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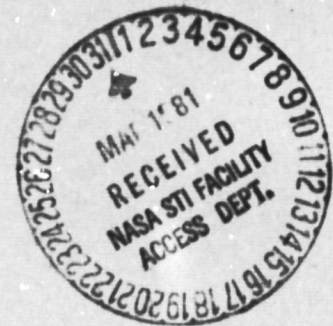
FOR AEROELASTIC ANALYSIS OF BLADED DISCS

by

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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

APPENDIX 1-a USER'S MANUAL SUPPLEMENT

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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 NASTRA 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 aerothermo-
elastic "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
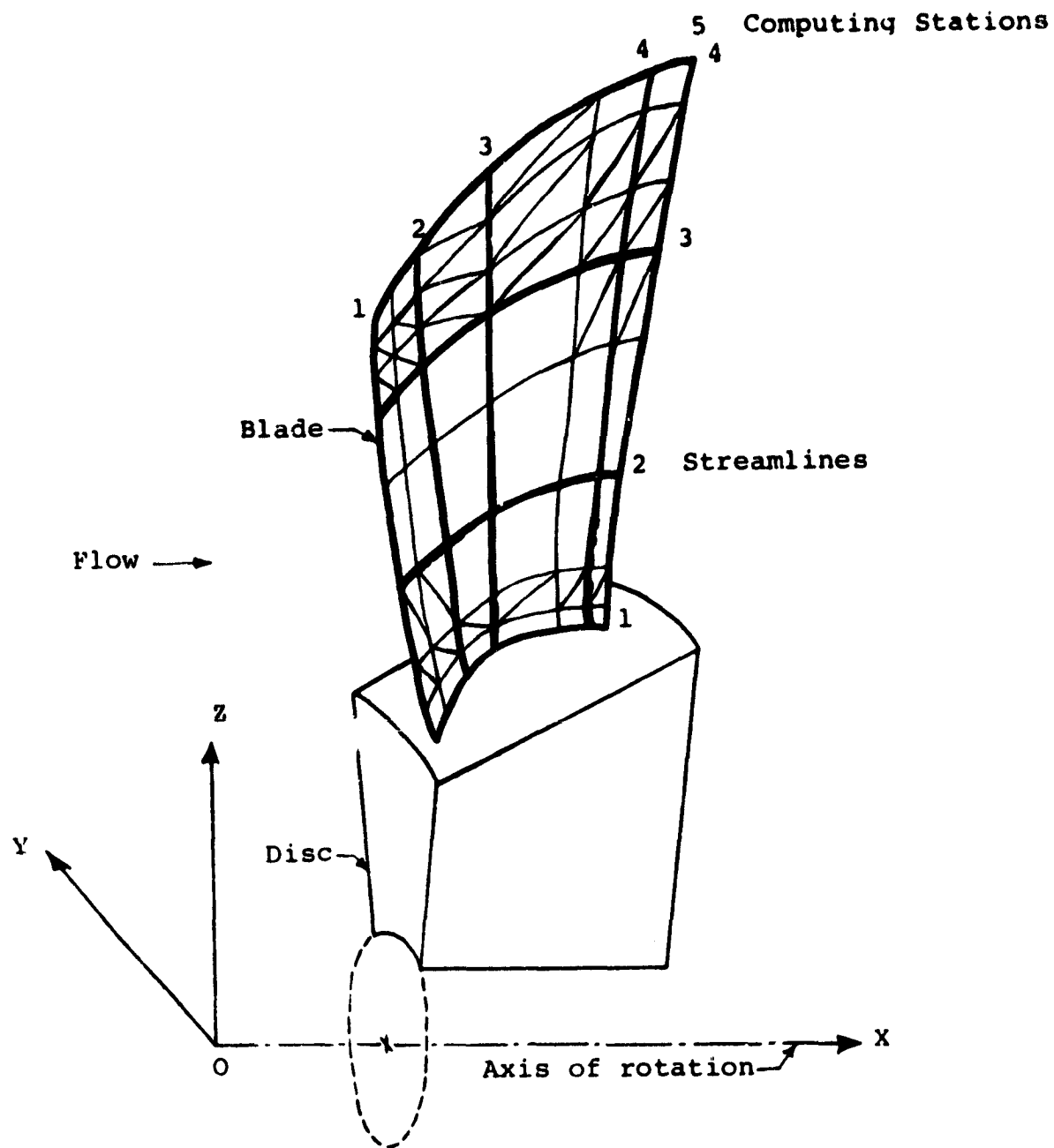
Figure 1   Bladed-disc Aerodynamic Grid And The
           Basic Coordinate System

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 th 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 turbo-machine. 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

XSTA RSTA   – Occurs KPTS times   Occurs NSTNS 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

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NRAD NDPTS NDATR NSWITC NLE NTE

XKSHPE SPEED

NOUT1 NOUT2 NOUT3 - Refers to leading
                    edge station

	Occurs for each	This group
NR NTERP NMACH NLOSS NL1	station	is used to
(cont.) NL2 NEVAL NCURVE NLITER NDEL	within	generate
(cont.) NOUT1 NOUT2 NOUT3 NBLAD	blade or	LOG5 data
R XLOSS - Occurs NR times	at trailing	for the
	edge	aerodynamic
		section

RTE   Occurs
                                             NRAD
DM DVFRAC] -Occurs NDPTS times   times

*   RDTE DELTAD AC-Occurs NDATR times

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 NEQW 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   Occurs
                                             NSTNS
XSTN RSTN - Occurs NSPEC times   Times

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NDATA NTERP NDIMEN NMACH

DATAC DATA1 DATA2 DATA3 - Occurs
                     NDATA times

Inlet condition specification

(LOG5)   NDATA NTERP NDIMEN NMACH NWORK

(cont.)   NLOSS NL1 NL2 NEVAL NCURVE NLITER

(cont.)   NDEL NOUT1 NOUT2 NOUT3 NBLADE

(LOG5)   SPEED-If NDATA >0

(LOG5)   DATAC DATA1 DATA2 DATA3 DATA4

(cont.)   DATA5

Occurs NDATA times

(LOG5)   DATA6 DATA7 DATA8 DATA9

DELC DELTA - Occurs NDEL times

For stations 2 thru NSTNS

WBLOCK BBLOCK BDIST -Occurs NSTNS times

NDIF

DIFF FDHUB FDMID FDTIP -Occurs NDIFF times

Occurs NSET1 times

NM NRAD

TERAD

DM WFRAC -Occurs NM times

Occurs NRAD times

Occurs NSET2 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).

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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 $2 \le$ NLINES ≤ 21.
NSTNS	The number of computing stations at which the stream surface radii are specified. Must satisfy $3 \le$ NSTNS ≤ 10.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \le$ NZ ≤ 15.
NSPEC	The number of radially disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \le$ NSPEC ≤ 21.
NPOINT	The number of points that will be generated to specify the pressure and suction surfaces of each blade section. Must satisfy $2 \le$ 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 conven-
tions. For compressor rotors, if the
machine rotates clockwise when viewed
from the front, set NSIGN to 1; other-
wise, 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 con-
                secutively 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
                $-2.0 < PP \leq 1.0$.

                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
                $0.0 < PP \leq 1.0$.

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 Bl, BS should have the same sign as Bl, otherwise, Bl 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 $1 \le NRAD \le 5$.
NDPTS	The number of points used to define each deviation curve. Must satisfy $1 \le NDPTS \le 11$.
NDATR	The number of radii at which an additional deviation angle increment and the point of maximum camber are specified. Must satisfy $1 \le NDATR \le 21$.
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 │   See definition for Aerodynamic Section.
NCURVE│
NLITER│
NDEL │
NOUT1 │
NOUT2 │
NOUT3 │
NBLAD ⎦

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 $3 \le$ NSTNS ≤ 30.

NSTRMS   Number of streamlines. Must satisfy $3 \le$ 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 stream-
               lines 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 stream-
               lines 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 approxi-

                mately 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 distri-

                butions at each computing station. There are

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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   See the Analytic Section.
NSIGN

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.   .)

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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 $2 \leq NSPEC \leq 21$, 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 $0 \leq NDATA \leq 21$, 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.

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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 specifies) 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 val.e 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 tota' 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 $\neq$ 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

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	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 $1 \leq NDIFF \leq 15$.
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 $1 \leq NM \leq 11$.
NRAD	The number of radial locations where NM loss fraction/chord points are given. Must satisfy $1 \leq NRAD \leq 5$.
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 print-out 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 ≠ -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.
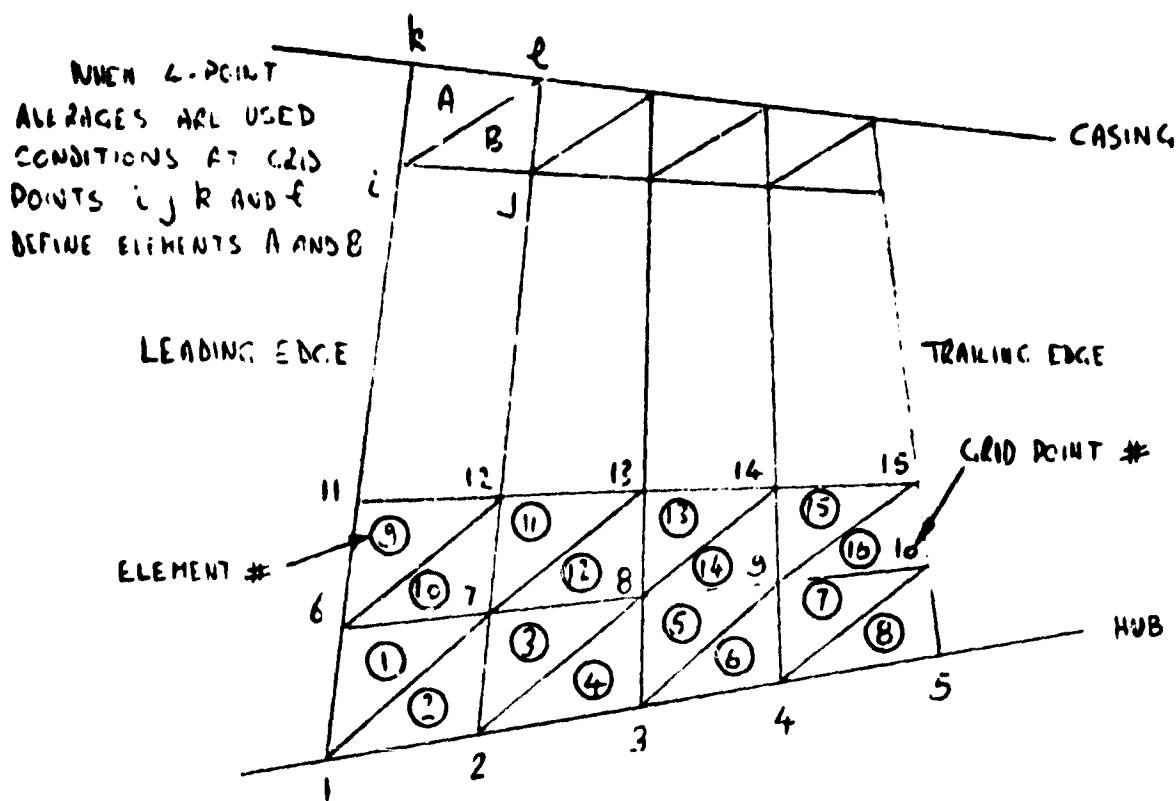
Figure 1.   NASTRAN Grid Point and Element Numbering
Scheme.

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:

$$D = 1 - \frac{V_{2r}}{V_{1r}} + \frac{V_{\theta 1r} \, V_{\theta 2r}}{2\sigma V_{1r}} \tag{2}$$

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 ≠ 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

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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 ou   rough 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 calcu-
lated 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 super-
sonic solution is required, or vice versa, the above message is printed. If
this occurs on the final iteration, failure is deemed to have occurred, calcu-
lation 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

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

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

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 <u>and</u> 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 <u>or</u> 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.

Blade ——————→

Flow

Hub ——————→

x
Ω

z

y

Axis of Rotation
(x-axis)
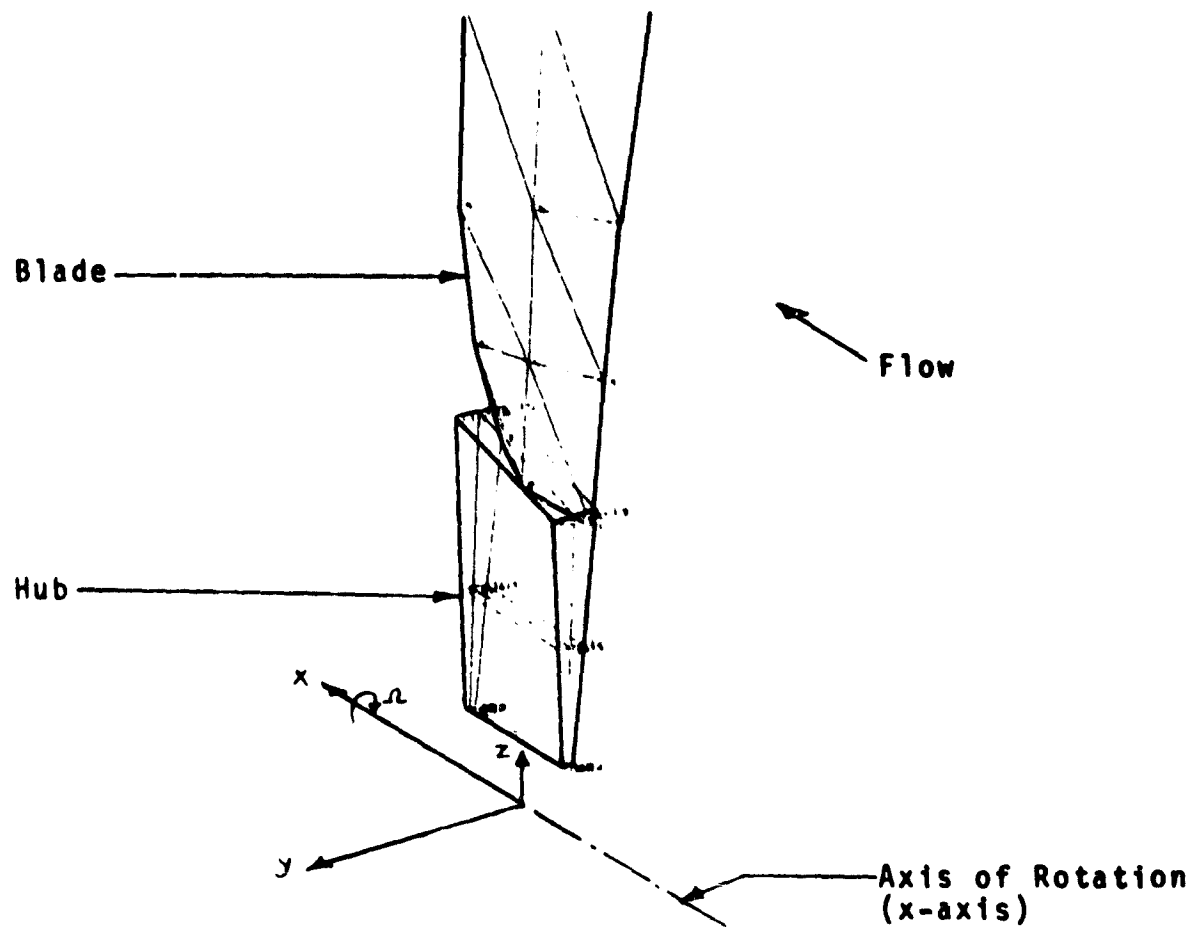
Figure 1. Finite Element Model of an Axial Flow Compressor
Bladed Disc Sector, and the Basic Coordinate System

1'   2   3   4   5   6   17 Computing Stations
(Aerodynamic Section)

1'   2   3   4   5 Computing Stations
(Analytic Meanline
Blade Section)

Streamline 4

3

Flow →

Blade →

2

1

Hub →

Axis of Rotation
Ω
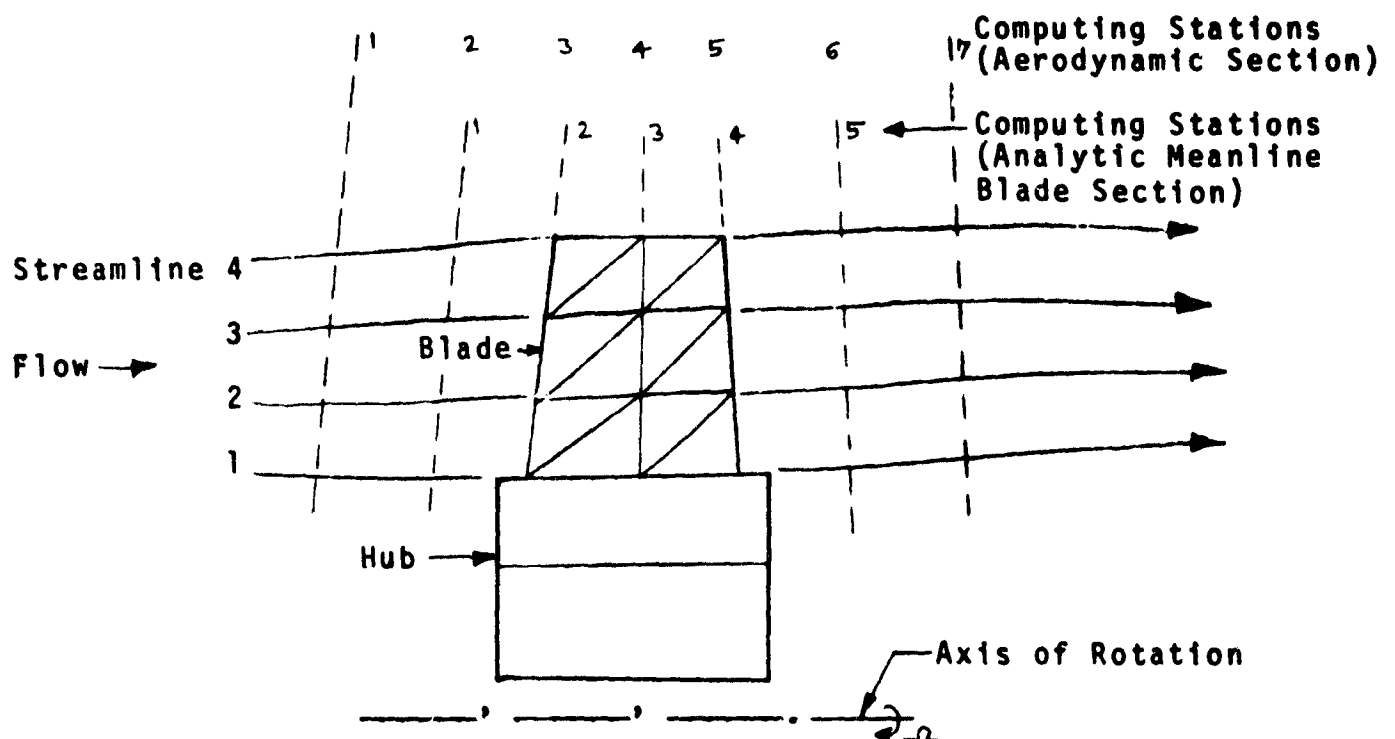
Figure 2. Aerodynamic Grid (See Section 1.15.3, User's Manual)

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   15
TIME  10
DIAG  14
CEND
```

-3-

Figure 3.   NASTRAN deck for Static Aerothermoelastic Design/Analysis

DESIGN OF BLADE

CASE CONTROL DECK ECHO

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 0,1
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

SORTED BULK DATA ECHO

CARD COUNT	. 1	. 2	.. 3	.. 4	.. 5	.. 6	.. 7	.. 8	.. 9	.. 10 .
1-	CHEXA1	201	1	101	103	104	108	113	115	ECH1
2-	ECH1	116	120	108	104	105	107	120	116	ECH2
3-	CHEXA1	202	1	121	123	124	128	101	103	ECH3
4-	ECH2	117	119	108						
5-	CHEXA1	203	1	128	124	125,	127	108	104	ECH4
6-	ECH3	104	108							
7-	CHEXA1	204	1	0.0	0.0	0.0	1.0	0.0	0.0	ECD1
8-	ECH4	105	107							
9-	CQD2QC	1	0.	0.0						
10-	ECD1	0.	2000	1.	4					
11-	CTRIA2	1	2000	1	5	5				
12-	CTRIA2	2	2005	2	2	5				
13-	CTRIA2	3	2005	2	6	6				
14-	CTRIA2	4	2010	4	3	7				
15-	CTRIA2	5	2010	4	8	8				
16-	CTRIA2	6	2015	5	5	8				
17-	CTRIA2	7	2015	5	9	9				
18-	CTRIA2	8	2020	7	11	10				
19-	CTRIA2	9	2020	7	8	11				
20-	CTRIA2	10	2025	8	12	11				
21-	CTRIA2	11	2025	8	9	12				
22-	CTRIA2	12	3	0	0					
23-	DTI	ALGO1			NASA LEWIS EXPERIMENTAL FAN			0	0	EALG01
24-	EALG01	ENDREC						ENDREC		
25-	DTI	ALGOB	1	1	0	0	ENDREC			
26-	DTI	ALGOB	2	GRID GENERATION ENDREC			FACREC			
27-	DTI	ALGOB	3	4	3	4	30	43	EALG41	
28-	DTI	ALGOB	4	5	3	3	0	0	EALG42	
29-	EALG41	2	0	2	1	0				
30-	EALG42	2	4	1	ENDREC					
31-	DTI	ALGOB	5	4.384	10.0	1.0	.0	11.0	ENDREC	EALG01
32-	DTI	ALGOB	6	2	0	ENDREC				
33-	DTI	ALGOB	7	-2.0	3.60	3.8				
34-	DTI	ALGOB	8	-2.0	10.04	5.5				
35-	DTI	ALGOB	9	3.6	.0	7.4				
36-	DTI	ALGOB	10	5.5	.0	10.0				
37-	DTI	ALGOB	11	7.4	.0					
38-	DTI	ALGOB	12	10.04	.0					
39-	DTI	ALGOB	13	4	1	ENDREC				
40-	DTI	ALGOB	14	-.898	3.8	ENDREC				
41-	DTI	ALGOB	15	-.763	5.5	ENDREC				
42-	DTI	ALGOB	16	-.629	7.4	ENDREC				
43-	DTI	ALGOB	17	-.424	10.0	ENDREC				
44-	EALGOB	18		3.8	.0	ENDREC				
45-	DTI	ALGOB	19	5.5	.0	ENDREC				
46-	DTI	ALGOB	20	7.4	.0	ENDREC				
47-	DTI	ALGOB	21	10.	.0	ENDREC				
48-	DTI	ALGOB	22	4	1	ENCREC				

SORTED ... CATA ECHO

	1	2	3	4	5	6	7	8	9	10
	DTI	ALGDR	25	.0	7.4	ENDREC				
	DTI	ALGDR	26	.0	10.	ENDREC				
	DTI	ALGDR	27	4.0	.0	ENDREC				
	DTI	ALGDR	28	5.5	.0	ENDREC				
	DTI	ALGDR	29	7.4	.0	ENDREC				
	DTI	ALGDR	30	10.	.0	ENDREC				
	DTI	ALGDR	31	4	1	ENDREC				
	DTI	ALGDR	32	.808	4.2	ENDREC				
	DTI	ALGDR	33	.780	5.5	ENDREC				
	DTI	ALGDR	34	.629	7.4	ENDREC				
	DTI	ALGDR	35	.424	10.	ENDREC				
	DTI	ALGDR	36	4.2	.0	ENDREC				
	DTI	ALGDR	37	5.5	.3	ENDREC				
	DTI	ALGDR	38	7.4	.0	ENDREC				
	DTI	ALGDR	39	10.	.0	ENDREC				
	DTI	ALGDR	40	2	0	ENDREC				
	DTI	ALGDR	41	2.0	4.4	ENDREC				
	DTI	ALGDR	42	2.0	10.04	ENDREC				
	DTI	ALGDR	43	4.4	.0	ENDREC				
	DTI	ALGDR	44	5.5	.0	ENDREC				
	DTI	ALGDR	45	7.4	.0	ENDREC				
	DTI	ALGDR	46	10.04	.0	ENDREC				
EALG471	DTI	ALGDR	47	1.0	-39.1	32.0	.0	.0	.01615	EALG471
EALG481	ENDREC		48	.0580	.01559	.56	1.796	.04722	-.02302	EALG481
EALG491	DTI	ALGDR	49	2.0	-45.0	-4.6	.0	.0	.01243	EALG491
EALG521	ENDREC		50	.0735	.01351	.54	1.851	.00722	-.02946	EALG501
EALG511	DTI	ALGDR	51	3.0	-53.2	-42.0	.0	.0	.03912	EALG511
EALG521	ENDREC		52	.026	.00566	.49	1.864	.00077	-.00689	EALG521
EALG531	DTI	ALGDR	53	4.0	-66.5	-59.6	.0	.0	.00482	EALG531
EALG541	ENDREC		54	.0268	.00429	.48	1.863	-.02667	.01423	EALG541
EALG551	DTI	ALGDR	55	1	5	1	2	2	4	EALG551
	ENDREC		90	1.0	16342.8	ENDREC				
	DTI	ALGDR	56	0	0	10	ENDREC			
	DTI	ALGDR	57	1	0	0	4	-1	-1	EALG581
EALG581	DTI	ALGDR	58	0	0	0	0	0	-43	EALG582
EALG582	ENDREC		1			ENDREC				
	DTI	ALGDR	59	.0	.0	ENDREC				
EALG601	DTI	ALGDR	60	8	0	0	1	-2	-2	EALG601
	-1		0	0	2	0	0	20	-43	EALG602
EALG632	ENDREC			4.20	.05	ENDREC				
	DTI	ALGDR	61							

DESIGN OF BLADE

SORTED ALLK DATA ECHO

CARD COUNT	1	2	3	4	5	6	7	8	9	10
101-	DTI	ALGDR	62	4.62	.05	ENDREC				
102-	DTI	ALGDR	63	5.50	.05	ENDREC				
103-	DTI	ALGDR	64	6.50	.05	ENDREC				
104-	DTI	ALGDR	65	7.400	.05	ENDREC				
105-	DTI	ALGDR	66	8.400	.05	ENDREC				
106-	DTI	ALGDR	67	9.500	.05	ENDREC				
107-	DTI	ALGDR	68	10.00	.05	ENDREC				
108-	DTI	ALGDR	69	.0	ENDREC					
109-	DTI	ALGDR	70	.00	.00	ENDREC				
110-	DTI	ALGDR	71	.25	.25	ENDREC				
111-	DTI	ALGDR	72	.50	.50	ENDREC				
112-	DTI	ALGDR	73	.75	.75	ENDREC				
113-	DTI	ALGDR	74	1.00	1.00	ENDREC				
114-	DTI	ALGDR	75	.0	.0	.5	ENDREC			
115-	DTI	ALGDR	76	AERODYNAMIC ANALYSIS OF NASA LEWIS BLADEENDREC						
116-	DTI	ALGDR	77	.0	.0	.0	.0			
117-	DTI	ALGDR	78	7	4	0	.40	0		EALG781
118-	EALG781	0	1	1	0	0	0	0		EALG782
119-	EALG782	3	0	0	3	3	5	1	ENDREC	
120-	DTI	ALGDR	79	.0	.0	5	ENDREC			
121-	DTI	ALGDR	80	.0	.0	.0	.001	.001	ENDREC	
122-	DTI	ALGDR	81	1.0	1.0	4.0	.0	.7	8.0	EALG811
123-	EALG811	ENDREC								
124-	DTI	ALGDR	82	.0	.0	ENDREC				
125-	DTI	ALGDR	83	73.146	1.0	ENDREC				
126-	DTI	ALGDR	84	2	ENDREC					
127-	DTI	ALGDR	85	-4.0	3.25	ENDREC				
128-	DTI	ALGDR	86	-4.0	10.34	ENDREC				
129-	DTI	ALGDR	87	2	ENDREC					
130-	DTI	ALGDR	88	-2.0	3.6	ENDREC				
131-	DTI	ALGDR	89	-2.0	10.04	ENDREC				
132-	DTI	ALGDR	90	4	ENDREC					
133-	DTI	ALGDR	91	-.898	3.5	ENDREC				
134-	DTI	ALGDR	92	-.763	5.5	ENDREC				
135-	DTI	ALGDR	93	-.629	7.4	ENDREC				
136-	DTI	ALGDR	94	-.424	10.0	ENDREC				
137-	DTI	ALGDR	95	4	ENDREC					
138-	DTI	ALGDR	96	.0	4.0	ENDREC				
139-	DTI	ALGDR	97	.0	5.5	ENDREC				
140-	DTI	ALGDR	98	.0	7.4	ENDREC				
141-	DTI	ALGDR	99	.0	10.0	ENDREC				
142-	DTI	ALGDR	100	4	ENDREC					
143-	DTI	ALGDR	101	.878	4.2	ENDREC				
144-	DTI	ALGDR	102	.780	5.5	ENDREC				
145-	DTI	ALGDR	103	.629	7.4	ENDREC				
146-	DTI	ALGDR	104	.424	10.0	ENDREC				
147-	DTI	ALGDR	105	2	ENDREC					
148-	DTI	ALGDR	106	2.0	4.4	ENDREC				
	DTI	ALGDR	107	2.0	13.?	ENDREC				

	1	2	3	4	5	6	7	8	9	10
151-	DTI	ALGDR	109	4.0	4.75	ENDREC	ENDREC			
152-	DTI	ALGDR	110	4.0	10.04	ENDREC	ENDREC			
153-	DTI	ALGDR	111	1	ENDREC					
154-	DTI	ALGDR	112	3.25	14.7	518.7	.0	ENDREC		
155-	DTI	ALGDR	113	0	ENDREC	FNDREC				
156-	DTI	ALGDR	114	4.0	.0	.0	FNDREC			
157-	DTI	ALGDR	115	10.0	1.0	1.0	ENDREC			
158-	DTI	ALGDR	116	0	ENDREC					
159-	DTI	ALGDR	117	0	ENDREC					
160-	DTI	ALGDR	118	.0	ENDREC					
161-	DTI	ALGDR	119	.0	ENDREC					
162-	DTI	ALGDR	120	.0	ENDREC					
163-	DTI	ALGDR	121	.0	ENDREC					
164-	DTI	ALGDR	122	.0	ENDREC					
165-	DTI	ALGDR	123	.0	ENDREC					
166-	DTI	ALGDR	124	.0	ENDREC					
167-	DTI	ALGDR	125	6	ENDREC					
168-	DTI	ALGDR	126	.0	.006	.006	.006	ENDREC		
169-	DTI	ALGDR	127	.2	.007	.007	.007	ENDREC		
170-	DTI	ALGDR	128	.4	.014	.014	.014	ENDREC		
171-	DTI	ALGDR	129	.6	.030	.031	.031	ENDREC		
172-	DTI	ALGDR	130	.8	.060	.060	.060	ENDREC		
173-	DTI	ALGDR	131	1.0	.125	.125	.125	ENDREC		
174-	DTI	ALGDR	132	2	1	ENDREC				
175-	DTI	ALGDR	133	.0	ENDREC					
176-	DTI	ALGDR	134	.0	ENDREC					
177-	DTI	ALGDR	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	.0205	5.5000				
183-	GRID	6		.7630	.2342	5.4450				
184-	GRID	7		-0.6290	-0.7454	7.3620				
185-	GRID	8		.0	.0131	7.4400				
186-	GRID	9		.6290	.6365	7.3725				
187-	GRID	10	1	-0.4240	-0.5230	9.9564				
188-	GRID	11	1	.0	-0.0221	10.0000				
189-	GRID	12	1	.4240	.7556	9.5711				
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	1			
199-	GRID	117	1	4.539	-4.186	.587	1			
200-	GRID	119	1	3.982	-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	-0.5E7	1	-1.0		
202-	GRID	121	1	.905	4.186	-0.5E7	1	-1.0		
203-	GRID	123	1	.905	4.186	.5E7	1	-1.0		
204-	GRID	124	1	.905	.0	.5E7	1	-1.0		
205-	GRID	125	1	.905	-4.186	.5E7	1	-1.0		
206-	GRID	127	1	.905	-4.186	-0.5E7	1	-1.0		
207-	GRID	128	1	.905	.0	-0.5E7	1	-1.0		
208-	MAT1	1	31.056		.3	7.36CE-4	1	-1.0		
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	500	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	500	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	500	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	ATCVP	1							
243-	PARAM	EXCPPR	.3							
244-	PARAM	FVCCPR	.3							
245-	PARAM	FZCPPR	.3							
246-	PARAM	IPRTCF	1							
247-	PARAM	IPRTCI	1							
248-	PARAM	IPRTCL	0							
249-	PARAM	PGEOM	3							

```
                    1         2      ..3..    4      ..5..   ..6..   ..7..   ..8..   ..9..    10
CARD
COUNT
251-    •PARAM   STREAML  -1
252-     PARAM   POSICN   •0
253-     DTRIA2   2000     1    •1040   0.0
254-     DTRIA2   2005     1    •1040   0.0
255-     DTRIA2   2010     1    •0707   0.0
256-     DTRIA2   2015     1    •0707   0.0
257-     DTRIA2   2020     1    •0422   0.0
258-     DTRIA2   2025     1    •0422   0.0
259-     EFCCE?   1        0     0      0.0    267.267
260-     SPC1     500      23   121     123    124     1.0     •0      •0      128
261-     SPC1     500      45   7       10     12
262-     SPC1     500      456  101     103    104     105     107     1C8
263-     SPC1     500      456  113     115    116     117     115     120
264-     SPC1     500      456  121     123    124     125     127     128
265-     STREAML11  1      1    THRU    2
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... 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. ... 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 obtained (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)

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

-3-

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.
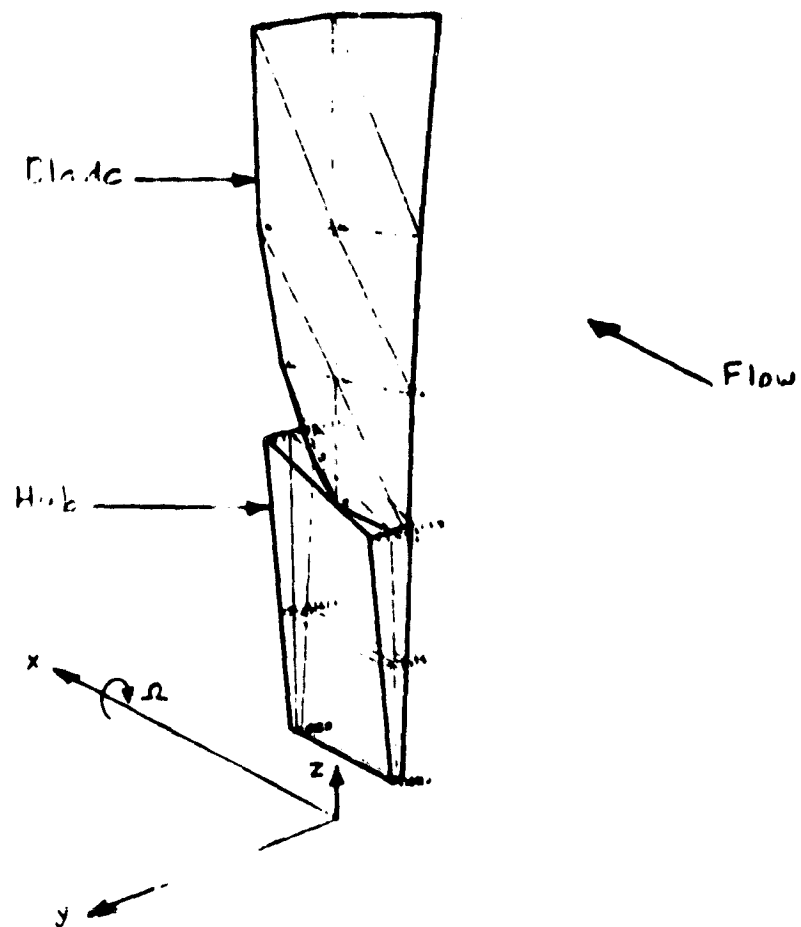
FIGURE 1.   FINITE ELEMENT MODEL
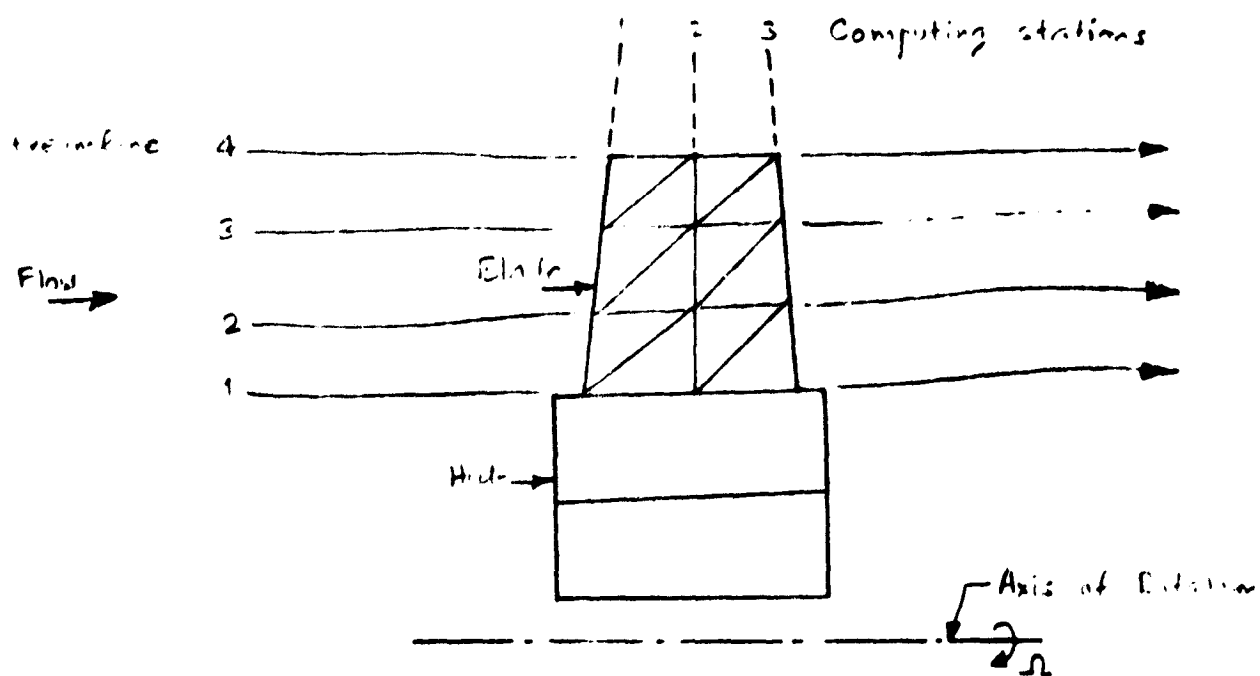
FIGURE 2.   AERODYNAMIC MODEL

NASTRAN   EXECUTIVE   CONTROL   DECK , ECHO

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

-6-

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

```
                    CASE  CONTROL  DECK  ECHO

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    YTITLE = 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
```

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AEROELASTIC FLUTTER ANALYSIS

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-   EEPD    0        1.364   1.86958  1.507-6
 2-   CHEXA1  201  1    120    101      103      104    108    113    115   ECH1
 3-   ECH1    115  120
 4-   CHEXA1  202  1    108    104      105      107    128    120    116   ECH2
 5-   ECH2    117  116
 6-   CHEXA1  203  1    121    123      124      128    101    101    103   ECH3
 7-   ECH3    104  108
 8-   CHEXA1  204  1    128    124      125      127    108    108    104   ECH4
 9-   ECH4    135  107
10-   CORD2R  1    0.   0.0    0.0      0.0      1.0    1.0    0.0    0.0   ECD1
11-   ECD1    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     123    103    115   EEIGC20
25-   CYJOIN  2    127   107   119      125     125    105    117   EEIGR10
26-   EIGC    20   HESS  MAX
27-   EEIGC20                                          3              3
28-   EIGC    10   INV   230.0 2000.0   2000.0   8     5             3
29-   EEIGR10 MAX
30-   FLFACT  1    .059164  .118328  .177492
31-   FLFACT  2    180.0
32-   FLFACT  3    .3       0.
33-   FLUTTER 30   K     .7    1        2       3      L             4
34-   GRID    1          -0.9979  -0.2814   3.7712
35-   GRID    2          .0001    .0516     4.0003
36-   GRID    3          .9981    -0.2461   4.1795
37-   GRID    4          -0.7776  -0.4744   5.4413
38-   GRID    5          -0.0031  .3228     5.5033
39-   GRID    6          .7797    .2247     5.4665
40-   GRID    7          -0.6646  -0.7062   7.3062
41-   GRID    8          -0.3157  .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     9.9043
46-   GRID    101  1     2.375    4.199     -0.567   1
47-   GRID    102  1     2.375    4.142     .587     1
48-   GRID    104  1     2.375    0.        .587     1
49-   GRID    105  1     2.375    -..       ..7      1
```

CARD COUNT	.	1	2	3	4	5	6	7	8	9	10
51-		GRID	103	1	2.375	.0	-0.5E7	1			
52-		GRID	113	1	3.632	4.186	-0.5E7	1			
53-		GRID	115	1	4.539	4.186	.587	1			
54-		GRID	116	1	4.539	.0	.5E7	1			
55-		GRID	117	1	4.539	-4.186	.5E7	1			
56-		GRID	119	1	3.632	-4.186	-0.5E7	1			
57-		GRID	120	1	3.782	.0	-0.5E7	1			
58-		GRID	121	1	.905	4.186	-0.5E7	1			
59-		GRID	123	1	.905	.0	.587	1			
60-		GRID	124	1	.905	-4.186	.587	1			
61-		GRID	125	1	.905	.0	.537	1			
62-		GRID	127	1	.905	-4.186	.587	1			
63-		GRID	128	1	.905	.0	-0.5E7	1			
64-		MAT1	1	31.0E6		.0	7.300E-4				
65-		PKAERO1	130.0			.3					
66-		EMKA1	0.3	0.7	1.0						EMKA1
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	500	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	KTYPEX	0							
89-		PARAM	LMODES	4							
90-		PARAM	MAXMACH	.90							
91-		PARAM	VLMACH	1.00							
92-		PARAM	MTYPE	CCSINE							
93-		PARAM	NSEGS	43							
94-		PARAM	PRINT	YESA							
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					

NASA LEWIS, BLADED SHROUDED DISK ANALYSIS
SAMPLE SINGLE-STAGE DESIGN OF ROTOR BLADE

AEROELASTIC FLUTTER ANALYSIS

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	28	
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	8		47.423	2.739	1.75600	3.98420	.58217	.656846	.069472	ESTRL 1
111-	ESTRL 1	719.0									
112-	STREAML22	3		23.534	1	.44	6.06653	.88674	.534388	.066610	ESTRL 2
113-	ESTPL 2	1014.2		55.107							
114-	STREAML23	3		44.697	1.86419	8.07620	1.18010	1.153666	.064685		ESTPL 3
115-	ESTRL 3	1282.1		60.380							
116-	STREAML24	3		62.028	1.86558	9.92791	1.45067	1.502276	.059201		ESTRL 4
117-	ESTPL 4	1592.6		60.687							
	ENDDATA										

-10-

NASTRAN DATA DECK

TIME K Required.

    K -- Maximum allowable execution time in minutes.

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

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

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

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

<div align="center">Displacement Approach Rigid Formats</div>

Kl	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

<div align="center">Heat Transfer Approach Rigid Formats</div>

Kl	An
1	STATICS
3	STEADY STATE
9	TRANSIENT

<div align="center">Aeroelastic Approach Rigid Format</div>

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

<div align="center">Subset Numbers</div>

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 SOLUTION set (components in the direct or modal formulation of the general K system) for dynamics problems:

1. SACCELERATION - 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. SVELOCITY - 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. NLLOAD - requests the nonlinear loads for a selected set of physical points (grid points and extra points introduced for dynamic analysis) in transient 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. ELFORCE - 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. SPCFORCES - 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. OLOAD - selects a set of applied loads for output.

5. ACCELERATION - 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. VELOCITY - 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. HARMONICS - 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. GPFORCE - 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.
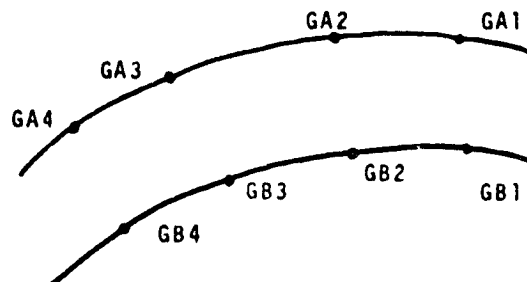
Interface contact surfaces represented by node pairs (GA1, GB1), (GA2, GB2), (GA3, GB3) and (GA4, GB4)

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	F	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.

BULK DATA DECK

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 $\geq$ 0).
MACH	Identification number of an FLFACT data card specifying MACH numbers or interblade phase angles (m) to be used in flutter analysis (integer $\geq$ 0).
RFREQ	Identification number of an FLFACT data card specifying reduced frequencies (k) to be used in flutter analysis (integer $\geq$ 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 $k = (REFC \cdot \omega / 2 \cdot V)$, 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, $1 \le i \le 8$).
k_j	List of reduced frequencies (Real, $1 \le j \le 8$).

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.

BULK DATA DECK

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
T4). 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
T5). 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. <u>SIGN</u> - 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. <u>ZØRIGN, FXCØØR, FYCØØR, FZCØØR</u> - 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. <u>MINMACH</u> - 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. <u>MAXMACH</u> - 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. <u>IREF</u> - 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. <u>MTYPE</u> - 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. <u>KTØUT</u> - 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. <u>KGGIN</u> - 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.

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
STREAHL2	S_N	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 $\leq$ 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 aerodynamic 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 <u>DMAP Sequence for Compressor Blade Mesh Generator</u>

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 STREAML' 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. PGEOM = 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.

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 O

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,GRDPNT=-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,GRDPNT $

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   ERRORS,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   LBL40,REACT $

62 JUMP   ERROR2 $

63 LABEL   LBL40 $

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 U

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,KG/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 O

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,, / CASECCA1,GEOM3A1 /S,Y,APRESS/S,Y,
               ATEMP /C,N,-1/C,N,-1/V,Y,IPRTC1/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       GEOM3A1,EQEXIN,GEOM2 /SLTA1,GPTTA1 / V,N,NOGRAV $

101  CHKPNT    SLTA1,GPTTA1 $

102  SSG1      SLTA1,UGPDT,,STM,SIL,EST,MPT,GPTTA1,EDT,MGG,CASECCA1,DIT /
               PGA1 / V,N,LUSET / C,N,1 $

103  CHKPNT    PGA1 $

104  ADD       PGVA,PGA1 / PG $

105  LABEL     NOAL $

106  EQUIV     PGVA,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 O

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,U $

120 LABEL   LBL9 $

121 SCR1   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,USEPSI/C,N,0.0/C,N,0.0 $

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 FORMATS

```
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,NOVS $

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,PGK/MPCF2 $

173  COND     LBLED,MPCF2 $

174  UMERGE   USET,PN,/PGK/C,N,0/C,N,N/C,N,M $

175  LABEL    LBLED $

176  ADD      PGK,PG/PGG/C,N,(-1.0,0.0) $

177  EQUIV    PGG,PG1/ALWAYS $

178  LABEL    PGOK $

179  ADD      PG1,/PGO/ $

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,CEOM3A /S,Y,
              ADRESS/S,Y,ATEMP/C,N,-1/C,N,-1/V,Y,IPRTCL/S,N,IFAIL/V,Y,SIGN/V,
```

RIGID FORMAT UMAP LISTING
SERIES J

DISPLACEMENT APPROACH, RIGID FORMAT 16

    LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

		Y,ZORIGN/V,Y,FXCOO:.../,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	LBL9J,IRES $
206	MATGPR	GPL,USET,SIL,RUBLV//C,N,L $
207	LABEL	LBL9J $
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,DUGV,CSTM,MPT,ECPT,GPCT,DIT/DKDGG/V,N,
            DSCOSET $

215 CHKPNT DKDGG $

216 MPYAD   DKDGG,UDGV,PGO/PGI1/C,N,0/C,N,1/C,N,1/C,N,1 $

217 ADD   PGI1,PGA / PGI2 $

218 DSCHK   PG2,PGI2,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,CCUNT/C,Y,BETAD=4 $

219 SAVE   DSEPSI,DONE,SHIFT,COUNT $

220 COND   DONE,DONE $

221 COND   SHIFT,SHIFT $

222 EQUIV   PG,PGI/NEVER $

223 EQUIV   PGI1,PGI/ALWAYS $

224 EQUIV   PGI,PGI1/NEVER $

225 REPT   INLPTOP,1000 $

226 TABPT   PGI1,PGI,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 $

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

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,,/
               OUBG1,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,DIFF STIF $

258 LABEL   ERROR2 $

259 PRTPARM   //C,N,-2/C,N,DIFF STIF $

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. PLOT 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. OFP 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.

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

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_ℓ) if no constraints applied.

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

111.   SSG2 applies constraints to static load vectors

$$\{P_g\} = \left\{\frac{\bar{P}_n}{P_m}\right\} \quad , \qquad \{P_n\} = \{\bar{P}_n\} + [G_m^T]\{P_m\} \quad ,$$

$$\{P_n\} = \left\{\frac{\bar{P}_f}{P_s}\right\} \quad , \qquad \{P_f\} = \{\bar{P}_f\} - [K_{fs}]\{Y_s\} \quad ,$$

$$\{P_f\} = \left\{\frac{P_a}{P_0}\right\} \quad \text{and} \quad \{P_\ell\} = \{P_a\} + [G_0^T]\{P_0\} \quad .$$

114.   SSG3 solves for displacements of independent coordinates

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

solves for displacements of omitted coordinates

$$\{u_0^0\} = [K_{oo}]^{-1}\{P_0\} \quad ,$$

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

$$\{\delta P_0\} = \{P_0\} - [K_{oo}]\{u_0^0\} \quad ,$$

$$\epsilon_0 = \frac{\{u_0^T\}\{\delta P_0\}}{\{P_0^T\}\{u_0^0\}}$$

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 (RUOV).

121. SDR1 recovers dependent displacements

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

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

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

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, ØOG1).

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

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

and performs matrix reduction $[K_{nn}^d] = [\bar{K}_{nn}^d] + [G_m^T][K_{mn}^d] + [K_{mn}^d][G_m] + [G_m^T][K_{mm}^d][G_m]$.

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

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

156. SCE1 partitions out single-point constraints

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

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

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

162. SMP2 partitions constrained differential stiffness matrix

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

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

165. ADD $[K_{aa}]$ and $[K_{aa}^d]$.CSIGN to form $[K_{\ell\ell}^b]$.

166. ADD $[K_{fs}]$ and $[K_{fs}^d]$.CSIGN to form $[K_{fs}^b]$.

167. ADD $[K_{ss}]$ and $[K_{ss}^d]$.CSIGN to form $[K_{ss}^b]$.

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

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

170. MPYAD multiply $[K_{fs}^b]$ 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 $\{P_g^x\}$.

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

177. Equivalence $\{P_{gg}\}$ to $\{P_{g1}\}$.

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.

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

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. INLPTOP 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

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

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

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

202. SSG3 solves for displacements of independent coordinates 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

$$(\delta P_\ell^b) = (P_\ell^b) - [K_{\ell\ell}^b](u_\ell^b) .$$

$$c_\ell^b = \frac{(u_\ell^b)^T(\delta P_\ell^b)}{(P_\ell^b)^T(u_\ell^b)} .$$

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

$$(u_o^b) = [G_o](u_\ell^b) + (u_o^{ob}) , \qquad \left\{\frac{u_\ell^b}{u_o^b}\right\} = (u_f^b) .$$

$$\left\{\frac{u_f^b}{\gamma_s^b}\right\} = (u_n^b) , \qquad (u_m^b) = [G_m](u_n^b) .$$

$$\left\{\frac{u_n^b}{u_m^b}\right\} = (u_g^b)$$

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

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

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.

$$(P_{g_{11}}) = K_{gg}^d](U_g^b) + (P_{go})$$

217. ADD $(P_{g_{11}})$ and (P_g^A) to form $(P_{g_{12}})$.

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 $-[\delta K_{gg}^d]$ and $[K_{gg}^d]$ to form $[K_{gg1}^d]$.

230. Equivalence (U_g^b) to (U_g) and $[K_{gg1}^d]$ to $[K_{gg}^d]$.

231. Equivalence breaks previous equivalence of $[K_{gg}^d]$ to $[K_{gg}^d]$ and (U_g) to (U_g^b).

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

234. TABPT table prints $[K_{gg1}^d]$, $[K_{gg}^d]$ 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 $[K_{gg}^d]$ 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 ERROR MESSAGE NO. 4 - MASS
     MATRIX REQUIRED FOR WEIGHT AND BALANCE CALCULATIONS.

263 STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 5 - NO
     INDEPENDENT DEGREES OF FREEDOM HAVE BEEN DEFINED.

RIGID FORMATS

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.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

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.

RIGID FORMATS

7. __EPSI𝜙__ - 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. __PGE𝜙M__ - 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. PGE𝜙M=3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default, -1, suppresses punching of any cards.

12. __I𝜙RT__ - 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. __Z𝜙RIGN, FXC𝜙𝜙R, FYC𝜙𝜙R, FZC𝜙𝜙R__ - optional in static aerothermoelastic analysis. These are modification factors. The defauls are Z𝜙RIGN = 0.0, FXCOOR = 1.0, FYCOOR = 1.0, and FZCOOR = 1.0.

15. <u>KTOUT</u> - 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/F SAVE=APPEND/CASEYY=APPEND/CLAMAL=
            APPEND/UVG=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     U1JE,D2JE/NOJJE $

 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      ERRJK1,NOSIMP $

15  PURGE     UGPST/GENEL $

16  CHKPNT    EST,GPECT,GEI,UGPST $

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

RIGID FORMAT DMAP LISTING
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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,

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,NCL,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 /CYCO/ V,Y,CTYPE / V,N,NOGO $

52   SAVE    NOGO $

53   CHKPNT  CYCO $

54   COND    ERROR6,NOGO $

55   COND    LBL4,GEVEL $

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 FORMATS

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,KCO,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,EGDYN/V,
              N,LUSET/V,N,LUSETD/V,N,NOTIL/V,N,NODLT/V,N,NUPSDL/V,N,NOFRL/V,
              N,VONLFT/V,N,NOTRL/V,N,NOEED/C,N,/V,N,NJUE $

84 SAVE   LUSETD,NOUE,NOEED $

85 COND   ERROR2,NOEED $

86 EQUIV   GO,GOD/NOUE/GM,GMD/NCUE $

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 $

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

94 PARAM   //C,N,MPY / V,N,CARDNO / C,N,0 / C,N,0 $

95 OFP   UEIGS,LAMK,,,, // V,N,CARDNO $

96 SAVE   CARDNO $

97 COND   ERROR4,NEIGV $

98 CYC12   CYCO,,,,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,,N S,, / 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 FORMATS

RIGID FORMAT DMAP LISTING
SERIES U

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,PHIAX,MI,LAMK,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   PLTSEIX,PLTPAR,GPSETS,LLSETS / 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,NODUE/V,N,XJHHL $

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,FEO,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/C,N,JJMPPLOT $

181  COND      FINIS,PJUMP $

182  MODACC    CASEYY,CLAMAL,PHIHL,CASECC,,/CLAMAL1,CPHIHL,CASEZZ,,/C,N,
                CEIGN $

183  CCR1      CPHIHL,PHIDH/CPHID $

184  CHKPNT    CPHID $
```

RIGID FORMAT DMAP LISTING
SERIES J

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

185 EQUIV   CPHID,CPHIP/NOA $

186 COND   LBL14,NOA $

187 SCR1   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   LBLNUE,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   LBLNUE $

195 SCR2   CASEZZ,CSTM,MPT,DIT,EQDYN,SILD,,,BGPDT,CLAMALI,QPC,CPHIP,EST,,/
              ,UQPC1,UCPHIP,UESC1,UEFL1,PCPHIP/C,N,CFIGN $

196 CHKPNT   PCPHIP $

197 UFP   UCPHIP,UQPC1,UESC1,UEFC1,,//V,N,CARDNO $

198 COND   P3,JUMPPLOT $

199 PLOT   PLTPAR,GPSETS,ELSETS,CASEZZ,BGPDT,EQDYN,SILD,,PCPHIP,,/PLOTX3/
              V,N,NSIL1/ V.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,F SUB SON $

205 LABEL   ERROR2 $

206 PRTPARM //C,N,-2/C,N,F SUB SCN $

207 LABEL   ERROR3 $

208 PRTPARM //C,N,-3/C,N,F SUB SCN $

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,FSUBSON $
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. OFP 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

$$[K_{gg}] = \begin{bmatrix} \bar{K}_{nn} & K_{nm} \\ K_{mn} & K_{mm} \end{bmatrix} \qquad \text{and} \qquad [M_{gg}] = \begin{bmatrix} \bar{M}_{nn} & M_{nm} \\ M_{mn} & M_{mm} \end{bmatrix}$$

and performs matrix reductions

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

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

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.

$$[K_{nn}] = \begin{bmatrix} K_{ff} & K_{fs} \\ K_{sf} & K_{ss} \end{bmatrix} \qquad \text{and} \qquad [M_{nn}] = \begin{bmatrix} M_{ff} & M_{fs} \\ M_{sf} & M_{ss} \end{bmatrix}$$

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

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

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

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

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

$$\{\phi_o\} = [G_o]\{\phi_a\} \quad , \qquad \left\{\frac{\phi_a}{\phi_o}\right\} = \{\phi_f\} \quad ,$$

$$\left\{\frac{\phi_f}{\phi_s}\right\} = \{\phi_n\} \quad , \qquad \{\phi_m\} = [G_m]\{\phi_n\} \quad .$$

$$\left\{\frac{\phi_n}{\phi_m}\right\} = \{\phi_g\}$$

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 $[C_{pp}^2]$.

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:

$$[K_{hh}] = \begin{bmatrix} k_i & \vdots & 0 \\ 0 & \vdots & 0 \end{bmatrix} + [\phi_{dh}^T][K_{dd}^2][\phi_{dh}] \quad .$$

$$[M_{hh}] = \begin{bmatrix} m_i & \vdots & 0 \\ 0 & \vdots & 0 \end{bmatrix} + [\phi_{dh}^T][M_{dd}^2][\phi_{dh}] \quad .$$

$$[B_{hh}] = \begin{bmatrix} b_i & \vdots & 0 \\ 0 & \vdots & 0 \end{bmatrix} + [\phi_{dh}^T][B_{dd}^2][\phi_{dh}] \quad .$$

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 $[D_{jk}^1]$ and $[D_{jk}^2]$.

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

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

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

$$[\phi_{dh}] = \begin{bmatrix} \phi_{ai} & | & \phi_{ae} \\ --- & | & ---- \\ \phi_{ei} & | & \phi_{ee} \end{bmatrix}$$

$$[G_{ki}] = [G_{ka}^T]^T[\phi_{ai}]$$

$$[D_{jh}^1] \leftarrow [D_{ji}^1 \mid D_{je}^1]$$

$$[D_{ji}^1] = [D_{jk}^1]^T[G_{ki}]$$

$$[D_{jh}^2] \leftarrow [D_{ji}^2 \mid D_{je}^2]$$

$$[D_{ji}^2] = [C_{jk}^2]^T[G_{ki}]$$

For each (m,k) pair:

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

for each group:

$$[Q_{jh}] = [A_{jj}^T]^{-1}_{group} [D_{jh}] \; group$$

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

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

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

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 $[M_{hh}^X]$, the total aerodynamic stiffness matrix $[K_{hh}^X]$ and the total aerodynamic damping matrix $[B_{hh}^X]$ as well as a looping table FSAVE. For the K-method

$$M_{hh}^X = (k^2/b^2)M_{hh} + (\rho/2) \; Q_{hh} \quad .$$

$$K_{hh}^X = K_{hh} \quad .$$

$$B_{hh}^X = 0$$

154.   CEAD extracts complex eigenvalues from the equation

$$[M_{hh}^X p^2 + B_{hh}^X p + K_{hh}^X](\phi_h) = 0$$

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

$$[\phi_d^C] = [\phi_{dh}][\phi_h] .$$

185.   Equivalence $[\phi_p^C]$ to $[\phi_p^C]$ if no constraints applied.

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

187.   SDR1 reccvers dependent components of eigenvectors

$$(\phi_d^C) = [G_o^d](\phi_d^C) \quad , \qquad \left\{ \begin{matrix} \phi_d \\ \delta_o \end{matrix} \right\} = (\phi_f^C + \phi_e^C) \quad .$$

$$\left\{ \begin{matrix} \phi_f^C + \phi_e^C \\ \hline \phi_s^C \end{matrix} \right\} = (\phi_n^C + \phi_e^C) \quad , \qquad (\phi_m^C) = [G_m^d](\phi_n^C + \phi_e^C) \quad .$$

$$\left\{ \begin{matrix} \phi_f^C + \phi_e^C \\ \hline \phi_e^C \end{matrix} \right\} = (\phi_p^C)$$

and recovers single-point forces of constraint $(q_s) =$

$$[K_{fs}^T](\phi_f), \quad \left\{ \begin{matrix} 0 \\ \hline q_s \end{matrix} \right\} = (Q_p^C) \quad .$$

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.

$$(\phi_d^C) = \left\{ \begin{matrix} \phi_a^C \\ \hline \phi_e^C \end{matrix} \right\}$$

195.   SDR2 calculates element forces and stresses (ØEFCl, ØESCl) and prepares eigenvectors and single-point forces of constraint for output (ØCPHlP, ØQPCl). It also prepares PCPHlP 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.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

208.   MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 3 - ATTEMPT TO
        EXECUTE MORE THAN 100 LOOPS.

210.   MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 4 - REAL EIGEN-
        VALUES REQUIRED FOR MODAL FORMULATION.

212.   NORMAL MODES WITH CYCLIC SYMMETRY ERROR MESSAGE NO. 4 - FREE BODY
        SUPPORTS NOT ALLOWED.

214.   NORMAL MODES WITH CYCLIC SYMMETRY ERROR MESSAGE NO. 5 - CYCLIC
        SYMMETRY DATA ERROR.

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 XYOUT 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 SOLUTION 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.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

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. <u>LFREQ and HFREQ</u> - 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. <u>LMØDES</u> - 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. <u>NØDJE</u> - 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. <u>P1, P2 and P3</u> - 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. <u>VREF</u> - 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. <u>PRINT</u> - 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. <u>CTYPE</u> - 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. <u>NSEGS</u> - required - the integer value of this parameter is the
    number of identical segments in the structural model.

12. <u>CYCSEQ</u> - 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. <u>KINDEX</u> - required in compressor blade cyclic modal flutter analysis.
The integer value of this parameter specifies a single value of
the harmonic index.

14. <u>MINMACH</u> - 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. <u>MAXMACH</u> - 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. <u>IREF</u> - 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. <u>MTYPE</u> - 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. <u>KGGIN</u> - 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, $\left\{{AUGV \atop UBGV}\right\}$, 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 scaler numbers and internal
          numbers

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

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 ten,eratures on the compressor blade. However, the aero-
     dynamic 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 aero-
     dynamic 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 GFØM3A

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

(d) Parameters STREAML and PCCØM 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)

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

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:

```
                              ┌─────────┐
                              │ UD0300  │
                              └────┬────┘
        ┌──────────────┬──────────┴──────────┬──────────────┐
  ┌──────────┐  ┌──────────┐      ┌──────────────────┐  ┌──────────┐
  │ UD03PR   │  │ UD03AN   │      │     UD03AR       │  │ UD03PQ   │
  │ UD03PB   │  │ UD0313   │      │ UD0301-UD0307    │  └──────────┘
  │ UD03AP   │  │ UD0314   │      │ UD0309-UD0312    │
  └──────────┘  │ UD0315   │      │     UD0325       │
                │ UD0316   │      │     UD0329       │
                │ UD0317   │      │     UD0330       │
                │ UD0318   │      │   UDG1-UDG9      │
                │ UD0319   │      └────────┬─────────┘
                └──────────┘       ┌───────┴────────┐
                           ┌──────────┐       ┌──────────┐
                           │ UD0308   │       │ UD0326   │
                           └────┬─────┘       └──────────┘
                           ┌──────────┐
                           │ /ALGλλ/  │
                           └──────────┘
```
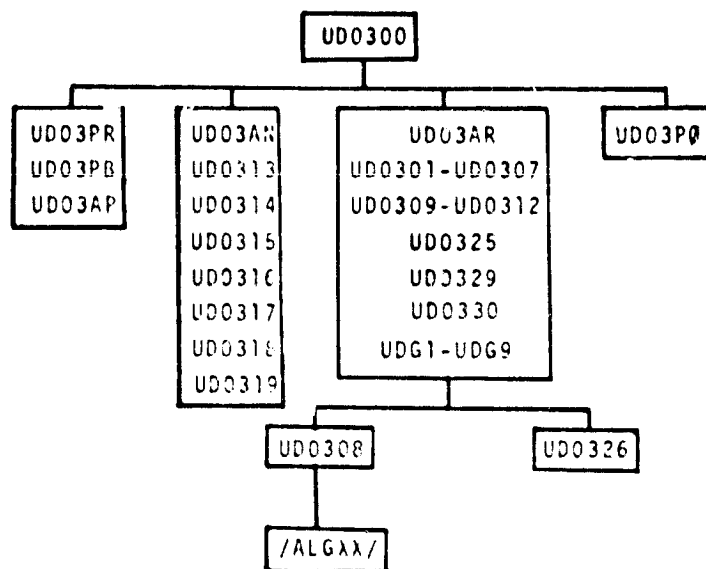
4.149.10 Diagnostic Messages

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

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

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.

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

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.

HAXMACH - 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.

MYTPE   - 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:

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

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

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

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

$$[G_{Kf}^T] = \begin{bmatrix} \bar{G}_{Ka}^T \\ \hline G_{K\emptyset}^T \end{bmatrix}$$

$$[G_{Ka}^T] = [G_\emptyset]^T [G_{K\emptyset}^T] + [\bar{G}_{Ka}^T]$$

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 $U_\emptyset$ 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 $[G_{Ka}^T]$.

3. Calling Sequence: CALL APDB1 (IBUF1, IBUF2, NEXT, LEFT, NSTNS, NLINES, LCSTM, ACSTM, NØDEX, NØDEI, ISILC, 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.

RIGID FORMAT DIAGNOSTIC MESSAGES

6.1.1.16 Rigid Format Error Messages for Static Aerothermoelastic Analysis with Differential Stiffness

NO. 1 - NO STRUCTURAL ELEMENTS HAVE BEEN DEFINED.

The differential stiffness matrix is null because no structural elements have been defined with Connection cards.

NO. 2 - FREE BODY SUPPORTS NOT ALLOWED.

Free bodies are not allowed in Static Analysis with Differential Stiffness. The SUPPORT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

NO. 3 - MASS MATRIX REQUIRED FOR WEIGHT AND BALANCE CALCULATIONS.

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.

NO. 5 - NO INDEPENDENT DEGREES OF FREEDOM HAVE BEEN DEFINED.

Either no degrees of freedom have been defined on GRID, SPOINT or Scalar Connection cards, or all defined degrees of freedom have been constrained by SPC, MPC, OMIT, or GRDSET cards, or grounded on Scalar Connection cards.

RIGID FORMAT DIAGNOSTIC MESSAGES

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.

NO. 5 - FREE BODY SUPPORTS NOT ALLOWED.

Free bodies are not allowed in Statics with Cyclic Symmetry. The SUPORT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

NO. 6 - CYCLIC SYMMETRY DATA ERROR.

See Section 1.12 for proper modeling techniques and corresponding PARAM card requirements.

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 ACCELERATION.
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.
AØUTS	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 function 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	I3	Wedge element connection definition card.

FORCE2	IB	Static load definition (magnitude and four grid points).
FORCEAX	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 GINO-written user tapes.
INPUTT2	FMU	Reads data blocks from FORTRAN-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	$[K_{ss}^d]$ - 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	$[K_{gg}^\ell]$ - 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	$[K_{gg}^{n\ell}]$ - 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	$[K_{gg}^x]$ - Stiffness matrix excluding general elements.
KGGXL	DBM	$[K_{gg}^{x\ell}]$ - 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.
METHØDS	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	PM	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	PM	A FORTRAN 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).
PCD3	DBT	Plot control data block (table for use with structure plotter functional module PLTSET).
PCONEAX	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 PLOT 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.
QVOL	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).