. The first two sections contain the important topics of modeling mass and damping

## INTRODUCTION

effects. The fourth section describes the modal and direct approach options available for formulating the solution matrices. A separate section is devoted to each of the individual types of solution: eigenvalue analysis, transient response, and frequency response. A summary of output selection procedures is presented, and this section is concluded by a set of annotated sample problems with input data listings.

## MASS MODELING

### 19.2 MASS MODELING

Mass matrix terms for NASTRAN dynamic analyses are input using structural elements, special mass elements, or direct input matrix terms and transfer function data.

#### 19.2.1 Inertia Properties of Structural Elements

All of the metric structural elements (rods, bars, shear panels, twist panels, plates, shells, and solid elements) may have uniformly distributed structural and nonstructural mass. Structural mass is calculated from material and geometric properties. The mass is assumed to be concentrated in the middle surface or along the neutral axis in the case of rods and bars, so that in-plane or in-line rotary inertia effects such as the torsional inertia of beams, are absent. Such effects can, of course, be assigned by the user to grid points. The masses of metric structural elements are transferred to the adjacent grid points at the option of the user by either of two methods, the Lumped Mass or Coupled ("consistent") Mass methods.

In the Lumped Mass method, the mass of an element is simply divided and assigned to surrounding grid points. Thus, for uniform rods and bars, one-half of the mass is placed at each end. For uniform triangles, one-third of the mass is placed at each corner. Quadrilaterals are treated as two pairs of overlapping triangles. Second mass moments are not computed with the Lumped Mass method. The virtues of the method derive from its simplicity.

In the Coupled Mass method, the mass matrix, computed for each structural element, includes off-diagonal coefficients that couple adjacent grid points. This "consistent mass method" is so named because in the element formulation the same assumed deformation shapes, which were used to develop the stiffness matrix terms, are also used to compute the inertial mass matrix terms. The relative accuracy of the two methods is discussed in Section 5.5.5 of the Theoretical Manual.

The options for coupled mass for individual element types (CPBAR, CPRØD, CPQUAD1, CPQUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPQDPLT, CPTRPLT, CPTRBSC) are controlled by the PARAM card. The PARAM data card option, CØUPMASS, causes generation of coupled mass data for all the element types listed above. The default definition of the CØUPMASS parameter produces lumped mass matrix terms.

#### 19.2.2 Concentrated Mass Elements

For modeling concentrated lumped masses, the NASTRAN elements CØNM1, CØNM2, and CMASS1 (i = 1,2,3,4) are used. Mass elements CØNM1 and CØNM2 are used to connect a mass to the six

degrees of freedom at a grid point. The CMASS1 elements are used to connect inertia effects directly to scalar degrees of freedom or grid point components. (See Section 5.5.1 of the Theoretical Manual for a discussion of the possible uses for these elements.)

### 19.2.3 Other Mass Options

Other useful options available in NASTRAN for mass matrix operations are:

1. A mass scale factor may be provided using the PARAM WTMASS data card. The mass matrix of the entire structure is scaled by this factor. Output from the structural weight summary are not scaled, resulting in mass printout in original units. The default value for WTMASS is 1.0.
2. A summary of the overall structural mass, center of gravity (CG), inertia, and principal axes orientation is controlled by the input parameter GRDPNT. If a grid point is specified, the data are calculated relative to that point in space. If zero is specified, the location of the CG and the inertia tensor are calculated relative to the origin of the basic coordinate system. (For details of the actual printout, see Section 1.3.9.4 of the User's Manual.)
3. Direct input mass matrix terms may be specified on DMIG bulk data cards. These are described in Section 19.4.

MASS MODELING

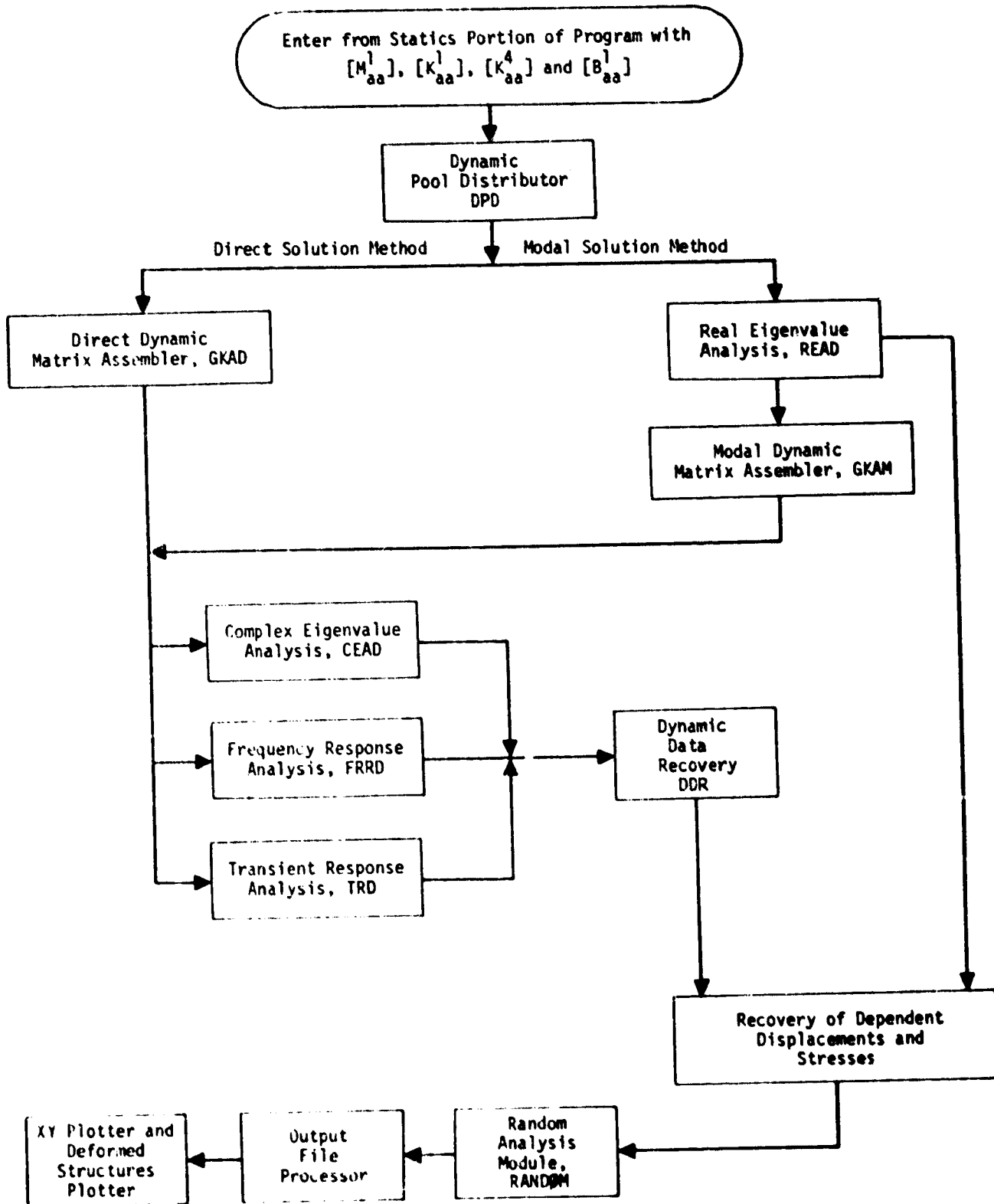


Figure 1. Simplified flow diagram for dynamic analysis by the displacement method.



## DAMPING EFFECTS

### 19.3 DAMPING EFFECTS

Damping effects are available via input options in all dynamic analyses except for real eigenvalue analysis (Rigid Format 3). The actual type of input damping data which may be used depends on the method of analysis formulation and solution defined by the Rigid Format. For example, in a modal formulation (Rigid Formats 10, 11, and 12), the equations of motion are normally uncoupled for solution of modal coordinate response. Therefore, uncoupled modal damping functions may be used as input.

The damping options available in NASTRAN are shown in Table 1. The different types of damping are described below.

1. Viscous Elements are defined on CVISC and CDAMPi bulk data cards. The VISC element connects two grid points and acts as a shock absorber. The DMAPi elements connect scalar degrees of freedom.
2. Structural Damping is proportional to stiffness matrix terms and is defined both on material (MATi) data cards and as an overall factor on the PARAM G data card. In direct complex eigenvalue analysis (Rigid Format 7) and frequency response (Rigid Format 8), the form of the matrix terms are imaginary stiffness matrix coefficients which approximate a hysteresis effect. In transient analysis, the damping matrix is scaled by frequency factors  $W_3$  and  $W_4$  on PARAM W3 and PARAM W4 data cards and are used as a viscous damping matrix.
3. Direct Input Damping matrices are defined using DMIG data cards. Symmetric, unsymmetric, and complex matrix terms may be input. The only restriction is that real terms only must be used in transient analysis.
4. Transfer Functions may be used to provide viscous damping either explicitly, through the coefficients added to the damping matrix, or implicitly, through an attached control system model. TF bulk data cards are used for this purpose.
5. Modal Damping Factors are used in modal formulations to provide damping on the individual, uncoupled modal coordinates. The damping function  $g(f) = 2\zeta$ , where  $\zeta$  is expressed as a percent of critical damping, is input on TABDMP1 data cards.

## DYNAMIC ANALYSES

Table 1. Available Types of Damping in the Dynamic Rigid Formats.

Type of Damping	Rigid Format					
	7	8	9	10	11	12
Viscous Elements	X	X	X			
Structure (Hysteresis)	X	X				
Structure (Viscous)			X			
Direct Input	X	X	X	X	X	X
Transfer Functions	X	X	X	X	X	X
Modal Damping Factors				X	X	X

## SPECIAL DYNAMIC EFFECTS

### 19.4 SPECIAL DYNAMIC EFFECTS

In NASTRAN, dynamic analysis is performed via a basic quadratic format,

$$[Mp^2 + Bp + K]\{u\} = \{P\} . \quad (1)$$

Situations occur, rather frequently, where some of the properties of a dynamic system cannot be expressed directly as constant coefficients in a mass, damping, or stiffness matrix. If the analysis is formulated in the frequency domain, as are many problems in aeroelasticity and hydroelasticity, terms may occur that have other than constant, linear, or quadratic dependence on the operator  $p$ . These terms, however, may be expressed as frequency-dependent coefficients in the mass, damping, or stiffness matrices. This creates a certain awkwardness in the solution of these dynamic problems.

Several options, as outlined below, are provided for modeling nonstructural dynamic effects including transfer functions, direct input matrices, and nonlinear transient loads. For convenience, and to avoid conflicts with static analyses, additional degrees of freedom, called extra points (EPPOINT data card), may be introduced for the dynamics Rigid Formats. (See Section 9.3 of the Theoretical Manual for details of the formulation equations.)

One example of the use of extra points is for structural/control system modeling. In order to facilitate the treatment of control systems, NASTRAN includes an input data format for the specification of transfer functions in the form

$$u_e = \frac{1}{b_0 + b_1 p + b_2 p^2} \sum_i (a_0^i + a_1^i p + a_2^i p^2) u_i , \quad (2)$$

which is interpreted by the program as a differential equation with terms in the rows of  $[M]$ ,  $[B]$ , and  $[K]$  corresponding to  $u_e$ .  $u_e$  must be an extra point, but  $u_i$  can either be an extra point or any structural point contained in  $u_g$ .

Structural loads proportional to displacements at extra points are represented by adding terms in the stiffness matrix at the intersections of rows corresponding to the structural points and columns corresponding to the extra points. Direct input data cards are provided for this purpose. The superposition of all such terms, including those generated by transfer functions, is called the direct input stiffness matrix,  $[K^2]$ . The direct input mass and damping matrices are

## DYNAMIC ANALYSES

$[N^2]$  and  $[B^2]$ . Terms in the direct input matrices may refer to extra points, to structural points, or to both. Since dynamic loads may also be applied to extra points, the means are available for the complete simulation of subsystems by means of extra points. Some applications to control system simulation are described in Section 14.2 of the Theoretical Manual.

In transient analysis, nonlinear effects may be modeled as an additional applied load vector  $\{N\}$ , whose elements are functions of the degrees of freedom (displacement or velocity). The vector,  $\{N\}$ , is added to the right side of the equation of motion and is treated in a similar but slightly different manner than the applied load vector during numerical integration.

In order to eliminate the cumbersome task of reducing nonlinear loads at each time step from the  $u_p$  displacement set to the solution set, it is required that the points to which the nonlinear loads refer belong to the solution set of coordinates. It is further required, for the same reason, that if a modal formulation is used, the points referenced by the nonlinear loads be members of the  $u_e$  set (extra points). Otherwise, two complete modal transformations (one for displacements and one for loads) would be required at each time step.

NASTRAN includes four different types of nonlinear elements. They are sufficient to generate many types of nonlinear relationships when used in conjunction with transfer functions and direct input matrices. These data are input on NØLINi bulk data cards.

## DIRECT VS. MODAL FORMULATION

### 19.5 DIRECT VS. MODAL FORMULATION

Both direct and modal formations for dynamic solution are available in NASTRAN. The direct method uses actual grid point, scalar point, and extra point degrees of freedom to define the solution matrices. The modal method transforms structural degrees of freedom into generalized coordinates representing displacements of the normal structural modes. The advantages of each method are summarized below.

The advantages of the Direct Formulation Method are:

1. No truncation of coordinates is involved. All modes participate, which provides more accuracy when a wide spectrum of frequencies is excited, such as for an impact problem.
2. All options for damping, initial conditions, and nonlinear effects are provided.
3. No extra transformations need to be performed on the load and displacement vectors.

The advantages of the Modal Formulation Method are:

1. Provides economic solutions when modal coordinates are uncoupled (no coupled, direct matrix input data are used), and/or a large number of time steps or frequencies are required.
2. The uncoupled transient solution algorithm performs an explicit integration with less error due to time step size.
3. The output of modal frequencies and mode shape vectors allows the user to identify significant modes and facilitates understanding of the dynamic responses.

From experience, the modal formulation has been the practical choice for most structural analyses involving low frequency excitation and a large number of time step or frequency solutions. The direct method is useful for special modeling requirements or when the modal formulation is otherwise inadequate.

With both methods, the use of matrix condensation (Guyan reduction) with the `QMIT`, `QMIT1`, `ASET`, or `ASET1` data cards is a valuable tool. This option produces a static condensation on the stiffness matrix and a related, consistent transformation on the mass, damping, direct input, and load matrices (see Section 3.5.3 of the Theoretical Manual for details). The result is a set of smaller-order solution matrices for both real eigenvalue solutions and direct formulation response problems.

## EIGENVALUE ANALYSIS

### 19.6 EIGENVALUE ANALYSIS

NASTRAN has provision for both real and complex eigenvalue analysis of dynamic systems. Real normal modes analysis is closely related to static analysis in that only undamped, real, symmetric matrices are used. Complex eigenvalue analysis is used to obtain general second-order eigenvalue solutions. Each type of analysis has several solution algorithm options, each with particular requirements and advantages. These are described next.

#### 19.6.1 Normal Modes Analysis

The NASTRAN normal modes solution equation has the form:

$$\left[ -\omega_i^2 M_{aa} + K_{aa} \right] \{U_{aj}\} = \{0\}, \quad (3)$$

where the mass,  $M_{aa}$ , and stiffness,  $K_{aa}$ , matrices correspond to the structural analysis displacement set after constraints and matrix condensation transformations have been applied. The matrices may represent free body structures. Obtaining the eigenvalues,  $\omega_i^2$ , and corresponding eigenvectors,  $\{U_{aj}\}$ , for Equation 3 comprises the basic solution for the analysis.

Data for control of real eigenvalue analysis are specified on the EIGR bulk data card. When free bodies are being analyzed, rigid body support coordinates may be specified on SUPORT data cards. The purpose of the SUPORT data are to instruct NASTRAN to calculate free body modes directly from the stiffness matrix, resulting in more accurate and economical solutions.

Different methods for extracting real eigenvalues may be selected using the EIGR bulk data card. Each method has unique characteristics, as described below:

1. The Givens-Householder or "GIV" method performs a Choleski decomposition on the mass matrix, multiplies the stiffness matrix by the inverse product, and performs a tri-diagonal transformation on the results. The method extracts all eigenvalues in the order of highest to lowest frequency. The method is efficient when the matrix size is small enough (250) to be held in core. The method also requires a nonsingular mass matrix. The Guyan reduction procedure (BMIT and ASET data cards) is ideal for eliminating singular mass points, such as those associated with rotations, and for reducing the size of the matrices. The advantage of this method is that it can calculate a large number of modes efficiently. Its disadvantages are that it is most efficient for

## DYNAMIC ANALYSES

smaller matrices, and it may produce numerical round-off errors for low frequency modes at or near zero frequency.

2. The Inverse Power or "INV" procedure performs "shifted-power method" vector iterations to compute each normal mode. Each iteration consists of several matrix-vector transformations. Since a sum of the mass and stiffness matrix may be decomposed several times during the solution, these matrices should be either well-banded or small for efficiency. The method allows singularities in the stiffness and mass matrix. However, the sum of these matrices must not be singular.

An advantage of the inverse power method is that a modal constructed for a static solution will require little additional data for a normal modes solution. There are several disadvantages to this method, lengthy computer runs are required to obtain a large number of modes. Also, the user must estimate the region of the frequencies and the number of modes in the region, requiring some prior knowledge of the solution. If the user overestimates these values, the run could be costly. If he undervalues them, some modes may not be computed.

3. The Fast Eigenvalue Extraction Routine, or "FEER" method provides a useful middle ground between the GIV and INV methods. The method uses a Rayleigh-Ritz procedure with shape functions obtained from a power method. The reduced equations are solved using a tridiagonalization procedure which simultaneously orthogonalizes the shape functions. The mass matrix may be singular. Sparse and banded matrices are desirable. The execution cost for a moderate number of modes will generally be less than the other methods where the cost of the required matrix condensation is included for the Givens method.
4. The Determinant, "DET," method has the same general characteristics as the usually more efficient inverse power method. The main advantage of including both methods is the redundancy that is provided in case one method should fail for a particular analysis.

### 19.6.2 Complex Eigenvalue Analysis

The complex eigenvalue analysis technique in NASTRAN is of the form:

$$\left[ M_p^2 + B_p + K \right] \{Q\} = 0 . \quad (4)$$

## EIGENVALUE ANALYSIS

The matrices  $M$ ,  $B$ , and  $K$  may be complex and nonsymmetric. The degrees of freedom may include extra points and modal coordinates. In the direct method of formulation (Rigid Format 7), the general form of damping is used. In the modal method (Rigid Format 10), only direct input damping matrices and modal damping are allowed. The uncoupled modal solutions define structural characteristics prior to the introduction of damping and coupling to the extra points.

The control data for extracting the eigenvalues are provided on the EIGC bulk data card. Unlike real normal mode analyses, no special provisions are included for free body modes. As in normal modes analysis, the FEER, inverse power, and determinant eigenvalue extraction methods are available. However, the Upper Hessenberg, "HESS," method replaces the Givens method for complex eigenvalue extraction.

Complete descriptions of each NASTRAN eigenvalue extraction method are presented in the Theoretical Manual, Section 10.



## FREQUENCY RESPONSE ANALYSIS

### 19.7 FREQUENCY RESPONSE ANALYSIS

In frequency response analysis the input loading is defined as a series of sinusoidal loads, each operating at a unique frequency. The steady state response of the structure at each solution frequency is also assumed to be sinusoidal with the magnitude and phase angle being defined by a complex number. The general solution matrix equation is:

$$\left[ -\omega^2[M] + i\omega[B] + [K] \right] \{u(\omega)\} e^{i\omega t} = P(\omega) e^{i\omega t}, \quad (5)$$

where  $\omega$  is the excitation frequency in radians of the input load  $\{P\}$ . All quantities including the output displacements,  $u(\omega)$ , may be complex numbers.

Figure 1 shows a simplified flow diagram for the frequency response module. The calculations are of two kinds: the generation of loads and the solution of the dynamic equations to obtain a displacement vector. In static analysis a number of automatic load generating subroutines (gravity load, pressure load, temperature-induced load, etc.) are employed in order to simplify the user's task of input data preparation. Similar schemes are not made available for dynamic analysis, mainly because of the great variety in the possible sources of dynamic loads. For frequency response analysis, the user is provided with a flexible input data format which provides a varying degree of generality versus simplicity.

In NASTRAN, the dynamic load vector that is used in a specific subcase,  $\{P_j^c\}$ , is constructed as a combination of component load sets,  $\{P_j^k\}$ .

$$\{P_j^c(\omega)\} = \sum_k S_{ck} \{P_j^k(\omega)\}, \quad (6)$$

where  $S_{ck}$  is a factor defined on a DLOAD bulk data card that gives the proportion of component load  $k$  used in combined load set  $c$ . The advantage of this system is that it facilitates the examination of different combinations of loads from different sources. The form provided for specifying a component load set is:

$$\{P_j^k(\omega)\} = (A_{jk} e^{i(\theta_{jk} - \omega\tau_{jk})}) \cdot G_k(\omega), \quad (7)$$

where  $A_{jk}$ ,  $\theta_{jk}$ , and  $\tau_{jk}$  are tabulated coefficients defined on DAREA, DPHASE, and DELAY data cards, respectively, that may be different for each degree of freedom ( $j$ ). A tabulated complex function

DYNAMIC ANALYSES

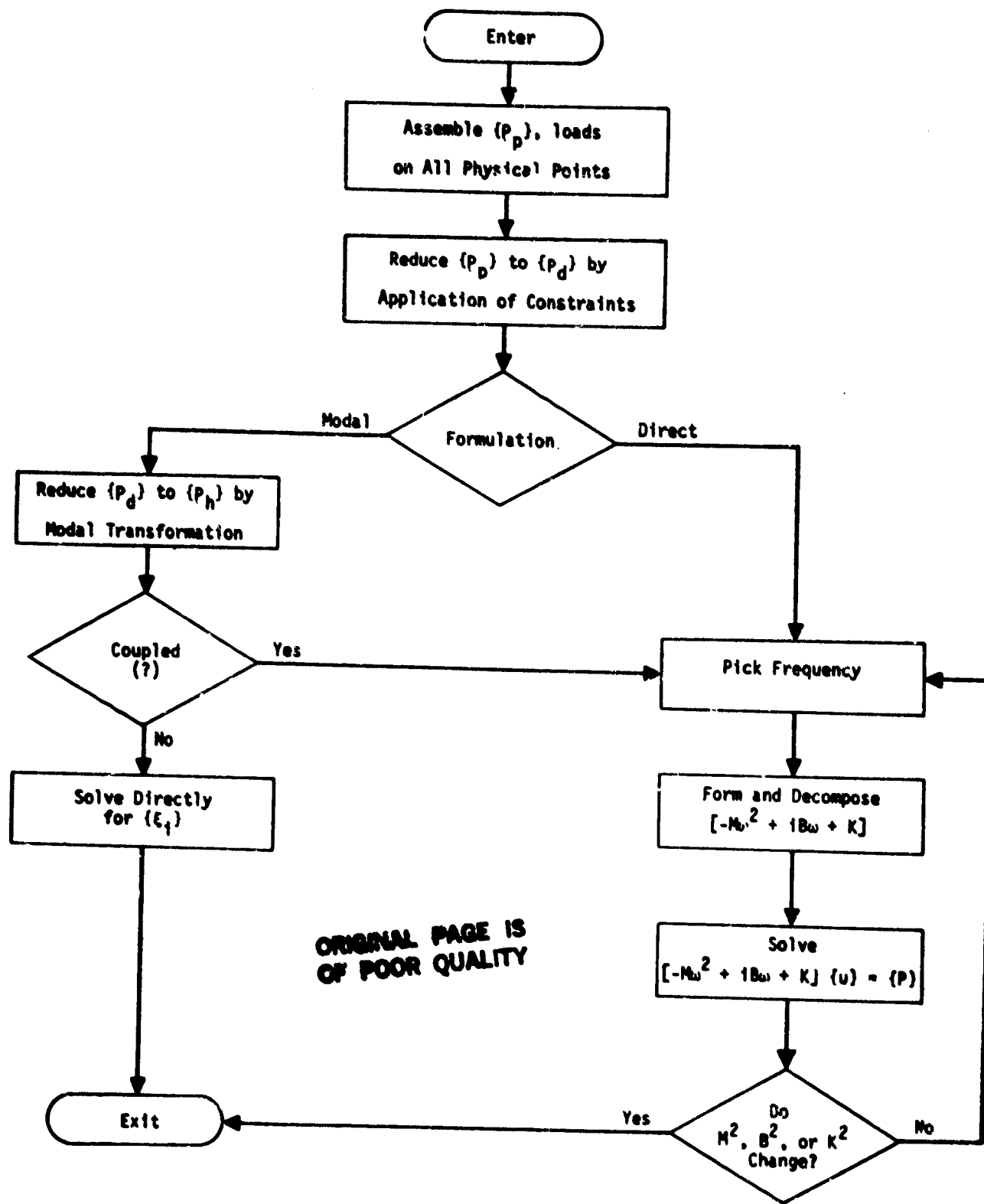


Figure 1. Flow diagram for frequency response module (FRD).

## FREQUENCY RESPONSE ANALYSIS

of frequency,  $G_k(\omega)$ , is provided (with two alternate forms on FLLOAD1 and RLLOAD2 data cards) to linearly interpolate to the frequencies,  $\omega_i$ , at which solutions are requested. The form provided by Equation 7 is most useful for loads due to traveling waves.

Meaningful interpretation of the symbols in Equation 7 for such applications is that  $G_k(\omega)$  is the pressure produced by the wave, that  $A_{jk}$  is the exposed area associated with the  $j^{\text{th}}$  degree of freedom, and that  $\tau_{jk}$  is the travel time required for the wave to reach the  $j^{\text{th}}$  degree of freedom.

The addition of damping effects (Section 19.3) are recommended for the avoidance of singularities at the natural frequencies of the system.

To define the results from these analyses, the other necessary input for frequency response analysis is a list of solution frequencies. These are specified on FREQ1 bulk data cards.

A complete description of NASTRAN frequency response analysis procedures is presented in Section 12 of the Theoretical Manual.

## 19.8 TRANSIENT RESPONSE ANALYSIS

Transient response analysis provides a direct simulation of the dynamic response of the system occurring due to initial conditions and time-varying excitation. The solution equation for transient response is:

$$[M]\{a\} + [B]\{v\} + [K]\{u\} = \{P(t)\} + \{N(\dot{u})\} + \{N(u)\}, \quad (8)$$

where  $P(t)$  is a user-defined load function calculated at each time step,  $t$ . The resulting displacements ( $u$ ), velocities ( $v$ ), and accelerations ( $a$ ), are calculated using either the direct method or the modal method. The nonlinear load vector  $\{N\}$  is calculated using user-supplied functions of displacement and/or velocity.

The generation of transient loads can be a formidable task. The most general form of loading is one which has a different time history of load for each point in the structure. Even for a problem of moderate size (say 50 loaded points and 200 time intervals), the data set required to specify a general loading is large ( $50 \times 200 = 10,000$  entries). Thus, it is essential to provide data formats that accommodate special cases.

In NASTRAN, the applied transient load vector,  $\{P_j^c\}$ , that is used in a specific subcase is constructed as a combination of component load sets,  $\{P_j^k\}$ ,

$$\{P_j^c(t)\} = \sum_k S_{ck} \{P_j^k(t)\}, \quad (9)$$

where  $S_{ck}$  is a factor defined on DL0AD bulk data cards that gives the proportion of component load set  $k$  used in combined load set  $c$ . The advantage of this system is that it facilitates the examination of different combinations of loads from different sources.

Two separate forms are provided for specifying component load sets. In the first, or general form, TL0ADI bulk data cards define the load function:

$$\{P_j^k(t)\} = \{A_{jk}\} F_k(t - \tau_{jk}), \quad (10)$$

where  $A_{jk}$  and  $\tau_{jk}$  are tabulated coefficients that may be different for each loaded degree of freedom ( $j$ ). The load coefficients  $A_{jk}$  may be static load vectors (FORCE, MOMENT, PL0ADI, etc.) in addition to the direct DAREA bulk data. A given table of coefficients ( $A$  or  $\tau$ ) may be

## DYNAMIC ANALYSES

referenced by more than one component load set. A tabulated function of time,  $F_k(t - \tau)$ , is linearly interpolated between entries. The form provided by Equation 10 is particularly useful for loads due to traveling waves. In such applications,  $F_k$  represents the pressure produced by the wave,  $A_{jk}$  is the exposed area associated with the  $j^{\text{th}}$  degree of freedom, and  $\tau_{jk}$  is the travel time required for the wave to reach the  $j^{\text{th}}$  degree of freedom.

In a second, for  $n$  of transient loading, the TLOAD bulk data card defines the function:

$$\{P_j^k(t)\} = \{A_{jk}\}(\bar{t})^{n_k} e^{\alpha_k \bar{t}} \cos(2\pi f_k \bar{t} + \phi_k), \quad 0 \leq \bar{t} \leq T_{2k} - T_{1k}, \quad (11)$$

$$\{P_j^k(t)\} = 0, \quad 0 > \bar{t} \quad \text{and} \quad \bar{t} > T_{2k} - T_{1k},$$

where

$$\bar{t} = t - T_{1k} - \tau_{jk}. \quad (12)$$

The coefficients  $A_{jk}$  and  $\tau_{jk}$  have the same meaning as they do in the general form, Equation 10. The six constants,  $T_{1k}$ ,  $T_{2k}$ ,  $n_k$ ,  $\alpha_k$ ,  $f_k$ , and  $\phi_k$  are entered on a separate data card for each load set. Although the appearance of Equation 11 is formidable, its application to a variety of special cases is straightforward. The time constants,  $T_{1k}$  and  $T_{2k}$ , define the time limits of non-zero load for a point at which the time delay  $\tau_{jk}$  is zero. A square wave between  $T_{1k}$  and  $T_{2k}$  is specified by setting  $n_k = \alpha_k = f_k = \phi_k = 0$ . A sine wave with frequency  $f$  starting at  $t = T_{1k}$  is specified by setting  $n_k = \alpha_k = 0$ ,  $f_k = f$  and  $\phi_k = -\pi/2$ . A polynomial function,  $P = a + bt + ct^2 + \dots$ , is specified by combining a number of load sets with different integral values of  $n_k$  and  $\alpha_k = \omega_k = \phi_k = 0$ . since blank entries are interpreted as zeros by the computer, the extra burden on the user due to the generality of Equation 11 is minimal in all of the above examples.

Other input data for transient analyses are initial conditions, time steps, and nonlinear loads. These data are selected using Case Control. The TIC (Transient Initial Condition) data cards are used to identify initial displacements and velocities. Default values are zero for grid point degrees of freedom without explicit deformations. Initial conditions may be applied only to solution grid point or extra point displacement (not modal) coordinates.

## TRANSIENT RESPONSE ANALYSIS

The TSTEP bulk data card is used to define different time intervals, each with different time step sizes. For each interval, the user defines the number of steps, the time increment, and the number of increments between each printed or plotted solution vector.

Nonlinear load data are input on NBLINI (1 = 1,2,3,4) bulk data cards. These are used to define external loads as functions of the current displacements or velocities. The degrees of freedom referenced by these data must be physical solution coordinates.

A thorough description of transient analysis procedures in NASTRAN is presented in the Theoretical Manual, Section 11.

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## EXAMPLES OF DYNAMIC ANALYSES

### 19.9 EXAMPLES OF DYNAMIC ANALYSES

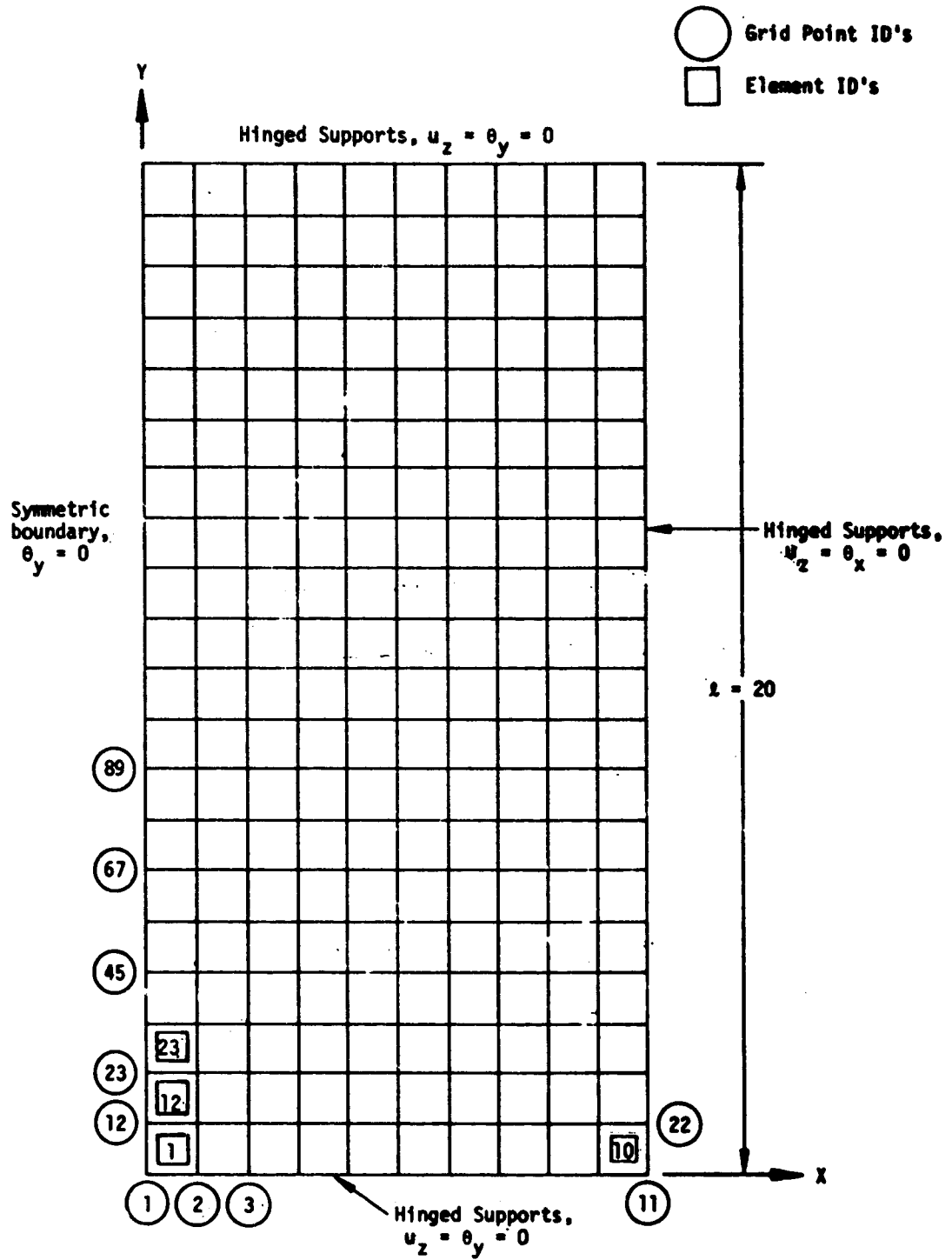
The following sample problems illustrate many of the options and controls used in typical dynamic analysis applications. The actual structural models are relatively small and simple for the purpose of illustration and for obtaining analytical and theoretical comparisons. However, nearly all the different types of bulk data are illustrated, along with many case control options such as subcases and plotting.

#### 19.9.1 Rigid Format 3 - Normal Modes Analysis of a Plate

This problem demonstrates the solution for natural frequencies of a large-order problem. The structural problem consists of a square plate with hinged supports on all boundaries. The 10x20 model, shown below, uses one half of the structure and symmetric boundary constraints on the mid-line in order to reduce the order of the problem and the bandwidth by one-half. The results of this analysis can be found in the Demonstration Problem Manual, Section 3.1.

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DYNAMIC ANALYSES





## EXAMPLES OF DYNAMIC ANALYSES

Because only the bending modes are desired, the in-plane deflections and rotations normal to the plane are constrained. The inverse power method of eigenvalue extraction is selected and both structural mass density and nonstructural mass-per-area are used to define the mass matrix.

### 19.9.1.1 Input Cards - With Structural Plotting

<u>Card No.</u>	
0	NASTRAN FILES = PLT2
1	ID DYNAMICS, NASTRAN
2	DIAG 8
3	APP DISPLACEMENT
4	SOL 3,1
5	TIME 32
6	CEND
7	TITLE = VIBRATIONS OF A 10 BY 20 PLATE
8	SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 3-1
9	\$
10	SPC = 37
11	METHOD = 3 \$ INV - ENCLOSES 1 MODE - FINDS 3 ROOTS
12	\$
13	OUTPUT
14	SET 1 = 1 THRU 11,34 THRU 44,56 THRU 66,78 THRU 88,111 THRU 121
15	SET 2 = 1 THRU 12,22,23,33,34,44,45,55,56,66,67,77,78,88,89,
16	99,100,110 THRU 121
17	DISPLACEMENTS = 1
18	SPCFORCE = 2
19	\$
20	PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 3-1-1
21	OUTPUT(PL0T)
22	PLOTTER SC
23	SET 1 INCLUDE PLOTTEL
24	SET 2 INCLUDE QUAD1
25	MAXIMUM DEFORMATION 1.0
26	FIND SCALE, ORIGIN 10
27	PTITLE UNDEFORMED SHAPE
28	PLOT ORIGIN 10, SET 2, LABELS
29	FIND SCALE, ORIGIN 11
30	PTITLE MODAL DEFORMATIONS
31	PLOT MODAL DEFORMATION1, ORIGIN 11, SHAPE
32	BEGIN BULK

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	1	2	3	4	5	6	7	8	9	10
33	CQUAD1	1	23	1	2	13	12	.00		
34	CQUAD1	219	23	219	220	231	232	.00		
35	EIGR	2	INV	.85	.89	1	1	0		CSIMPL-1
36	+SIMPL-1	MAX								
37	EIGR	12	DET	.89	29.0	20	20	0		+EIG1220
38	+EIG1220	MAX								
39	GRDSET							126		
40	GRID	1		.0000	.000	.000				
41	GRID	231		10.000	20.000	.000				
42	MAT1	2	3.0+7		.300	200.0				MAT1
43	+MAT1	30000.	28000.							
44	PARAM	GRDPNT	111							
45	PLØTEL	301	1	11		302	11	231		
46	PLØTEL	397	36	25		398	25	3		
47	PQUAD1	23	2	1.0	2	.083333			6.04303	+PQUAD1
48	+PQUAD1	0.5	0.0							
49	SCPC	37	5	1	12	23	34	45	58	+31001H
50	+31001H	67	78	89	100	111	122	133	144	+31002H
51	+31002H	155	166	177	188	199	210	221		
52	SPC1	37	35	221	222	223	224	225	226	+21001H
53	+21001H	227	228	229	230	231				
54	ENDDATA									

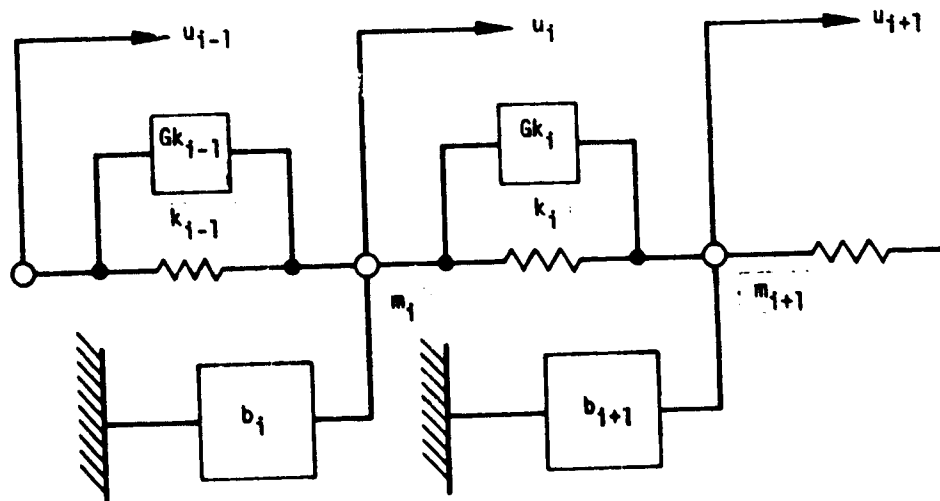
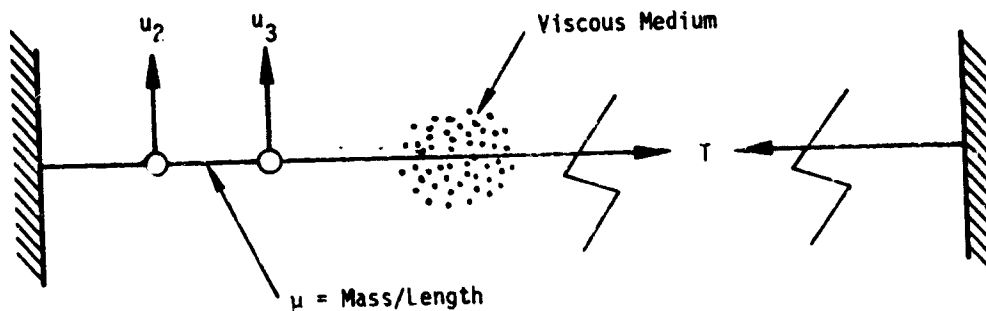
19.9.1.2 Notes on Data Cards

- 4. Selects Rigid Format 3 for a Normal Modes Analysis.
- 11. Selects method of real eigenvalue extraction from Bulk Data.
- 13-18. Requests printout of results.
- 20-28. Sets up for orthographic projection plotting of the original model, undeformed.
- 29-31. Sets up for orthographic projection plotting of the mode shapes using the first element set (PLØTEL) for each of the three mode shapes generated.
- 33-34. Quadrilateral plate element connectivities.
- 35-37. Specify methods for real eigenvalue extraction.
- 39-41. Grid point location and default single-point constraints.
- 45-46. Defines line elements for plotting.
- 47-48. Quadrilateral plate element properties.
- 49-53. Single-point constraints to define support conditions and symmetry boundary conditions.

## EXAMPLES OF DYNAMIC ANALYSES

### 19.9.2 Rigid Format 7 - Damped Vibration of a String

This problem demonstrates the use of direct complex eigenvalue analysis and the various methods of supplying damping to the structure. The simulated model is a string under tension having uniform viscous and structural damping, as shown below. The stiffness due to tension is modeled with scalar springs, the mass is represented by scalar masses, and the viscous damping is provided by scalar dampers connected on one end to the points and fixed on the other end. The structural damping is provided by the scalar springs and an overall damping factor,  $G$ . The user is encouraged to refer to the Demonstration Problem Manual, Section 7.1 for a detailed discussion of the theory and background to this problem.



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19.9.2.1 Input Cards - Scalar Elements

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Card  
No.

1 ID DEM701, NASTRAN  
2 TIME 8  
3 APP DISP  
4 SOL 7,1  
5 CEND  
  
6 TITLE = COMPLEX EIGENVALUES OF A 500 CELL STRING  
7 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 7-1-1  
8 CMETHOD = 1 \$ FEER  
9 OUTPUT  
10 SET 1 = 1,51,101,151,201,251,301,351,401,451,501  
11 DISP = 1  
12 BEGIN BULK

	1	2	3	4	5	6	7	8	9	10
13	CDAMP3	60002	401	2	0					
14	CDAMP3	60499	401	499	0	60500	401	500	0	
15	CELAS3	1	101	0	2	2	101	2	3	
16	CELAS3	400	101	499	500	500	101	500	0	
17	CMASS3	40002	301	2	0					
18	CMASS3	40499	301	499	0	40500	301	500	0	
19	EIGC	1	FEER	MAX			1.0-5			+CFEER
20	+CFEER	-1.0	15.0							
21	PARAM	G	.05							
22	PDAMP	481	6.283185							
23	PELAS	101	1.0+07	.05	10.0					
24	PMASS	301	10.0							
25	ENDDATA									

19.9.2.2 Notes on Data Cards

- 4. Selects the Direct Complex Eigenvalue Analysis approach.
- 8. Selects the FEER method of complex eigenvalue extraction from Bulk Data.
- 9-11. Requests printout of displacements for all grid points in set 1 which will be printed for each mode shape, real components only.
- 13-14. Scalar damper connectivities.
- 15-16. Scalar spring connectivities.
- 17-18. Scalar masses.
- 19-20. Specifies parameters and method for complex eigenvalue extraction.
- 21. Defines a uniform structural damping coefficient.
- 22-24. Defines scalar element properties.

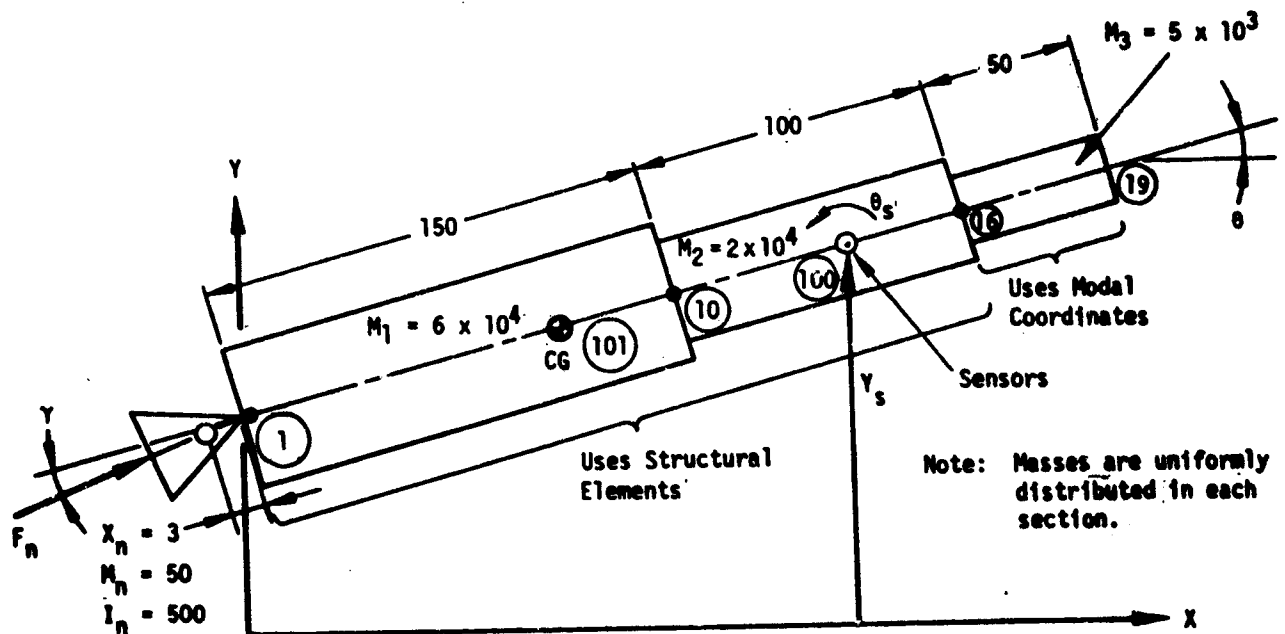
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## EXAMPLES OF DYNAMIC ANALYSES

### 19.9.3 Rigid Format 10 - Rocket Guidance and Control

This problem, although a simplified model, contains all of the elements used in a linear control system analysis. The flexible structure, shown below, consists of three sections: two sections are constructed of structural finite elements; the third section is formulated in terms of its modal coordinates. A sensor is located at an arbitrary point on the structure and connected to a structural point with multipoint constraints. The measured attitude and position of the sensor point is used to generate a voltage to control the gimbal angle of the thrust nozzle. The nozzle control is in itself a servomechanism consisting of an amplifier, a motor, and a position and velocity feedback control. The nozzle produces a force on the structure due to its mass, acceleration, and the angle of thrust. The motion of any point on the structure is dependent on the elastic motions and the large-angle effects due to free-body rotations.

The user should refer to the Demonstration Problem Manual, Section 10.1 for the discussion of the control system, the associated transfer function parameters, and other modeling details.



DYNAMIC ANALYSES

19.9.3.1 Input Cards - DMAP Alter, Transfer Function and Resequencing

Card  
No.

1 ID DEM1001, NASTRAN  
 2 DIAG 14  
 3 TIME 5  
 4 APP DISPLACEMENT  
 5 SOL 10,1  
 6 ALTER 103  
 7 MATGPR GPLD,USETD,SILD,PHIA//C,N,H/C,N,A \$  
 8 ENDALTER  
 9 CEND

10 TITLE = COMPLEX EIGENVALUE ANALYSIS - ROCKET CONTROL SYSTEM  
 11 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 10-1-1  
 LABEL = FLEXIBLE STRUCTURE CASE

13 MPC = 101  
 14 METHOD = 2  
 15 TFL = 20  
 16 CMETHOD = 11

17 OUTPUT  
 18 SET 1 = 1,100,101,1010 THRU 1090  
 19 SVECTOR (SORT1,PHASE) = ALL  
 20 DISPLACEMENT (SORT1,PHASE) = 1  
 21 BEGIN BULK

	1	2	3	4	5	6	7	8	9	10
22	BAROR									
23	CBAR	1	10	1	2	.0	10.0	.0	1	
24	CBAR	15	20	15	16					
25	CELAS4	1001	2.026+7	1001		1002	32.42+7	1002		
26	CELAS4	1003	164.1+7	1003		1004	518.7+7	1004		
27	CMASS4	2001	2.5+3	1001	2001	2002	2.5+3	1002		
28	CMASS4	2003	2.5+3	1003	2003	2004	2.5+3	1004	2002	
29	CONM2	101	1		3333.3				2004	
30	CONM2	119	19		833.3					
31	EIGC	11	DET	MAX						
32	+EC	-2.0	-1.0	-2.0	10.0	10.0	6	6		+EC
33	EIGP	11	0.0	0.0	2					
34	EIGR	2	INV	0.0	50.0	8	8	2		+E2
35	+E2	MASS								
36	EPINT	1010	1011	1030	1040	1050	1060	1070	1080	
37	GRDSET							1345		
38	GRID	1		0.0	0.0	0.0				
39	GRID	101	116.176	0.0	0.0					
40	MAT1	1	10.4+6	4.0+6						
41	MPC	3	16	6	-1	1001		.0628318		+161
42	MPC	100	11	6	1.0	100	6	-1.0		
43	MPCADD	101	100	3						
44	PARAM	GRDPNT	101							
45	PARAM	LMODES	4							
46	PBAR	10	1	4.0+2	6.0+4	6.0+4				
47	PBAR	20	1	2.0+2	2.0+4	2.0+4				
48	SEQGP	100	10.5	101	7.5					
49	SPINT	1001	1002	1003	1004	2001	2002	2003	2004	
50	SUPORT	101	2	101	6					
51	TF	20	1	2	.0	.0	50.0			+T6
52	TF	20	1080				8.5+4			+TX
53	+TX	100	6	-4.25+6						
54	ENDDATA									

## EXAMPLES OF DYNAMIC ANALYSES

### 19.9.3.2 Notes on Data Cards

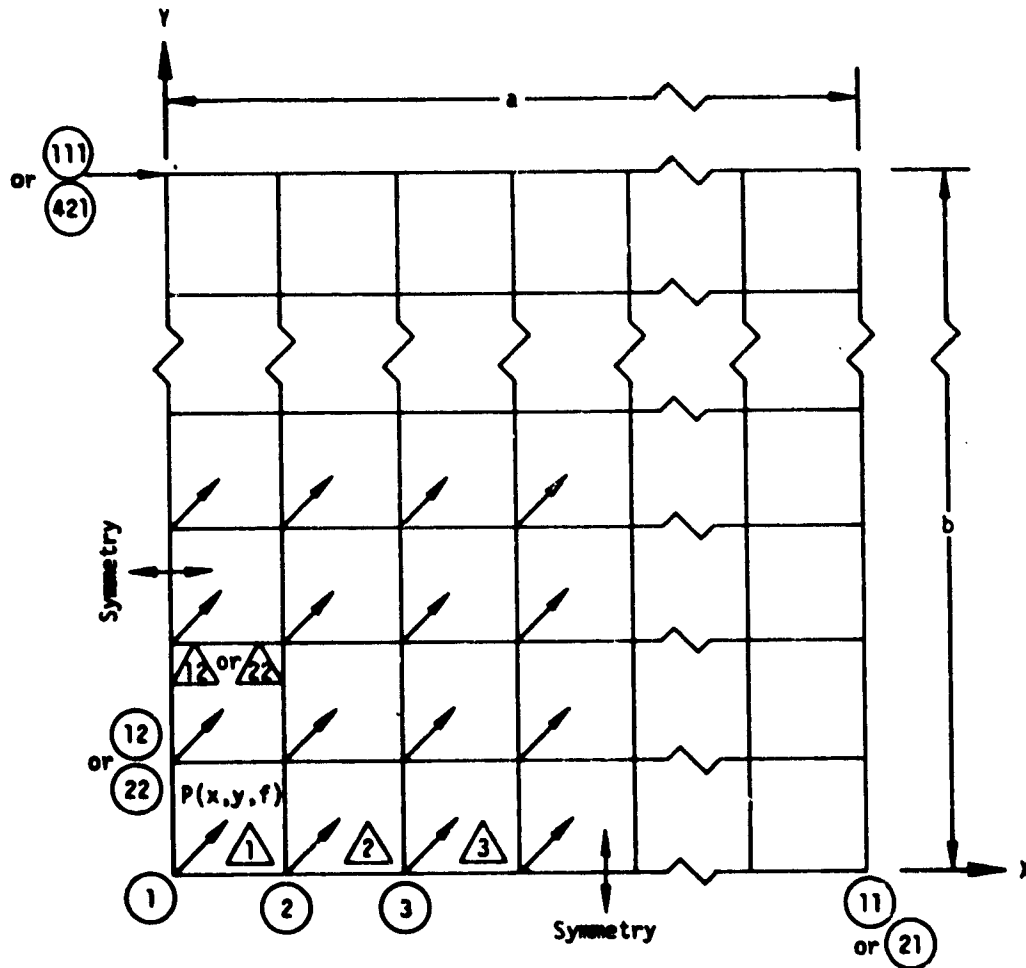
5. Selects the Modal Complex Eigenvalue Analysis approach.
- 6-8. DMAP alter package to print out the grid point list (GPLD), u-set degrees of freedom (USETD), scalar index list (SILD), and the normal modes matrix for the a-set displacements.
13. Selects a multipoint constraint set from Bulk Data.
14. Selects a method for real eigenvalue extraction from Bulk Data.
15. Selects the transfer function (TF) set from Bulk Data.
16. Selects the method for complex eigenvalue extraction from Bulk Data.
- 17-20. Request printout of SOLUTION set displacements and displacements for structural grid points of set 1 for each mode shape in magnitude/phase angle format.
- 22-24. Beam element connectivity.
- 25-28. Scalar element connectivity.
- 29-30. Concentrated mass data.
- 31-35. Parameters for methods of eigenvalue extraction. Card 33 defines poles in complex plane that are used with the associated EIGC parameters.
36. Definition of extra points used to define control system parameters.
- 37-39. Defines location of grid points and default single point constraints.
- 40-43. Multipoint constraint equations used to represent modal coordinates of model between grid points 16 and 19.
44. Requests weight and balance printout.
45. Defines number of lowest modes to be used in this modal formulation.
- 46-47. Beam element properties.
48. Specified resequencing of grid points 100 and 101.
49. Scalar point definition (need not be defined on SPPOINT card if number is used with scalar element definition, e.g., cards 25-28).
50. Defines degrees of freedom for use in computing determinate reactions for constraining rigid body motion.
- 51-53. Specification of transfer function parameters.

## DYNAMIC ANALYSES

### 19.9.4 Rigid Format 8 - Direct Frequency Response of a Plate

This problem illustrates the use of the direct method of determining structural response to steady-state sinusoidal loads. The steady-state response of the structure at each frequency is calculated in terms of complex numbers which reflect the magnitudes and phases of the results.

The particular model for this study is a square plate composed of quadrilateral plate elements, as shown below. The exterior edges are supported on hinged supports and symmetric boundaries are used along  $x=0$  and  $y=0$ . The applied load is sinusoidally distributed over the panel and increases with respect to frequency. For further details on the input and results, see the Demonstration Problem Manual, Section 8.0.





## EXAMPLES OF DYNAMIC ANALYSES

### 19.9.4.1 Input Cards - Frequency Dependent Loading

Card  
No.

```

1 ID CMB01X10, NASTRAN
2 APP DISPLACEMENT
3 SOL 8,1
4 TIME 12
5 CEND
6 TITLE = FREQUENCY RESPONSE OF A SQUARE PLATE
7 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 8-1-1
8 SPC = 37
9 DL0AD = 8
10 FREQUENCY = 8
11 OUTPUT
12 SET 1 = 1,4,7,11,45,55,78,88,111,114,117,121
13 DISPLACEMENT (SORT2,PHASE) = 1
14 SPCFORCE (SORT2,PHASE) = 1
15 BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
16	CQUAD1	1	23	1	2	13	12	.00		
17	CQUAD1	109	23	109	110	121	120	.00		
18	DAREA*	37		1		3		2.500000E-01		
19	DAREA*	37		109		3		2.4471748E-02		
20	FREQ	8	0.0	8.0	9.0	10.0	11.0			
21	GRDSET							126		
22	GRID	1		.0	.0	.0				
23	GRID	121		10.0	10.0	.0				
24	MAT1	8	3.0+7		.300					
25	PQUAD1	23			8	.6656667			13.55715	
26	RL0AD1	8	37			1				
27	SPC1	37	4	1	2	3	4	5	6	
28	+41001H	7	8	9	10	11				
29	SPC1	37	35	111	112	113	114	115	116	+21001H
30	+21001H	117	118	119	120	121				+T1
31	TABLED1	1								
32	+T1	0.0	10.0	100.0	40.0	ENDT				
33	ENDDATA									

### 19.9.4.2 Notes on Data Cards:

3. Selects Direct Frequency and Random Response Analysis approach.
9. Selects the RL0AD1 frequency response dynamic loading condition from Bulk Data.
10. Required to select from Bulk Data the set of frequencies to be solved.
13. Request the displacements for grid points of set 1 to be printed in magnitude/phase format, sorted by grid point.
14. Requests support forces to be printed at grid points of set 1 to be printed in magnitude/phase format, sorted by grid point.
- 16-17. Quadrilateral element connectivities.
- 18-19. Specifies the dynamic load scale factor and point of application in double precision format.
20. Defines set of frequencies for solution. Output will also be printed at these frequencies because no DFREQUENCY card is used.

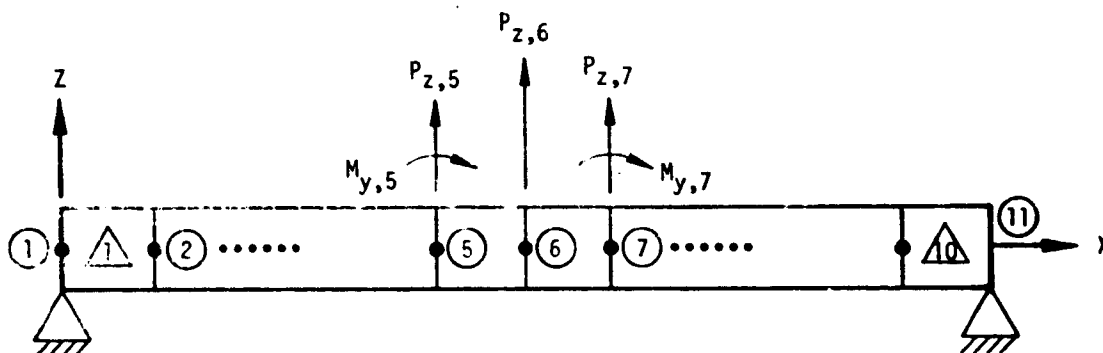
## DYNAMIC ANALYSES

- 21-23. Provides gridpoint locations and default single point constraints.
- 24-25. Defines material and element properties.
- 26. Defines frequency dependent dynamic load function.
- 27-30. Specifies support and symmetric boundary single point constraints.
- 31-32. Defines table of frequency dependent coefficients referenced, in this case, by RLOAD1 (field 6).

19.9.5 Rigid Format 11 - Modal Frequency and Random Response of a Beam

This problem demonstrates the frequency response solution of a structure using an uncoupled modal formulation. The structural degrees of freedom are the uncoupled modal displacements. This problem also illustrates various methods of applying frequency response loads which may be input as complex numbers and added together for each subcase.

The structure to be solved consists of a beam with simple supports, as shown below. Included in the structural model is a "general element" representing the first two cells of the ten-cell beam. The applied load for the three subcases are applied to the center three points on the beam. The random analysis data consists of a flat power spectral density function ("white noise") for the three loading subcases. The first subcase spectral density is correlated to the third subcase spectral density, simulating two interdependent probability functions. The XY-plotter capability is used for output. For further details and theory, see the Demonstration Problem Manual, Section 11.1.



19.9.5.1 Input Cards - "Complex" Loading and Random Response Output

Card No.	
0	NASTRAN FILES = (PLT2,NPTP)
1	ID DEM1101, NASTRAN
2	DIAG 14
3	CHKPNT YES
4	APP DISPLACEMENT
5	SOL 11,3
6	TIME
7	ALTER 112
8	MATPRN PHIA...// \$
9	ENDALTER
10	CEND

DYNAMIC ANALYSES

Card  
No.

```

11 MAXLINES = 50000
12 TITLE = FREQUENCY AND RANDOM RESPONSE OF A 10 CELL BEAM
13 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 11-1-1
14 SPC = 11
15 METHOD = 2
16 FREQUENCY = 503
17 RANDOM = 11
18 SDAMPING = 11
19 OUTPUT
20 SET 2 = 5,10
21 SET 6 = 6
22 SET 10 = 6,11
23 DISP(SORT2,PHASE) = 10
24 ACCELER(SORT2,PHASE) = 10
25 LOAD = 6
26 ELFORCE(SORT2,PHASE) = 2
27 SUBCASE 1
28 LABEL = THREE POINTS LOADED WITH TWO SETS
29 LOAD = 506
30 SUBCASE 2
31 LABEL = ONE POINT LOADED WITH TWO SETS AND TIME DELAYS
32 LOAD = 507
33 SUBCASE 3
34 LABEL = ONE POINT LOADED WITH TWO TABULAR LOADS
35 LOAD = 510
36 $ * * * * *
37 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 11-1-1
38 OUTPUT(XYOUT)
39 PLOTTER SC
40 CAMERA = 3
41 SKIP BETWEEN FRAMES = 1
42 XGRID LINE = YES
43 YGRID LINE = YES
44 XLOG = YES
45 YLOG = YES
46 XTITLE = FREQUENCY (HERTZ)
47 YTITLE = S
48 TCURVE = POWER SPECTRAL DENSITY OF POINT 6 DISPLACEMENT
49 XYPLOT,XYPRINT DISP PSDF / 6(T3)
50 $
51 TCURVE = POWER SPECTRAL DENSITY OF POINT 6 ACCELERATION
52 XYPLOT ACCELERATION PSDF / 6(T3)
53 $
54 XLOG = NO
55 YLOG = NO
56 XTITLE = TIME LAG (SECONDS)
57 YTITLE = R
58 TCURVE = AUTOCORRELATION FUNCTION FOR POINT 6 DISPLACEMENT
59 XYPLOT,XYPRINT DISP AUTO / 6(T3)
60 BEGIN BULK

```

EXAMPLES OF DYNAMIC ANALYSES

	1	2	3	4	5	6	7	8	9	10
61	CBAR	3	1	3	4	20.	.0	1.	1	
62	CBAR	10	1	10	11	20.	.0	1.	1	
63	CONN2*	11		1				5.34604-3		*M1
64	*M1	0.0								
65	CONN2*	12		2				1.069208-2		*M2
66	*M2	0.		0.						
67	CONN2*	13		3				5.34604-3		*M3
68	*M3									
69	DAREA	2	5	5	-100.					
70	DAREA	2	6	3	50.	5	3	50.		
71	DAREA	2	7	3	50.	7	5	100.		
72	DAREA	3	6	3	100.					
73	DAREA	510	6	3	1.0					
74	DELAY	1	6	3	.5555-2					
75	DLBAD	506	1.	1.	5	1.	6			
76	DLBAD	507	1.	1.	5	1.	7			
77	DLBAD	510	2.0	1.0	5101	1.0	5102			
78	DPHASE	1	6	3	30.					
79	DPHASE	5102	6	3	-30.0					
80	EIGR	2	INV	40.	1000.	3	5			+EG
81	+EG	MASS								
82	FREQ1	508	.0	5.0	40					
83	GENEL	1101		2	1	2	3	2	5	+1
84	+1	3	1	3	3	3	5			+2
85	+2	UD		1	1	1	3	1	5	*30
86	*30	2		.89044935-8		0.		0.		*31
87	*31	.89044935-8		0.		0.		3.08298-6		*40
88	*40	-2.31696-6		0.		7.7232005-6		-2.31696-6		*41
89	*41	2.31696-6		0.		-6.9508804-6		2.31696-6		*50
90	*50	1.7808987-8		0.		0.		24.714241-6		*51
91	*51	-9.26784-6		4.6339203-6						+60
92	+60	S	1.0	010	0.0	0.0	1.0	-2.0	0.0	+70
93	+70	0.0	1.0	1.0	0.0	0.0	0.0	1.0	-4.0	+80
94	+80	0.0	0.0	1.0						
95	GRDSET							246		
96	GRID	1		.0	.0	.0				
97	GRID	11		20.	.0	.0				
98	MAT1	1	10.4+6	4.+6		.2523-3				
99	PARAM	GRDPNT	0							
100	PARAM	LMODES	4							
101	PBAR	1		21.189	.083	.083				
102	RANDPS	11	1	1	.5		11			
103	RANDPS	11	1	3	.5		11			
104	RANDPS	11	2	2	1.0		11			
105	RANDPS	11	3	3	.5		11			
106	RANDT1	11	100	.0	.1					
107	RLBAD1	101	510			5101				
108	RLBAD1	5102	510		5102		5102			
109	RLBAD2	5	2			1				
110	RLBAD2	6	3		1	1	2			
111	RLBAD2	7	3	1		1				
112	SPC	1	1	13		11	13			
113	SPC	11	1	13		11	3			
114	TABDMP1	11								+DAMP
115	+DAMP	0.0	0.0	50.0	0.02	ENDT				
116	TABLED1	1								+TAUJ
117	+TAUJ	0.0	1.	100.	1.	ENDT				
118	TABLED1	2								+TAD21
119	+TAD21	0.0	30.	100.	30.	ENDT				
120	TABLED1	5101								+TAD30
121	+TAD30	0.0	75.0	1..0	75.0	ENDT				

## DYNAMIC ANALYSES

	1	2	3	4	5	6	7	8	9	10
122	TABLED1	5102								
123	+TAD31	0.0	50.0	100.	50.0	ENDT				+TAD31
124	TABRND1	11								
125	+TR	-1.0	0.0	0.0	100.0	100.0	100.0	100.0	0.0	+TR
126	+TR2	101.0	0.0	ENDT						+TR2
127	ENDDATA									

### 19.9.5.2 Notes on Data Cards

3. Checkpoint is requested to be taken.
5. Selects modal approach for Frequency and Random Response analysis removing the looping and mode acceleration computations.
- 7-9. DMAP alter to obtain a printout of the mode shapes for the analysis set of displacements generated during the real eigenvalue analysis. (This output is not otherwise available with this Rigid Format.)
11. Specifies a user limit in NASTRAN for a maximum of 50,000 lines of output.
14. Selects a set of single point constraints from Bulk Data.
15. Selects the method to be used for real eigenvalue extraction required to get the appropriate modal coordinate data for this modal approach.
16. Selects the set of frequencies required for solution of the frequency response analysis.
17. Selects the power spectral density factors (RANDPS) and autocorrelation function time lag (RANDT1) from Bulk Data required for the random response analysis.
18. Defines the equivalent of structural damping as a function of frequency in modal formulation problems (TM 9.3.4).
- 19-26. Specifies output sets for displacements, accelerations, loads and element forces. Note that the loads will be output for all frequencies at each grid point (SORT2) and in real/imaginary format. Because SORT2 was specified for other output quantities it overrides the SORT1 default for loads. Also note that requests for output of the results of the Random Response analysis are part of the XY plot output package.
- 27-29. Defines the first dynamic load to be analyzed.
- 30-32. Defines the second dynamic load to be analyzed.
- 33-35. Defines the third dynamic load to be analyzed.
- 37-40. Sets up for XY plots using Stromberg Carlson requesting both film and paper inserting one blank frame between each plot.
42. Requests drawing of vertical grid lines at each tic mark.
43. Requests drawing of horizontal grid lines at each tic mark.
- 46-47. Provides axis labeling information.
48. Provides label to identify curve being plotted.
49. Requests both plotted and printed output of the z-displacement power spectral density function for grid point 6.
51. Provides label to identify next curve to be plotted.
52. Requests plotted output of the z-acceleration power spectral density function for grid point 6.
- 54-55. Requests scalar distribution of tic marks for both the X and Y axes.
- 56-58. Provides titling information for next curve to be plotted.

## EXAMPLES OF DYNAMIC ANALYSES

- 59. Requests both plotted and printed output of the autocorrelation function for the z-displacement at grid point 6.
- 61-62. Defines beam element connectivities.
- 63-68. Defines concentrated mass elements in double precision format.
- 69-73. Specified dynamic load scale factor sets and the points of application.
- 74. Provides for the dynamic load time delay to be referenced by the RLOAD2 (SID=7 in field 4) card number 111.
- 75-77. Specifies the dynamic load combinations to be applied.
- 78-79. Provides for the dynamic load phase lead to be referenced in field 5 of the RLOAD2 and RLOADi cards 125 and 123, respectively.
- 80-81. Specified parameters for real eigenvalue extraction.
- 82. Specified frequency range and intervals for use in frequency response analysis ( $f_i = 0.0, 5.0, 10.0, \dots, 200.0$ ) or 40 increments.
- 83-94. Specifies general element matrix data (TM 5.7).
- 95-97. Defines grid point locations and default single point constraints.
- 98. Defines material properties.
- 99. Requests output for weight and balance.
- 100. Requests the four fundamental modes to be used as modal coordinates.
- 101. Beam element properties.
- 102-105. Specification of input power spectral density function.
- 106-111. Frequency response dynamic load functions.
- 112-113. Single point constraint sets (set 11 was selected).
- 114-115. Frequency dependent damping coefficient table referenced by SDAMP in Case Control.
- 116-123. Tabular definition of frequency dependent load coefficients referenced by RLOAD1 and RLOAD2 cards.
- 124-126. Tabular function of power spectral density function referenced by RANDPS cards.

## DYNAMIC ANALYSES

### 19.9.6 Rigid Format 9 - Direct Transient Analysis with Direct Matrix Input

This problem demonstrates the capability of NASTRAN to perform a transient analysis on a system having nonsymmetric stiffness, damping, and mass matrices. The problem is formulated with direct matrix input without the use of elements. It illustrates the use of time step changes, selection of printout intervals, application of loads, initial conditions, and a simple curve plot package. For details of the problem formulation and the results, see the Demonstration Problem Manual, Section 9.1.

#### 19.9.6.1 Input Cards - Direct Matrix Input and XYOUT Plotting

```
Card
No.
0  NASTRAN FILES = PLT2
1  ID DEM901, NASTRAN
2  DIAG 14
3  APP DISPLACEMENT
4  SOL 9,1
5  TIME 5
6  CEND

7  TITLE = TRANSIENT ANALYSIS WITH DIRECT MATRIX INPUT
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 9-1-1
9  TSTEP = 32
10 IC = 32
11 DLOAD = 32
12 K2PP=KCOMP
13 M2PP=MCOMP
14 B2PP=BCOMP
15 OUTPUT
16   SVELD = ALL
17   DISP(SORT2) = ALL
18   DLOAD(SORT2) = ALL
19 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 9-1-1
20 OUTPUT(XYOUT)
21   PLOTTER SC
22   CAMERA = 3
23   SKIP BETWEEN FRAMES = 1
24   TCURVE = * * * * EPINT DISPLACEMENT(INCHES) * * * *
25   XTITLE =      TIME(SECONDS)
26 $
27   YVALUE PRINT SKIP = 1
28   XDIVISIONS = 25
29   XVALUE PRINT SKIP = 1
30 $ * * * * * * * * * * FULL FRAME PLOTS * * * * *
31   YGRID LINES = YES
32   YGRID LINES = YES
33   YDIVISIONS = 22
34 $
```



EXAMPLES OF DYNAMIC ANALYSES

```

Card
No.
35      YTITLE = EP0INT 10      DISPLACEMENT *INCH*
36      XYPL0T DISP / 10(T1)
37      $
38      YDIVISIONS = 20
39      YTITLE = EP0INT 11      DISPLACEMENT *INCH*
40      XYPL0T DISP / 11(T1)
41      $
42      YTITLE = EP0INT 12      DISPLACEMENT *INCH*
43      XYPL0T DISP / 12(T1)
44      $
45      YTITLE = EP0INT 13      DISPLACEMENT *INCH*
46      XYPL0T DISP / 13(T1)
47      BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
48	DAREA	1	10		=1.5	11		-1.0		
49	DAREA	1	12		-13.5	13		36.0		
50	DELAY	1	10		1.0	11	1.0			
51	DELAY	1	12		1.0	13		1.0		
52	DMIG	BCOMP	0	1	1	2				
53	DMIG	BCOMP	11	0		10	0	-15.0		+BC1
54	+BC1	11	0	30.0		12	0	-15.0		
55	DMIG	BCOMP	12	0		11	0	-24.0		+BC2
56	+BC2	12	0	48.0		13	0	-24.0		
57	DMIG	BCOMP	13	0		12	0	-2.0		+BC3
58	+BC3	13	0	4.0						
59	DMIG	KCOMP	0	1	1	2				
60	DMIG	KCOMP	10	0		10	0	2000.		+KC1
61	+KC1	11	0	-1000.						
62	DMIG	DCOMP	12	0		11	0	-100.8		+KC2
63	+KC2	12	0	200.0		13	0	-100.0		
64	DMIG	KCOMP	13	0		12	0	-20.0		+KC3
65	+KC3	13	0	40.0						
66	DMIG	MCOMP	0	1	1	2				
67	DMIG	MCOMP	10	0		10	0	20.0		+MC1
68	+MC1	11	0	-10.0						
69	DMIG	MCOMP	11	0		18	0	-1.5		+MC2
70	+MC2	11	0	3.0		12	0	-1.5		
71	DMIG	MCOMP	12	0		11	0	-4.0		+MC4
72	+MC4	12	0	8.0		13	0	-4.0		
73	EP0INT	10	11	12	13					
74	TABLED1	1								
75	+T1	-1.0	0.0	0.0	0.0	.00	1.0	100.0	1.0	+T1
76	+T2	ENDT								+T2
77	TIC	32	10		0.0	10.0				
78	TIC	32	11		.0	.5				
79	TIC	32	12		.0	.0				
80	TIC	32	13		-10.0	.0				
81	TLOAD1	32	1	1		1				
82	TSTEP	32	40	.025	2					+S1
83	+S1		100	.015	5					
84	ENDDATA									

19.9.6.2 Notes on Data Cards:

4. Selects the direct approach to Transient Analysis.
9. Selects the integration time steps from Bulk Data (TSTEP)

## DYNAMIC ANALYSES

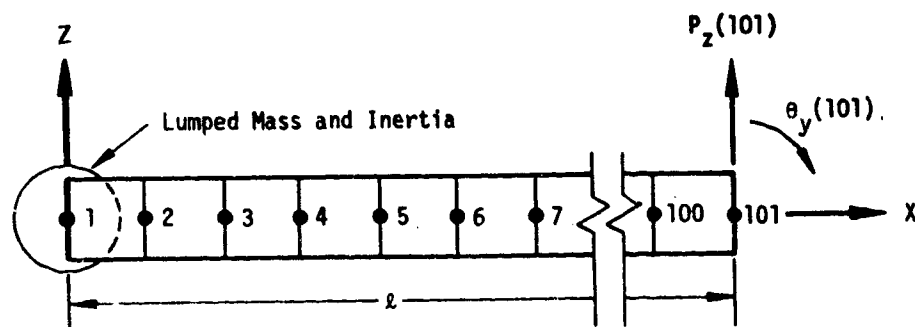
10. Selects the initial conditions from Bulk Data (TIC).
11. Selects the dynamic loading function from Bulk Data (TL0AD1).
- 12-14. Specifies the direct matrix input for stiffness, mass and damping respectively.
- 15-18. Specifies output requirements for all degrees of freedom in the model. Notice that because one output quantity specifies SORT2, all time steps for each degree of freedom, the SVELOCITY request will default also to SORT2.
- 19-23. Sets up for plotting with the XY-curve plotter.
- 24-25. Labeling information.
  27. Plot the value for every other tic mark along the Y-axis.
  28. Provide 25 divisions along the X-axis.
  29. Plot the value for every other tic mark along the X-axis.
- 31-32. Plot grid lines for each tic mark in both directions.
  33. Provide 22 divisions along the Y-axis.
  35. Title for Y-axis.
  36. Requests plot of displacement for extra point 10 versus time.
- 38-39. Provide 20 divisions and new title for Y-axis.
  40. Requests plot of displacement for extra point 11 versus time.
  42. Use same 20 divisions and new title for Y-axis.
  43. Requests plot of displacement for extra point 12 versus time.
- 45-46. Repeat 42 and 43 for plot of displacements for extra point 13.
- 48-49. Dynamic load factors applied to extra points.
- 50-51. Delay factors for each extra point loading.
- 52-58. Direct matrix input at extra points for damping.
- 59-65. Direct matrix input at extra points for stiffness.
- 66-72. Direct matrix input at extra points for mass.
  73. Provides identification for extra points (single degree of freedom per point).
- 74-76. Table of dynamic load coefficients versus time referenced by TL0AD1 card (field 6).
- 77-80. Specifies time dependent loading function.
  81. Specifies time dependent loading function.
- 82-83. Specifies two sets of time step intervals for integration of the transient response and user specifies output interval.

**SPECIAL NOTE:** No structural elements were used in this problem. All degrees of freedom were identified with separate extra points.

## EXAMPLES OF DYNAMIC ANALYSES

### 19.9.7 Rigid Format 12 - Modal Transient Response of a Beam

This problem demonstrates the transient analysis of a free-body using the integration algorithm for uncoupled modal formulation. A hundred-cell beam model is shown below. Modal damping is included as a function of natural frequency. The omitted coordinate feature was used to reduce the number of degrees of freedom to an analysis set equivalent to eleven grid points. Both structural and curve plots are requested. For further details and the results, see the Demonstration Problem Manual, Section 12.1



#### 19.9.7.1 Input Cards - Both Structural and XYOUT Plotting

```

Card
No.
0  NASTRAN FILES = PLT2
1  ID DEM1201, NASTRAN
3  APP DISPLACEMENT
4  SOL 12,3
5  TIME 10
6  CEND

7  TITLE = TRANSIENT ANALYSIS OF A FREE ONE HUNDRED CELL BEAM
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 12-1-1
9  DLOAD = 516
10 SDAMP = 15
11 TSTEP = 516
12 METHOD = 2
13 OUTPUT
14 SET 1 = 1, 26, 51, 75, 100
15 SET 2 = 1, 26, 76
16 DISPLACEMENT = 2
17 STRESS = 1
18 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 12-1-1
19 OUTPUT(PLT)
20 PLOTTER SC
    
```

DYNAMIC ANALYSES

Card  
No.

```

21 SET 1 INCLUDE BAR EXCLUDE GRID POINTS 1 THRU 9,11 THRU 20
22 22 THRU 30,32 THRU 40,42 THRU 50,52 THRU 60,62 THRU 70
23 72 THRU 80,82 THRU 90,92 THRU 100
24 MAXIMUM DEFORMATION 2.0
25 STEREO PROJECTION
26 FIND SCALE, ORIGIN 100, VANTAGE POINT, SET 1
27 PLOT SET 1, ORIGIN 100, SHAPE, LABELS
28 PLOT TRANSIENT DEFORMATION 1, TIME .012, 0.013,
29 MAXIMUM DEFORMATION 0.76, SET 1, ORIGIN 100, SHAPE
30 ORTHOGRAPHIC PROJECTION
31 FIND SCALE, ORIGIN 1, REGION 0.0,0.0,1.0,0.5
32 FIND SCALE, ORIGIN 2, REGION 0.0,0.5,1.0,1.0
33 PLOT TRANSIENT DEFORMATION 1, TIME .012, .016
34 MAXIMUM DEFORMATION 1.0,
35 SET1, ORIGIN 1, SHAPE ,
36 SET 1, ORIGIN 2, VECTOR Z
37 $
38 OUTPUT(XYOUT)
39 PLOTTER SC
40 CAMERA = 3
41 SKIP BETWEEN FRAMES = 1
42 YGRID LINES = YES
43 XGRID LINES = YES
44 YDIVISIONS = 10
45 XDIVISIONS = 10
46 XVALUE PRINT SKIP = 1
47 YVALUE PRINT SKIP = 1
48 XTITLE = TIME (SECONDS)
49 YTITLE = DISP * INCH *
50 TCURVE = ***** GRID 51 *****
51 XPL0T,XYPRINT,DISP RESP / 51 51(T3)
52 TCURVE = ***** GRID 101 *****
53 XYPL0T,XYPRINT,DISP RESP / 101(T3)
54 YTITLE = ACCELERATION
55 TCURVE = ***** GRID 51 *****
56 YXPL0T,XYPRINT,ACCE RESP / 51(T3)
57 TCURVE = ***** GRID 101 *****
58 XYPL0T,XYPRINT,ACCE RESP / 101(T3)
59 BEGIN BULK

```

	1	2	3	4	5	6	7	8	9	10
60 BAR0R						10.0	.0	100.0	1	
61 CBAR	1	17		1	2					
62 CBAR	100	17		100	101					
63 CONM2	20	1			10.0					+M1
64 +M1				1666.7						
65 DAREA	1	101		3	100.					
66 EIGR	2	INV		.0	1500.	5	6			+EG
67 +EG		MASS								
68 GRDSET								1246		
69 GRID	1			.00	.00	.00				
70 GRID	101			20.00	.00	.00				
71 MAT1	1		10.4+6	4.+6		.2523-3				+MAT1
72 +MAT1	111.11		11.111							
73 OMIT1	53	2		3	4	5	6	7	8	+100
74 +201	98	99		100						
75 PARAM	GRDPNT	0								
76 PARAM	LMODES									

### EXAMPLES OF DYNAMIC ANALYSES

	1	2	3	4	5	6	7	8	9	10
77	PBAR	17	1	1.	.083	.083				+PBAR
78	+PBAR	1.111	-1.111							
79	SUPORT	1	3	1	5					+TDI1
80	TABDMP1	15								
81	+TDI1	10.0	.01	100.	.1	3000.	.1	ENDT		
82	TLØAD2	516	1			.0	.1	60.		
83	TSTEP	516	104	.00139	1					
84	ENDDATA									

#### 19.9.7.2 Notes on Data Cards

4. Selects the modal approach to Transient Analysis without looping and without modal acceleration computations.
- 9-11. Selects dynamic load function, frequency dependent equivalent coefficients for structural damping (TM 9.3.4) and integration time step intervals from Bulk Data.
12. Selects method for real eigenvalue extraction.
- 13-17. Specifies desired output for displacements and element stresses.
- 18-20. Sets up for structural plotting.
- 21-23. Defines elements and grid points to be plotted.
24. Specifies the maximum deformation to be plotted on a scale of 2.0 relative to the length of the beam (I - 20.0). Note, must come before the FIND card.
25. Requests the following plots be in stereo.
26. Sets up plot parameters.
27. Plot element set 1 as undeformed structure.
28. Plot transient deformations in the time range from 0.012 to 0.013 without the underlay of the undeformed model. Note that only one subcase is implied even though no subcase delimiter is present. Also, the maximum deformation will be plotted to 76 percent of originally defined scale for all mode shapes.
30. Sets up now for orthographic projection.
31. Sets parameters for a plot on the lower half page.
32. Sets parameters for a plot on the upper half page.
- 33-36. Requests two plots of transient response within the time range of 0.012 to 0.016. The deformed shape is plotted in the lower half of the plot page and the z-component vectors are plotted in the upper half of the plot page.
- 38-41. Sets up for XY curve plotting.
- 42-43. Requests plots of grid lines both in X and Y directions.
- 44-45. Specifies ten intervals in both X and Y directions.
- 46-47. Requests values be plotted for every other tick mark.
- 48-50. Axes and curve labeling informations.
51. Requests both plotted and printed output of the z-displacement response at grid point 51.
- 52-53. New curve title and same output request for grid point 101.
- 54-58. New axis and curve label information and a request for both plotted and printed output of the z-acceleration response at grid points 51 and 101.
- 60-62. Beam default parameters and element connectivities.
- 63-64. Concentrated mass inertial properties.

## DYNAMIC ANALYSES

- 65. Dynamic load factor and point of application.
- 66-67. Specified parameters for real eigenvalue extraction.
- 68-70. Gridpoint location and default single point constraints.
- 71-72. Material properties.
- 73-74. Specifies degrees of freedom to be omitted by Guyan reduction.
- 75-76. Requests weight and balance output and specified first six fundamental modes be used as modal coordinates.
- 77-78. Beam properties.
  - 79. Provides fictitious components for computing determinate reactions for constraining free body acceleration.
- 80-81. Defines frequency dependent coefficients for equivalent structural damping to be selected from Case Control (SDAMP).
- 82. Specifies transient response dynamic load.
- 83. Specified integration time step intervals and the interval for which output is generated.

## 20. SUBSTRUCTURING AND MODAL SYNTHESIS

### 20.1 INTRODUCTION

Substructuring is an analytical technique used to facilitate the solution of structural problems by subdividing the structural models into smaller, more manageable components. The most elementary component, or basic substructure, is modeled separately just as any finite element model would be. These basic substructures are combined to build more complex substructures which, in turn, can be progressively combined with other substructures in stages to eventually arrive at the final desired solution model. Once the solution model is analyzed, the results at each stage of the combination process may be recovered until, ultimately, the detailed solution data are recovered for each of the original basic substructures. In effect, substructuring is an extension of basic finite element theory itself whereby the usual simple beam, plate, and solid elements are replaced by basic substructures which themselves may be viewed as components of even more complex substructure.

To provide maximum program flexibility, both manual and automated approaches to substructuring are available. The manual approach requires user-generated DMAP alters and can be used in all Rigid Formats except Piecewise Linear Analysis. The procedures for single-stage manual substructuring are discussed and illustrated with a complete and fully annotated example of the input in Section 1.10 of the User's Manual.

The following discussion is concerned entirely with automated multi-stage substructuring, which provides the following features:

1. Simple commands to control execution and data recovery at all stages of analysis.
2. Automatically generated DMAP alters.
3. Automated procedures to control and maintain the extensive data files required.
4. Data storage on single direct access file.
5. Data transfer between IBM, CDC, or UNIVAC computers at any stage in the analysis.
6. No restrictions on grid point and element numbering.
7. Modeling only one of two or more identical substructure components.
8. Substructure reduction to model coordinates (modal synthesis).

To effectively employ this automated substructuring capability of NASTRAN for static and dynamic analyses, the user should gain an overall understanding of the basic program design concepts, the data base on which it operates, and the control functions provided. These topics are discussed in the sections which follow.

## SUBSTRUCTURING AND MODAL SYNTHESIS

Complete examples of substructuring analysis with listings and explanations of input data cards are included in Section 20.19. The new user would benefit greatly by executing these examples as a first test of the automated substructuring system.

A complete description of all aspects of automated substructuring is presented in the User's Manual, Section 1.10.2. In that section, many details of using the SBF, interpreting substructuring diagnostic printout, etc., are presented and thus not presented here in the User's Guide. A detailed description of the substructuring control cards and a summary of pertinent bulk data cards is provided in Section 2.7 of the User's Manual. A detailed description of each of these bulk data cards is included alphabetically along with all other bulk data cards in the User's Manual, Section 2.4. The basic theory of automated substructuring is presented in Section 4.6 of the Theoretical Manual. The special transformations for modal synthesis are developed in Section 18 of the Theoretical Manual.

It should be noted that cyclic symmetry is available as an alternate formulation for substructuring structures with rotational or dihedral symmetry. This capability is described in the User's Guide, Section 23.



## BASIC CONCEPTS

### 20.2 BASIC CONCEPTS

Automated substructuring analysis is available for use with NASTRAN Rigid Formats 1, 2, 3, 8, and 9. This provides capability for static analysis, static analysis with inertial relief for unsupported structures, normal modes, frequency response, and transient response analyses. The capability allows an unlimited number of substructures to be combined and/or reduced in any sequence desired. Each substructure is represented by its mass, stiffness, and damping matrices. A reduction in size or condensation of these matrices is accomplished using the Guyan reduction technique or reduction to normal or complex modal coordinates.

Although the NASTRAN substructuring system may be very effectively used for small and moderate size problems, several features were designed and implemented to accommodate very large problems. The most important of these features is the automated data base management system used to maintain the Substructure Operating File (SØF) on which all pertinent matrix and substructural loading data and associated control files are stored. This SØF carries all the information needed from run to run throughout a substructuring analysis.

Processing of a substructuring analysis is subdivided into three phases:

Phase 1: Initial generation of individual basic matrices.

Phase 2: Substructure matrix reduction and assembly, solution of the assembled substructure, and recovery of substructure displacements and reaction forces.

Phase 3: Completion of the analysis with conventional selective output for each individual basic substructure.

A NASTRAN substructuring run generally proceeds in the following manner: First, several separate Phase 1 executions are performed, one for each basic substructure. Second, one or more Phase 2 executions may be performed. In a Phase 2 run, any number of substructure reductions and/or combinations, resulting in higher level (more complex) pseudostructures, may be performed. Phase 2 processing may be halted at any stage of the model assembly and then continued in a subsequent Phase 2 execution. The results at each step in the operation are stored in the SØF so as to be available for subsequent execution. The final steps of a Phase 2 operation would be the solution step for the highest level structure and the data recovery steps with limited output capability (displacements, forces of constraint, modal energies, and applied loads only) for any lower level substructure. Complete and detailed

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**SUBSTRUCTURING AND MODAL SYNTHESIS**

data recovery for the basic substructures must be obtained by separate Phase 3 executions, one for each basic substructure. This level of data recovery may include any or all of the NASTRAN output normal for a non-substructure analysis.

All Phase 2 operations except the solution step may also be performed in a Phase 1 execution. However, the user must remember that the first step of a Phase 1 execution must involve the creation of a new basic substructure.

Automated substructuring allows each basic substructure to be defined independently. This concept is represented by three key features of the system.

1. There are no restrictions as to duplication of grid point or element identification numbers, load sets, individual coordinate systems, etc. All data for a given substructure is associated with an assigned unique name for that structure. The only data restriction is one of proper modeling, i.e., common boundaries require grid points to be located in a consistent manner relative to one another for each connecting substructure.
2. No substructure may appear as a component of another substructure more than once, and no degrees of freedom within a substructure may be connected ("combined") to other degrees of freedom in that same substructure except by multipoint constraints imposed at the solution step operation or in Phase 1 creation of the substructure.
3. All pertinent substructure data are stored on the SØF, an expandable direct access file. This file may be selectively edited and/or dumped to tape and transmitted to another user who may have need of the data. Provision is made for automated tape conversion among CDC, IBM, and UNIVAC computers to facilitate such data transmittal between different users. Use of this file is described in Section 1.10.2 of the User's Manual.

Control of the automated substructuring system is obtained through the use of linguistic commands, similar to those of Case Control. These commands are placed in the Substructure Control Deck shown in Figure 1. This Substructure Control Deck is input between the Executive Control and Case Control Decks.

Each substructure control command is automatically translated into appropriate DMAP ALTER cards to augment the requested Rigid Format sequence. The user may also include his own DMAP

BASIC CONCEPTS

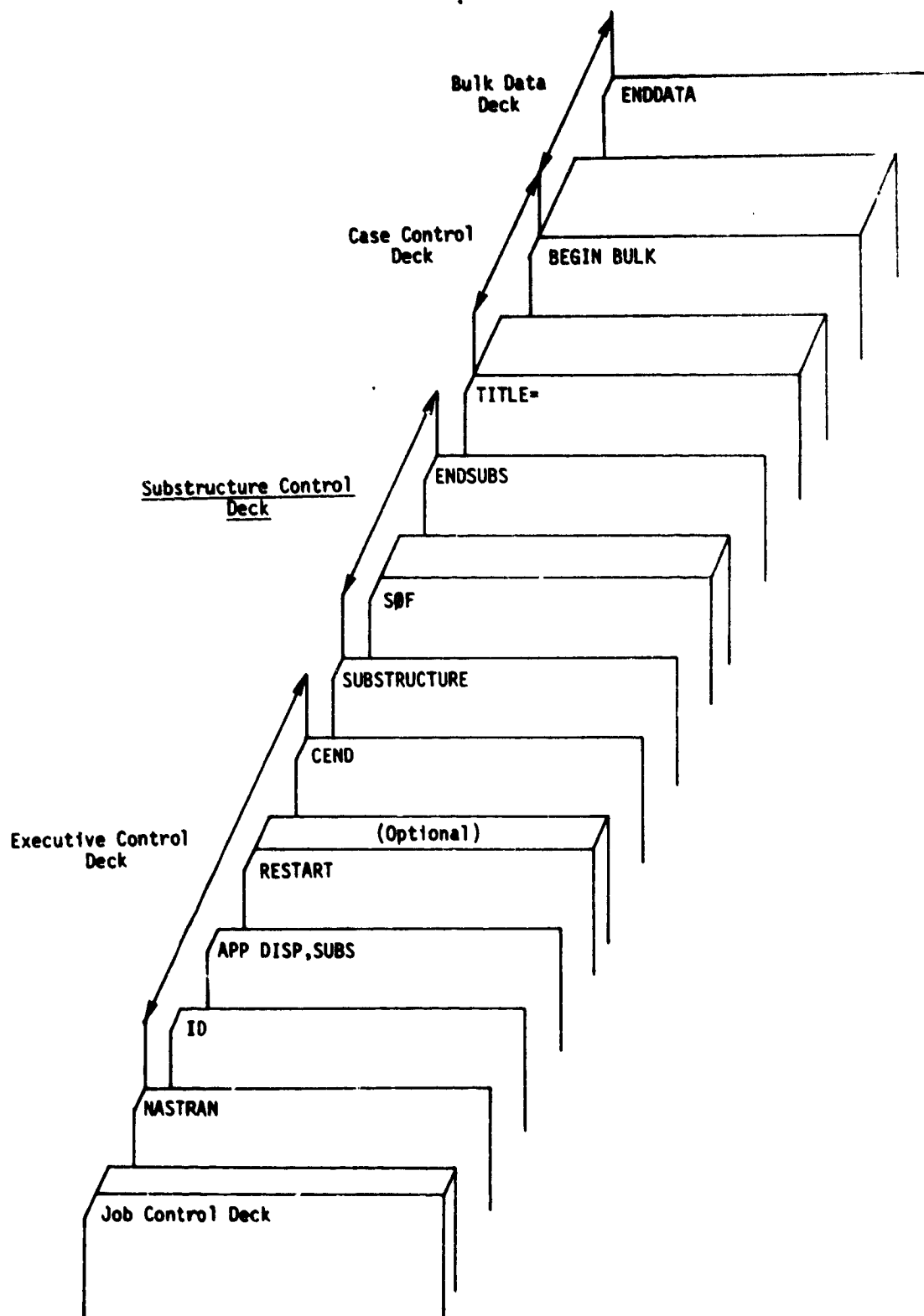


Figure 1. Substructuring Input Data Deck.

## SUBSTRUCTURING AND MODAL SYNTHESIS

ALTER commands, or he may modify a previously defined DMAP sequence. A description of how the user may interface with this NASTRAN-generated substructuring DMAP is presented in Section 2.7.2 of the User's Manual. Listings of the DMAP ALTER's generated by each substructure command are presented in Section 5.9 of the User's Manual. Descriptions of the corresponding modules provided for substructuring are found in the NASTRAN Programmer's Manual.

## SUMMARY OF OPERATIONAL COMMANDS

### 20.3 SUMMARY OF OPERATIONAL COMMANDS

User control of the automated multi-stage substructuring system is obtained via the Substructure Control Deck commands. The key terms used to describe these commands and their functions are defined in Table 1. A summary of the substructuring command options is presented in Table 2. Some of these commands require specific bulk data cards which are listed for each reference in Table 3. The user should also refer to Section 2.7 of the User's Manual for a complete description of the Substructure Control Deck commands and to Section 2.3 for detailed descriptions of the corresponding bulk data cards.

#### 20.3.1 The Substructure Analysis Tree

The operation and control functions of automated substructuring analysis are best illustrated and explained using the "tree" structure presented in Figure 1. This figure defines the genealogy of all the component substructures used in building the final model. Basic substructures are created at the Phase 1 level. Substructures "A," "B," and "E" are shown in solid boxes indicating they were formed from actual data deck submittals and are physically different models. The dotted boxes are called "image" substructures and are the result of the EQUIVALENCE operation, described next.

#### 20.3.2 Equivalence Operation

To reduce the potential for input error and to simplify the bookkeeping tasks, all specific references to loadings and grid points for connections, boundary sets, constraints, etc., are made with respect to the basic substructure name only. No component substructure name may be used more than once while building the solution structure. If the same component substructure is to be used more than once, the EQUIVALENCE operations should be used to assign unique names to all substructures comprising that component. The dotted boxes in Figure 1 are called "image" substructures and are the result of an EQUIVALENCE operation rather than an actual Phase 1 data deck submittal. The EQUIVALENCE operation defines a new substructure which is a duplicate of an existing substructure and automatically creates all equivalent lower level component substructures. The term "lower level" refers to the less complex of the component substructures which are used to create a higher level, or more complex substructure. Thus, space is saved on the data files by eliminating storage of redundant matrix data. A four-bladed propeller, for example, could be seen to consist of four identical components and, hence, only one need

SUBSTRUCTURING AND MODAL SYNTHESIS

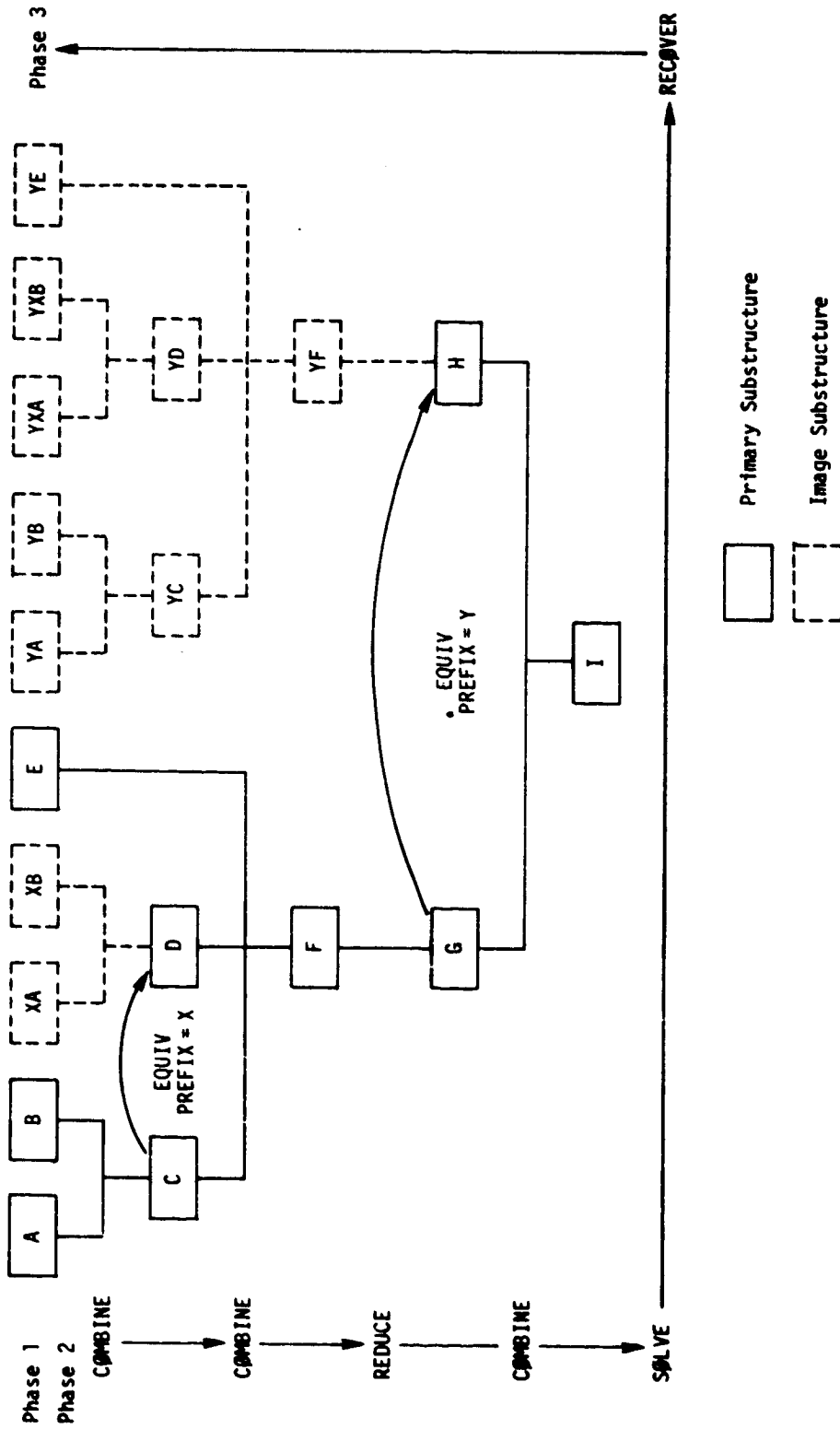


Figure 1. Example of Multi-Stage Substructuring.

## SUMMARY OF OPERATIONAL COMMANDS

be explicitly modeled. The other three blades could be defined solely by using the EQUIVALENCE command.

The image substructures exist in name only. Note in Figure 1 that the names of the image structures are identical to the equivalent parent structure, with the exception of a prefix character. The new names would be created automatically by NASTRAN with the use of the PREFIX subcommand to EQUIVALENCE. These new prefixed names would then be used to reference the appropriate component substructure as if it were created independently.

From the user point of view, all substructures shown in Figure 1, with either solid or dotted boxes, are separate and distinct substructures. They may have different applied loads, boundary conditions, and responses. For example, though only A, B and E represent actual Phase 1 executions, Phase 3 data recovery executions may be made for A, B, E, XA, XB, YA, YB, YXA, YXB, and YE, each of which generally would have different results.

Substructure names are allowed no more than eight alphanumeric characters. Notice in the EQUIVALENCE operation shown in Figure 1, the required subcommand PREFIX generates an additional character which is placed ahead of the existing name as a prefix to the parent substructure name. Care must be taken with successive EQUIV operations to monitor the growth of image substructure names so as not to exceed the eight-character limit. If the limit is exceeded, the right-most character will be truncated. Therefore, it is possible to inadvertently create duplicate substructure names as more prefixes are added. It is recommended, therefore, that the entire tree structure for the analysis be prepared ahead of time to help avoid these problems. This preplanning will also be an invaluable aid to the task of data preparation and proper sequencing of the individual steps in the analysis.

## SUBSTRUCTURING AND MODAL SYNTHESIS

### 20.3.3 Combine Operation

The `COMBINE` command (see Table 2) with its numerous subcommands, offers flexibility in the assembly of substructures into a higher level substructure. The `COMBINE` capability allows component substructures to be translated, rotated, and/or symmetrically transformed via mirror image transformation for proper positioning in space.

For example, the right wing of an aircraft is first modeled and an `EQUIVALENCE` operation is performed to define an identical duplicate wing. Then, in the `COMBINE` operation, a `SYMTRANSFORM` is applied so that the wing now appear as the actual left wing (a mirror image of the right wing), and a `TRANSFORM` is applied to properly position it on the left side of the aircraft. Caution is advised in that the symmetry transformation (`SYMTRAN`) is always applied to the component in its own basic coordinate system before the usual translation and rotation (`TRANS`) for final positioning. The mathematical implications of these commands are discussed in Section 4.6 of the Theoretical Manual.

Substructures which may change due to design iterations should be combined with other structures as late in the sequence of `COMBINE` operations as possible. This will minimize the cost of creating a new solution structure. Also, if the design iteration changes are minor and their impact on other substructures in the model can be neglected, then `RECOVER` operations (described later) need be performed only from the lowest level of substructure affected by the changes. Frequently, these design changes can be evaluated using only the Phase 3 recovery calculation. Of course, care must be taken to maintain compatibility with the degree of freedom list defining the solution displacement vector. That is, the boundary grid points and connections should not be changed.

Careful ordering of the list of substructure names for any `COMBINE` command is advised for the purposes of controlling the bandwidth of the resulting matrices. For example, the commands

```
COMBINE A, B, C, D
NAME = ABCD
```

yield substructure ABCD with matrix row and column sequences defined by:

```
A          INTERIOR
AB         BOUNDARY
```



#### SUMMARY OF OPERATIONAL COMMANDS

C	INTERIOR
AC	BOUNDARY
BC	BOUNDARY
ABC	BOUNDARY
C	INTERIOR
etc.	

Thus, control of matrix bandwidth is possible with the COMBINE command just as it is at the component level with grid point sequencing.

Another factor to consider in ordering the substructure names in the COMBINE command is the sum of matrix multiply times required for execution. To minimize the time required for the COMBINE matrix multiply operations the list of substructures, A, B, C, etc., should be smallest model to largest model (using matrix size as the criterion).

#### 20.3.4 Reduce Operation

The REDUCE command causes a Guyan reduction to be performed on an existing substructure. The user specifies which degrees of freedom are to be retained using the BDYC and BDYS (or BDYS1) bulk data cards provided. The degrees of freedom retained are all called boundary degrees of freedom although they need not ever appear on the boundary with another substructure. Obviously, all degrees of freedom eventually needed for boundary connections must be retained, i.e., they must not be reduced out. However, care must be taken to retain in this boundary set all the appropriate degrees of freedom needed to represent the dominant displacement patterns for accurate calculation of eigenvalues and eigenvectors for normal modes analyses.

#### 20.3.5 MREDUCE or CREDUCE Operation

The MREDUCE and CREDUCE commands provide a modal synthesis capability to automated multi-stage substructuring. With these commands the user defines boundary degrees of freedom to identify degrees of freedom retained as physical coordinates. The remaining degrees of freedom are replaced by a smaller set of normal (MREDUCE) or complex (CREDUCE) generalized modal coordinates. MREDUCE may be used when real symmetric mass and stiffness matrices are used to define the model. CREDUCE provides a general model reduction capability when damped modes are desired or complex or unsymmetric matrices are present.

## SUBSTRUCTURING AND MODAL SYNTHESIS

The user may also define constraints for the structure to be applied only for the purpose of calculating the modes. BDYC and BDYS (or BDYS1) bulk data cards are used to define these degrees of freedom and are requested by the subcommand FIXED.

Note that for both the REDUCE and MREDUCE substructure commands, the damping matrices, B and K4, and the load vectors, P, are transformed to the reduced set of coordinates. The reduced substructures may be processed with any of the other substructure operations. However, substructures generated with the complex modal reduction, CREDUCE, may not be processed with any commands requiring real arithmetic, namely REDUCE, MREDUCE, or SOLVE with Rigid Formats 1, 2, 3, or 9.

### 20.3.6 Solve Operation

As many EQUIVALENCE, COMBINE, REDUCE, MREDUCE, or CREDUCE commands as desired may be used in one or more Phase 1 or Phase 2 executions. However, only one SOLVE command is allowed in any single Phase 2 execution, and the SOLVE command is not allowed in Phase 1 executions. As indicated in the definitions of Table 1, the SOLVE command requests a solution for structural response to applied static loads (Rigid Formats 1 and 2), the calculation of normal modes (Rigid Format 3), or structural response to frequency dependent or time loads (Rigid Formats 8 and 9) of the substructure named in the command.

### 20.3.7 Recover Operations

The RECOVER command is used to recover the solution data for successively lower level substructures. Only the displacements, forces of constraint, modal energies, and applied loads can be selectively output for any component substructure with this command. The BRECOVER command is then used in a Phase 3 execution to obtain all the detail response output normally provided by NASTRAN for each desired basic substructure. The command, MRECOVER, is used to recover mode shape data for modal reduced substructures.

### 20.3.8 Plot Operations

Capability for creating structural model plots is provided in substructuring in either Phase 1, 2, or 3. Undeformed plots may be developed in Phase 1 or 2, and deformed structural plots of individual substructures may be generated in Phase 3. XY response plots may be generated in either Phase 2 or 3.

## SUMMARY OF OPERATIONAL COMMANDS

Phase 1 plotting may be performed in two ways. First, all structural plot requests in the Case Control Deck will be executed for the basic substructure model data submitted. Second, any Substructure Control Deck commands of the form

PLØT name

will cause all Case Control Deck plot requests to be executed for the named substructure. Plot executed for the named substructure. Plot data are generated in this case only if the SAVEPLØT = N command was used in the Phase 1 executions for those basic substructures which form the named substructure. The SAVEPLØT = N command causes plot set N to be saved for that substructure. Note, only one plot set may be saved for any substructure.

Undeformed structural plots are generated in Phase 2 under the following conditions:

1. The SAVEPLØT command was used in the Phase 1 runs and plot sets were defined in the Case Control Deck for those runs.
2. The PLØT command is used in the Phase 2 Substructure Control Deck.
3. Case Control Deck cards for structural plots are present.

XY response plots may be generated in Phase 2 under the following conditions:

1. The Phase 2 run must include a RECOVER operation (normally follows a SOLVE command).
2. The Rigid Format must be either 8 or 9.
3. The Case Control Deck XY plot requests must reference only the scalar degrees of freedom associated with the SOLVED structure.

Structural plots and XY plots are generated in Phase 3 runs using Case Control Deck cards in the same way as for non-substructuring analyses. All output requested with these Case Control Deck cards is associated with the particular substructure involved in the Phase 3 run. No Substructure Control Deck PLØT commands are used in Phase 3.

Examples of plotting with substructure analysis are presented in Section 20.4 following.

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 1. Definitions of Substructure Terminology

Basic Substructure	- A structure formulated from finite elements in Phase 1.
Boundary Set	- Set of degrees of freedom to be retained in a reduce operation.
Combine Operation	- Merge two or more structures by connecting related degrees of freedom. The matrix elements for connected degrees of freedom are added to produce the combined structure matrices, and the substructure load vectors are processed and stored for subsequent combination at solution time.
Component Substructure	- Any basic or pseudostructure comprising a part of an assembled substructure.
Connection Set	- Set of grid points and their component degrees of freedom to be connected in adjoining structures.
Equivalence Operation	- The creation of a secondary substructure equivalent to a primary substructure. Also creates image substructures back to the basic substructure level.
Image Substructure	- A substructure equivalent to an existing component substructure. May have different applied loads and/or solution vectors but had identical stiffness and mass matrices. Image substructures are automatically created as a result of an equivalence operation.
Phase (1, 2, or 3)	- Basic steps required for multi-stage substructure processing with NASTRAN - creation, combination, reduction, solution and recovery, and data recovery.
Primary Substructure	- Any basic substructure or any substructure resulting from a combine or reduce operation.
Pseudostructure	- A combination of component substructures.
Reduce Operation	- Structural matrix and load vector Guyan or modal reduction process to obtain smaller matrices.
Secondary Substructure	- A substructure created from an equivalence operation.
SOF	- Substructure Operating File. Contains all data necessary to define a structure at any stage, including solutions.
Solution Structure	- The resulting substructure to be used in the solve operation.
Solve Operation	- To obtain solutions using the present structural matrices and user-defined input data.

## SUMMARY OF OPERATIONAL COMMANDS

Table 2. Summary of Substructure Commands

### A. Phase and Mode Control

# SUBSTRUCTURE	- Defines execution phase (1, 2, or 3)
NAME*	- Specifies Phase 1 or Phase 3 substructure name (not used in Phase 2)
SAVEPLOT	- Requests plot data be saved in Phase 1
OPTIONS	- Defines matrix options (K, B, K4, M, P, or PA)
RUN	- Limits mode of execution (DRY, G0, DRYG0, STEP)
# ENDSUBS	- Terminates Substructure Control Deck

### B. S0F Controls

# S0F	- Assigns physical file for storage of the S0F
PASSWORD*	- Protects and ensures access to correct file
S0FOUT or S0FIN	- Copies S0F data to or from an external file
POSITION	- Specifies initial position of input file
NAMES	- Specifies substructure name used for input
ITEMS	- Specifies data items to be copied in or out
S0FPRINT	- Prints selected items from the S0F
DUMP	- Dumps entire S0F to a backup file
RESTORE	- Restores entire S0F from a previous DUMP operation
CHECK	- Checks contents of external file created by S0FOUT
DELETE	- Deletes out selected groups of items from the S0F
EDIT	- Edits out selected groups of items from the S0F
DESTROY	- Destroys <u>all</u> data for a named substructure and <u>all</u> the substructures which it is a component

### C. Substructure Operations

COMBINE	- Combines sets of substructures
NAME*	- Names the resulting substructure
TOLERANCE*	- Limits distance between automatically connected grids
CONNECT	- Defines sets for manually connected grids and releases
OUTPUT	- Specifies optional output results
COMPONENT	- Identifies component substructure for special processing
TRANSFORM	- Defines transformations for named component substructures
SYMTRANSFORM	- Specifies symmetry transformation
SEARCH	- Limits search for automatic connects
EQUIV	- Creates a new equivalent substructure
PREFIX*	- Prefix to rename equivalenced lower level substructures

# Mandatory Control Cards

\* Required Subcommand

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 2. Summary of Substructure Commands (continued)

### C. Substructure Operations (continued)

REDUCE	- Reduces substructure matrices
NAME*	- Names the resulting substructure
BOUNDARY*	- Defines set of retained degrees of freedom
RSAVE	- Indicates the decomposition product of the interior point stiffness matrix is to be saved on the SØF
OUTPUT	- Specifies optional output requests
MREDUCE	- Reduces substructure matrices using a normal modes transformation
NAME*	- Names the resulting substructure
BOUNDARY*	- Defines set of retained degrees of freedom
FIXED	- Defines set of constrained degrees of freedom for modes calculation
RNAME	- Specifies basic substructure to define reference point for inertia relief shapes
RGRID	- Specifies grid point in the basic substructure to define reference point for inertia relief shapes. Defaults to origin of basic substructure coordinate system
METHOD	- Identifies IEGR Bulk Data card
RANGE	- Identifies frequency range for retained modal coordinates
NMAX	- Identifies number of lowest frequency modes for retained modal coordinates
ØLDMØDES	- Flag to identify rerunning problem with previously computed modal data
ØLDBØUND	- Flag to identify rerunning problem with previously defined boundary set
USEMØDES	- Flag to indicate modal data have been input on bulk data
OUTPUT	- Specifies optional output requests
RSAVE	- Indicates the decomposition product of the interior point stiffness matrix is to be stored on the SØF
CREDUCE	- Reduces substructure matrices using a complex modes transformation
NAME*	- Names the resulting substructure
BOUNDARY*	- Defines set of retained degrees of freedom
FIXED	- Defines set of constrained degrees of freedom for modes calculation
METHOD	- Identifies EIGC Bulk Data card
RANGE	- Identifies frequency range of imaginary part of the root for retained modal coordinates
NMAX	- Identifies number of lowest frequency modes for retained modal coordinates
ØLDMØDES	- Flag to identify rerunning problem with previously computed modal data
GPARAM	- Specifies structural damping parameter
OUTPUT	- Specifies optional output requests
RSAVE	- Indicates the decomposition product of the interior point stiffness matrix is to be stored on the SØF

\* Required Subcommand

## SUMMARY OF OPERATIONAL COMMANDS

Table 2. Summary of Substructure Commands (continued)

### C. Substructure Operations (continued)

MRECOVER	- Recovers mode shape data from an MREDUCE or CREDUCE operation
SAVE	- Stores modal data on SDF
PRINT	- Stores modal data and prints data requested
SOLVE	- Initiates substructure solution (statics, normal modes, frequency response, or transient analysis)
RECOVER	- Recovers Phase 2 solution data
SAVE	- Stores solution data on SDF
PRINT	- Stores solution and prints data requested
BRECOVER	- Basic substructure data recovery, Phase 3
PLOT	- Initiates substructure undeformed plots

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 3. Substructure Bulk Data Card Summary

### A. Bulk Data Used by Substructure Commands REDUCE, MREDUCE, and CREDUCE

- BDYC** - Combination of substructure boundary sets of retained degrees of freedom or fixed degrees of freedom for modes calculation
- BDYS** - Boundary set definition
- BDYS1** - Alternate boundary set definition

### B. Bulk Data Used by Substructure Command COMBINE

- CONCT** - Specifies grid points and degrees of freedom for manually specified connectivities - will be overridden by RELES data
- CONCT1** - Alternate specification of connectivities
- RELES** - Specifies grid point degrees of freedom to be disconnected - overrides CONCT and automatic connectivities
- GTRAN** - Redefines the output coordinate system grid point displacement sets
- TRANS** - Specifies coordinate systems for substructure and grid point transformations

### C. Bulk Data Used by Substructure Command SOLVE

- LOADC** - Defines loading conditions for static analysis
- MPCS** - Specifies multipoint constraints
- SPCS** - Specifies single-point constraints
- SPCS1** - Alternate specification of single-point constraints
- SPCSD** - Specifies enforced displacements for single-point constraints
- DAREAS** - Specifies dynamic loadings
- DELAYS** - Specifies time delays for dynamic loads
- DPHASES** - Specifies phase lead terms for dynamic loads
- TICS** - Specifies transient initial conditions



## SUBSTRUCTURE ANALYSIS EXAMPLES

### 20.4 SUBSTRUCTURE ANALYSIS EXAMPLES

Two example problems are presented to assist the user in setting up decks for an actual analysis. The first is a structural analysis using equivalent substructures, COMBINE and REDUCE operations, and substructure plotting. The second example illustrates the use of modal synthesis techniques in automated substructuring.

#### 20.4.1 Problem 1 - Substructure Analysis Using Rigid Format 1 and 2

Figure 1 shows two basic substructures, Table and LEGS. Note that these structures have different basic coordinate systems, as shown in the figure. Figure 1 shows a combined structure which is assembled from the two basic substructures. All of the data decks used to generate and analyze the composite structure are listed in Tables 1-4. These include the data for the Phase 1 generation of the basic substructures, the Phase 2 assembly of the complete structure, its solution and data recovery, and the Phase 3 data recovery. Tables 5-8 present a detailed description of each of the data decks used in this analysis.

#### 20.4.2 Problem 2 - Dynamic Analysis of a Truss Using Automated Modal Synthesis and Rigid Format 9

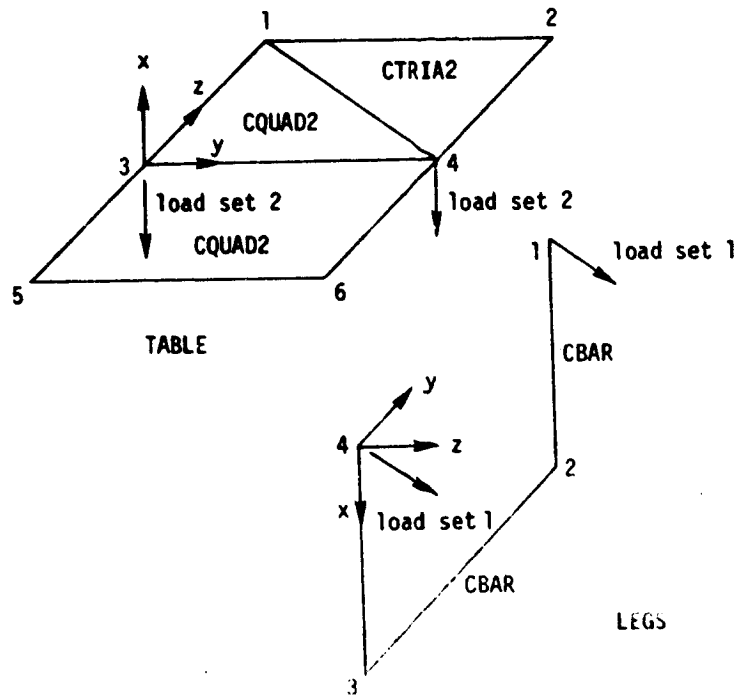
##### 20.4.2.1 Description

This problem illustrates the automated substructuring and modal synthesis procedures which provide accurate, efficient solutions in dynamic analysis. Each component substructure is reduced to modal and boundary degrees of freedom prior to the substructure combine operation. The combination structure, formulated in terms of the component modes, is also reduced to modal degrees of freedom for solution by the transient analysis Rigid Format.

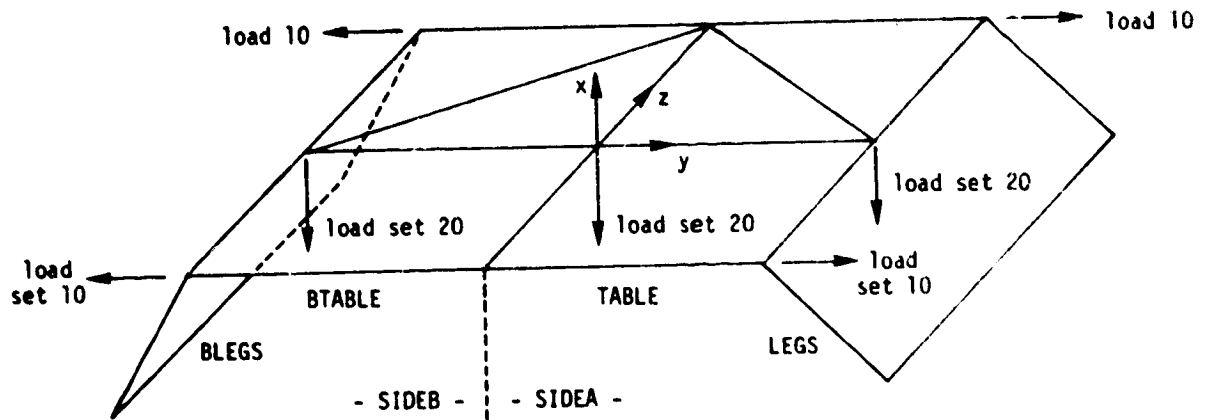
##### 20.4.2.2 Input

The geometry for the two basic substructures is shown in Figure 2. All members are RBD elements. All grid points are constrained to include only in-plane displacements. The basic input data and the substructure control data are described below.

# SUBSTRUCTURING AND MODAL SYNTHESIS



a. Phase 1 Basic Substructures.



b. Phase 2 Combined Substructure.

Figure 1. Example Problem 1.

SUBSTRUCTURE ANALYSIS EXAMPLES

● - Boundary Points

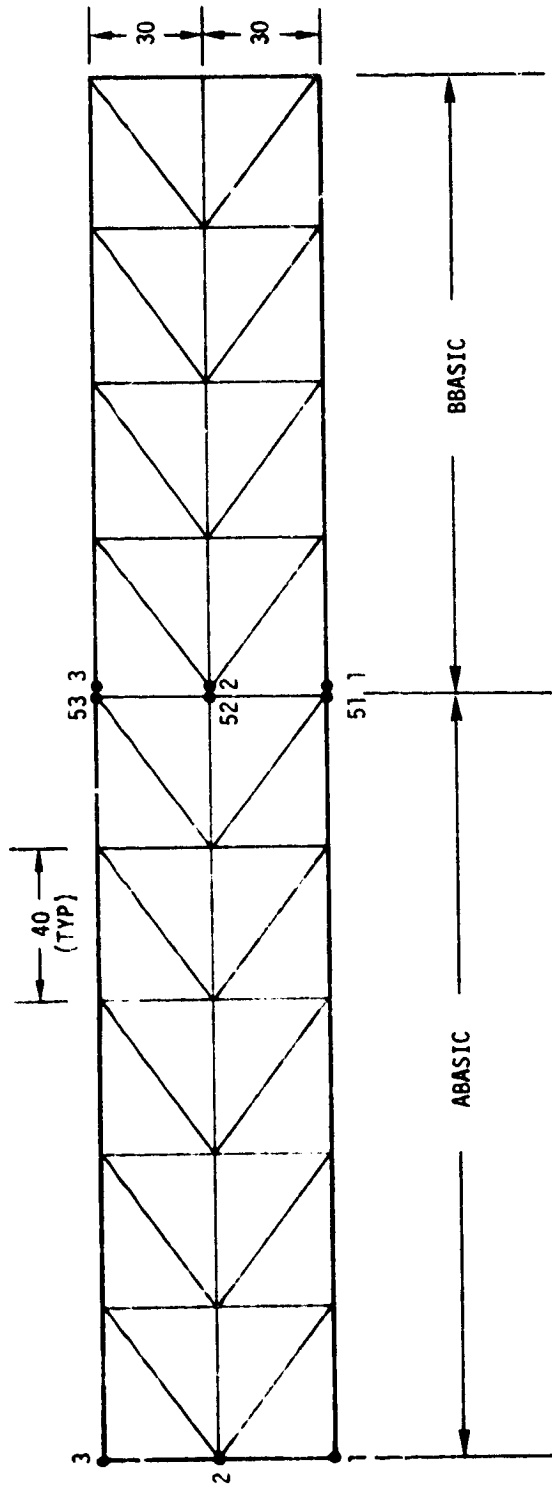


Figure 2. Nine-Cell Truss Basic Substructures.

## SUBSTRUCTURING AND MODAL SYNTHESIS

### 1. Parameters

$a = 40$	(typical frame width)
$h = 30$	(typical frame height)
$A = 0.3$	(cross section of members)
$E = 10^6$	(Young's Modulus)
$P = 2.5 \times 10^{-3}$	(density)

### 2. Constraints

$u_z = \theta_x = \theta_y = \theta_z = 0$  all points  
(Boundary conditions are applied only during solution.)

### 3. Loads

$P_{y42} = 10^3$  (load on substructure BBASIC)

### 4. Transient Loads

$U_{y42} = .143$  @  $t = 0$  (initial condition)  
 $P_{y42} = 10^3$   $0 < t < .12$  (load history)  
 $0$   $t > .12$

The basic run sequence and substructure operations are shown in Figure 3. Each box defines a component substructure. Each trapezoid defines output data resulting from a substructure operation. Four separate runs are performed as described below.

1. Runs 1 & 2 The NASTRAN Phase 1 operations formulate the finite element matrices and basic static loads.
2. Run 3 In Phase 2 the basic substructures are reduced to modal coordinates and combined together. Another modal synthesis reduction is performed on the combination and the resulting eigenvectors are printed.
3. Run 4 In the second Phase 2 operation, the transient analysis is performed on the reduced structure using the SOLVE operation. The transient output data is transformed back to the original grid point definitions with the RECOVER command.
4. Listings of the four runs are presented in Tables 9-12.

**SUBSTRUCTURE ANALYSIS EXAMPLES**

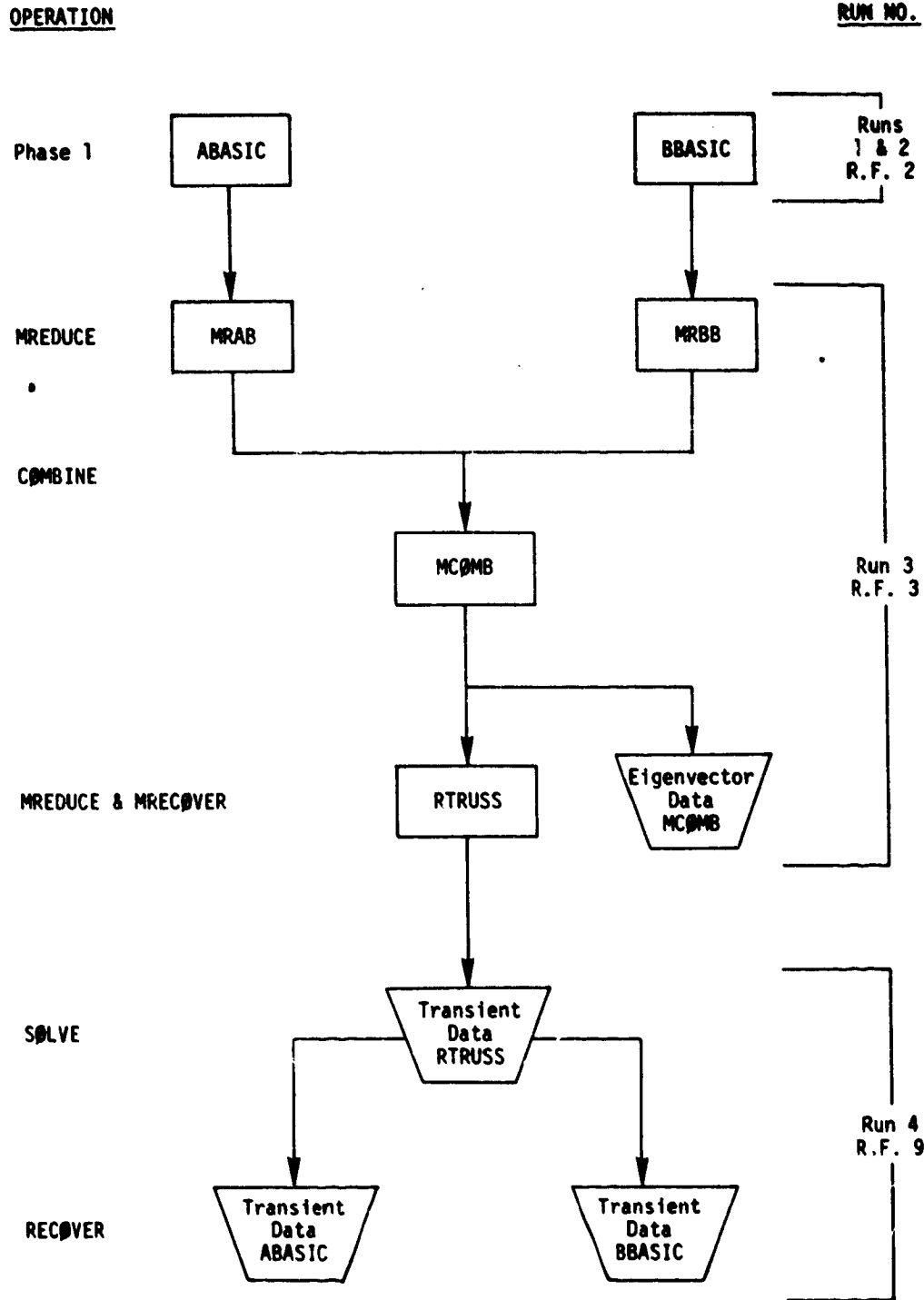


Figure 3. Substructure Formulation Tree and Solution Sequence.

## SUBSTRUCTURING AND MODAL SYNTHESIS

### 20.4.2.3 Results

For assessing the accuracy of the modal synthesis, the whole structure was run in Rigid Format 3 to determine natural frequency and mode shapes. This procedure eliminates the effects of finite element errors common to both methods.

Natural frequencies for the combined system are shown in Table 13 along with the error ratios of the difference. Note that the lowest frequency component mode omitted from the analysis was 197.2 Hz. Below this frequency, the resulting modes are excellent.

The transient response of the resulting structure is illustrated in Figure 4 for a typical point in the system. Note that very little excitation of the higher frequency modes occurred.

SUBSTRUCTURE ANALYSIS EXAMPLES

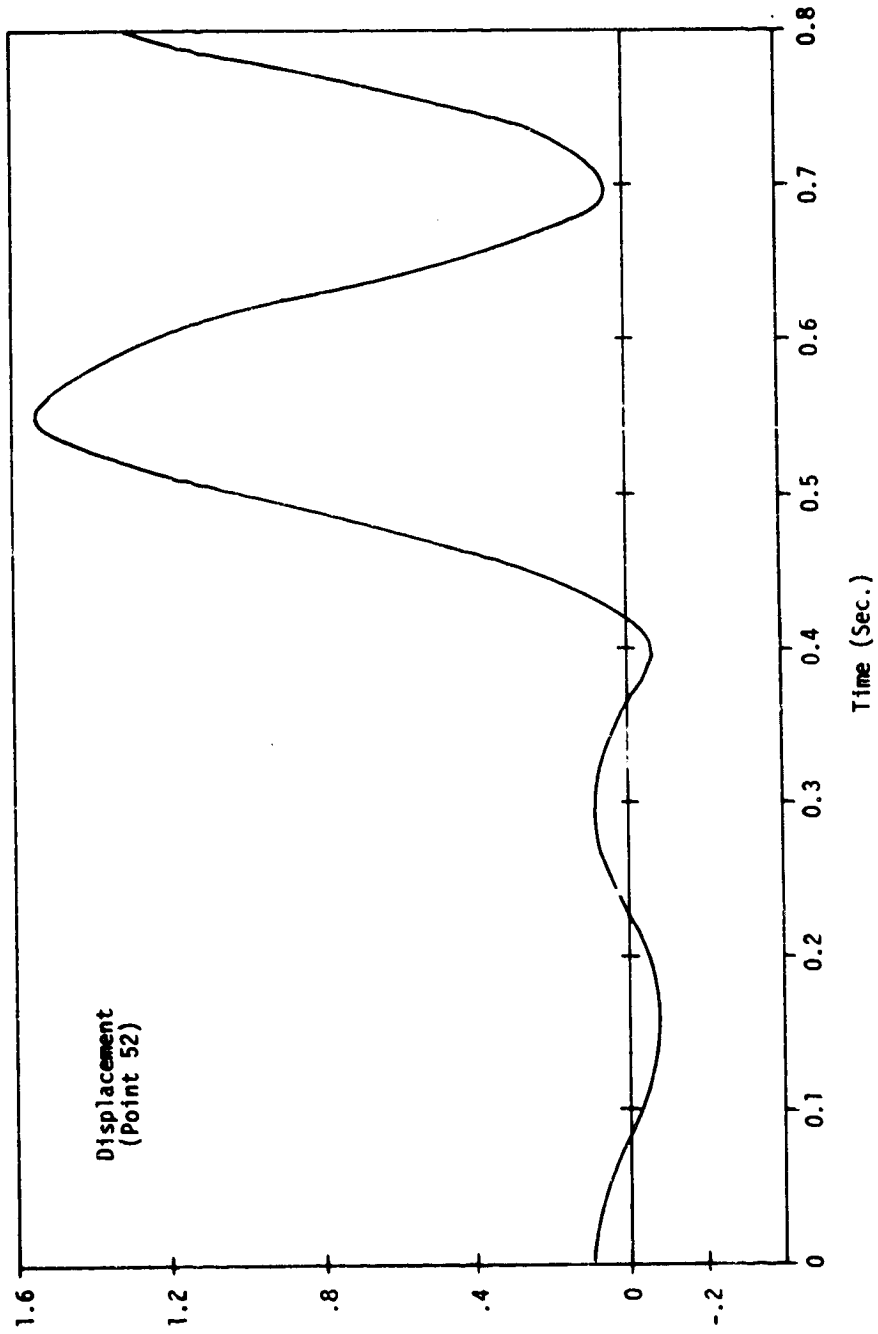


Figure 4. Transient Response of a Nine-Cell Truss with Modal Synthesis Formulation.

SUBSTRUCTURING AND MODAL SYNTHESIS

Table 1. Phase 1 Data Deck for Subroutine TABLE

Card  
No.

0 NASTRAN FILES = NPTP  
1 ID TABLE,BASIC  
2 APP DISP,SUBS  
3 SOL 2,0  
4 TIME 1  
5 CHPNT YES  
6 CEND

7 SUBSTRUCTURE PHASE1  
8 PASSWORD=PROJECTX  
9 SDF(1)=SDF1,250,NEW  
10 NAME=TABLE  
11 SAVEPLOT=1  
12 SDFPRINT TDC  
13 ENDSUBS

14 TITLE=TABLE, PHASE ONE  
15 LOAD=2  
16 OUTPUT(PL0T)  
17 SET 1=ALL  
18 PLOT  
19 BEGIN BULK

	1	2	3	4	5	6	7	8	9	10
20	CQUAD2	3	2	5	6	4	3			
21	CTRIA2	1	1	1	2	4				
22	CTRIA2	2	1	3	4	1				
23	FORCE	2	3		10.0	-1.0				
24	FORCE	2	4		10.0	-1.0				
25	GRID	1		0.0	0.0	5.				
26	GRID	2		0.0	7.	5.				
27	GRID	3		0.0	0.0	0.0				
28	GRID	4		0.0	7.	0.0				
29	GRID	5		0.0	0.0	-5.				
30	GRID	6		0.0	7.	-5.				
31	GRID	7						123456		
32	MAT1	1	3.+7		.3	4.3				
33	PQUAD2	2	1	.1						
34	PTRIA2	1	1	.1						
35	ENDDATA									



SUBSTRUCTURE ANALYSIS EXAMPLES

Table 2. Phase 1 Data Deck for Substructure LEGS

```

Card
No.
0  NASTRAN FILES=(NPTP,INP3)
1  ID LEGS,BASIC
2  APP DISP, SUBS
3  SOL 2,0
4  TIME 1
5  CHPNT YES
6  CEND

7  SUBSTRUCTURE PHASE1
8  PASSWORD=PROJECTY
9  SQF(1)=SQF4,7500
10 NAME=LEGS
11 SAVEPLOT=1
12 SQFOUT INP3
13   POSITION=REWIND
14   NAME=LEGS
15 EDIT(32) LEGS
16 ENDSUBS

17 TITLE=LEGS PHASE ONE
18 LOAD=1
19 OUTPUT(PLOT)
20 SET 1=ALL
21 PLOT
22 BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
23	CBAR	1	1	1	2	5			2	
24	CBAR	2	1	3	2	5			2	
25	CBAR	3	1	4	3	5			2	
26	FORCE	1	1		2.0	3.0	.0	4.0		
27	FORCE	1	4		2.0	3.0	.0	4.0		
28	GRID	1		0.0	10.	0.0				
29	GRID	2		5.	10.	0.0				
30	GRID	3		5.	0.0	0.0				
31	GRID	4		0.0	0.0	0.0				
32	GRID	5		100.	100.	0.0		123456		
33	MAT1	1	3.+7		.3	4.3				
34	PBAR	1	1	1.0	50.	100.	10.			
35	ENDDATA									

# SUBSTRUCTURING AND MODAL SYNTHESIS

Table 3. Phase 2 Data Deck

<u>Card No.</u>	
1	ID SUBSTR,PHASE2
2	APP DISP,SUBS
3	SOL 1,0
4	TIME 1
5	DIAG 23
6	CEND
7	SUBSTRUCTURE PHASE2
8	PASSWORD=PROJECTX
9	SOF(1)=SOF1,250
10	OPTIONS=K,M,P
11	SOFOUT,INP4,TAPE
12	POSITION=REWIND
13	NAME=TABLE
14	SOFPRINT T0C
15	COMBINE LEGS,TABLE
16	NAME=SIDEA
17	TOLER=0.001
18	OUTPUT=1,2,7,11,12,13,14,15,16,17
19	COMPONENT LEGS
20	TRANS=10
21	EQUIV SIDEA,SIDEB
22	PREFIX=B
23	COMBINE SIDEA,SIDEB
24	NAME=BIGTABLE
25	TOLER=0.001
26	OUTPUT=1,2,7,11,12,13,14,15,16,17
27	COMPONENT SIDEB
28	SYMT=Y
29	REDUCE BIGTABLE
30	NAME=SMALTABL
31	BOUNDARY=100
32	OUTPUT=1,2,3,4,5,6,7,8
33	SOFPRINT T0C
34	PL0T SMALTABL
35	SOLVE SMALTABL
36	RECOVER SMALTABL
37	PRINT BIGTABLE
38	SAVE BTABLE
39	SOFPRINT T0C
40	ENDSUBS
41	TITLE=PHASE TWO SUBSTRUCTURE
42	DISP=ALL
43	SPCF=ALL
44	LOAD=ALL
45	SPC=10
46	SUBCASE 1
47	LOAD=10
48	SUBCASE 2
49	LOAD=20
50	OUTPUT(PL0T)
51	SET 1=ALL
52	PL0T
53	BEGIN BULK

SUBSTRUCTURE ANALYSIS EXAMPLES

Table 3. Phase 2 Data Deck (cont'd)

Card No.	1	2	3	4	5	6	7	8	9	10
54	BDYC	100	LEGS	20	BLEGS	20				
55	+A		TABLE	10	BTABLE	10				+A
56	BDYS1	10	4	1	3	4	5			
57	BDYS1	10	123456	2	6					
58	BDYS1	20	123456	2	3					
59	LOADC	10	1.0	LEGS	1	1.0	BLEGS	1	1.0	
60	LOADC	20	1.0	TABLE	2	1.0	BTABLE	2	1.0	
61	SPCS1	10	BLEGS	123456	2	3				
62	SPCS1	10	BTABLE	4	1	3	4	5		
63	SPCS1	10	LEGS	123456	2	3				
64	SPCS1	10	TABLE	4	1	3	4	5		
65	TRANS	10		.0	7.0	-5.0	3.0	11.0	-5.0	+B
66	+B	0.0	8.0	-5.0						
67	ENDDATA									

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 4. Phase 3 Data Deck

Card  
No.

```
0 NASTRAN FILES = @PTP
1 ID TABLE,BASIC
2 APP DISP,SUBS
3 SOL 1,0
4 TIME 1
5 RESTART TABLE, BASIC (Restart deck)
6 CEND

7 SUBSTRUCTURE PHASE3
8 PASSWORD=PROJECTX
9 S0F(1)=S0F1,250
10 BRECOVER BTABLE
11 ENDSUBS

12 TITLE=PHASE THREE FOR REFLECTED TABLE
13 DISP=ALL
14 @LOAD-ALL
15 SPCF=ALL
16 STRESS=ALL
17 SUBCASE 1
18 SUBCASE 2
19 LOAD=2
20 BEGIN BULK
21 ENDDATA
```

## SUBSTRUCTURE ANALYSIS EXAMPLES

Table 5. Description of Phase 1 Data Deck for Substructure TABLE

<u>Card No.</u>	Refer to Table 1 for input cards described below.
1-6	Standard NASTRAN Executive Control Deck <u>except</u> the 'SUBS' option is selected on the APP card.
7	First card of Substructure Control Deck. Phase 1 is selected.
8	Password protection on the SØF is 'PRØJECTX'.
9	The SØF consists of one physical file with an index of one. (Indices must begin with one and increase sequentially.) The name of the file is 'SØF1' and it has a maximum size of 250,000 words. The file is to be initialized. (Internal pointers will be set to indicate that the SØF contains no data.)
10	The basic substructure to be generated will be identified by the name TABLE.
11	Plot set 1 will be saved on the SØF for performing plots of the combined structure in Phase 2.
12	Print a table of contents for the SØF. This includes a list of all substructures and their data items.
13	End of Substructure Control Deck.
15	Selects the load to be saved on the SØF for use in Phase 2. Note that multiple loads may be saved by using multiple subcases. In addition to external static loads, thermal loads and element deformation loads may be selected.
16-18	Plot control cards are required if the SAVEPLØT subcommand is used in the Substructure Control Deck. These cards are used to define the plot sets for Phase 2 plotting. It is not necessary that a plot tape be set up in Phase 1.
19-35	Standard NASTRAN Bulk Data Deck. These cards define the mathematical model of the basic substructure.

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 6. Description of Phase 1 Data Deck for Substructure LEGS

<u>Card No.</u>	
	Refer to Table 2 for input cards described below.
1-6	Standard NASTRAN Executive Control Deck <u>except</u> the 'SUBS' option is selected on the APP card.
7	First card of the Substructure Control Deck. Phase 1 is selected.
8	Password protection on the SØF is 'PROØJECTY'.
9	The SØF consists of one physical file with an index of one. (Indices must begin with one and increase sequentially.) The name of the file is 'SØF4' and it has a maximum size of 250,000 words. The file was used previously as on SØF (Phase 1 for TABLE).
10	The basic substructure to be generated will be identified by the name LEGS.
11	Plot set 1 will be saved on the SØF for performing plots of the combined structure in Phase 2.
12-14	After substructure LEGS has been generated and saved on the SØF, it is copied out to user tape INP3.
15	All data items for substructure LEGS are removed from the SØF. (The substructure name remains in the SØF directory, however.)
16	End of Substructure Control Deck
18	Selects the load to be saved on the SØF for use in Phase 2. Note that multiple loads may be saved by using multiple subcases. In addition to external static loads, thermal loads, and element deformation loads may be selected.
19-21	Plot control cards are required if the SAVEPLOT subcommand is used in the Substructure Control Deck. These cards are used to define the plot sets for Phase 2 plotting. It is not necessary that a plot tape be set up in Phase 1.
22-35	Standard NASTRAN Bulk Data Deck. These cards define the mathematical model of the basic substructure.

## SUBSTRUCTURE ANALYSIS EXAMPLES

Table 7. Description of Phase 2 Data Deck

- Card No. Refer to Table 3 for input cards described below.
- 1-6 Standard NASTRAN Executive Control Deck except the 'SUBS' option is selected on the APP card. DIAG 23 requests an echo of the automatic DMAP alters generated.
  - 7 First card of the Substructure Control Deck. Phase 2 is selected.
  - 8,9 These cards specify the same SØF used in Phase 1 for substructure TABLE.
  - 10 The card causes matrix operations to be performed on stiffness, mass, and load matrices. The default for Rigid Format 1 is stiffness and loads only. However, Rigid Format 2 was selected in the Phase decks. This caused all three matrix types to be generated in Phase 1.
  - 11-13 Basic substructure TABLE is copied from the SØF to user tape INP4.
  - 14 Print the SØF table of contents.
  - 15-20 Perform an automatic combination of substructures TABLE and LEGS. The resultant combined pseudostructure will be named SIDEA. The tolerance for connections is 0.001 units. Detailed output is requested (see Substructure Command CØMBINE). The basic coordinate system for substructure LEGS is transformed according to transformation set 10 in the Bulk Data.
  - 21,22 Create a new secondary substructure SIDEB which is equivalent to SIDEA. This operation causes image substructure BLEGS and BTABLE to be generated.
  - 23-28 Perform an automatic combination of substructures SIDEA and SIDEB. The resultant combined pseudostructure will be named BIGTABLE. The tolerance for connections is 0.001 units. Detailed output is requested. The basic coordinate system for pseudostructure SIDEB is symmetrically transformed about the XZ plane, identified by Y, the axis normal to the plane (sign change for all 'Y' degrees of freedom).
  - 29-32 Perform a matrix reduction on the matrices of substructure BIGTABLE. The resultant reduced pseudostructure will be named SMALTABL. The retained degrees of freedom are selected in boundary set 100 in the Bulk Data. Detailed output is requested.
  - 33 Print the SØF table of contents.
  - 34 Plot pseudostructure SMALTABL. The plot control cards in the Case Control Deck are used to define the plots.
  - 35 Perform a static solution of pseudostructure SMALTABL. The constraint sets and loads selected in the Case Control Deck are used.
  - 36-38 Recover the displacements of substructures BIGTABLE and BTABLE from the solution of SMALTABL and save them on the SØF. Also, print the results for substructure BIGTABLE. The output requests in the Case Control Deck are referenced when the PRINT subcommand is invoked.
  - 39 Print the SØF table of contents.
  - 40 End of the Substructure Control Deck.
  - 42-44 Case Control output requests. Referenced by the PRINT subcommand of the RECOVER command.
  - 45-49 Constraint and load set selections are referenced by the SØLVE command.
  - 50-52 Plot control cards are referenced by the PLØT command.

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 7. Description of Phase 3 Data Deck (continued)

<u>Card No.</u>	
	Refer to Table 3 for input cards described below.
54-58	These Bulk Data cards define the boundary set of retained degrees of freedom which was selected in the REDUCE operation (cards 29-32).
59-64	These cards define the loads and constraints selected in the Case Control Deck for the substructure SOLVE operation.
65,66	These cards define the transformation which is applied to the basic coordinate system of substructure LEGS in the first COMBINE operation (cards 15-20).



## SUBSTRUCTURE ANALYSIS EXAMPLES

Table 8. Description of Phase 3 Data Deck for Substructure BTABLE

- Card No. Refer to Table 4 for input cards described below.
- 1-6 Standard NASTRAN Executive Control Deck except the 'SUBS' option is selected on the APP DISP card. "Card" 5 is actually the Restart deck punched out in Phase 1 for substructure TABLE.
- 7 First card of the Substructure Control Deck. Phase 3 is selected.
- 8,9 These cards specify the same SØF used in Phase 2.
- 10 This card causes the data for the image basic substructure BTABLE to be copied from the SØF to GINØ data blocks. The data can then be used for data recovery operations, i.e., deformed structure plots, stresses, etc.
- 11 End of Substructure Control Deck.
- 13-16 Output requests for Phase 3 data recovery.
- 17-19 The Subcase Definitions in Phase 3 must be identical to those used in the SØLVE operation in Phase 2. SPC and MPC constraints in Phase 3 must be the same as those used in Phase 2. Load sets selected in Phase 3 must correspond to those selected in Phase 2 for each subcase. However, load sets selected in Phase 2 which do not exist for this particular or basic substructure can not be selected in Phase 3. See Section 1.14.4 for a more detailed discussion of the Phase 3 Case Control Deck.

SUBSTRUCTURING AND MODAL SYNTHESIS

Table 9. Phase 1 Data Deck for Substructure ABASIC

```

NASTRAN NLINES=35,BUFFSIZE=500
ID DEMO1,RUN1
APP DISP,SUBS
SOL 2,0
TIME 1
CEND
SUBSTRUCTURE PHASE1
SOF(1) = FT10,500,NEW
PASSWORD = MDLSYN
NAME = ABASIC
SOPPRINT TQC
ENDSUBS
TITLE = DEMO PROBLEM 165A MODAL SYNTHESIS OF A NINE-CELL TRUSS
SUBTITLE = RUN 1 - BASIC SUBSTRUCTURE A
LOAD = 980 $ 1 G ACCELERATION IN -Y DIRECTION
BEGIN BULK
CR0D 1 1 1 2
CR0D 2 1 2 3
CR0D 11 1 11 12
CR0D 12 1 12 13
CR0D 21 1 21 22
CR0D 22 1 22 23
CR0D 31 1 31 32
CR0D 32 1 32 33
CR0D 41 1 41 42
CR0D 42 1 42 43
CR0D 51 1 51 52
CR0D 52 1 52 53
CR0D 111 1 1 11
CR0D 112 1 2 12
CR0D 113 1 3 13
CR0D 121 1 11 21
CR0D 122 1 12 22
CR0D 123 1 13 23
CR0D 131 1 21 31
CR0D 132 1 22 32
CR0D 133 1 23 33
CR0D 141 1 31 41
CR0D 142 1 32 42
CR0D 143 1 33 43
CR0D 151 1 41 51
CR0D 152 1 42 52
CR0D 153 1 43 53
CR0D 211 1 2 11
CR0D 212 1 2 13
CR0D 221 1 12 21
CR0D 222 1 12 23
CR0D 231 1 22 31
CR0D 232 1 22 33
CR0D 241 1 32 41
CR0D 242 1 32 43
CR0D 251 1 42 51
CR0D 252 1 42 53
GRAV 980 980.0 0.0 -1.0 0.0
GROSET 3456
GRID 1 0.0 -30.0 0.0
GRID 2 0.0 0.0 0.0
GRID 3 0.0 30.0 0.0
GRID 11 40.0 -30.0 0.0
GRID 12 40.0 0.0 0.0
GRID 13 40.0 30.0 0.0
    
```

SUBSTRUCTURE ANALYSIS EXAMPLES

Table 9. Phase 1 Data Deck for Substructure ABASIC (continued)

GRID	21		80.0	-30.0	0.0
GRID	22		80.0	0.0	0.0
GRID	23		80.0	30.0	0.0
GRID	31		120.0	-30.0	0.0
GRID	32		120.0	0.0	0.0
GRID	33		120.0	30.0	0.0
GRID	41		160.0	-30.0	0.0
GRID	42		160.0	0.0	0.0
GRID	43		160.0	30.0	0.0
GRID	51		200.0	-30.0	0.0
GRID	52		200.0	0.0	0.0
GRID	53		200.0	30.0	0.0
MAT1	1	10.0+6		0.3	2.5-3
PROD	1	1	0.3		
ENDATA					

SUBSTRUCTURING AND MODAL SYNTHESIS

Table 10. Phase 1 Data Deck for Substructure BBASIC

```

NASTRAN NLINES=35,BUFFSIZE=500
ID DEMO1,RUN2
APP DISP,SUBS
SOL 2,0
TIME 1
CEND
SUBSTRUCTURE PHASE1
SOF(1) = FT10,500
PASSWORD = MDLSYN
NAME = BBASIC
SOFPRINT T0C
ENDSUBS
TITLE = DEMO PROBLEM 165A MODAL SYNTHESIS OF A NINE-CELL TRUSS
SUBTITLE = RUN 2 - BASIC SUBSTRUCTURE B
LOAD = 980 $ 1 G ACCELERATION IN -Y DIRECTION
BEGIN BULK
CR0D 1 1 1 2
CR0D 2 1 2 3
CR0D 11 1 11 12
CR0D 12 1 12 13
CR0D 21 1 21 22
CR0D 22 1 22 23
CR0D 31 1 31 32
CR0D 32 1 32 33
CR0D 41 1 41 42
CR0D 42 1 42 43
CR0D 111 1 1 11
CR0D 112 1 2 12
CR0D 113 1 3 13
CR0D 121 1 11 21
CR0D 122 1 12 22
CR0D 123 1 13 23
CR0D 131 1 21 31
CR0D 132 1 22 32
CR0D 133 1 23 33
CR0D 141 1 31 41
CR0D 142 1 32 42
CR0D 143 1 33 43
CR0D 211 1 2 11
CR0D 212 1 2 13
CR0D 221 1 12 21
CR0D 222 1 12 23
CR0D 231 1 22 31
CR0D 232 1 22 33
CR0D 241 1 32 41
CR0D 242 1 32 43
GRAV 980 980.0 0.0 -1.0 0.0
GRDSET 3456
GRID 1 0.0 -30.0 0.0
GRID 2 0.0 0.0 0.0
GRID 3 0.0 30.0 0.0
GRID 11 40.0 -30.0 0.0
GRID 12 40.0 0.0 0.0
GRID 13 40.0 30.0 0.0
GRID 21 80.0 -30.0 0.0
GRID 22 80.0 0.0 0.0
GRID 23 80.0 30.0 0.0
GRID 31 120.0 -30.0 0.0
GRID 32 120.0 0.0 0.0
GRID 33 120.0 30.0 0.0
GRID 41 160.0 -30.0 0.0

```

SUBSTRUCTURE ANALYSIS EXAMPLES

Table 10. Phase 1 Data Deck for Substructure BBASIC (continued)

GRID	42		160.0	-30.0	0.0
GRID	43		160.0	30.0	0.0
MAT1	1	10.0+6		0.3	2.5-3
PRØD	1	1	0.3		
ENDDATA					

SUBSTRUCTURING AND MODAL SYNTHESIS

Table 11. Phase 2 Deck for COMBINE and MREDUCE Operations

```

NASTRAN NLINES=35,BUFSIZE=500
ID DEMO1,RUN3
APP DISP,SUBS
SOL 3,0
TIME 5
DIAG 8,19
CEND
SUBSTRUCTURE PHASE2
SOF(1) = FT10,500
PASSWORD = MDLSYN
OPTIONS K,M,P
SOFPRINT T0C
MREDUCE ABASIC
NAME MRAB
BOUNDARY 5
FIXED 5
METHOD 9
OUTPUT 1,5,6,9,10
SOFPRINT T0C
MREDUCE BBASIC
NAME MRBB
BOUNDARY 4
FIXED 4
METHOD 9
OUTPUT 1,5,6,9,10
SOFPRINT T0C
COMBINE MRAB,MRBB
NAME MCOMB
TOLERANCE 0.001
OUTPUT 2,7,12
COMPONENT MRBB
TRANSFORM 40
SOFPRINT T0C
MREDUCE MCOMB
NAME RTRUSS
BOUNDARY 42
FIXED 9
METHOD 90
NMAX 18
OUTPUT 1,5,6,9,10
SOFPRINT T0C
ENDSUBS
TITLE = DEMO PROBLEM 165A MODAL SYNTHESIS OF A NINE-CELL TRUSS
SUBTITLE = RUN 3 - MODAL REDUCTIONS AND COMBINE OPERATIONS
LABEL = USE 7 MODES PER COMPONENT AND 18 MODES OF COMBINATION
BEGIN BULK
BOYC 4 BBASIC 2
BOYC 5 ABASIC 1
BOYC 9 ABASIC 2
BOYC 42 ABASIC 2 BBASIC 42
BDYS1 1 12 1 2 3 51 52 53
BDYS1 2 12 1 2 3
BDYS1 42 2 2
EIGR 9 GIV 0.0 10000.0 7 +E1
+E1 MAX
EIGR 90 GIV 0.0 10000.0 20 +E2
+E2 MAX
TRANS 40 200.0 0.0 0.0 200.0 0.0 1.0 +T1
+T1 201.0 0.0 0.0
ENDDATA

```

## SUBSTRUCTURE ANALYSIS EXAMPLES

Table 12. Phase 2 Deck for SOLVE and RECOVER Operations

```

NASTRAN N LINES=35,BUFFSIZE=500
ID DEMO1,RUN4
APP DISP,SUBS
SOL 9,0
TIME 5
CEND
SUBSTRUCTURE PHASE2
SOF(1) = FT10,500
PASSWORD = MDLSYN
OPTIONS K,M,P
SOFPRINT TOC
SOLVE RTRUSS
RECOVER RTRUSS
PRINT ABASIC
UIIMPROVE
  RANGE 0,0,0,4
  ENERGY ALL
  PRINT MRAB
  PRINT BBASIC
UIIMPROVE
  RANGE 0,0,0,4
  ENERGY ALL
  PRINT MRBB
SOFPRINT TOC
ENDSUBS
TITLE = DEMO PROBLEM 165A MODAL SYNTHESIS OF A NINE-CELL TRUSS
SUBTITLE = RUN 4 - TRANSIENT RESPONSE ANALYSIS
LABEL = REDUCED TO MODAL DEGREES OF FREEDOM
SET 1 = 7 THRU 13
SPC = 123
LOAD = 101
IC = 522
TSTEP = 40
DISP = ALL
SDISP(SORT2) = 1
BEGIN BULK
DAREAS 980      BBASIC   2      2      1.0+3
LOADC 980      1.0      ABASIC  980      1.0
PARAM G        0.05
PARAM W3       0.01
SPCS1 123      ABASIC   12     1      2      3
TICS 522      BBASIC   2      2      0.1
TLAD2 101      980
TSTEP 40      40      2.0-2  1      0.4      12.0
ENDDATA

```

## SUBSTRUCTURING AND MODAL SYNTHESIS

Table 13. NASTRAN Natural Frequencies and Differences for 20 Degrees of Freedom Mode Synthesis.

Mode No.	Frequency ( $H_z$ )	% Difference From Full Modal
1	3.596	.0085
2	17.564	.0012
3	28.492	.0639
4	39.507	.0011
5	61.099	.0050
6	80.280	.0066
7	84.454	.379
8	98.898	.039
9	111.764	.018
10	123.348	.345
11	127.556	.548
12	130.359	.155
13	134.922	2.220
14	153.606	.174
15	162.019	2.98
16	180.321	5.27
17	200.702	14.89



## 21. AEROELASTIC ANALYSIS

### 21.1 INTRODUCTION TO NASTRAN AEROELASTICITY

Aerodynamic analysis, like structural analysis, is based upon a finite element approach. The finite elements are strips or boxes for which there are aerodynamic forces. There are two major points to be considered. The aerodynamic elements, even for rather complex vehicles, tend to be in regular arrays. Thus, while NASTRAN has the provision to generate arrays of structural elements, it is also desirable to generate arrays of aerodynamic elements. In particular, the aerodynamic elements for lattice methods are arrays of trapezoidal boxes whose sides are parallel to the air-flow. These should be described simply by defining properties of the array (panel). The grid points defining the structure usually will not coincide with the grid points defining the aerodynamic elements. Provision has been made to generate equations of constraint between the two sets of grid points. The geometry interpolation is a key feature, since it allows the choice of structural and aerodynamic elements to be based upon structural and aerodynamic considerations separately.

Aerodynamic forces are generated via the flow surrounding the structure. The theory produces a matrix defining the forces upon the structure in terms of the deflections of the structure. State-of-the-art methods which involve interactions between aerodynamic elements are available only for sinusoidal motion. Phase lags occur between the motions and the forces, thus the matrices are complex. Furthermore, these complex matrices depend upon parameters of the flow, namely reduced frequency (ratio of frequency to velocity) and Mach number (ratio of velocity to speed of sound). Such a matrix, if computed by an interaction theory such as the doublet lattice method, will be expensive to produce. The most effective method to evaluate the matrix for a large number of parameter values is to compute the matrix for a few selected ones, and then interpolate to others. This parametric interpolation is an automatic feature of the solution modules for modal aeroelastic analysis.

## 21.2 DATA INPUT AND GENERATION

Aerodynamic elements are strips, boxes or bodies which represent the structure for computation of aerodynamic forces. These elements, like the structural elements, are defined by their geometry, and their motions are defined by degrees of freedom at associated aerodynamic grid points. Often requirements of the aerodynamic theory will dictate the geometry of the boxes. For example, the doublet lattice theory requires trapezoidal boxes with their parallel edges along the streamlines. Also, if one box lies in the wake of another, their edges must be on the same two streamlines. Aerodynamic elements and grid points will be generated to reduce the labor of the user (many less data cards will be required) and to help insure that theoretical requirements are met.

Aerodynamic calculations are made in a cartesian aerodynamic coordinate system. By the usual convention the flow is in the positive x direction. The basic coordinate system was not chosen, since it would place an undesirable restriction upon the description of the structural model. Any NASTRAN cartesian system may be specified, and flow will be defined in the direction of its positive x axis. All aerodynamic calculations are made initially in the aerodynamic coordinate system. All element and aerodynamic grid point data, computed initially in the basic coordinate system, will be converted to the aerodynamic coordinate system. The global (displacement) coordinate system of the aerodynamic grid points will have its T1 direction in the flow direction. T3 is normal to the element for boxes, and parallel to the aerodynamic Z direction in the case of bodies. Coordinate system data are generated for the aerodynamic grid points.

The grid points are physically located at the centers of the boxes and body elements. Permanent constraints are generated for the unused degrees of freedom. A second set of grid points, used only for undeformed plotting, is located at the element corners. All six degrees of freedom associated with each grid point in this second set are permanently constrained. Grid point numbers are generated based upon the element identification number. For any panel, the external grid point numbers for the boxes start with the panel identification number and increase consecutively.

Aerodynamic degrees of freedom, along with the extra points, are added after the structural matrices and modes have been determined. This introduces the following displacement sets:

- $u_k$  Aerodynamic box and body degrees of freedom
- $u_{sA}$  Permanently constrained degrees of freedom associated with aerodynamic grid points
- $u_{ps}$  Union of  $u_p$  (physical) and  $u_{sA}$
- $u_{pA}$  Union of  $u_k$  and  $u_{ps}$  (physical and aerodynamic)

The set  $u_{pA}$  replaces  $u_p$  as the set available for output at grid, scalar and extra points.

## STRUCTURAL-AERODYNAMIC INTERCONNECTIONS

### 21.3 STRUCTURAL-AERODYNAMIC INTERCONNECTIONS

The interpolation between the structural and aerodynamic degrees of freedom is based upon the theory of splines (Figure 1). High aspect ratio wings, bodies, or other beamlike structures should use linear splines. Low aspect ratio wings, where the structural grid points are distributed over an area, should use surface splines. Several splines can be used to interpolate to the boxes on a panel or elements on a body; however, each point can refer to only one spline. Any box or body element not referenced by a spline will be "fixed" and have no motion. For any point, especially a control surface degree of freedom, a linear relationship (like an MPC) may be specified.

For all types of splines, the user must specify the structural degrees of freedom and the aerodynamic points involved. The structural points, called the g-set, can be specified by a list or by specifying a volume in space and determining all the grid points in the volume. The degrees of freedom retained at the grid points include only the normal displacements for surface splines. For linear splines, the normal displacement is always used and, by user option, torsional rotations or slopes may be included. The global transformation at structural points is automatically applied for surface and linear splines.

The SPLINE1 data card defines a surface spline. This can interpolate for any "rectangular" subarray of boxes on a panel. For example, one spline can be used for the inboard end of a panel and another for the outboard end. The interpolated grid points (k-set) are specified by naming the lowest and highest aerodynamic grid point numbers in the area to be splines. The two methods for specifying the grid points use SET1 and SET2 data cards. A parameter DZ is used to allow some smoothing of the spline fit. If  $DZ = 0$  (the usual value), the spline will pass through all deflected grid points. If  $DZ > 0$ , then the spline (a plate) is attached to the grid deflections via springs, which produce a smoother interpolation that does not necessarily pass exactly through any of the points. The flexibility of the springs is proportional to DZ.

The SPLINE2 data card defines a linear spline. As can be seen from Figure 1, this is really a generalization of a simple spline to allow for interpolation over an area. It is similar to the method often used by aeronautical engineers who assume that an airfoil chord is rigid. The portion of a panel to be interpolated and the set of structural points are determined in the same manner as with SPLINE1. A NASTRAN coordinate system must be supplied to determine the axis of the splint. Since the spline has torsion as well as bending flexibility, the user may specify

## AEROELASTIC ANALYSIS

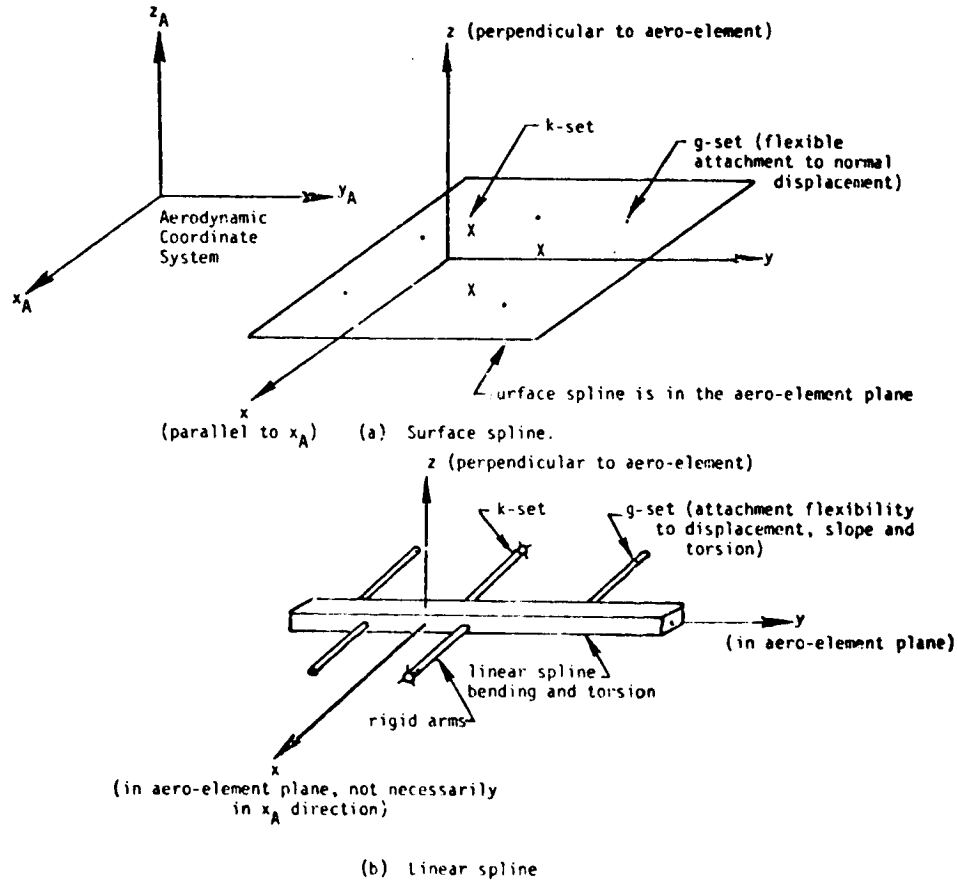
the ratio of flexibilities; the default value for this ratio is 1.0. The attachment flexibilities,  $D_z$ ,  $D_{\theta x}$ , and  $D_{\theta y}$ , allow for smoothing, but usually all values are taken to be zero. An exception would occur if the structural model does not have slopes defined, in which case the flexibility  $D_{\theta x}$  must be infinite; the convention  $D_{\theta x} = -1.0$  is used in this case. When used with bodies, there is no torsion and the spline axis is along the body.

There are certain cases with splines where attachment flexibility is either required or should not be used. The following special cases should be noted.

1. Two or more grid points, when projected onto the plane of the element (or the axis of a body) may have the same location. To avoid a singular interpolation matrix, a positive attachment flexibility must be used.
2. With linear splines, three deflections with the same spline y-coordinate would overdetermine the interpolated deflections since the perpendicular arms are rigid. A positive  $D_z$  is needed to make the interpolation matrix nonsingular.
3. With linear splines, two slopes (or twists) at the same y-coordinate would lead to a singular interpolation matrix. Use  $D_{\theta x} > 0$  (or  $D_{\theta y} > 0$ ) to allow interpolation.
4. For some modeling techniques, i.e., those which use only displacement degrees of freedom, the rotations of the structural model are constrained to zero to avoid matrix singularities. If a linear spline is used, the rotational constraints should not be enforced to these zero values. When used for panels, negative values of  $D_{\theta x}$  will disconnect the slope, and negative values of  $D_{\theta y}$  will disconnect the twist. For bodies,  $D_{\theta y}$  constrains the slopes since there is no twist degree of freedom for body interpolation. For a linear spline, if all of the structural points lie on a straight line, the use of infinite (negative  $D_{\theta x}$  or  $D_{\theta y}$ ) rotational flexibility results in a kinematically unstable idealization.

For linear splines used with wings, the parameter  $DTOR$  should be selected as a representative value of  $EI/GJ$ .

STRUCTURAL-AERODYNAMIC INTERCONNECTIONS



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Figure 1. Splines and their coordinate systems.

## AERODYNAMIC MODELING

### 21.4 AERODYNAMIC MODELING

Aerodynamic elements define the interaction between the structure and an airflow. Since the elements usually occur in regular arrays, the connection cards are designed to specify arrays. The grid points associated with the elements in an array are generated within the program. Spline methods are used to interpolate for aerodynamic grid point deflection in terms of structural points.

For every aerodynamic problem, basic parameters are specified on the AERØ bulk data card. A rectangular aerodynamic coordinate system must be identified. The flow is in the positive X-direction in this system. The use of symmetry (or antisymmetry) is recommended to analyze symmetric structures, to simulate ground effects, or to simulate wind tunnel walls. Any consistent set of units can be used for the dimensional quantities.

The types of elements available are shown in Table 1. Every CAERØi element must reference a PAERØi data card, which is used for additional parameters. Lists of real numbers are sometimes required, which are given on AEFACT lists. These lists may include division points (for unequal box sizes) are parameter values.

#### 21.4.1 Modal Flutter Analysis

The purpose of modal flutter analysis is to study the stability of an aeroelastic system with a minimum number of degrees of freedom. A prerequisite to modal flutter analysis is the calculation of an aerodynamic matrix with a transformation to modal coordinates. This operation is often very costly and care should be taken to avoid unnecessary computations. One method is to compute the modal aerodynamic matrix at a few Mach numbers and reduced frequencies and interpolate to others. Matrix interpolation is an automatic feature of the flutter rigid format. The MKAERØ1 and MKAERØ2 data cards allow the selection of parameters for the aerodynamic matrix calculation on which the interpolation is based.

The method of flutter analysis is specified on the FLUTTER bulk data card. The FLUTTER card is selected in case control by an FMETHØD card. Three methods of flutter analysis are available; K, KE and PK. These are shown in Table 2.

## AEROELASTIC ANALYSIS

### 21.4.1.1 The K-Method

The K-method allows looping through three sets of parameters: density ratio ( $\rho/\rho_{ref}$ ;  $\rho_{ref}$  is given on an AERO data card); Mach number  $m$ ; and reduced frequency  $k$ . For example, if the user specifies two values of each, there will be eight loops in the following order.

LOOP (CURVE)	DENS	MACH	REFREQ
1	1	1	1
2	2	1	1
3	1	1	2
4	2	1	2
5	1	2	1
6	2	2	1
7	1	2	2
8	2	2	2

Values for the parameters are listed on FLFACT bulk data cards. Usually, one or two of the parameters will have only a single value. Caution: do not set up a large number of loops; it may take an excessive time to execute.

A parameter VREF may be used to scale the output velocity. This can be used to convert from consistent units (e.g., in/sec) to any units the user may desire (e.g., knots), determined from  $V_{out} = V/V_{REF}$ . Another use of this parameter is to compute the flutter index, by choosing  $V_{REF} = b\omega_0 \sqrt{\mu}$ .

### 21.4.1.2 The KE-Method

The KE-method is similar to the K method. By restricting the option, the KE-method is a more efficient K-method. The two major restrictions are that no damping (B) matrix is allowed and no eigenvector recovery is made. This means that the KE-method is not suitable for a control system, but it is a good method for producing a large number of points for the classical V-g curve. The KE-method also sorts the data for plotting. A plot request for one curve gives all the reduced frequencies for a mode while a similar request in the K-method gives all of the modes at one  $k$  value.

## AERODYNAMIC MODELING

### 21.4.1.3 The PK-Method

The PK-method treats the aerodynamic matrices as frequency dependent springs and dampers. A frequency is estimated and the eigenvalues are found. From an eigenvalue, a new frequency is found. The convergence to a consistent root is very rapid. The major advantage of the method is that the damping values obtained at subcritical flutter conditions appear to be more representative of the physical damping. Another advantage occurs when the stability at a specified velocity is required since many fewer eigenvalue analyses are needed to find the behavior at one velocity.

The input data for the PK-method also allows looping, as in the K method. The inner loop of the user data is velocity, with Mach number and density on outer loops. Thus, the effects of varying any or all of the three parameters on one run is possible.

### 21.4.2 Aeroelastic Response Analysis

The purpose of the modal aeroelastic response analysis is to study the behavior of an aeroelastic system resulting from applied loads and gusts. One rigid format can solve frequency response, random response, and transient response problems. The capability includes control systems (using NASTRAN Extra Points and Transfer Functions), multiple loading conditions (with SUBCASES), and rigid body modes.

The input data deck is the same as for the flutter analysis, except for load requests and output selection. The point loads are applied with standard RL0AD (frequency response) or TL0AD (transient response) data cards. For gust fields, which are only implemented for the Doublet-Lattice/Body Aerodynamic theory, the vertical stationary gust velocity can be specified with either RL0AD or TL0AD cards. In this manner, the response to either random or time-dependent gusts may be obtained.

For random response analysis, the power spectral density of the load must be supplied. For gusts, either the Von Karman or the Dryden formula can be selected. The output power spectral density is requested by the XY0UT Case Control cards. The r.m.s. value and  $N_0$ , the expected frequency, are automatically printed when PSDF information is requested.

The user must supply the basic flight conditions. The velocity is specified by the AER0 data card, while Mach number and dynamic pressure ( $q$ ) are supplied on PARAM bulk data cards.



## AEROELASTIC ANALYSIS

The damping must be modal damping. Ordinarily, a modal viscous damping is assumed, as in the NASTRAN model dynamic rigid format. A parameter KDAMP = -1 can be used to substitute modal structural damping, the modal stiffness is multiplied by  $[1+ig(\omega)]$ .

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## AERODYNAMIC MODELING

Table 1. Aerodynamic Elements.

Type	Doublet Lattice Panel	Lifting Body (Interference)	Mach Box Surface	Strip Theory	Piston Theory
Data Cards	CAER01 PAER01	CAER02 PAER02	CAER03 PAER03	CAER04 PAER04	CAER05 PAER05
Mach Number	Subsonic	Subsonic	Supersonic	All regimes	Hypersonic
Symmetry Options	2 planes y = 0 z = 0	2 planes y = 0 z = 0	1 plane required	None	None
Interaction	Panels and bodies in the same group		Boxes on one surface	None	None
Comments			One or two control surfaces	Control surface allowed. User may vary parameters.	A strip theory. coefficients from piston or Van Dyke theory. Control surface
Interconnection to Structure	Box centers	Slender body element centers	User specified locations	Strip 1/4-chord	Strip 1/4-chord
Displacement Components Used at Connection Points	3,5	3,5 z-bodies 2,6 y-bodies	3	3,5 No control 3,5,6 Control	3,5 No control 3,5,6 Control

## AEROELASTIC ANALYSIS

Table 2. Flutter Analysis Methods.

	"K"	"KE"	"PK"
<b>Structural Matrices</b>	K (complex) B (complex) M (complex)	K (complex) M (complex)	K (real) B (real) M (real)
<b>Aerodynamic Matrices</b>	M (complex)	M (complex)	K (real) B (real)
<b>User Input Loops</b>	$\rho$ -density m-Mach number k-reduced frequency	$\rho$ -density m-Mach number k-reduced frequency	$\rho$ -density m-density V-velocity
<b>Output</b>	V-g curve Complex modes Displacements Deformed plots	V-g curve	V-g curve Complex modes Displacements Deformed plots
<b>Method</b>	Compute roots for user input $\rho$ , m, k.	Compute roots for user input $\rho$ , m, k. Reorder output so a "curve" refers to a mode.	For each $\rho$ , m, V, iterate on each root to find consistent results. (Details in the Theoretical Manual.)
<b>Eigenvalue Method</b>	Several methods available, selected by user via CMETHOD in case control.	Complex Upper* Hessenberg	Real Upper* Hessenberg

\* No CMETHOD card is used.

## MODAL FLUTTER ANALYSIS EXAMPLE

### 21.5 MODAL FLUTTER ANALYSIS EXAMPLE

This problem illustrates the use of the aeroelastic analysis to determine flutter frequencies and mode shapes for an untapered wing having 15° sweep and an aspect ratio of 5.34 as shown in Figure 1.

#### 21.5.1 Input

Bulk data cards used include CAER01, PAER01, SPLINE2, SET1, AER0, MKAER01, FLUTTER, and FLFACT as illustrated in User's Manual Section 1.11.

#### 21.5.2 Theory

Reference 1 specifies the reduced frequency  $k = .1314$  (p.17), frequency ratio  $\omega/\omega_\alpha = 0.51$  (p.35) and torsion frequency  $\omega_\alpha = 1488$  (p.17).

The flutter velocity is found from

$$V = \frac{b\omega}{k} = \frac{\frac{REFC}{2} \times \omega_\alpha \times \frac{\omega}{\omega_\alpha}}{k} = 5980 \text{ in/sec.} \quad (1)$$

where REFC is the reference length input on the AER0 bulk data card.

The flutter frequency is found from

$$f = \frac{\omega_\alpha \times \frac{\omega}{\omega_\alpha}}{2\pi} = 121 \text{ Hz} \quad (2)$$

#### 21.5.3 Results

The results obtained are compared with both theoretical results using the modified strip analysis method and with experimental results. The flutter velocity is in good agreement. (See Figure 2.)

Frequencies are automatically output while mode shapes used in the modal formulation are obtained using an ALTER to the Rigid Format following the Real Eigenvalue Analysis Module.

Mode shapes for all points in the model may be obtained by checkpointing the problem using the Normal Mode Analysis (Rigid Format 3) and subsequently restarting using the Aeroelastic Analysis.

## AEROELASTIC ANALYSIS

### 21.5.4 Driver Deck and Sample Bulk Data

Card  
No.

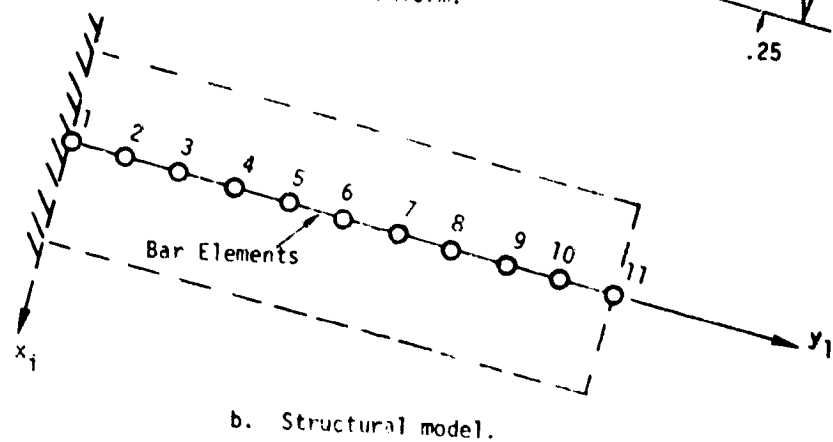
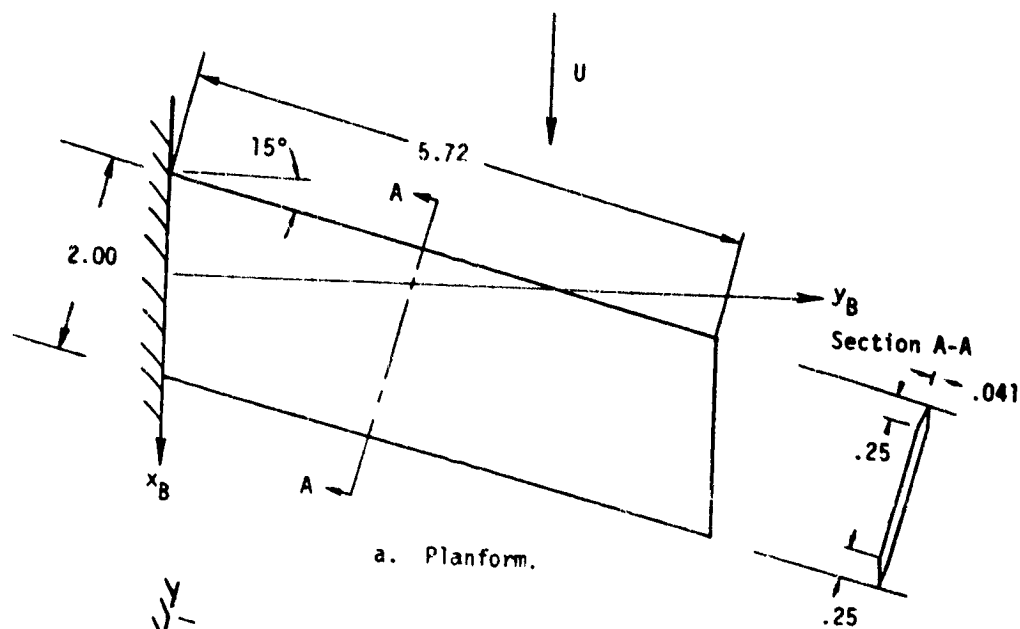
```

0  NASTRAN FILES=UMF
1  ID      DEM10021,NASTRAN
2  UMF     1978      100210
3  APP     AERØ
4  SOL     10,0
5  TIME    10
6  DIAG    14
7  ALTER   94 $
8  MATGPR  GPL,USET,SIL,PHIA//C,N,FE/C,N,A $
9  ENDALTER $
10 DIAG 18
11 CEND

12 TITLE = AERØELASTIC FLUTTER ANALYSIS ØF A FIFTEEN DEGREE SWOPT WING
13 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 10-2-1
14 LABEL = K VALUES .200(*) .167(0) .143(1) .125(2) .111(3) .100(4)
15 ECHO = BØTH
16 SPC = 1
17 METHOD = 10
18 CMETHOD = 20
19 FMETHOD = 30
20 ØUTPUT(XYØUT)
21 XTITLE = VELOCITY
22 YTTITLE = DAMPLING (G)
23 YBTITLE = FREQUENCY (F)
24 TCURVE = V-G AND V-F DATA POINTS
25 CURVELINESYMBOL = -1
26 XYPAPERPLOT VG / 1(G,F) 2(G,F) 3(G,F) 4(G,F) 5(G,F) 6(G,F)
27 BEGIN BULK
28 ENDDATA
    
```

	1	2	3	4	5	6	7	8	9	10
AERØ	0		1.3+4	2.0706	1.145-7					
CAERØ1	101		1	1	6	4			1	+CA101
+CA101	-1.		-.26795	0.0	2.0706	-1.	5.45205	0.0	2.0706	
CBAR	1		1	1	2	0.0	0.0	1.	1	
CMASS2	12		2.8-6	2	5					
CØRD2R	1			0.0	0.0	0.0	0.0	0.0	1.	+C1
+C1	.96593		-.25882	0.0						
ETGC	20		HESS	MAX						+EC
+EC										
EIGR	10		GIV	.3	.1		6			+ER
+ER	MAX									
FLFACT	1		.967							
FLUTTER	30		KE	1	2	3	L	3		
GRDSET			1				1	126		
GRID	1			0.0	.0	0.0				
MAT1	1		10.4+6	3.9+6		2.61-4				
MKAERØ1	.45									+MK
+MK	0.0001		.1	.2						
PAERØ1	1									
PARAM	CØUPMASS	1								
PARAM	LMØDES	3								
PBAR	1									
SET1	100			7.175-2	9.83-6		36.8-6			
SPC1	1			THRU	11					
SPLINE2	100		345	1						
+SP	0.0		101	101	124	100	0.0	1.	1	

MODAL FLUTTER ANALYSIS EXAMPLE



101					
102	105	109	113	117	121
103	106	110	114	118	122
104	107	111	115	119	123
	108	112	116	120	124

c. Aerodynamic model.

Figure 1. Fifteen degree sweep model.

AEROELASTIC ANALYSIS

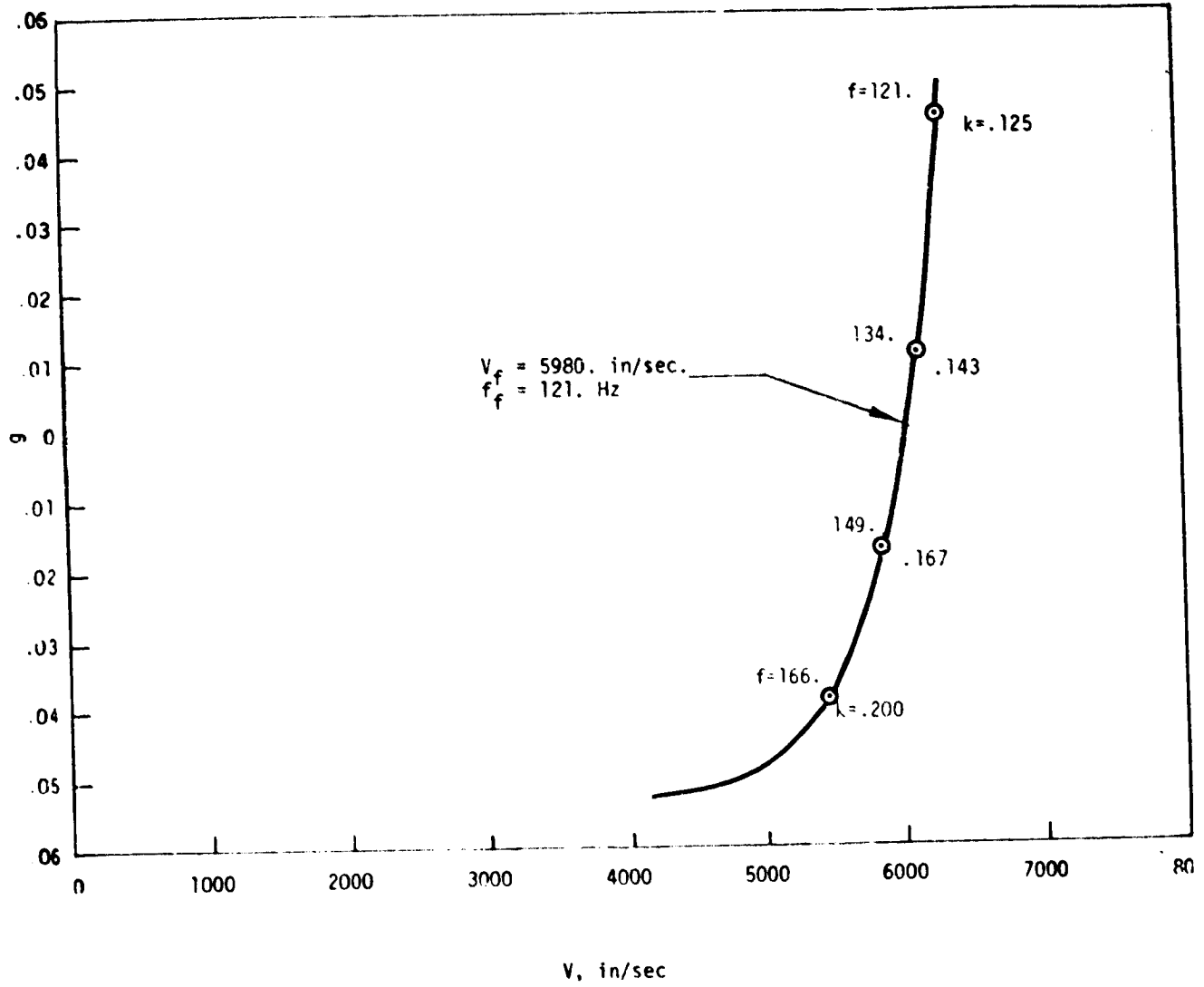


Figure 2. V-g results for fifteen degree sweep model.

## AEROELASTIC RESPONSE EXAMPLE

### 21.6 AEROELASTIC RESPONSE EXAMPLE

This example illustrates the use of the aeroelastic response analysis to perform frequency, random, and transient response calculations for a structure excited by aerodynamic loadings. This problem is also discussed in Section 1.11.5 of the User's Manual.

The structural model represents a wing and aileron configuration as shown in Figure 1. For this demonstration problem, the aileron is locked and the fuselage to which the wing is attached is a rigid body represented by grid point 11. Only out-of-plane motions are retained in the model. The wing is modeled with GENEL data defining the flexibility matrix, [Z], and a free-body matrix, [S]. The aileron also is modeled as a rigid body with the hinge line at point 8. The vertical flap deflection at point 12 is defined by an MPC equation.

The aerodynamic model consists of 42 doublet lattice aerodynamic boxes, forming one coupled group as shown in Figure 2. Three CAER01 aerodynamic elements are used to define the areas of uniform mesh on the wing. The aerodynamic degrees of freedom, implicitly defined by the CAER01 data, are coupled to the structure with surface splines defined on SPLINE2 data cards.

#### 21.6.1 Frequency Response Input

This example illustrates the frequency response analysis for a smooth gust shape and generates spectral density output plots for a random gust magnitude.

##### 1. Parameters:

- $V = 5183.2$  (Airstream velocity)  
 $M = 0.62$  (Airstream mach number)  
 $\rho = 1.1468 \times 10^{-7}$  (Air density)  
 $g = 0.06$  (Structural damping)

##### 2. Constraints:

- $\theta_y = \theta_z = 0$  Grid 11 (No fuselage isolation)  
 $u_x = u_y = \theta_z = 0$  All Grids  
 $\theta_x = \theta_y = 0$  All Grids except 11 and 12

##### 3. Load:

$$V_g = \frac{8360}{2} (1 - \cos 2\pi t) \quad (t < 1) \quad \text{Gust Velocity}$$



## AEROELASTIC ANALYSIS

### 21.6.2 Frequency Response Results

Figures 3 and 4 show plots of the fuselage plunge and aileron displacement as real and imaginary functions of frequency.

### 21.6.3 Frequency Response Driver Deck and Sample Bulk Data

```

Card
No.
0  NASTRAN FILES=UMF
1  ID      DEM11031,NASTRAN
2  UMF     1978    110310
3  APP     AERØ
4  SOL     11,0
5  TIME    3
6  CEND

7  TITLE = JET TRANSPORT WING DYNAMIC ANALYSIS
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 11-3-1
9  LABEL = SYMMETRIC RESPONSE , STIFF AILERON
10 ECHO = BOTH
11 $
12 $      MODEL DESCRIPTION                JET TRANSPORT WING EXAMPLE
13 $                                           SYMMETRIC RESPONSE TO A RANDOM
14 $                                           GUST WITH A STIFF AILERON
15 $
16 SPC = 14 $ SYM , NO PITCH
17 MPC = 1
18 METHOD = 10 $ GIVENS
19 SDMAP = 2000
20 FREQ = 40
21 RANDOM = 1031 $ EMPIRICAL PSDF
22 OUTPUT
23 $
24 $      SOLUTION                          RANDOM ANALYSIS USING
25 $                                           DOUBLET-LATTICE METHOD AERODYNAMICS
26 $                                           AT MACH. NO. OF .62
27 $
28 SET 1 = 1 , 2 , 12 $
29 SET 2 = 1 , 9 THRU 12 , 1040
30 SET 3 = 11
31 SET 4 = 1001, 1022 , 1023 , 1040 , 1041 $
32 SDISP(IMAG) = 1
33 DISP(IMAG) = 2
34 SPCF(IMAG) = 3
35 AERØF = 4
36 SUBCASE 1
37 LABEL = RANDOM GUST ANALYSIS
38 GUST = 3002
39 $
40 $      PRODUCES XY PAPER PLOTS OF MODAL AND GRID POINT DISPLACEMENTS
41 $      AND WING ROOT BENDING MOMENTS
42 $
43 OUTPUT(XYOUT) $ FREQ RESP PACKAGE (COMPLEX NUMBERS)
44 CURVELINESYMBOL = 1
45 XTITLE = FREQUENCY(HERTZ)                JET TRANSPORT , FREQUENCY RESPONSE
    
```

AEROELASTIC RESPONSE EXAMPLE

```

46 YTITLE = MODAL DEFLECTION
47 TCURVE = FIRST MODE (PLUNGE)
48 XYPAPERPLOT SDISP / 1(T1RM) , 1(T1IP)
49 TCURVE = SECOND MODE (WING BENDING)
50 XYPAPERPLOT SDISP / 2(T1RM) , 2(T1IP)
51 TCURVE = TWELFTH MODE (AILERON)
52 XYPAPERPLOT SDISP / 12(T1RM) , 12(T1IP)
53 YTITLE = PHYSICAL DEFLECTION
54 TCURVE = WING ( 3/4 CHORD , 1/4 CHORD , STA 458 )
55 XYPAPERPLOT DISP / 10(T3RM) , 10(T3IP) , 9(T3RM) , 9(T3IP)
56 TCURVE = FUSELAGE PLUNGE
57 XYPAPERPLOT DISP / 11(T3RM) , 11(T3IP)
58 TCURVE = AILERON DEFLECTION
59 XYPAPERPLOT DISP / 12(R2RM) , 12(R2IP)
60 TCURVE = AERODYNAMIC BOX NEAR TIP , PITCH
61 XYPAPERPLOT DISP / 1040(R2RM) , 1040(R2IP)
62 TCURVE = WING ROOT BENDING MOMENT
63 YTITLE = ROTATIONAL CONSTRAINTS
64 XYPAPERPLOT SPCF / 11(R3RM) , 11(R3IP)
65 $ RANDOM ANALYSIS OUTPUT REQUESTS
66 XTITLE = FREQUENCY (HERTZ) JET TRANSPORT , RANDOM ANALYSIS
67 TCURVE = POWER SPECTRAL DENSITY FUNCTION
68 YTITLE = FUSELAGE PLUNGE (11T3) , PSDF , GUST LOAD
69 XYPAPERPLOT DISP PSDF / 11(T3)
70 YTITLE = WING TIP DISPLACEMENT (9T3) , PSDF , GUST LOAD
71 XYPAPERPLOT DISP PSDF / 9(T3)
72 YTITLE = WING ROOT BENDING MOMENT (11R3) , PSDF , GUST LOAD
73 XYPAPERPLOT SPCF PSDF / 11(R3)
74 BEGIN BULK
75 ENDDATA

```

	1	2	3	4	5	6	7	8	9	10
AFACT	1		0.0	.09	.21	.33	.45	.56	.66	+AET
+AET	.74									
AERØ	1		8360.	131.232	1.1468-7	1				SYM
CAERØ1	1001		1000	0						+CAO1
+CAO1	78.75		0.	0.	225.	35.	1	4	1	
CELAS2	3		5142671.	12	5		500.	0.	100.	
CMASS2	2		13967.2	12	5					
CØNM1	1		11							
+51	17400.					4.37+7				+51
CØRD2R	1			0.0	0.0	0.0	0.0	0.0	-1.	+52
+C1	-1.		0.	0.						+C1
DAREA	9999		11	1	1.					
EIGR	10		GIV	0.0	1.		12			DUMMY
+EIGR	MAX									+EIGR
FREQ1	40		0.0	.25	39					
GENEL	432			1	3	2	3	3	3	+01
+01	4		3	5	3	6	3	7	3	+02
GRID	1			20.25	90.			12456		
GUST	3002		3002	1.1962-4	0.0	8360.				
MKAERØ1	.62									
+MK	.02		0.10	0.50						+MK
MPC	1		12	3	-1.0	8	3	1.5		
+MPC1			7	3	-0.5	12	5	33.25		+MPC1
PAERØ1	1000									
PARAM	GUSTAERØ		1							
PARAM	LMØDES		12							
PARAM	MACH		.62							
PARAM	Q		4.00747							
PARAM	WTMASS		.0025907							

## AEROELASTIC ANALYSIS

RANDPS	1031	1	1	1.	1004	1032			
RLDAD1	3002	9999							
SET1	14	1	THRU	11					
SPC	14	11	45						
SPLINE1	104	1022	1026	1039	15				
SPLINE2	101	1001	1001	1021	14	0.0	2.	0.	+SP1
+SP1	-1.0	-1.0							
SUPPORT	11	3							
TABDMP1	2000								+T2000
+T2000	0.	.06	10.	.06	ENDT				
TABLED1	1004								+T1004
+T1004	0.	0.	.01	1.	10.	1.	ENDT		
TABRND1	1032								+001
+001	0.00	2.8708+0	0.25	1.2641+0	0.50	4.7188-1	0.75	2.3080-1	+002

### 21.6.4 Transient Response Input

This example illustrates the transient response solution using a Fourier transform of the frequency response solution.

#### 1. Parameters:

- $V = 5183.2$  (Airstream velocity)  
 $M = 0.62$  (Airstream mach number)  
 $\rho = 1.1468 \times 10^{-7}$  (Air density)  
 $g = 0.06$  (Structural damping)

#### 2. Constraints:

- $\theta_y = \theta_z = 0$  Grid 11 (no fuselage isolation)  
 $u_x = u_y = \theta_z = 0$  All Grids  
 $\theta_x = \theta_y = 0$  All Grids except 11 and 12

#### 3. Load:

$$V_g = \begin{cases} 8360 & (t < 1.0) \\ -16720 & (t > 1.0) \end{cases} \quad \text{Gust Velocity}$$

### 21.6.5 Transient Response Results

Figures 5 and 6 are the same quantities as shown in Figures 3 and 4 for the transient solution

## AEROELASTIC RESPONSE EXAMPLE

### 21.6.6 Transient Response Driver Deck and Sample Bulk Data

```

Card
No.
0  NASTRAN FILES=UMF
1  ID      DEM11032.NASTRAN
2  UMF     1978  110320
3  APP     AERØ
4  SOL     11,0
5  TIME    3
6  CEND

7  TITLE = JET TRANSPORT WING DYNAMIC ANALYSIS
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 11-3-2
9  LABEL = SYMMETRIC RESPONSE , SQUARE EDGE GUST , TRANSIENT ANALYSIS
10 ECHO = BOTH
11 $
12 $      MODEL DESCRIPTION          JET TRANSPORT WING EXAMPLE
13 $
14 $      SYMMETRIC RESPONSE TO A SQUARE
15 $      EDGE GUST WITH A STIFF AILERON
16 $
17 $      SPC = 14 $ SYM , NO PITCH
18 $      MPC = 1
19 $      METHOD = 10 $ GIVENS
20 $      SDAMP = 2000
21 $      FREQ = 40
22 $      TSTEP = 41
23 $$$$$$ TWELVE MODES AND FORTY TWO BOXES   AERØ CALC THREE K VALUES
24 $      GUST = 1011 $ SQUARE
25 $      DLOAD = 9999 $ NEEDED TO FORCE APPROACH TRANSIENT GUST
26 $
27 $      SOLUTION                    TRANSIENT ANALYSIS USING
28 $      DOUBLET-LATTICE METHOD AERØDYNAMICS
29 $      AT MACH NO. OF 0.62
30 $
31 $      SET 1 = 1 , 2 , 12 $
32 $      SET 2 = 1 , 9 THRU 12 , 1040
33 $      SET 3 = 11
34 $      SDISP = 1
35 $      DISP = 2
36 $      SPCF = 3
37 $
38 $      PRODUCES XY PAPER PLOTS OF MODAL AND GRID POINT DISPLACEMENTS
39 $      AND WING ROOT BENDING MOMENT TIME HISTORIES
40 $
41 $      OUTPUT(XYOUT) $ TRANSIENT PACKAGE (REAL NUMBERS)
42 $      CURVELINES(MBØL = 1
43 $      XTITLE = TIME(SECONDS)          JET TRANSPORT , SQUARE GUST
44 $      TCURVE = FIRST MODE (PLUNGE)
45 $      YTITLE = MODAL DEFLECTION
46 $      XYPAPERPLOT   SDISP / 1(T1)
47 $      TCURVE = SECOND MODE (WING BENDING)
48 $      XYPAPERPLOT   SDISP / 2(T1)
49 $      TCURVE = TWELFTH MODE (AILERON)
50 $      XYPAPERPLOT   SDISP / 12(T1)
51 $      YTITLE = PHYSICAL DEFLECTION
52 $      TCURVE = WING ( 3/4 CHORD , 1/4 CHORD , STA 458 )
53 $      XYPAPERPLOT   DISP / 10(T3) , 9(T3)

```

AEROELASTIC ANALYSIS

54 TCURVE = FUSELAGE PLUNGE  
 55 XYPAPERPLØT DISP / 11(T3)  
 56 TCURVE = AILERØN DEFLECTION  
 57 XYPAPERPLØT DISP / 12(R2)  
 58 TCURVE = AERØDYNAMIC BØX NEAR TIP , PITCH  
 59 XYPAPERPLØT DISP / 104Ø(R2)  
 60 YTITLE = ROTATIONAL CØNSTRAINTS  
 61 TCURVE = WING RØØT BENDING MØMENT  
 62 XYPAPERPLØT SPCF / 11(R3)  
 63 BEGIN BULK  
 64 ENDDATA

	1	2	3	4	5	6	7	8	9	10
AFACT	1		0.0	.09	.21	.33	.45	.56	.66	+AE1
+AE1	.74									
AERØ	1	8360.	131.232	1.1468-7	1					SYM
CAERØ1	1001	1000	0							+CAØ1
+CAØ1	78.75	0.	0.	225.	35.	1	500.	4	1	100.
CELAS2	3	5142671.	12	5						
CMASS2	2	13967.2	12	5						
CØNM1	1	11								
+S1	17400.					4.37+7				+S1
CØRD2R	1		0.0	0.0	0.0	0.0	0.0	0.0	-1.	+S2
+C1	-1.	0.	0.							+C1
DAREA	1001	12	5	5142671.						
EIGR	10	GIV	0.0	1.			12			+EIGR
+EIGR	MAX									
FREQ1	40	0.0	.25	39						
GENEL	432		1	3	2	3	3	3	3	+Ø1
+Ø1	4	3	5	3	6	3	7	3	3	+Ø2
GRID	1		20.25	90.				12456		
GUST	1011	1000	1.	0.0	8360.					
MKAERØ1	.62									+MK
+MK	.02	0.10	0.50							
MPC	1	12	3	-1.0	8	3	1.5			+MPC1
+MPC1		7	3	-0.5	12	5	33.25			
PAERØ1	1000									
PARAM	GUSTAERØ	1								
PARAM	IFTM	0								
PARAM	LMØDES	12								
PARAM	MACH	.62								
PARAM	Q	4.00747								
PARAM	WTMASS	.0025907								
SET1	14	1	THRU	11						
SPC	14	11	45							
SPLINE1	104	1022	1026	1039	15					
SPLINE2	101	1001	1001	1021	14	0.0	2.	0.		+SP1
+SP1	-1.0	-1.0								
SUPØRT	11	3								
TABDMP1	2000									+T2000
+T2000	0.	.06	10.	.06	ENDT					
TABLED1	1003									+T1003
+T1003	0.	1.	1.	1.	1.	-1.	2.	-1.		+T1003A
TLØAD1	1000	1001			1003					
TSTEP	41	40	.1	1						

## AEROELASTIC RESPONSE EXAMPLE

### REFERENCES

1. Yates, E. C. and R. M. Bennett, "Use of Aerodynamic Parameters From Nonlinear Theory in Modified-Strip-Analysis Flutter Calculations for Finite-Span Wings at Supersonic Speeds; NASA TN D-1024, July 1963.

# AEROELASTIC ANALYSIS

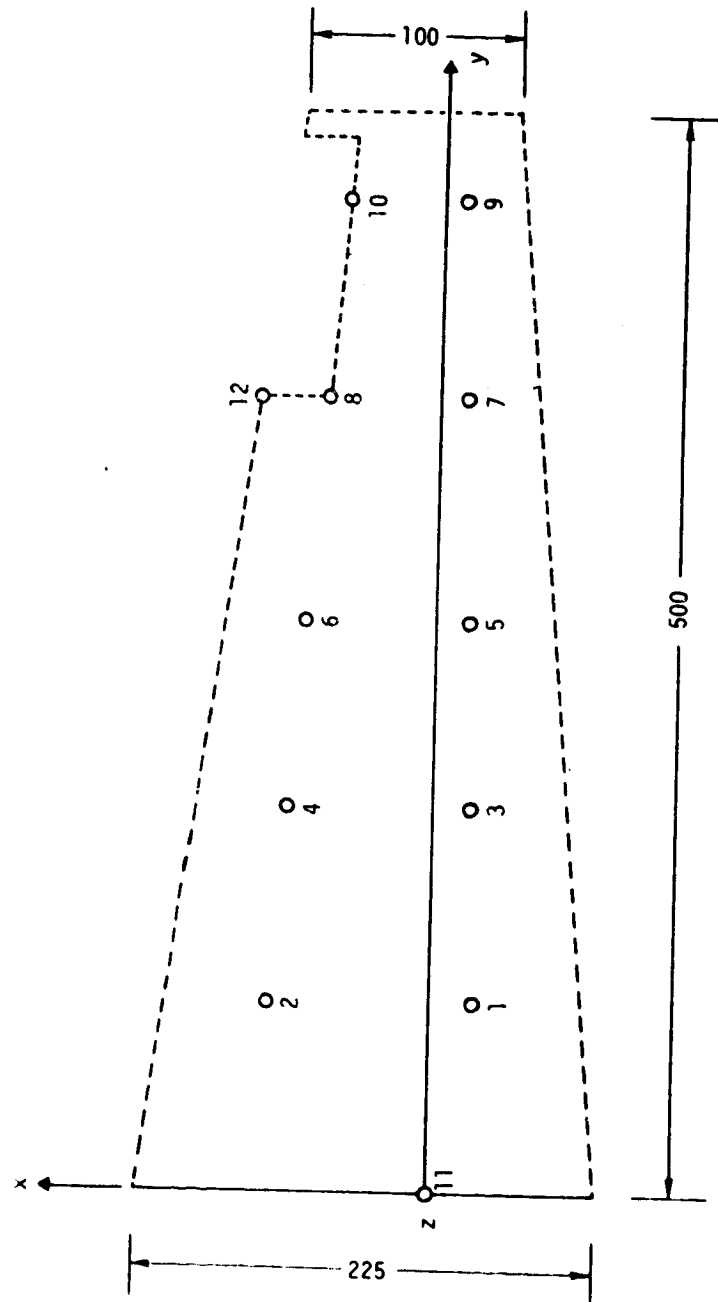


Figure 1. Structural definition of the transport wing.

# AEROELASTIC RESPONSE EXAMPLE

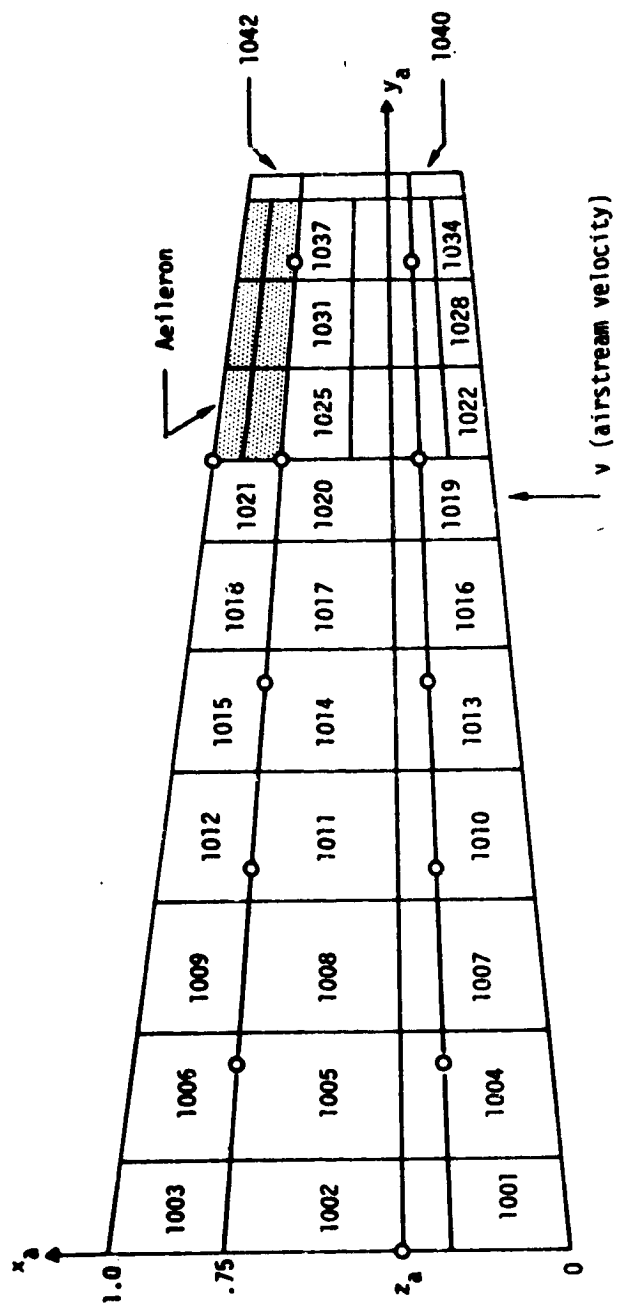


Figure 2. Aerodynamic element model.



AEROELASTIC ANALYSIS

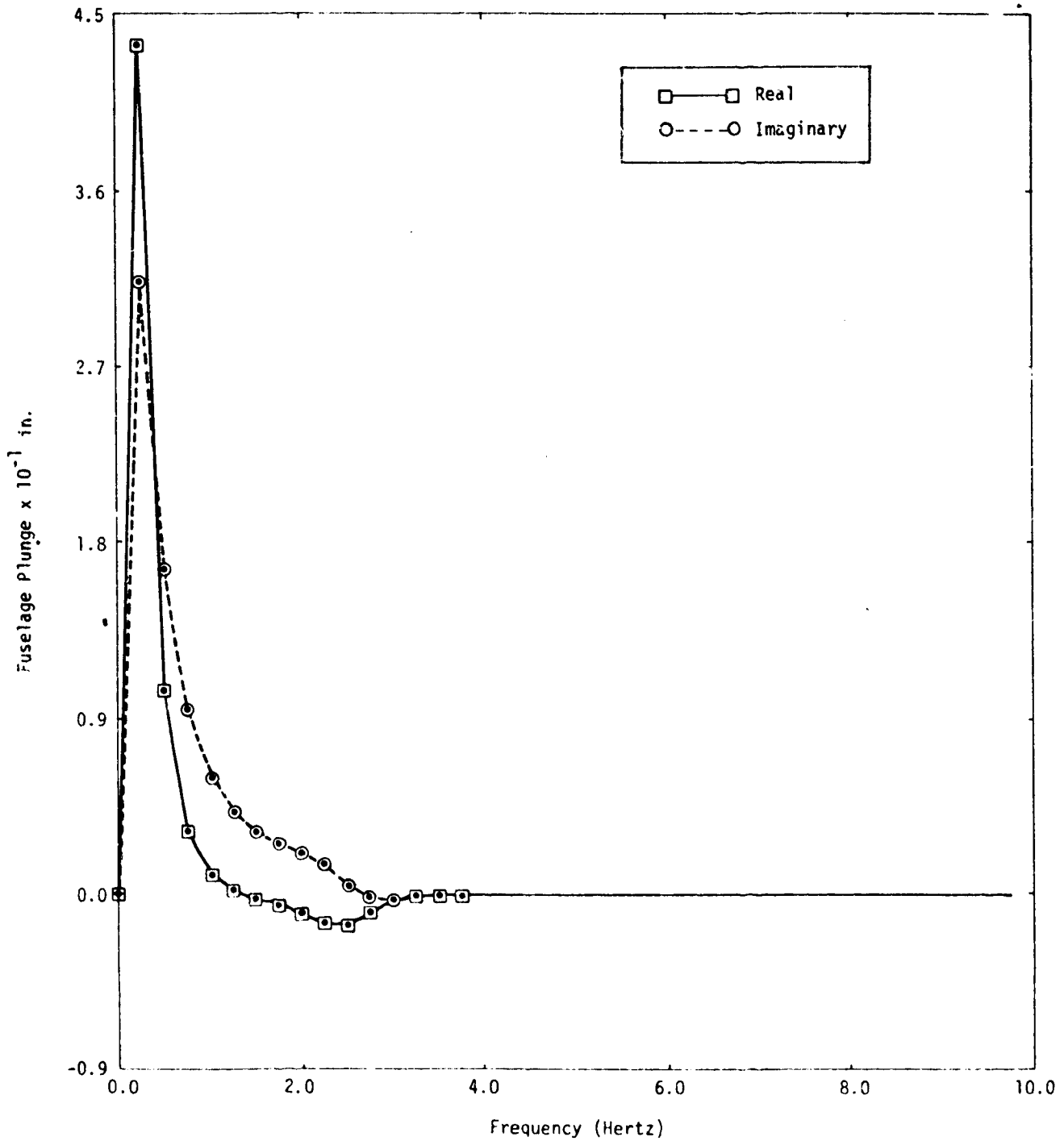


Figure 3. Fuselage plunge versus frequency at grid point 11.

# AEROELASTIC RESPONSE EXAMPLE

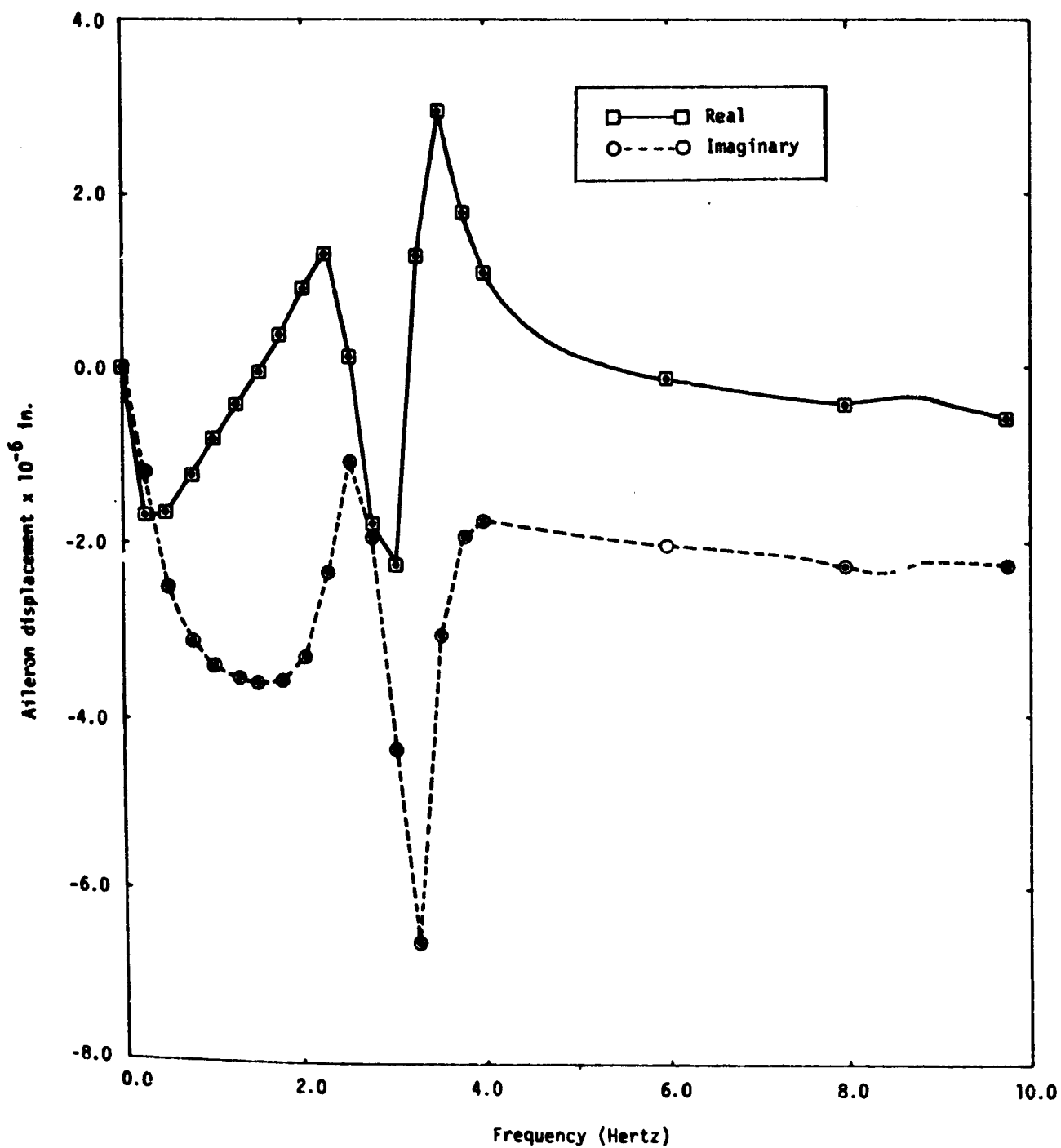


Figure 4. Aileron displacement versus frequency at grid point 12.

# AEROELASTIC ANALYSIS

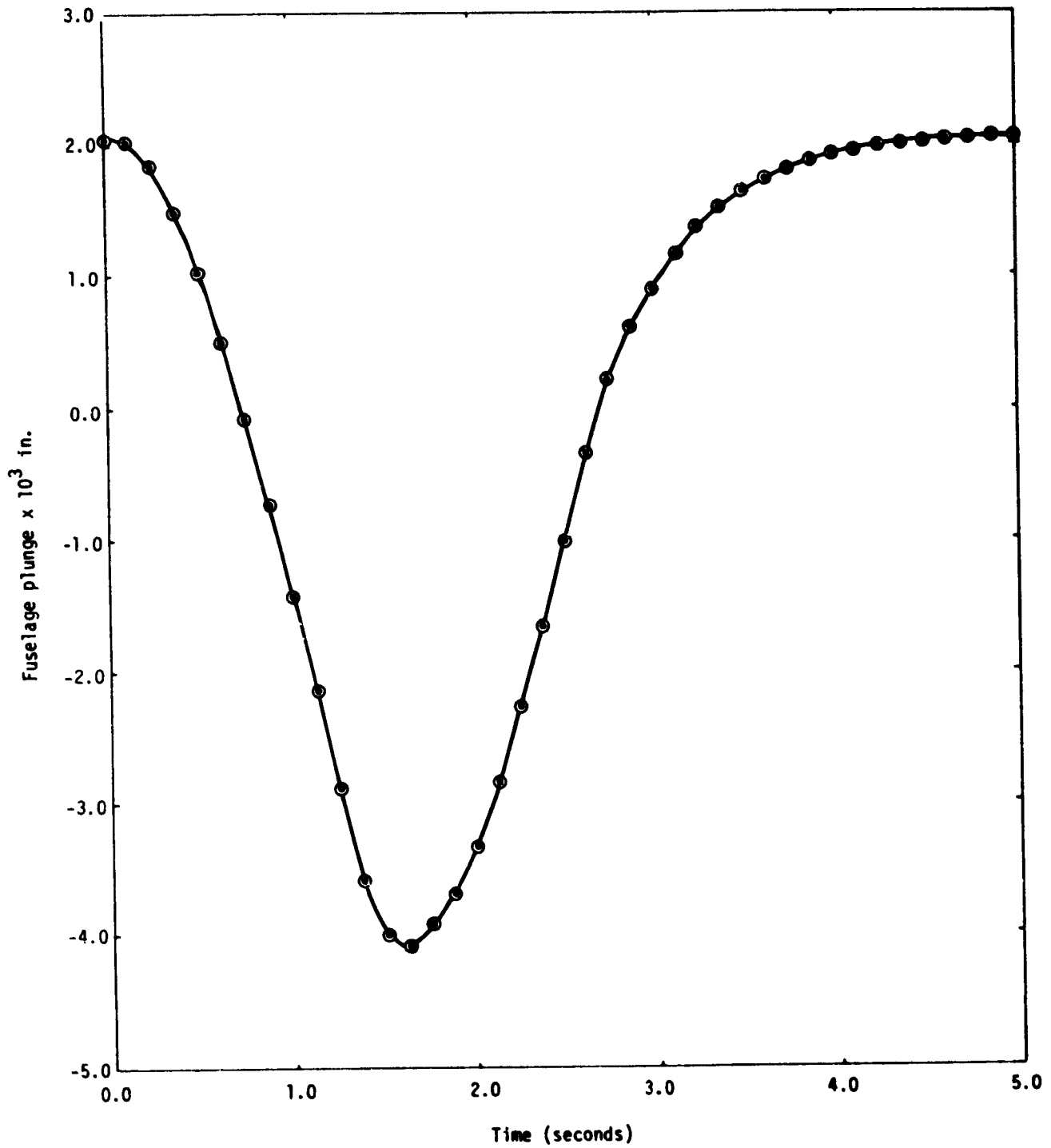


Figure 5. Fuselage plunge versus time at grid point 11.

# AEROELASTIC RESPONSE EXAMPLE

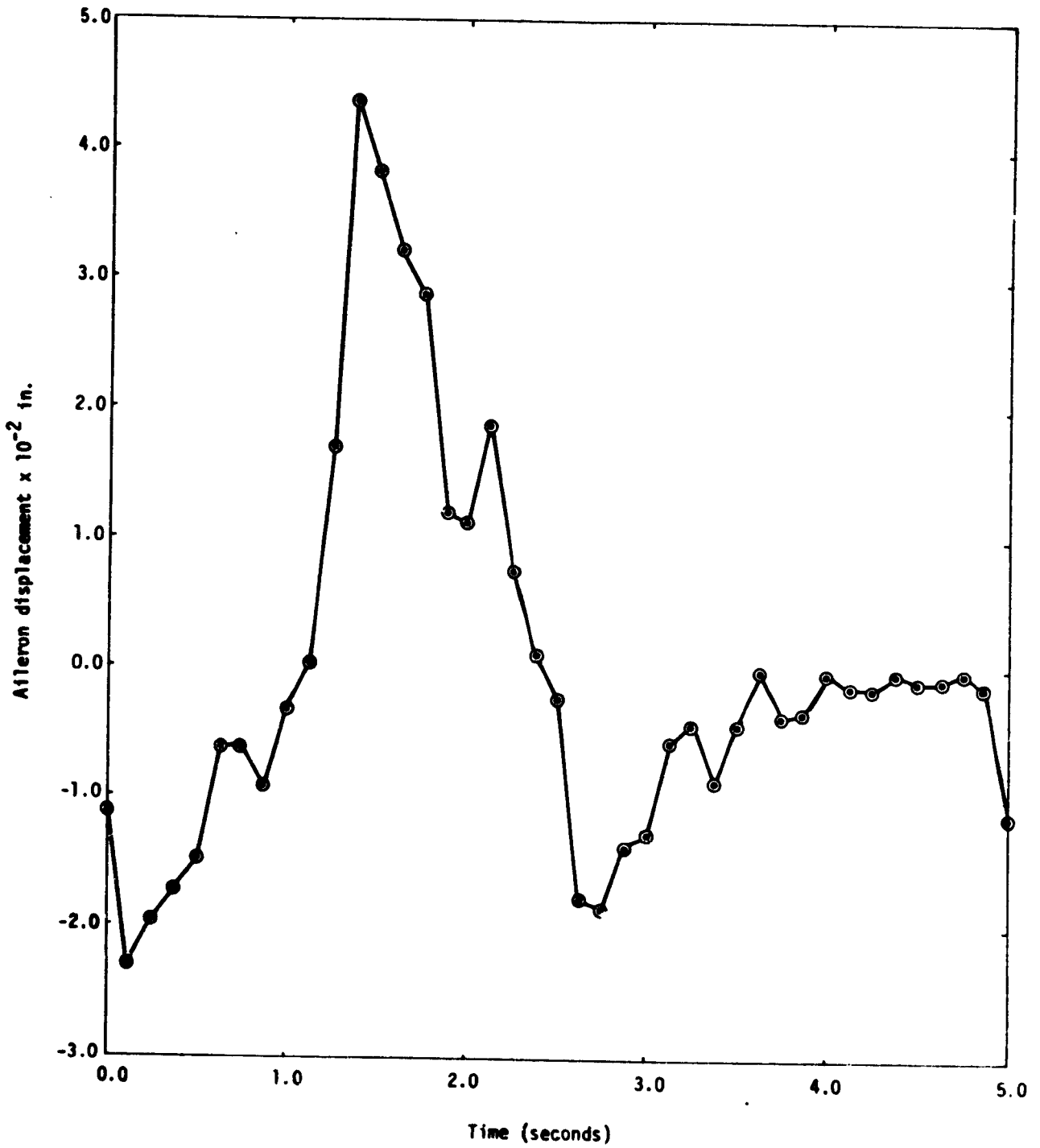


Figure 6. Aileron displacement versus time at grid point 12.

## 22. HEAT TRANSFER ANALYSIS

### 22.1 INTRODUCTION TO NASTRAN HEAT TRANSFER

NASTRAN heat flow capability may be used either as a separate analysis to determine temperatures and fluxes, or to determine temperature inputs for structural problems. Steady state and transient problems can be solved, including heat conduction (with variable conductivity for static analysis), film heat transfer, and nonlinear (fourth power law) radiation.

The heat flow problem is similar, in many ways, to structural analysis (Figure 1). The same model can be used for both analyses if the same finite elements are appropriate. The same grid points, coordinate systems, elements, constraints, and sequencing can be used for both problems. There are several differences, such as the number of degrees of freedom per grid point and the methods of specifying loads, boundary film heat conduction, and nonlinear elements. For heat flow problems, the only unknown at a grid point is the temperature (cf. structural analysis with three translations and three rotations), and hence, there is one degree of freedom per grid point. Additional grid or scalar points are introduced for fluid ambient temperatures in convective film heat transfer. If radiation effects are included or the conductivity of an element is temperature dependent, the problem becomes nonlinear (cf. structural analysis with temperature dependent materials which only requires looking up material properties and computing thermal loads.)

As in structural analysis, the choice of a finite element model is left to the analyst. Temperature distributions can be output in a format which can be used as input to structural problems. Heat flow analysis uses the special cards shown in Table 1 and many structural NASTRAN Bulk Data cards. These include (where i means there is more than one type): CBAR, CDAMPi, CELASi, CHEXAi, CIHEXi, C~~OR~~R~~OD~~, ~~R~~ORDi, CQ~~L~~M, CQ~~D~~PLT, COUADi, CR~~OD~~, CTETRA, CTRAPRG, CTRIAi, CTRIAG, CTRMEM, CTUBE, CVISC, CWEDGE, DAREA, DELAY, DL~~OAD~~, DMI, DMIG, EP~~INT~~, GRDSET, GRID, L~~OAD~~, MPC, MPCADD, N~~OL~~INI, OMITi, PARAM, Piii (for elements requiring properties), PL~~OTEL~~, SEQGP, SL~~OAD~~, SPCi, SPCADD, SP~~INT~~, TABLEDi, TF, TL~~OAD~~i, and TSTEP.

An explanation of the DMAP statements and information on Case Control Deck requirements for each Rigid Format, relevant to heat transfer analysis, are presented in the User's Manual, sections 3.17, 3.18, and 3.19. A detailed consideration of theory and applications of heat transfer may be found in the publication NASTRAN Thermal Analyzer--Theory and Application Including a Guide to Modeling Engineering Problems, Hwa-Ping Lee, NASA Report TM X-3503, April 1977.

## HEAT TRANSFER ELEMENTS

### 22.2 HEAT TRANSFER ELEMENTS

The basic heat conduction elements are the same as NASTRAN structural elements. These elements are shown in the following table:

Heat Conduction Elements	
Type	Elements
Linear	BAR, ROD, CONROD, TUBE
Membrane	TRMEM, TRAI1, TRAI2, QDMEM, QUAD1, QUAD2
Solid of Revolution	TRIARG, TRAPRG
Solid	TETRA, WEDGE, HEXA1, HEXA2, IHEX1, IHEX2, IHEX3
Scalar	CELAS1, CDAMP1

A connection card (Cxxx) and, if applicable, a property card (Pxxx) is defined for each of these elements. These heat conduction elements are composed of constant gradient lines, triangles, and tetrahedra. Linear elements have a constant cross-sectional area. The offset on the BAR is treated as a perfect conductor (no temperature drop). For the membrane elements, the heat conduction thickness is the membrane thickness. The bending characteristics of the elements do not enter into heat conduction problems. The solid of revolution element, TRAPRG, has been generalized to accept general quadrilateral rings (i.e., the top and bottom need not be perpendicular to the z-axis for heat conduction). The quadrilaterals are composed of overlapping triangles, and the wedges and hexahedra from subtetrahedra. Scalar spring elements are used for transient analysis temperature constraints and scalar damping elements are used to add thermal mass. Gradients and fluxes may be output by requesting ELFORCE.

Thermal material conductivities and heat capacities are given on MAT4 (isotropic) and MAT5 (anisotropic) Bulk Data cards. Temperature dependent conductivities are given on MATT4 and MATT5 Bulk Data cards, which can only be used for nonlinear static analysis. The heat capacity per unit volume is specified as the product of density and heat capacity per unit mass ( $\rho C_p$ ). Lumped conductivities and thermal capacitance may be defined by the CELAS1 and CDAMP1 elements, respectively.

## HEAT TRANSFER ANALYSIS

A special element (HBDY) defines an area for boundary conditions. There are five basic types called PPOINT, LINE, REV, AREA3, and AREA4. A sixth type, ELCYL, is for use only with QVECT radiation. The HBDY is considered an element, since it can add terms to the conduction and heat capacity matrices. Hence, there is a CHBDY connection and PHBDY property card. When a film heat transfer condition is desired, film conductivity and heat capacity per unit area are specified on MAT4 data cards. The ambient temperature is specified with additional points (GRID or SPPOINT) listed on the CHBDY connection card. See Figure 2 for geometry. The several types of power input to the HBDY elements can be output by the ELFORCE request.

Radiation heat exchange may be included between HBDY elements. A list of HBDY elements must be specified on a RADLST Bulk Data card, and the emissivities are specified on the PHBDY cards. The Stefan-Boltzmann constant (SIGMA) and absolute reference temperature (TABS) are specified on PARAM Bulk Data cards. Radiation exchange coefficients (default is zero) are specified on RADMTX Bulk Data cards.

Grid point temperatures for thermal stress analysis (static structural analysis) are specified on TEMP bulk data cards. If the heat conduction model is the same as the structural model with the same grid, connection and property cards, the temperature cards for the structural analysis can be directly output from the heat conduction analysis. The output request in Case Control is THERMAL (PUNCH), and the format of the card is exactly that of a double field TEMP data card.

## CONSTRAINTS AND PARTITIONING

### 22.3 CONSTRAINTS AND PARTITIONING

Constraints are applied to provide boundary conditions, represent "perfect" conductors, and provide other desired characteristics for the heat transfer model.

Single point constraints are used to specify the temperature at a point. The grid or scalar points are listed on SPC or SPC1 Bulk Data cards, not GRDSET or GRID cards, because in heat transfer analysis there is but one degree of freedom per point. The component on the data card must be "0" or "1", which declares the degree of freedom to be in the  $u_s$  set. The method of specifying temperature is dependent upon the problem type. In linear statics analysis, the SPC or SPC1 card is used to constrain grid points at a fixed temperature. In nonlinear statics analysis, the SPC or SPC1 card is used to designate the grid point ID which is to be constrained. The actual value of the temperature is indicated on a TEMP card, selected by TEMP(MATERIAL) in the Case Control deck. In transient analysis, the SPC or SPC1 card may be used to fix the temperature of a grid point only when the temperature is zero. When the temperature is non-zero a large conductive coupling to a "ground" at absolute temperature must be defined. From the structural relationship  $F=Kx$ , the thermal analogy is made where  $K$  is the conductive coupling,  $F$  is an applied load, and  $x$  is the fixed temperature. In this case,  $x$  is adjusted to the desired temperature by defining the spring constant,  $K$ , of a CELAS1 element, which is connected to "ground," and a load,  $F$ , which is applied to the grid point in question. The numerical value of  $K$  should be several orders of magnitude greater than the numerical value of the conductances prescribed for the rest of the model.

Multipoint constraints are linear relationships between temperatures at several grid points and are specified on MPC cards. The first entry on an MPC card will be in the  $u_m$  set. The type of constraint is limited if nonlinear elements are present. If a member of set  $u_m$  touches a non-linear (conduction or radiation) element, the constraint relationship is restricted to an "equivalence." The term "equivalence" means that the value of the member of the  $u_m$  set will be equal to one of the members of the  $u_n$  set (a point not multipoint constrained). Those points not touching nonlinear elements are not so limited. The user will be responsible for satisfying the equivalence requirement by having only two entries on the MPC data card.



## THERMAL LOADS

### 22.4 THERMAL LOADS

Thermal "loads" may be boundary heat fluxes or volume heat addition. As in the case of structural analysis, the method of specifying loads is different for static and transient analysis. The HBDY element is used for boundaries of conducting regions. Surface heat flux input can be specified for HBDY elements with QBDY1 and QBDY2 data cards. These two cards are for constant and (spatially) variable flux, respectively. Flux can be specified with the QHBDY data card without reference to an HBDY element. Vector flux, such as solar radiation, depends upon the angle between the flux and the element normal, and is specified for HBDY elements with the QVECT data card. This requires that the HBDY element orientation be defined on the CHBDY card. Volume heat addition into a conduction element is specified on a QVOL data card.

Static thermal loads are requested in Case Control with the LOAD card. All of the above load types plus SLLOAD can be requested. Transient loads are requested in Case Control with a DLOAD card to select TLOAD time functions. Transient thermal loads may use DAREA (as in structural transient), and/or the QBDY1, QBDY2, QHBDY, QVECT, QVOL, and SLLOAD cards. The resultant thermal load will be the sum of all loads applied. This means the LOAD SIDs and DAREA SIDs must be the same when referenced on a TLOADI card.

## STATIC ANALYSIS

### 22.5 STATIC ANALYSIS

Linear static analysis uses APPROACH HEAT SOLUTION 1. The Rigid Format is the same as that used for static structural analysis. This implies that several loading conditions and constraint sets can be solved in one job by using subcases in the Case Control deck.

Nonlinear static analysis uses APPROACH HEAT, SOLUTION 3. This specially designed Rigid Format will allow temperature dependent conductivities of the elements, nonlinear radiation exchange and a limited use of multipoint constraints. There is no looping for load and constraints, and the solution is iterative. The user can supply values on PARAM Bulk Data cards for:

MAXIT (integer) Maximum number of iterations (default 4).  
EPSHT (real)  $\epsilon$  convergence parameter (default .001).  
TABS (real) Absolute reference temperature (default 0.0).  
SIGMA (real) Stefan-Boltzmann radiation constant (default 0.0).  
IRES (integer) Request residual vector output if positive (default -1).

The user must supply an estimate of the temperature distribution vector  $\{u^1\}$ . This estimate is used to calculate the reference conductivity plus radiation matrix needed for the iteration.  $\{u^1\}$  is also used at all points in the  $u_s$  set to specify a boundary temperature. The values of  $\{u^1\}$  are given on TEMP Bulk Data cards, and they are selected by TEMP(MATERIAL) in Case Control.

Iteration may stop for the following reasons:

1. Normal convergence:  $\epsilon_T < \text{EPSHT}$ , where  $\epsilon_T$  is the per unit error estimate of the temperatures calculated.
2. Number of iterations  $> \text{MAXIT}$ .
3. Unstable:  $|\lambda_1| < 1$  and the number of iterations  $> 3$ , where  $\lambda_1$  is a stability estimator.
4. Insufficient time to perform another iteration.

The precise explanations and definitions are given in the NASTRAN Theoretical Manual, Section 8.4. Error estimates  $\epsilon_p$ ,  $\lambda_1$ , and  $\epsilon_T$  for all iterations may be output with the Executive Control card DIAG 18, where  $\epsilon_p$  is the ratio of the Euclidian norms of the residual (error) loads to the applied loads on the unconstrained degrees of freedom.

## TRANSIENT ANALYSIS

### 22.6 TRANSIENT ANALYSIS

Transient analysis uses APPROACH HEAT SOLUTION 9. This Rigid Format may include conduction film heat transfer, nonlinear radiation, and NASTRAN nonlinear elements. Extra points are used as in structural transient analysis. All points associated with nonlinear loads must be in the solution set. Loads may be applied with TLOAD and DAREA cards as in structural analysis. Also, the thermal static load cards can be modified by a function of time for use in transient analysis. If the static load data is used to define a transient load, the static load set identification is referenced on the TLOAD card in the DAREA field. Loads are requested in Case Control with DLOAD. Initial temperatures are specified on TEMP Bulk Data cards and are requested by IC in Case Control. Previous static or transient solutions can easily be used as initial conditions, since they can be punched in the correct format. An estimate of the temperature ( $u^1$ ) is specified on TEMP Bulk Data cards for transient with radiation, and is requested by TEMP(MATERIAL). The parameters available are:

TABS (real)	Absolute reference temperature (default 0.0).
SIGMA (real)	Stefan-Boltzmann radiation constant (default 0.0).
BETA (real)	Forward difference integration factor (default .55).
RADLIN (integer)	Radiation is linearized if positive (default -1).

## HEAT TRANSFER EXAMPLE

### 22.7 HEAT TRANSFER EXAMPLE

The sample problem below illustrates the capability of NASTRAN to solve heat conduction problems. Linear solid state conduction through a washer is solved in two ways: (1) using solid elements and (2) using ring elements. The washer, shown in Figure 3, has a radial heat conduction with the temperature specified at the outside and a film heat transfer condition at the inner edge. Due to symmetry about the axis and the assumption of negligible axial gradients, the temperature depends only upon the radius.

#### 22.7.1 Input

The first NASTRAN model is shown in Figure 4. The solid elements (HEXA1, HEXA2, WEDGE, and TETRA) and boundary condition element (HBDY, type AREA4) are used. The conductivity of the material is specified on a MAT4 card. Temperatures are specified at the outer boundary with SPC cards. Punched temperature output is placed on TEMP bulk data cards suitable for static analysis. Another variation of the problem is shown in Figure 5. Solid of revolution elements (TRIARG and TRAPRG) and boundary condition element (HBDY, type REV) are used. The conductivity of the material and the convective film coefficient are specified on a MAT4 card. The CHBDY card references a scalar point at which the ambient temperature is specified using an SPC card. An SPC1 card is used to constrain the temperature to zero degrees at gridpoints on the outer surface.

#### 22.7.2 Theory

The mathematical theory for the continuum is simple, and can be solved in closed form. The differential equation is

$$\frac{1}{r} \frac{\partial}{\partial r} (rk \frac{\partial U}{\partial r}) = 0. \quad (1)$$

The boundary conditions are

$$-k \frac{\partial U}{\partial r} = H(U_a - U) \text{ at } r = r_1, \quad (2)$$

and

$$U = 0 \quad \text{at } r = r_2. \quad (3)$$

## HEAT TRANSFER ANALYSIS

The solution is

$$U(r) = \frac{HU_a}{(k/r_1) + Hn(r_2/r_1)} n(r_2/r)$$

$$= 288.516 n(2/r)$$

### 22.7.3 Results

A comparison of theoretical temperatures with the NASTRAN results is shown in Table 2.

### 22.7.4 Driver Deck and Sample Bulk Data

Note: Only one data card of each type is listed to illustrate its use.

Card  
No.

```

0  NASTRAN FILES = UMF
1  ID      DEM1121,NASTRAN
2  UMF     1977   11210
3  TIME    1
4  APP     HEAT
5  SOL     1,1
6  CEND

7  TITLE = LINEAR STEADY STATE HEAT CONDUCTION THROUGH A WASHER
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-12-1
9  LABEL = SOLID ELEMENTS,SURFACE FILM HEAT TRANSFER
10 @LOAD = ALL
11 SPCFORCES = ALL
12 THERMAL(PRINT,PUNCH) = ALL
13 ELFORCE = ALL
14 SUBCASE 123
15 LABEL = TEMPERATURE SPECIFIED AT OUTER BOUNDARY
16 SPC = 351
17 LOAD = 251
18 BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
19	CHBDY	701	702	AREA4	1	12	112	101		
20	CHEXA1	1	200	1	2	13	12	101	+SOL1	
21	+SOL1	113	112							
22	CHEXA2	2	200	2	3	14	13	102	103	+SOL2
23	+SOL2	114	113							
24	CORD2C	111	0	.0	.0	.0	.0	.0	100.0	+CORD111
25	+CORD111	100.0	.0	.0						
26	CTETRA	3	200	104	114	3	103			
27	CWEDGE	8	200	4	5	15	104	105	115	
28	GRDSET						111			
29	GRID	1	111	1.0	.0	.0				
30	MAT4	200	1.0							
31	PARAM	IRES	1							
32	PHBDY	702	200							

## HEAT TRANSFER EXAMPLE

	1	2	3	4	5	6	7	8	9	10
33	QBDY1	251	288.5	701						
34	SEQGP	12	1.1	13	2.1	14	3.1	15	4.1	
35	SPC	351	11	1	.0	22	1	.0		

36 ENDDATA

### Notes on Cards for the Solid Element Solution

Card No.

- 12 This card in the Case Control Deck requests that the temperatures of all points be printed on paper and punched on cards.
- 19 The CHBDY card defines a boundary element which is used for heat flux, thermal vector flux, convection and/or radiation.
- 31 A positive integer value of the IRES parameter in a HEAT statics problem will cause the printing of all residual vectors.
- 32 The PHBDY card defines the properties of the HBDY element.
- 33 The QBDY1 card defines a uniform heat flux into HBDY elements. To be used in a static run, this card must be requested in the Case Control Deck (LOAD=SID).

Card No.

- 0 NASTRAN FILES=UMF
- 1 ID DEMI122,NASTRAN
- 2 UMF 1977 11220
- 3 APP HEAT
- 4 SOL 1,0
- 5 TIME 10
- 6 CEND
- 7 TITLE = LINEAR STEADY STATE CONDITION THROUGH A WASHER
- 8 SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-12-2
- 9 LABEL = RING ELEMENTS, FILM HEAT TRANSFER
- 10 OUTPUT
- 11 @LOAD = ALL
- 12 SPCFORCE = ALL
- 13 THERMAL (PRINT,PUNCH) = ALL
- 14 ELFORCE = ALL
- 15 SPC = 350
- 16 BEGIN BULK

	1	2	3	4	5	6	7	8	9	10
17	CHBDY	14	100	REV	1	12				+HBDY14
18	+HBDY14	23	23							
19	CTRPRG	7	4	5	16	15	.0	200		
20	GRID	1		1.0	.0	.0				
21	MAT4	200	.10							
22	PHBDY	100	300							
23	SEQGP	12	1.1	13	2.1	14	3.1	15	4.1	
24	SPC	352	23		488.5					
25	SPC1	351	1	11	22					
26	SPCADD	350	351	352						
27	SPINT	23								
28	TEMPO	201	.0							

29 ENDDATA

## HEAT TRANSFER ANALYSIS

### Notes on Cards for the Ring Element Solution

Card  
No.

- 13 This card in the Case Control Deck requests that the temperatures of all points be printed on paper and punched on cards.
- 17 The CHBDY data card defines a boundary element which is used for heat flux, thermal vector flux, convection and/or radiation.
- 22 The PHBDY card defines the properties of the HBDY element.
- 28 The TEMPD card defines a default temperature for all grid points of the structural model which have not been given a temperature on a TEMP card. Temperature sets must be selected in the Case Control Deck (TEMP=SID) to be used by NASTRAN.

## HEAT TRANSFER EXAMPLE

Table 1. Bulk Data Cards of Special Reference to Heat Transfer Analysis

CHBDY	Heat Boundary Element
MATT3	Material Temperature Dependence
MATT4	Material Temperature Dependence
MATT5	Material Temperature Dependence
PHBDY	Property of Heat Boundary Element
QBDY1	Boundary Heat Flux Load
QBCY2	Boundary Heat Flux Load
QHBDY	Boundary Heat Flux Load
QVECT	Thermal Vector Flux Load
QVOL	Volume Heat Addition
RADLST	List of Radiation Areas
KADMTX	Radiation Matrix
TABLEM1	Material Property Table
TABLEM2	Material Property Table
TABLEM3	Material Property Table
TABLEM4	Material Property Table
TEMP	Grid Point Temperature Field
TEMPAX	Axisymmetric Temperature
TEMPD	Grid Point Temperature Field Default



## HEAT TRANSFER ANALYSIS

Table 2. Comparison of Theoretical and NASTRAN Temperatures for Heat Conduction in a Washer

r(radius)	Theoretical Temperatures	NASTRAN Temperatures (Solids)*	NASTRAN Temperatures (Rings)*
1.0	199.984	202.396	199.932
1.1	172.486	173.904	172.448
1.2	147.381	148.833	147.355
1.3	124.288	124.783	124.269
1.4	102.906	102.852	102.894
1.5	83.001	82.913	82.992
1.6	64.380	64.306	64.375
1.7	46.889	46.832	46.886
1.8	30.398	30.356	30.397
1.9	14.799	14.773	14.798
2.0	0.000	0.000	0.000

\* These are the average temperatures at a radius.

HEAT TRANSFER EXAMPLE

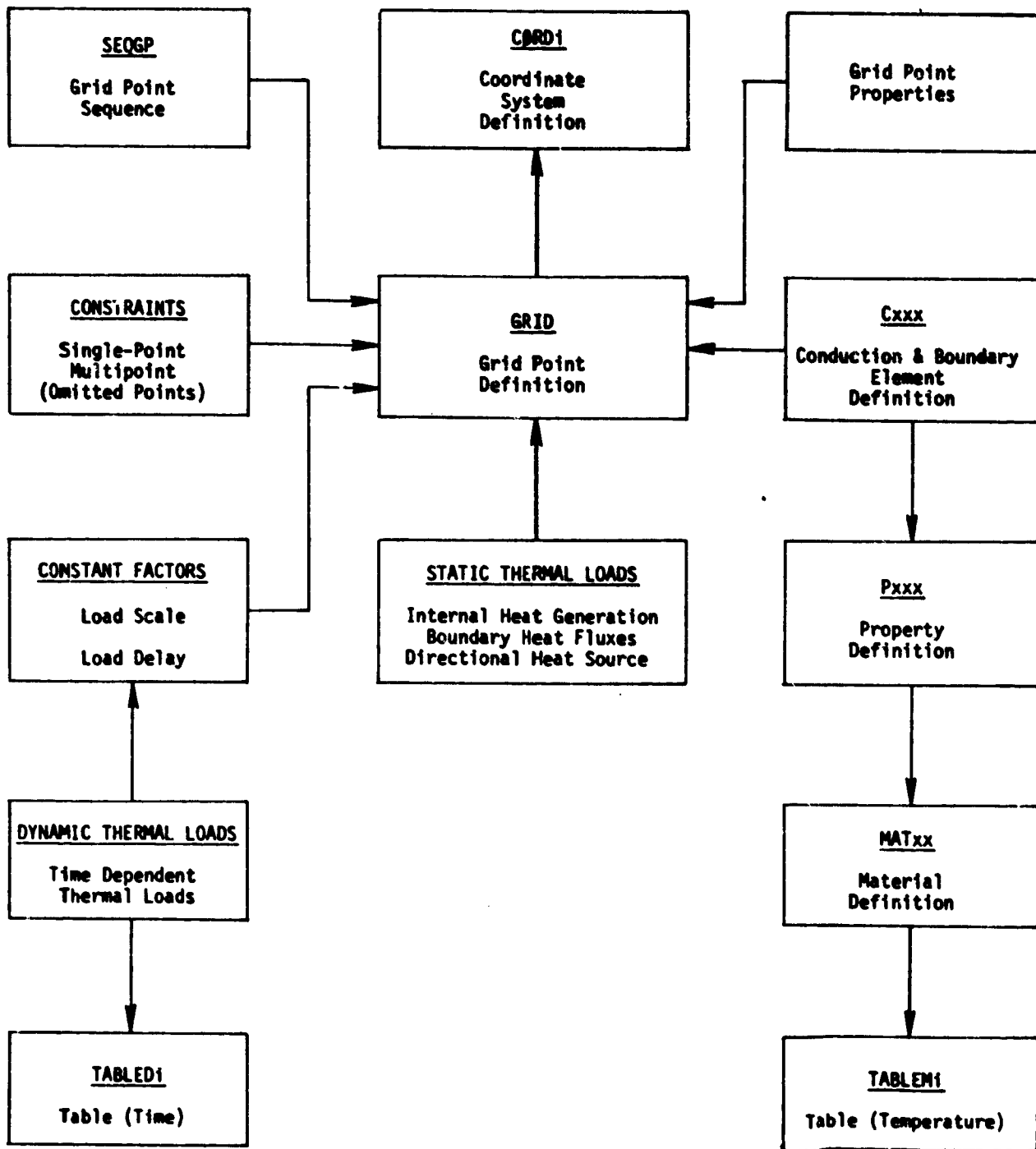
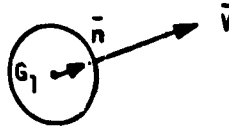


Figure 1. Thermal model diagram.

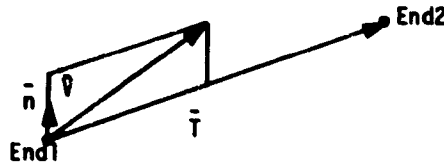
## HEAT TRANSFER ANALYSIS

### Type = POINT



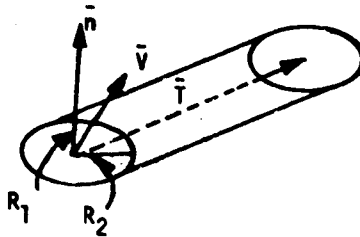
The unit normal vector is given by  $\bar{n} = \bar{V}/|\bar{V}|$ , where  $\bar{V}$  is given in the basic system at the referenced grid point (see CHBDY data card, fields 16-18).

### Type = LINE



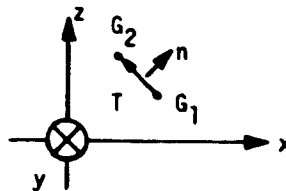
The unit normal lies in the plane of  $\bar{V}$  and  $\bar{T}$ , is perpendicular to  $\bar{T}$ , and is given by  $\bar{n} = (\bar{T} \times (\bar{V} \times \bar{T})) / |\bar{T} \times (\bar{V} \times \bar{T})|$ .

### Type = ELCYL



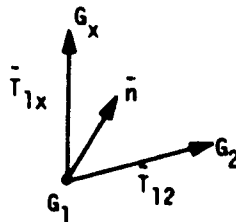
The same logic is used to determine  $\bar{n}$  as for type = LINE. The "radius"  $R_1$  is in the  $\bar{n}$  direction and  $R_2$  is perpendicular to  $\bar{n}$  and  $\bar{T}$  (see fields 7 and 8 of PHBDY card).

### Type = REV



The unit normal lies in the x-z plane, and is given by  $\bar{n} = (\bar{e}_y \times \bar{T}) / |\bar{e}_y \times \bar{T}|$ .  $\bar{e}_y$  is the unit vector in the y direction.

### Type = AREA3 or AREA4



The unit normal vector is given by  $\bar{n} = (\bar{T}_{12} \times \bar{T}_{1x}) / |\bar{T}_{12} \times \bar{T}_{1x}|$ , where  $x = 3$  for triangles and  $x = 4$  for quadrilaterals.

Figure 2. HBDY element orientation (for QVECT flux).

# HEAT TRANSFER EXAMPLE

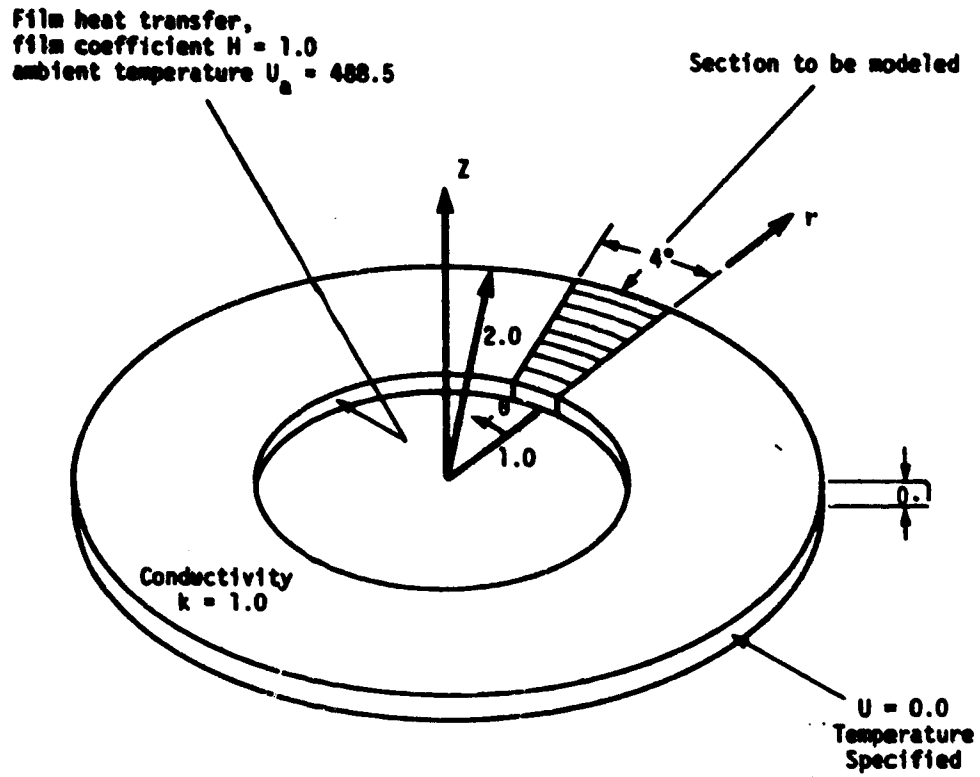


Figure 3. Washer Analyzed in Heat Conduction Demonstration Problem.

# HEAT TRANSFER ANALYSIS

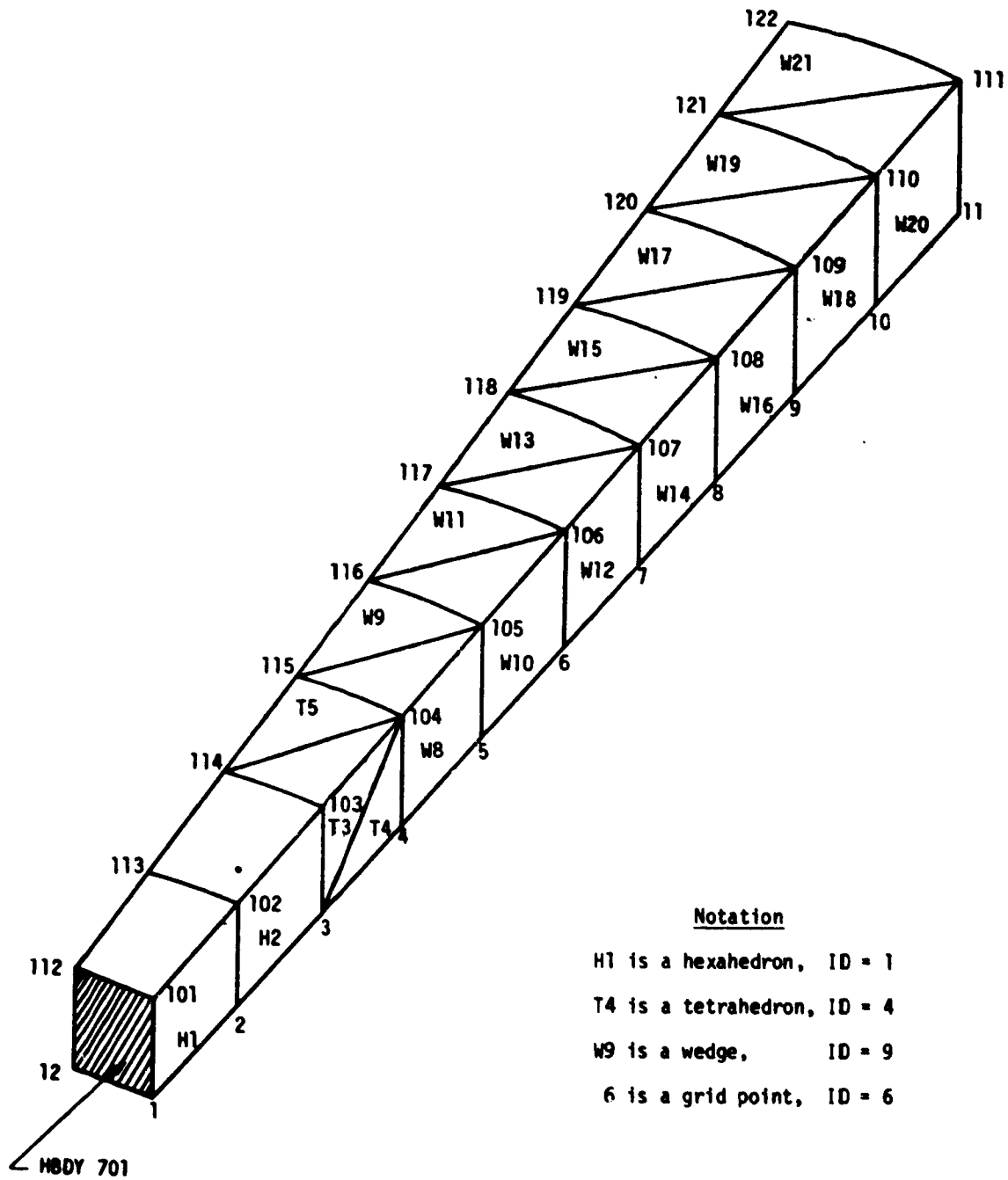
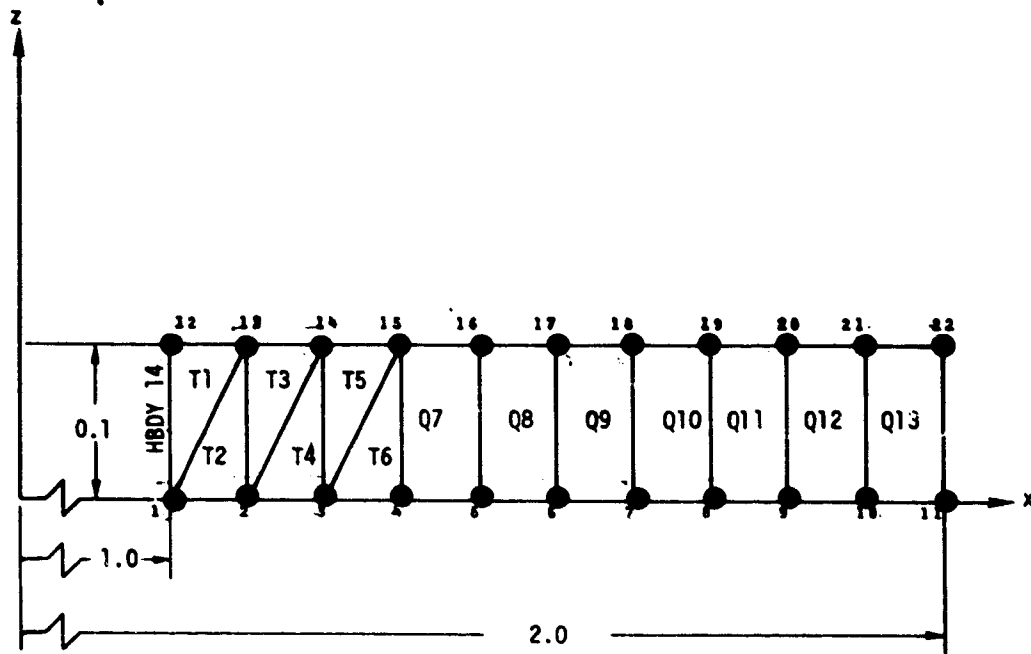


Figure 4. Elements and Grid Points.

# HEAT TRANSFER EXAMPLE



T TRIARG elements  
 Q TRAPRG elements  
 $U_a = 488.5$  at left end  
 $U_a = 0.0$  at right end

Figure 5. Section of a pipe, modeled with ring elements.

## 23. CYCLIC SYMMETRY MODELING

### 23.1 CYCLIC SYMMETRY MODELS

Many structures, including pressure vessels, rotating machines and antennae for space communications, are made up of virtually identical segments that are symmetrically arranged with respect to an axis. There are two types of cyclic symmetry as shown in Figures 1 and 2: simple rotational symmetry, in which the segments do not have planes of reflective symmetry and the boundaries between segments may be general doubly-curved surfaces; and dihedral symmetry, in which each segment has a plane of reflective symmetry and the boundaries between segments are planar. The use of cyclic symmetry allows the user to model only one of the identical sub-structures which will result in a large saving of data preparation and computer time for most problems. Table 1 summarizes the Bulk Data cards of special relevance to cyclic symmetry. The theoretical treatment for cyclic symmetry is given in Section 4.5 of the Theoretical Manual.

The total model consists of N identical segments which are numbered consecutively from 1 to N. The user supplies a NASTRAN model for one segment using regular elements and standard modeling techniques, except that, grid points are not permitted on the polar axis. All other segments and their coordinate systems are automatically rotated by the program to equally spaced positions about the polar axis. The boundaries must be conformable, i.e., the segments must coincide. This is easiest to insure if a cylindrical or spherical coordinate system is used, but such is not required. CTYPE on the PARAM card is used to specify either rotational symmetry or dihedral symmetry. The number of segments, N, in the structural model is specified also on the PARAM card, NSEGS. As indicated in Figure 2, dihedral symmetry provides solutions for each segment and its reflected image. This requires application of both symmetric and antisymmetric boundary conditions.

In rotational symmetry the basic transformation equation between the structure segments  $n = 1, 2, \text{etc.}$ , and the harmonic indices  $k = 0, 1, 2, \text{etc.}$ , is

$$u^n = \bar{u}^0 + \sum_{k=1}^{KMAX} [\bar{u}^{kc} \cos(n-1)ka + \bar{u}^{ks} \sin(n-1)ka] \quad (1)$$

where

$u^n$  is any displacement, load, stress, etc., on the  $n^{\text{th}}$  segment ( $n = 1, 2, \dots, \text{NSEGS}$ ),  
 $\bar{u}^0, \bar{u}^{kc}, \bar{u}^{ks}$  are the corresponding cyclic coefficients used in the solution which define the entire structure,

## CYCLIC SYMMETRY MODELING

$k$  is the cyclic index (i.e., KINDEX),

KMAX is the limit ( $KMAX \leq \frac{N}{2}$ ) of  $k$ . (If all values of  $k$  are used, the transformation is exact),

and

$a = \frac{2\pi}{NSEG}$  is the circumferential angle for each segment.

In the case of dihedral symmetry, the repeated segment may be divided into two half-segments divided by a plane of symmetry. The reason for using dihedral symmetry is to reduce the size of the model by one half. The solution is obtained for symmetric motions (S) and antisymmetric motions (A) of the right half segment which is the one to be modeled by the user. Thus, for each cyclic index,  $K$ , four coefficients are obtained defining the variable,  $n$ , i.e.,  $\bar{u}^{ks,S}$ ,  $\bar{u}^{ks,A}$ . In the right hand segment the terms are added

$$\text{Right side:} \quad \bar{u}^{ks} = \bar{u}^{ks,S} + \bar{u}^{ks,A} \quad (2)$$

In the left hand mirror image the antisymmetric solution is subtracted.

$$\text{Left Side:} \quad \bar{u}^{ks} = \bar{u}^{ks,S} - \bar{u}^{ks,A} \quad (3)$$

The two boundaries are called sides 1 and 2. In the case of rotational symmetry, side 2 of segment  $n$  is connected to side 1 of segment  $n+1$ , as shown in Figure 1. In the case of dihedral symmetry, side 1 is on the boundary of the segment and side 2 is on the plane of symmetry for the segment, as shown in Figure 2. In either case the grid point numbers on sides 1 and 2 must be specified on the bulk data card, CYJØIN.

No restrictions are placed on the use of the single point constraint, the multipoint constraint, or the ØMIT feature of NASTRAN. However, the constraints are assumed to be the same for each segment. Constraints between segments are automatically applied to the degrees of freedom, which are not otherwise constrained, at grid points specified on CYJØIN bulk data cards. The SPCD bulk data card may be used to vary the magnitude of enforced displacements for each of the segments.

For purposes of minimizing matrix bandwidth, the equations of the solution set are normally sequenced with the cosine terms alternating with the sine terms. The user may request an alternate sequence on the PARAM card, CYSEQ, which orders all cosine terms before all sine terms. The latter may improve efficiency when all of the interior points have been omitted.



## STATIC ANALYSIS

### 23.2 STATIC ANALYSIS

Static loads are applied to the structural model in the usual way. NASTRAN assumes that separate subcases are defined for each segment. If there are multiple loads, a set of sequential ordered subcases, one subcase per load, must be defined for each segment in Case Control. In effect, it is as each segment of the model is treated as a separate structure with its own load. All segments, of course, must have the same number of consecutive subcases, one for each static load applied to the whole model. In the case of rotational symmetry, there will be a number of subcases equal to the number of segments in the structural model times the number of loading conditions. In the case of dihedral symmetry, there will be twice as many subcases as for rotational symmetry because of the two symmetric components. If there is more than a single loading condition, the number of loading conditions must be specified on the PARAM card, NLOAD.

When loadings are specified in this manner, by physical segment, the data reduction will also be done in terms of the physical segments. All the normal output is available by segment and loading including structure plots plus the symmetrical components of displacement, internal forces and stresses.

An alternate procedure for specifying the static loads may be used if the transformed values of the forcing functions are known. In this case, the transformed values of the loads are specified directly on the usual loading cards. The PARAM card, CYCIP, must be included in the Bulk Data Deck to indicate that cyclic transform representation rather than physical segment representation is being used for the static loads. If this option is used, the subcases must be ordered according to the symmetrical components with the cosine cases preceding the sine cases for each symmetrical component. The output quantities will also be presented in terms of the symmetric components.

As indicated in the Theoretical Manual, Section 4.5, the cyclic symmetry uses a finite Fourier transformation. Hence, the use of cyclic symmetry procedures does not introduce any additional approximations beyond those normally associated with finite element analysis. In the case of static analysis, a shortened approximate method may be used where the maximum value of the harmonic index is specified on the PARAM card, KMAX. The default procedure is to include all harmonic indices. The use of a smaller number of harmonic indices is similar to truncating a Fourier series. The stiffness associated with the higher harmonic indices tends to be large, so that these components of displacements tend to be small.

## CYCLIC SYMMETRY MODELING

The OMIT feature may be used to remove all degrees of freedom at internal grid points without any loss of accuracy. Since this reduction is applied to a single segment prior to the symmetry transformations, it can greatly reduce the amount of subsequent calculation.

## NORMAL MODES ANALYSIS

### 23.3 NORMAL MODES ANALYSIS

When dihedral symmetry is involved in normal modes analysis, only the modes for the symmetrical components  $\bar{u}^{kc,S}$  and  $\bar{u}^{ks,A}$  are obtained. The modes for the other two terms are identical and correspond to a one-segment rotation of the structure.

The Fourier transform solutions are performed separately for each harmonic index. The harmonic index for each solution is specified on the PARAM card, KINDEX. The standard restart procedures can be used to calculate vibration modes for additional harmonic indices. Note, however, that no provision is made to recover solution data in terms of the physical segment.

The OMIT feature is used in the usual way to reduce the size of the analysis set and involves the usual approximations. The SUPPORT card for free bodies cannot be used with cyclic symmetry.

## CYCLIC SYMMETRY EXAMPLE

### 23.4 CYCLIC SYMMETRY EXAMPLE

An example to illustrate the handling of cyclic symmetry by Rigid Format 14 is presented. Another problem processed by Rigid Format 15 may be found in the NASTRAN Demonstration Problem Manual.

#### 23.4.1 Description

A constant thickness circular plate with six radial stiffeners and a central hole, shown in Figure 3 is analyzed using dihedral symmetry. The plate is subjected to a uniform pressure load applied over a 60° segment of the plate.

The finite element model is shown in Figure 4. The stringers are 60° apart but only 30° of the structure needs to be modeled when using the dihedral symmetry option. There are 12 subcases since these are two half segments in a 60° segment and only one loading condition. The CYJØIN bulk data card defines those points in the middle of the segment (SIDE 2) and those points on the boundary between segments (SIDE 1).

#### 23.4.2 Input

Parameters:

- $R_o = 1.0$  (outside radius)
- $R_i = .14$  (inside radius)
- $t = .01$  (plate thickness)
- $a = .06$  (height and width of stiffeners)
- $E = 10.6 \times 10^6$  (modulus of elasticity)
- $\nu = .325$  (Poisson's ratio)

Boundary Conditions:

- $U_r = U_\theta = e_z = 0$  (all points)
- $U_z = \theta_r = 0$  (along  $r = 1.0$ )

Applied loads::

- Pressure = 200.0 between  $\theta = 60^\circ$  and  $120^\circ$

Cyclic symmetry parameters:

- CTYPE = DRL
- KMAX = 2
- NSEGS = 6
- NLOAD = 1

## CYCLIC SYMMETRY MODELING

### 23.4.3 Results

The structure can be analyzed using rotational symmetry or dihedral symmetry described here and the results will be identical. The results for the normal displacements are given in table 1 for  $r = 0.46$ .

### 23.4.4 Driver and Sample Bulk Data

Note: Only one data card of each type is listed to illustrate its use.

Card No.	ID	DEMI4011, NASTRAN
1	APP	DISPLACEMENT
2	SØL	14,0
3	TIME	5
4	DIAG	8
5	CEND	
6		
7	TITLE	= STATIC ANALYSIS OF A CIRCULAR PLATE
8	SUBTITLE	= NASTRAN DEMONSTRATION PROBLEM NO. 14-1-1
9	LABEL	= DIHEDRAL CYCLIC SYMMETRY
10	SPS	= 101
11	ØOUTPUT	
12	ØLOAD	= ALL
13	DISP	= ALL
14	SPCF	= ALL
15	SUBCASE	1
16	LABEL	= SEGMENT 1 RIGHT
17	SUBCASE	2
18	LABEL	= SEGMENT 1 LEFT
19	SUBCASE	3
20	LABEL	= SEGMENT 2 RIGHT
21	LOAD	= 102
22	SUBCASE	4
23	LABEL	= SEGMENT 2 LEFT
24	LOAD	= 102
25	SUBCASE	5
26	LABEL	= SEGMENT 3 RIGHT
27	SUBCASE	6
28	LABEL	= SEGMENT 3 LEFT
29	SUBCASE	7
30	LABEL	= SEGMENT 4 RIGHT
31	SUBCASE	8
32	LABEL	= SEGMENT 4 LEFT
33	SUBCASE	9
34	LABEL	= SEGMENT 5 RIGHT
35	SUBCASE	10
36	LABEL	= SEGMENT 5 LEFT
37	SUBCASE	11
38	LABEL	= SEGMENT 6 RIGHT
39	SUBCASE	12
40	LABEL	= SEGMENT 6 LEFT
41	BEGIN BULK	

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CYCLIC SYMMETRY EXAMPLE

Card No.	1	2	3	4	5	6	7	8	9	10
42	CBAR	1	1	10	20	.0	.0	1.	1	
43	CNGRNT	10	11							
44	CØRD2C	1	0	.0	.0	.0	.0	.0	1.	+C1
45	+C1	1.	.0	.0						
46	10	1	10	11	21	20				
47	CYJØIN	1	C	10	20	30	40	50	60	CYC SYM
48	GRØSET		1							
49	GRID	10		1.0	.0	.0				
50	MATT	1	10.6+6		.325	2.59-4	12.9-6			
51	PARAM	CTYPE	DRL							CYC SYM
52	PBAR	1	1	1.8-3	5.4-7	5.4-7	1.0-6			+PB1
53	+PB1	.0	.03	.03	.0	.03	.03	.03	-.03	
54	PLØAD2	102	200.	10	20	30	40	50		
55	SPC1	110	12346	10	11	12				
56	SPCADD	101	110	112						
57	ENDDATA									

Data Deck Notes

- Card No.
- 3 The SØL card references Rigid Format 14, which is a special set of DMAP instructions for static analysis using cyclic symmetry.
  - 47 The CYJØIN card is used only for cyclic symmetry problems. It defines the boundary points of a segment of a structural model.
  - 51 The CTYPE parameter is required for Rigid Formats 14 and 15. The value of the parameter defines the type of cyclic symmetry.

C-6

## CYCLIC SYMMETRY MODELING

Table 1. Bulk Data Cards of Special Relevance to Cyclic Symmetry

CYJOIN	Boundary points of a segment
PARAM(CTYPE)	Defines the type of cyclic symmetry (required)
PARAM(NSEGS)	Number of identical segments in the model (required)
PARAM(NLOAD)	Number of static loading conditions (optional in static analysis)
PARAM(CYCI@)	Form of input and output data (optional in static analysis)
PARAM(CYCSEQ)	Procedure for sequencing the equations in the solution set (optional)
PARAM(KMAX)	Maximum value of the harmonic index (optional in static analysis)
PARAM(KINDEX)	Specified a single value of the harmonic index (required in normal modes analysis)

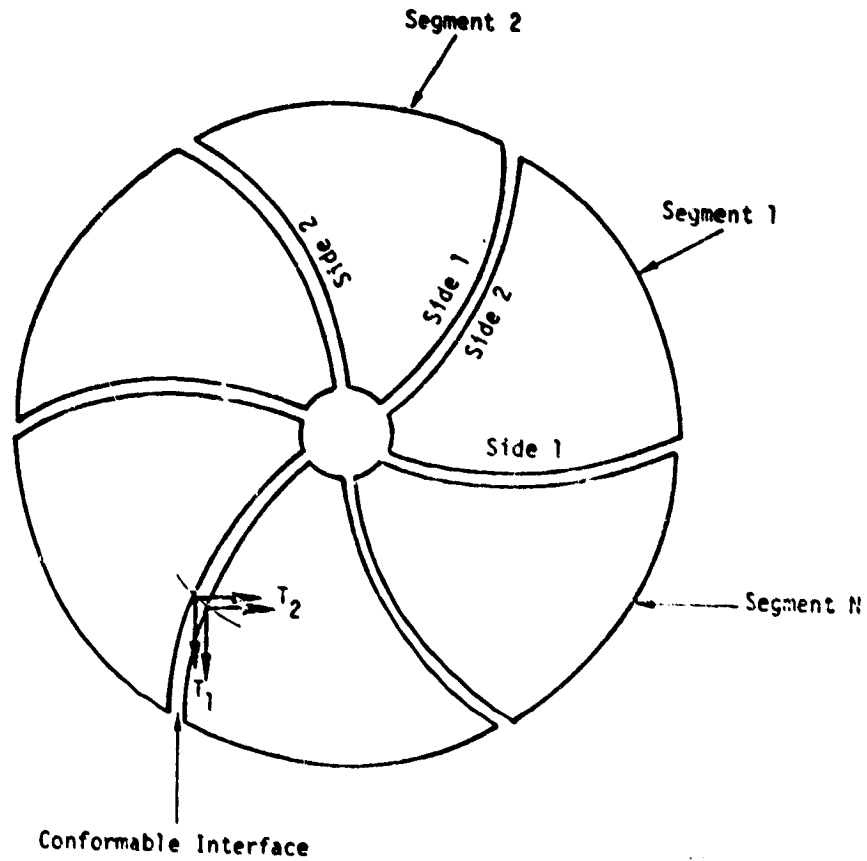
CYCLIC SYMMETRY EXAMPLE

Table 2. Displacements of Circular Plate Under Pressure Load at  $r = 0.46$

$\theta$	DIEDRAL METHOD		Value
	Subcase	Grid	
0	1	30	1.365
15	1	31	1.379
30	1	32	
	2	32	
45	2	31	1.412
60	2	30	
	3	30	1.430
75	3	31	1.464
90	3	32	
	4	32	1.484
105	4	31	
120	4	30	
	5	30	1.430
135	5	31	1.412
150	5	32	
	6	32	1.396
165	6	31	1.379
180	6	30	
	7	30	1.365
195	7	31	1.359
210	7	32	
	8	32	1.354
225	8	31	1.349
240	8	30	
	9	30	1.345
255	9	31	1.344
270	9	32	
	10	32	1.345
285	10	31	1.344
300	10	30	
	11	30	1.345
315	11	31	1.349
330	11	32	
	12	32	1.354
345	12	31	1.359
360	12	30	1.365



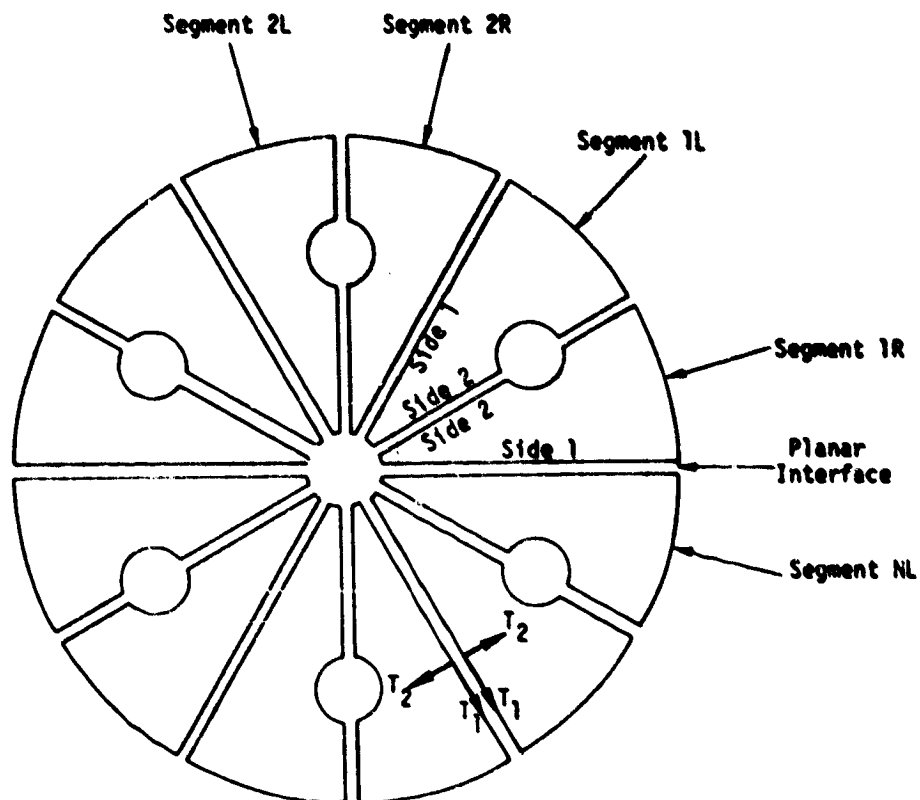
## CYCLIC SYMMETRY MODELING



1. The user models one segment.
2. Each segment has its own coordinate system which rotates with the segment.
3. Segment boundaries may be curved surfaces. The local displacement coordinate systems must conform at the joining points. The user gives a paired list of points on Side 1 and Side 2 which are to be joined.

Figure 1. Rotational symmetry.

## CYCLIC SYMMETRY EXAMPLE



1. The user models one-half segment (an R segment). The L half segments are mirror images of the R half segments.
2. Each half segment has its own coordinate system which rotates with the segment. The L half segments use left hand coordinate systems.
3. Segment boundaries must be planar. Local displacement systems axes, associated with inter-segment boundaries, must be in the plane or normal to the plane. The user lists the points on Side 1 and Side 2 which are to be joined.

Figure 2. Dihedral symmetry.

CYCLIC SYMMETRY MODELING

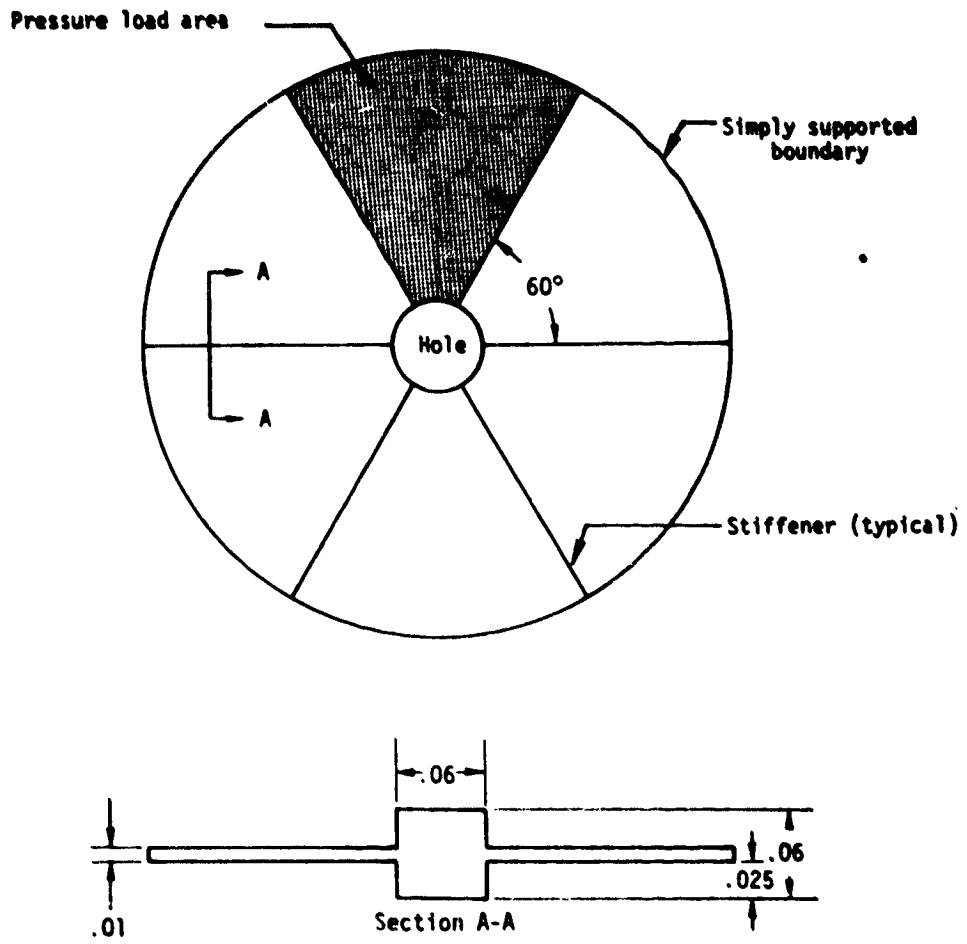


Figure 3. Circular plate with stiffeners.

CYCLIC SYMMETRY EXAMPLE

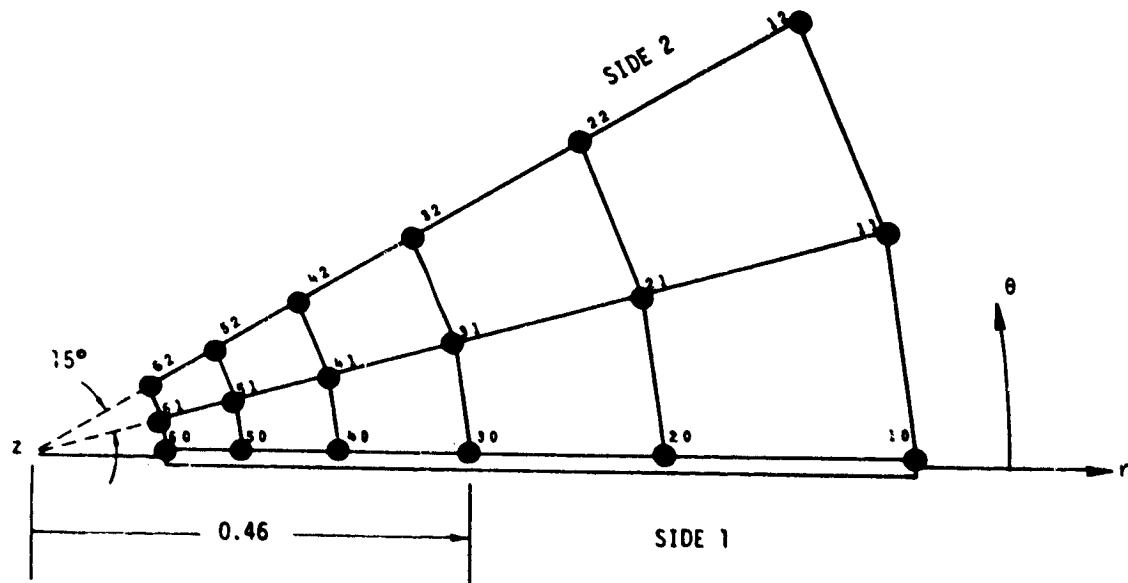


Figure 4. Finite element model.

## 24. HYDROELASTIC ANALYSIS

### 24.1 SOLUTION OF THE FLUID MODEL

The NASTRAN hydroelastic option allows the user to solve a wide variety of fluid problems having structural interfaces, compressibility, and gravity effects. A complete derivation of the NASTRAN model and an explanation of the assumptions are given in the Theoretical Manual, Section 16.1. The input data and the solution logic have many similarities to those of a structural model. The Bulk Data cards of special relevance to hydroelastic analysis are listed in Table 1. The standard normal modes analysis, transient analysis, complex eigenvalue analysis, and frequency response solutions are available with minor restrictions. The differences between a NASTRAN fluid model and an ordinary structural problem are due to the physical properties of a fluid, which are:

1. The independent degrees of freedom for a fluid are the Fourier coefficients of the pressure function (i.e., "harmonic pressures") in an axisymmetric coordinate system. The independent degrees of freedom for a structure are typically displacements and rotations at a physical point in space.
2. Much like the structural model, the fluid data will produce "stiffness" and "mass" equivalent matrices. Because they now relate pressure and flow instead of displacement and force, their physical meaning is quite different. The user may not apply loads, constraints, or sequencing, directly on the fluid points involved. Instead, the user supplies information related to the boundaries and NASTRAN generates the correct constraints, sequencing, and matrix terms internally. Indirect methods, however, are available to the user for utilizing the internally generated points as normal grid or scalar points. See Section 24.4 for the identification code.
3. When a physical structure is to be connected to the fluid, the user supplies a list of fluid points and a related list of special structural grid points and NASTRAN produces the unsymmetric matrix terms which define the actual physical relations. A special provision is included in NASTRAN for the structure which has planes of symmetry. The user may, if he wishes, define only a section of the boundary and solve his problem with symmetric or antisymmetric constraints. The fluid-structure interface will take the missing sections of structural boundary into account.

## HYDROELASTIC ANALYSIS

4. Because of the special nature of fluid problems, various user convenience options are absent. The fluid elements and harmonic pressures may not be included in the structural plots at present. Plotting the harmonic pressures versus frequency or time may not be requested directly. Because mass matrix terms are automatically generated if compressibility or free surface effects are present, the weight and C.G. calculations may not be correct and should be avoided if fluid elements are present. Also, the Inertia Relief Rigid Format uses the mass matrix to produce internal loads and if fluids are included, the special fluid terms in the mass matrix may produce erroneous results.

In spite of the numerous differences between a NASTRAN structural model and a NASTRAN fluid model, the similarities allow the user to formulate a model with a minimum of data preparation and to obtain efficient solutions to large order problems. The similarities of the fluid model to the NASTRAN structural model are:

1. The fluid is described by points in space and finite element connections. The locations of the axisymmetric fluid points are described by rings (RINGFL) about a polar axis, much like the axisymmetric conical shell. The rings are connected by elements (CFLUIDi) which have the properties of density and bulk modulus of compressibility. Each fluid ring produces internally a series of NASTRAN scalar points which represent "harmonic pressures"  $p^n$  and  $p^{n^*}$ . The pressure function  $p(\phi)$  is defined by the following equation:

$$p(\phi) = p^0 + \sum_{n=1}^N p^n \cos n\phi + \sum_{n=1}^N p^{n^*} \sin n\phi \quad 0 < N < 100$$

where the set of harmonics 0, n and n\* are selected by the user. If the user desires the output of pressure at specific points on the circular ring, he may identify them as "pressure points" (PRESPT) by giving a point number and an angle on a specified fluid ring. The output data will have the values of pressure at the angle,  $\phi$ , given in the above equation. The output of free surface displacements normal to the surface (FREEPT) is also available at specified angles,  $\phi$ .

2. The input data to NASTRAN may include all of the existing options except axisymmetric structural element data. All of the existing case control options may be included

## SOLUTION OF THE FLUID MODEL

with the addition of source fluid case control requests. The case control card option "AXISYM=FLUID" is necessary when any harmonic fluid degrees of freedom are included. All of the structural element and constraint data may be used (but not connected to RINGFL, PRESPT, or FREEPT fluid points). The structure-fluid boundary is defined with the aid of special grid points (GRIDB) which may be used for any purpose that a structural grid point is presently used.

3. The output data options for the structural part of a hydroelastic model are unchanged from the existing NASTRAN options. The output values for the fluid will be produced in similar format as the displacement vectors with modifications for the harmonic data. Printed output for the fluid may include both real and complex values. Pressures and free surface displacements, and their velocities and accelerations, may be printed with the same request (the case control request PRESSURE=SET is equivalent to DISP=SET) as structural displacements, velocities and accelerations. Structural plots are restricted to GRID and GRIDB points and any elements connected to them. X-Y plot and Random Analysis capabilities are available for FREEPT and PRESPT points if they are treated as scalar points. The RINGFL point identification numbers may not be used in any plot request. Instead, the special internally generated points used for harmonics may be requested in X-Y plots and Random Analysis. See Section 24.4 for the identification numbering code. No element stress or force data is produced for the fluid elements. As in the axisymmetric conical shell problem, the case control request HARMONICS=N is used to select up to the Nth harmonic for output.

## HYDROELASTIC INPUT DATA

### 24.2 HYDROELASTIC INPUT DATA

A number of special NASTRAN bulk data cards are required for fluid analysis problems. These cards are compatible with structural NASTRAN data. A brief description of the uses for each bulk data card follows.

#### AXIF

This card controls the formulation of the axisymmetric fluid problem. It is required card if any of the subsequent fluid-related cards are present. The data references a fluid-related coordinate system to define the axis of symmetry. The gravity parameter is included on this card rather than on the GRAV card because the direction of gravity must be parallel to the axis of symmetry. For convenience, the values of density and bulk elastic modulus may also be input on this card in the event that these properties are constant throughout the fluid. A list of harmonics and the request for the nonsymmetric (sine) coefficients are included on this card to allow the user to select any of the harmonics without producing extra matrix terms for the missing harmonics. A change in this list, however, will force the RESTART logic to start at the beginning of the problem.

#### RINGFL

The geometry of the fluid model about the axis of symmetry is defined with the aid of these data cards. The RINGFL data cards serve somewhat the same function for the fluid as the GRID cards serve for the structure. In fact, each RINGFL card will produce a special grid point internally for each of the various harmonics selected on the AXIF data card. These internally generated points may not be connected directly to normal NASTRAN structural elements (see GRID8 and BDYLIST data cards), nor may constraints be applied directly to RINGFL fluid points.

#### CFLUID1

The data on these cards are used to define a volume of fluid bounded by the referenced RINGFL points. The volume is called an element and logically serves the same purpose as a structural finite element. The physical properties (density and bulk modulus) of the fluid element may be defined on this card if they are variables with respect to the geometry. If a property is not defined, the default values on the AXIF card are assumed. Two connected circles (RINGFL) are used to define fluid elements containing the axis of symmetry. A choice of three or four points is available in the remainder of the fluid.



## HYDROELASTIC ANALYSIS

### GRIDB

This card provides an alternate to the GRID card by defining of structural grid points indirectly as a location on a fluid ring. It is used to identify the structural grid point with a particular RINGFL fluid point for hydroelastic problems. The particular purpose for this card is to force the user to place structural boundary points in exactly the same locations as the fluid points on the boundary. The format of the GRIDB card is identical to the format of the GRID card except that one additional field is used to identify the corresponding RINGFL point. The GROSET card, however, for GRIDB data does not supply defaults.

If the user desires, he may use GRIDB cards without a fluid model. This is convenient in case the user wished to solve his structural problem first and to add the fluid effects later without converting GRID cards to GRIDB cards. The referenced RINGFL point must still be included in a boundary list (BDYLIST), see below, and the AXIF card must always be present when GRIDB cards are used. (The fluid effects are eliminated by specifying no harmonics on the AXIF card.

### FREEPT, PRESPT

These cards are used to define points on a free surface for surface displacement output and pressure output for points in the fluid. No constraints may be applied to these points. Scalar elements and direct matrix data may be connected to these points, but since the generalized displacements actually represent pressures, the physical meaning of the elements will be different than in the structural sense.

### FSLIST, BDYLIST

The purpose for these cards is to allow the user to define the boundaries of the fluid with a complete freedom of choice. The FLIST card defines a list of fluid points which lie on a free surface. The BDYLIST data is a list of fluid points to which structural GRIDB points are connected. Points on the boundary of the fluid for which SPC, BDYLIST or FSLIST data are not defined are assumed to be rigidly restrained from motion in a direction normal to the surface.

With both of these lists the sequence of the listed points determines the nature of the boundary. The following directions will aid the user in producing a list.

1. Draw the z axis upward and the r axis to the right. Plot the locations of the fluid points on the right hand side of z.

## HYDROELASTIC INPUT DATA

2. If one imagines himself traveling along the free surface or boundary with the fluid on his right side, the sequence of points encountered is used for the list. If the surface or boundary touches the axis, the word "AXIS" is placed in the list. "AXIS" may be used only for the first and/or last point in the list.
3. The free surface must be consistent with static equilibrium. With no gravity field, any free surface consistent with axial symmetry is allowed. With gravity, the free surface must be a plane perpendicular to the z axis of the fluid coordinate system.
4. Multiple free surface lists and boundary lists are allowed. A fluid point may be included in any number of lists.

Figure 1 illustrates a typical application of the free surface and structural boundary lists.

### FLSYM

This card allows the user the option of modeling a portion of the structure with planes of symmetry containing the polar axis of the fluid. The first plane of symmetry is assumed at  $\phi = 0.0$  and the second plane of symmetry is assumed at  $\phi = 360^\circ/M$  where M is an integer specified on the card. Also specified are the types of symmetry for each plane, symmetric (S) or antisymmetric (A). The user must also supply the relevant constraint data for the structure. The solution is performed correctly only for those harmonic coefficients that are compatible with the symmetry conditions as illustrated in the following example for quarter symmetry,  $M = 4$ .

Series	Plane 1	Plane	
		S	A
Cosine	S	0,2,4,...	1,3,5,...
	A	none	none
Sine (* )	S	none	none
	A	1,3,5,...	2,4,6,...

### DMIAX

These cards are used for Direct Matrix Input for special purposes such as surface friction effects. They are equivalent to the DMIG cards, the only difference being the capability to

## HYDROELASTIC ANALYSIS

specify the harmonic numbers for the degrees of freedom. A matrix may be defined with either DMIG or DMIAX cards, but not with both.

## RIGID FORMATS

### 24.3 RIGID FORMATS

The characteristics of the fluid analysis problems which cause restrictions on the type of solution are:

1. The fluid-structure interface is mathematically described by a set of unsymmetric matrices. Since the first six Rigid Formats are restricted to the use of symmetric matrices, the fluid-structure boundary is ignored. Thus, for any of these Rigid Formats the program solves the problem for a fluid in a rigid container with an optional free surface and an uncoupled elastic structure with no fluid present.
2. No means are provided for the direct input of applied loads on the fluid. The only direct means of exciting the fluid is through the structure-fluid boundary. The fluid problem may be formulated in any Rigid Format, however, only some will provide non-trivial solutions.

The suggested Rigid Formats for the analysis of axisymmetric fluids and the restrictions on each are described below:

#### Rigid Format No. 3 - Normal Modes Analysis

The modes of a fluid in a rigid container may be extracted with a conventional solution request. Free surface effects with or without gravity may be accounted for. Any structure data in the deck will be treated as a disjoint problem. (The structure may also produce normal modes.) Normalization of the eigenvectors using the POINT option will cause a fatal error.

#### Rigid Format No. 7 - Direct Complex Eigenvalue Analysis

The coupled modes of the fluid and structure must be solved with this Rigid Format. If no damping or direct input matrices are added, the resulting complex roots will be purely imaginary numbers, whose values are the natural frequencies of the system. The mode shape of the combination may be normalized to the maximum quantity (harmonic pressure or structural displacement) or to a specified structural point displacement.

#### Rigid Format No. 8 - Direct Frequency and Random Response

This solution may be used directly if the loads are applied only to the structural points. The use of overall damping (parameter g) is not recommended since the fluid matrices derived would not have physical significance. Output restrictions are listed on page

## HYDROELASTIC ANALYSIS

### Rigid Format No. 9 - Direct Transient Response

Transient analysis may be performed directly on the fluid-structure system if the following rules are followed.

1. Applied loads and initial conditions are only given to the structural points.
2. All quantities are measured relative to static equilibrium. The initial values of the pressures are assumed to be at equilibrium.
3. Overall structural damping parameters  $w_3$  and  $g$  should not be used.

### Rigid Formats 10, 11, and 12 - Modal Formulations

Although these Rigid Formats may be used to solve fluid dynamics problems, their practicality is limited. The modal coordinates used to formulate the dynamic matrices will be the normal modes of both the fluid and the structure solved as uncoupled systems. Even though the range of natural frequencies would be typically very different for the fluid than for the structure, NASTRAN will select both sets of modes from a given fixed frequency range. The safest method with the present system is the extraction of all modes for both systems with the Tridiagonalization Method. This procedure, however, results in a dynamic system with large full matrices. The Direct Formulation would be more efficient in that case. At present, the capability for fluid-structure boundary coupling is not provided with Rigid Formats 10, 11, and 12. However, the capability may be provided by means of ALTERs using the same logic as in the direct formulations.

## HYDROELASTIC DATA PROCESSING

### 24.4 HYDROELASTIC DATA PROCESSING

The fluid related data cards submitted by the user are processed by the NASTRAN preface module to produce equivalent grid point, scalar point, element connection, and constraint data card images. Each specified harmonic,  $N$ , of the Fourier series solution produces a complete set of special grid and connection card images. In order to retain unique internal identification numbers, the user identification numbers are encoded according to the algorithm below:

RINGFL points:

$$\text{NASTRAN grid Id.} = \text{User ring Id.} + 1,000,000 \times I_N$$

where

$$I_N = N + 1 \quad \text{cosine series}$$

$$I_N = N + 1/2 \quad \text{sine series}$$

CFLUIDi connection cards:

$$\text{NASTRAN element Id.} = \text{User element Id.} + 1000 \times I_N$$

where  $I_N$  is defined above for each harmonic  $N$ .

For example, if the user requested all harmonics from zero to two, including the sine(\*) series, each RINGFL card will produce five special grid cards internally. If the user's identification number (in field 2 of the RINGFL data card) were 37, the internally generated grid points would have the following identification numbers:

<u>Harmonic</u>	<u>Id.</u>
0	1,000,037
1*	1,500,037
1	2,000,037
2*	2,500,037
2	3,000,037

These equivalent grid points are resequenced automatically by NASTRAN to be adjacent to the original RINGFL identification number. A RINGFL point may not be resequenced by the user.

The output from matrix printout, table printout, and error messages will have the fluid points labeled in this form. If the user wished, he may use these numbers as scalar points for Random Analysis, X-Y plotting, or for any other purpose.

## HYDROELASTIC ANALYSIS

In addition to the multiple sets of points and connection cards, the NASTRAN perface also may generate constraint sets. For example, if a free surface (FSLIST) is specified in a zero-gravity field, the pressures are constrained by NASTRAN to zero. For this case the internally generated set of single point constraints are internally combined with any user defined structural constraints and will always be selected automatically.

If pressures at points in the fluid (PRESPT) or gravity-dependent normal displacements on the free surface (FREEPT) are requested, the program will convert them to scalar points and create a set of multipoint constraints with the scalar points as dependent variables. The constraint set will be internally combined with any user defined sets and will be selected automatically.

The PRESPT and FREEPT scalar points may be used as normal scalar points for purposes such as plotting versus frequency or time. Although the FREEPT values are displacements, scalar elements connected to them will have a different meaning than in the structural sense. Any restrictions on their motion will negate their basic definition.

## HYDROELASTIC SAMPLE PROBLEM

### 24.5 HYDROELASTIC SAMPLE PROBLEM

#### 24.5.1 Description

Section 24.5.2 lists the data deck for a sample hydroelastic problem. Figures 1 and 2 describe the problem and list the parameters of the model. The relatively small number of grid points were chosen to keep the problem simple, not for accuracy. Structural data cards are included in their standard formats. Explanations for key Case Control and Bulk Data cards are given in the following notes:

1. The "AXISYM=FLUID" card is necessary to control the constraint set selections and the output formats for a fluid problem. It must appear above the subcase level.
2. "DISPLACEMENT=" and "PRESSURE=" case control cards are pseudonyms. "DISP=ALL" will produce all structure displacements, free surface displacements, and all fluid pressure values in the output. The "HARMONICS=" control is a limit on the harmonic data and has the same function as in an axisymmetrical conical shell problem.
3. The AXIF card defines the existence of a hydroelastic problem. It is used to define overall parameters and select the harmonic degrees of freedom, N=1 and N=2.
4. The RINGFL cards define the five points on the fluid cross section.
5. The CFLUIDI cards are used to define the volume of the fluid as finite elements connected by the RINGFL points. Since parameters  $\rho$  and B are missing, the default values on the AXIF card will be used.
6. The FSLIST card is used to define the free surface at  $z = 10.0$ . The density factor,  $\rho$ , is placed on the card in this case. If blank, the default value on the AXIF card is used.
7. The fluid-structure boundary is defined on the BODYLIST card. The AXIF default density is used.
8. The GRID8 cards define the structure points on the fluid boundary. Points #3 through #6 are connected to the #2 fluid ring. The rotation in the r direction ("S" in field 8) is constrained.



## HYDROELASTIC ANALYSIS

9. The fact that one-quarter symmetry was used for the structure requires the use of the FLSYM card. Symmetric-Antisymmetric boundaries indicate that only the cosine terms for the odd harmonics will interact with the structure. If Symmetric-Symmetric boundary conditions were chosen on the FLSYM data card, only the even harmonics of the cosine series would interact with the structure.

### 24.5.2 Driver Deck and Bulk Data Listing

Card  
No.

```

1  ID  HYDRO,USER
2  APP  DISP
3  SOL  7,0
4  TIME  2
5  CEND
6  TITLE = SAMPLE HYDROELASTIC PROBLEM
7  SUBTITLE = EIGENVALUE ANALYSIS WITH FLEXIBLE BOUNDARY
8  AXISYM=FLUID
9  SPC = 3
10 CMETHOD = 1
11 OUTPUT
12     DISP = ALL
13     HARMONICS = ALL
14     ELFORCE = ALL
15 BEGIN BULK
  
```

#### BULK DATA FIELD

	1	2	3	4	5	6	7	8	9	10
16	AXIF	2	32.2	0.03	NØ					+AX
17	+AX	1	3							
18	CORD2C	2		0.	0.	0.	0.	0.	1.0	+CØ
19	+CØ	1.0	0.	0.						
20	RINGFL	1	4.0		10.0	2	8.0		10.0	
21	RINGFL	7	4.0		5.0	8	8.0		5.0	
22	RINGFL	13	4.0		0.0					
23	CFLUID2	101	1	7						
24	CFLUID2	102	7	13						
25	CFLUID3	103	7	8	13					
26	CFLUID4	104	1	2	7	8				
27	FLIST	0.03	AXIS	1	2					
28	BDYLIST		2	8	13					

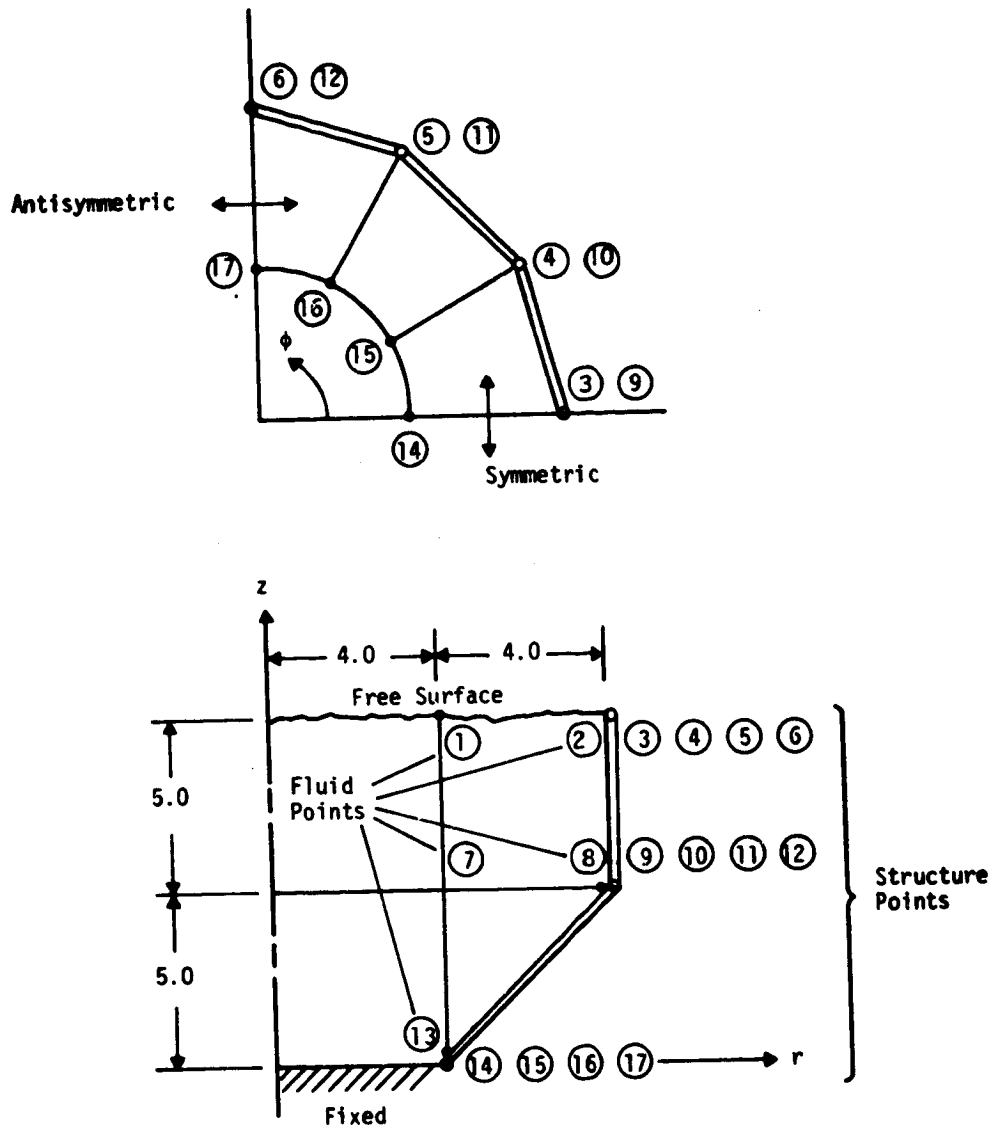
HYDROELASTIC SAMPLE PROBLEM

	1	2	3	4	5	6	7	8	9	10
29	GRIDB	3			0.0		2	4	2	
30	GRIDB	4			30.0		2	4	2	
31	GRIDB	5			60.0		2	4	2	
32	GRIDB	6			90.0		2	4	2	
33	GRIDB	9			0.		2		8	
34	GRIDB	10			30.		2		8	
35	GRIDB	11			60.		2		8	
36	GRIDB	12			90.		2		8	
37	GRIDB	14			0.		2		13	
38	GRIDB	15			30.		2		13	
39	GRIDB	16			60.		2		13	
40	GRIDB	17			90.		2		13	
41	CQUAD2	10	11	3	9	10	4			
42	CQUAD2	11	11	4	10	11	5			
43	CQUAD2	12	11	5	11	12	6			
44	CQUAD2	13	11	9	14	15	10			
45	CQUAD2	14	11	10	15	16	11			
46	CQUAD2	15	11	11	16	17	12			
47	PQUAD2	11	12	0.5						
48	MAT1	12	10.6+6		0.3	0.05				
49	SPC1	3	246	3	9	14				
50	SPC1	3	135	6	12	17				
51	SPC1	3	135	14	15	16				
52	FLSYM	4	S	A						
53	EIGC	1	INV	MAX						+EI
54	+EI	0.	0.	0.	5.	3.	2	2		
55	ENDDATA									

Table 1. Bulk Data Cards of Special Relevance to Hydroelastic Analysis

- AXIF Indicates the existence of an axisymmetric fluid analysis.
- BDYLIST Defines the boundary between a fluid and a structure.
- CFLUID1  
(i=2,3 or 4) Defines three types of fluid elements.
- DMIAX Direct input matrix terms for axisymmetric fluid or structure problems.
- FLSYM Allows fluid boundary matrices to conform to structural symmetry definitions.
- FREEPT Defines points on the surface of a fluid for surface displacement output.
- FSLIST Defines the fluid points which lie on a free surface boundary.
- GRIDB Defines structural grid points as locations on a fluid ring.
- PRESPT Defines pressure points in the fluid for pressure data output.
- RINGFL Defines a point on a fluid ring.

# HYDROELASTIC ANALYSIS

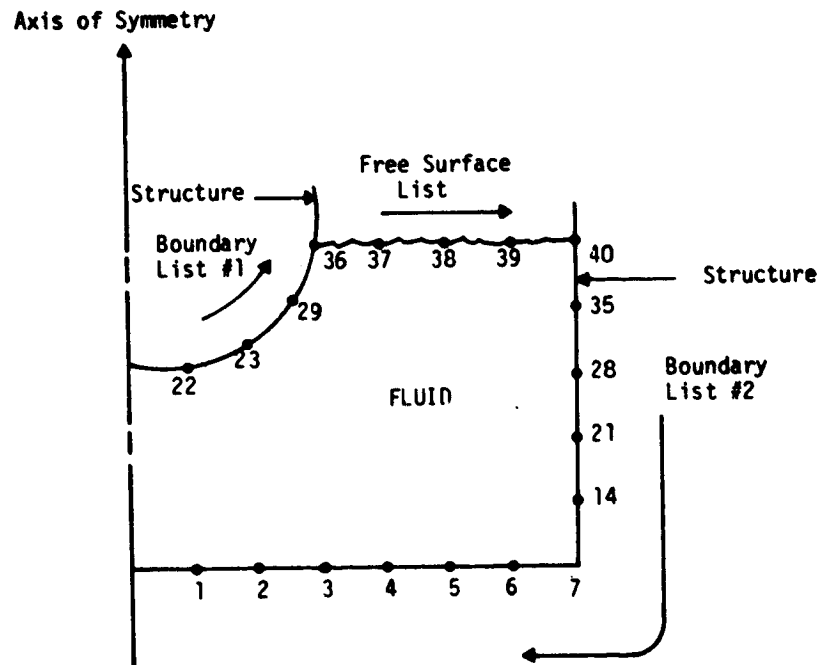


Fluid: Density,  $\rho = 0.03$   
 Bulk Modulus,  $B = \infty$   
 Gravity,  $g = 32.2$

Structure: Thickness,  $= 0.5$   
 Density,  $\rho = 0.05$

Figure 1. Sample hydroelastic problem.

# HYDROELASTIC SAMPLE PROBLEM



FSLIST: : 36, 37, 38, 39, 40

BDYLIST #1: AXIS, 22, 23, 29, 36

BDYLIST #2: 40, 35, 28, 21, 14, 7, 6, 5, 4, 3, 2, 1, AXIS

Figure 2. Examples of boundary lists.

## 25. ACOUSTIC CAVITY ANALYSIS

### 25.1 MODELING OF THE ACOUSTIC CAVITY

The NASTRAN structural analysis system is used as the basis for acoustic cavity analysis. Many of the structural analysis options such as selecting boundary conditions, applying loading conditions, and selecting output data are also available for acoustics. The data cards specifically used for acoustic cavity analysis are listed in Table 1 and described below. The card formats are exhibited in Section 2.4 of the User's Manual. Their purposes are analogous to the use of structural data cards. A gridwork of points is distributed over the longitudinal cross section of an acoustic cavity and finite elements are connected between these points to define the enclosed volume.

The points are defined by GRIDF data cards for the axisymmetric central fluid cavity and by GRIDS data cards for the radial slots. The GRIDF points are interconnected by finite elements via the CAXIF2, CAXIF3, and CAXIF4 data cards to define a cross sectional area of the body of rotation. The CAXIF2 element data card defines the area of the cross section between the axis and two points off the axis (the GRIDF points may not have a zero radius). The CAXIF3 and CAXIF4 data cards define triangular or quadrilateral cross sections and connect three or four GRIDF points respectively. The density and/or bulk modulus at each location of the enclosed fluid may also be defined on these cards.

The GRIDS points in the slot region are interconnected by finite elements via the CSLØT3 and CSLØT4 data cards. These define finite elements with triangular and quadrilateral cross-sectional shapes respectively. The width of the slot and the number of slots may be defined by default values on the AXSLØT data card. If the width of the slots is a variable, the value is specified on the GRIDS cards at each point. The number of slots, the density, and/or the bulk modulus of the fluid may also be defined individually for each element on the CSLØT3 and CSLØT4 cards.

The AXSLØT data card is used to define the overall parameters for the system. Some of these parameters are called the "default" values and may be selectively changed at particular cross sections of the structure. The values given on the AXSLØT card will be used if a corresponding value on the GRIDS, CAXIF<sub>i</sub>, or CSLØT<sub>i</sub> is left blank. The parameters  $\rho$  (density) and  $B$  (bulk modulus) are properties of the fluid. If the value given for bulk modulus is zero, the fluid is considered incompressible to the program. The parameters  $M$  (number of slots)

## ACOUSTIC CAVITY ANALYSIS

and  $W$  (slot width) are properties of the geometry. The parameter  $M$  defines the number of equally spaced slots around the circumference with the first slot located at  $\phi = 0^\circ$ . The parameter  $N$  (harmonic number) is selected by the user to analyze a particular set of acoustic modes. The pressure is assumed to have the following distribution.

$$p(r,z,\phi) = p(r,z) \cos N\phi$$

If  $N = 0$ , the breathing and longitudinal modes will result. If  $N = 1$  the pressure at  $\phi = 180^\circ$  will be the negative of the pressure at  $\phi = 0^\circ$ . If  $N = 2$ , the pressures at  $\phi = 90^\circ$  and  $\phi = 270^\circ$  will be the negative of that at  $\phi = 0^\circ$ . Values of  $N$  larger than  $M/2$  have no significance.

The interface between the central cavity and the slots is defined with the SLBDY data cards. The data for each card consists of the density of the fluid at the interface, the number of radial slots around the circumference, and a list of GRIDS points that are listed in the sequence in which they occur as the boundary is traversed. In order to ensure continuity between GRIDF and GRIDS points at the interface, the GRIDF points on the boundary between the cylindrical cavity and the slots are identified on the corresponding GRIDS data cards rather than on GRIDF cards. Thus, the locations of the GRIDF points will be exactly the same as the locations of the corresponding GRIDS points.

Various standard NASTRAN data cards may be used for special purposes in acoustic analysis. The SPC1 data card may be used to constrain the pressures to zero at specified points such as at a free boundary. The formats for these cards are included in Section 2.4 of the User's Manual. Dynamic load cards, direct input matrices, and scalar elements may be introduced to account for special effects. The reader is referred to Sections 1.4 and 1.5 of the User's Manual for instruction in the use of these cards.

## ASSUMPTIONS AND LIMITATIONS

### 25.2 ASSUMPTIONS AND LIMITATIONS

The accuracy of the acoustic model will be dependent on the selection of the mesh of finite elements. The assumption for each element is that the pressure field has a linear variation over the cross section and a sinusoidal variation around the axis in the circumferential direction. In areas where the pressure gradient changes are large, such as near a sharp corner, the points in the mesh should be placed closer together so that large changes in flow may be defined accurately by the finite elements. The shape of the finite elements plays an important part in the accuracy of the results. It has been observed that long narrow elements produce disproportionate errors. Cutting a large square into two rectangles will not improve the results whereas dividing the square into four smaller squares may decrease the local error by as much as a factor of ten.

The slot portion of the cavity is limited to certain shapes because of basic assumptions in the algorithms. The cross section of the cavity normal to the axis must have a shape that is reasonably well defined by a central circular cavity having equally spaced, narrow slots. Various shapes are shown in Figure 1 in the order of increasing expected error. It is recommended that shapes such as the cloverleaf and square cross section be analyzed with a full three-dimensional technique. The assumption of negligible pressure gradient in the circumferential direction within a slot is not valid in these cases.

The harmonic orders of the solutions are also limited by the width of the slots. The harmonic number,  $N$ , should be no greater than the number of slots divided by two. The response of the higher harmonics is approximated by the slot width correction terms discussed in the NASTRAN Theoretical Manual, Section 17.1.

The output data for the acoustic analysis consists of the values of pressure in the displacement vector selected via the case control card "PRESSURE = i." The velocity vector components corresponding to each mode may be optionally requested by the case control card "STRESS = i," where  $i$  is the set number indicating the element numbers to be used for output, or by the words "STRESS = ALL." The "SET=" card lists the element or point numbers to be output.

Plots of the finite element model and/or of the pressure field may be requested with the NASTRAN plot request data cards. The central cavity cross section will be positioned in the XY plane of the Basic Coordinate System of NASTRAN. The slot elements are offset from the XY

## ACOUSTIC CAVITY ANALYSIS

plane by the width of the slot in the +Z direction. The radial direction corresponds to Z and the axial direction corresponds to the Y direction. Pressures will be plotted in the Z direction for both the slot points and the central cavity points. The Case Control data cards for plotting are documented in the User's Manual. The PLOTTEL elements are used for plotting the acoustic cavity shape. The plot request card "SET n INCLUDE PLOTTEL" must be used where n is a set number.



## ACOUSTIC CAVITY SAMPLE PROBLEM

### 25.3 ACOUSTIC CAVITY SAMPLE PROBLEM

#### 25.3.1 Description

Section 25.3.2 contains a listing of the data cards used as a simple example of acoustic cavity analysis. The problem to be solved is illustrated in Figure 2. The model was subdivided into only ten finite elements in order to limit the number of data cards. For reasonable engineering accuracy, this model should be subdivided into at least four times that number of elements.

Each data card in the listing is given a number on the left side. The following is a brief description of each card:

#### Card(s)

- 1-5 Each data card in the Executive Control Deck has the format of a request word and a selection separated by blanks or a comma. The ID card is first, the CEND card is last, but the intermediate cards may appear in any order. The user may put any pair of words on the ID card for identification purposes. In this particular case Rigid Format number 3 (SOL 3,0) was chosen which is Normal Modes analysis. A limit of two minutes CPU time was set (TIME 2).
- 6-7 The TITLE= and SUBTITLE= cards may contain any list of letters and numbers following the (=) sign. This list will appear on the first two lines of each output page.
- 8 The method of eigenvalue extraction is selected with the METHOD= data card. The number 11 refers to the identification number of an EIGR bulk data card which appears below as card 32 and 33.
- 9-11 A simple output request is illustrated with these cards. PRES=ALL will result in printout of all pressures at the GRIDF and GRIDS points. STRESS=ALL will result in the printout of all velocities in the elements. This printout will occur for all extracted eigenvectors. Selected points or elements can be printed via the SET card described in the User's Manual.
- 12 The BEGIN BULK card denotes the beginning of the Bulk Data Deck. The Bulk Data Deck cards may occur in any order. Putting these cards in alphabetic sort will save NASTRAN sorting time in large problems, however.

## ACOUSTIC CAVITY ANALYSIS

- 13 In this problem all the parameters except slot width  $w_d$  are constant throughout the volume. The data values on the AXSLØT card will be used whenever a corresponding entry in the following cards is blank.
- 14-20 The location of points on the slot are defined with these cards. Cards 14, 16, 18 and 20 serve a dual purpose by defining a GRIDS point identification number in field 2 and a GRIDF point identification number in field 6. The two types of points thereby are forced to have the same locations at the interface.
- 21,22 The location of points within the axisymmetric fluid cavity are described by the GRIDF card. No points are allowed to have a zero or negative radius.
- 23-31 These cards describe the elements shown in Figure 2. Each element is given a unique identification number and a list of the connected GRIDS or GRIDF points. Since the parameters  $\rho$  and  $B$  are constants, these fields are left blank so the values on the AXSLØT card will be used.
- 32,33 The EIGR card is used to define parameters for eigenvalue extraction (resonant frequencies). More than one of these cards may appear. The method to be used is selected with the METHOD= data card in the Case Control Deck (card 8). With this particular card we selected the Givens Tridiagonalization method (GIV) with a desired number of three ( $Nd = 3$ ) output mode shapes. The modes will be normalized such that the maximum pressure is 1.0 ( $NØRM=MAX$ ). These two cards illustrate a continuation card.
- 34 The SLBDY card defines the boundary between the slot and the central cavity. Both the density ( $\rho$ ) and the number of radial slots ( $M$ ) are blank so the AXSLØT defaults are used, i.e.,  $\rho = 1.2 \times 10^{-7}$  and  $M = 4$ . Only four GRIDS points are on the boundary so a continuation card is not necessary. Field 8 being blank signifies the last entry.
35. The ENDDATA card is required to denote the end of the bulk data. Any following cards will be ignored by NASTRAN.

ACOUSTIC CAVITY SAMPLE PROBLEM

25.3.2 Driver Deck and Bulk Data Listing

Card  
No.

```

1  ID ACOUS,CAY
2  APP DISP
3  SOL 3,0
4  TIME 2
5  CEND
                                     Executive Control Cards

6  TITLE = ACOUSTIC CAVITY EXAMPLE PROBLEM
7  SUBTITLE = FIRST HARMONIC
8  METHOD = 11
9  OUTPUT
                                     Case Control Data Cards
10     PRES = ALL
11     STRESS = ALL
12  BEGIN BULK
    
```

	1	2	3	4	5	6	7	8	9	10
13	AXSLØT	1.2-7	21.0	1		4				
14	GRIDS	2	4.0	0.0	0.2E 01	1				
15	GRIDS	3	8.0	.0	1.0					
16	GRIDS	5	4.0	4.0	2.0	4				
17	GRIDS	6	8.0	4.0	1.0					
18	GRIDS	8	4.0	8.0	2.0	7				
19	GRIDS	9	8.0	8.0	1.0					
20	GRIDS	12	4.0	1.2+1	2.0	11				
21	GRIDF	10	2.0	12.0						
22	GRIDF	13	2.0	1.4E1						
23	CSLØT4	1	2	3	6	5				
24	CSLØT4	2	5	6	9	8				
25	CSLØT3	3	8	9	12					
26	CAXIF2	4	1	4						
27	CAXIF2	5	4	7						
28	CAXIF2	6	7	10						
29	CAXIF2	9	10	13						
30	CAXIF3	7	7	10	11					
31	CAXIF3	8	10	11	13					
32	EIGR	11	GIV				3			+AB
33	+AB	MAX								
34	SLBDY			12	8	5	2			
35	ENDDATA									

## ACOUSTIC CAVITY ANALYSIS

Table 1. Bulk Data Cards of Special Relevance to Acoustic Cavity Analysis

AXSLØT	Contains the harmonic index and default values for several parameters.
CAXIFi (i=2,3 or 4)	Defines an axisymmetric element which connects i fluid points.
CSLØTi (i=3 or 4)	Defines evenly spaced radial slots.
GRIDF	Defines a scalar degree of freedom for harmonic analysis of a fluid.
GRIDS	Defines a scalar degree of freedom with a two-dimensional location.
SLBDY	Defines a list of slot points which lie on an interface between an axisymmetric fluid and a set of evenly spaced radial slots.

ACOUSTIC CAVITY SAMPLE PROBLEM

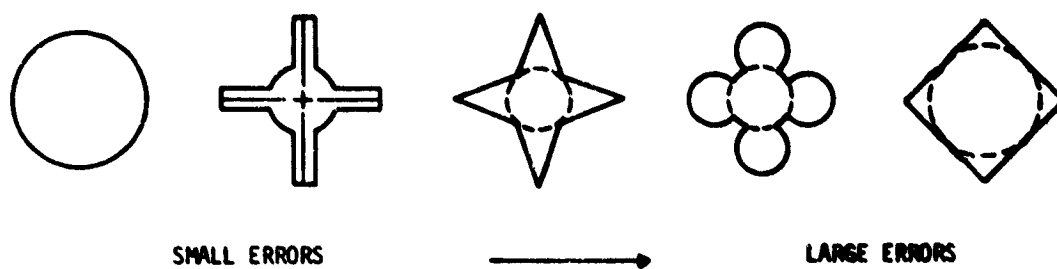
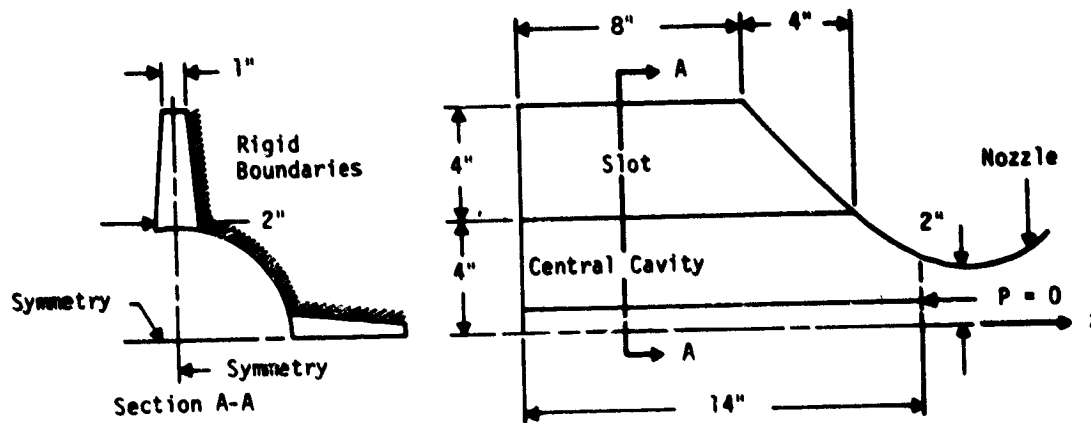


Figure 1. Modeling errors for various shapes.

## ACOUSTIC CAVITY ANALYSIS



### Parameters:

Density:  $\rho = 1.1463 \times 10^{-7} \text{ lb-sec}^2/\text{in}^4$   
 Bulk Modulus:  $B = \rho a^2 = \gamma RT = 20.59 \text{ lb/in}^2$   
 Harmonic:  $N = 1$   
 Number of slots:  $M = 4$   
 Note: Consistent Dimensional Units must be used.

### FINITE ELEMENT MODEL:

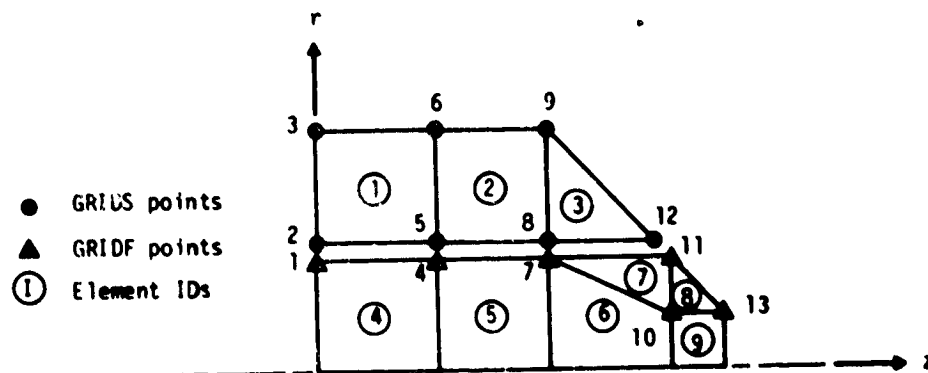


Figure 2. Description of example problem.

## 26. FULLY STRESSED DESIGN ANALYSIS

### 26.1 FULLY STRESSED DESIGN THEORY

The fully stressed design option is part of the static analysis Rigid Format for structural analysis. The theoretical basis is presented more fully in the Theoretical Manual. The Bulk Data cards of special relevance to fully stressed design are listed in Table 1. Essentially, however, the process begins by performing a static analysis for all loading conditions using the initial values for all element properties. A new property,  $P_2$ , will be scaled such that

$$P_2 = P_1 \left[ \frac{\alpha}{\alpha + (1-\alpha)\gamma} \right] \quad (1)$$

where  $P_1$  is the current property value of  $\gamma$  is an iteration factor with a default value of unity. The scale factor,  $\alpha$ , is defined as follows:

$$\alpha = \text{Max} \left( \frac{\sigma}{\sigma_L} \right) \quad (2)$$

where  $\sigma$  is a stress value and  $\sigma_L$  is a stress limit. The maximum value of  $\alpha$  is taken for all loading conditions. Values of  $\gamma$  smaller than unity limit the property change in a single iteration, and thereby tend to improve the stability of the process. The maximum change in any property is limited by

$$K_{\min} < \frac{P_2}{P_1} < K_{\max} \quad (3)$$

where  $P_1$  is the initial value of property and  $K_{\min}$  and  $K_{\max}$  are user-supplied limits.

Convergence is achieved by completing the user-specified number of iterations, by having all selected element properties reach the user-specified limits, or by satisfying the following convergence criteria:

$$\frac{|\sigma - \sigma_L|}{\sigma_L} < \epsilon \quad (4)$$

where  $\epsilon$  is a user-supplied convergence limit.

## APPLICATION

### 26.2 APPLICATION

Functional modules (ØPTR1 AND ØPTR2) are provided to automatically adjust the properties based on maximum stress levels, and to control the number of design iterations based on user-supplied convergence criteria. All elements using a common property are sized together, i.e., a plate with uniform thickness remains uniform. If the user wishes to scale the properties for each element separately, each element must have its own property card. After a sufficient number of iterations, the element properties will be adjusted to the minimum values necessary to carry the prescribed loads. The following actions are required by the user to utilize the fully stressed design capability:

1. The user must select stress output in the Case Control Deck for all elements that will participate in the fully stressed design.
2. All required stress limits must be specified on the structural material cards associated with element properties that will participate in the fully stressed design.
3. The property optimization parameters must be specified on the bulk data card PØPT. This card contains user-specified values for the maximum number of iterations, the convergence criteria ( $\epsilon$ ), the iteration factor ( $\gamma$ ), and output options to print and/or punch the calculated values of the element properties.
4. The property optimization limits ( $K_{\min}$  and  $K_{\max}$ ) must be specified on the PLIMIT bulk data card if the user wishes to limit the maximum and minimum values of the element properties.

The detailed definitions of the scale factors for each of the element types are given in Table 1. The symbols  $\sigma_t$ ,  $\sigma_c$ , and  $\sigma_s$  represent the limiting stress values in tension, compression and shear, given on the structural material cards. All of the properties listed for each element are scaled in the same way, i.e., both are the area and torsional constant for the RØØ are modified using the same scale factor. Some bulk data cards which are of special importance to this type of problem are listed in Table 2.



## SAMPLE PROBLEM

### 26.3 SAMPLE PROBLEM

An example is presented here to illustrate the fully stressed design technique using Rigid Format 1.

#### 26.3.1 Description

A flat plate with a reinforced hole in the center is optimized for stresses due to a uniform end load. Restrictions on the minimum thickness are maintained. The plate is shown in Figure 1, and the finite element idealization is illustrated in Figure 2. This problem has been investigated by G. G. Pope (Reference 1). Due to symmetry, only one quadrant is modeled. Due to the membrane load, all rotations and normal displacements are constrained. The QCMEM and TRMEM elements are used for the plate and R0D elements for the reinforcement around the hole.

The problem demonstrates several features unique to fully stressed design capability to NASTRAN.

1. Elements with no limits on the range of the property change, i.e., the R0D has no PLIMIT data.
2. Elements with a lower limit on the property optimization card. All membrane elements are required to have a resultant thickness which must not be less than a minimum thickness. This minimum is determined from the thickness obtained when the plate without a hole is subjected to an end load at a prescribed stress limit.
3. Elements whose stress is not inspected but being in an area of nearly uniform stress have their properties changed due to another element's stress. Element 7 has no stress request but does have the same property identification number as element 17. This type of optimization can save computer time at the expense of a design that may not be truly optimized.
4. A property whose value depends on the maximum stress of two elements. Elements 5 and 15 have the same property card. This option may be necessary if insufficient core is allocated.
5. Temperature dependent stress limits for material 3.

## FULLY STRESSED DESIGN ANALYSIS

- Using one stress limit only. The membrane elements use the maximum principal shear only which is  $1/2$  the major principal stress allowed. This stress limit was chosen to model better the octahedral limit uses in Reference 1.

The rod elements use only the tension and compression stress appropriate to the given property, namely, area.

- An additional load case that was not included in the fully stressed design because a stress request was not made. The second subcase may be considered a displacement verification of this load case.

### 26.3.2 Input

- Parameters

$l = 30.0$  in (total length)

$w = 20.0$  in (total width)

$d = 10.0$  in (hole diameter)

$t_0 = 3.348$  in (initial plate thickness)

$A_0 = 1.674$  in<sup>2</sup> (initial rod cross sectional area)

$E = 30. \times 10^6$  psi (modulus of elasticity)

$\nu = 0.3$  (Poisson's ratio)

$t_e = 1.0$  in (lower limit for plate thickness corresponding to a  $25.0 \times 10^3$  maximum principal stress)

- Boundary conditions:

on  $y = 0$  plane,  $u_y = 0$  (symmetry)

on  $x = 0$  plane,  $u_x = 0$  (symmetry)

all points  $u_z = \theta_x = \theta_y = \theta_z = 0$  (permanent constraints)

- Loads:

First subcase: uniform load,  $F_{10} = 25.0 \times 10^3$  lb/in

Second subcase: at grid points 69 and 79,  $F_{12} = 1000.0$  lb

at grid point 78,  $F_{12} = -2000.0$  lb

(contact load on rim of hole - displacement check only)

## SAMPLE PROBLEM

### 26.3.3 Theory

The mathematical programming technique used in Reference 1, from which the example problem was taken, differs from the one used in NASTRAN or described above and in the Theoretical Manual, Section 4.4. The two techniques might be expected to give similar results when the same model is used. However, Reference 1 employs elements which allow varying properties and stresses, while NASTRAN elements allow only constant properties and stresses. Somewhat different geometry is used in the NASTRAN model to include the use of quadrilateral elements for illustration. Additional features of the NASTRAN model are discussed in items 3, 4 and 5, Section 26.3.1 above.

### 26.3.4 Results

The optimization process in this problem is terminated at five iterations. The initial-weight-to-final-weight ratio is 2.70, compared to Pope's result of 2.63. Tables 3 and 4 show the optimized nondimensional properties of the elements around the arch. Note that the results from reference 1 are averaged to provide an equivalent constant property element for comparison.

## FULLY STRESSED DESIGN ANALYSIS

### 26.3.5 Driver Deck and Sample Bulk Data

Card  
No.

```

0  NASTRAN FILES=(PLT2)
1  ID      DEM1161,NASTRAN
2  APP     DISPLACEMENT
3  SOL     1,0
4  TIME    9
5  DIAG    8
6  CEND

7  TITLE = FULLY STRESSED DESIGN OF A PLATE WITH A REINFORCED HOLE
8  SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 1-16-1
9  LABEL = TEMPERATURE DEPENDENT MATERIALS.
10 TEMPERATURE(MATERIALS) = 3000
11 SPC = 11
12 DISPLACEMENT = ALL
13 SUBCASE 10
14 LABEL = DESIGN CASE - UNIFORM END LOAD
15 SET 111 = 1 THRU 105 EXCEPT 7
16 STRESS = 111
17 LOAD = 10
18 SUBCASE 12
19 LABEL = CHECK CASE - CONTACT LOAD AT NOZZLE.
20 LOAD = 12
21 PLOTID = NASTRAN DEMONSTRATION PROBLEM NO. 1-16-1
22 OUTPUT(PLT)
23 PLOTTER SC
24 SET 1 = 1, 7, 38, 61, 69
25 SET 2 = INCLUDE ELEMENTS QDMEM, TRMEM
26 MAXIMUM DEFORMATION 0.8
27 AXES Z, X, Y
28 VIEW 0.0, 0.0, 0.0
29 FIND SCALE, ORIGIN 12, SET 1
30 PTITLE = ARCH MODEL
31 PLOT SET 2, ORIGIN 12 LABEL
32 PTITLE = DEFLECTION VECTORS FOR BOTH LOADS AND EACH ITERATION
33 PLOT STATIC DEFORMATION SET 2, ORIGIN 12, VECTOR RXY, SYMBOL 7
34 FIND SCALE, ORIGIN 12, SET 1, REGION 0.0, 0.0, 0.6, 1.0
35 PTITLE = ARCH MODEL REFLECTED ABOUT VERTICAL AXIS
36 PLOT SET 2, ORIGIN 12, SYMMETRY X, SET 2, ORIGIN 12
37 BEGIN BULK
    
```

SAMPLE PROBLEM

	1	2	3	4	5	6	7	8	9	10
38	CQMEM	1		11	13	3	1			
39	CRØD	101		48	49	102	102	49	59	
40	CTRMEM	11		13	11	21				
41	FØRCE	10	1		.3125E5	.0	1.0	.0		
42	GRDSET							3456		
43	GRID	1		-10.	15.					
44	MAT1	1	30.E06		.3	.283		70.0		+CØNST
45	+CØNST			12.5E3						+MATT1
46	MATT1	2								
47	+MATT1			222						
48	PARAM	GRDPNT	0							
49	PLIMIT	QDMEM	.2986858		1	THRU	61			FSD
50	PØPT	5	.04	.95	2	YES				FSD
51	PQDMEM	1	1	3.348						
52	PRØD	101	3	1.674						
53	PTRMEM	11	1	3.348						
54	SPC1	11	1	9	19	29	39	48		+TAB-M1
55	TABLEM1	222								
56	+TAB-M1	1.	12.5E3	10.	12.5E3	ENDT				
57	TEMPD	3000	80.							
58	ENDDATA									

FULLY STRESSED DESIGN ANALYSIS

Table 1. Scale Factors for Fully Stressed Design

Element	Stress Value Used	Scale Factor ( $\alpha$ )	Properties Changed
RØD TUBE	Axial Tension ( $\sigma_1$ ) Axial Compression ( $\sigma_2$ ) Torsion ( $\tau$ )	$\text{Max} \left( \frac{\sigma_1}{\sigma_t}, \frac{\sigma_2}{\sigma_c}, \frac{\tau}{\sigma_s} \right)$	Area (A) Torsional Constant (J)
BAR	Fiber Stress { End a ( $\sigma_{a1}$ ) Tension { End b ( $\sigma_{b1}$ ) Fiber Stress { End a ( $\sigma_{a2}$ ) Compression { End b ( $\sigma_{b2}$ )	$\text{Max} \left( \frac{\sigma_{a1}}{\sigma_t}, \frac{\sigma_{b1}}{\sigma_t}, \frac{\sigma_{a2}}{\sigma_c}, \frac{\sigma_{b2}}{\sigma_c} \right)$	Area (A) Torsional Constant (J) Moments of Inertia ( $I_1, I_2, I_{12}$ )
TRMEM QDMEM	Principal Tension ( $\sigma_1$ ) Principal Compression ( $\sigma_2$ ) Maximum Shear ( $\tau_m$ )	$\text{Max} \left( \frac{\sigma_1}{\sigma_t}, \frac{\sigma_2}{\sigma_c}, \frac{\tau_m}{\sigma_s} \right)$	Thickness (t)
TRPLT QDPLT TRBSC	Same as Above (Fiber Distances $z_1$ & $z_2$ )	Same as Above	Moment of Inertia (I)
TRIA1 QUAD1	Same as Above	Same as Above	Moment of Inertia (I) Membrane Thickness ( $t_1$ )
TRIA2 QUAD2	Same as Above	Same as Above	Thickness (t)
SHEAR	Maximum Shear ( $\tau_m$ )	$\frac{\tau_m}{\sigma_s}$	Thickness (t)

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SAMPLE PROBLEM

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Table 2. Bulk Data Cards of Special Relevance to Fully Stressed Design

FORCE	Defines a static load at a grid point.
MAT1	Defines the material properties for linear, temperature-independent, isotropic materials.
MATT1	Specifies table references for material properties which are temperature dependent.
PLIMIT	Defines the maximum and minimum limits for ratio at new property to original property.
POPT	Defines the basic parameters and existence of a property optimization analysis.
TABLEM1	Defines a tabular function for use in generating temperature-dependent material properties.
TEMPO	Defines a default temperature for all grid points at the structural model which have not been given a temperature on a TEMP card.

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## FULLY STRESSED DESIGN ANALYSIS

**Table 3. Optimized Nondimensional Thickness Comparisons.**

Element	Original $t/t_e$	Reference 1 Average $t/t_e$	NASTRAN $t/t_e$
37	3.348	1.24	1.00
38	3.348	1.00	1.04
39	3.348	1.00	1.00
46	3.348	2.10	1.14
47	3.348	1.34	2.00
57	3.348	3.32	1.34
59	3.348	3.19	4.40
67	3.348	4.58	5.47
68	3.348	3.26	1.00
59	3.348	4.52	5.49

**Table 4. Optimized Nondimensional Area Comparisons.**

Element	Original $A/dt_e$	Reference 1 Average $A/dt_e$	NASTRAN $A/dt_e$
101	.1674	.0249	.00716
102	.1674	.0238	0.0 effective
103	.1674	.0636	.05019
104	.1674	.1880	.1839
105	.1674	.3540	.3287



SAMPLE PROBLEM

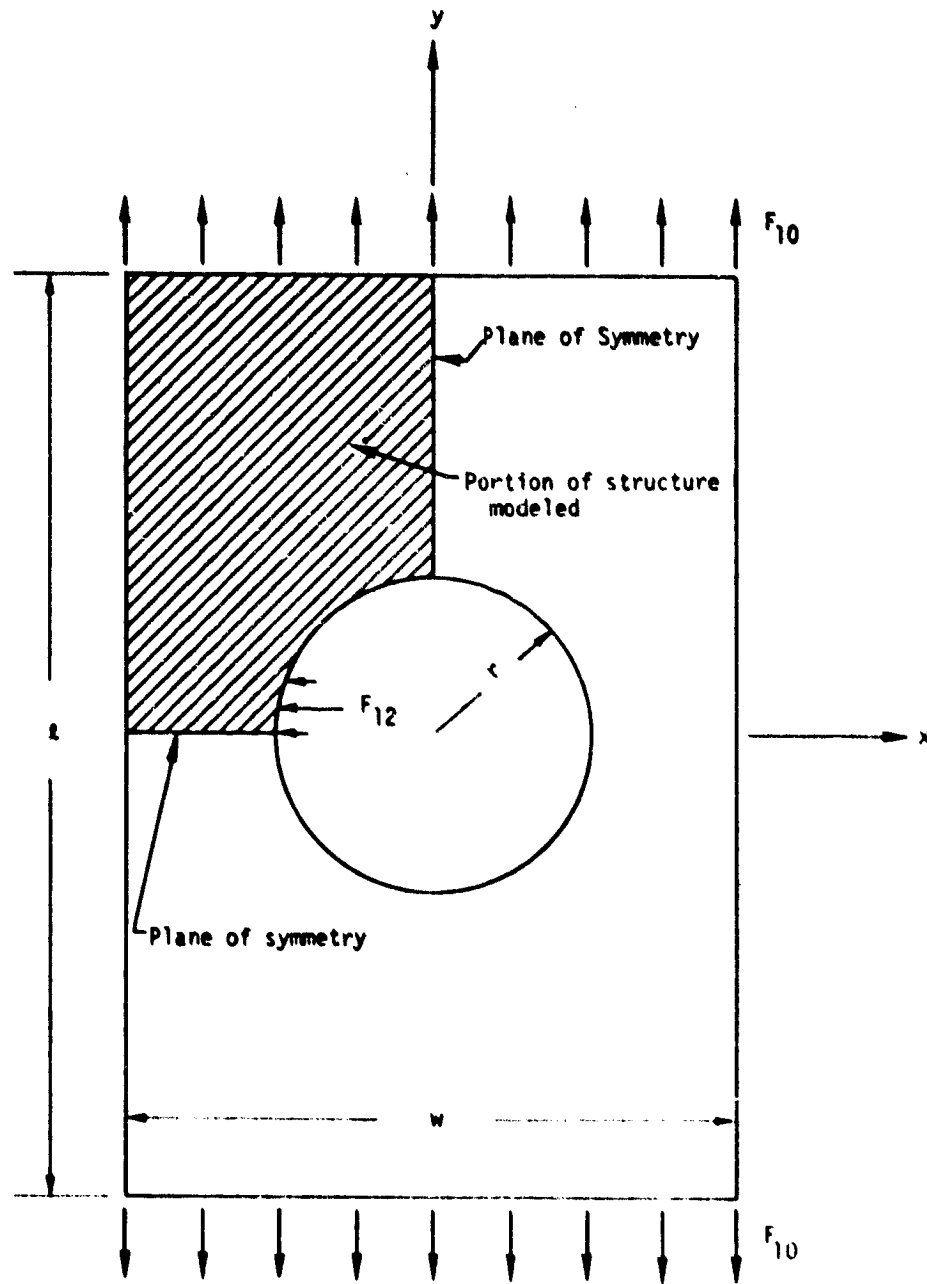


Figure 1. Plate with reinforced hole.

# FULLY STRESSED DESIGN ANALYSIS

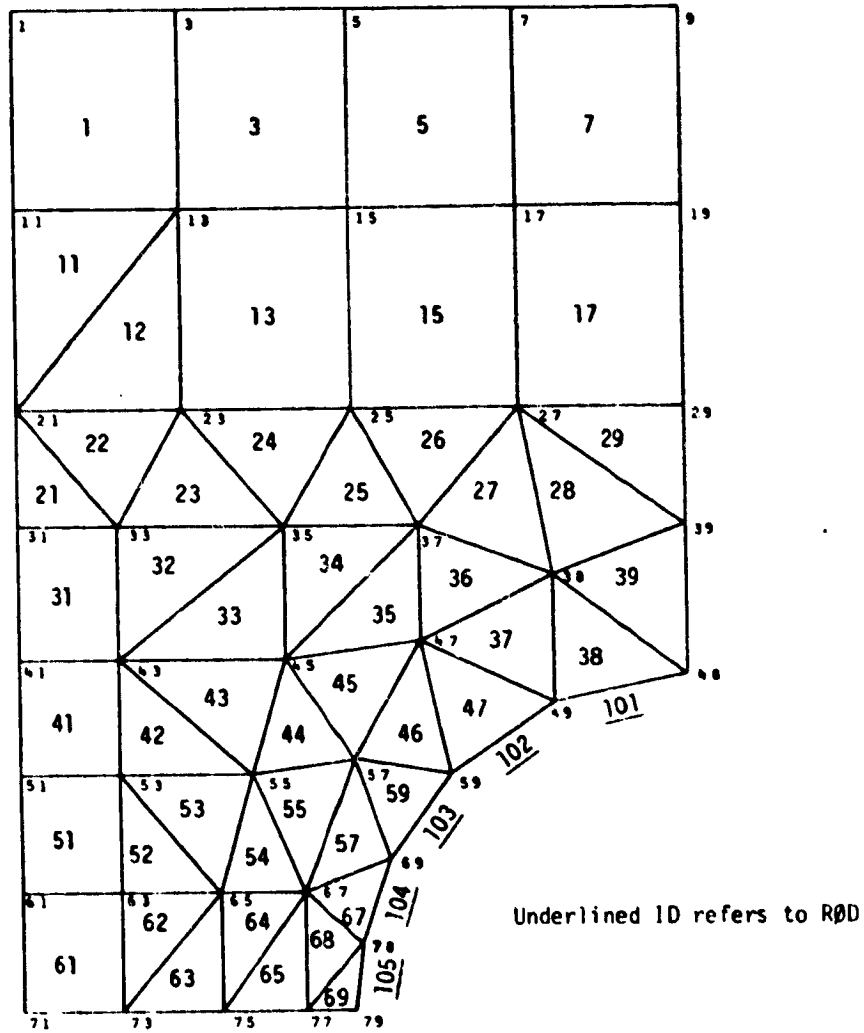


Figure 2. Finite element model.

**END**

**DATE**

**FILMED**

MAR 12 1982