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NASTRAN LEVEL 16 USER'S MANUAL UPDATES FOR AEROELASTIC ANALYSIS OF BLADED DISCS

by

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-20382

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INTRODUCTION

A computer program based on state-of-the-art compressor and structural technologies applied to bladed shrouded discs has been developed and made operational in NASTRAN Level 16.

The problems encompassed include aeroelastic analyses, modes and flutter.

The program is documented in the form of five NASA Contractor's Reports —— one Technical Report and four Updates to NASTRAN Level 16 Theoretical, User's, Programmer's and Demonstration manuals. This report describes the User's manual updates.

USER'S MANUAL UPDATES

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USER'S MANUAL UPDATES

STRUCTURAL MODELING

1.15 STATIC AEROELASTIC AND FLUTTER MODELING OF AXIAL FLOW TURBOMACHINES

1.15.1 Introduction

The NASTRAN aeroelastic and flutter capability has been extended to solve a class of problems associated with axial flow turbomachines. The capabilities included are:

1. Steady state aerothermoelastic analysis of compressors to determine:

(a) The change in geometry between the design point operating shape and the "as manufactured" shape of the flexible blade to ensure the required performance (pressure ratio, flow rate, rpm) at the design point. (This is termed the "design" problem.)

(b) The performance at off-design operating conditions for a given "as manufactured" blade shape. (This is termed the "analysis" problem.)

(c) Displacements, stresses, reactions, plots, etc., at selected operating points over the compressor map.

(d) A differential stiffness matrix due to centrifugal and aerodynamic pressure and thermal loads for use in subsequent modal analysis.

2. Modal, unstalled flutter and subcritical roots analysis of compressors and turbines.

The rotor/stator of a single-stage, or each stage of a multi-stage compressor or turbine is analyzed as an isolated structure. Two new Rigid Formats (Displacement RF 16 and Aero RF 9) have been developed, one each for the aeroelastic steady state and the oscillatory state problems (see Sections 3.21, 3.22, 3.23). The rotational cyclic symmetry (see Section 1.12) inherent in these structures about the axis of rotation has been taken into account in designing the capability, so that only a representative one-blade sector need be idealized.

The steady aerothermoelastic analysis is based on the theory described in Volume I of Reference 1. The computer code of the same reference (Volume II), with minor changes, has been adapted for NASTRAN in the functional module ALG. The current NASTRAN Static Analysis with Differential Stiffness Rigid Format has been accordingly modified to include the effect of centrifugal, aerodynamic pressure and temperature loads.

The existing features of NASTRAN for Normal Modes Analysis using Cyclic Symmetry (Section 3.16) and Modal Flutter Analysis (Section 3.20) have been suitably combined for the modal flutter and subcritical roots analysis of the axial flow turbomachinery rotor/stator.

These developments are compatible with the general structural capability in NASTRAN. The structural part of the problem is modeled as described in Section 1 of the User's Manual. This section deals with the aerodynamic data pertaining to the bladed disc sector. The associated aerodynamic modeling is discussed in Section 1.15.2.

Section 1.15.3 describes the steady aerothermoelastic "design/analysis" formulations.

Section 1.15.5 presents the modal, flutter and subcritical roots analyses.

Sample problems and their solutions are presented in Sections 1.15.4 and 1.15.6.

1.15.2 Aerodynamic Modeling

The aerodynamic model is based on a grid generated by the intersection of a series of streamlines and "computing stations" (similar to potential lines) as shown in Figure 1. This arrangement also facilitates the subsequent use of two-dimensional, unsteady, subsonic and supersonic infinite cascade theories (see Section of the Theoretical Manual) in the flutter problem. They are used in a strip-theory manner on the various streamlines spanning the blade.

The aerodynamic loads are assumed significant only on the bladed portion of a bladed disc and no other part of the structure need be modeled aerodynamically. The data required to generate the aerodynamic model for the steady state aeroelastic analyses are specified on DTI bulk data cards, and are described in Section 1.15.3.1 of the User's Manual. Blade streamline data for flutter and subcritical roots analyses are specified on STREAMLi bulk data cards.

The streamlines are defined by the intersection of the blade mean surface and a set of coaxial cylindrical (or conical) surfaces. The axis of the cylinders (cones) coincides with the axis of rotation of the turbomachine. The "computing stations" lie on the blade mean surface and divide it from the leading edge to the trailing edge. The choice of the number and location of the streamlines and the "computing stations" is dictated by the expected variation of the relative flow properties across the blade span, and the complexity of the mode shapes exhibited by this part of the structure. However, a minimum of three streamlines (including the blade root and

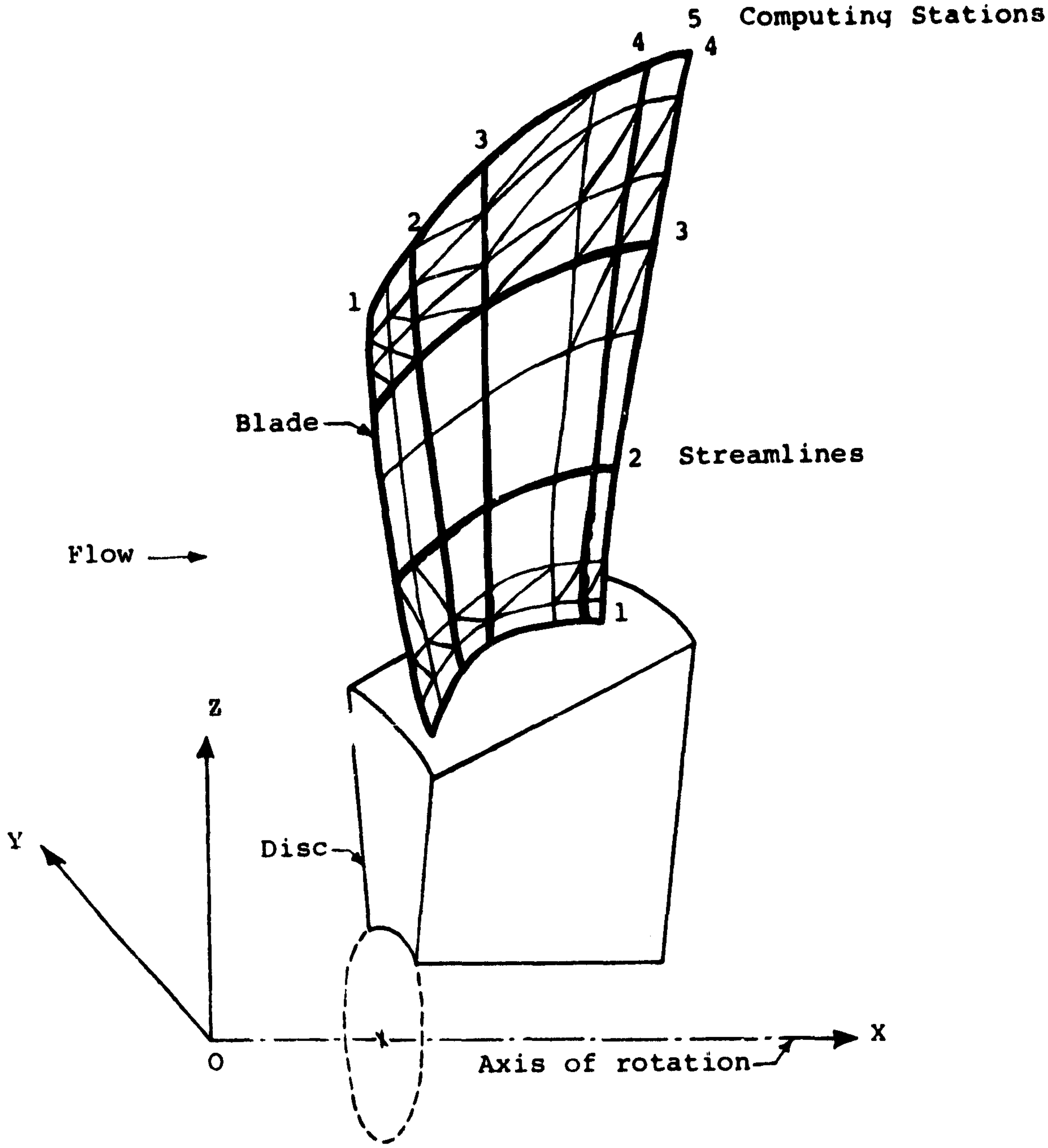


Figure 1 Bladed-disc Aerodynamic Grid And The Basic Coordinate System

the tip) and three "computing stations" (including the blade leading edge and the trailing edge) must be specified.

The distribution of the aerodynamic parameters over the blade is, in general, different from that of the structural parameters such as stress, strain, etc. Accordingly, the aerodynamic model and the structural model of the blade, in general, may differ. The difference currently permitted in the two models is as seen in Figure 1 wherein the aerodynamic grid is shown to be a part of the structural grid.

The x-axis of the BASIC coordinate system (Figure 1) is chosen to coincide with the axis of rotation and is oriented in the direction of the flow. The location of the origin is arbitrary. The z-plane (BASIC) lies normal to the "mean" meridional plane passing through the blade, with the z-axis (BASIC) directed towards the blade. The aerodynamic grid can be specified in any coordinate system (CP). The aerodynamic model data mainly related to the bladed disc problems are specified on the DTI, STREAML1 and STREAML2 bulk data cards.

1.15.3 Steady Aerothermoelastic "Design/Analysis"

An operating point on a compressor map defines a distribution of centrifugal force and aerodynamic pressure and temperature loads on the bladed-disc of the axial flow turbomachine. The equilibrium, deformed shape of the elastic structure is reached at the end of a series of quasi-equilibrium states during which the loads on the bladed-disc and its geometric stiffness change as a function of the deformation. The operating point pressure ratio (given the flow rate and the rpm), in effect, also changes during this process.

Two different problems can thus be stated:

1. Given the desired design operating point and the "rigid" geometry, to determine the "as manufactured" geometry ("design" problem) that would produce the design conditions and

2. Given the "as manufactured" geometry, to determine the performance of the flexible blade at off-design operating points ("analysis" problem).

Rigid format Displacement 16 has been developed to solve these "design/analysis" problems. The value of the PARAMeter SIGN (= ± 1) selects the analysis or the design mode of the rigid format. Deformation of the structure as a result of the applied centrifugal and aerodynamic loads is used to revise the blade geometry each time through the differential stiffness loop of the rigid format. Because of the non-linear relationship between the blade geometry and the resulting operating point pressure ratio, provision is made to control the fraction of the displacements used to redefine the blade geometry. This is especially helpful in the solution of the "design" problem. The fractions of the displacements used to redefine the blade geometry are specified via the FXCOOR, FYCOOR and FZCOOR parameters. The application of the aerodynamic pressure and thermal loads is controlled respectively by the parameters APRESS and ATEMP. These parameters also enable the inclusion of the centrifugal loads alone.

The functional module ALG is used in the rigid format before, within and after the differential stiffness loops (see Section) to generate the aerodynamic loads. Printed output from this module during these three stages can respectively be controlled through the use of the parameters IPRTCI, IPRTCL and IPRTCF. This enables observation of the variation in the aerodynamic loads as a function of the blade geometry.

GRID, CTRIA2 and PTRIA2 bulk data cards for the final blade shape can be punched out using the parameter PGEØM. At the end of a "design" run, these define the "as manufactured" blade shape which can subsequently be "analyzed" at selected operating points over the compressor map. In an "analysis" run at any operating point, the total stiffness (elastic and geometric) of the bladed-disc structure can be saved via the parameter KTØUT for use in subsequent modal, modal flutter and subcritical roots analyses.

The subsections 1.15.3.1 and 1.15.3.2 describe the aerodynamic Direct Table Input and the output data for the steady state analyses.

1.15.3.1 Aerodynamic DTI Data

The input data consist of an initial indication of the number of entries that are to be made to each of the two program sections (analytic meanline blade section and aerodynamic section), and then a data-set for each entry to each section. The data that are required for the interfacing of the output from the analytic meanline blade section to the aerodynamic section are included in the data-set for the analytic meanline section. Because partial input to the aerodynamic section is generated by execution of the analytic meanline section, the input for the aerodynamic section to be supplied directly by the user varies. This is indicated in the charts below by giving the variable name LOG5 for the file from which any data are taken that are not always supplied directly.

LOG5 is the file from which input is taken that is generated by the analytic meanline section. When the analytic meanline section has been directed to produce data for the aerodynamic section for a particular computing station, LOG5 becomes an internally generated scratchfile. Otherwise, LOG5 is attached to the standard input unit and the user supplies the data.

The following input data items must be input using NASTRAN Direct Table Input (DTI) bulk data cards. A description of the DTI card is in the NASTRAN User's Manual on page 2.4-105. The table data block name must be ALGDB. The trailer value for T1 is the number of logical records in the DTI table, not counting the header record. This is the same as the maximum value of IREC used in the table. The trailer values for T2 through T6 are all zero. Each of the following input cards corresponds to one logical record of the DTI table.

Trailing zeroes need not be input. Data types, i.e., alphanumeric (BCD), real and integer, must correspond to those specified for each data item. Data item names that begin with the letters I,J,K,L,M, and N are to be input as integers while all others are input as real numbers. Titles are input as alphanumeric (BCD) with the restriction that only alphabetic letters occupy the first character in each field of the DTI card. Titles may use up to nine DTI fields.

In the following chart, one line, which may be continued, corresponds to one logical record of a DTI card.

TITLE1

NANAL NAERO

The following data-set is input to the analytic meanline section, and will occur NANAL times. The last record in this set is indicated with an asterisk.

TITLE2

NLINES NSTNS NZ NSPEC NPOINT NBLADE ISTAK

(cont.) IPUNCH ISECN IFCORD IFPLOT IPRINT ISPLIT INAST

(cont.) IRLE IRTE NSIGN

ZINNER ZOUTER SCALE STACKX PLTSZE

KPTS IFANGS		Occurs NSTNS Times
XSTA RSTA	- Occurs KPTS times	
R BLAFOR	- Occurs NLINES times	
ZR B1 B2 PP QQ RLE		Occurs NSPEC Times
TC TE Z CORD DELX DELY		
S BS - Only if ISECN = 1 or 3		

NRAD NDPTS NDATR NSWITC NLE NTE

XKSHPE SPEED

NOUT1 NOUT2 NOUT3 - Refers to leading edge station

NR NTERP NMACH NLOSS NL1

(cont.) NL2 NEVAL NCURVE NLITER NDEL

(cont.) NOUT1 NOUT2 NOUT3 NBLAD

R XLOSS - Occurs NR times

] Occurs for each station within blade or at trailing edge

RTE

DM DVFRAC] -Occurs NDPTS times

] Occurs NRAD times

* RDTE DELTAD AC-Occurs NDATR times

] This group is used to generate LOG5 data for the aerodynamic section

The following data-set is input to the aerodynamic section and the last record in this set is indicated with a double asterisk.

TITLE3

CP GASR G EJ

NSTNS NSTRMS NMAX NFORCE NBL NCASE

(cont.) NSPLIT NSET1 NSET2 NREAD NPUNCH NPLOT

(cont.) NPAGE NTRANS NMIX NMANY NSTPLT NEQN NLE NTE NSIGN

NWHICH - Occurs NMANY times on the same card

G EJ SCLFAC TOLNCE VISK SHAPE

XSCALE PSCALE RLOW PLOW XMMAX RCONST

CONTR CONMX

FLOW SPDFAC

NSPEC

XSTN RSTN - Occurs NSPEC times

] Occurs NSTNS Times

```
          NDATA NTERP NDIMEN NMACH                          ] Inlet
                                                            ] condition
          DATAC DATA1 DATA2 DATA3 - Occurs                  ] specification
                                    NDATA times             ]

(LOG5)    NDATA NTERP NDIMEN NMACH NWORK                            ]
(cont.)   NLOSS NL1 NL2 NEVAL NCURVE NLITER                         ]
(cont.)   NDEL NOUT1 NOUT2 NOUT3 NBLADE                             ] For
(LOG5)    SPEED-If NDATA >0                                         ] sta-
(LOG5)    DATAC DATA1 DATA2 DATA3 DATA4  ] Occurs                   ] tions
(cont.)   DATA5                          ] NDATA                    ] 2
(LOG5)    DATA6 DATA7 DATA8 DATA9        ] times                    ] thru
          DELC DELTA - Occurs NDEL times                            ] NSTNS

          WBLOCK BBLOCK BDIST -Occurs NSTNS times

          NDIF                                           ] Occurs
          DIFF FDHUB FDMID FDTIP -Occurs NDIFF           ] NSET1
                                   times                 ] times

          NM NRAD                                        ] Occurs
          TERAD                           ] Occurs       ] NSET2
          DM WFRAC -Occurs NM times       ] NRAD times   ] Times

          DELF(1) DELF(2)....DELF (NSTRMS) - if NSPLIT = 1
                                             or NREAD  = 1

**        R X XL II JJ - Occurs NSTRMS times for NSTNS stations
                         if NREAD = 1
```

Data Item Defintions:

The aerodynamic section may be used with any self-consistent unit system and, additionally, a "linear dimension scaling factor" (SCLFAC) is incorporated into the input so that some commonly used but inconsistent unit sytems may be used. This is principally intended to allow the use of inches for physical dimensions and yet retain feet for velocities. The basic dimensions used in the data are length (L), time (T), and force (F). Angles are expressed in degrees (A), and temperatures on an absolute temperature scale (D). Heat capacities (H) are also required. Some possible unit systems are given below, togehter with the corresponding value of SCLFAC.

L	T	F	D	H	SCLFAC
Feet	Seconds	Pounds	Deg. Rankine	BTU	1.0
Inches	Seconds	Pounds	Deg. Rankine	BTU	12.0
Meters	Seconds	Kilograms	Deg. Kelvin	CHU	1.0

Note that some data names are used in more than one section; care should be taken to consult the correct sub-division below for defintions.

a. Initial Directives

TITLE1 This is a title card for the run.

NANAL Set NANAL = 1

NAERO Set NAERO = 1

b. Analytic Meanline Blade Section

For a more detailed discussion of the input to this section through item XB, see Reference and . For this section, the dimensioned input is either in degree (A) or in length (L).

TITLE2	A title card for the analytic meanline section of the program.
NLINES	The number of stream surfaces which are defined, and on which blade sections will be designed. Must satisfy $2 \leq$ NLINES ≤ 21.
NSTNS	The number of computing stations at which the stream surface radii are specified. Must satisfy $3 \leq$ NSTNS ≤ 10.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq$ NZ ≤ 15.
NSPEC	The number of radially disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq$ NSPEC ≤ 21.
NPOINT	The number of points that will be generated to specify the pressure and suction surfaces of each blade section. Must satisfy $2 \leq$ NPOINT ≤ 80. Generally, no less than 30 should be used.
NBLADE	The number of blades in the blade row.
ISTAK	If ISTAK = 0, the blade will be stacked at the leading edge. If ISTAK = 1, the blade will be stacked at the trailing edge.

If ISTAK = 2, the blade will be stacked at, or offset from, the section centroid.

IPUNCH — Set IPUNCH = 0

ISECN — If ISECN = 0, the blade will be constructed using the polynomial camber line and the standard (i.e., double-cubic) thickness distribution.

If ISECN = 1, the exponential camber line and the standard thickness distribution will be used.

If ISECN = 2, the circular arc camber line and the double-circular-arc thickness distribution will be used.

If ISECN = 3, the multiple-circular-arc meanline and the standard thickness distribution will be used.

IFCORD — If IFCORD = 0, the meridional projection of the stream surface blade section chords are specified.

If IFCORD = 1, the stream surface blade section chords are specified.

IFPLOT — Set IFPLOT = 0

IPRINT — The input data is always listed by the program. Details of the stream surface and manufacturing sections are printed as prescribed by IPRINT.

	If IPRINT = 0, details of the stream surface and manufacturing sections are printed.
	If IPRINT = 1, details of stream surface sections are printed.
	If IPRINT = 2, details of manufacturing sections are printed.
	If IPRINT = 3, details of neither stream surface nor manufacturing sections are printed. (The interface data for use with the aerodynamic section of the program is is still displayed.)
ISPLIT	Set ISPLIT = 0
INAST	Set INAST = 0. See the Output Data description (Section) for further details.
IRLE	The computing station number at the blade leading edge.
IRTE	The computing station number at the blade trailing edge.
NSIGN	Indicator used to sign blade pressure forces according to program sign conventions. For compressor rotors, if the machine rotates clockwise when viewed from the front, set NSIGN to 1; otherwise, set NSIGN to -1. For compressor stators, the two values given for NSIGN are reversed.

ZINNER, ZOUTER	The NZ manufacturing sections are equi-spaced between z equals ZINNER and ZOUTER.
SCALE	Set scale = 0.0.
STACKX	This is the axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.
PLTSZE	Set PLTSZE = 0.0.
KPTS	The number of points provided to specify the shape of a computing station. If KPTS = 1, the computing station is upright and linear. If KPTS = 2, the computing station is linear and either upright or inclined. If KPTS >2, a spline curve is fit through the points provided to specify the shape of the station.
IFANGS	If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station. If IFANGS = 1, these calculations will be performed at that station.
XSTA	An array of KPTS axial coordinates (relative to an arbitrary origin) which, toghter with RSTA, specify the shape of a particular computing station.

RSTA	An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.
R	The stream surface radii at NLINES locations at each of the NSTNS stations.
BLAFOR	Set BLAFOR = 0.0.
ZR	The variation of properties of the stream surface blade section is specified as a function of stream surface number. The various quantitites are then interpolated (or extrapolated) at each stream surface. The stream surfaces are numbered consecutively from the inner-most outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.
B1	The blade inlet angle.
B2	The blade outlet angle.
PP	If ISECN = 0, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value. Must satisfy $-2.0 < PP < 1.0$. If ISECN = 1, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value forward of the inflection point. Must satisfy $0.0 < PP < 1.0$.

	If ISECN = 2 or 3, PP is superfluous.
QQ	If ISECN = 0, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value. Must satisfy $0.0 \leq QQ \leq 1.0$.
	If ISECN = 1, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value rearward of the inflection point. Must satisfy $0.0 < QQ \leq 1.0$.
	If ISECN = 2 or 3, QQ is superfluous.
RLE	The ratio of blade leading edge radius to chord.
TC	The ratio of blade maximum thickness to chord.
TE	The ratio of blade trailing edge half-thickness to chord.
	If ISECN = 2, TE is superfluous.
Z	The location of the blade maximum thickness, as a fraction of camber line length from the leading edge.
	If ISECN = 2, Z is superfluous.
CORD	If IFCORD = 0, CORD is the meridional projection of the blade chord.
	If IFCORD = 1, CORD is the blade chord.
DELX, DELY	The stacking axis passes through the stream surface blade sections, offset from the centroids, leading, or trailing edge by DELX

	and DELY in the x and y directions respectively.
S, BS	If ISECN = 1 or 3, S and BS are used to specify the locations of the inflection point (as a fraction of the meridionally-projected chord length) and the change in camber angle from the leading edge to the inflection point. If the absolute value of the angle at the inflection point is larger than the absolute value of B1, BS should have the same sign as B1, otherwise, B1 and BS should be of opposite signs.
NRAD	The number of radii at which a distribution of the fraction of trailing edge deviation is input. Must satisfy 1 ≤ NRAD ≤ 5.
NDPTS	The number of points used to define each deviation curve. Must satisfy 1 ≤ NDPTS ≤ 11.
NDATR	The number of radii at which an additional deviation angle increment and the point of maximum camber are specified. Must satisfy 1 ≤ NDATR ≤ 21.
NSWITC	If NSWITC = 1, the deviation correlation parameter "m" for the NACA (A_{10}) meanline is used. If NSWITC = 2, the deviation correlation parameter "m" for double-circular-arc blades is used.
NLE	Station number at leading edge.
NTE	Station number at trailing edge.
XKSHPE	The blade shape correction factor in the deviation rule.

SPEED	See definition for Aerodynamic Section.
NR	The number of radii where a "loss" is input.
NTERP NMACH NLOSS NL1 NL2 NEVAL NCURVE NLITER NDEL NOUT1 NOUT2 NOUT3 NBLAD	See definition for Aerodynamic Section.
R	Radius at which loss is specified.
XLOSS	Loss description. The form is prescribed by NLOSS; see aerodynamic section.
RTE	Radius at blade trailing edge where the following deviation fraction/chord curve applies. If NRAD = 1, it has no significance. Must increase monotonically.
DM	The location on the meridional chord where the deviation fraction is given. Expressed as a fraction of the meridional chord from the leading edge. Must increase monotonically.
DVFRAC	Fraction of trailing -edge deviation that occurs at location DM.
RDTE	Radius at trailing edge where additional deviation and point of maximum camber are specified.

DELTAD	Additional deviation angle added to that determined by deviation rule. Input positive for conventionally positive deviation for both rotors and stators.
AC	Fraction of blade chord from leading edge where maximum camber occurs.

c. Aerodynamic Section

TITLE3	A title card for the aerodynamic section of the program.
CP	Specific heat at constant pressure. An input value of zero will be reset to 0.24. Units: H/F/D.
GASR	Gas constant. An input value of zero will be reset to 53.32. Units: L/SCLFAC/D.
G	Acceleration due to gravity. An input value of zero will be reset to 32.174. Units: L/SCLFAC/T/T.
EJ	Joules equivalent. An input value of zero will be reset to 778.16. Units: LF/SCLFAC/H.
NSTNS	Number of computing stations. Must satisfy 3 ≤ NSTNS ≤ 30.
NSTRMS	Number of streamlines. Must satisfy 3 ≤ NSTRMS ≤ 21. An input value of zero will be reset to 11.
NMAX	Maximum number of passes through the iterative streamline determination procedure. An input value of zero will be reset to 40.
NFORCE	The first NFORCE passes are performed with arbitrary numbers inserted should any calculation produce impossible values. Thereafter, execution will cease, the calculation having "failed". An input value of zero will be reset to 10.
NBL	If NBL = 0, the annulus wall boundary layer blockage allowance will be held at the values prescribed by WBLOCK. If NBL = 1, blockage due to annulus wall boundary layers will be recalculated except at station 1. VISK and SHAPE are used in the calculation.

NCASE	Set NCASE = 1.
NSPLIT	If NSPLIT = 0, the flow distribution between the streamlines will be determined by the program so that roughly uniform increments of computing station will occur between the streamlines at station 1. If NSPLIT = 1, the flow distribution between the streamlines is read in (see DELF).
NSET1	The blade loss coefficient re-evaluation option (specified by NEVAL) requires loss parameter/diffusion factor data. NSET1 sets of data are input, the set numbers being allocated according to the order in which they are input. Up to 4 sets may be input (see NDIFF).
NSET2	When NLOSS = 4, the loss coefficients at the station are determined as a fraction of the value at the trailing edge. Then, NSET2 sets of curves are input to define this fraction at a function of radius and meridional chord. Up to 2 sets may be input (see NM).
NREAD	If NREAD = 0, the initial streamline pattern estimate is generated by the program. If NREAD = 1, the initial streamline pattern estimate and also the DELF values are read in. (See DELF, R, X, XL.)
NPUNCH	Set NPUNCH = 0
NPLOT	Set NPLOT = 0
NPAGE	The maximum number of lines printed per page. An input value of zero will be reset to 60.
NTRANS	IF NTRANS = 0, no action is taken. If NTRANS = 1, relative total pressure loss coefficients will be modified to account for radial transfer of wakes. See Section V.11, Ref. .

NMIX — If NMIX = 0, no action is taken.
If NMIX = 1, entropy, angular momentum, and total enthalpy distributions will be modified to account for turbulent mixing. See Section V.12, Ref. .

NMANY — The number of computing stations for which blade descriptive data is being generated by the analytic meanline section.

NSTPLT — If NSTPLT = 0, no action is taken.
If NSTPLT = 1, a line-printer plot of the changes made to the midstreamline 'ℓ' coordinate is made for each computing station. If more than 59 passes through the iterative procedure have been made, then the plots will show the changes for the last 59 passes. The graph should decay approximately exponentially towards zero, indicating that the streamline locations are stabilizing. Decaying oscillations are equally acceptable, but, growing oscillations show the need for heavier damping in the streamline relocation calculations, that is, a decrease in RCONST.

NEQN — This item controls the selection of the form of momentum equation that will be used to compute the meridional velocity distributions at each computing station. There are two basic forms, and for each case, one may select not to compute the terms relating to blade forces. (See also Section V. 1, Ref. .

If NEQN = 0, the momentum equation involves the differential form of the continuity equations and hence $(1-M_m^2)$ terms in the denominator. Streamwise gradients of entropy and angular momentum (blade forces) are computed within blades and at the blade edges (provided data that describe the blades are given). Elsewhere, streamwise entropy gradients only are included in a simpler form of the momentum equation, except that at the first and last computing station, all streamwise gradients are taken to be zero. This is generally the preferred option when computing stations are located within the blade rows.

If NEQN = 1, the momentum equation form is similar to that used when NEQN = 0, but angular momentum gradients (blade force terms) are nowhere computed. This generally is the preferred option when computing stations are located at the blade edges only.

If NEQN = 2, the momentum equation includes an explicit dVm/dm term instead of the $(1-M_m^2)$

denominator terms. All streamwise gradients (including blade force terms) are computed as for the case NEQN = 0. When computing stations are located within the blade rows, the results will generally be similar to those obtained with NEQN = 0, and solutions may be found that cannot be computed with NEQN = 0 due to high meridional Mach numbers.

If NEQN = 3, the momentum equation is similar to that used when NEQN = 1, but (as for the case NEQN = 1) no angular momentum gradients are computed. This may be used when computing stations are located only at the blade edges and high meridional Mach numbers preclude the use of NEQN = 1.

NLE NTE NSIGN	See the Analytic Section.
NWHICH	The numbers of each of the computing stations for which blade descriptive data is being generated by the analytic meanline section.
SCLFAC	Linear dimension scale factor , see page . An input value of zero will be reset to 12.0.
TOLNCE	Basic tolerance in iterative calculation scheme. An input value of zero will be reset to 0.001. (See discussion of tolerance scheme in Section VI, Ref. .)

VISK	Kinematic viscosity of gas (for annulus wall boundary layer calculations). An input value of zero will be reset to 0.00018. Units: LL/SCLFAC/SCLFAC/T.
SHAPE	Shape factor for annulus wall boundary layer calculations. An input value of zero will be reset to 0.7.
XSCALE, PSCALE, RLOW, PLOW	Set each equal to 0.0.
XMMAX	The square of the Mach number that appears in the equation for the streamline relocation relaxation factor is limited to be not greater than XMMAX. Thus, at computing stations where the appropriate Mach number is high enough for the limit to be imposed, a decrease in XMMAX corresponds to an increase in damping. If a value of zero is input, it is reset to 0.6.
RCONST	The constant in the equation for the streamline relocation relaxation factor. The value of 8.0 that the analysis yields is often too high for stability. If zero is input, it is reset to 6.0.
CONTR	The constant in the blade wake radial transfer calculations.
CONMX	The eddy viscosity for the turbulent mixing calculations. Units: $L^2/SCLFAC^2/T$.

FLOW	**Compressor flow rate. Units: F/T.**
SPDFAC	**The speed of rotation of each computing station is SPDFAC times SPEED (I). The units for the product are revolutions/(60xT).**
NSPEC	The number of points used to define a computing station. Must satisfy 2 ≤ NSPEC ≤ 21, and also the sum of NSPEC for all stations ≤ 150. If 2 points are used, the station is a straight line. Otherwise, a spline-curve is fitted through the given points.
XSTN, RSTN	The axial and radial coordinates, respectively, of a point defining a computing station. The first point must be on the hub and the last point must be on the casing. Units: L.
NDATA	Number of points defining conditions or blade geometry at a computing station. Must satisfy 0 ≤ NDATA ≤ 21, and also the sum of NDATA for all stations ≤ 100.
NTERP	If NTERP = 0, and NDATA ≥ 3, interpolation of the data at the station is by spline-fit. If NTERP = 1 (or NDATA ≤ 2), interpolation is linear point-to-point.
NDIMEN	If NDIMEN = 0, the data are input as a function of radius. If NDIMEN = 1, the data are input as a function of radius normalized with respect to tip radius. If NDIMEN = 2, the data are input as a function of distance along the computing station from the hub. If NDIMEN = 3, the data are input as a function of distance along the computing station normalized with respect to the total computing station length.
NMACH	If NMACH = 0, the subsonic solution to the continuity equation is sought. If NMACH = 1, the supersonic solution to the continuity equation is sought. This should only be used at stations where the relative flow angle is specified, that is, NWORK = 5, 6, or 7.
DATAC	The coordinate on the computing station, defined according to NDIMEN, where the following data items apply. Must increase monotonically. For dimensional cases, units are L.

DATA1 — At Station 1 and if NWORK = 1, DATA1 is total pressure. Units: F/L/L.

If NWORK = 0 and the station is at a blade leading edge, by setting NDATA ≠ 0, the blade leading edge may be described. Then DATA1 is the blade angle measured in the cylindrical plane. Generally negative for a rotor, positive for a stator. (Define the blade lean angle (DATA3) also). Units: A.

If NWORK = 2, DATA1 is total enthalpy. Units: H/F.

If NWORK = 3, DATA1 is angular momentum (radius times absolute whirl velocity). Units: LL/SCLFAC/T.

If NWORK = 4, DATA1 is absolute whirl velocity. Units: L/SCLFAC/T.

If NWORK = 5, DATA1 is blade angle measured in the streamsurface plane. Generally negative for a rotor, positive for a stator. If zero deviation is input, it becomes the relative flow angle. Units: A.

If NWORK = 6, DATA1 is the blade angle measured in the cylindrical plane. Generally negative for a rotor, positive for a stator. If zero deviation is input, it becomes, after correction for streamsurface orientation and station lean angle, the relative flow angle. Units: A.

If NWORK = 7, DATA1 is the reference relative outlet flow angle measured in the streamsurface plane. Generally negative for a rotor, positive for a stator. Units: A.

DATA2 — At Station 1, DATA2 is total temperature. Units: D.

If NLOSS = 1, DATA2 is the relative total pressure loss coefficient. The relative total pressure loss is measured from the station that is NL1 stations removed from the current station, NL1 being negative to indicate an upstream station. The relative dynamic head is determined NL2 stations removed from the current station, positive for a downstream station, negative for an upstream station.

If NLOSS = 2, DATA2 is the isentropic efficiency of compression relative to conditions NL1 stations removed, NL1 being negative to indicate an upstream station.

If NLOSS = 3, DATA2 is the entropy rise relative to the value NL1 stations removed, NL1 being negative to indicate an upstream station. Units: H/F/D.

If NLOSS = 4, DATA2 is not used, but a relative total pressure loss coefficient is determined from the trailing edge value and curve set number NCURVE of the NSET2 families of curves. NL1 and NL2 apply as for NLOSS = 1.

If NWORK = 7, DATA 2 is the reference (minimum) relative total pressure loss coefficient. NL1 and NL2 apply as for NLOSS = 1.

DATA3	The blade lean angle measured from the projection of a radial line in the plane of the computing station, positive when the innermost portion of the blade precedes the outermost in the direction of rotor rotation. Units: A.
DATA4	The fraction of the periphery that is blocked by the presence of the blades.
DATA5	Cascade solidity. When a number of stations are used to describe the flow through a blade, values are only required at the trailing edge. (They are used in the loss coefficient re-estimation procedure, and to evaluate diffusion factors for the output.)
DATA6	If NWORK = 5 or 6, DATA6 is the deviation angle measured in the streamsurface plane. Generally negative for a rotor, positive for a stator. Units: A. If NWORK = 7, DATA6 is reference relative inlet angle, to which the minimum loss coefficient (DATA2) and the reference relative outlet angle (DATA7) correspond. Measured in the streamsurface plane and generally negative for a rotor, positive for a stator. Units: A.
DATA7	If NWORK = 7, DATA7 is the rate of change of relative outlet angle with relative inlet angle.
DATA8	If NWORK = 7, DATA8 is the relative inlet angle larger than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.

DATA9	**If NWORK = 7, DATA9 is the relative inlet angle smaller than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.**
NWORK	If NWORK = 0, constant entropy, angular momentum, and total enthalpy exist along streamlines from the previous station. (If NMIX = 1, the distributions will be modified.)
	If NWORK = 1, the total pressure distribution at the computing station is specified. Use for rotors only.
	If NWORK = 2, the total enthalpy distribution at the computing station is specified. Use for rotors only.
	If NWORK = 3, the absolute angular momentum distribution at the computing station is specified.
	If NWORK = 4, the absolute whirl velocity distribution at the computing station is specified.
	If NWORK = 5, the relative flow angle distribution at the station is specified by giving blade angles and deviation angles, both measured in the streamsurface plane.
	If NWORK = 6, the relative flow angle distribution at the station is specified by giving the blade angles measured in the cylindrical plane, and the deviation angles measured in the streamsurface plane.
	If NWORK = 7, the relative flow angle and relative total pressure loss coefficient distributions are specified by means of an off-design analysis procedure. "Reference", "stalling", and "choking" relative inlet angles are specified. The minimum loss coefficient varies parabolically with the relative inlet angle so that it is twice the minimum value at the "stalling" or "choking" values. A maximum value of 0.5 is imposed. "Reference" relative outlet angles and the rate of change of outlet angle with inlet angle are specified, and the relative outlet angle varies linearly from the reference value with the relative inlet angle. NLOSS should be set to zero.
NLOSS	If NLOSS = 1, the relative total pressure loss coefficient distribution is specified.
	If NLOSS = 2, the isentropic efficiency (for compression) distribution is specified.
	If NLOSS = 3, the entropy rise distribution is specified.

If NLOSS = 4, the total pressure loss coefficient distribution is specified by use of curve-set NCURVE of the NSET2 families of curves giving the fraction of final (trailing edge) loss coefficient.

NL1 — The station from which the loss(in whatever form NLOSS specifices) is measured, is NL1 stations removed from the station being evaluated. NL1 is negative to indicate an upstream station.

NL2 — When a relative total pressure loss coefficient is used to specify losses, the relative dynamic head is taken NL2 stations removed from the station being evaluated. NL2 may be positive, zero, or negative; a positive value indicates a downstream station, a negative value indicates an upstream station.

NEVAL — If NEVAL = 0, no action is taken.

If NEVAL > 0, curve-set number NEVAL of the NSET1 families of curve giving diffusion loss parameter as a function of diffusion factor will be used to re-estimate the relative total pressure loss coefficient. NLOSS must be 1, and NL1 and NL2 must specify the leading edge of the blade. See also NDEL.

If NEVAL 0, curve-set number NEVAL is used as NAVAL 0, except that the re-estimation is only made after the overall computation is completed (with the input losses). The resulting loss coefficients are displayed but not incorporated into the overall calculation. See also NDEL.

NCURVE — When NLOSS = 4, curve-set NCURVE of the NSET2 families of curves, specifying the fraction of trailing-edge ;pss coefficient as a function of meridional chord is used.

NLITER	When NEVAL > 0, up to NLITER re-estimations of the loss coefficient will be made at a given station during any one pass through the overall iterative procedure. Less than NLITER re-estimations will be made if the velocity profile is unchanged by re-estimating the loss coefficients. (See discussion of tolerance scheme in Section VI, Ref .)
NDEL	When NEVAL = 0, set NDEL to 0. When NEVAL $\neq 0$, and NDEL > 0, a component of the re-estimated loss coefficient is a shock loss. The relative inlet Mach number is expanded (or compressed) through a Prandtl-Meyer expansion on the suction surface, and NDEL is the number of points at which the Prandtl-Meyer angle is given. If NDEL = 0, the shock loss is set at zero. Must satisfy $0 \leq$ NDEL ≤ 21, and also the sum of NDEL for all stations ≤ 100.
NOUT1	Set NOUT1 = 0
NOUT2	Set NOUT2 = 0
NOUT3	This data item controls the generation of NASTRAN - compatible temperature and pressure difference output for use in subsequent blade stress analyses. For details of the triangular mesh that is used, see the Output Description in Section .

NOUT3 = XY, where

If X = 1, the station is at a blade leading edge.

If X = 2, the station is at a blade trailing edge.

If Y = 0, then both temperature and pressure data will be generated.

If Y = 1, then only pressure data will be generated.

If Y = 2, then only temperature data will be generated.

If NOUT3 = 0, the station may be between blade rows, or within a blade row for which output is required, depending upon the use of NOUT3 ≠ 0 elsewhere. See also description of NBLADE below.

NBLADE — This item is used in determining the pressure difference across the blade. The number of blades is | NBLADE | . If NBLADE is positive, "three-point averaging" is used to determine the pressure difference across each blade element. If NBLADE is negative, "four point averaging" is used. (See the Output Description in Section .) If NBLADE is input as zero, a value of +10 is used. At a leading edge, the value for the following station is used: elsewhere the value at a station applies to the interval

	upstream of the station. Thus by varying the sign of NBLADE, the averaging method used for the pressure forces may be varied for different axial segments of a blade row.
SPEED	This card is omitted if NDATA = 0. The speed of rotation of the blade. At a blade leading edge, it should be set to zero. The product SPDFAC times SPEED has units of revolutions/(T x 60).
DELC	The coordinate at which Prandtl-Meyer expansion angles are given. It defines the angle as a function of the dimensions of the leading edge station, in the manner specified by NDIMEN for the current, that is trailing edge station. Must increase monotonically. For dimensional cases, units are L.
DELTA	The Prandtl-Meyer expansion angles. A positive value implies expansion. If blade angles are given at the leading edge, the incidence angles are added to the value specified by DELTA. Units: A. (Blade angles are measured in the cylindrical plane.)
WBLOCK	A blockage factor that is incorporated into the continuity equation to account for annulus wall boundary layers. It is expressed as the fraction of total area at the computing station that is blocked. If NBL = 1, values (except at Station 1) are revised during computation, involving data items VISK and SHAPE.

BBLOCK, BDIST	A blockage factor is incorporated into the continuity equation that may be used to account for blade wakes or other effects. It varies linearly with distance along the computing station. BBLOCK is the value at mid-station (expressed as the fraction of the periphery blocked), and BDIST is the ratio of the value on the hub to the mid-value.
NDIFF	When NSET1 > 0, there are NDIFF points defining loss diffusion parameter as a function of diffusion factor. Must satisfy $1 \le$ NDIFF ≤ 15.
DIFF	The diffusion factor at which loss parameters are specified. Must increase monotonically.
FDHUB	Diffusion loss parameter at 10 per cent of the radial blade height.
FDMID	Diffusion loss parameter at 50 per cent of the radial blade height.
FDTIP	Diffusion loss parameter at 90 per cent of the radial blade height.
NM	When NSET2 > 0, there are NM points defining the fraction of trailing edge loss coefficient as a function of meridional chord. Must satisfy $1 \le$ NM ≤ 11.
NRAD	The number of radial locations where NM loss fraction/chord points are given. Must satisfy $1 \le$ NRAD ≤ 5.
TERAD	The fraction of radial blade height at the trailing edge where the following loss fraction/chord curve applies. If NRAD = 1, it has no significance.
DM	The location on the meridional chord where the loss fraction is given. Expressed as a fraction of meridional chord from the leading edge. Must increase monotonically.
WFRAC	Fraction of trailing edge loss coefficient that occurs at location DM.

DELF	The fraction of the total flow that is to occur between the hub and each streamline. The hub and casing are included, so that the first value must be 0.0, and the last (NSTRM) value must be 1.0.
R	Estimated streamline radius. (These data are input from hub to tip for the first station, from hub to tip for the second station, and so on.) Units: L.
X	Estimated axial coordinate at intersection of streamline with computing station. Units: L.
XL	Estimated distance along computing station from hub to intersection of streamline with computing station. Units: L.
II, JJ	Station and streamline number. These are merely read in and printed out to give a check on the order of the cards.

1.15.3.2 AERODYNAMIC OUTPUT DATA

1. ANALYTIC MEANLINE SECTION

Printed output may be considered to consist of four sections; a printout of the input data, details of the blade sections on each streamsurface, a listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below. In the explanation which follows, parenthetical statements are understood to refer to the particular case of the double-circular-arc blade (ISECN = 2).

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the parameters defining the blade section. These are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the section specified, except that the meridional projection of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord; stagger angle; camber angle; section area; location of the centroid of the section; second moments of area of the section about the centroid; orientation of the principal axes; and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. NPOINT values are given.

A lineprinter plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page, so that the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give a blade section as defined by IFCORD and CORD. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord; radius and location of center of leading (and trailing) edge(s); section area, the second moments of area of the section about the centroid and the principal second moments of area of the section about the centroid. The coordinates of NPOINT points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at (roughly) six degree intervals around the leading (and trailing) edges. Finally, the coordinates of the blade surfaces and points around the leading (and trailing) edge(s) is (are) shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, blade section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station. The blade section angle is measured in the cylindrical plane, and the blade lean angle is measured in the constant-axial-coordinate plane.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER, and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area; the location of the centroid of the section; the second moments of area of the section about the centroid; the principal second moments of area of the section about the centroid; the orientation of the principal axes; and the section torsional constant. Then the coordinates of NPOINT points on the blade section surfaces are listed, followed by 31 points around the leading (and trailing) edge(s).

If NAERO = 1, the additional input and output required for, and generated by, the interface are also printed. (Apart from the input data printout, this is the only printed output when IPRINT = 3.)

If the NASTRAN parameter PGEOM $\neq$ -1 then cards are punched that may be used as input for the NASTRAN stress analysis program. For the purpose of stress analysis, the blade is divided into a number of triangular elements, each defined by three grid points. The intersections between computing stations and streamsurfaces are used as the grid points and the grid points and element numbering scheme adopted is illustrated in Figure 1.

TheNASTRAN input data format includes cards identified by the codes GRID, CTRIA2 and PTRIA2. The data are fully described in Reference 7, but briefly, the GRID cards each define a grid point number and give the coordinates at the grid point, the CTRIA2 cards each define an element in terms of the three appropriate grid points (by number, and in a significant order), the PTRIA2 cards each give an average blade thickness for an element.

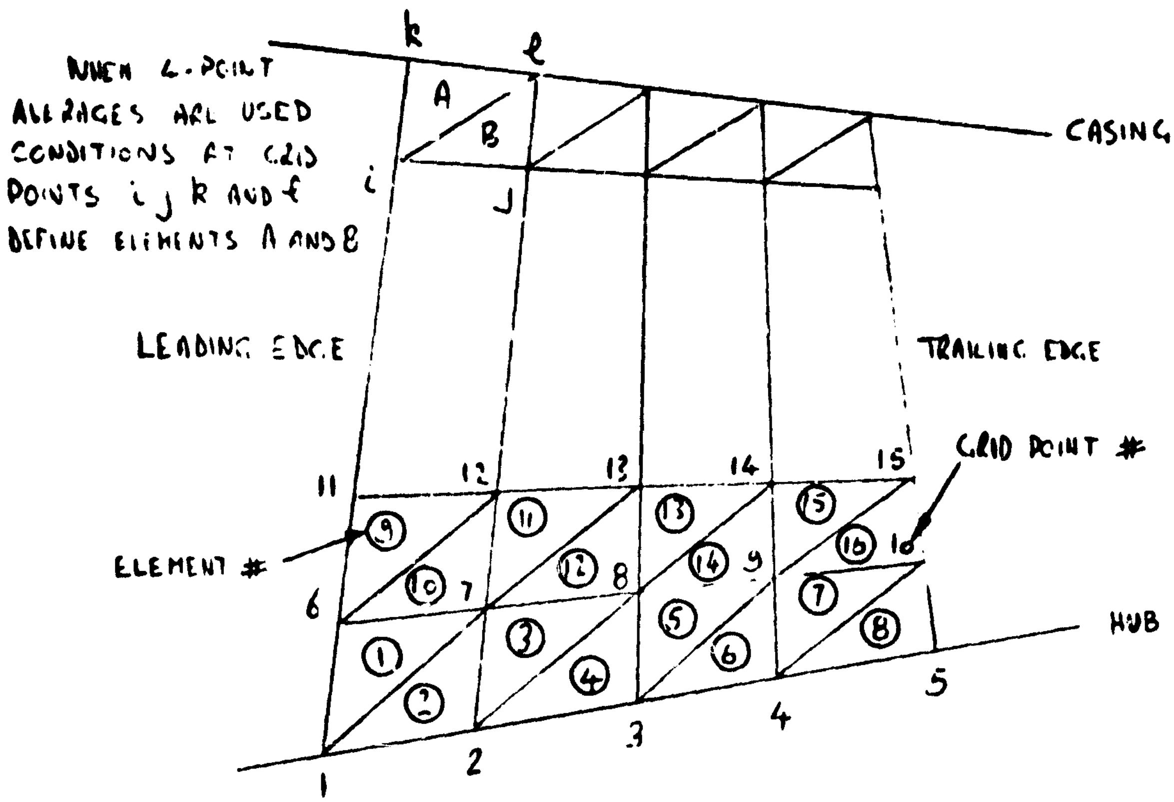


Figure 1. NASTRAN Grid Point and Element Numbering Scheme.

2. AERODYNAMIC SECTION

a. Regular Printed Output

The input data are first printed out in its entirety, and the results for each running point follow. The output is generally self-explanatory and definitions are given here for some derived quantities. Tabular output is generally not started on a page unless it can be completed on the same page, according to the maximum number of lines permitted by the input variable NPAGE.

The results of each running point are given under a heading giving the running point number. Any diagnostics generated during the calculation will appear first under the heading. (Diagnostics are described in the following section.) Then, a station-by-station print out follows for each station through to the last station, or to the station where the calculation failed, if this occurred. One or more diagnostics will indicate the reason for the failure, in this event. Included in the meshpoint coordinate data is the distance along the computing station from the hub to the interception of the streamline with the station (L), and the station lean angle (GAMA). Where the radius of curvature of a streamline is shown as zero, the streamline has no curvature. The whirl angle is defined by

$$\tan \alpha = \frac{V_\theta}{V_m} \tag{1}$$

For stations within a blade, or at a blade trailing edge, a relative total pressure loss coefficient is shown. The loss of relative total pressure is computed from the station defined by the input variable NL1. If a loss coefficient was used in the input for the station (NLOSS = 1 or 4, or NWORK = 7), the input variable NL2 defines the station where the normalizing relative dynamic head is taken; otherwise, it is taken at the station defined by NL1. If the cascade solidity is given as anything but zero, it is used in the determination of diffusion factors. The following definition is used:

$$D = 1 - \frac{V_{2r}}{V_{1r}} + \frac{V_{\theta_{1r}} \quad V_{\theta_{2r}}}{2\sigma V_{1r}} \tag{2}$$

Inlet conditions (subscript 1) are taken from the station defined by the input variable NL1.

The last term in Equation 2 is multiplied by -1 if the blade speed is greater than zero, or the blade speed is zero and the preceding rotating blade row has negative rotation. This is necessary because relative whirl angles are (generally) negative for rotor blades and for stator blades that follow a rotor having "negative" wheel speed. Incidence and deviation angles are treated in the same way, so that positive and negative values have their conventional significance for all blades.

If annulus wall boundary layer computations were made (NBL = 1), details are shown for each station. Then, an overall result is given, including a statement of the number of passes that have been performed and whether the calculation is converged, unconverged, or failed. When the calculation is unconverged, the number of mesh points where the meridional velocity component has not remained constant to within the specified tolerance (TOLNCE) on the last two passes is shown as IVFAIL. Similarily, the number of streamtubes, defined by the hub and each streamline in turn, where the fraction of the flow is not within the same tolerance of the target value is shown as IFFAIL. If these numbers are small, say less than 10% of the maximum possible values, the results may generally be used. Otherwise, the computation should be rerun, either for a greater number of passes, or with modified relaxation factor constants. The default option relaxation constants will generally be satisfactory but may need modification for some cases. If insufficient damping is specified by the constants, the streamlines generated will tend to oscillate and this may be detected by observing a relatively small radius of curvature for the mid-passage streamline that also changes sign from one station to the next. This may be corrected by rerunning the problem (from scratch) with a lower value input for RCONST, say, of 4.0 instead of 6.0. When the damping is excessive, the velocities will tend to remain constant while the streamlines will not adjust rapidly to the correct locations. This will be indicated by a small IVFAIL and a relatively large IFFAIL. For optimum program performance, RCONST should be increased, and the streamline pattern generated thus far could be used as a starting point. The second constant XMMAX (the maximum value of the square of Mach number used in the relaxation factor) is incorporated so that in high subsonic or supersonic cases the damping does not decrease unacceptably. The default value of 0.6 may be too low for rapid program convergence in some such cases.

If the generation of blade pressure load data for the NASTRAN program is specified (by the input variable NOUT3), a self-explanatory printout is also made. The blade element numbering scheme is the same as that incorporated into both blading sections of the program, and illustrated in Figure 1.

If the loss coefficient re-estimation routine has been used for any bladerow(s) (NEVAL $\neq$ 0), a printout summarizing the computations made will follow. A heading indicating whether the re-estimation was incorporated into the overall iterative procedure or whether it was merely made "after the event" is first printed. Then follows a self-explanatory tabulation of various quantities involved in the redetermination of the loss coefficient on each streamline.

b. Diagnostic Printed Output

The various diagnostic messages that may be produced by the aerodynamic section of the program are all shown. Where a computed value will occur, "x" is shown here.

JOB STOPPED - TOO MUCH INPUT DATA

The above message will occur if the sum of NSPEC or NDATA or NDEL for all stations is above the permitted limit. Execution ceases.

STATIC ENTHALPY BELOW LIMIT AT xxx.xxxxxExxx

The output routine (subroutine UD0311) calculates static enthalpy at each meshpoint when computing the various output parameters and this message will occur if a value below the limit (HMIN) occurs. The limiting value will be used, and the results printed become correspondingly arbitrary. HMIN is set in the Program UD03AR and should be maintained at some positive value well below any value that will be validly encountered in calculation.

PASSxxx STATIONxxx STREAMLINExxx PRANDTL-MEYER
FUNCTION NOT CONVERGED - USE INLET MACH NO

The loss coefficient re-estimation procedure involves iteratively solving for the Mach number in the Prandtl-Meyer function. If the calculation does not converge in 20 attempts, the above message is printed, and as indicated, the Mach number following the expansion (or compression) is assumed to equal the inlet value. (The routine only prints output following the completion of all computations and printing of the station-by-station output data.)

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
MERIDIONAL VELOCITY UNCONVERGED VM = xx.xxxxxxExx
VM(OLD) = xx.xxxxxxExx

For "analysis" cases, that is at stations where relative flow angle is specified, the calculation of meridional velocity proceeds iteratively at each meshpoint from the mid-streamline to the case and then to the hub. The variable LPMAX (set to 10 in Subroutines UD0308 and UD0326) limits the maximum number of iterations that may be made at a streamline without the velocity being converged before the calculation proceeds to the next streamline. The above message will occur if all iterations are used without achieving convergence, and the pass number is greater than NFORCE. Convergence is here defined as occurring when the velocity repeats to within TOLNCE/5.0, applied nondimensionally. No other program action occurs.

PASSxxx STATIONxxx MOMENTUM AND/OR CONTINUITY UNCONVERGED W/W SPEC = xx.xxxxx VM/VM (OLD) HUB = xx.xxxxxMID=xx.xxxxx TIP = xx.xxxxx

If, following completion of all ITMAX iterations permitted for the flow rate or meridional velocity, the simultaneous solution of the momentum and continuity equations profile is unconverged, and the pass number is greater than NFORCE, the above message occurs. Here converged means that the flow rate equals the specified value, and the meridional velocity repeats, to within TOLNCE/5.0, applied nondimensionally. If loss coefficient re-estimation is specified (NEVAL > 0), an additional iteration is involved, and the tolerance is halved. No further program action occurs.

PASSxxx STATIONxxx VM PROFILE NOT CONVERGED WITH LOSS RECALC VM NEW/VM PREV HUB = xx.xxxxxx MID = xx.xxxxxx CASE = xx.xxxxxx

When loss re-estimation is specified (NEVAL > 0), up to NLITER solutions to the momentum and continuity equations are completed, each with a revised loss coefficient variation. If, when the pass number is greater than NFORCE, the velocity profile is not converged after the NLITER cycles of calculation have been performed, the above message is issued. For convergence, the meridional velocities must repeat to within TOLNCE/5.0, applied nondimensionally. No further program action occurs.

A further check on the convergence of this procedure is to compare the loss coefficients used on the final pass of calculation, and thus shown in the station-by-station results, with those shown in the output from the loss coefficient re-estimation routine, which are computed from the final velocities, etc.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx STATIC ENTHALPY BELOW LIMIT IN MOMENTUM EQUATION AT xxx. xxxxxExxx

The static enthalpy is calculated (to find the static temperature) during computation of the "design" case momentum equation, that is, when whirl velocity is specified. If a value lower than HMIN (see discussion of second diagnostic message) is produced, the limiting value is inserted. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx LOOPxxx STATIC H IN MOMENTUM EQUN. BELOW LIMIT AT xxx. xxxxxExxx

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur on the final iteration and loop.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx MERIDIONAL MACH NUMBER ABOVE LIMIT AT xxx. xxxxxExx

When Subroutine UD0308 is selected (NEQN = 0 or 1), the meridional Mach number is calculated during computation of the design momentum equation, and a maximum value of 0. 99 is permitted. If a higher value is calculated, the limiting value is inserted. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx LOOPxxx MERIDIONAL MACH NUMBER ABOVE LIMIT AT xxx. xxxxxExxx

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur at the final iteration and loop.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx MOMENTUM EQUATION EXPONENT ABOVE LIMIT AT xxx. xxxxxExxx

An exponentiation is performed during the computation of the design case momentum equation, and the maximum value of the exponent is limited to 88. 0. If this substitution is required when IPASS > NFORCE, the above message is printed. If it occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONSxxx STREAMLINExxx (MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT xxx.xxxxxExxx.

If a meridional velocity, squared, of less than 1.0 is calculated during computation of the design-case momentum equation, this limit is imposed. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed out through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx LOOPxxx (MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT xxx.xxxxxExxx.

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur on the last iteration and loop.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx STATIC ENTHALPY BELOW LIMIT IN CONTINUITY EQUATION AT xxx.xxxxxExxx.

The static enthalpy is calculated during computation of the continuity equation. If a value lower than HMIN (see discussion of second diagnostic message) is produced, the limiting value is imposed. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed out through to this station.

PASSxxx STATIONxx ITERATIONxxx STREAMLINExxx MERIDIONAL VELOCITY BELOW LIMIT IN CONTINUITY AT xxx.xxxxxExxx.

If a meridional velocity of less than 1.0 is calculated when the velocity profile is incremented by the amount estimated to be required to satisfy continuity, this limit is imposed. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx OTHER CONTINUITY EQUATION BRANCH REQUIRED

If when IPASS>NFORCE, a velocity profile is produced that corresponds to a subsonic solution to the continuity equation when a supersonic solution is required, or vice versa, the above message is printed. If this occurs on the final iteration, failure is deemed to have occurred, calculation ceases, and results are printed out through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
MERIDIONAL VELOCITY GREATER THAN TWICE MID VALUE

During integration of the "design" momentum equations, no meridional velocity is permitted to be greater than twice the value on the mid-streamline. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station. In the event that this limit interferes with a valid velocity profile, the constants that appear on cards 08. 272, 08. 279, 26. 229, and 26. 236 may be modified accordingly. Note that as the calculation is at this point working with the square of the meridional velocity, the constant for a limit of 2. 0 times the mid-streamline value, for instance, appears as 4. 0.

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
LOOPxxx MERIDIONAL VELOCITY ABOVE LIMIT xxxxxExx
LIMIT = xxxxxExx.

During integration of the "analysis" momentum equations, no meridional velocity is permitted to be greater than three times the value on the mid-streamline. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final loop of the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station. In the event that the limit interferes with a valid velocity profile, the constants that appear on cards 08. 398, 08. 409, 26. 323, 26. 334, and 26. 329 may be modified accordingly. In each case except that of the last card noted, the program is working with meridional velocity squared, so that a limit of, for instance, 3. 0 times the mid-streamline value appears as 9. 0.

PASSxxx STATIONxxx STREAMLINExxx LIMITING MERIDIONAL
VELOCITY SQUARED = xxxxxExx.

In the Subroutine UD0308 (NEQN= 0 or 1), a maximum permissable meridional velocity (equal to the speed of sound) is established for each streamline at the beginning of each pass. The calculation yields the square of the velocity, and if a value of less than 1. 0 is obtained, a value of 6250000. 0 is superimposed (which corresponds to a meridional velocity of 2500. 0). If this occurs when IPASS >NFORCE, the above message is printed, and the calculation is deemed to have failed. Calculation ceases after the station computations are made, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx MERIDIONAL VELOCITY ABOVE SOUND SPEED VM = xxxx.xx A = xxxx.xx.

In Subroutine UD0308 (NEQN = 0 or 1), no meridional velocity is permitted to be larger than the speed of sound. The above message will occur if this limit is violated during integration of the "design" momentum when IPASS > NFORCE. If the limit is violated at any point when IPASS > NFORCE and on the last permitted iteration (last permitted loop also in the case of the "analysis" momentum equation), the calculation is deemed to have failed. Calculation ceases, and the results are printed through to this station.

MIXING CALCULATION FAILURE NO. n

The above message occurs when flow mixing calculations are specified, and the computation fails. The overall calculation is halted, and results are printed through to the station that is the upstream boundary for the mixing interval in which the failure occurred. The integer n takes on different values to indicate the specific problems as follows.

n = 1 — In solving for the static pressure distribution at the upstream boundary of each mixing step, the average static enthalpy is determined in each streamtube (defined by an adjacent pair of streamlines). This failure indicates that a value less than HMIN was determined.

n = 2 — Calculation of the static pressure distribution at the upstream boundary of the mixing step is iterative. This failure indicates that the procedure was not converged after 10 iterations.

n = 3 — The static enthalpy on each streamline at the mixing step upstream boundary is determined from the static pressure and entropy there. This failure indicates that a value less than HMIN was determined.

n = 4 — The axial velocity distribution at the mixing step upstream boundary is determined from the total enthalpy, static enthalpy, and tangential velocity distributions. This failure indicates that a value less than VMIN was determined.

n = 5 — In solving for the static pressure distribution at the downstream boundary of each mixing step, the average static enthalpy is determined in each streamtube (defined by an adjacent pair of streamlines). This failure indicates that a value less than HMIN was determined.

n = 6 — Calculation of the static pressure distribution at the downstream boundary of the mixing step is iterative. This failure indicates that the procedure was not converged after 10 iterations.

n = 7 — The static enthalpy distribution at the mixing step downstream boundary is found from the total enthalpy, axial velocity, and tangential velocity distributions. This failure indicates that a value less than HMIN was determined.

n = 8 — In order to satisfy continuity, the static pressure level at the mixing step downstream boundary is iteratively determined. This failure indicates that after 15 attempts, the procedure was unconverged.

c. Aerodynamic Load and Temperature Output

Four output options may result in cards being produced by the aerodynamic section of the program. Use of the input item NOUT3 gives "PLOAD2 and Temperature - Cards" punched in a format compatible with the NASTRAN stress program. For the purposes of stress analysis, the blade is taken to be composed of a number of triangular elements. Two such elements are formed by the quadrilateral defined by two adjacent streamlines and two adjacent computing stations. The way that each quadrilateral is divided into two triangles, and the element numbering scheme that is used, are illustrated in Figure 1, The pressure difference for each element is given by an average of either three or four values at surrounding meshpoints. The pressure difference at each meshpoint is computed from the equation

$$\Delta p = \frac{2\pi r \rho}{N} \left\{ \sin\beta \cos\beta \, g J t \frac{dS}{dm} + \frac{V_m}{r} \frac{d}{dm}(rV_\theta) \right\} \qquad (3)$$

and as follows. At the blade leading edge a forward difference is used to determine the meridional gradients. At the blade trailing edge the pressure difference is taken to be zero. At stations with the bladerow (following a leading edge), mean central differences are used to determine the meridional gradients. When the input item NBLADE is positive (or zero) for a particular blade axial segment, then three-point averaging is used. For instance, for element number 1 in Figure 1, pressure differences at grid points 1, 6, and 7 would be used. If NBLADE is negative, four-point averaging is used. For instance for element number 1, pressure differences at grid points 1, 2, 6 and 7 would be used. The same average would also apply to element number 2. Relative total temperatures are output at the grid points on the blade. A TEMPD value is also output using the average temperature at the blade root for the grid points on the rest of the structure.

1.15.4 Sample Problem

To be written

USER'S MANUAL UPDATES

1.15.4 Sample Problem

The Static Aerothermoelastic Design/Analysis procedure for the bladed disc of an axial flow compressor rotor is illustrated by this sample problem. As explained in Section 1.15.3 the Design and Analysis steps are carried out only at the design operating point of the compressor bladed disc - the "as manufactured" structure being only "analyzed" at off-design operating points. The Design or Analysis mode of the Displacement Rigid Format 16 is selected by the PARAMETER SIGN. The present example uses the Design mode (SIGN = -1) of the rigid format.

The finite element model of a sector of the bladed disc is shown in Figure 1. The blade grid is specified in the Basic coordinate system located on the axis of rotation as shown in the figure. The hub is specified in a cylindrical coordinate system with the origin and the z-axis respectively coincident with the origin and the x-axis of the Basic system. A schematic of the aerodynamic model used is shown in Figure 2 wherein the aerodynamic mesh is generated by the intersection of 4 streamlines and 5 computing stations, three of which lie on the blade. Two additional computing stations have been used for the aerodynamic section (see Section 1.15.3.1), one each upstream and downstream of the blade to enable flow description in these regions. The NASTRAN deck for the use of the rigid format is listed in Figure 3.

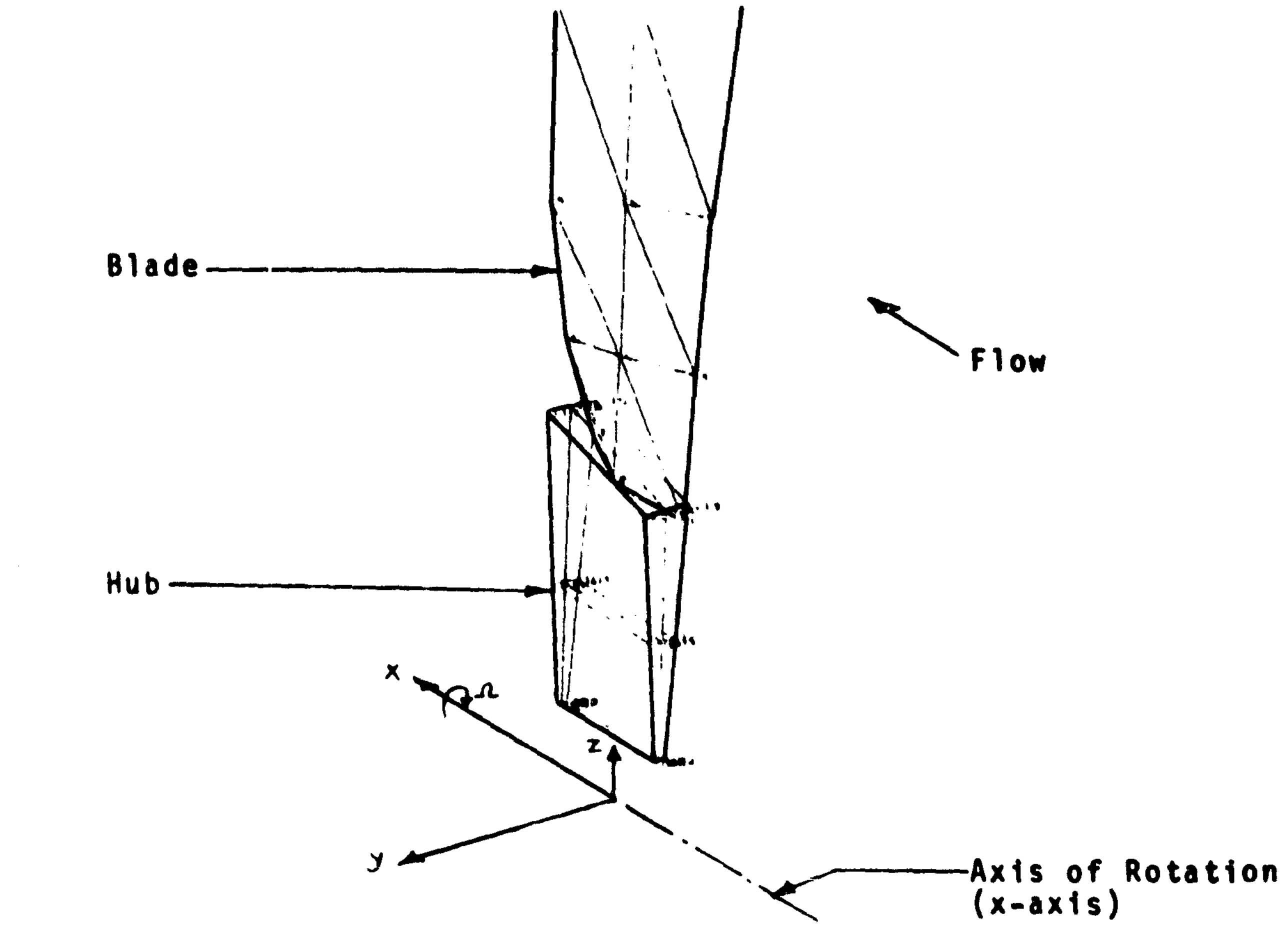


Figure 1. Finite Element Model of an Axial Flow Compressor Bladed Disc Sector, and the Basic Coordinate System

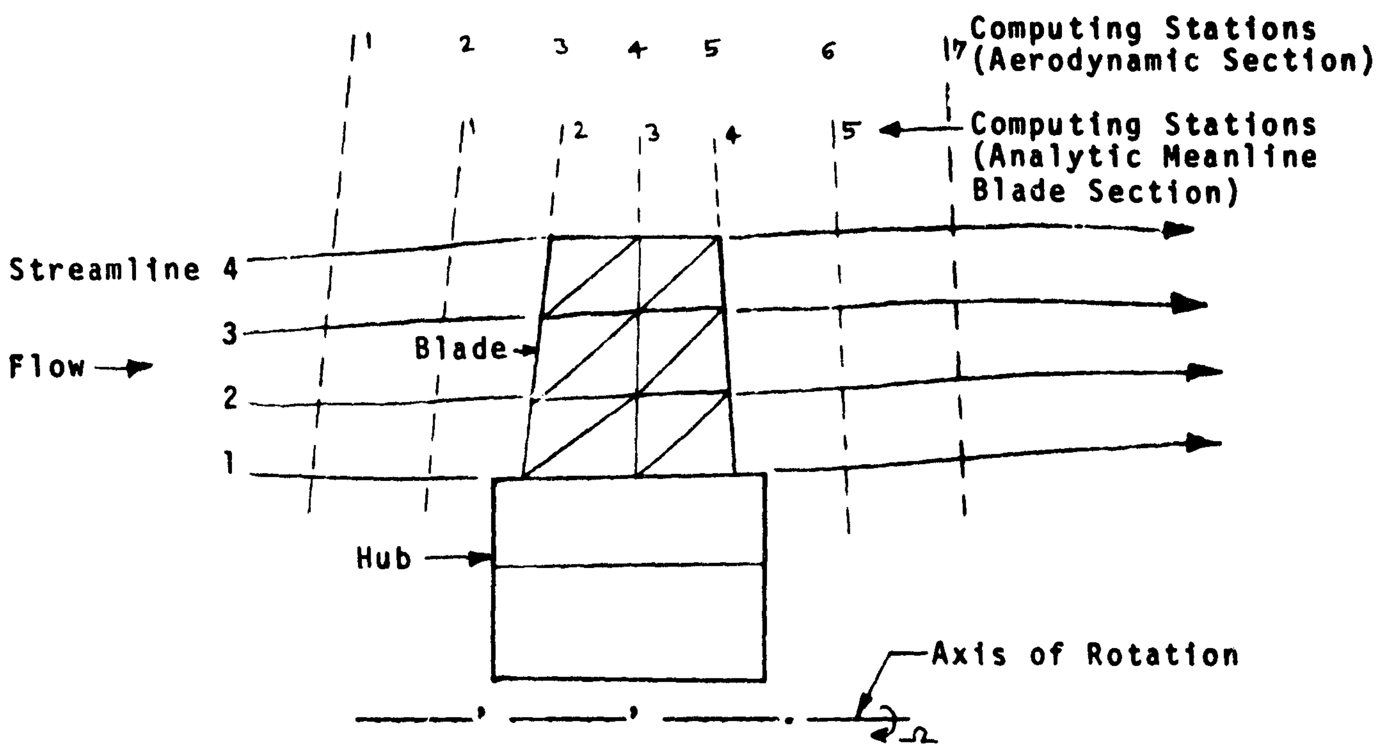


Figure 2. Aerodynamic Grid (See Section 1.15.3, User's Manual)

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

```
ID    NASA , LEWIS
APP   DISPLACEMENT
SOL  16
TIME 10
DIAG 14
CEND
```

Figure 3. NASTRAN deck for Static Aerothermoelastic Design/Analysis

DESIGN OF BLADE

```
                              C A S E   C O N T R O L   D E C K   E C H O
CARD
COUNT
  1      TITLE = NASA LEWIS, BLADED SHROUDED DISK ANALYSIS
  2      SUBTITLE = EXAMPLE SINGLE-STAGE DESIGN OF ROTOR BLADE
  3      LABEL = DESIGN OF BLADE
  4      SPC = 500
  5      MPC = 600
  6      LOAD = 1
  7      DISP = ALL
  8      SPCF = ALL
  9      OLOAD = ALL
 10      STRESS = ALL
 11      FORCE  = ALL
 12      SUBCASE 1
 13      LABEL = LINEAR SOLUTION OF ROTOR BLADE
 14      SUBCASE 2
 15      LABEL = NONLINEAR SOLUTION OF ROTOR BLADE
 16      GPFORCE=ALL
 17      OUTPUT(PLOT)
 18      PLOTTER NASTPLT, MODEL D,1
 19      PAPER SIZE 12.0 X 11.5
 20      SET 1 = ALL
 21      ORTHOGRAPHIC PROJECTION
 22      MAXIMUM DEFORMATION 0.5
 23      AXES X,Y,Z
 24      VIEW 0.0,0.0,0.0
 25      FIND SCALE, ORIGIN 1, SET 1
 26      PLOT SET 1, ORIGIN 1, LABEL
 27      AXES Y,Z,X
 28      FIND SCALE, ORIGIN 2, SET 1
 29      PLOT SET 1, ORIGIN 2, LABEL
 30      AXES Z,X,Y
 31      FIND SCALE, ORIGIN 3, SET 1
 32      PLOT SET 1, ORIGIN 3, LABEL
 33      AXES X,Y,Z
 34      VIEW 34.27,23.17,0.0
 35      FIND SCALE, ORIGIN 4, SET 1
 36      PLOT STATIC DEFORMATION 0,   SET 1, ORIGIN 4, LABEL
 37      AXES Z,X,Y
 38      VIEW 0.0,0.0,0.0
 39      FIND SCALE, ORIGIN 5, SET 1
 40      PLOT STATIC DEFORMATION 0,   SET 1, ORIGIN 5, LABEL
 41      BEGIN BULK
```

* USER INFORMATION MESSAGE 207, BULK DATA NOT SORTED,XSORT WILL RE-ORDER DECK.

DESIGN OF BLADE

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

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
1-	CHEXA1	201	1	101	103	104	108	113	115	&CH1
2-	&CH1	116	120							
3-	CHEXA1	202	1	108	104	105	107	120	116	&CH2
4-	&CH2	117	119							
5-	CHEXA1	203	1	121	123	124	128	101	103	&CH3
6-	&CH3	104	108							
7-	CHEXA1	204	1	128	124	125	127	108	104	&CH4
8-	&CH4	105	107							
9-	CORD2C	1		0.0	0.0	0.0	1.0	0.0	0.0	&CD1
10-	&CD1	0.	0.	1.						
11-	CTRIA2	1	2000	1	5	4				
12-	CTRIA2	2	2000	1	2	5				
13-	CTRIA2	3	2005	2	6	5				
14-	CTRIA2	4	2005	2	3	6				
15-	CTRIA2	5	2010	4	8	7				
16-	CTRIA2	6	2010	4	5	8				
17-	CTRIA2	7	2015	5	9	8				
18-	CTRIA2	8	2015	5	6	9				
19-	CTRIA2	9	2020	7	11	10				
20-	CTRIA2	10	2020	7	8	11				
21-	CTRIA2	11	2025	8	12	11				
22-	CTRIA2	12	2025	8	9	12				
23-	DTI	ALGDB	0	0	0	0	0	0	0	&ALG01
24-	&ALG01	ENDREC								
25-	DTI	ALGDB	1	NASA LEWIS EXPERIMENTAL FAN				ENDREC		
26-	DTI	ALGDB	2	1	1	0	0	ENDREC		
27-	DTI	ALGDB	3	GRID GENERATION		ENDREC				
28-	DTI	ALGDB	4	4	5	3	4	30	43	&ALG41
29-	&ALG41	2	0	2	1	0	3	0	0	&ALG42
30-	&ALG42	2	4	1	ENDREC					
31-	DTI	ALGDB	5	4.384	10.0	1.0	.0	11.0	ENDREC	
32-	DTI	ALGDB	6	2	0	ENDREC				
33-	DTI	ALGDB	7	-2.0	3.60	ENDREC				
34-	DTI	ALGDB	8	-2.0	10.04	ENDREC				
35-	DTI	ALGDB	9	3.6	.0	ENDREC				
36-	DTI	ALGDB	10	5.5	.0	ENDREC				
37-	DTI	ALGDB	11	7.4	.0	ENDREC				
38-	DTI	ALGDB	12	10.04	.0	ENDREC				
39-	DTI	ALGDB	13	4	1	ENDREC				
40-	DTI	ALGDB	14	-.898	3.8	ENDREC				
41-	DTI	ALGDB	15	-.763	5.5	ENDREC				
42-	DTI	ALGDB	16	-.629	7.4	ENDREC				
43-	DTI	ALGDB	17	-.424	10.0	ENDREC				
44-	DTI	ALGDB	18	3.8	.0	ENDREC				
45-	DTI	ALGDB	19	5.5	.0	ENDREC				
46-	DTI	ALGDB	20	7.4	.0	ENDREC				
47-	DTI	ALGDB	21	10.	.0	ENDREC				
48-	DTI	ALGDB	22	4	1	ENDREC				

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

CARD COUNT	1	2	3	4	5	6	7	8	9	10
51-	DTI	ALGDB	25	.0	7.4	ENDREC				
52-	DTI	ALGDB	26	.0	10.	ENDREC				
53-	DTI	ALGDB	27	4.0	.0	ENDREC				
54-	DTI	ALGDB	28	5.5	.0	ENDREC				
55-	DTI	ALGDB	29	7.4	.0	ENDREC				
56-	DTI	ALGDB	30	10.	.0	ENDREC				
57-	DTI	ALGDB	31	4	1	ENDREC				
58-	DTI	ALGDB	32	.898	4.2	ENDREC				
59-	DTI	ALGDB	33	.780	5.5	ENDREC				
60-	DTI	ALGDB	34	.629	7.4	ENDREC				
61-	DTI	ALGDB	35	.424	10.	ENDREC				
62-	DTI	ALGDB	36	4.2	.0	ENDREC				
63-	DTI	ALGDB	37	5.5	.0	ENDREC				
64-	DTI	ALGDB	38	7.4	.0	ENDREC				
65-	DTI	ALGDB	39	10.	.0	ENDREC				
66-	DTI	ALGDB	40	2	0	ENDREC				
67-	DTI	ALGDB	41	2.0	4.4	ENDREC				
68-	DTI	ALGDB	42	2.0	10.04	ENDREC				
69-	DTI	ALGDB	43	4.4	.0	ENDREC				
70-	DTI	ALGDB	44	5.5	.0	ENDREC				
71-	DTI	ALGDB	45	7.4	.0	ENDREC				
72-	DTI	ALGDB	46	10.04	.0	ENDREC				
73-	DTI	ALGDB	47	1.0	-38.1	32.0	.0	.0	.01615	$ALG471
74-	$ALG471	ENDREC								
75-	DTI	ALGDB	48	.0980	.01559	.56	1.796	.04722	-.02302	$ALG481
76-	$ALG481	ENDREC								
77-	DTI	ALGDB	49	2.0	-45.0	-4.6	.0	.0	.01243	$ALG491
78-	$ALG491	ENDREC								
79-	DTI	ALGDB	50	.0735	.01351	.54	1.851	.00722	-.02946	$ALG501
80-	$ALG501	ENDREC								
81-	DTI	ALGDB	51	3.0	-53.2	-42.0	.0	.0	.00912	$ALG511
82-	$ALG511	ENDREC								
83-	DTI	ALGDB	52	.036	.00566	.49	1.864	.00077	-.00689	$ALG521
84-	$ALG521	ENDREC								
85-	DTI	ALGDB	53	4.0	-66.5	-59.6	.0	.0	.00482	$ALG531
86-	$ALG531	ENDREC								
87-	DTI	ALGDB	54	.0268	.00429	.48	1.863	-.02667	.01423	$ALG541
88-	$ALG541	ENDREC								
89-	DTI	ALGDB	55	1	5	1	2	2	4	$ALG551
90-	$ALG551	ENDREC								
91-	DTI	ALGDB	56	1.0	16342.8	ENDREC				
92-	DTI	ALGDB	57	0	0	10	ENDREC			
93-	DTI	ALGDB	58	1	0	0	4	-1	-1	$ALG581
94-	$ALG581	0	1	0	0	0	0	0	-43	$ALG582
95-	$ALG582	ENDREC								
96-	DTI	ALGDB	59	.0	.0	ENDREC				
97-	DTI	ALGDB	60	8	0	0	1	-2	-2	$ALG601
98-	$ALG601	-1	0	0	2	0	0	20	-43	$ALG602
99-	$ALG602	ENDREC								
100-	DTI	ALGDB	61	4.20	.05	ENDREC				

DESIGN OF BLADE

SORTED BULK DATA ECHO

```
CARD
COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
 101-    DTI       ALGDB    62    4.62      .05       ENDREC
 102-    DTI       ALGDB    63    5.50      .05       ENDREC
 103-    DTI       ALGDB    64    6.50      .05       ENDREC
 104-    DTI       ALGDB    65    7.400     .05       ENDREC
 105-    DTI       ALGDB    66    8.400     .05       ENDREC
 106-    DTI       ALGDB    67    9.500     .05       ENDREC
 107-    DTI       ALGDB    68    10.00     .05       ENDREC
 108-    DTI       ALGDB    69    .0        ENDREC
 109-    DTI       ALGDB    70    .00       .00       ENDREC
 110-    DTI       ALGDB    71    .25       .25       ENDREC
 111-    DTI       ALGDB    72    .50       .50       ENDREC
 112-    DTI       ALGDB    73    .75       .75       ENDREC
 113-    DTI       ALGDB    74    1.00      1.00      ENDREC
 114-    DTI       ALGDB    75    .0        .0        .5        ENDREC
 115-    DTI       ALGDB    76    AERODYNAMIC ANALYSIS OF NASA LEWIS BLADEENDREC
 116-    DTI       ALGDB    77    .0        .0        .0        .0        ENDREC
 117-    DTI       ALGDB    78    7         4         0         40        0         0         &ALG781
 118-    &ALG781   0        1     1         0         0         0         0         0         &ALG782
 119-    &ALG782   0        3     0         0         3         5         1         ENDREC
 120-    DTI       ALGDB    79    3         4         5         ENDREC
 121-    DTI       ALGDB    80    .0        .0        .0        .001      ENDREC
 122-    DTI       ALGDB    81    1.0       1.0       4.0       .0        .7        8.0       &ALG811
 123-    &ALG811   ENDREC
 124-    DTI       ALGDB    82    .0        .0        ENDREC
 125-    DTI       ALGDB    83    73.146    1.0       ENDREC
 126-    DTI       ALGDB    84    2         ENDREC
 127-    DTI       ALGDB    85    -4.0      3.25      ENDREC
 128-    DTI       ALGDB    86    -4.0      10.04     ENDREC
 129-    DTI       ALGDB    87    2         ENDREC
 130-    DTI       ALGDB    88    -2.0      3.6       ENDREC
 131-    DTI       ALGDB    89    -2.0      10.04     ENDREC
 132-    DTI       ALGDB    90    4         ENDREC
 133-    DTI       ALGDB    91    -.898     3.5       ENDREC
 134-    DTI       ALGDB    92    -.763     5.5       ENDREC
 135-    DTI       ALGDB    93    -.629     7.4       ENDREC
 136-    DTI       ALGDB    94    -.424     10.0      ENDREC
 137-    DTI       ALGDB    95    4         ENDREC
 138-    DTI       ALGDB    96    .0        4.0       ENDREC
 139-    DTI       ALGDB    97    .0        5.5       ENDREC
 140-    DTI       ALGDB    98    .0        7.4       ENDREC
 141-    DTI       ALGDB    99    .0        10.0      ENDREC
 142-    DTI       ALGDB    100   4         ENDREC
 143-    DTI       ALGDB    101   .898      4.2       ENDREC
 144-    DTI       ALGDB    102   .780      5.5       ENDREC
 145-    DTI       ALGDB    103   .629      7.4       ENDREC
 146-    DTI       ALGDB    104   .424      10.0      ENDREC
 147-    DTI       ALGDB    105   2         ENDREC
 148-    DTI       ALGDB    106   2.0       4.4       ENDREC
 [illegible] DTI   ALGDB    107   2.0       [illegible] ENDREC
```

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
151-	DTI	ALGDB	109	4.0	4.75	ENDREC				
152-	DTI	ALGDB	110	4.0	10.04	ENDREC				
153-	DTI	ALGDB	111	1	ENDREC					
154-	DTI	ALGDB	112	3.25	14.7	518.7	.0	ENDREC		
155-	DTI	ALGDB	113	0	ENDREC					
156-	DTI	ALGDB	114	4.0	.0	ENDREC				
157-	DTI	ALGDB	115	10.0	1.0	ENDREC				
158-	DTI	ALGDB	116	0	ENDREC					
159-	DTI	ALGDB	117	0	ENDREC					
160-	DTI	ALGDB	118	.0	ENDREC					
161-	DTI	ALGDB	119	.0	ENDREC					
162-	DTI	ALGDB	120	.0	ENDREC					
163-	DTI	ALGDB	121	.0	ENDREC					
164-	DTI	ALGDB	122	.0	ENDREC					
165-	DTI	ALGDB	123	.0	ENDREC					
166-	DTI	ALGDB	124	.0	ENDREC					
167-	DTI	ALGDB	125	6	ENDREC					
168-	DTI	ALGDB	126	.0	.006	.006	.006	ENDREC		
169-	DTI	ALGDB	127	.2	.007	.007	.007	ENDREC		
170-	DTI	ALGDB	128	.4	.014	.014	.014	ENDREC		
171-	DTI	ALGDB	129	.6	.030	.031	.031	ENDREC		
172-	DTI	ALGDB	130	.8	.060	.060	.060	ENDREC		
173-	DTI	ALGDB	131	1.0	.125	.125	.125	ENDREC		
174-	DTI	ALGDB	132	2	1	ENDREC				
175-	DTI	ALGDB	133	.0	ENDREC					
176-	DTI	ALGDB	134	.0	ENDREC					
177-	DTI	ALGDB	135	1.0	ENDREC					
178-	GRID	1		-0.8980	-0.2732	3.7502				
179-	GRID	2		.0	.0532	3.9556				
180-	GRID	3		.8980	-0.2459	4.1926				
181-	GRID	4		-0.7630	-0.5004	5.4772				
182-	GRID	5		.0	.0209	5.5000				
183-	GRID	6		.7800	.2342	5.4950				
184-	GRID	7		-0.6290	-0.7494	7.3620				
185-	GRID	8		.0	.0131	7.4000				
186-	GRID	9		.6290	.6369	7.3725				
187-	GRID	10		-0.4240	-0.9230	9.9564				
188-	GRID	11		.0	-0.0221	10.0000				
189-	GRID	12		.4240	.7558	9.9711				
190-	GRID	101	1	2.375	4.186	-0.587	1			
191-	GRID	103	1	2.375	4.186	.587	1			
192-	GRID	104	1	2.375	.0	.587	1			
193-	GRID	105	1	2.375	-4.186	.587	1			
194-	GRID	107	1	2.375	-4.186	-0.587	1			
195-	GRID	108	1	2.375	.0	-0.587	1			
196-	GRID	113	1	3.982	4.186	-0.587	1			
197-	GRID	115	1	4.539	4.186	.587	1			
198-	GRID	116	1	4.539	.0	.587				
199-	GRID	117	1	4.539	-4.186	.587	1			
200-	GRID	119	1	3.992	-4.186	-0.587	1			

DESIGN OF BLADE

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
201-	GRID	120	1	3.982	.0	-0.987				
202-	GRID	121	1	.905	4.186	-0.987	1			
203-	GRID	123	1	.905	4.186	.987	1			
204-	GRID	124	1	.905	.0	.987	1			
205-	GRID	125	1	.905	-4.186	.987	1			
206-	GRID	127	1	.905	-4.186	-0.987	1			
207-	GRID	128	1	.905	.0	-0.987	1			
208-	MAT1	1	31.0E6		.3	7.300E-4				
209-	MPC	600	1	1	1.0	2	1	-1.0		
210-	MPC	600	1	2	1.0	2	2	-1.0		
211-	MPC	600	1	3	1.0	2	3	-1.0		
212-	MPC	600	1	4	1.0	2	4	-1.0		
213-	MPC	600	1	5	1.0	2	5	-1.0		
214-	MPC	600	1	6	1.0	2	6	-1.0		
215-	MPC	600	3	1	1.0	2	1	-1.0		
216-	MPC	600	3	2	1.0	2	2	-1.0		
217-	MPC	600	3	3	1.0	2	3	-1.0		
218-	MPC	600	3	4	1.0	2	4	-1.0		
219-	MPC	600	3	5	1.0	2	5	-1.0		
220-	MPC	600	3	6	1.0	2	6	-1.0		
221-	MPC	600	101	1	1.0	107	1	-1.0		
222-	MPC	600	101	2	1.0	107	2	-1.0		
223-	MPC	600	101	3	1.0	107	3	-1.0		
224-	MPC	600	103	1	1.0	105	1	-1.0		
225-	MPC	600	103	2	1.0	105	2	-1.0		
226-	MPC	600	103	3	1.0	105	3	-1.0		
227-	MPC	600	113	1	1.0	119	1	-1.0		
228-	MPC	600	113	2	1.0	119	2	-1.0		
229-	MPC	600	113	3	1.0	119	3	-1.0		
230-	MPC	600	115	1	1.0	117	1	-1.0		
231-	MPC	600	115	2	1.0	117	2	-1.0		
232-	MPC	600	115	3	1.0	117	3	-1.0		
233-	MPC	600	116	1	1.0	2	1	-1.0		
234-	MPC	600	116	2	1.0	2	2	-1.0		
235-	MPC	600	116	3	1.0	2	3	-1.0		
236-	MPC	600	120	1	1.0	2	1	-1.0		
237-	MPC	600	120	2	1.0	2	2	-1.0		
238-	MPC	600	120	3	1.0	2	3	-1.0		
239-	MPC	600	121	1	1.0	127	1	-1.0		
240-	MPC	600	123	1	1.0	125	1	-1.0		
241-	PARAM	APRESS	1							
242-	PARAM	ATEMP	1							
243-	PARAM	FXCOOR	.3							
244-	PARAM	FYCOOR	.3							
245-	PARAM	FZCOOR	.3							
246-	PARAM	IPRTCF	1							
247-	PARAM	IPRTCI	1							
248-	PARAM	IPRTCL	0							
249-	PARAM	PGEOM	3							

```
                                           S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 251-       PARAM   STREAML -1
 252-       PARAM   ZORIGN  .0
 253-       PTRIA2  2000    1       .1040   0.0
 254-       PTRIA2  2005    1       .1040   0.0
 255-       PTRIA2  2010    1       .0707   0.0
 256-       PTRIA2  2015    1       .0707   0.0
 257-       PTRIA2  2020    1       .0422   0.0
 258-       PTRIA2  2025    1       .0422   0.0
 259-       FORCE   1       0       0       267.367 1.0     .0      .0
 260-       SPC1    500     23      121     123     124     125     127     128
 261-       SPC1    500     45      7       10      12
 262-       SPC1    500     456     101     103     104     105     107     108
 263-       SPC1    500     456     113     115     116     117     119     120
 264-       SPC1    500     456     121     123     124     125     127     128
 265-       STREAML1        1       THRU    3
 266-       STREAML12       4       THRU    6
 267-       STREAML13       7       THRU    9
 268-       STREAML14       10      THRU    12
            ENDDATA
```

The Executive Control Deck consists of cards from ID to CEND. SØL 16 and APP Displacement are used for the Steady Ar[illegible]hermoelastic Design/Analysis problem. CPU time (in minutes) is estimated on the TIME card. DIAG (optional) is used to request diagnostic output.

The Case Control Deck is used to select the boundary conditions imposed on, and the loads applied to the structure. [illegible] extent and the form of the output desired is also selected in this deck. In this problem, SPC set 500 is used to restrain the hub-shaft attachment degrees of freedom from moving in the axial and tangential direction. MPC set 600 is used to define the blade-hub attachment and the relative motion of the corresponding grid points on the two sides of the cyclic sector. Two subcases must be defined for this rigid format. Subcase 1 is for the linear solution based on the elastic stiffness while Subcase 2 solution includes the differential stiffness effects. The ØUTPUT (PLØT) packet requests the plots, and is explained in Section 4. of the User's Manual.

The blade is idealized by 12 CTRIA2 plate elements while 4 CHEXA1 solid elements are used to model the hub. The aerodynamic data describing the blade geometry (blade angle, chords, stagger angles etc.) and the operating conditions (flow rate, speed, losses etc.) are specified in the ALGDB data block input via the DTI bulk data cards. The geometry, material and constraint bulk data are as discussed in previous sections of this manual. Parameters APRESS = 1 and ATEMP = 1 enable the inclusion of the aerodynamic pressure and thermal loads. FXCØØR, FYCØØR and FZCØØR parameters each equal to 0.3 indicate that, in this design example, three tenths of the displacements cbtained (both linear and non-linear) are used to redefine the blade geometry. Parameters IPRTCF = 1 and IPRTCI = 1 are used for a detailed printout from the ALG module upon final and initial entries. IPRTCL = 0 requests a summary from the ALG module during the differential stiffness loop (see Section 18 of the Theoretical Manual). PGEØM = 3 causes the GRID, CTRIA2, PTRIA2 and DTI bulk data cards to be punched out during the final pass through the ALG module. These cards represent the final blade geometry and the operating conditions. Parameter STREAML = -1 suppresses the output of STREAML1 and STREAML2 bulk data cards, while ZØRIGN = 0 only is currently permitted. STREAML1 cards identify the grid points defining the blade.

Results are presented in the Demonstration Problems Manual.

1.15.5 Modal, Flutter & Subcritical Roots Analyses

Cyclic symmetric flow is assumed while analyzing the turbomachinery rotor/stator. Due to rotational cyclic symmetry, only one-bladed disc sector is modeled. The harmonic number dependent cyclic normal modal analysis of such structures is described in Section 1.12 of the User's Manual. In the present development, the results of the normal modes analysis using cyclic symmetry have been appropriately integrated with unsteady cascade aerodynamic theories and the existing k-method of modal flutter analysis. The Mach number parameter has been conveniently replaced by the interblade phase angle parameter for blade flutter problems. The discussion that follows is to bring out the features pertinent to bladed disc analysis.

In a compressor or turbine, an operating point implies an equilibrium of flow properties such as density, velocity, Mach number, flow angle, etc., that vary across the blade span. Blade properties like the blade angles, stagger angle, chord, etc., also, in general, change from the blade root to the tip. The resulting spanwise variation in the local reduced frequency and the relative Mach number must be accounted for in estimating the chordwise generalized aerodynamic forces per unit span at each streamline. Integration of these forces over the blade span yields the blade generalized aerodynamic force matrix. In order to nondimensionalize this matrix, the flow and blade properties at a referenced streamline are used. The reference streamline number, IREF, is specified on a PARAM bulk data card.

Since the relative Mach number varies along the blade span, necessitating the use of either the subsonic or supersonic cascade theories, parameters MAXMACH and MINMACH are used respectively to specify the upper and lower limits below and above which the subsonic and supersonic unsteady cascade theories are applicable. For streamlines with relative Mach numbers between the limits MAXMACH and MINMACH, linear interpolation is used. No transonic cascade theories have been incorporated.

It should be noted that for a given interblade phase angle and reference reduced frequency, chordwise generalized aerodynamic matrices corresponding to local spacing, stagger and Mach number at the selected operating point will be generated for each streamline on the blade. This is an expensive operation and should be carefully controlled to reduce the computational work. The aerodynamic matrices are, therefore, computed at a few interblade phase angles and reduced frequencies, and interpolated for others. These parameters are selected on the MKAERO1 and MKAERO2 bulk data cards. Matrix interpolation is an automatic feature of Rigid Format Aero 9. Additional aerodynamic matrices may be generated and appended to the previous group on restart with new MKAERO1 cards, provided the rest of the data used for the matrix calculation remain unaltered.

To save further computational time, the chordwise generalized aerodynamic matrices are first computed for "aerodynamic modes" (see the Theoretical Manual, Section). The aerodynamic matrices for chordwise structural modes are then determined from bilinear transformations along each streamline prior to the spanwise integration to obtain the complete blade generalized aerodynamic matrix. This permits a change in the structural mode shapes of the same or a different harmonic number to be included in the flutter analysis without having to recompute the modal aerodynamic matrices for aerodynamic modes. This can be achieved by appropriate ALTERS to the Rigid Format.

For non-zero harmonic numbers, the normal modes analysis using cyclic symmetry results in both "sine" and "cosine" mode shapes (Section 1.12). The BCD value of the parameter MTYPE on a PARAM bulk data card selects the type of mode shapes to be used in flutter calculations. It is immaterial which is selected.

The method of flutter analysis is specified on the FLUTTER bulk data card. The FLUTTER card is selected by an FMETHØD card. At the present time, only the k-method of flutter analysis is available. This allows looping through three sets of parameters: density ratio (ρ/ρ_{ref}; ρ_{ref} is given on AERØ card); interblade phase angle (σ); and reduced frequency, (k.) For example, if the user specifies two values of each, there will be eight loops in the following order.

LØØP	DENS	σ	RFREQ
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.

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., mph), determined from $V_{out} = V/V_{REF}$. Another use of this parameter is to compute flutter index, by choosing $V_{REF} = b\omega_\theta \sqrt{\mu}$.

If physical output (grid point deflections or element forces, plots, etc.) is desired rather than modal amplitudes, this data recovery can be made upon a user selected subset of the cases. The selection is based upon the velocity; the method is discussed in Section 3.23.3.

1.15.6 Sample Problem

(To be written)

USER'S MANUAL UPDATES

1.15.6 Sample Problem

The problem of determining the complete, unstalled flutter boundaries of a compressor or turbine bladed disc involves each member set of an appropriate whole series of harmonic families of modes of the cyclically symmetric bladed discs, and effects of interblade phase angle, over an adequate set of operating points (flow rates, speeds, pressure ratios, implied Mach numbers, etc.). This sample problem, therefore, is only to illustrate the procedure to obtain typical data leading to the definition of flutter boundaries.

The finite element model of the compressor bladed disc sector is shown in Figure 1. The aerodynamic model (see Section 1.15.2) with 4 streamlines and 3 computing stations is shown in Figure 2. The first four of the zeroth harmonic family of natural modes and frequencies are chosen for flutter investigation via the PARAMeters LMØDES = 4 and KINDEX = 0. Operating point conditions of 73.15 lb m/sec flow rate, 16043 rpm, and 1.84 total pressure ratio are selected so as to demonstrate the use of the total stiffness matrix, for cyclic modal analysis, saved from the Static Aerothermoelastic Analysis at this operating point (see Demonstration Manual examples 9-5-1 and 16-1). For this, the Parameter KGGIN is set equal to 1. The k-method of flutter analysis is used which is the only method currently permitted. The NASTRAN deck used is listed in Figure 3.

The Executive Control Deck, cards ID through CEND, selects the Cyclic Modal Flutter Analysis Rigid Format via the SØL 9 and APP AERØ cards. An estimated CPU TIME of 20 minutes is indicated for this example. The DIAG 14 card is optional and lists the Rigid Format.

The Case Control Deck is used to select constraints, methods and output. In this problem, SPC set 500 is used to constrain the hub-shaft attachment degrees of freedom to move only in the radial direction. MPC set 600 is used to define the blade-hub connection. A METHØD card must select an EIGR bulk data card for real eigenvalue analysis. An FMETHØD card must be used to select a FLUTTER data card for flutter analysis. A CMETHØD card must select an EIGC data card for complex eigenvalue extraction. For a flutter summary printout, the parameter PRINT is set to YESB. The XYPAPERPLØT request shown will plot V-g and V-f split frame "plots" on the printer output. To produce plots, it is necessary to specify a plotter, request a plot tape, and specify XYPAPERPLØT VG. The "curves" refer to the loops of the flutter analysis, and in this example the 9 loops have been arranged with 3 loops to each frame.

The blade and the hub are respectively modeled by 12 CTRIA2 and 4 CHEXA1 elements. The geometry, material and constraint bulk data are as discussed in previous sections of this manual, and there are no special rules for aeroelastic flutter analysis. CYJØIN data card specifies the pairs of corresponding grid points on the two sides of the cyclic sector. INV method of real eigenvalue extraction is selected on an EIGR card wherein five mode shapes and frequencies are requested.

Of these, the first four (Parameter LMØDES = 4) modes are used to form the modal flutter equations. The AERØ bulk data card is used to specify the reference chord and reference density. For bladed disc flutter analysis, the other two parameters on the AERØ card are of no significance. The MKAERØ1 data card causes the aerodynamic matrices to be computed for three inter-blade phase angle-reduced frequency pairs, i.e. ($\sigma = 180^\circ$, $k = 0.3$), (180°, 0.7) and (180°, 1.0).

The FLUTTER bulk data card selects the presently permitted k-method of flutter analysis and refers to the FLFACT cards specifying density ratios, interblade phase angles, and reduced frequencies. The analysis loops through all combinations of densities, interblade phase angles and reduced frequencies, with density on the inner loop and interblade phase angle on the outermost loop. In this example, 3 density ratios, 1 inter-blade phase angle and 3 reduced frequencies (on FLFACT cards) result in (3 x 1 x 3 =) 9 loops. Both linear and surface splines are available for interpolation of aerodynamic matrices to intermediate values of interblade phase angle and reduced frequency. The EIGC card is required and the HESS method is used. The number of complex eigenvectors to be extracted must be specified, and will usually agree with the number of modes saved for output specified on the FLUTTER data card.

For bladed discs, STREAML1 and STREAML2 data cards are required. The grid points on each streamline on the blade are identified on the STREAML1 card. The flow and blade geometry is specified for each streamline on the STREAML2 cards. It should be noted that at least 3 streamlines per blade (including the root and the tip) and 3 grid points per streamline must be selected for cyclic modal flutter analysis.

Results are presented in the Demonstration Problems Manual.

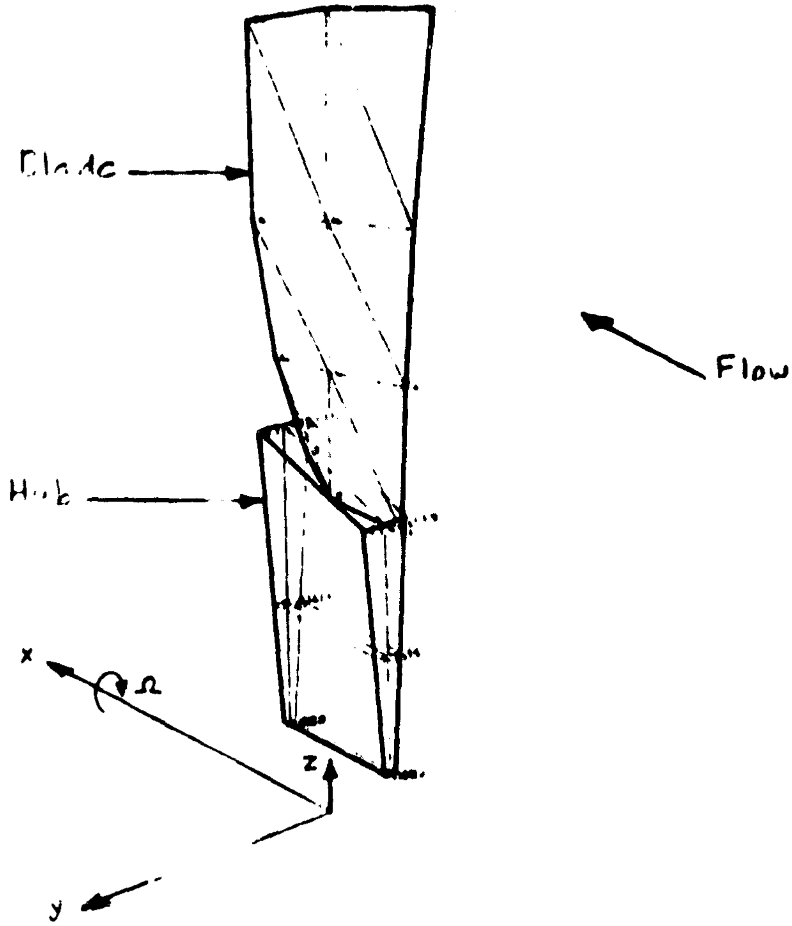


FIGURE 1. FINITE ELEMENT MODEL

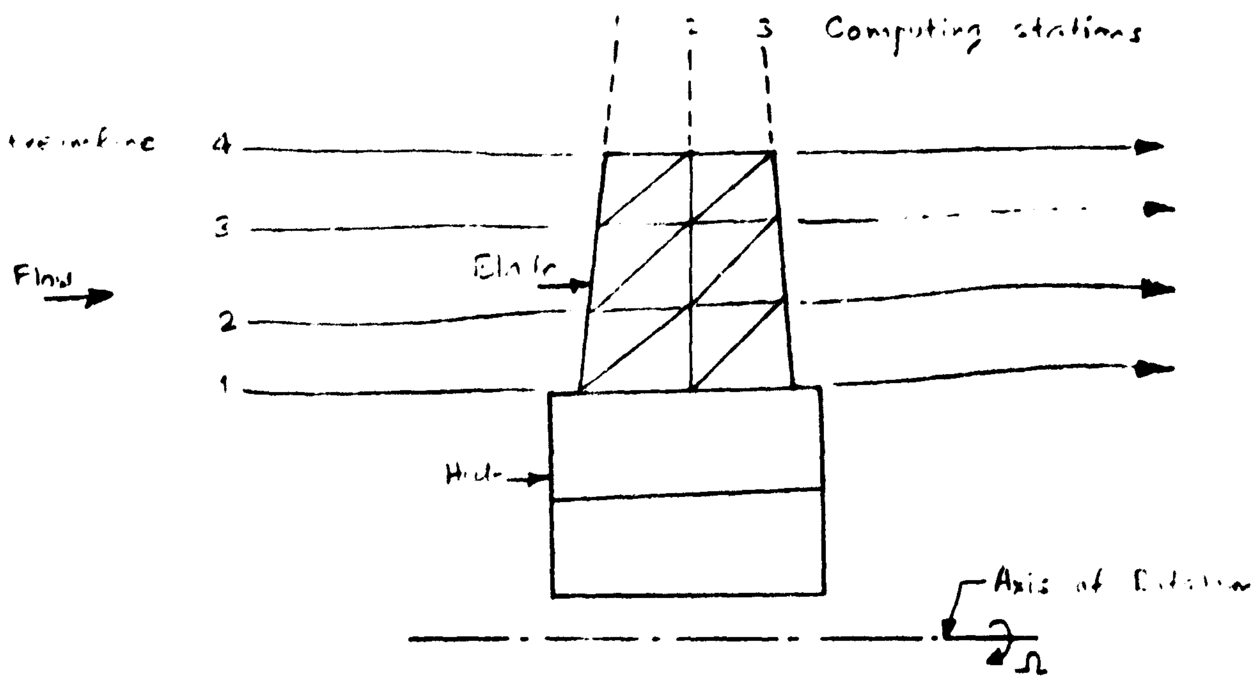


FIGURE 2. AERODYNAMIC MODEL

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

```
ID    NASA , LEWIS
APP   AERO
SOL 9
TIME 20
DIAG 14
CEND
```


Figure 3. NASTRAN DECK FOR CYCLIC MODAL FLUTTER ANALYSIS OF BLADED DISCS

```
                         C A S E   C O N T R O L   D E C K   E C H O
 CARD
 COUNT
   1      TITLE = NASA LEWIS, BLADED SHROUDED DISK ANALYSIS
   2      SUBTITLE = EXAMPLE SINGLE-STAGE DESIGN OF ROTOR BLADE
   3      LABEL = AEROELASTIC FLUTTER ANALYSIS
   4      FMETHOD = 30
   5      SPC = 500
   6      MPC = 600
   7      METHOD = 10
   8      CMETHOD = 20
   9      DISP = ALL
  10      OUTPUT(XYOUT)
  11      XTITLE = VELOCITY-V
  12      YTTITLE = DAMPING-G
  13      YBTITLE = FREQUENCY-F
  14      XYPAPERPLOT VG /1(G,F),4(G,F),7(G,F)/2(G,F),5(G,F),8(G,F)/
  15                     3(G,F),6(G,F),9(G,F)
  16      BEGIN BULK
```

AEROELASTIC FLUTTER ANALYSIS

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
1-	AERO	0	1.384	1.86958	1.507-6					
2-	CHEXA1	201	1	101	103	104	108	113	115	&CH1
3-	&CH1	116	120							
4-	CHEXA1	202	1	108	104	105	107	120	116	&CH2
5-	&CH2	117	119							
6-	CHEXA1	203	1	121	123	124	128	101	103	&CH3
7-	&CH3	104	108							
8-	CHEXA1	204	1	128	124	125	127	108	104	&CH4
9-	&CH4	105	107							
10-	CORD2C	1		0.0	0.0	0.0	1.0	0.0	0.0	&CD1
11-	&CD1	0.	0.	1.						
12-	CTRIA2	1	2000	1	5	4				
13-	CTRIA2	2	2000	1	2	5				
14-	CTRIA2	3	2005	2	6	5				
15-	CTRIA2	4	2005	2	3	6				
16-	CTRIA2	5	2010	4	8	7				
17-	CTRIA2	6	2010	4	5	8				
18-	CTRIA2	7	2015	5	9	8				
19-	CTRIA2	8	2015	5	6	9				
20-	CTRIA2	9	2020	7	11	10				
21-	CTRIA2	10	2020	7	8	11				
22-	CTRIA2	11	2025	8	12	11				
23-	CTRIA2	12	2025	8	9	12				
24-	CYJOIN	1		121	101	113	123	103	115	
25-	CYJOIN	2		127	107	119	125	105	117	
26-	EIGC	20	HESS	MAX						&EIGC20
27-	&EIGC20							3		
28-	EIGR	10	INV	200.0	2000.0	8	5			&EIGR10
29-	&EIGR10	MAX								
30-	FLFACT	1	.059164	.118328	.177492					
31-	FLFACT	2	180.0							
32-	FLFACT	3	.3	.7	1.0					
33-	FLUTTER	30	K	1	2	3	L	4		
34-	GRID	1		-0.8979	-0.2814	3.7712				
35-	GRID	2		.0001	.0516	4.0003				
36-	GRID	3		.8981	-0.2461	4.1795				
37-	GRID	4		-0.7736	-0.4744	5.4413				
38-	GRID	5		-0.0031	.0228	5.5033				
39-	GRID	6		.7797	.2247	5.4885				
40-	GRID	7		-0.6646	-0.7082	7.3082				
41-	GRID	8		-0.0157	.0164	7.4058				
42-	GRID	9		.6303	.5962	7.3237				
43-	GRID	10		-0.5237	-1.1552	9.8520				
44-	GRID	11		-0.0320	-0.0656	10.0079				
45-	GRID	12		.4130	.7325	9.9093				
46-	GRID	101	1	2.375	4.19[illegible]	-0.987	1			
47-	GRID	103	1	2.375	4.1[illegible]	.987	1			
48-	GRID	104	1	2.375	.0.	.987	1			
49-	GRID	105	1	2.375	-[illegible]	[illegible]7	1			

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

```
CARD
COUNT    .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  51-    GRID    103     1        2.375   .0      -0.587   1
  52-    GRID    113     1        3.932   4.186   -0.587   1
  53-    GRID    115     1        4.539   4.186   .587     1
  54-    GRID    116     1        4.539   .0      .587
  55-    GRID    117     1        4.539   -4.186  .587     1
  56-    GRID    119     1        3.982   -4.186  -0.587   1
  57-    GRID    120     1        3.982   .0      -0.587
  58-    GRID    121     1        .905    4.186   -0.587   1
  59-    GRID    123     1        .905    4.186   .587     1
  60-    GRID    124     1        .905    .0      .587     1
  61-    GRID    125     1        .905    -4.186  .587     1
  62-    GRID    127     1        .905    -4.186  -0.587   1
  63-    GRID    128     1        .905    .0      -0.587   1
  64-    MAT1    1       31.0E6           .3      7.300E-4
  65-    MKAERO1 130.0                                                                   EMKA1
  66-    EMKA1   0.3     0.7      1.0
  67-    MPC     600     1        1       1.0     2        1          -1.0
  68-    MPC     600     1        2       1.0     2        2          -1.0
  69-    MPC     600     1        3       1.0     2        3          -1.0
  70-    MPC     600     1        4       1.0     2        4          -1.0
  71-    MPC     600     1        5       1.0     2        5          -1.0
  72-    MPC     600     1        6       1.0     2        6          -1.0
  73-    MPC     600     3        1       1.0     2        1          -1.0
  74-    MPC     600     3        2       1.0     2        2          -1.0
  75-    MPC     600     3        3       1.0     2        3          -1.0
  76-    MPC     600     3        4       1.0     2        4          -1.0
  77-    MPC     600     3        5       1.0     2        5          -1.0
  78-    MPC     600     3        6       1.0     2        6          -1.0
  79-    MPC     600     116      1       1.0     2        1          -1.0
  80-    MPC     600     116      2       1.0     2        2          -1.0
  81-    MPC     600     116      3       1.0     2        3          -1.0
  82-    MPC     600     120      1       1.0     2        1          -1.0
  83-    MPC     600     120      2       1.0     2        2          -1.0
  84-    MPC     600     120      3       1.0     2        3          -1.0
  85-    PARAM   CTYPE   ROT
  86-    PARAM   IREF    4
  87-    PARAM   KGGIN   1
  88-    PARAM   KINDEX  0
  89-    PARAM   LMODES  4
  90-    PARAM   MAXMACH .90
  91-    PARAM   MINMACH 1.00
  92-    PARAM   MTYPE   COSINE
  93-    PARAM   NSEGS   43
  94-    PARAM   PRINT   YESB
  95-    PTRIA2  2000    1        .1040   0.0
  96-    PTRIA2  2005    1        .1040   0.0
  97-    PTRIA2  2010    1        .0707   0.0
  98-    PTRIA2  2015    1        .0707   0.0
  99-    PTRIA2  2020    1        .0422   0.0
 100-    PTRIA2  2025    1        .0422   0.0
```

```
                                       S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  101-        SPC1    500     23      121     123     124     125     127     128
  102-        SPC1    500     45      7       10      12
  103-        SPC1    500     456     101     103     104     105     107     108
  104-        SPC1    500     456     113     115     116     117     119     120
  105-        SPC1    500     456     121     123     124     125     127     128
  106-        STREAML11       1       2       3
  107-        STREAML12       4       5       6
  108-        STREAML13       7       8       9
  109-        STREAML14       10      11      12
  110-        STREAML21       3       2.739   1.79600 3.98420 .58217  .656846 .069472 &STRL 1
  111-        &STRL 1 719.0   47.423
  112-        STREAML22       3       23.534  1 [illegible]44 6.06653 .88674  .934388 .066610 &STRL 2
  113-        &STRL 2 1014.2  55.107
  114-        STREAML23       3       44.697  1.86419 8.07620 1.18010 1.153666.064685 &STRL 3
  115-        &STRL 3 1283.1  60.380
  116-        STREAML24       3       62.028  1.86558 9.92791 1.45067 1.502276.059201 &STRL 4
  117-        &STRL 4 1592.6  60.687
              ENDDATA
```

TIME K Required.

K -- Maximum allowable execution time in minutes.

SØL K1[,Ki] or SØL An [,Ki] **Required when using a rigid format** (see Section 3.1 for available options).

K1 -- Solution number of Rigid Format (see table below and Section 3.1).

Ki -- Subset numbers for solution K1, default value = 0. Multiple subsets may be selected by using multiple integers separated by commas.

An -- Name of Rigid Format (see table below)

Displacement Approach Rigid Formats

K1	An
1	STATICS
2	INERTIA RELIEF
3	MØDES or NØRMAL MØDES or REAL EIGENVALUES
4	DIFFERENTIAL STIFFNESS
5	BUCKLING
6	PIECEWISE LINEAR
7	DIRECT CØMPLEX EIGENVALUES
8	DIRECT FREQUENCY RESPØNSE
9	DIRECT TRANSIENT RESPØNSE
10	MØDAL CØMPLEX EIGENVALUES
11	MØDAL FREQUENCY RESPØNSE
12	MØDAL TRANSIENT RESPØNSE
13	NØRMAL MØDES ANALYSIS WITH DIFFERENTIAL STIFFNESS
14	STATICS CYCLIC SYMMETRY
15	MØDES CYCLIC SYMMETRY
16	STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

Heat Transfer Approach Rigid Formats

K1	An
1	STATICS
3	STEADY STATE
9	TRANSIENT

Aeroelastic Approach Rigid Format

K1	An
9	CØMPRESSOR BLADE CYCLIC MØDAL FLUTTER ANALYSIS
10	MØDAL FLUTTER ANALYSIS

Subset Numbers

1. Delete loop control.
2. Delete mode acceleration method of data recovery (modal transient and modal frequency response).
3. Combine subsets 1 and 2.
4. Check all structural and aerodynamic data without execution of the aeroelastic problem.

5. Check only the aerodynamic data without execution of the aeroelastic problem.
6. Delete checkpoint instructions.
7. Delete structure plotting and X-Y plotting.
8. Delete Grid Point Weight Generator.
9. Delete fully stressed design (static analysis).

The following cards are used to make output requests for the calculated response of components in the SØLUTIØN set (components in the direct or modal formulation of the general K system) for dynamics problems:

1. SACCELERATIØN - requests the acceleration of the independent components for a selected set of points or modal coordinates.

2. SDISPLACEMENT - requests the displacements of the independent components for a selected set of points or modal coordinates or the temperatures of the independent components for a selected set of points in heat transfer.

3. SVELØCITY - requests the velocities of the independent components for a selected set of points or modal coordinates or the change in temperature with respect to time of the independent components for a selected set of points in heat transfer.

4. NLLØAD - requests the nonlinear loads for a selected set of physical points (grid points and extra points introduced for dynamic analysis) intransient response problems.

The following cards are used to make output requests for stresses and forces, as well as the calculated response of degrees of freedom used in the model:

1. ELFØRCE - requests the forces in a set of structural elements or the temperature gradients and fluxes in a set of structural or heat elements in heat transfer.

2. STRESS - requests the stresses in a set of structural elements or the velocity components in a fluid element in acoustic cavity analysis.

3. SPCFØRCES - requests the single-point forces of constraint at a set of points or the thermal power transmitted at a selected set of points in heat transfer.

4. ØLØAD - selects a set of applied loads for output.

5. ACCELERATIØN - requests the accelerations for a selected set of PHYSICAL points (grid, scalar and fluid points plus extra points introduced for dynamic analysis).

6. DISPLACEMENT - requests the displacements for a selected set of PHYSICAL points or the temperatures for a selected set of PHYSICAL points in heat transfer or the pressures for a selected set of PHYSICAL points in hydroelasticity.

7. VELØCITY - requests the velocities for a selected set of PHYSICAL points or the change in temperatures with respect to time for a selected set of PHYSICAL points in heat transfer.

8. HARMØNICS - controls the number of harmonics that will be output for requests associated with the conical shell, axisymmetric solids and hydroelastic problems.

9. ESE - requests structural element strain energies in Rigid Format 1.

10. GPFØRCE - requests grid point force balance due to element forces, forces of single point constraint, and applied loads in Rigid Format 1.

11. THERMAL - requests temperatures for a set of PHYSICAL points in heat transfer.

12. PRESSURE - requests pressures for a set of PHYSICAL points in hydroelasticity.

13. CSP - selects contact surface points to be output

2.3.3 Subcase Definition

In general, a separate subcase is defined for each loading condition. In statics problems separate subcases are also defined for each set of constraints. In complex eigenvalue analysis

Case Control Data Card **CSP** - Contact Surface Point Selection

Description: Selects the interface contact surface points for a static aeroelastic analysis.

Format and Examples:

CSP = n

CSP = 31

Option:	Meaning
n	Set identification number of a CSP card (integer > 0).

Remarks:

1. The normal displacement difference will be output for the selected interface contact surface points.

2. This card should select only those points of the interface contact surfaces where "contact" constraint conditions were not invoked. Use the GPFØRCE Case Control Card to select points for which "contact" constraint conditions were invoked.

Input Data Card **CSP** Contact Surface Points

Description: Defines interface contact surface points for use in static aeroelastic problems.

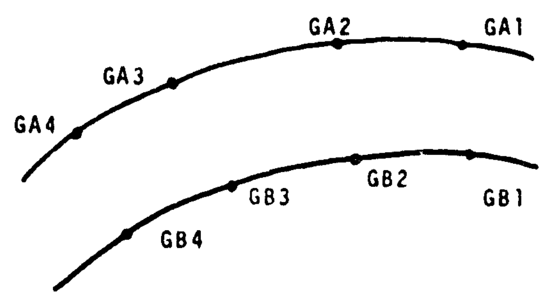
Format and Example:

1	2	3	4	5	6	7	8	9	10
CSP	SID	GA1	GB1	GA2	GB2	GA3	GB3		+ABC
CSP	13	5	9	10	12	13	23		+CSP1
+ABC	GA4	GB4	GA5	GB5	-etc-				
+CSP1									

Field	Contents
SID	Identification number of contact surface set (integer > 0).
GAi, GBi	Grid point identification numbers of node point pairs at interface contact locations (integer > 0).

Remarks:

1. Contact surface sets must be selected in the Case Control Deck (CSP = SID) to be used by NASTRAN
2. The normal displacement difference between each GAi and GBi pair will be output if this SID is selected.
3. Only those points where "contact" constraints were not invoked should be selected here. Contact surface points where "contact" constraints were invoked should be selected by a GPFØRCE data card to output element forces at the contact locations.



Interface contact surfaces represented by node pairs (GA1, GB1), (GA2, GB2), (GA3, GB3) and (GA4, GB4)

BULK DATA DECK

Input Data Card **FLFACT** Aerodynamic Physical Data

Description: Used to specify densities, Mach numbers or interblade phase angles, and reduced frequencies for flutter analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FLFACT	SID	F1	F2	F3	F4	F5	F6	F7	ABC
FLFACT	97	.3	.7	3.5					

+BC	F8	F9	-etc-						

Field	Contents
SID	Set identification number (unique integer > 0).
Fi	Aerodynamic factor (real).

Remarks:

1. These factors must be selected by a FLUTTER data card to be used by NASTRAN.

2. Imbedded blank fields are forbidden.

3. Parameters must be listed in the order in which they are to be used within the looping of flutter analysis.

Input Data Card **FLUTTER** Aerodynamic Flutter Data

Description: Defines data needed to perform flutter analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHØD	DENS	MACH	RFREQ	IMETH	NVALUE		
FLUTTER	19	K	119	219	319	S	5		

Field

SID — Set identification number (unique integer > 0).

METHØD — Flutter analysis method, "K" for k-method (BCD).

DENS — Identification number of an FLFACT data card specifying density ratios to be used in flutter analysis (integer ≥ 0).

MACH — Identification number of an FLFACT data card specifying MACH numbers or interblade phase angles (m) to be used in flutter analysis (integer ≥ 0).

RFREQ — Identification number of an FLFACT data card specifying reduced frequencies (k) to be used in flutter analysis (integer ≥ 0).

IMETH — Choice of interpolation method for matrix interpolation (BCD: L - linear, S = surface, default is S).

NVALUE — Number of eigenvalues for output and plots (integer > 0).

Remarks:

1. The FLUTTER data card must be selected in Case Control Deck (FMETHØD - SID).

2. The density is given by $\rho \cdot$ RHØREF where ρ is the density ratio given on the FLFACT data card and RHØREF is the reference density given on the AERØ data card.

3. The reduced frequency is given by $k = (\text{REFC}\cdot\omega/2\cdot V)$, where REFC is given on the AERØ data card, ω is the circular frequency and V is the velocity.

BULK DATA DECK

Input Data Card **MKAERØ1** Mach Number - Frequency Table

Description: Provides a table of Mach numbers or interblade phase angles (m) and reduced frequencies (k) for aerodynamic matrix calculation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MKAERØ1	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	ABC
MKAERØ1	.1	.7							+ABC
+BC	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	
+BC	.3	.6	1.0						

Field	Contents
m_i	List of Mach numbers or interblade phase angles (Real, $1 \leq i \leq 8$).
k_j	List of reduced frequencies (Real, $1 \leq j \leq 8$).

Remarks:

1. Blank fields end the list, and thus cannot be used for 0.0.
2. Combinations of (m,k) will be used.
3. The continuation card is required.
4. Mach numbers are input for wing flutter and interblade phase angles for blade flutter.

Input Data Card **MKAERØ2** Mach Number - Frequency Table

Description: Provides a list of Mach numbers or interblade phase angles (m) and reduced frequencies (k) for aerodynamic matrix calculation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MKAERØ2	m_1	k_1	m_2	k_2	m_3	k_3	m_4	k_4	
MKAERØ2	.10	.30	.10	.60	.70	.30	.70	1.0	

Field	Contents
m_i, k_i	List of pairs of Mach numbers or interblade phase angles (Real) and reduced frequencies (Real) (imbedded blank pairs are skipped).

Remarks:

1. This card will cause the aerodynamic matrices to be computed for a set of parameter pairs.

2. Several MKAERØ2 cards may be in the deck.

3. Mach numbers are input for wing flutter and interblade phase angle for blade flutter.

y. KMAX - optional in static analysis with cyclic symmetry (rigid format 14). The integer value of this parameter specifies the maximum value of the harmonic index. The default value is ALL which is NSEGS/2 for NSEGS even and (NSEGS-1)/2 for NSEGS odd.

z. KINDEX - required in normal modes with cyclic symmetry (rigid format 15). The integer value of this parameter specifies a single value of the harmonic index.

aa. NØDJE - optional in modal flutter analysis. A positive integer of this parameter indicates user supplied downwash matrices due to extra points are to be read from tape via the INPUTT2 module in the rigid format. The default value is -1.

ab. P1, P2 and P3 - required in modal flutter analysis when using NØDJE parameter. See Section 5.3.2 for tape operation parameters required by INPUTT2 module. The defaults for P1, P2 and P3 are -1, 11 and TAPEID, respectively.

ac. VREF - optional in modal flutter analysis. Velocities are divided by the real value of this parameter to convert units or to compute flutter indices. The default value is 1.0.

ad. PRINT - optional in modal flutter analysis. The BCD value, NØ, of this parameter will suppress the automatic printing of the flutter summary for the k method. The flutter summary table will be printed if the BCD value is YES for wing flutter, or YESB for blade flutter. The default is YES.

ae. APRESS - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic pressures. A negative value (the default) will suppress the generation of aerodynamic pressure loads.

af. ATEMP - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic temperature loads. A negative value (the default) will suppress the generation of aerodynamic thermal loads.

ag. STREAML - optional in static aerothermoelastic analysis. STREAML=1 causes the punching of STREAML1 bulk data cards. STREAML= 2 causes the punching of STREAML2 bulk data cards. STREAML=3 causes both STREAML1 and STREAML2 cards to be punched. The default value, -1, suppresses punching of any cards.

ah. PGEØM - optional in static aerothermoelastic analysis. PGEØM = 1 causes the punching of GRID bulk data cards. PGEØM = 2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEØM = 3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default, -1, suppresses punching of any cards.

ai. IPRT - optional in static aerothermoelastic analysis. If IPRT > 0, then intermediate print will be generated in the ALG module based on the print option in the ALGDB data table. If IPRT = 0 (the default), no intermediate print will be generated.

aj. SIGN - optional in static aerothermoelastic analysis. Controls the type of analysis being performed. SIGN = 1.0 for a standard analysis SIGN = -1.0 for a design analysis. The default is 1.0.

ak. ZØRIGN, FXCØØR, FYCØØR, FZCØØR - optional in static aerothermoelastic analysis. These are modification factors. The defaults are ZØRIGN = 0.0, FXCØØR = 1.0, FYCØØR = 1.0, and FZCØØR = 1.0.

al. MINMACH - optional in blade flutter analysis. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid. The default is 1.01.

am. MAXMACH - optional in blade flutter analysis. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid. The default value is 0.80.

an. IREF - optional in blade flutter analysis. This defines the reference streamline number. IREF must be equal to a SLN on a STREAML2 bulk data card. The default value, -1, represents the streamline at the blade tip. If IREF does not correspond to a SLN, then the default will be taken.

ao. MTYPE - optional in cyclic modal blade flutter analysis. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = COSINE for cosine components. The default BCD value is COSINE.

ap. KTØUT - optional in static aerothermoelastic analysis. A positive integer of this parameter indicates that the user wants to save the total stiffness matrix on tape (GINØ file INPT) via the ØUTPUT1 module in the rigid format. The default is -1.

aq. KGGIN - optional in compressor blade cyclic modal flutter analysis. A positive integer of this parameter indicates that the user supplied stiffness matrix is to be read from tape (GINØ file INPT) via the INPUTT1 module in the rigid format. The default is -1.

BULK DATA DECK

Input Data Card **STREAML1** Blade Streamline Data

Description: Defines grid points on the blade streamline from blade leading edge to blade trailing edge.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML1	SLN	G1	G2	G3	G4	G5	G6	G7	+ABC
STREAML1	3	2	4	6	8	10			

+ABC	G8	G9	-etc-						
+ABC									

Alternate Form:

STREAML1	SLN	GID1	"THRU"	GID2					
STREAML1	5	6	THRU	12					

Field	Contents
SLN	Streamline number (integer > 0).
Gi, GIDi	Grid point identification numbers (integer > 0).

Remarks:

1. This card is required for blade steady aeroelastic and blade flutter problems.
2. There must be one STREAML1 card for each streamline on the blade. For blade flutter problems, there must be an equal number of STREAML1 and STREAML2 cards.
3. The streamline numbers, SLN, must increase with increasing radial distance of the blade section from the axis of rotation. The lowest and the highest SLN, respectively, will be assumed to represent the blade sections closest to and farthest from the axis of rotation.
4. All grid points should be unique.
5. All grid points referenced by GID1 through GID2 must exist.
6. Each STREAML1 card must have the same number of grid points. The nodes must be input from the blade leading edge to the blade trailing edge in the correct positional order.

C-2

BULK DATA DECK

Input Data Card **STREAML2** **Blade Streamline Data**

Description: Define aerodynamic data for a blade streamline.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML2	SLN	NSTNS	STAGGER	CHORD	RADIUS	BSPACE	MACH	DEN	+abc
STREAML2	2	3	23.5	1.85	6.07	.886	.934	.066	

+abc	VEL	FLOWA							
+ABC	1014.2	55.12							

Field	Contents
SLN	Streamline number (Integer >0)
NSTNS	Number of computing stations on the blade streamline. ($3 \leq$ NSTNS ≤ 10, Integer)
STAGGER	Blade stagger angle (-90.0 < stagger <90.0, degrees)
CHORD	Blade chord (real >0.0)
RADIUS	Radius of streamline (real >0.0)
BSPACE	Blade spacing (real >0.0)
MACH	Relative flow mach number at blade leading edge (real >0.0)
DEN	Gas density at blade leading edge (real >0.0)
VEL	Relative flow velocity at blade leading edge (real >0.0)
FLOWA	Relative flow angle at blade leading edge (-90.0 < FLOWA <90.0, degrees)

Remarks:

1. At least three (3) and no more than ten (10) STREAML2 cards are required for a blade flutter analysis.

2. The streamline number, SLN, must be the same as its corresponding SLN on a STREAML1 card. There must be a STREAML1 card for each STREAML2 card.

3. It is not required that all streamlines be used to define the aerodynam c matrices used on blade flutter.

RIGID FORMATS

The following rigid formats for structural analysis are currently included in NASTRAN:

1. Static Analysis
2. Static Analysis with Inertia Relief
3. Normal Mode Analysis
4. Static Analysis with Differential Stiffness
5. Buckling Analysis
6. Piecewise Linear Analysis
7. Direct Complex Eigenvalue Analysis
8. Direct Frequency and Random Response
9. Direct Transient Response
10. Modal Complex Eigenvalue Analysis
11. Modal Frequency and Random Response
12. Modal Transient Response
13. Normal Modes Analysis with Differential Stiffness
14. Static Analysis with Cyclic Symmetry
15. Normal Modes Analysis with Cyclic Symmetry
16. Static Aerothermoelastic Analysis with Differential Stiffness

The following rigid formats for heat transfer analysis are included in NASTRAN:

1. Linear Static Heat Transfer Analysis
3. Nonlinear Static Heat Transfer Analysis
9. Transient Heat Transfer Analysis

The following rigid formats for aeroelastic analysis are included in NASTRAN:

9. Compressor Blade Cyclic Modal Flutter Analysis (Subsonic and Supersonic)
10. Modal Flutter Analysis (Subsonic)

3.1.1 Input File Processor

The Input File Processor operates in the Preface prior to the execution of the DMAP operations in the rigid format. A complete description of the operations in the Preface is given in the Programmer's Manual. The main interest here is to indicate the source of data blocks that are created in the Preface and hence appear only as inputs in the DMAP sequences of the rigid formats. None of the data blocks created by the Input File Processor are checkpointed, as they are always regenerated on restart. The Input File Processor is divided into five parts. The first part (IFP1) processes the Case Control Deck, the second part (IFP) processes the Bulk Data

3.21 COMPRESSOR BLADE MESH GENERATOR

3.21.1 DMAP Sequence for Compressor Blade Mesh Generator

RIGID FORMAT DMAP LISTING

SERIES 0

DMAP APPROACH, COMPRESSOR BLADE MESH GENERATOR

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
OPTIONS IN EFFECT'  GO     ERR=2   NOLIST   NODECK   NOREF   NOOSCAR

    1  BEGIN $

    2  ALG       CASECC,,,,ALGDB,, / CASECCA,GEOM3A / C,N,-1 / C,N,-1 /
                 V,Y,STREAML=1 / V,Y,PGEOM=2 / V,Y,IPRT=1  $

    3  END $
```

3.21.2 Description of DMAP Operations for Compressor Blade Mesh Generator

2. ALG generates GRID, CTRIA2, PTRIA2 and STREAML1 bulk data cards. These cards are output via the system card punch. The GRID and CTRIA2 cards represent a compressor blade mesh. The aerodynamic input data is checked by performing an aerodynamic analysis.

3.21.3 Output for the Compressor Blade Mesh Generator

The GRID, CTRIA2, PTRIA2 and STREAML1 bulk data cards are punched. Aerodynamic output is printed.

3.21.4 Case Control Deck, DTI Table and Parameters for the Compressor Blade Mesh Generator

1. Only TITLE, SUBTITLE and LABEL cards are processed, all other case control cards are ignored.
2. The only required input is the ALGBD data table. This data block is input via Direct Table Input (DTI) bulk data cards. ALGDB contains all the aerodynamic input necessary for the ALG module. For a detailed description of the ALGDB data block input see Section 1.15.3.1 of the User's Manual.

The following user parameters are used by the Compressor Blade Mesh Generator.

1. STREAML - Optional - A value of 1 casues the punching of STREAML1 bulk data cards. A value of 2 causes the punching of STREAML2 bulk data cards. A value of 3 causes the punching of both STREAML1 and STREAML2 cards. The default value, -1, suppresses the punching of all cards.
2. PGEOM - Optional - A value of 1 causes the punching of GRID bulk data cards. A value of 2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEØM = 3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default value, -1, suppresses the punching of all cards.
3. IPRT - Optional - a non-negative value of this parameter will allow intermediate print to be generated by the ALG module based on the print option in the ALGDB data table. The default value, 0, suppresses all intermediate print.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

3.22 Static Aerothermoelastic Analysis with Differential Stiffness

3.22.1 DMAP Sequence for Static Aerothermoelastic Analysis with Differential Stiffness.

```
RIGID FORMAT DMAP LISTING
SERIES J

DISPLACEMENT APPROACH, RIGID FORMAT 16

   LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT  GO     ERR=2   NOLIST  NODECK  NOREF   NOOSCAR

   1  BEGIN    NO.16 STATIC AEROTHERMOELASTIC WITH DIFFERENTIAL STIFFNESS $
   2  GP1      GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/V,N,LUSET/  V,N,
               NOGPDT $
   3  SAVE     LUSET,NOGPDT $
   4  COND     ERROR1,NOGPDT $
   5  CHKPNT   GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL $
   6  GP2      GEOM2,EQEXIN/ECT $
   7  CHKPNT   ECT $
   8  PARAML   PCDB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NOPCDB $
   9  PARAMR   // C,N,COMPLEX / / V,Y,SIGN / C,N,0.0 / V,N,CSIGN $
  10  PURGE    PLTSETX,PLTPAR,GPSETS,ELSETS/NOPCDB $
  11  COND     P1,NOPCDB $
  12  PLTSET   PCDB,EQEXIN,ECT/PLTSETX,PLTPAR,GPSETS,ELSETS/V,N,NSIL/   V,N,
               JUMPPLOT=-1 $
  13  SAVE     NSIL,JUMPPLOT $
  14  PRTMSG   PLTSETX// $
  15  PARAM    //C,N,MPY/V,N,PLTFLG/C,N,1/C,N,1 $
  16  PARAM    //C,N,MPY/V,N,PFILE/C,N,0/C,N,0 $
  17  COND     P1,JUMPPLOT $
  18  PLOT     PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,,,,/PLOTX1/   V,N,
               NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $
  19  SAVE     JUMPPLOT,PLTFLG,PFILE $
  20  PRTMSG   PLOTX1// $
  21  LABEL    P1 $
  22  CHKPNT   PLTPAR,GPSETS,ELSETS $
```

RIGID FORMAT DMAP LISTING
SERIES D

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
23  GP3      GEOM3,EQEXIN,GEOM2/SLT,GPTT/V,N,NOGRAV $
24  SAVE     NOGRAV $
25  PARAM    //C,N,AND/V,N,NOMGG/V,N,NOGRAV/V,Y,GROPNT=-1 $
26  CHKPNT   SLT,GPTT $
27  TA1      ECT,EPT,BGPDT,SIL,GPTT,CSTM/EST,GEI,GPECT,/V,N,LUSET/   V,N,
             NOSIMP/C,N,1/V,N,NOGENL/V,N,GENEL $
28  SAVE     NOSIMP,NOGENL,GENEL $
29  COND     ERROR1,NOSIMP $
30  PURGE    OGPST/GENEL $
31  CHKPNT   EST,GPECT,GEI,OGPST $
32  PARAM    //C,N,ADD/V,N,NOKGGX/C,N,1/C,N,0 $
33  EMG      EST,CSTM,MPT,DIT,GEOM2,/KELM,KDICT,MELM,MDICT,,/V,N,NOKGGX/ V,
             N,NOMGG/C,N,/C,N,/C,N,/C,Y,COUPMASS/C,Y,CPBAR/C,Y,CPROD/C,Y,
             CPQUAD1/C,Y,CPQUAD2/C,Y,CPTRIA1/C,Y,CPTRIA2/  C,Y,CPTUBE/C,Y,
             CPQDPLT/C,Y,CPTRPLT/C,Y,CPTRBSC $
34  SAVE     NOKGGX,NOMGG $
35  CHKPNT   KELM,KDICT,MELM,MDICT $
36  COND     JMPKGG,NOKGGX $
37  EMA      GPECT,KDICT,KELM/KGGX,GPST $
38  CHKPNT   KGGX,GPST $
39  LABEL    JMPKGG $
40  COND     JMPMGG,NOMGG $
41  EMA      GPECT,MDICT,MELM/MGG,/C,N,-1/C,Y,WTMASS=1.0 $
42  CHKPNT   MGG $
43  LABEL    JMPMGG $
44  COND     LBL1,GROPNT $
45  COND     ERROR4,NOMGG $
```

RIGID FORMAT DMAP LISTING
SERIES U

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
46  GPWG     BGPDT,CSTM,EQEXIN,MGG/OGPWG/V,Y,GRDPNT/C,Y,WTMASS $
47  OFP      OGPWG,,,,,// $
48  LABEL    LBL1 $
49  EQUIV    KGGX,KGG/NOGENL $
50  CHKPNT   KGG $
51  COND     LBL11,NOGENL $
52  SMA3     GEI,KGGX/KGG/V,N,LUSET/V,N,NOGENL/V,N,NOSIMP $
53  CHKPNT   KGG $
54  LABEL    LBL11 $
55  PARAM    //C,N,MPY/V,N,NSKIP/C,N,0/C,N,0 $
56  GP4      CASECC,GEOM4,EQEXIN,SIL,GPDT,BGPDT,CSTM/RG,YS,USET,ASET/V,N,
             LUSET/V,N,MPCF1/V,N,MPCF2/V,N,SINGLE/V,N,OMIT/V,N,REACT/V,N,
             NSKIP/V,N,REPEAT/V,N,NOSET/V,N,NOL/V,N,NOA/C,Y,SUBID $
57  SAVE     MPCF1,MPCF2,SINGLE,OMIT,REACT,NSKIP,REPEAT,NOSET,NOL,NOA $
58  COND     ERROR5,NOL $
59  PURGE    GM/MPCF1/GO,KOO,LOO,PO,UOOV,RUOV/OMIT/PS,KFS,KSS,QG/SINGLE/
             UBOOV/OMIT/YBS,PBS,KBFS,KBSS,KDFS,KDSS/SINGLE $
60  CHKPNT   GM,RG,GO,KOO,LOO,PO,UOOV,RUOV,YS,PS,KFS,KSS,USET,ASET,   UBOOV,
             YBS,PBS,KBFS,KBSS,KDFS,KDSS,QG $
61  COND     LBL4D,REACT $
62  JUMP     ERROR2 $
63  LABEL    LBL4D $
64  COND     LBL4,GENEL$
65  GPSP     GPL,GPST,USET,SIL/OGPST/V,N,NOGPST $
66  SAVE     NOGPST $
67  COND     LBL4,NOGPST $
68  OFP      OGPST,,,,,// $
```

RIGID FORMAT DMAP LISTING
SERIES O

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
69  LABEL   LBL4 $
70  EQUIV   KGG,KNN/MPCF1 $
71  CHKPNT  KNN $
72  COND    LBL2,MPCF2 $
73  MCE1    USET,RG/GM $
74  CHKPNT  GM $
75  MCE2    USET,GM,KGG,,,/KNN,,, $
76  CHKPNT  KNN $
77  LABEL   LBL2 $
78  EQUIV   KNN,KFF/SINGLE $
79  CHKPNT  KFF $
80  COND    LBL3,SINGLE $
81  SCE1    USET,KNN,,,/KFF,KFS,KSS,,, $
82  CHKPNT  KFS,KSS,KFF $
83  LABEL   LBL3 $
84  EQUIV   KFF,KAA/OMIT $
85  CHKPNT  KAA $
86  COND    LBL5,OMIT $
87  SMP1    USET,KFF,,,/GO,KAA,KOO,LOO,,,,, $
88  CHKPNT  GO,KAA,KOO,LOO $
89  LABEL   LBL5 $
90  RBMG2   KAA/LLL $
91  CHKPNT  LLL $
92  SSG1    SLT,BGPDT,CSTM,SIL,EST,MPT,GPTT,EDT,MGG,CASECC,DIT/PGNA / V,N,
            LUSET/C,N,1 $
93  CHKPNT  PGNA $
```

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
 94  PARAM    //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $
 95  COND     NOAL,ALOAD $
 96  ALG      CASECC,,EQEXIN,,ALGDB,, / CASECCAL,GEOM3AL /S,Y,APRESS/S,Y,
              ATEMP/C,N,-1/C,N,-1/V,Y,IPRTCI/S,N,IFAIL $
 97  COND     FINIS,IFAIL $
 98  PARAM    //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $
 99  COND     NOAL,ALOAD $
100  GP3      GEOM3AL,EQEXIN,GEOM2 /SLTAL,GPTTAL / V,N,NOGRAV $
101  CHKPNT   SLTAL,GPTTAL $
102  SSG1     SLTAL,BGPDT,CSTM,SIL,EST,MPT,GPTTAL,EDT,MGG,CASECCAL,DIT /
              PGAL / V,N,LUSET / C,N,1 $
103  CHKPNT   PGAL $
104  ADD      PGNA,PGAL / PG $
105  LABEL    NOAL $
106  EQUIV    PGNA,PG/ALOAD $
107  CHKPNT   PG $
108  EQUIV    PG,PL/NOSET $
109  CHKPNT   PL $
110  COND     LBL10,NOSET $
111  SSG2     USET,GM,YS,KFS,GO,,PG/,PO,PS,PL $
112  CHKPNT   PO,PS,PL $
113  LABEL    LBL10 $
114  SSG3     LLL,KAA,PL,LOO,KOO,PO/ULV,UOOV,RULV,RUOV/V,N,OMIT/V,Y,IRES=-1/
              C,N,1/V,N,EPSI $
115  SAVE     EPSI $
116  CHKPNT   ULV,UOOV,RULV,RUOV $
117  COND     LBL9,IRES $
```

RIGID FORMAT DMAP LISTING
SERIES D

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
118  MATGPR   GPL,USET,SIL,RULV//C,N,L $
119  MATGPR   GPL,USET,SIL,RUOV//C,N,O $
120  LABEL    LBL9 $
121  SDR1     USET,,ULV,UOOV,YS,GO,GM,PS,KFS,KSS,/UGV,PG1,QG/C,N,1/C,N,DSO $
122  CHKPNT   UGV,QG $
123  SDR2     CASECC,CSTM,MPT,DIT,EQEXIN,SIL,GPTT,EDT,BGPDT,,QG,UGV,EST,,PG/
              OPG1,OQG1,OUGV1,OES1,OEF1,PUGV1/C,N,DSO $
124  PARAM    //C,N,MPY/V,N,CARDNO/C,N,0/C,N,0 $
125  OFP      OUGV1,OPG1,OQG1,OEF1,OES1,//V,N,CARDNO $
126  SAVE     CARDNO $
127  COND     P2,JUMPPLOT $
128  PLOT     PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,PUGV1,,GPECT,OES1/
              PLOTX2/V,N,NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $
129  SAVE     PFILE $
130  PRTMSG   PLOTX2// $
131  LABEL    P2 $
132  TA1      ECT,EPT,BGPDT,SIL,GPTT,CSTM/X1,X2,ECPT,GPCT/V,N,LUSET/  V,N,
              NOSIMP/C,N,0/V,N,NOGENL/V,N,GENEL $
133  DSMG1    CASECC,GPTT,SIL,EDT,UGV,CSTM,MPT,ECPT,GPCT,DIT/KDGG/  V,N,
              DSCOSET$
134  CHKPNT   KDGG $
135  COND     NOALO,ALOAD $
136  EQUIV    PGNA,PG $
137  LABEL    NOALO $
138  PARAM    //C,N,ADD/V,N,SHIFT/C,N,-1/C,N,0 $
139  PARAM    //C,N,ADD/V,N,COUNT/V,N,ALWAYS=-1/V,N,NEVER= 1 $
140  PARAMR   //C,N,ADD/V,N,DSEPSI/C,N,0.0/C,N,0.0 $
```

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT DMAP LISTING
SERIES D

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
141  PARAML   YS//C,N,NULL/C,N,/C,N,/C,N,/V,N,NOYS $
142  JUMP     OUTLPTOP $
143  LABEL    OUTLPTOP $
144  EQUIV    PG,PG1/NOYS $
145  CHKPNT   PG1 $
146  PARAM    //C,N,KLOCK,V,N,TO $
147  EQUIV    KDGG,KDNN/MPCF2 $
148  CHKPNT   KDNN $
149  COND     LBL2D,MPCF2 $
150  MCE2     USET,GM,KDGG,,,/KDNN,,, $
151  CHKPNT   KDNN $
152  LABEL    LBL2D $
153  EQUIV    KDNN,KDFF/SINGLE $
154  CHKPNT   KDFF $
155  COND     LBL3D,SINGLE $
156  SCE1     USET,KDNN,,,/KDFF,KDFS,KDSS,,, $
157  CHKPNT   KDFF,KDFS,KDSS $
158  LABEL    LBL3D $
159  EQUIV    KDFF,KDAA/OMIT $
160  CHKPNT   KDAA $
161  COND     LBL5D,OMIT $
162  SMP2     USET,GO,KDFF/KDAA $
163  CHKPNT   KDAA $
164  LABEL    LBL5D $
165  ADD      KAA,KDAA / KBLL / C,N,(1.0,0.0) / V,N,CSIGN $
```

RIGID FORMAT DMAP LISTING
SERIES O
DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
166  ADD      KFS,KDFS/ KDFS / C,N,(1.0,0.0) / V,N,CSIGN $
167  ADD      KSS,KDSS/ KBSS / C,N,(1.0,0.0) / V,N,CSIGN $
168  COND     PGOK,NOYS $
169  MPYAD    KBSS,YS,/PSS/C,N,0/C,N,1/C,N,1/C,N,1 $
170  MPYAD    KBFS,YS,/PFS/C,N,0/C,N,1/C,N,1/C,N,1 $
171  UMERGE   USET,PFS,PSS/PN/C,N,N/C,N,F/C,N,S $
172  EQUIV    PN,PGX/MPCF2 $
173  COND     LBL6D,MPCF2 $
174  UMERGE   USET,PN,/PGX/C,N,O/C,N,N/C,N,M $
175  LABEL    LBL6D $
176  ADD      PG4,PG/PGG/C,N,(-1.0,0.0) $
177  EQUIV    PGG,PG1/ALWAYS $
178  LABEL    PGOK $
179  ADD      PG1,/PGJ/ $
180  COPY     UGV / AUGV $
181  RBMG2    KBLL/LBLL/V,N,POWER/V,N,DET $
182  SAVE     DET,POWER $
183  CHKPNT   LBLL $
184  PRTPARM  //C,N,0/C,N,DET $
185  PRTPARM  //C,N,0/C,N,POWER $
186  JUMP     INLPTCP $
187  LABEL    INLPTCP $
188  PARAM    //C,N,KLOCK/V,N,TI $
189  COND     NOALL,ALCAD $
190  ALG      CASECC,EDT,EQEXIN,AUGV,ALGDB,CSTM,BGPDT / CASECCA,GEOM3A /S,Y,
              APRESS/S,Y,ATEMP/C,N,-1/C,N,-1/V,Y,IPRTCL/S,N,IFAIL/V,Y,SIGN/V,
```

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
                Y,ZORIGN/V,Y,FXCO[illegible],FYCOOR/V,Y,FZCOOR $
191  COND       DONE,IFAIL $
192  PARAM      //C,N,MPY /V,Y,IPRTCL /C,N,0 $
193  PARAM      //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $
194  COND       NOAL1,ALOAD $
195  GP3        GEOM3A,EQEXIN,GEOM2/SLTA,GPTTA/V,N,NOASL/V,N,NOGRAV/V,N,NOATL $
196  SSG1       SLTA,BGPDT,CSTM,SIL,EST,MPT,GPTTA,EDT,MGG,CASECCA,DIT /PGA /V,
                N,LUSET /C,N,1$
197  ADD        PG1,PGA / PG2 $
198  LABEL      NOAL1 $
199  EQUIV      PG1,PG2 / ALOAD $
200  CHKPNT     PG2 $
201  SSG2       USET,GM,YS,KDFS,GO,,PG2 /,PBO,PBS,PBL $
202  SSG3       LBLL,KBLL,PBL,,,/UBLV,,RUBLV,/C,N,-1/V,Y,IRES/V,N,NOSKIP/V,N,
                EPSI $
203  SAVE       EPSI $
204  CHKPNT     UBLV,RUBLV $
205  COND       LBL90,IRES $
206  MATGPR     GPL,USET,SIL,RUBLV//C,N,L $
207  LABEL      LBL90 $
208  SDR1       USET,,UBLV,,YS,GO,GM,PBS,KBFS,KBSS,/UBGV,,QBG/C,N,1/C,N,DS1 $
209  CHKPNT     UBGV,QBG $
210  COND       NOAL2,ALOAD $
211  EQUIV      UBGV,AUGV $
212  LABEL      NOAL2 $
213  ADD        UBGV,UGV/DUGV/C,N,(-1.0,0.0) $
```

RIGID FORMAT DMAP LISTING
SERIES O

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
214  DSMG1    CASECC,GPTT,SIL,EDT,UGV,CSTM,MPT,ECPT,GPCT,DIT/DKDGG/V,N,
              DSCOSET $
215  CHKPNT   DKDGG $
216  MPYAD    DKDGG,UBGV,PGO/PG11/C,N,0/C,N,1/C,N,1/C,N,1 $
217  ADD      PG11,PGA / PG12 $
218  DSCHK    PG2,PG12,UBGV //C,Y,EPSIO=1.E-5 /V,N,DSEPSI / C,Y,NT=10 /V,N,
              TO /V,N,TI /V,N,DONE /V,N,SHIFT /V,N,COUNT/C,Y,BETAD=4 $
219  SAVE     DSEPSI,DONE,SHIFT,COUNT $
220  COND     DONE,DONE $
221  COND     SHIFT,SHIFT $
222  EQUIV    PG,PG1/NEVER $
223  EQUIV    PG11,PG1/ALWAYS $
224  EQUIV    PG1,PG11/NEVER $
225  REPT     INLPTOP,1000 $
226  TABPT    PG11,PG1,PG,,// $
227  LABEL    SHIFT $
228  ADD      DKDGG,KDGG/KDGG1/C,N,(-1.0,0.0) $
229  CHKPNT   KDGG1 $
230  EQUIV    UBGV,UGV/ALWAYS/KDGG1,KDGG/ALWAYS $
231  CHKPNT   KDGG $
232  EQUIV    KDGG,KDGG1/NEVER/UGV,UBGV/NEVER $
233  REPT     OUTLPTOP,1000 $
234  TABPT    KDGG1,KDGG,UGV,,// $
235  LABEL    DONE $
236  PARAM    //C,N,NOP / V,Y,KTOUT=-1 $
237  COND     JMPKTOUT,KTOUT $
```

RIGID FORMAT DMAP LISTING
SERIES D

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
238  ADD      KGG,KDGG / KTOTAL / C,N,(1.0,0.0) / V,N,CSIGN $
239  OUTPUT1  KTOTAL,,,, // C,Y,LOCATION=-1 / C,Y,INPTUNIT=0 $
240  OUTPUT1  ,,,, // C,N,-3 / C,N,0 $
241  LABEL    JMPKTOUT $
242  CHKPNT   CSTM $
243  ALG      CASECC,EDT,EQEXIN,UBGV,ALGDB,CSTM,BGPDT / CASECCB,GEOM3B /C,N,
              -1/C,N,-1/V,Y,STREAML/V,Y,PGEOM/V,Y,IPRTCF/S,N,IFAIL/V,Y,SIGN/
              V,Y,ZORIGN/V,Y,FXCOOR/V,Y,FYCOOR/V,Y,FZCOOR $
244  SDR2     CASECC,CSTM,MPT,DIT,EQEXIN,SIL,GPTT,EDT,BGPDT,,QBG,UBGV,EST,,/,
              OQBG1,OUBGV1,OESB1,OEFB1,PUBGV1/C,N,DS1 $
245  OFP      OUBGV1,OQBG1,OEFB1,OESB1,,//V,N,CARDNO $
246  SAVE     CARDNO $
247  SDR1     USET,PG2,UBLV,,YS,GO,GM,PBS,KBFS,KBSS, / AUBGV,APGG,AQBG /C,N,
              1 /C,N,DS1 $
248  GPFDR    CASECC,AUBGV,KELM,KDICT,ECT,EQEXIN,GPECT,APGG,AQBG /ONRGY1,
              OGPFB1 / C,N,STATICS $
249  OFP      ONRGY1,OGPFB1,,,, // $
250  COND     P3,JUMPPLOT $
251  PLOT     PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,PUBGV1,,GPECT,
              OESB1/PLOTX3/V,N,NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,
              PFILE $
252  SAVE     PFILE $
253  PRTMSG   PLOTX3// $
254  LABEL    P3 $
255  JUMP     FINIS $
256  LABEL    ERROR1 $
257  PRTPARM  //C,N,-1/C,N,DIFFSTIF $
258  LABEL    ERROR2 $
259  PRTPARM  //C,N,-2/C,N,DIFFSTIF $
```

RIGID FORMAT DMAP LISTING
SERIES D

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
260  LABEL    ERROR4 $
261  PRTPARM  //C,N,-4/C,N,DIFFSTIF $
262  LABEL    ERROR5 $
263  PRTPARM  //C,N,-5/C,N,DIFFSTIF $
264  LABEL    FINIS $
265  END      $
```

NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM

3.22.2 Description of DMAP Operations for Static Aerothermoelastic Analysis with Differential Stiffness

2. GP1 generates coordinate system transformation matrices, tables of grid point locations, and tables for relating internal and external grid point numbers.

4. Go to DMAP No. 256 if no grid point definition table.

6. GP2 generates Element Connection Table with internal indices.

9. PARAMR sets CSIGN=(SIGN, 0.0), where SIGN is +1.0 or -1.0 for analysis or design type run.

11. Go to DMAP No. 21 if no plot package is present.

12. PLTSET transforms user input into a form used to drive structure plotter.

14. PRTMSG prints error messages associated with structure plotter.

17. Go to DMAP No. 21 if no undeformed structure plot request.

18. PLØT generates all requested undeformed structure plots.

20. PRTMSG prints plotter data and engineering data for each undeformed plot generated.

23. GP3 generates Static Loads Table and Grid Point Temperature Table.

27. TA1 generates element tables for use in matrix assembly and stress recovery.

29. Go to DMAP No. 256 and print error message if no structural elements.

33. EMG generates structural element matrix tables and dictionaries for later assembly.

36. Go to DMAP No. 39 if no stiffness matrix is to be assembled.

37. EMA assembles stiffness matrix $[K^x_{gg}]$ and Grid Point Singularity Table.

40. Go to DMAP No. 43 if no mass matrix is to be assembled.

41. EMA assembles mass matrix $[M_{gg}]$.

44. Go to DMAP No. 48 if no weight and balance request.

45. Go to DMAP No. 260 and print error message if no mass matrix exists.

46. GPWG generates weight and balance information.

47. ØFP formats weight and balance information and places it on the system output file for printing.

49. Equivalence $[K^x_{gg}]$ to $[K_{gg}]$ if no general elements.

51. Go to DMAP No. 54 if no general elements.

52. SMA3 adds general elements to $[K^x_{gg}]$ to obtain stiffness matrix $[K_{gg}]$.

56. GP4 generates flags defining members of various displacement sets (USET), forms multipoint constraint equations $[R_g]\{u_g\} = 0$ and forms enforced displacement vector $\{Y_s\}$.

58. Go to DMAP No. 262 and print error message if no independent degrees of freedom are defined.

61. Go to DMAP No. 63 if no free-body supports supplied, otherwise go to DMAP No. 258.

64. Go to DMAP No. 67 if general elements present.

65. GPSP determines if possible grid point singularities remain.

67. Go to DMAP No. 69 if no Grid Point Singularity Table.

68. ØFP formats table of possible grid point singularities and places it on the system output file for printing.

70. Equivalence $[K_{gg}]$ to $[K_{nn}]$ if no multipoint constraints.

72. Go to DMAP No. 77 if MCE1 and MCE2 have already been executed for current set of multipoint constraints.

73. MCE1 partitions multipoint constraint equations $[R_g] = [R_m \vdots R_n]$ and solves for multipoint constraint transformation matrix $[G_m] = -[R_m]^{-1}[R_n]$.

75. MCE2 partitions stiffness matrix

$$[K_{gg}] = \left[\begin{array}{c|c} \bar{K}_{nn} & K_{nm} \\ \hline K_{mn} & K_{mm} \end{array}\right]$$

and performs matrix reduction

$$[K_{nn}] = [\bar{K}_{nn}] + [G_m^T][K_{mn}] + [K_{mn}^T][G_m] + [G_m^T][K_{mm}][G_m].$$

78. Equivalence $[K_{nn}]$ to $[K_{ff}]$ if no single-point constraints.

80. Go to DMAP No. 83 if no single-point constraints.

81. SCE1 partitions out single-point constraints.

$$[K_{nn}] = \left[\begin{array}{c|c} K_{ff} & K_{fs} \\ \hline K_{sf} & K_{ss} \end{array}\right]$$

83. Equivalence $[K_{ff}]$ to $[K_{aa}]$ if no omitted coordinates.

86. Go to DMAP No. 89 if no omitted coordinates.

87. SMP1 partitions constrained stiffness matrix

$$[K_{ff}] = \left[\begin{array}{c|c} \bar{K}_{aa} & K_{ao} \\ \hline K_{oa} & K_{oo} \end{array}\right]$$

solves for transformation matrix $[G_o] = -[K_{oo}]^{-1}[K_{oa}]$

and performs matrix reduction $[K_{aa}] = [\bar{K}_{aa}] + [K_{oa}^T][G_o]$.

90. RMBG2 decomposes constrained stiffness matrix $[K_{aa}] = [L_{\ell\ell}][U_{\ell\ell}]$.

92. SSG1 generates non-aerodynamic static load vectors $\{P_g^{NA}\}$.

95. Go to DMAP No. 105 if no aerodynamic loads.

96. ALG generates aerodynamic load data.

102. SSG1 generates aerodynamic load vector $\{P_g^A\}$.

104. Add $\{P_g^{NA}\}$ and $\{P_g^A\}$ to form total load vector $\{P_g\}$.

106. Equivalence $\{P_g\}$ to $\{P_g^{NA}\}$ if no aerodynamic loads.

108. Equivalence $\{P_g\}$ to $\{P_\ell\}$ if no constraints applied .

110. Go to DMAP No. 113 if no constraints applied.

111. SSG2 applies constraints to static load vectors

$$\{P_g\} = \begin{Bmatrix} \bar{P}_n \\ \hline P_m \end{Bmatrix} , \qquad \{P_n\} = \{\bar{P}_n\} + [G_m^T]\{P_m\} ,$$

$$\{P_n\} = \begin{Bmatrix} \bar{P}_f \\ \hline P_s \end{Bmatrix} , \qquad \{P_f\} = \{\bar{P}_f\} - [K_{fs}]\{Y_s\} ,$$

$$\{P_f\} = \begin{Bmatrix} P_a \\ \hline P_o \end{Bmatrix} \quad \text{and} \quad \{P_\ell\} = \{P_a\} + [G_o^T]\{P_o\} .$$

114. SSG3 solves for displacements of independent coordinates

$$\{u_\ell\} = [K_{aa}]^{-1}\{P_\ell\} ,$$

solves for displacements of omitted coordinates

$$\{u_o^o\} = [K_{oo}]^{-1}\{P_o\} ,$$

calculates residual vector (RULV) and residual vector error ratio for independent coordinates

$$\{\delta P_\ell\} = \{P_\ell\} - [K_{aa}]\{u_\ell\}$$

$$\epsilon_\ell = \frac{\{u_\ell^T\}\{\delta P_\ell\}}{\{P_\ell^T\}\{u_\ell\}}$$

and calculates residual vector (RUØV) and residual vector error ratio for omitted coordinates

$$\{\delta P_o\} = \{P_o\} - [K_{oo}]\{u_o^o\} ,$$

$$\epsilon_o = \frac{\{u_o^T\}\{\delta P_o\}}{\{P_o^T\}\{u_o^o\}}$$

117. Go to DMAP No. 120 if residual vectors are not to be printed.

118. Print residual vector for independent coordinates (RULV).

119. Print residual vector for omitted coordinates (RUØV).

121. SDR1 recovers dependent displacements

$$\{u_o\} = [G_o]\{u_\ell\} + \{u_o^o\} \quad ,$$

$$\left\{\begin{array}{c} u_a \\ \hline u_o \end{array}\right\} = \{u_f\} \quad , \qquad \left\{\begin{array}{c} u_f \\ \hline Y_s \end{array}\right\} = \{u_n\} \quad ,$$

$$\{u_m\} = [G_m]\{u_n\}, \qquad \left\{\begin{array}{c} u_n \\ \hline u_m \end{array}\right\} = \{u_g\} \quad ,$$

and recovers single-point forces of constraint

$$\{q_s\} = -\{P_s\} + [K_{fs}^T]\{u_f\} + [K_{ss}]\{Y_s\}.$$

122. SDR2 calculates element forces and stresses (ØEF1, ØES1) and prepares load vectors, displacement vectors and single-point forces of constraint for output (ØPG1, ØUGV1, PUGV1, ØQG1).

125. ØFP formats tables prepared by SDR2 and places them on the system output file for printing.

127. Go to DMAP No. 131 if no static deformed structure plots are requested.

128. PLØT generates all requested static deformed structure plots.

130. PRTMSG prints plotter data and engineering data for each deformed plot generated.

132. TA1 generates element tables for use in differential stiffness matrix assembly.

133. DSMG1 generates differential stiffness matrix $[K_{gg}^d]$.

135. Go to DMAP No. 137 if no aerodynamic loads.

136. Equivalence $\{P_g^{NA}\}$ to $\{P_g\}$ to remove aerodynamic loads from total load vector before entering differential stiffness loop. New aerodynamic loads will be generated in loop.

142. Go to next DMAP instruction if cold start or modified restart. ØUTLPTØP will be altered by the Executive System to the proper location inside the loop for unmodified restarts within the loop.

143. Beginning of outer loop for differential stiffness iteration.

144. Equivalence $\{P_g\}$ to $\{P_g\}$ if no enforced displacements.

147. Equivalence $[K_{gg}^d]$ to $[K_{nn}^d]$ if no multipoint constraints.

149. Go to DMAP No. 152 if no multipoint constraints.

150. MCE2 partitions differential stiffness matrix

$$[K^d_{gg}] = \left[\begin{array}{c|c} \bar{K}^d_{nn} & K^d_{nm} \\ \hline K^d_{mn} & K^d_{mm} \end{array}\right]$$

and performs matrix reduction $[K^d_{nn}] = [\bar{K}^d_{nn}] + [G^T_m][K^d_{mn}] + [K^d_{mn}][G_m] + [G^T_m][K^d_{mm}][G_m]$.

153. Equivalence $[K^d_{nn}]$ to $[K^d_{ff}]$ if no single-point constraints.

155. Go to DMAP No. 158 if no single-point constraints.

156. SCE1 partitions out single-point constraints

$$[K^d_{nn}] = \left[\begin{array}{c|c} K^d_{ff} & K^d_{fs} \\ \hline K^d_{sf} & K^d_{ss} \end{array}\right]$$

159. Equivalence $[K^d_{ff}]$ to $[K^d_{aa}]$ if no omitted coordinates.

161. Go to DMAP No. 164 if no omitted coordinates.

162. SMP2 partitions constrained differential stiffness matrix

$$[K^d_{ff}] = \left[\begin{array}{c|c} \bar{K}^d_{aa} & K^d_{ao} \\ \hline K^d_{oa} & K^d_{oo} \end{array}\right]$$

and performs matrix reduction $[K^d_{aa}] = [\bar{K}^d_{aa}] + [K^d_{oa}]^T[G_o] + [G_o]^T[K^d_{oa}] + [G_o]^T[K^d_{oo}][G_o]$.

165. ADD $[K_{aa}]$ and $[K^d_{aa}]$.CSIGN to form $[K^b_{\ell\ell}]$.

166. ADD $[K_{fs}]$ and $[K^d_{fs}]$.CSIGN to form $[K^b_{fs}]$.

167. ADD $[K_{ss}]$ and $[K^d_{ss}]$.CSIGN to form $[K^b_{ss}]$.

168. Go to DMAP No. 178 if no enforced displacements.

169. MPYAD multiply $[K^b_{ss}]$ and $\{Y_s\}$ to form $\{P_{ss}\}$.

170. MPYAD multiply $[K^b_{fs}]$ and $\{Y_s\}$ to form $\{P_{fs}\}$.

171. UMERGE expand $\{P_{fs}\}$ and $\{P_{ss}\}$ to form $\{P_n\}$.

174. UMERGE expand $\{P_n\}$ to form $\{P^x_g\}$.

176. ADD $-\{P^x_g\}$ and $\{P_g\}$ to form $\{P_{gg}\}$.

177. Equivalence $\{P_{gg}\}$ to $\{P_{gl}\}$.

179. ADD $\{P_{g1}\}$ and nothing to create $\{P_{go}\}$.

180. Copy $\{u_g\}$ to $\{u_g^A\}$ to initialize aerodynamic displacements.

181. RBMG2 decomposes the combined differential stiffness matrix and elastic stiffness matrix.

$$[K_{\ell\ell}^b] = [L_{\ell\ell}^b][U_{\ell\ell}^b].$$

184. PRTPARM prints the scaled value of the determinant of the combined differential stiffness matrix and elastic stiffness matrix.

185. PRTPARM prints the scale factor (power of ten) of the determinant of the combined differential stiffness matrix and the elastic stiffness matrix.

186. Go to next DMAP instruction if cold start or modified restart. INLPTØP will be altered by the executive system to the proper location inside the loop for unmodified restarts within the loop.

187. Beginning of inner loop for differential stiffness iteration.

189. Go to DMAP No. 194 if no aerodynamic loads.

190. ALG generates aerodynamic load data.

191. Go to DMAP No. 235 if ALG fails to converge while generating aerodynamic load data.

196. SSG1 generates aerodynamic load vector $\{P_g^A\}$.

197. ADD $\{P_{g1}\}$ and $\{P_g^A\}$ to form total load vector $\{P_{g2}\}$.

201. SSG2 applies constraints to static load vectors

$$\{P_{g2}\} = \begin{Bmatrix} \bar{p}_n^b \\ \hline p_m^b \end{Bmatrix} \quad , \qquad \{p_n^b\} = \{\bar{p}_n^b\} + [G_m^T]\{p_m^b\} \ ,$$

$$\{p_n^b\} = \begin{Bmatrix} \bar{p}_f^b \\ \hline p_s^b \end{Bmatrix} \quad , \qquad \{p_f\} = \{\bar{p}_f^b\} - [K_{fs}^d]\{Y_s\},$$

$$\{p_f^b\} = \begin{Bmatrix} p_a^b \\ \hline p_o^b \end{Bmatrix} \quad \text{and} \qquad \{p_\ell^b\} = \{p_a^b\} + [G_o^T]\{p_o^b\} \ .$$

202. SSG3 solves for displacements of independent coordir tes for current differential stiffness load vector

$$\{u_\ell^b\} = [K_{\ell\ell}^b]^{-1}\{p_\ell^b\}$$

and calculates residual vector (RBULV) and residual vector error ratio for current differential stiffness load vector

$$\{\delta P_\ell^b\} = \{P_\ell^b\} - [K_{\ell\ell}^b]\{u_\ell^b\} ,$$

$$\varepsilon_\ell^b = \frac{\{u_\ell^b\}^T\{\delta P_\ell^b\}}{\{P_\ell^b\}^T\{u_\ell^b\}} .$$

205. Go to DMAP No. 207 if residual vector for current differential stiffness solution is not to be printed.

206. Print residual vector for current differential stiffness solution.

208. SDR1 recovers dependent displacements for current differential stiffness solution

$$\{u_o^b\} = [G_o]\{u_\ell^b\} + \{u_o^{ob}\} , \quad \left\{\begin{matrix} u_\ell^b \\ \hline u_o^b \end{matrix}\right\} = \{u_f^b\} ,$$

$$\left\{\begin{matrix} u_f^b \\ \hline Y_s^b \end{matrix}\right\} = \{u_n^b\} , \quad \{u_m^b\} = [G_m]\{u_n^b\} ,$$

$$\left\{\begin{matrix} u_n^b \\ \hline u_m^b \end{matrix}\right\} = \{u_g^b\}$$

and recovers single-point forces of constraint for current differential stiffness solution

$$\{q_s^b\} = -\{P_s^b\}+[K_{sf}^b]\{u_f^b\}+[K_{ff}^b]\{Y_s^b\} .$$

210. Go to DMAP No. 212 if no aerodynamic loads.

211. Equivalence $\{u_g^B\}$ to $\{u_g^A\}$.

213. ADD $-\{U_g^b\}$ and $\{U_g\}$ to form $\{U_g^d\}$.

214. DSMG1 generates differential stiffness matrix $[\delta K_{gg}^d]$.

216. MPYAD form load vector for inner loop iteration.

$$\{P_{g_{I1}}\} = \quad K_{gg}^d]\{U_g^b\}+\{P_{go}\}$$

217. ADD $\{P_{g_{I1}}\}$ and $\{P_g^A\}$ to form $\{P_{g_{I2}}\}$.

218. DSCHK performs differential stiffness convergence checks.

220. Go to DMAP No. 235 if differential stiffness iteration is complete.

221. Go to DMAP No. 227 if additional differential stiffness matrix changes are necessary for further iteration.

222. Equivalence breaks previous equivalence of $\{P_g\}$ to $\{P_{g1}\}$.

223. Equivalence $\{P_{g_{11}}\}$ to $\{P_{g1}\}$.

224. Equivalence breaks previous equivalence of $\{P_{g1}\}$ to $\{P_{g_{11}}\}$.

225. Go to DMAP No. 187 for additional inner loop differential stiffness iteration.

226. TABPT table prints vectors $\{P_{g_{11}}\}$, $\{P_{g1}\}$, and $\{P_g\}$.

228. ADD $-[\delta K^d_{gg}]$ and $[K^d_{gg}]$ to form $[K^d_{gg1}]$.

230. Equivalence $\{U^b_g\}$ to $\{U_g\}$ and $[K^d_{gg1}]$ to $[K^d_{gg}]$.

232. Equivalence breaks previous equivalence of $[K^d_{gg}]$ to $[K^d_{gg}]$ and $\{U_g\}$ to $\{U^b_g\}$.

233. Go to DMAP No. 143 for additional outer loop differential stiffness iteration.

234. TABPT table prints $[K^d_{gg1}]$, $[K^d_{gg}]$ and $\{U_g\}$.

237. Go to DMAP No. 241 if the total stiffness matrix is not to be saved on tape.

238. ADD $[K_{gg}]$ and $[K^d_{gg}]$ to form [KTOTAL].

239. OUTPUT1 outputs [KTOTAL] to tape.

240. OUTPUT1 prints the names of the data blocks on the output tape.

243. ALG generates final aerodynamic results and generates GRID and STREAML2 bulk data cards on the system punch, if requested.

244. SDR2 calculates element forces and stresses (ØEFB1, ØESB1) and prepares displacement vectors and single-point forces of constraint for output (ØUBGV1, PUBGV1, ØOBG1) for all differential stiffness solutions.

245. ØFP formats tables prepared by SDR2 and places them on the system output file for printing.

247. SDR1 recovers dependent displacements after differential stiffness loop for grid point force balance.

248. GPFDR calculates for requested sets the grid point force balance and element strain energy for output.

249. OFP formats the tables prepared by GPFDR and places them on the system output file for printing.

250. Go to DMAP No. 254 if no deformed differential stiffness structure plots are requested.

251. PLØT generates all requested deformed differential stiffness structure plots.

253. PRTMSG prints plotter data and engineering data for each deformed plot generated.

255. Go to DMAP No. 264 and make normal exit.

257. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERRØR MESSAGE NØ. 1 - NØ STRUCTURAL ELEMENTS HAVE BEEN DEFINED.

259. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERRØR MESSAGE NØ. 2 - FREE BØDY-SUPPØRTS NØT ALLØWED.

261. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERRØR MESSAGE NØ. 4 - MASS MATRIX REQUIRED FØR WEIGHT AND BALANCE CALCULATIONS.

263 STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERRØR MESSAGE NØ. 5 - NØ INDEPENDENT DEGREES OF FREEDØM HAVE BEEN DEFINED.

3.22.3 Automatic Output for Static Aerothermoelastic Analysis with Differential Stiffness

The value of the determinant of the sum of the elastic stiffness and the differential stiffness is automatically printed for each differential stiffness loading condition.

Iterative differential stiffness computations are terminated for one of five reasons. Iteration termination reasons are automatically printed in an information message. These reasons have the following meanings:

1. REASON 0 means the iteration procedure was incomplete at the time of exit. This is caused by an unexpected interruption of the iteration procedure prior to the time the subroutine has had a chance to perform necessary checks and tests. Not much more has happened other than to initialize the exit mode to REASON 0.

2. REASON 1 means the iteration procedure converged to the EPSIØ value supplied by the user on a PARAM bulk data card. (The default value of EPSIØ is 1.0E-5.)

3. REASON 2 means iteration procedure is diverging from the EPSIØ value supplied by the user on a PARAM bulk data card. (The default value of EPSIØ is 1.0E-5.)

4. reason 3 means insufficient time remaining to achieve convergence to the EPSIØ value supplied by the user on a PARAM bulk data card. (The default value of EPSIØ is 1.0E-5.)

5. REASON 4 means the number of iterations supplied by the user on a PARAM bulk data card has been met. (The default number of iterations is 10.)

Parameter values at the time of exit are automatically output as follows:

1. Parameter DØNE: -1 is normal; + N is the estimate of the number of iterations required to achieve convergence.

2. Parameter SHIFT: +1 indicates a return to the top of the inner loop was scheduled; -1 indicates a return to top of the outer loop was scheduled following the current iteration.

3. Parameter DSEPSI: the value of the ratio of energy error to total energy at the time of exit.

3.22.4 Case Control Deck DTI Table and Parameters for Static Aerothermoelastic Analysis with Differential Stiffness

The following items relate to subcase definition and data selection for Static Aerothermoelastic Analysis with Differential Stiffness:

1. The Case Control Deck must contain two subcases.

2. A static loading condition must be defined above the subcase level with a LØAD, TEMPERATURE(LOAD), or DEFORM selection, unless all loading is specified by grid point displacements on SPC cards.

3. An SPC set must be selected above the subcase level unless all constraints are specified on GRID cards.

4. Output requests that apply only to the linear solution must appear in the first subcase.

5. Output requests that apply only to the solution with differential stiffness must be placed in the second subcase.

6. Output requests that apply to both solutions, with and without differential stiffness may be placed above the subcase leve.

7. Aerodynamic input for the Aerodynamic Load Generator (ALG) module is input via data block ALGDB. This data block must be input using Direct Table Input (DTI) bulk data cards. For a detailed description of the ALGDB data block input see Section 1.15.3.1 of the User's Manual.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

The following output may be requested for Static Aerothermoelastic Analysis with Differential Stiffness:

1. Nonzero Components of the applied static load for the linear solution at selected grid points.

2. Displacement and nonzero components of the single-point forces of constraint, with and without differential stiffness, at selected grid points.

3. Forces and stresses in selected elements, with and without differential stiffness.

4. Undeformed and deformed plots of the structural model.

1. GRDPNT - optional - a positive integer value of this parameter will cause the Grid Point Weight Generator to be executed and the resulting weight and balance information to be printed.

2. WTMASS - optional - the terms of the mass matrix are multiplied by the real value of this parameter when they are generated in EMG.

3. IRES - optional - a positive integer value of this parameter will cause the printing of the residual vectors following the execution of SSG3.

4. CØUPMASS - CPBAR, CPRØD, CPQUAD1, CPQUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPQDPLT, CPTRPLT, CPTRBSC - optional - these parameters will cause the generation of coupled mass matrices rather than lumped mass matrices for all bar elements, rod elements, and plate elements that include bending stiffness.

5. BETAD - optional- the integer value of this parameter is the assumed number of iterations for the inner loop in shift decisions for iterated differential stiffness. The default value is 4 iterations.

6. NT - optional - the integer value of this parameter limits the maximum number of iterations. The default value is 10 iterations.

7. EPSIØ - optional - the real value of this parameter is used to test the convergence of iterated differential stiffness. The default value is 10^{-5}.

8. APRESS - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic pressures. A negative value (the default) will suppress the generation of aerodynamic pressure loads.

9. ATEMP - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic temperature loads. A negative value (the default) will suppress the generation of aerodynamic thermal loads.

10. STREAML - optional in static aerothermoelastic analysis. STREAML=1 causes the punching of STREAML1 bulk data cards. STREAML = 2 causes the punching of STREAML2 bulk data cards. STREAML=3 causes both STREAML1 and STREAML2 cards to be punched. The default value, -1, suppresses punching of any cards.

11. PGEØM - optional in static aerothermoelastic analysis. PGEOM=1 causes the punching of GRID bulk data cards. PGEOM=2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEØM=3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default, -1, suppresses punching of any cards.

12. IPRT - optional in static aerothermoelastic analysis. If IPRT > 0, then intermediate print will be generated in the ALG module based on the print option in the ALGDB data table. If IPRT = 0 (the default), no intermediate print will be generated. (IPRTCI, IPRTCL, IPRTCF)

13. SIGN - optional in static aerothermoelastic analysis. Controls the type of analysis being performed. SIGN = 1.0 for a standard analysis. SIGN = -1.0 for a design analysis. The default is 1.0.

14. ZØRIGN, FXCØØR, FYCØØR, FZCØØR - optional in static aerothermoelastic analysis. These are modification factors. The defauls are ZØRIGN = 0.0, FXCOOR = 1.0, FYCOOR = 1.0, and FZCOOR = 1.0.

15. KTOUT - optional in static aerothermoelastic analyses. A positive integer of this parameter indicates that the user wants to save the total stiffness matrix on tape (GINO file INPT) via the OUTPUT1 module in the rigid format. The default is -1.

3.23 COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

3.23.1 DMAP Sequence For Compressor Blade Cyclic Modal Flutter Analysis

RIGID FORMAT DMAP LISTING
SERIES O

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
OPTIONS IN EFFECT  GO      ERR=2   NOLIST  NODECK  NOREF   NOUSCAR

  1  BEGIN     AERO NO.9 COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS $

  2  FILE      PHIHL=APPEND/AJJL=APPEND/FSAVE=APPEND/CASEYY=APPEND/CLAMAL=
               APPEND/OVG=APPEND/QHHL=APPEND $

  3  GP1       GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/V,N,LUSET/  V,N,
               NOGPDT $

  4  SAVE      LUSET,NOGPDT $

  5  COND      ERROR1,NOGPDT $

  6  CHKPNT    GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL $

  7  PURGE     D1JE,D2JE/NODJE $

  8  GP2       GEOM2,EQEXIN/ECT $

  9  CHKPNT    ECT $

 10  GP3       GEOM3,EQEXIN,GEOM2/,GPTT/V,N,NOGRAV $

 11  CHKPNT    GPTT $

 12  TA1       ECT,EPT,BGPDT,SIL,GPTT,CSTM/EST,GEI,GPECT,/V,N,LUSET/   V,N,
               NOSIMP/C,N,1/V,N,NOGENL/V,N,GENEL $

 13  SAVE      NOGENL,NOSIMP,GENEL $

 14  COND      ERROR1,NOSIMP $

 15  PURGE     OGPST/GENEL $

 16  CHKPNT    EST,GPECT,GEI,OGPST $

 17  PARAM     //C,N,ADD/V,N,NOKGGX/C,N,1/C,N,0 $

 18  PARAM     //C,N,ADD/V,N,NOMGG/C,N,1/C,N,0 $

 19  PARAM     // C,N,NOP / V,Y,KGGIN=-1 $

 20  COND      JMPKGGIN,KGGIN $

 21  PARAM     //C,N,ADD /V,N,NOKGGX /C,N,-1 /C,N,0 $

 22  INPUTT1   / KGGIN,,,,/C,Y,LOCATION=-1 /C,Y,INPTUNIT=0 $
```

RIGID FORMAT DMAP LISTING
SERIES D

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
23  EQUIV   KGGIN,KGGX $
24  CHKPNT  KGGX $
25  LABEL   JMPKGGIN $
26  EMG     EST,CSTM,MPT,DIT,GEOM2,/KELM,KDICT,MELM,MDICT,,/V,N,NOKGGX/ V,
            N,NOMGG/C,N,/C,N,/C,N,/C,Y,COUPMASS/C,Y,CPBAR/C,Y,CPROD/  C,Y,
            CPQUAD1/C,Y,CPQUAD2/C,Y,CPTRIA1/C,Y,CPTRIA2/C,Y,CPTUBE/  C,Y,
            CPQDPLT/C,Y,CPTRPLT/C,Y,CPTRBSC $
27  SAVE    NOKGGX,NOMGG $
28  CHKPNT  KELM,KDICT,MELM,MDICT $
29  COND    JMPKGGX,NOKGGX $
30  EMA     GPECT,KDICT,KELM/KGGX,GPST $
31  CHKPNT  KGGX,GPST $
32  LABEL   JMPKGGX $
33  COND    ERROR1,NOMGG $
34  EMA     GPECT,MDICT,MELM/MGG,/C,N,-1/C,Y,WTMASS=1.0 $
35  CHKPNT  MGG $
36  COND    LGPWG,GRDPNT $
37  GPWG    BGPDT,CSTM,EQEXIN,MGG/OGPWG/V,Y,GRDPNT=-1/C,Y,WTMASS $
38  OFP     OGPWG,,,,,// $
39  LABEL   LGPWG $
40  EQUIV   KGGX,KGG/NOGENL $
41  CHKPNT  KGG $
42  COND    LBL11,NOGENL $
43  SMA3    GEI,KGGX/KGG/V,N,LUSET/V,N,NOGENL/V,N,NOSIMP $
44  CHKPNT  KGG $
45  LABEL   LBL11 $
46  GP4     CASECC,GEOM4,EQEXIN,SIL,GPDT,BGPDT,CSTM/RG,,USET,ASET/  V,N,
```

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES O

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
                 LUSET/V,N,MPCF1/V,N,MPCF2/V,N,SINGLE/V,N,OMIT/V,N,REACT/C,N,0/
                 V,N,REPEAT/V,N,NOSET/V,N,NOL/V,N,NOA/C,Y,SUBID $

47   SAVE        MPCF1,SINGLE,OMIT,REACT,NOSET,MPCF2,REPEAT,NOL,NOA $

48   PARAM       //C,N,NOT/V,N,REACDATA /V,N,REACT $

49   COND        ERROR5,REACDATA $

50   PURGE       GM,GMD/MPCF1/GO,GOD/OMIT/KFS,QPC/SINGLE $

51   GPCYC       GEOM4,EQEXIN,USET /CYCD/ V,Y,CTYPE / V,N,NOGO $

52   SAVE        NOGO $

53   CHKPNT      CYCD $

54   COND        ERROR6,NOGO $

55   COND        LBL4,GENEL $

56   GPSP        GPL,GPST,USET,SIL/OGPST/V,N,NOGPST $

57   SAVE        NOGPST $

58   COND        LBL4,NOGPST $

59   OFP         OGPST,,,,,// $

60   LABEL       LBL4 $

61   EQUIV       KGG,KNN/MPCF1/MGG,MNN/MPCF1 $

62   CHKPNT      KNN,MNN $

63   COND        LBL2,MPCF1 $

64   MCE1        USET,RG/GM $

65   CHKPNT      GM $

66   MCE2        USET,GM,KGG,MGG,,/KNN,MNN,, $

67   CHKPNT      KNN,MNN $

68   LABEL       LBL2 $

69   EQUIV       KNN,KFF/SINGLE/MNN,MFF/SINGLE $

70   CHKPNT      KFF,MFF $
```

RIGID FORMAT DMAP LISTING
SERIES D

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
71  COND    LBL3,SINGLE $
72  SCE1    USET,KNN,MNN,,/KFF,KFS,,MFF,, $
73  CHKPNT  KFF,KFS,MFF $
74  LABEL   LBL3 $
75  EQUIV   KFF,KAA/OMIT/ MFF,MAA/OMIT $
76  CHKPNT  KAA,MAA $
77  COND    LBL5,OMIT $
78  SMP1    USET,KFF,,,/GO,KAA,KOO,LOO,,,,, $
79  CHKPNT  GO,KAA $
80  SMP2    USET,GO,MFF/MAA $
81  CHKPNT  MAA $
82  LABEL   LBL5 $
83  DPD     DYNAMICS,GPL,SIL,USET/GPLD,SILD,USETD,TFPOOL,,,,,,EED,EQDYN/V,
            N,LUSET/V,N,LUSETD/V,N,NOTFL/V,N,NODLT/V,N,NOPSDL/V,N,NOFRL/V,
            N,NONLFT/V,N,NOTRL/V,N,NOEED/C,N,/V,N,NOUE $
84  SAVE    LUSETD,NOUE,NOEED $
85  COND    ERROR2,NOEED $
86  EQUIV   GO,GOD/NOUE/GM,GMD/NOUE $
87  CYCT2   CYCD,KAA,MAA,,, /KKK,MKK,,, / C,N,FORE / V,Y,NSEGS=-1 /V,Y,
            KINDEX=-1 / V,Y,CYCSEQ=-1 / C,N,1 / V,N,NOGO $
88  SAVE    NOGO $
89  CHKPNT  KKK,MKK $
90  COND    ERROR6,NOGO $
91  READ    KKK,MKK,,,EED,,CASECC / LAMK,PHIK, ,OEIGS / C,N,MODES /V,N,
            NEIGV $
92  SAVE    NEIGV $
93  CHKPNT  LAMK,PHIK,MI,OEIGS $
```

RIGID FORMAT DMAP LISTING
SERIES O

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
 94  PARAM     //C,N,MPY / V,N,CARDNO / C,N,0 / C,N,0 $
 95  OFP       OEIGS,LAMK,,,, // V,N,CARDNO $
 96  SAVE      CARDNO $
 97  COND      ERROR4,NEIGV $
 98  CYCT2     CYCD,,,,PHIK,LAMK /,,,PHIA,LAMA / C,N,BACK / V,Y,NSEGS /V,Y,
               KINDEX / V,Y,CYCSEQ / C,N,1 / V,N,NOGO $
 99  SAVE      NOGO $
100  CHKPNT    LAMA,PHIA $
101  COND      ERROR6,NOGO $
102  SDR1      USET,,PHIA,,,GO,GM,,KFS,, / PHIG,, / C,N,1 / C,N,REIG $
103  SDR2      CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LAMA,,PHIG,EST,, / ,,
               OPHIG,,, / C,N,REIG $
104  OFP       OPHIG,,,,,// V,N,CARDNO $
105  SAVE      CARDNO $
106  APDB      EDT,USET,BGPDT,CSTM,EQEXIN,GM,GO / AERO,ACPT,FLIST,GTKA,PVECT/
               V,N,NK/V,N,NJ/V,Y,MINMACH/V,Y,MAXMACH/V,Y,IREF/V,Y,MTYPE/V,N,
               NEIGV/V,Y,KINDEX=-1 $
107  SAVE      NK,NJ $
108  CHKPNT    AERO,ACPT,FLIST,GTKA,PVECT $
109  PARTN     PHIA,PVECT, / PHIAX,,, / C,N,1 $
110  SMPYAD    PHIAX,MAA,PHIAX,,, / MI / C,N,3/C,N,1/C,N,1/C,N,0/C,N,1 $
111  MTRXIN    CASECC,MATPOOL,EQDYN,,TFPOOL/K2PP,M2PP,B2PP/V,N,LUSETD/V,N,
               NOK2PP/V,N,NOM2PP/V,N,NOB2PP $
112  SAVE      NOK2PP,NOM2PP,NOB2PP $
113  PURGE     K2DD/NOK2PP/M2DD/NOM2PP/B2DD/NOB2PP $
114  EQUIV     M2PP,M2DD/NOSET/B2PP,B2DD/NOSET/K2PP,K2DD/NOSET $
115  CHKPNT    K2PP,M2PP,B2PP,K2DD,M2DD,B2DD $
116  GKAD      USETD,GM,GO,,,,,K2PP,M2PP,B2PP/,,,GMD,GOD,K2DD,M2DD,B2DD/C,N,
```

RIGID FORMAT DMAP LISTING
SERIES D

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
             CMPLEV/C,N,DISP/C,N,MODAL/C,N,0.0/C,N,0.0/C,N,0.0/V,N,NOK2PP/V,
             N,NOM2PP/V,N,NOB2PP/V,N,MPCF1/V,N,SINGLE/V,N,OMIT/V,N,NOUE/ C,
             N,-1/C,N,-1/C,N,-1/C,N,-1 $

117  CHKPNT  K2DD,M2DD,B2DD,GOD,GMD $

118  GKAM    USETD,PHIA,MI,LAMA,DIT,M2DD,B2DD,K2DD,CASECC / MHH,BHH,KHH,
             PHIDH / V,N,NOUE/C,Y,LMODES=999999/C,Y,LFREQ=0.0/C,Y,HFREQ=0.0/
             V,N,NOM2PP/V,N,NOB2PP/V,N,NOK2PP/V,N,NONCUP/V,N,FMODE/C,Y,
             KDAMP=-1 $

119  SAVE    NONCUP,FMODE $

120  CHKPNT  MHH,BHH,KHH,PHIDH $

121  PARAML  PCDB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NOPCDB $

122  PURGE   PLTSETX,PLTPAR,GPSETS,ELSETS / NOPCDB $

123  COND    P2,NOPCDB $

124  PLTSET  PCDB,EQDYN,ECT / PLTSETX,PLTPAR,GPSETS,ELSETS / V,N,NSIL1 /V,N,
             JUMPPLOT=-1 $

125  SAVE    NSIL1,JUMPPLOT $

126  PRTMSG  PLTSETX // $

127  PARAM   //C,N,MPY/V,N,PLTFLG/C,N,1/C,N,1 $

128  PARAM   //C,N,MPY/V,N,PFILE/C,N,0/C,N,0 $

129  COND    P2,JUMPPLOT $

130  PLOT    PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQDYN,,,,,/PLOTX1/V,N,NSIL1/
             V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $

131  SAVE    JUMPPLOT,PLTFLG,PFILE $

132  PRTMSG  PLOTX1 // $

133  LABEL   P2 $

134  COND    ERROR2,NOEED $

135  PARAM   //C,N,ADD/V,N,DESTRY/C,N,0/C,N,1 $

136  AMG     AERO,ACPT/AJJL,SKJ,D1JK,D2JK/V,N,NK/V,N,NJ/V,N,DESTRY $

137  SAVE    DESTRY $
```

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES U

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
138  CHKPNT    AJJL,SKJ,D1JK,D2JK $
139  COND      NODJE,NODJE $
140  INPUTT2   /D1JE,D2JE,,,/C,Y,POSITION=-1/C,Y,UNITNUM=11/   C,Y,USRLABEL=
               TAPEID $
141  LABEL     NODJE $
142  PARAM     //C,N,ADD/V,N,XQHHL/C,N,1/C,N,0 $
143  AMP       AJJL,SKJ,D1JK,D2JK,GTKA,PHIDH,D1JE,D2JE,USETD,AERO/QHHL,QJHL/V,
               N,NODE/V,N,XQHHL $
144  SAVE      XQHHL $
145  CHKPNT    QHHL,QJHL $
146  PARAM     //C,N,MPY/V,N,NOP/C,N,-1/C,N,1 $
147  PARAM     //C,N,MPY/V,N,NOP/C,N,1/C,N,1 $
148  PARAM     //C,N,MPY/V,N,NOH/C,N,0/C,N,1 $
149  PARAM     //C,N,MPY/V,N,FLOOP/V,Y,NODJE=-1/C,N,0 $
150  JUMP      LOOPTOP $
151  LABEL     LOOPTOP $
152  FA1       KHH,BHH,MHH,QHHL,CASECC,FLIST/FSAVE,KXHH,BXHH,MXHH/V,N,FLOOP/V,
               N,TSTART $
153  SAVE      FLOOP,TSTART $
154  CEAD      KXHH,BXHH,MXHH,EED,CASECC/PHIH,CLAMA,OCEIGS/V,N,EIGVS $
155  SAVE      EIGVS $
156  COND      LBLZAP,EIGVS $
157  COND      LBL16,NOH $
158  VDR       CASECC,EQDYN,USETD,PHIH,CLAMA,,/OPHIH,/C,N,CEIGEN/C,N,MODAL/C,
               N,123/V,N,NOH/V,N,NOP/V,N,FMODE $
159  SAVE      NOH,NOP $
160  COND      LBL16,NOH $
```

RIGID FURMAT DMAP LISTING
SERIES J

AERO APPROACH, RIGID FURMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
161  OFP      OPHIH,,,,,//V,N,CARDNO $
162  SAVE     CARDNO $
163  LABEL    LBL16 $
164  FA2      PHIH,CLAMA,FSAVE/PHIHL,CLAMAL,CASEYY,OVG/V,N,TSTART/C,Y,VREF=
              1.0/C,Y,PRINT=YESB $
165  SAVE     TSTART $
166  CHKPNT   PHIHL,CLAMAL,CASEYY,OVG $
167  COND     CONTINUE,TSTART $
168  LABEL    LBLZAP $
169  COND     CONTINUE,FLOOP $
170  REPT     LOOPTOP,100  $
171  JUMP     ERROR3 $
172  LABEL    CONTINUE $
173  CHKPNT   OVG $
174  PARAML   XYCDB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NOXYCDB $
175  COND     NOXYOUT,NOXYCDB $
176  XYTRAN   XYCDB,OVG,,,,/XYPLTCE/C,N,VG/C,N,PSET/V,N,PFILE/V,N,CARDNO $
177  SAVE     PFILE,CARDNO $
178  XYPLOT   XYPLTCE// $
179  LABEL    NOXYOUT $
180  PARAM    //C,N,AND/V,N,PJUMP/V,N,NOP=-1/V,N,JUMPPLOT $
181  COND     FINIS,PJUMP $
182  MODACC   CASEYY,CLAMAL,PHIHL,CASECC,,/CLAMAL1,CPHIH1,CASEZZ,,/C,N,
              CEIGN $
183  DDR1     CPHIH1,PHIDH/CPHID $
184  CHKPNT   CPHID $
```

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES D

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
185  EQUIV    CPHID,CPHIP/NOA $
186  COND     LBL14,NOA $
187  SDR1     USETD,,CPHID,,,GOD,GMD,,KFS,,/CPHIP,,QPC/C,N,1/C,N,DYNAMICS $
188  LABEL    LBL14 $
189  CHKPNT   CPHIP,QPC $
190  EQUIV    CPHID,CPHIA/NOUE $
191  COND     LBLNOE,NOUE $
192  VEC      USETD/RP/C,N,D/C,N,A/C,N,E $
193  PARTN    CPHID,,RP/CPHIA,,,/C,N,1/C,N,3 $
194  LABEL    LBLNOE $
195  SDR2     CASEZZ,CSTM,MPT,DIT,EQDYN,SILD,,,BGPDT,CLAMAL1,QPC,CPHIP,EST,,/
              ,OQPC1,OCPHIP,OESC1,OEFC1,PCPHIP/C,N,CEIGN $
196  CHKPNT   PCPHIP $
197  OFP      OCPHIP,OQPC1,OESC1,OEFC1,,//V,N,CARDNO $
198  COND     P3,JUMPPLOT $
199  PLOT     PLTPAR,GPSETS,ELSETS,CASEZZ,BGPDT,EQDYN,SILD,,PCPHIP,,/PLOTX3/
              V,N,NSIL1/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE $
200  PRTMSG   PLOTX3// $
201  LABEL    P3 $
202  JUMP     FINIS $
203  LABEL    ERROR1 $
204  PRTPARM  //C,N,-1/C,N,FSUBSCN $
205  LABEL    ERROR2 $
206  PRTPARM  //C,N,-2/C,N,FSUBSCN $
207  LABEL    ERROR3 $
208  PRTPARM  //C,N,-3/C,N,FSUBSCN $
```

RIGID FORMAT DMAP LISTING
SERIES O

AERO APPROACH, RIGID FORMAT 9

```
    LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

209  LABEL     ERROR4 $
210  PRTPARM   //C,N,-4/C,N,FSUBSGN $
211  LABEL     ERROR5 $
212  PRTPARM   // C,N,-4 / C,N,CYCMODES $
213  LABEL     ERROR6 $
214  PRTPARM   // C,N,-5 / C,N,CYCMODES $
215  LABEL     FINIS $
216  END       $

     **NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM**
```

3.23.2 Description of DMAP Operations for Compressor Blade Cyclic Modal Flutter Analysis

3. GP1 generates coordinate system transformation matrices, tables of grid point locations, and tables for relating internal and external grid point numbers.

5. Go to DMAP No. 203 and print error message if no grid points are present.

8. GP2 generates Element Connection Table with internal indices.

10. GP3 generates Static Loads Table and Grid Point Temperature Table.

12. TA1 generates element tables for use in matrix assembly and stress recovery.

14. Go to DMAP No. 203 and print error message if no elements have been defined.

20. Go to DMAP No. 25 if stiffness matrix is not user input.

21. Set parameter NOKGGX = -1 so that the stiffness matrix will not be generated in DMAP No. 26.

22. INPUTT1 reads the user supplied stiffness matrix from tape (GINO file INPT).

23. Equivalence $[K_{gg}^{x}]$ to $[K_{gg}^{IN}]$.

26. EMG generates structural element matrix tables and dictionaries for later assembly.

29. Go to DMAP No. 32 if no stiffness matrix is to be assembled.

30. EMA assembles stiffness matrix $[K_{gg}^{x}]$ and Grid Point Singularity Table.

33. Go to DMAP No. 203 and print error message if no mass matrix exists.

34. EMA assembles mass matrix $[M_{gg}]$.

36. Go to DMAP No. 39 if no weight and balance request.

37. GPWG generates weight and balance information.

38. ØFP formats weight and balance information and places it on the system output file for printing.

40. Equivalence $[K_{gg}^{x}]$ to $[K_{gg}]$ if no general elements.

42. Go to DMAP No. 45 if no general elements.

43. SMA3 adds general elements to $[K_{gg}^{x}]$ to obtain stiffness matrix $[K_{gg}]$.

46. GP4 generates flags defining members of various displacement sets (USET), forms multipoint constraint equations $[R_g]\{u_g\} = 0$.

49. Go to DMAP No. 211 and print error message if free-body supports are present.

51. GPCYC prepares segment boundary table.

54. Go to DMAP No. 213 and print error message if CYJOIN data is inconsistent.

55. Go to DMAP No. 60 if general elements present.

56. GPSP determines if possible grid point singularities remain.

58. Go to DMAP No. 60 if no grid point singularities remain.

59. ØFP formats the table of possible grid point singularities and places it on the system output file for printing.

61. Equivalence $[K_{gg}]$ to $[K_{nn}]$ and $[M_{gg}]$ to $[M_{nn}]$ if no multipoint constraints.

63. Go to DMAP No. 68 if MCE1 and MCE2 have already been executed for current set of multipoint constraints.

64. MCE1 partitions multipoint constraint equations $[R_g] = [R_m \mid R_n]$ and solves for multipoint constraint transformation matrix $[G_m] = -[R_m]^{-1}[R_n]$.

66. MCE2 partitions stiffness and mass matrices

$$[K_{gg}] = \left[\begin{array}{c|c} \bar{K}_{nn} & K_{nm} \\ \hline K_{mn} & K_{mm} \end{array}\right] \quad \text{and} \quad [M_{gg}] = \begin{bmatrix} \bar{M}_{nn} & M_{nm} \\ M_{mn} & M_{mm} \end{bmatrix}$$

and performs matrix reductions

$$[K_{nn}] = [\bar{K}_{nn}] + [G_M^T][K_{mn}] + [K_{mn}^T][G_m] + [G_m^T][K_{mm}][G_m] \text{ and}$$

$$[M_{nn}] = [\bar{M}_{nn}] + [G_M^T][M_{mn}] + [M_{mn}^T][G_m] + [G_m^T][M_{mm}][G_m].$$

69. Equivalence $[K_{nn}]$ to $[K_{ff}]$ and $[M_{nn}]$ to $[M_{ff}]$ if no single-point constraints.

71. Go to DMAP No. 74 if no single-point constraints.

72. SCE1 partitions out single-point constraints.

$$[K_{nn}] = \left[\begin{array}{c|c} K_{ff} & K_{fs} \\ \hline K_{sf} & K_{ss} \end{array}\right] \quad \text{and} \quad [M_{nn}] = \left[\begin{array}{c|c} M_{ff} & M_{fs} \\ \hline M_{sf} & M_{ss} \end{array}\right]$$

75. Equivalence $[K_{ff}]$ to $[K_{aa}]$ and $[M_{ff}]$ to $[M_{aa}]$ if no omitted degrees of freedom.

77. Go to DMAP No. 82 if no omitted coordinates.

78. SMP1 partitions constrained stiffness matrix

$$[K_{ff}] = \begin{bmatrix} \bar{K}_{aa} & \vdots & K_{ao} \\ \cdots & + & \cdots \\ K_{oa} & \vdots & K_{oo} \end{bmatrix}$$

and solves for transformation matrix $[G_o] = -[K_{oo}]^{-1}[K_{oa}]$

and performs matrix reduction $[K_{aa}] = [\bar{K}_{aa}] + [K_{oa}^T][G_o]$.

80. SMP2 partitions constrained mass matrix

$$[M_{ff}] = \begin{bmatrix} \bar{M}_{aa} & \vdots & M_{ao} \\ \cdots & + & \cdots \\ M_{oa} & \vdots & M_{oo} \end{bmatrix}$$

and performs matrix reduction

$$[M_{aa}] = [\bar{M}_{aa}] + [M_{oa}^T][G_o] + [G_o^T][M_{oo}][G_o] + [G_o^T][M_{oa}].$$

83. DPD generates flags defining members of various displacement sets used in dynamic analysis (USETD), tables relating internal and external grid point numbers, including extra points introduced for dynamic analysis, and prepares Transfer Function Pool and Eigenvalue Extraction Data.

85. Go to DMAP No. 205 and print error message if no Eigenvalue Extraction Data.

86. Equivalence $[G_o]$ to $[G_o^d]$ and $[G_m]$ to $[G_m^d]$ if no extra points introduced for dynamic analysis.

87. CYCT2 transforms matrices from symmetric components to solution set.

90. Go to DMAP No. 213 and print error message if CYCT2 error was found.

91. READ extracts real eigenvalues from the equation

$$[K_{kk} - \lambda M_{kk}]\{u_k\} = 0 \quad ,$$

and normalizes eigenvectors according to one of the following user requests:

1) Unit value of selected coordinate
2) Unit value of largest components
3) Unit value of generalized mass.

95. ØFP formats eigenvalues and summary of eigenvalue extraction information and places them on the system output file for printing.

97. Go to DMAP No. 209 and exit if no eigenvalues found.

98. CYCT2 finds symmetric components of eigenvectors from solution set eigenvectors.

101. Go to DMAP No. 213 and print error message if CYCT2 error was found.

102. SDR1 recovers dependent components of the eigenvectors

$$\{\phi_o\} = [G_o]\{\phi_a\} \quad , \qquad \left\{\begin{array}{c}\phi_a \\ \hline \phi_o\end{array}\right\} = \{\phi_f\} \quad ,$$

$$\left\{\begin{array}{c}\phi_f \\ \hline \phi_s\end{array}\right\} = \{\phi_n\} \quad , \qquad \{\phi_m\} \; [G_m]\{\phi_n\} \quad ,$$

$$\left\{\begin{array}{c}\phi_n \\ \hline \phi_m\end{array}\right\} = \{\phi_g\}$$

103. SDR2 prepares eigenvectors for output (ØPHIG).

104. ØFP formats tables prepared by SDR2 and places them on the system output file for printing.

105. APDB processes the aerodynamic data cards from EDT. AERO and ACPT reflect the aerodynamic parameters. PVECT is a partitioning vector and GTKA is a transformation matrix between aerodynamic (K) and structural (a) degrees of freedom.

109. PARTN partitions the eigenvector into all sine or all cosine components.

110. SMPYAD calculates modal mass matrix

$$[M] = [\phi_a^x]^T \, [M_{aa}] \, [\phi_a^x]$$

111. MTRXIN selects the direct input matrices $[K_{pp}^2]$, $[M_{pp}^2]$, and $[B_{pp}^2]$.

114. Equivalence $[M_{pp}^2]$ to $[M_{dd}^2]$, $[B_{pp}^2]$ to $[B_{dd}^2]$ and $[K_{pp}^2]$ to $[K_{dd}^2]$ if no no constraints applied.

116. GKAD applies constraints to direct input matrices $[K_{pp}^2]$, $[M_{pp}^2]$, and $[M_{dd}^2]$, and $[B_{dd}^2]$ (see Section 9.3.3 of the Theoretical Manual) and forms $[G_{md}]$ and $[G_{od}]$.

118. GKAM selects eigenvectors to form $[\phi_{dh}]$ and assembles stiffness, matrices and damping matrices in modal coordinates:

$$[K_{hh}] = \begin{bmatrix} k_i & 0 \\ 0 & 0 \end{bmatrix} + [\phi^T_{dh}][K^2_{dd}][\phi_{dh}] \, ,$$

$$[M_{hh}] = \begin{bmatrix} m_i & 0 \\ 0 & 0 \end{bmatrix} + [\phi^T_{dh}][M^2_{dd}][\phi_{dh}] \, ,$$

$$[B_{hh}] = \begin{bmatrix} b_i & 0 \\ 0 & 0 \end{bmatrix} + [\phi^T_{dh}][B^2_{dd}][\phi_{dh}] \, .$$

where

KDAMP = 1	KDAMP = -1 (default)
m_i = modal masses	m_i = modal masses
$b_i = m_i \, 2\pi \, f_i g(f_i)$	$b_i = 0$
$k_i = m_i \, 4\pi^2 \, f_i$	$k_i = (1+ig(f_i)) \, 4\pi^2 f_i^2 m_i$

123. Go to DMAP No. 133 if no plot package is present.

124. PLTSET transforms user input into a form used to drive structure plotter.

126. PRTMSG prints error messages associated with structure plotter.

129. GO to DMAP No. 133 if no undeformed aerodynamic structure plot request.

130. PLØT generates all requested undeformed structure plots.

132. PRTMSG prints plotter data and engineering data for each undeformed aerodynamic plot generated.

134. Go to DMAP No. 205 and print error message if no Eigenvalue Extraction Data.

136. AMG forms the aerodynamic materix list $[A_{jj}]$, the area matrix $[S_{kj}]$, and the downwash coefficients $[D^1_{jk}]$ and $[D^2_{jk}]$.

139. Go to DMAP No. 141 if no user-supplied downwash coefficients.

140. INPUTT2 provides the user-supplied downwash factors due to extra points($[D^1_{je}]$, $[D^2_{je}]$).

143. AMP computes the aerodynamic matrix list related to the modal coordinates as follows:

$$[\phi_{dh}] = \left[\begin{array}{c|c} \phi_{ai} & \phi_{ae} \\ \hline \phi_{ei} & \phi_{ee} \end{array}\right] \qquad [G_{ki}] = [G^T_{ka}]^T[\phi_{ai}]$$

$$[D^1_{jh}] \leftarrow [D^1_{ji} \mid D^1_{je}] \qquad [D^1_{ji}] = [D^1_{jk}]^T[G_{ki}]$$

$$[D^2_{jh}] \leftarrow [D^2_{ji} \mid D^2_{je}] \qquad [D^2_{ji}] = [C^2_{jk}]^T[G_{ki}]$$

For each (m,k) pair:

$$[D_{jh}] = [D^1_{jh}] + ik[D^2_{jh}]$$

for each group:

$$[Q_{jh}] = [A^T_{jj}]^{-1}_{group}\ [D_{jh}]\ \text{group}$$

$$[Q_{kh}] = [S_{kj}][Q_{jh}]$$

$$[Q_{ih}] = [G_{ki}]^T[Q_{kh}]$$

$$[Q_{hh}] \leftarrow \begin{bmatrix} Q_{ih} \\ \hline Q_{eh} \end{bmatrix}$$

149. PARAM initializes the flutter loop couter (FLØØP) to zero.

150. Go to next DMAP instruction if cold start or modified restart. LØØPTØP will be altered by the Executive System to the proper location inside the loop for unmodified restarts within the loop.

151. Beginning of loop for flutter.

152. FA1 computes the total aerodynamic mass matrix $[M^x_{hh}]$, the total aerodynamic stiffness matrix $[K^x_{hh}]$ and the total aerodynamic damping matrix $[B^x_{hh}]$ as well as a looping table FSAVE. For the K-method

$$M^x_{hh} = (k^2/b^2)M_{hh} + (\rho/2)\,Q_{hh} \;,$$

$$K^x_{hh} = K_{hh} \;,$$

$$B^x_{hh} = 0$$

154. CEAD extracts complex eigenvalues from the equation

$$[M^x_{hh}p^2 + B^x_{hh}p + K^x_{hh}]\{\phi_h\} = 0$$

and normalizes eigenvectors to unit magnitude of largest component.

156. Go to DMAP No. 168 if no complex eigenvalues found.

157. Go to DMAP No. 163 if no output request for the extra points introduced for dynamic analysis or modal coordinates.

158. VDR prepares eigenvectors for output, using only the extra points introduced for dynamic analysis and modal coordinates.

160. Go to DMAP No. 163 if no output request for the extra points introduced for dynamic analysis or modal coordinates.

161 ØFP formats eigenvectors for extra points introduced for dynamic analysis and modal coordinates and places them on the system output file for printing.

164. FA2 appends eigenvectors to PHIHL, eigenvalues to CLAMAL, Case Control to CASEYY, and V-g plot data to ØVG.

167. Go to DMAP No. 172 if there is insufficient time for another flutter loop.

169. Go to DMAP No. 172 if flutter loop complete.

171. Go to DMAP No. 207 for additional aerodynamic configuration triplet values.

175. Go to DMAP No. 179 if no X-Y plot package is present.

176. XYTRAN prepares the input for requested X-Y plots.

178. XYPLØT prepares requested X-Y plots of displacements, velocities, accelerations, forces, stresses, loads or single-point forces of constraint vs. time.

181. Go to DMAP No. 215 if no output requests involve dependent degrees of freedom or forces and stresses.

182. MØDACC selects a list of eigenvalues and vectors whose imaginary parts (velocity in input units) are close to a user input list.

183. DDR1 transforms the complex eigenvectors from modal to physical coordinates

$$[\phi^c_d] = [\phi_{dh}][\phi_h] .$$

185. Equivalence $[\phi^c_p]$ to $[\phi^c_p]$ if no constraints applied.

186 Go to DMAP No. 188 if no constraints applied.

187. SDR1 recovers dependent components of eigenvectors

$$\{\phi_d^c\} = [G_o^d]\{\phi_d^c\} \quad , \qquad \begin{Bmatrix}\phi_d \\ \phi_o\end{Bmatrix} = \{\phi_f^c + \phi_e^c\} \quad .$$

$$\begin{Bmatrix}\phi_f^c + \phi_e^c \\ \phi_s^c\end{Bmatrix} = \{\phi_n^c + \phi_e^c\} \quad , \qquad \{\phi_m^c\} = [G_m^d]\{\phi_n^c + \phi_e^c\} \quad .$$

$$\begin{Bmatrix}\phi_f^c + \phi_e^c \\ \phi_e^c\end{Bmatrix} = \{\phi_p^c\}$$

and recovers single-point forces of constraint $\{q_s\}$ =

$$[K_{fs}^T]\{\phi_f\}, \quad \begin{Bmatrix}0 \\ q_s\end{Bmatrix} = \{Q_p^c\} \quad .$$

190. Equivalence $[\phi_d^c]$ to $[\phi_a^c]$ if no extra points introduced for dynamic analysis.

191. Go to DMAP No. 194 if no extra points present.

192. VEC generates a d-size partitioning vector (RP) for the a and e sets.

193. PARTN performs partition of $[\phi_d^c]$ using RP.

$$\{\phi_d^c\} = \begin{Bmatrix}\phi_a^c \\ \phi_e^c\end{Bmatrix}$$

195. SDR2 calculates element forces and stresses (ØEFC1, ØESC1) and prepares eigenvectors and single-point forces of constraint for output (ØCPHIP, ØQPC1). It also prepares PCPHIP for deformed plotting.

197. ØFP formats tables prepared by SDR2 and places them on the system output file for printing.

198. Go to DMAP No. 194 if no deformed structure plots are requested.

199. PLØT prepares all deformed structure plots.

200. PRTMSG prints plotter data and engineering data for each deformed plot generated.

202. Go to DMAP No. 215 and make normal exit.

204. MØDAL CØMPLEX EIGENVALUE ANALYSIS ERRØR MESSAGE NØ. 1 - MASS MATRIX REQUIRED FØR MØDAL FØRMULATIØN.

206. MØDAL CØMPLEX EIGENVALUE ANALYSIS ERRØR MESSAGE NØ. 2 - EIGENVALUE EXTRACTIØN DATA PEQUIRED FØR REAL EIGENVALUE ANALYSIS.

208. MØDAL CØMPLEX EIGENVALUE ANALYSIS ERRØR MESSAGE NØ. 3 - ATTEMPT TO EXECUTE MØRE THAN 100 LØØPS.

210. MØDAL CØMPLEX EIGENVALUE ANALYSIS ERRØR MESSAGE NØ. 4 - REAL EIGENVALUES REQUIRED FØR MØDAL FØRMULATIØN.

212. NØRMAL MØDES WITH CYCLIC SYMMETRY ERRØR MESSAGE NØ. 4 - FREE BØDY SUPPØRTS NØT ALLØWED.

214. NØRMAL MØDES WITH CYCLIC SYMMETRY ERRØR MESSAGE NØ. 5 - CYCLIC SYMMETRY DATA ERRØR.

3.23.3 Output for Compressor Blade Modal Flutter Analysis

The Real Eigen value Summary Table and the Real Eigenvalue Analysis summary, as described under Normal Mode Analysis, are automatically printed. All real eigenvalues are included even though all may not be used in the modal formulation.

The grid point singularities from the structural model are also output.

A flutter summary for each value of the configuration parameters is printed out if PRINT=YESB. This shows ρ, k, 1/k, σ, $\sigma * V_{sound}$, V, g and f for each complex eigenvalue.

V-g and V-f plots may be requested by the XYØUT control cards by specifying the curve type as VG. The "points" are loop numbers and the "components" are G or F.

Printed output of the following types, sorted by complex eigenvalue root number (SORT1) and (m, k, ρ) may be requested for all complex eigenvalues kept, as either real and imaginary parts or magnitude and phase angle (0° - 360° lead):

1. The eigenvector for a list of PHYSICAL points (grid points, extra points) or SØLUTION points (modal coordinates and extra points).

2. Nonzero components of the single-point forces of constraint for a list of PHYSICAL points.

3. Complex stresses and forces in selected elements.

The ØFREQUENCY case control card can select a subset of the complex eigenvectors for data recovery. In addition, undeformed and deformed shapes may be requested. Undeformed shapes may include only structural elements.

3.23.4 Case Control Deck and Parameters for Compressor Blade Cyclic Modal Flutter Analysis

1. Only one subcase is allowed
2. Desired direct input matrices for stiffness $[K^2_{pp}]$, mass $[M^2_{pp}]$, and damping $[B^2_{pp}]$ must be selected via the keywords K2PP, M2PP, or B2PP.
3. CMETHØD must be used to select an EIGC card from the Bulk Data Deck.
4. FMETHØD must be used to select a FLUTTER card from the Bulk Data Deck.
5. METHØD must be used to select an EIGR card that exists in the Bulk Data Deck.
6. SDAMPING must be used to select a TABDMP1 table if structural damping is desired.
7. 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.
8. Each NASTRAN run calculates modes for only one symmetry index, K.

The following user parameters are used in Compressor Blade Cyclic Modal Flutter Analysis.

1. GRDPNT - optional - A positive integer value of this parameter will cause the Grid Point Weight Generator to be executed and the resulting weight and balance information to be printed. All fluid related masses are ignored.
2. WTMASS - optional - The terms of the structural mass matrix are multiplied by the real value of this parameter when they are generated in SMA2. Not recommended for use in hydroelastic problems.
3. CØUPMASS - CPBAR, CPRØD, CPQUAD1, CPQUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPQDPLT, CPTRPLT, CPTRBSC - optional - These parameters will cause the generation of coupled mass matrices rather than lumped mass matrices for all bar elements, rod elements, and plate elements that include bending stiffness.

4. LFREQ and HFREQ - required unless LMØDES is used. The real values of these parameters give the frequency range (LFREQ is lower limit and HFREQ is upper limit) of the modes to be used in the modal formulation. To use this option, LMØDES must be set to 0.

5. LMØDES - used unless set to 0. The integer value of this parameter is the number of lowest modes to be used in the modal formulation. The defalult value will request all modes to be used.

6. NØDJE - optional in modal flutter analysis. A positive integer of this parameter indicates that user supplied downwash matrices due to extra points are to be read from tape via the INPUTT2 module in the rigid format. The default value is -1.

7. P1, P2 and P3 - required in modal flutter analysis when using NØDJE parameter. See Section 5.3.2 for tape operation parameters required by INPUTT2 module. The defaults for P1, P2, and P3 are -1, 11 and TAPEID, respectively.

8. VREF - optional in modal flutter analysis. Velocities are divided by the real value of this parameter to convert units or to compute flutter indices. The default value is 1.0.

9. PRINT - optional in modal flutter analysis. The BCD value NØ, of this parameter will suppress the automatic printing of the flutter summary for the k method. The flutter summary table will be printed if the BCD value is YES for wing flutter, or YESB for blade flutter. The default is YES.

10. CTYPE - required - the BCD value of this parameter defines the type of cyclic symmetry as follows:

    (1) RØT - rotational symmetry

    (2) DRL - dihedral symmetry, using right and left halves

    (3) DSA - dihedral symmetry, using symmetric and anti-symmetric components

11. NSEGS - required - the integer value of this parameter is the number of identical segments in the structural model.

12. CYCSEQ - optional - the integer value of this parameter specifies the procedure for sequencing the equations in the solution set. A value of +1 specifies that all cosine terms should be sequenced before all sine terms, and a value of -1 for alternating the cosine and sine terms. The default value is -1.

13. KINDEX - required in compressor blade cyclic modal flutter analysis. The integer value of this parameter specifies a single value of the harmonic index.

14. MINMACH - optional in blade flutter analysis. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid. The default is 1.01.

15. MAXMACH - optional in blade flutter analysis. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid. The default value is 0.80.

16. IREF - optional in blade flutter analysis. This defines the reference streamline number. IREF must be equal to a SLN on a STREAML2 bulk data card. The default value, -1, represents the streamsurface at the blade tip. If IREF does not correspond to a SLN, then the default will be taken.

17. MTYPE - optional in cyclic modal blade flutter analysis. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = COSINE for cosine components. The default BCD value is COSINE.

18. KGGIN - optional in blade flutter analysis. A positive integer of this parameter indicates that the user supplied stiffness matrix is to be read from tape (GINO file INPT) via the INPUTT1 module in the rigid format. The default is -1.

4.149 FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149.1 Entry Point: UD0300

4.149.2 Purpose

The principal function of ALG is to generate an aerodynamic pressure and/or temperature distribution for compressor blades. The ALG module may also be used as a compressor blade mesh generator to punch GRID, CTRIA2 and PTRIA2 bulk data cards. Bulk data cards STREAML1 and STREAML2 can also be generated by ALG by user request.

4.149.3 DMAP Calling Sequence

```
ALG  CASECC, EDT, EQEXIN, {AUGV / UBGV}, ALGDB, CSTM, BGPDT/ CASECCA, GEØM3A/
     S, Y, APRESS/ S, Y, ATEMP/ V, Y, STREAML/ V, Y, PGEØM/ V, Y, IPRT/
     S, N, IFAIL/ V, Y, SIGN/ V, Y, ZØRIGN/ V, Y, FXCØØR/ V, Y, FYCØØR/
     V, Y, FZCØØR $
```

4.149.4 Input Data Blocks

CASECC - Case control data table

EDT - Aerodynamic bulk data cards

EQEXIN - Equivalence between external grid or scalar numbers and internal numbers

AUGV / UBGV } - Displacement vector matrix giving displacements in the g-set

ALGDB - Compressor blade data table

CSTM - Coordinate system transformation matrices

BGPDT - Basic grid point definition table

Notes:

1. CASECC and ALGDB cannot be purged.

2. AUGV or UBGV can be purged.

3. EQEXIN, CSTM and BGPDT can be purged if AUGV is purged.

4. EDT can be purged if AUGV is purged and parameter STREAML = -1.

5. ALGDB may be input via DTI bulk data cards.

4.149.5 Output Data Blocks

CASECCA - Revised case control data table

GEØM3A - Static load and temperature table

Note:

1. CASECCA and GEØM3A may not be purged.

4.149.6 Parameters

APRESS - Input - integer - default = -1. If APRESS > 0, then aerodynamic pressures will be generated.

ATEMP - Input - integer - default = -1. If ATEMP > 0, then aerodynamic temperatures will be generated.

STREAML - Input - integer - default = -1. Controls the punching of STREAML1 and STREAML2 cards. STREAML = 1, punch STREAML1 cards. STREAML = 2, punch STREAML2 cards. STREAML = 3, punch both STREAML1 and STREAML2 cards.

PGEØM - Input - integer - default = -1. Controls the punching of blade geometry bulk data cards. PGEØM = 1, punch GRID cards. PGEØM = 2, punch GRID, CTRIA2 and PTRIA2 cards. PGEOM = 3, punch GRID cards and the modified ALGDB table on DTI cards.

IPRT - Input - integer - default = 0. If IPRT > 0, then intermediate print will be generated based on the print option in ALGDB data table.

IFAIL - Output - integer - default = 0. Set to -1 if there is a convergence failure.

SIGN - Input - real - default = 1.0. Controls the type of analysis being performed. SIGN = 1.0 for standard blade analysis. SIGN = -1.0 for design analysis.

ZØRIGN - Input - real - default = 0.0. Modification factor.

FXCØØR - Input - real - default = 1.0. Modification factor.

FYCØØR - Input - real - default = 1.0. Modification factor.

FZCØØR - Input - real - default = 1.0. Modification factor.

4.149.7 Method

(a) Data block ALGDB contains all the input needed to generate the aerodynamic pressures and temperatures on the compressor blade. However, the aerodynamic loads are a function of the blade shape and the data defined in ALGDB must first be modified to account for any change in the blade shape or input via the displacement vector matrix AUGV. If AUGV is purged, then ALGDB is not modified. The ALGDB data block is read and the aerodynamic loads are calculated for the compressor blade being analyzed.

(b) The CASECC data block is read and a copy of it is output to CASECCA with changes to data items 4 and 7 for all subcases. In CASECCA, word 4 is set to 60 if aerodynamic pressure loads were generated, and word 7 is set to 70 if aerodynamic thermal loads were generated.

(c) The GEØM3A data block contains aerodynamic load and temperature data. If parameter APRESS > 0, then PLØAD2 cards with set identification number 60 are stored on GEØM3A. If parameter ATEMP > 0, then TEMP and TEMPD cards with set identification number 70 are stored on GEØM3A

(d) Parameters STREAML and PGEØM control the punching of bulk data cards STREAML1, STREAML2, GRID, CTRIA2, PTRIA2 and DTI. The ALG module may be used in a one module DMAP program as a compressor blade mesh and geometry generator as follows:

```
BEGIN $

ALG CASECC,,,,ALGDB,,/CASECCA,GEØM3A/C,N,-1/C,N,-1/C,N,3/C,N,2/C,N,1$

END $
```

4.149.8 Subroutines Called

4.149.8.1 Utility subroutines GMMATS, PRETRS and TRANSS are called.

4.149.8.2 Subroutine Name: UD03PR

1. Entry Point: UD03PR

2. Purpose: Modify ALGDB data block.

3. Calling Sequence: CALL UD03PR (IERR)

4.149.8.3 Subroutine Name: UD03PB

1. Entry Point: UD03PB

2. Purpose: Identify data fields as being either BCD alpha, real or integer.

3. Calling Sequence: CALL UD03PB (IDAT, NTYPE)

4.149.8.4 Subroutine Name: UD03PØ

1. Entry Point: UD03PØ

2. Purpose: Generate data blocks CASECCA and GEØM3A.

3. Calling Sequence: CALL UD03PØ (SCR1)

4.149.8.5 Subroutine Name: UDO3AP

1. Entry Point: UDO3AP

2. Purpose: Punch the modified ALGDB table data block on DTI Bulk Data cards if parameter PGEØM - 3.

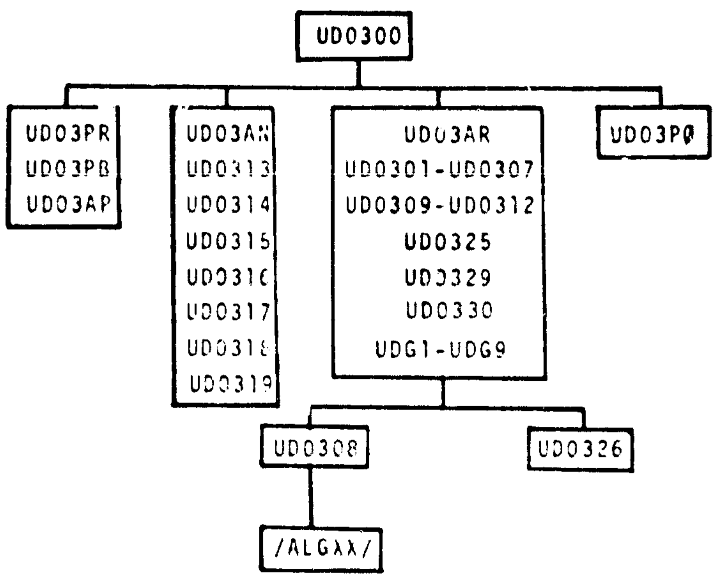
3. Calling Sequence: CALL UDO3AP (IFNAME, IFNM)

4.149.8.6 Subroutines: UD03AN, UD03AR, UD03C1-UD0319, UD0325, UD0326, UD0329, UD0330 and UDG1-UDG9 are described in references ARL-72-0171, AD-756879; and ARL-75-0001, AD-A009273.

4.149.9 Design Requirements

1. ALG uses 4 scratch files.

2. Overlay considerations - to maximize open core, ALG could look as follows:



4.149.10 Diagnostic Messages

The following messages may occur: 3001, 3002, 3003 and 3008.

4.150 FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

4.150.1 Entry Point: APDB

4.150.2 Purpose

Bulk data cards which control the solution of aerodynamic problems are processed and assembled into various blocks for convenience and efficiency in the solution of the aerodynamic problem. APDB also generates the transformation matrix $[G_{ka}]^T$ (GTKA) and the partitioning vector PVECT.

4.150.3 DMAP Calling Sequence

```
APDB     EDT, USET, BGPDT, CSTM, EQEXIN, GM, GØ/ AERØ, ACPT, FLIST, GTKA,
         PVECT/ V, N, NK/ V, N, NJ/ V, Y, MINMACH/ V, Y, MAXMACH/ V, Y, IREF/
         V, Y, MTYPE/ V, N, NEIGV/ V, Y, KINDEX = -1 $
```

4.150.4 Input Data Blocks

EDT - Aerodynamic bulk data cards

USET - Displacement set definition table

BGPDT - Basic grid point definition table

CSTM - Coordinate system transformation matrices

EQEXIN - Equivalence between external points and scalar index values

GM - Multipoint constraint transformation matrix

GØ - Structural matrix partitioning transformation matrix

Notes:

1. EDT, USET, BGPDT and EQEXIN cannot be purged.

2. CSTM may be purged if all points are in the basic system.

3. GM and GØ may be purged if there are no multipoint or no omitted points.

4.150.5 Output Data Blocks

AERØ - Control information for control of aerodynamic matrix generation and flutter analysis

ACPT - Information pertaining to each independent group of aerodynamic elements

FLIST - Contains AERØ, FLFACT and FLUTTER cards copied from EDT

GTKA - Aerodynamic transformation matrix - K set to a set

PVECT - Cyclic modes partitioning vector for matrix PHIA from module CYCT2

Notes:

1. AERØ, ACPT, FLIST and GTKA cannot be purged.

2. PVECT may be purged if there are no cyclic modes to be partitioned.

4.150.6 Parameters

NK - Output - integer - no default. Degrees of freedom in the NK displacement set.

NJ - Output - integer - no default. Degrees of freedom in the NJ displacement set.

MINMACH - Input - real - default = 0.8. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid.

MAXMACH - Input - real - default = 1.01. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid.

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

IREF - Input - integer - default = -1. This defines the streamline number of the reference stream surface. IREF must equal an SLN on a STREAML2 card. The default value, -1, represents the stream surface at the blade tip. If IREF does not correspond to an SLN, then the default will be taken.

MTYPE - Input - BCD - default = CØSINE. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = CØSINE for cosine components.

NEIGV - Input - BCD - no default. The number of eigenvalues found. Usually output by the READ module.

KINDEX - Input - BCD - default = -1. Harmonic index number used in cyclic analyses.

4.150.7 Method

Subroutine APDB is the main control program for this module. It allocates buffers, reads input files, and initializes output files. APDB creates the AERØ, ACPT and FLIST tables and generates the PVECT partitioning vector. Subroutine APDB1 generates the GTKA transformation matrix. APDB1 reduces $[G^T_{Kg}]$ to $[G^T_{ka}]$, much like module SSG2, using the following matrix operations:

$$[G^T_{Kg}] \rightarrow \begin{bmatrix} \bar{G}^T_{KN} \\ \hline G^T_{KM} \end{bmatrix}$$

$$[G^T_{KN}] = [G_M]^T \, [G^T_{KM}] + [\bar{G}^T_{KN}]$$

$$[G^T_{KN}] \rightarrow \begin{bmatrix} G^T_{Kf} \\ \hline G^T_{KS} \end{bmatrix}$$

$$[G^T_{Kf}] \rightarrow \begin{bmatrix} \bar{G}^T_{Ka} \\ \hline G^T_{K\phi} \end{bmatrix}$$

$$[G^T_{Ka}] = [G_\phi]^T [G^T_{K\phi}] + [\bar{G}^T_{Ka}]$$

At each step where a matrix multiply is indicated, the multiply is skipped if the result is known to be zero (i.e., U_n or U_ϕ are null).

4.150.8 Subroutines Called

Utility routines BISLØC, CALCV, SSG2B, TRANSS and GMMATS all called.

4.150.8.1 Subroutine Name: APDB1

1. Entry Point: APDB1
2. Purpose: To generate transformation matrix $[G^T_{Ka}]$.
3. Calling Sequence: CALL APDB1 (IBUF1, IBUF2, NEXT, LEFT, NTN, NLINE$, LC$TM, AC$TM, NØDEX, NØDEI, I$ILC, XYZB).

4.150.9 Design Requirements

Open core is located at /APDBZZ/. APDB uses five scratch files.

4.150.10 Diagnostic Messages

System fatal messages 3001, 3002, 3003, 3008 and 3037 may occur. The APDB module also generates its own messages that are not numbered. These messages are self-explanatory.

6.1.1.16 Rigid Format Error Messages for Static Aerothermoelastic Analysis with Differential Stiffness

NØ. 1 - NØ STRUCTURAL ELEMENTS HAVE BEEN DEFINED.

The differential stiffness matrix is null because no structural elements have been defined with Connection cards.

NØ. 2 - FREE BØDY SUPPØRTS NØT ALLØWED.

Free bodies are not allowed in Static Analysis with Differential Stiffness. The SUPPØRT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

NØ. 3 - MASS MATRIX REQUIRED FØR WEIGHT AND BALANCE CALCULATIØNS.

The mass matrix is null because either no elements were defined with Connection cards, nonstructural mass was not defined on a Property card, or the density was not defined on a Material card.

NØ. 5 - NØ INDEPENDENT DEGREES ØF FREEDØM HAVE BEEN DEFINED.

Either no degrees of freedom have been defined on GRID, SPØINT or Scalar Connection cards, or all defined degrees of freedom have been constrained by SPC, MPC, ØMIT, or GRDSET cards, or grounded on Scalar Connection cards.

6.1.3 Aero Approach Rigid Formats

The texts of the rigid format error messages are given in the following section for the aero approach rigid formats. The text for each message is given in capital letters and is followed by additional explanatory material, including suggestions for remedial action.

6.1.3.1 Rigid Format Error Messages for Modal Flutter Analysis

NØ. 1 - MASS MATRIX REQUIRED FØR MØDAL FØRMULATIØN.

The mass matrix is null because either no structural elements were defined with Connection cards, nonstructural mass was not defined on a Property card or the density was not defined on a Material card.

NØ. 2 - EIGENVALUE EXTRACTIØN DATA REQUIRED FØR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHØD must select an EIGR set in the Case Control Deck.

NØ. 3 - ATTEMPT TØ EXECUTE MØRE THAN 100 LØØPS.

An attempt has been made to use more than 100 different sets of direct input matrices. This number can be increased by altering the REPT instruction following FA2.

NØ. 4 - REAL EIGENVALUES REQUIRED FØR MØDAL FØRMULATIØN.

No real eigenvalues were found in the frequency range specified by the user.

6.1.3.2 Rigid Format Error Messages for Compressor Blade Cyclic Modal Flutter Analysis.

NØ. 1 - MASS MATRIX REQUIRED FØR MØDAL FØRMULATIØN

The mass matrix is null because either no structural elements were defined with Connection cards,nonstructural mass was not defined on a Property card or the density was not defined on a Material card.

NØ. 2 - EIGENVALUE EXTRACTIØN DATA REQUIRED FØR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHØD must select an EIGR set in the Case Control Deck.

NØ. 3 - ATTEMPT TØ EXECUTE MØRE THAN 100 LØØPS.

An attempt has been made to use more than 100 different sets of direct input matrices. This number can be increased by altering the REPT instruction following FA2.

NØ. 4 - REAL EIGENVALUES REQUIRED FØR MØDAL FØRMULATIØN.

No real eigenvalues were found in the frequency range specified by the user.

NØ. 5 - FREE BØDY SUPPØRTS NØT ALLØWED.

Free bodies are not allowed in Statics with Cyclic Symmetry. The SUPØRT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

NØ. 6 - CYCLIC SYMMETRY DATA ERRØR.

See Section 1.12 for proper modeling techniques and corresponding PARAM card requirements.

NASTRAN DICTIONARY

A	P	Parameter value used to control utility module MATGPR print of A-set matrices.
ABFL	DBM	$[A_{b,f\ell}]$ = Hydroelastic boundary area factor matrix.
ABFLT	DBM	Transpose of $[A_{b,f\ell}]$
ACCE	IC	Abbreviated form of ACCELERATIØN.
ACCELERATIØN	IC	Output request for acceleration vector. (UM-2.3, 4.2)
ACPT	DBT	Aerodynamic Connection and Property Data.
Active Column	PH	Column containing at least one nonzero term outside the band.
ADD	FMM	Functional module to add two matrices together.
ADD	M	Parameter constant used in utility module PARAM.
ADD5	FMM	Functional Module to add up to five matrices together.
ADUMi	IB	Defines attributes of dummy elements 1 through 9.
AEFACT	IB	Used to input lists of real numbers for aeroelastic analysis.
AERØ	DBT	Aerodynamic Matrix Generation Data.
AERØ	IB	Gives basic aerodynamic parameters.
AJJL	DBML	Aerodynamic Influence Matrix List.
ALG	FMS	Aerodynamic load generator.
ALGDB	DBT	Aerodynamic Load input for ALG (D-16).
ALL	IC	Output request for all of a specified type of output.
ALLEDGE TICS	IC	Request tic marks on all edges of X-Y plot.
ALOAD	P	Set negative if no aerodynamic loads (D-16).
ALTER	IA	Alter statement for DMAP or rigid format.
ALWAYS	P	Parameter set to -1 by a PARAM statement in the Piecewise Linear Analysis Rigid Format (D-6).
AMG	FMS	Aerodynamic Matrix Generator
AMP	FMS	Aerodynamic Matrix Processor.
AND	M	Parameter constant used in executive module PARAM.
AØUT$	M	Indicates restart with solution set output request.
APD	FMS	Aerodynamic pool distributor and element generator.

NASTRAN DICTIONARY

APDB	FMS	Aerodynamic pool distributor for blades.
APP	1A	Control card which specifies approach (DISP or DMAP).
APPEND	M	Fiel may be extended (see FILE).
APRESS	PU	Positive Value generates aerodynamic pressures.
ASET	IB	Analysis set coordinate definition card.
ASET1	IB	Analysis set coordinate definition card
ATEMP	PU	Positive value generates aerodynamic temperatures.
AUTØ	IC	Requests X-Y plot of autocorrelation function.
AUTØ	DBT	Autocorrelation funciion table.

CQDMEM2	IB	Quadrilateral membrane element connection definition card.
CQDPLT	IB	Quadrilateral bending element connection definition card.
CQUAD1	IB	General Quadrilateral element connection definition card.
CQUAD2	IB	Homogeneous quadrilateral element connection definition card.
CRØD	IB	Rod element connection definition card.
CSHEAR	IB	Shear panel element connection definition card.
CSLØT3	IB	Triangular slot element connection definition card for acoustic analysis.
CSLØT4	IB	Quadrilateral slot element connection definition card for acoustic analysis.
CSP	IC	Selects a set of contact surface points.
CSP	IB	Contact surface point set definition.
CSTM	DBT	Coordinate System Transformation Matrices.
CSTMA	DBT	Coordinate System Transformation Matrices - Aerodynamics.
CTETRA	IB	Tetrahedron element connection definition card.
CTØRDRG	IB	Toroidal ring element connection card.
CTRAPRG	IB	Trapezoidal ring element connection card.
CTRBSC	IB	Basic bending triangular element connection definition card.
CTRIA1	IB	General triangular element connection definition card.
CTRIA2	IB	Homogeneous triangular element connection definition card.
CTRIARG	IB	Triangular ring element connection card.
CTRMEM	IB	Triangular membrane element connection definition card.
CTRPLT	IB	Triangular bending element connection definition card.
CTUBE	IB	Tube element connection definition card.
CTWIST	IB	Twist panel element connection definition card.
CURVLINESYMBØL	IC	Request to connect points with lines and/or to use symbols for X-Y plots.
CVISC	IB	Viscous damper element connection definition card.
CWEDGE	IB	Wedge element connection definition card.

FØRCE2	IB	Static load definition (magnitude and four grid points).
FØRCEAX	IB	Static load definition for conical shell problem.
FREEPT	IB	Defines point on a free surface of a fluid for output purposes.
FREQ	IB	Frequency list definition.
FREQ$	M	Indicates restart with change in frequencies to be solved.
FREQ1	IB	Frequency list definition (linear increments).
FREQ2	IB	Frequency list definition (logarithmic increments).
FREQRESP	P	Parameter used in SDR2 to indicate a frequency response problem.
FREQUENCY	IC	Selects the set of frequencies to be solved in frequency response problems.
FRL	DBT	Frequency Response List.
FRQSET	P	Used in FRRD to indicate user selected frequency set.
FRRD	FMS	Frequency and Random Response - Displacement approach.
FSAVE	DBT	Flutter Storage Save Table.
FSLIST	IB	Defines a free surface of a fluid in a hydroelastic problem.
Functional Module	PH	An independent group of subroutines that perform a structural analysis function.
FXCOOR	PU	Aerodynamic modification factor (D-16).
FYCOOR	PU	Aerodynamic modification factor (D-16).
FZCOOR	PU	Aerodynamic modification factor (D-16).

IC	IC	Transient analysis initial condition set selection.
ID	IA	The first card of any data deck is the identification (ID) card. The two data items on this card are BCD values.
IFAIL	P	Set negative by ALG if convergence fails (D-16).
IFP	EM	Input File Processor. The preface module which processes the sorted Bulk Data Deck and outputs various data blocks depending on the card types present in the Bulk Data Deck.
IFP1	EM	Input File Processor 1. The preface module which processes the Case Control Deck and writes the CASECC, PCDB and XYCDB data blocks.
IFP3	EM	Input File Processor 3. The preface module which processes bulk data cards for a conical shell problem.
IFP4	EM	Input File Processor 4. The preface module which processes bulk data cards for a hydroelastic problem.
IMAG	IC	Output request for real and imaginary parts of some quantity such as displacement, load, single point force of constraint element force, or stress.
IMPL	P	Parameter constant used in executive module PARAM.
INCLUDE	IC	Used in set definition for structure plots.
INERTIA	P	Used in printing rigid format error messages for Static Analysis with Inertia Relief (D-2).
INERTIA RELIEF	IA	Selects rigid format for static analysis with inertia relief.
INPT	M	A reserved NASTRAN physical unit (Tape) which must be set up by the user when used.
INPUT	FMU	Generates most of bulk data for selected academic problems.
Input Data Block	PH	A data block input to a module. An input data block must have been previously output from some module and may not be written on.
Input Data Cards	PH	The card input data to the NASTRAN system are in 3 sets, the Executive Control Deck, the Case Control Deck, and the Bulk Data Deck.
INPUTT1	FMU	Reads data blocks from GINØ-written user tapes.
INPUTT2	FMU	Reads data blocks from FØRTRAN-written user tapes.
INPUTT3	FMX	Dummy user input module.
INPUTT4	FMX	Dummy user input module.
Internal Sort	PH	Same order as external sort except when SEQGP or SEQEP bulk data cards are used to change the sequence.
INV	IB	Inverse power eigenvalue analysis option - specified on EIGR, EIGB or EIGC cards.
IPRT	PU	Controls printing of aerodynamic results.
IREF	PU	Defines reference streamline for blade flutter.
IRES	P	Causes printout of residual vectors in statics rigid formats when set nonnegative via a PARAM bulk data card. (D-1, D-2, D-4, D-5, D-6).

KDSS	DBM	$[K^d_{ss}]$ - Partition of differential stiffness matrix.
KFF	DBM	$[K_{ff}]$ - Partition of stiffness matrix.
KFS	DBM	$[K_{fs}]$ - Partition of stiffness matrix.
KGG	DBM	$[K_{gg}]$ - Stiffness matrix generated by Structural Matrix Assembler.
KGGIN	PU	Positive value selects KGGX from INPUTT1.
KGGIN	DBM	Sum of elastic and differential stiffness matrices (D-16, A-9).
KGGL	DBM	$[K^{\ell}_{gg}]$ - Stiffness matrix for linear elements. Used only in the Piecewise Linear Analysis Rigid Format (D-6).
KGGLPG	P	Purge flag for KGGL matrix. If set to -1, it implies that there are no linear elements in the structural model. (D-6).
KGGNL	DBM	$[K^{n\ell}_{gg}]$ - Stiffness matrix for the nonlinear elements. Used in the Piecewise Linear Analysis Rigid Format only. (D-6).
KGGSUM	DBM	Sum of KGGNL and KGGL. Used in the Piecewise Linear Analysis Rigid Format only. (D-6).
KGGX	DBM	$[K^x_{gg}]$ - Stiffness matrix excluding general elements.
KGGXL	DBM	$[K^{x\ell}_{gg}]$ - Stiffness matrix for linear elements (excluding general elements). Used in the Piecewise Linear Rigid Format only. (D-6).
KHH	DBM	$[K_{hh}]$ - Stiffness matrix used in modal formulation of dynamics problems (D-10 thru D-12).
KLL	DBM	$[K_{\ell\ell}]$ - Stiffness matrix used in solution of problems in static analysis (D-1, D-2, D-4, D-5, D-6).
KLR	DBM	$[K_{\ell r}]$ - Partition of stiffness matrix.
KNN	DBM	$[K_{nn}]$ - Partition of stiffness matrix.
KØØ	DBM	$[K_{oo}]$ - Partition of stiffness matrix.
KRR	DBM	$[K_{rr}]$ - Partition of stiffness matrix.
KSS	DBM	$[K_{ss}]$ - Partition of stiffness matrix.
KTOTAL	DBM	Sum of elastic and differential stiffness matrices (D-16, A-9).
KTOUT	PU	Postive value outputs KTOTAL to OUTPUT1.
KXHH	DBM	Total modal stiffness matrix - h-set.

MATT5	IB	Specifies table references for temperature-dependent, anisotropic, thermal material properties.
MAX	IB	Eigenvector normalization option - used on EIGR, EIGB and EIGC cards.
MAXIMUM DEFØRMATIØN	IC	Indicates scale for deformed structure plots.
MAXIT	P	Limits maximum number of iterations in nonlinear heat transfer analysis.
MAXLINES	IC	Maximum printer output line count - default value is 20000.
MAXMACH	PU	Controls subsonic unsteady cascade calculations.
MCE1	FMS	Multipoint Constraint Eliminator - part 1.
MCE2	FMS	Multipoint Constraint Eliminator - part 2.
MDD	DBM	$[M_{dd}]$ - Mass matrix used in direct formulation of dynamics problems (D-7 thru D-9).
MDEMA	P	Parameter indicating equivalence of MDD and MAA.
MDLCEAD	P	Used in printing rigid format error messages for modal complex eigenvalue analysis (D-10).
MDLFRRD	P	Used in printing rigid format error messages for modal frequency response (D-11).
MDLTRD	P	Used in printing rigid format error messages for modal transient response (D-12).
MERGE	FMM	Matrix merge functional module.
METHØD	IC	Selects method for real eigenvalue analysis.
METHØD$	M	Indicates restart with change in eigenvalue extraction procedures.
MFF	DBM	$[M_{ff}]$ - Partition of mass matrix.
MGG	DBM	$[M_{gg}]$ - Mass matrix generated by Structural Matrix Assembler.
MHH	DBM	$[M_{hh}]$ - Mass matrix used in modal formulation of dynamics problems (D-10 thru D-12).
MI	DBM	[m] - Modal mass matrix.
MINMACH	PU	Controls supersonic unsteady cascade calculations.
MKAERØ1	IB	Provides table of Mach numbers and reduced frequencies (k).
MKAERØ2	IB	Provides list of Mach numbers (m) and reduced frequencies (k).
MLL	DBM	$[M_{\ell\ell}]$ - Partition of mass matrix.
MLR	DBM	$[M_{\ell r}]$ - Partition of mass matrix.
MNN	DBM	$[M_{nn}]$ - Partition of mass matrix.
MØA	DBM	$[\bar{M}_{oa}]$ - Partition of mass matrix.
MØDA	FMX	This module is reserved for user implementation.
MØDACC	FMS	Mode Acceleration Output Reduction Module.
MTYPE	PU	Controls cyclic mode component selection.

P	P	Parameter value used in MATGPR to print P-set matrices.
Packed Format	PH	A matrix is said to be in packed format if only the nonzero elements of the matrix are written.
PAPER SIZE	IC	Selects paper size for structure plots using table plotters.
PARAM	FMU	Performs specified operations on DMAP parameters.
PARAM	IB	Parameter definition card.
Parameter	PH	A FØRTRAN variable communicated to a DMAP module by the NASTRAN Executive System through blank common. A parameter's position in the DMAP calling sequence to a module corresponds to the position of the parameter in blank common at module execution time.
PARAML	FMU	Selects parameters from a user input matrix or table.
PARAMR	FMU	Performs specified operations on real or complex parameters.
PARTN	FMM	Matrix partitioning functional module.
PBAR	IB	Bar property definition card.
PBL	DBM	A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).
PBS	DBM	A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).
PCDB	DBT	Plot control data block (table for use with structure plotter functional module PLTSET).
PCØNEAX	IB	Conical shell element property definition card.
PDAMP	IB	Scalar damper property definition card.
PDF	DBM	Dynamic load matrix for frequency analysis.
PDT	DBM	Linear dynamic load matrix for transient analysis.
PDUMi	IB	Property definition card for dummy elements 1 through 9.
PELAS	IB	Scalar elastic property definition card.
PEN	IC	Selects pen size for structure plots using table plotters.
PENSIZE	IC	Selects pen size for X-Y plots using table plotters.
PERSPECTIVE	IC	Specifies perspective projection for structure plots.
PFILE	P	Parameter used by PLØT module.
PG	DBM	Incremental load vector used in Piecewise Linear Analysis (D-6).
PG	DBM	Statics load vector generated by SSG1.
PG1	DBM	Static load vector for Piecewise Linear Analysis (D-6).
PGEOM	PU	Controls punching of GRID, CTRIA2, PTRIA2 and DTI cards from ALG.
PGG	DBM	Appended static load vector (D-1, D-2).

PUGV1	DBT	Displacement components used to plot deformed shape (D-6).
PUNCH	IC	Output media request (PRINT or PUNCH).
PURGE	EM	DMAP statement which causes conditional purging of data blocks.
Purge	PH	A data block is said to be purged when it is flagged in the FIAT so that it will not be allocated to a physical file and so that modules attempting to access it will be signaled.
PVECT	DBM	Partitioning vector for cyclic modes (A-9).
PVISC	IB	Viscous element property definition card.
PVT	PH	Parameter value table. The PVT contains BCD names and values of all parameters input by means of PARAM bulk data cards. It is generated by the preface module IFP and is written on the Problem Tape.
P1	PU	INPUTT2 rewind option.
P2	PU	INPUTT2 unit number.
P3	PU	INPUTT2 tape ID.
QBDY1	IB	Defines uniform heat flux into HBDY elements.
QBDY2	IB	Defines grid point heat flux into HBDY elements.
QBG	DBM	Single point forces of constraint in the Differential Stiffness Rigid Format (D-4).
QDMEM	IC	Requests structure plot for all QDMEM elements.
QDMEM1	IC	Requests structure plot for all QDMEM1 elements.
QDMEM2	IC	Requests structure plot for all QDMEM2 elements.
QDPLT	IC	Requests structure plot for all QDPLT elements.
QG	DBM	Constraint forces for all grid points.
QHBDY	IB	Defines thermal load for steady-state heat conduction.
QHHL	DBML	Aerodynamic matrix list - h-set.
QJHL	DBML	Aerodynamic transformation matrix between h and j sets.
QP	DBM	Constraint forces for all physical points.
QPC	DBM	Complex single point forces of constraint for all physical points.
QR	DBM	$\{q_r\}$ - Determinant support forces.
QS	DBM	$\{q_s\}$ - Single-point constraint forces.
QUAD1	IC	Requests structure plot for all QUAD1 elements.
QUAD2	IC	Requests structure plot for all QUAD2 elements.
QVECT	IB	Defines thermal vector flux from distant source.
QVØL	IB	Defines volume heat generation.

SIGMA	P	Defines Stefan-Boltzmann constant in heat transfer analysis.
SIGN	PU	Controls the type of static aerothermo-elastic analysis performed.
SIL	DBT	Scalar Index List for all grid points.
SILA	DBT	Scalar Index List - Aerodynamics.
SILD	DBT	Scalar Index List for all grid points and extra scalar points introduced for dynamic analysis.
SILGA	DBT	Scalar Index List - Aerodynamic boxes only.
SINE	IC	Conical shell request for sine set boundary conditions.
SINGLE	P	No single-point constraints.
SKIP BETWEEN FRAMES	IC	Request to insert blank frames on SC 4020 plotter for X-Y plots.
SKJ	DBM	Integration matrix.
SKPMGG	P	Parameter used in statics to control execution of functional module SMA2.
SLBDY	IB	Defines list of points on interface between axisymmetric fluid and radial slots.
SLØAD	IB	Scalar point load definition.
SLT	DBT	Static Loads Table.
SMA1	FMS	Structural Matrix Assembler - phase 1 - generates stiffness matrix $[K_{gg}]$ and structural damping matrix $[K^4_{gg}]$.
SMA2	FMS	Structural Matrix Assembler - phase 2 - generates mass matrix $[M_{gg}]$ and viscous damping matrix $[B_{gg}]$.
SMA3	FMS	Structural Matrix Assembler - phase 3 - add general element contributions to the stiffness matrix $[K_{gg}]$.
SMP1	FMS	Structural Matrix Partitioner - part 1.
SMP2	FMS	Structural Matrix Partitioner - part 2.
SMPYAD	FMM	Performs multiply-add matrix operation for up to five multiplications and one addition.
SØL	IA	Specifies which rigid format solution is to be used when APP is DISPLACEMENT.
Solution Points	PH	Points used in the formulation of the general K system.
SØLVE	FMM	Solves a set of linear algebraic equations.
SØRT1	IC	Output is sorted by frequency or time and then by external ID.
SØRT2	IC	Output is sorted by external ID and then by frequency or time.
SØRT3	M	Output is sorted by individual item or component and then by frequency or time.
SPC	IB	Single-point constraint and enforced deformation definition.

SPC	IC	Single-point constraint set selection.
SPC$	M	Indicates restart with change in single-point constraint set selection.
SPC1	IB	Single-point constraint definition.
SPCADD	IB	Single-point constraint set combination definition.
SPCAX	IB	Conical shell single-point constraint definition.
SPCF	IC	Abbreviated form of SPCFØRCE.
SPCFØRCE	IC	Single-point constraint force output request. (UM-2.3,4.2)
Spill	PH	Secondary storage devices are used because there is insufficient main storage to perform a matrix calculation or a data processing operation.
SPLINE	DBT	Splining Data Table.
SPLINE1	IB	Defines surface spline.
SPLINE2	IB	Defines beam spline.
SPØINT	IB	Scalar point definition card.
SSG1	FMS	Static Solution Generator - part 1.
SSG2	FMS	Static Solution Generator - part 2.
SSG3	FMS	Static Solution Generator - part 3.
SSG4	FMS	Static Solution Generator - part 4.
SSGHT	FMH	Solution generator for nonlinear heat transfer analysis.
STATIC	IC	Requests deformed structure plot for problem in Static Analysis.
STATICS	IA	Selects statics rigid format for heat transfer or structural analysis.
STATICS	P	Parameter used in SDR2 to indicate Static Analysis.
STEADY STATE	IA	Selects rigid format for nonlinear static heat transfer analysis.
STEREØSCØPIC	IC	Requests stereoscopic projections for structure plot.
STREAML	PU	Controls the punching of STREAML1 and STREAML2 cards from ALG.
STREAML1	IB	Gives blade streamline data.
STREAML2	IB	Gives blade streamline data.
STRESS	IC	Element stress output request. (UM-2.3, 4.2)
Structural Element	PH	One of the finite elements used to represent a part of a structure.
SUBCASE	IC	Subcase definition.
SUBCØM	IC	This subcase is a linear combination of previous subcases.
SUBSEQ	IC	Specifies coefficients for SUBCØM subcases.
SUBTITLE	IC	Output labeling data for printer output.
SUPAX	IB	Ficticious support for conical shell problem.

ZORIGN	PU	Aerodynamic modification factor (D 16).