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

by

V. ELCHURI
A. M. GALLO

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-20382

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO

MARCH 1980
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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.
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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 NASTRAN Static Analysis with Differential Stiffness Rigid Format has been accordingly modified to include the effect of centrifugal, aerodynamic pressure and temperature loads.

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

These developments are compatible with the general structural capability in NASTRAN. The structural part of the problem is modeled as described in Section 1 of the User's Manual. This section deals with the aerodynamic data pertaining to the bladed disc sector. The associated aerodynamic modeling is discussed in Section 1.15.2.
Section 1.15.3 describes the steady aerothermoelastic "design/analysis" formulations.

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

Sample problems and their solutions are presented in Sections 1.15.4 and 1.15.6.
1.15.2 **Aerodynamic Modeling**

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

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

The streamlines are defined by the intersection of the blade mean surface and a set of coaxial cylindrical (or conical) surfaces. The axis of the cylinders (cones) coincides with the axis of rotation of the turbomachine. The "computing stations" lie on the blade mean surface and divide it from the leading edge to the trailing edge. The choice of the number and location of the streamlines and the "computing stations" is dictated by the expected variation of the relative flow properties across the blade span, and the complexity of the mode shapes exhibited by this part of the structure. However, a minimum of three streamlines (including the blade root and
Figure 1  Bladed-disc Aerodynamic Grid And The Basic Coordinate System
the tip) and three "computing stations" (including the blade leading edge and the trailing edge) must be specified.

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

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

An operating point on a compressor map defines a distribution of centrifugal force and aerodynamic pressure and temperature loads on the bladed-disc of the axial flow 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 LOGS 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 IPLOT IPRINT ISPLIT INAST**

(cont.) **IRLE IRTE NSIGN**

**ZINNER ZOUTER SCALE STACKX PLTSZE**

**KPTS IFANGS**

**XSTA RSTA**  - Occurs **KPTS times**

**R BLAFOR**  - Occurs **NLINES times**

**ZR B1 B2 PP QQ RLE**

**TC TE Z CORD DELX DELY**

**S BS** **- Only if ISECN = 1 or 3**
NRAD NDPTS NDATR NSWITC NLE NTE

**XKSHPE SPEED**

NOUT1 NOUT2 NOUT3 - Refers to leading edge station

NR NTERP NMACH NLOSS NL1

(continuation)

NL2 NEVAL NCURVE NLITER NDEL

(continuation)

NOUT1 NOUT2 NOUT3 NBLAD

R XLOSS - Occurs NR times

RTE

DM DVFRAC] - Occurs NDPTS times

* RDTE DELTAD AC- Occurs NDATR times

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

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

**TITLE3**

CP GASR G EJ

NSTNS NSTRMS NMAX NFORCE NBL NCASE

(continuation)

NSPLIT NSET1 NSET2 NREAD NPUNCH NPLLOT

(continuation)

NPAGE NTRANS NMIX NMANY NSTPLT NEQN NLE NTE NSIGN

NWHICH - Occurs NMANY times on the same card

G EJ SCLFAC TOLNCE VISK SHAPE

XSCALE PSICAL: RLOW PLOW XMAX RCONST

CONTR CONMX

FLOW SPDFAC

NSPEC

XSTN RSTN - Occurs NSPEC times

-11-
NDATA NTERP NDIMEN NMACH

DATAC DATA1 DATA2 DATA3 - Occurs NDATA times

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

LOG5 DATA6 DATA7 DATA8 DATA9

DELC DELTA - Occurs NDEL times

WBLOCK BBLOCK BDIST - Occurs NSTNS times

NDIF

DIFF FDHUB FDMID FDTIP - Occurs NDIFF times

NM NRAD

TERAD

DM WFRAC - Occurs NM 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 Definition:

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 systems 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, together with the corresponding value of SCLFAC.

<table>
<thead>
<tr>
<th>L</th>
<th>T</th>
<th>F</th>
<th>D</th>
<th>H</th>
<th>SCLFAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet</td>
<td>Seconds</td>
<td>Pounds</td>
<td>Deg. Rankine</td>
<td>BTU</td>
<td>1.0</td>
</tr>
<tr>
<td>Inches</td>
<td>Seconds</td>
<td>Pounds</td>
<td>Deg. Rankine</td>
<td>BTU</td>
<td>12.0</td>
</tr>
<tr>
<td>Meters</td>
<td>Seconds</td>
<td>Kilograms</td>
<td>Deg. Kelvin</td>
<td>CHU</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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

a. Initial Directives

TITLEI 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).
NLINES
The number of stream surfaces which are defined, and on which blade sections will be designed. Must satisfy $2 \leq \text{NLINES} \leq 21$.

NSTNS
The number of computing stations at which the stream surface radii are specified. Must satisfy $3 \leq \text{NSTNS} \leq 10$.

NZ
The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq \text{NZ} \leq 15$.

NSPEC
The number of radially disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq \text{NSPEC} \leq 21$.

NPOINT
The number of points that will be generated to specify the pressure and suction surfaces of each blade section. Must satisfy $2 \leq \text{NPOINT} \leq 80$. 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 still displayed.)

**ISPLIT**  Set ISPLIT = 0

**INAST**  Set INAST = 0. See the Output Data description (Section ) for further details.

**IRLE**  The computing station number at the blade leading edge.

**IRTE**  The computing station number at the blade trailing edge.

**NSIGN**  Indicator used to sign blade pressure forces according to program sign conventions. For compressor rotors, if the machine rotates clockwise when viewed from the front, set NSIGN to 1; otherwise, set NSIGN to -1. For compressor stators, the two values given for NSIGN are reversed.

-16-
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.

Set PLTSZE = 0.0.

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.

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.

An array of KPTS axial coordinates (relative to an arbitrary origin) which, together 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 N>LINES 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 quantities are then interpolated (or extrapolated) at each stream surface. The stream surfaces are numbered consecutively from the inner-most outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.

B1

The blade inlet angle.

B2

The blade outlet angle.

PP

If ISECN = 0, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value. Must satisfy 

\[-2.0 < PP < 1.0.\]

If ISECN = 1, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value forward of the inflection point. Must satisfy 

\[0.0 < PP < 1.0.\]
If ISECN = 2 or 3, PP is superfluous.

**QQ**

If ISECN = 0, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value. Must satisfy $0.0 \leq QQ \leq 1.0$.

If ISECN = 1, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value rearward of the inflection point. Must satisfy $0.0 < QQ < 1.0$.

If ISECN = 2 or 3, QQ is superfluous.

**RLE**
The ratio of blade leading edge radius to chord.

**TC**
The ratio of blade maximum thickness to chord.

**TE**
The ratio of blade trailing edge half-thickness to chord.

If ISECN = 2, TE is superfluous.

**Z**
The location of the blade maximum thickness, as a fraction of camber line length from the leading edge.

If ISECN = 2, Z is superfluous.

**CORD**
If IFCORD = 0, CORD is the meridional projection of the blade chord.

If IFCORD = 1, CORD is the blade chord.

**DELX, DELY**
The stacking axis passes through the stream surface blade sections, offset from the centroids, leading, or trailing edge by DELX.
and DELY in the x and y directions respectively.

\[ S, BS \]

If ISECN = 1 or 3, S and BS are used to specify the locations of the inflection point (as a fraction of the meridionally-projected chord length) and the change in camber angle from the leading edge to the inflection point. If the absolute value of the angle at the inflection point is larger than the absolute value of B1, BS should have the same sign as B1, otherwise, B1 and BS should be of opposite signs.

\[ NRAD \]

The number of radii at which a distribution of the fraction of trailing edge deviation is input. Must satisfy \( 1 \leq NRAD \leq 5 \).

\[ NDPTS \]

The number of points used to define each deviation curve. Must satisfy \( 1 \leq NDPTS \leq 11 \).

\[ NDATR \]

The number of radii at which an additional deviation angle increment and the point of maximum camber are specified. Must satisfy \( 1 \leq NDATR \leq 21 \).

\[ NSWITC \]

If NSWITC = 1, the deviation correlation parameter "m" for the NACA (A10) 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.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEED</td>
<td>See definition for Aerodynamic Section.</td>
</tr>
<tr>
<td>NR</td>
<td>The number of radii where a &quot;loss&quot; is specified.</td>
</tr>
<tr>
<td>NTERP</td>
<td></td>
</tr>
<tr>
<td>NMACH</td>
<td></td>
</tr>
<tr>
<td>NLOSS</td>
<td></td>
</tr>
<tr>
<td>NL1</td>
<td></td>
</tr>
<tr>
<td>NL2</td>
<td></td>
</tr>
<tr>
<td>NEVAL</td>
<td></td>
</tr>
<tr>
<td>NCURVE</td>
<td>See definition for Aerodynamic Section.</td>
</tr>
<tr>
<td>NLITER</td>
<td></td>
</tr>
<tr>
<td>NDELT1</td>
<td></td>
</tr>
<tr>
<td>NOUT1</td>
<td></td>
</tr>
<tr>
<td>NOUT2</td>
<td></td>
</tr>
<tr>
<td>NOUT3</td>
<td></td>
</tr>
<tr>
<td>NLBLAD</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Radius at which loss is specified.</td>
</tr>
<tr>
<td>XLOSS</td>
<td>Loss description. The form is prescribed by NLOSS; see aerodynamic section.</td>
</tr>
<tr>
<td>RTE</td>
<td>Radius at blade trailing edge where the following deviation fraction/chord curve applies. If NRAD = 1, it has no significance. Must increase monotonically.</td>
</tr>
<tr>
<td>DM</td>
<td>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.</td>
</tr>
<tr>
<td>DVFRAC</td>
<td>Fraction of trailing-edge deviation that occurs at location DM.</td>
</tr>
<tr>
<td>RDTE</td>
<td>Radius at trailing edge where additional deviation and point of maximum camber are specified.</td>
</tr>
</tbody>
</table>
DELTAD Additional deviation angle added to that determined by deviation rule. Input positive for conventionally positive deviation for both rotors and stators.

AC Fraction of blade chord from leading edge where maximum camber occurs.

c. Aerodynamic Section

TITLE3 A title card for the aerodynamic section of the program.

CP Specific heat at constant pressure. An input value of zero will be reset to 0.24. Units: H/F/D.

GASR Gas constant. An input value of zero will be reset to 53.32. Units: L/SCLFAC/D.

G Acceleration due to gravity. An input value of zero will be reset to 32.174. Units: L/SCLFAC/T/T.

EJ Joules equivalent. An input value of zero will be reset to 778.16. Units: LF/SCLFAC/H.

NSTNS Number of computing stations. Must satisfy 3 ≤ NSTNS ≤ 30.

NSTRMS Number of streamlines. Must satisfy 3 ≤ NSTRMS ≤ 21. An input value of zero will be reset to 11.

NMAX Maximum number of passes through the iterative streamline determination procedure. An input value of zero will be reset to 40.

NFORCE The first NFORCE passes are performed with arbitrary numbers inserted should any calculation produce impossible values. Thereafter, execution will cease, the calculation having "failed". An input value of zero will be reset to 10.

NBL If NBL = 0, the annulus wall boundary layer blockage allowance will be held at the values prescribed by WBLOCK.

If NBL = 1, blockage due to annulus wall boundary layers will be recalculated except at station 1. VISK and SHAPE are used in the calculation.
NCASE
Set NCASE = 1.

NSPLIT
If NSPLIT = 0, the flow distribution between the streamlines will be determined by the program so that roughly uniform increments of computing station will occur between the streamlines at station 1.

If NSPLIT = 1, the flow distribution between the streamlines is read in (see DELF).

NSET1
The blade loss coefficient re-evaluation option (specified by NEVAL) requires loss parameter/diffusion factor data. NSET1 sets of data are input, the set numbers being allocated according to the order in which they are input. Up to 4 sets may be input (see NDIFF).

NSET2
When NLOSS = 4, the loss coefficients at the station are determined as a fraction of the value at the trailing edge. Then, NSET2 sets of curves are input to define this fraction at a function of radius and meridional chord. Up to 2 sets may be input (see NM).

NREAD
If NREAD = 0, the initial streamline pattern estimate is generated by the program.

If NREAD = 1, the initial streamline pattern estimate and also the DELF values are read in. (See DELF, R, X, XL.)

NPUNCH
Set NPUNCH = 0

NLOT
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. .
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. MANY.

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

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

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

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

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

If NEQN = 2, the momentum equation includes an explicit \(dV_m/dm\) term instead of the \((1-M_m^2)\)
denominator terms. All streamwise gradients (including blade force terms) are computed as for the case \( \text{NEQN} = 0 \).

When computing stations are located within the blade rows, the results will generally be similar to those obtained with \( \text{NEQN} = 0 \), and solutions may be found that cannot be computed with \( \text{NEQN} = 0 \) due to high meridional Mach numbers.

If \( \text{NEQN} = 3 \), the momentum equation is similar to that used when \( \text{NEQN} = 1 \), but (as for the case \( \text{NEQN} = 1 \)) 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 \( \text{NEQN} = 1 \).

See the Analytic Section.

The numbers of each of the computing stations for which blade descriptive data is being generated by the analytic meanline section.

Linear dimension scale factor, see page .

An input value of zero will be reset to 12.0.

Basic tolerance in iterative calculation scheme. An input value of zero will be reset to 0.001. (See discussion of tolerance scheme in Section VI, Ref. .)
VISK  Kinematic viscosity of gas (for annulus wall boundary layer calculations). An input value of zero will be reset to 0.00018. Units: LL/SCLFAC/SCLFAC/T.

SHAPE  Shape factor for annulus wall boundary layer calculations. An input value of zero will be reset to 0.7.

XSCLAE  PSCLAE  RLOW  PLOW  XMMAX  Set each equal to 0.0.

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: L²/SCLFAC²/T.
| **FLOW** | Compressor flow rate. Units: F/T. |
| **SPDFAC** | The speed of rotation of each computing station is SPDFAC times SPEED (1). The units for the product are revolutions/ (60×T). |
| **NSPEC** | The number of points used to define a computing station. Must satisfy 2 ≤ NSPEC ≤ 21, and also the sum of NSPEC for all stations ≤ 150. If 2 points are used, the station is a straight line. Otherwise, a spline-curve is fitted through the given points. |
| **XSN, RSTN** | The axial and radial coordinates, respectively, of a point defining a computing station. The first point must be on the hub and the last point must be on the casing. Units: L. |
| **NDATA** | Number of points defining conditions or blade geometry at a computing station. Must satisfy 0 ≤ NDATA ≤ 21, and also the sum of NDATA for all stations ≤ 100. |
| **NTERP** | If NTERP = 0, and NDATA ≥ 3, interpolation of the data at the station is by spline-fit. If NTERP = 1 (or NDATA ≤ 2), interpolation is linear point-to-point. |
| **NDIMEN** | If NDIMEN = 0, the data are input as a function of radius. If NDIMEN = 1, the data are input as a function of radius normalized with respect to tip radius. If NDIMEN = 2, the data are input as a function of distance along the computing station from the hub. If NDIMEN = 3, the data are input as a function of distance along the computing station normalized with respect to the total computing station length. |
| **NMACH** | If NMACH = 0, the subsonic solution to the continuity equation is sought. If NMACH = 1, the supersonic solution to the continuity equation is sought. This should only be used at stations where the relative flow angle is specified, that is, NWORK = 5, 6, or 7. |
| **DATA** | 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 stream surface 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 stream surface 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 stream surface 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: HI/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 \( SET2 \) families of curves. \( NL1 \) and \( NL2 \) apply as for \( NLOSS = 1 \).

If \( NWORK = 7 \), \( DATA2 \) is the reference (minimum) relative total pressure loss coefficient. \( NL1 \) and \( NL2 \) apply as for \( NLOSS = 1 \).

\( DATA3 \) The blade lean angle measured from the projection of a radial line in the plane of the computing station, positive when the innermost portion of the blade precedes the outermost in the direction of rotor rotation. Units: A.

\( DATA4 \) The fraction of the periphery that is blocked by the presence of the blades.

\( DATA5 \) Cascade solidity. When a number of stations are used to describe the flow through a blade, values are only required at the trailing edge. (They are used in the loss coefficient re-estimation procedure, and to evaluate diffusion factors for the output.)

\( DATA6 \) If \( NWORK = 5 \) or \( 6 \), \( DATA6 \) is the deviation angle measured in the streamsurface plane. Generally negative for a rotor, positive for a stator. Units: A.

If \( NWORK = 7 \), \( DATA6 \) is reference relative inlet angle, to which the minimum loss coefficient (\( DATA2 \)) and the reference relative outlet angle (\( DATA7 \)) correspond. Measured in the streamsurface plane and generally negative for a rotor, positive for a stator. Units: A.

\( DATA7 \) If \( NWORK = 7 \), \( DATA7 \) is the rate of change of relative outlet angle with relative inlet angle.

\( DATA8 \) If \( NWORK = 7 \), \( DATA8 \) is the relative inlet angle larger than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.
DATA9

If NWORK = 7, DATA9 is the relative inlet angle smaller than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.

NWORK

If NWORK = 0, constant entropy, angular momentum, and total enthalpy exist along streamlines from the previous station. (If NMIX = 1, the distributions will be modified.)

If NWORK = 1, the total pressure distribution at the computing station is specified. Use for rotors only.

If NWORK = 2, the total enthalpy distribution at the computing station is specified. Use for rotors only.

If NWORK = 3, the absolute angular momentum distribution at the computing station is specified.

If NWORK = 4, the absolute whirl velocity distribution at the computing station is specified.

If NWORK = 5, the relative flow angle distribution at the station is specified by giving blade angles and deviation angles, both measured in the streamsurface plane.

If NWORK = 6, the relative flow angle distribution at the station is specified by giving the blade angles measured in the cylindrical plane, and the deviation angles measured in the streamsurface plane.

If NWORK = 7, the relative flow angle and relative total pressure loss coefficient distributions are specified by means of an off-design analysis procedure. "Reference", "stalling", and "choking" relative inlet angles are specified. The minimum loss coefficient varies parabolically with the relative inlet angle so that it is twice the minimum value at the "stalling" or "choking" values. A maximum value of 0.5 is imposed. "Reference" relative outlet angles and the rate of change of outlet angle with inlet angle are specified, and the relative outlet angle varies linearly from the reference value with the relative inlet angle. NLOSS should be set to zero.

NLOSS

If NLOSS = 1, the relative total pressure loss coefficient distribution is specified.

If NLOSS = 2, the isentropic efficiency (for compression) distribution is specified.

If NLOSS = 3, the entropy rise distribution is specified.
If $NLOSS = 4$, the total pressure loss coefficient distribution is specified by use of curve-set $NCURVE$ of the NSET2 families of curves giving the fraction of final (trailing edge) loss coefficient.

**NL1**

The station from which the loss (in whatever form $NLOSS$ 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 value indicates a downstream station, a negative value indicates an upstream station.

**NEVAL**

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

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

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

**NCURVE**

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

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 $0 \leq NDEL \leq 21$, and also the sum of $NDEL$ for all stations $\leq 100$.

Set $NOUT1 = 0$

Set $NOUT2 = 0$

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.  

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NOUT3 = XY, where
If X = 1, the station is at a blade leading edge.
If X = 2, the station is at a blade trailing edge.
If Y = 0, then both temperature and pressure data will be generated.
If Y = 1, then only pressure data will be generated.
If Y = 2, then only temperature data will be generated.
If NOUT3 = 0, the station may be between blade rows, or within a blade row for which output is required, depending upon the use of NOUT3 ≠ 0 elsewhere. See also description of NBLADE below.

NBLADE
This item is used in determining the pressure difference across the blade. The number of blades is | NBLADE | . If NBLADE is positive, "three-point averaging" is used to determine the pressure difference across each blade element. If NBLADE is negative, "four point averaging" is used. (See the Output Description in Section .)
If NBLADE is input as zero, a value of +10 is used. At a leading edge, the value for the following station is used: elsewhere the value at a station applies to the interval
upstream of the station. Thus by varying the sign of NBLADE, the averaging method used for the pressure forces may be varied for different axial segments of a blade row.

SPEED
This card is omitted if NDATA = 0. The speed of rotation of the blade. At a blade leading edge, it should be set to zero. The product SPDFAC times SPEED has units of revolutions/(T x 60).

DELC
The coordinate at which Prandtl-Meyer expansion angles are given. It defines the angle as a function of the dimensions of the leading edge station, in the manner specified by NDIMEN for the current, that is trailing edge station. Must increase monotonically. For dimensional cases, units are L.

DELT A
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.
<table>
<thead>
<tr>
<th><strong>BBLOCK, BDIST</strong></th>
<th>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. <strong>BBLOCK</strong> is the value at mid-station (expressed as the fraction of the periphery blocked), and <strong>BDIST</strong> is the ratio of the value on the hub to the mid-value.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NDIFF</strong></td>
<td>When NSET1 &gt; 0, there are NDIFF points defining loss diffusion parameter as a function of diffusion factor. Must satisfy 1 ≤ NDIFF ≤ 15.</td>
</tr>
<tr>
<td><strong>DIFF</strong></td>
<td>The diffusion factor at which loss parameters are specified. Must increase monotonically.</td>
</tr>
<tr>
<td><strong>FDHUB</strong></td>
<td>Diffusion loss parameter at 10 per cent of the radial blade height.</td>
</tr>
<tr>
<td><strong>FDMID</strong></td>
<td>Diffusion loss parameter at 50 per cent of the radial blade height.</td>
</tr>
<tr>
<td><strong>FDTIP</strong></td>
<td>Diffusion loss parameter at 90 per cent of the radial blade height.</td>
</tr>
<tr>
<td><strong>NM</strong></td>
<td>When NSET2 &gt; 0, there are NM points defining the fraction of trailing edge loss coefficient as a function of meridional chord. Must satisfy 1 ≤ NM ≤ 11.</td>
</tr>
<tr>
<td><strong>NRAD</strong></td>
<td>The number of radial locations where NM loss fraction/chord points are given. Must satisfy 1 ≤ NRAD ≤ 5.</td>
</tr>
<tr>
<td><strong>TERAD</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>DM</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>WFRAC</strong></td>
<td>Fraction of trailing edge loss coefficient that occurs at location DM.</td>
</tr>
</tbody>
</table>
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.
AERODYNAMIC OUTPUT DATA

1. ANALYTIC MEANLINE SECTION

Printed output may be considered to consist of four sections; a printout of the input data, details of the blade sections on each stream surface, 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 stream surface blade sections are printed if IPRINT = 0 or 1. Listed first are the parameters defining the blade section. These are interpolated at the stream surface 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) edges 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.

The NASTRAN 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.
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 calcul-
ation 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 inter-
ception 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

$$\tan \alpha = \frac{V_{\theta}}{V_m}$$  \hspace{1cm} (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:

$$D = 1 - \frac{V_{tr}}{V_{ir}} + \frac{V_{\theta tr} V_{\theta 2r}}{2 \sigma V_{ir}}$$  \hspace{1cm} (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 (TOLNCB) on the last two passes is shown as IVFAIL. Similarly, 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 XMMA (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 ENTHALPHY BELOW LIMIT AT xxx.xxx

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

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

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.

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

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 STREAMLINE
(MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT
xxx.xxx.xxx.xxx.

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 STREAMLINE
(MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT
xxx.xxx.xxx.xxx.

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 STREAMTUBE
STATIC ENTHALPY BELOW LIMIT IN CONTINUITY EQUATION
AT xxx.xxx.xxx.xxx.

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 STATIONxxx ITERATIONxxx STREAMLINE
MERIDIONAL VELOCITY BELOW LIMIT IN CONTINUITY AT
xxx.xxx.xxx.xxx.

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, calcula-
tion ceases, and results are printed out through to this station.

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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 permissible 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 = xxxxx.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.
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.

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 $H_{MIN}$ was determined.

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 unconverted.

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

$$\Delta p = \frac{2\pi r^2 \rho}{N} \left\{ \sum \beta \cos \beta_j \int \frac{dS}{\beta_m} + \frac{V_m}{r} \frac{d}{dm} (rV_o) \right\}$$

(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

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

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

Figure 2. Aerodynamic Grid (See Section 1.15.3, User's Manual)
Figure 3. NASTRAN deck for Static Aero thermoelastic Design/Analysis
DESIGN OF BLADE

CASE CONTROL DECK ECHO

1 TITLE = NASA LEWIS, BLADED SHROUDED DISK ANALYSIS
2 SUBTITLE = EXAMPLE SINGLE-STAGE DESIGN OF ROTOR BLADE
3 LABEL = DESIGN OF BLADE
4 CPC = 500
5 DP = 600
6 LOAD = 1
7 DISC = ALL
8 SPCF = ALL
9 OLOAD = ALL
10 STRESS = ALL
11 PINCE = ALL
12 SUBCASE 1
13 LABEL = LINEAR SOLUTION OF ROTOR BLADE
14 SUBCASE 2
15 LABEL = NONLINEAR SOLUTION OF ROTOR BLADE
16 GFPOCE=ALL
17 OUTPUT (PLOT)
18 PLETTER MASTPLY, MODEL 0.1
19 PAPER SIZE 12.0 X 11.5
20 SET 1 = ALL
21 AXONOMETRIC PROJECTION
22 MAXIMUM DEFORMATION 0.5
23 AXES X,Y,Z
24 VIEW 0.5,0.0,0.0
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,Y,X
31 FIND SCALF, 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 Y,Z,X
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, RULK DATA NOT SORTED. XSOFT WILL RE-CREAD DECK.
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### Design of Blade

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**Note:** This is a simplified representation of a table from a document. The actual content may include more detailed data or code not visible in this excerpt. The table represents data likely related to a computational analysis or simulation, possibly for a project or study involving blade design and aerodynamic analysis.
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- **GRID**: Identification number for the bulk data.
- **Bulk Data**: Values for the bulk data columns.
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- STREAM1: 2
- STREAM2: 3
- STREAM3: 4
- STREAM4: 5
- STREAM5: 6
- STREAM6: 7
- STREAM7: 8
- STREAM8: 9
- STREAM9: 10
- STREAM10: 11

Note: The table is incomplete and may require further context to accurately interpret.
The Executive Control Deck consists of cards from ID to CEND. SOL 16 and APP Displacement are used for the Steady Aerothermoelastic 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. The 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 OUTPUT (PLOT) 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. FXC00R, FYC00R
and \text{FZC\$QR} 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 IPRTC\$F = 1$ and IPRTC\$I = 1$ are used for a detailed printout from the ALG module upon final and initial entries. IPRTC\$L = 0$ requests a summary from the ALG module during the differential stiffness loop (see Section 18 of the Theoretical Manual). PG\$\text{EOM} = 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 STREAM\$L = -1$ suppresses the output of STREAM\$L1$ and STREAM\$L2$ bulk data cards, while Z\$\text{ORIGN} = 0$ only is currently permitted. STREAM\$L1$ 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 FMETH0D card. At the present time, only the k-method of flutter analysis is available. This allows looping through three sets
of parameters: density ratio \( \rho / \rho_{\text{ref}} ; \rho_{\text{ref}} \) is given on AERØ card); interblade phase angle \( \alpha \); and reduced frequency, \( k \). For example, if the user specifies two values of each, there will be eight loops in the following order.

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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 \( V_{\text{REF}} \) 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 \( V_{\text{out}} = V / V_{\text{REF}} \). Another use of this parameter is to compute flutter index, by choosing \( V_{\text{REF}} = b \omega_0 \sqrt{\mu} \).

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

1.15.6 Sample Problem

(To be written)
USER'S MANUAL UPDATES

1.15.6 Sample Problem

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

The finite element model of the compressor bladed disc sector is shown in Figure 1. The aerodynamic model (see Section 1.15.2) with 4 streamlines and 3 computing stations is shown in Figure 2. The first four of the zeroth harmonic family of natural modes and frequencies are chosen for flutter investigation via the PARAMETERS LMODES = 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 SOL 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. CYJOIN 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 LMODES = 4) modes are used to form the modal flutter equations. The AERO bulk data card is used to specify the reference chord and reference density. For bladed disc flutter analysis, the other two parameters on the AERO card are of no significance. The MKAERO1 data card causes the aerodynamic matrices to be computed for three interblade phase angle-reduced frequency pairs, i.e. \((\varphi = 180^0, k = 0.3), (180^0, 0.7)\) and \((180^0, 1.0)\).

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 interblade phase angle and 3 reduced frequencies (on FLFACT cards) result in \((3 \times 1 \times 3 =) \) 9 loops. Both linear and surface splines are available for interpolation of aerodynamic matrices to intermediate values of interblade phase angle and reduced frequency. The EIGC card is required and the HESS method is used. The number of complex eigenvectors to be extracted must be specified, and will usually agree with the number of modes saved for output specified on the FLUTTER data card.

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

Results are presented in the Demonstration Problems Manual.
FIGURE 1. FINITE ELEMENT MODEL

FIGURE 2. AERODYNAMIC MODEL
CASE LEWIS, FLOATED SHOWN DISK ANALYSIS
EXAMPLE SINGLE-STAGE DESIGN OF ROTOR BLADE

AEREOELASTIC FLUTTER ANALYSIS

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ENDATA
NASTRAN DATA DECK

TIME K Required.

K -- Maximum allowable execution time in minutes.

SOL K1(K1) or SOL An(K1) Required when using a rigid format (see Section 3.1 for available options).

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

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

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

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Heat Transfer Approach Rigid Formats

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Aeroelastic Approach Rigid Format

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Subset Numbers

1. Delete loop control.
2. Delete mode acceleration method of data recovery (modal transient and modal frequency response).
3. Combine subsets 1 and 2.
4. Check all structural and aerodynamic data without execution of the aeroelastic problem.
5. Check only the aerodynamic data without execution of the aeroelastic problem.
6. Delete checkpoint instructions.
8. Delete Grid Point Weight Generator.
9. Delete fully stressed design (static analysis).
CASE CONTROL DECK

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. **ACCELERATION** - requests the acceleration of the independent components for a selected set of points or nodal coordinates.

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

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

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

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

1. **EL force** - 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. **LOAD** - 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. **FSE** - 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 DECK

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 GPFORCE 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:

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Field Contents

SID Identification number of contact surface set (integer > 0).

GA1, GB1 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 GA1 and GB1 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 GPFORCE 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 F9 -etc-

Field Contents
SID  Set identification number (unique integer > 0).
F1  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.

2.4-116a (9/30/78)
BULK DATA DECK

Input Data Card FLUTTER Aerodynamic Flutter Data

Description: Defines data needed to perform flutter analysis.

Format and Example:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUTTER</td>
<td>SID</td>
<td>METHOD</td>
<td>DENS</td>
<td>MACH</td>
<td>RFREQ</td>
<td>IMETH</td>
<td>NVALUE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUTTER</td>
<td>19</td>
<td>K</td>
<td>119</td>
<td>219</td>
<td>319</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Field

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

METHOD: Flutter analysis method, "K" for k-method (BCD).

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

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

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


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

Remarks:

1. The FLUTTER data card must be selected in Case Control Deck (FMETH0D - SID).

2. The density is given by \( \rho \cdot \rho_{\text{REF}} \) where \( \rho \) is the density ratio given on the FLFACT data card and \( \rho_{\text{REF}} \) is the reference density given on the AER0 data card.

3. The reduced frequency is given by \( k = \left( \text{REFC} \cdot \omega / 2 \cdot V \right) \), where \( \text{REFC} \) is given on the AER0 data card, \( \omega \) is the circular frequency and \( V \) is the velocity.

2.4-116c (9/30/78)
**BULK DATA DECK**

**Input Data Card**

**MKAER01**

**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:**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKAER01</td>
<td>( m_1 )</td>
<td>( m_2 )</td>
<td>( m_3 )</td>
<td>( m_4 )</td>
<td>( m_5 )</td>
<td>( m_6 )</td>
<td>( m_7 )</td>
<td>( m_8 )</td>
<td>ABC</td>
<td></td>
</tr>
<tr>
<td>MKAER01</td>
<td>.1</td>
<td>.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+BC</td>
<td>( k_1 )</td>
<td>( k_2 )</td>
<td>( k_3 )</td>
<td>( k_4 )</td>
<td>( k_5 )</td>
<td>( k_6 )</td>
<td>( k_7 )</td>
<td>( k_8 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+BC</td>
<td>.3</td>
<td>.6</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Field**

| m | List of Mach numbers or interblade phase angles (Real, \( 1 \leq i \leq 8 \)). |
| k | List of reduced frequencies (Real, \( 1 \leq j \leq 8 \)). |

**Remarks:**

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

Input Data Card  MKAER02  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
MKAER02 m_1 k_1 m_2 k_2 m_3 k_3 m_4 k_4
MKAER02 .10  .30 .10  .60 .70  .30 .70  1.0
```

<table>
<thead>
<tr>
<th>Field</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_i,k_i</td>
<td>List of pairs of Mach numbers (m) or interblade phase angles (Real) and reduced frequencies (k) (imbedded blank pairs are skipped).</td>
</tr>
</tbody>
</table>

Remarks:

1. This card will cause the aerodynamic matrices to be computed for a set of parameter pairs.
2. Several MKAER02 cards may be in the deck.
3. Mach numbers are input for wing flutter and interblade phase angle for blade flutter.
NASTRAN DATA DECK

PARAM (Cont.)

y. KMAX - optional in static analysis with cyclic symmetry (rigid format T5). 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. NODJE - 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 NODJE 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, NO, 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 STREAM1 bulk data cards. STREAML=2 causes the punching of STREAM2 bulk data cards. STREAML=3 causes both STREAM1 and STREAM2 cards to be punched. The default value, -1, suppresses punching of any cards.

ah. PGEQM - optional in static aerothermoelastic analysis. PGEQM = 1 causes the punching of GRID bulk data cards. PGEQM = 2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEQM = 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.
NJSTAN DATA DECK

PARAM (Cont.)

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

ak. ZORIGN, FXCOOR, FYCOOR, F2COOR - optional in static aerothermoelastic analysis. These are modification factors. The defaults are ZORIGN = 0.0, FXCOOR = 1.0, FYCOOR = 1.0, and F2COOR = 1.0.

cl. MINMACH - optional in blade flutter analysis. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid. The default is 1.0.

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

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

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

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

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

Input Data Card  STREAM1  Blade Streamline Data

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

Format and Example:

<table>
<thead>
<tr>
<th>SLN</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>G6</th>
<th>G7</th>
<th>etc-</th>
<th>+ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

+ABC  | G8  | G9  | etc- | etc- | etc- | etc- | etc- | etc- | etc- |
+ABC  | etc-| etc-| etc- | etc- | etc- | etc- | etc- | etc- | etc- |

Alternate Form:

<table>
<thead>
<tr>
<th>SLN</th>
<th>GID1</th>
<th>&quot;THRU&quot;</th>
<th>GID2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>&quot;THRU&quot;</td>
<td>6</td>
</tr>
</tbody>
</table>

Field          Contents
SLN            Streamline number (integer > 0).
G1, GID1       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 STREAM1 card for each streamline on the blade. For blade flutter problems, there must be an equal number of STREAM1 and STREAM2 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 STREAM1 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.

2.4-266a (9/30/78)
**BULK DATA DECK**

**Input Data Card**

**STREAML2**

**Blade Streamline Data**

**Description:** Define aerodynamic data for a blade streamline.

**Format and Example:**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAML2</td>
<td>S.N</td>
<td>NSTNS</td>
<td>STAGGER</td>
<td>CHORD</td>
<td>RADIUS</td>
<td>BSPACE</td>
<td>MACH</td>
<td>DEN</td>
<td>+abc</td>
</tr>
<tr>
<td>STREAML2</td>
<td>2</td>
<td>3</td>
<td>23.5</td>
<td>1.85</td>
<td>6.07</td>
<td>.886</td>
<td>.934</td>
<td>.066</td>
<td></td>
</tr>
<tr>
<td>+abc</td>
<td>VEL</td>
<td>FLOWA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ABC</td>
<td>1014.2</td>
<td>55.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Field Contents**

<table>
<thead>
<tr>
<th>Field</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLN</td>
<td>Streamline number (integer &gt;0)</td>
</tr>
<tr>
<td>NSTNS</td>
<td>Number of computing stations on the blade streamline.</td>
</tr>
<tr>
<td></td>
<td>(3 &lt; NSTNS &lt; 10, integer)</td>
</tr>
<tr>
<td>STAGGER</td>
<td>Blade stagger angle (-90.0 &lt; stagger &lt;90.0, degrees)</td>
</tr>
<tr>
<td>CHORD</td>
<td>Blade chord (real &gt;0.0)</td>
</tr>
<tr>
<td>RADIUS</td>
<td>Radius of streamline (real &gt;0.0)</td>
</tr>
<tr>
<td>BSPACE</td>
<td>Blade spacing (real &gt;0.0)</td>
</tr>
<tr>
<td>MACH</td>
<td>Relative flow mach number at blade leading edge (real &gt;0.0)</td>
</tr>
<tr>
<td>DEN</td>
<td>Gas density at blade leading edge (real &gt;0.0)</td>
</tr>
<tr>
<td>VEL</td>
<td>Relative flow velocity at blade leading edge (real &gt;0.0)</td>
</tr>
<tr>
<td>FLOWA</td>
<td>Relative flow angle at blade leading edge (-90.0 &lt; FLOWA &lt;90.0, degrees)</td>
</tr>
</tbody>
</table>

2.4-266b (9/30/78)
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 Aeroelastic 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 DHAP 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

3.1-2 (9/30/78)
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
COMPRESSOR BLADE MESH GENERATOR

3.21 COMPRESSOR BLADE MESH GENERATOR

3.21.1 DMAP Sequence for Compressor Blade Mesh Generator

RIGID FORMAT DMAP LISTING

SERIES 0

DMAP APPROACH, COMPRESSOR BLADE MESH GENERATOR

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GO ERR=2 NOLIST NODECK NOREF NOOSCAR

1 BEGIN $

2 ALG CASECC,,ALGDB,, / CASECCA,GEOM3A / C,N,-1 / C,N,-1 / V,Y,STREAML=1 / V,Y,PGEOH=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 STREAM1 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 ALGDB 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 causes 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 NASRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GO ERR=2 NOLIST NOCHECK NOREF NOUSCAR

1 BEGIN NO.16 STATIC AEROTHERMOELASTIC WITH DIFFERENTIAL STIFFNESS $
2 GPL GEM1,GEUM2;/GPL,GEUM2,/GPL,GEUM2,GPOT,CSTM,BGPDOT,SL/V,N,LASET/V,N, 
3 SAVE LASET,NUGPOT $
4 UND ERR1,NUGPOT $
5 CHKPT GPL,GEUM2,GPOT,CSTM,BGPDOT,SL $
6 GPL2 GFOM2,GEUM2/ECT $
7 CHKPT ECT $
8 PARAM PCNB,/C,N,PRES/C,N,C,N,C,N,V,N,NOPCDB $
9 PARAM //C,N,COMPLEX //V,Y,SIGN //C,N,O,0 //V,N,VSIGN $
10 PRTUX PLSETX,PLTMAP,GPSETS,ELSETS/NOPCDB $
11 UND P1,NOPCDB $
12 PLTSET PC01,GEUM2,LCT/PLTSETX,PLTMAP,GPSETS,ELSETS/V,N NSIL/V,N, 
13 SAVE NSIL,JUMPPLUT $
14 PRT45S PLTSETX/$
15 PARAM //C,N,4PY/V,N,PLTFLG/C,N,1/C,N,1 $
16 PARAM //C,N,4PY/V,N,PFILE/C,N,0/C,N,0 $
17 UND P1,JUMPPLUT $
18 PLOT PLTMAP,GPSETS,ELSETS,CASECC,BGPDOT,GEUM2,SL/V,N, 
19 SAVE JUMPPLUT,PLTFLG,PFILE $
20 PRT45S PLTSETX/$
21 LARIL P1 $
22 CHKPT PLTMAP,GPSETS,FLSFTS $

3.22-1 (9/30/78)
RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

23 GP3 GEOM3,FQEXIN,GEOM2/SLT,GPIT/V,N,NUGRAV $  
24 SAVE NUGRAV $ 
25 PARAM //C,N,AND/V,N,NOMGG/V,N,NUGRAV/V,Y,GRUPNT=-1 $  
26 CHKPT SLT,GPIT $  
27 TAL EST,EP1,BGPT,T,SLT,GPIT,T,CTM/EST,GE1,GPECT,/,V,N,LUSET/V,N,  
NUSIMP/C,N,1/V,N,NUGRAV/L,V,N,GENEL $  
28 SAVE NUSIMP,NUGRAV,GENEL $  
29 EMA ERRJR1,NUSIMP $  
30 PUNG UGPST/GENEL $  
31 CHKPT EST,GPECT,GP1,UGPST $  
32 PARAM //C,N,ADU/V,N,NUGGGX/C,N,1/C,N,0 $  
33 EMG EST,CSIM,MPT,UTL,GEIM2,/*KLEM,KUICT,MELM,NIICT,/,V,N,NUGGGX/V,N,  
NOMGG/C,N,C,N/C,Y,COPMMASS/C,Y,CPBAR/C,Y,CPRE/C,Y,  
CPQUDI/C,Y,CPQUD2/C,Y,CPKIA1/C,Y,CPKIA2/C,Y,CPVIBU/C,Y,  
CPQOPL/C,Y,CPQOPL/C,Y,CPTRPL/C,Y,CPTRBSC $  
34 SAVE NUGGGX,NOMGG $  
35 CHKPT KLEM,KUICT,MELM,NIICT $  
36 EMA JMPKGG,NUGGGX $  
37 EMA GPECT,KUICT,KLEM,KUGX,GPST $  
38 CHKPT KUGX,GPST $  
39 LABEL JMPKGG $  
40 EMA JMPNNG,NOMGG $  
41 EMA GPFCT,MDICT,MELM/MUG,1/C,N,-1/C,Y,WMTASS=1.0 $  
42 CHKPT MGG $  
43 LABEL JMP4GG $  
44 EMA LBL1,GRUPNT $  
45 EMA ERRJR4,NOMGG $
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 10
LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

40 GPNG UGPOT, CSTM, EJXIN, MUG, UX, UMG/V, GRDPNT/C, Y, WTMES 8
41 DNP DGPNG, // 8
42 LABEL LBL 1 8
43 EQUV RGG, KGG/NOGENL 8
44 CHKPT RGG 8
45 CONU LBL 11, NOGENL 8
46 SEDA GEI, KGG/X/KGG/V, N, LUSE1/V, N, NOGENL/V, N, NSIMP 8
47 CHKPT RGG 8
48 LABEL LBL 1 8
49 PARAM //L, N, MPY/V, N, NSKIP/C, N, O/C, N, O 8
51 SAVE MPCF1, MPCF2, SINGLE, UMIT, REACT, NSKIP, REPEAT, NOSF1, NOL, NOA 8
52 CONU ERKOR5, NUL 8
53 PURGE GM/NPCF1/G0, KOU, LUG, PO, UXOVO, RU0V/OMIT/PS, KFS, KSS, Q/G/SINGLE/ U00V/OMIT/YB, PS, KBFS, KBSS, KUFS, KUSS/SINGLE 8
54 CHKPT GM, R, GD, KOU, LUG, PO, UXOVO, RU0V, YS, PS, KFS, KSS, USET, ASET, U00V, YBS, PBS, KBFS, KBSS, KUFS, KUSS, QG 8
55 CONU LBL 40, REAL 8
56 JUMP ERKOR 2 8
57 LABEL LBL 40 8
58 CONU LBL 4, UGENL 8
59 GPSP GPL, PS1, USET, SIL/OGPS1/V, N, NOGPS1 8
60 SAVE NOGPS1 8
61 CONU LBL 4, NUGPS1 8
62 DNP UG**ST, // 8

3.27-3 (9/30/78)
RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTKAN DMAP COMPILER - SOURCE LISTING

69  LABEL   LBL4 $  
70  EQUIV   KGG,KNN/HPCF1 $  
71  CHKPTN  KNN $  
72  COND    LBL2,HPCF2 $  
73  NCEL    USET,KG/GM $  
74  CHKPTN  GM $  
75  NCEL2   USLT,GGM,KGG,,KNN,, $  
76  CHKPTN  KNN $  
77  LABEL   LBL2 $  
78  EQUIV   KNN,KFF/SINGLE $  
79  CHKPTN  KFF $  
80  COND    LBL3,SINGLE $  
81  NCEL    USET,KNN,,KFF,KFS,KSS,,, $  
82  CHKPTN  KIS,KSS,KFF $  
83  LABEL   LBL3 $  
84  EQUIV   KFF,KAA/OMIT $  
85  CHKPTN  KAA $  
86  COND    LBL5,OMIT $  
87  SMPI    USET,KFF,,,GO,KAA,KCG,LOD,,, $  
88  CHKPTN  GO,KAA,KCG,LOD $  
89  LABEL   LBL5 $  
90  KAMC2   KAA/LLL $  
91  CHKPTN  LLL $  
92  SSGI    SLT,UGPT1,CSTM,SIL,EST,MPT,GPIT,EDT,NGG,CASECC,DIT/PGA / V,N,  
           LAUSET/C,H,L $  
93  CHKPTN  PGA $  

3.22-4 (9/3C/78)
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT DMAP LISTING

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 CIND NUAI,ALOAD $
96 ALG CASECC1,EQUIN,ALGO, / CASECCAL,GEOM2 /S,Y,APRES$
97 COND FINISH,FAIL $
98 PARAM //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $
99 COND NUAI,ALOAD $
100 GP3 GEOM3AI,GEOM2/SLTAL,GPTTAI / V,N,NOGRAV $
101 CHKPT SLTAL,GPTTAI $
102 SSG1 SLTAL,GPTTAI,STM,SLT,EST,MPT,GPTTAI,EDT,MGG,CASECCAL,DIT / PA$A1 / V,N,LUSE1 / C,N+1 $
103 CHKPT PGA1 $
104 ACC PGVA,PGA1 / PG $
105 LABEL NUAI $
106 EQUIV PGVA,PG/ALOAD $
107 CHKPT PG $
108 EQUIV PG,PL/LUSET $
109 CHKPT PL $
110 COND LBL10,NUSET $
111 SSG2 LUSE1,GM,Y,S,KF,S0,,PG/PS,PL $
112 CHKPT PU,PS,PL $
113 LABEL LBL10 $
114 SSG3 LLL,KAAL,PL,KDD,PG/ULV,UOOG/RULV,ROOV/V,N,OMIT/V,Y,IERES=--1 / C,N+1/V,N,EPSt $
115 SAVE EPS1 $
116 CHKPT ULV,UGUV,RULV,ROOV $
117 COND LBL9,IERES $
RIGID FORMATS

RIGID FORMAT DMAF LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16
LEVEL 2.0 NASTRAN DMAF COMPILER - SOURCE LISTING

118 NATGPR GPL, USET, SIL, RULV/C, N, 0
119 NATGPR GPL, USET, SIL, RUUV/C, N, 0
120 LABEL LUL9 8
121 SCR1 USET, ULV, UD3V, V, YS, GM, PS, KFS, KSS, UGV, PGI, OUP/C, N, 1/C, N, DSO 8
122 CHKPNK UGV, QG 8
123 SDR2 CASECC, CSTM, MPT, DT, EQE, IN, SIL, GPTT, EOT, BGPOT, QG, UGV, EST, PGI, OUPG, V, USI, OEF, UGV, EOT, BGPOT, IN, QG, UGV, EST, PGI, OUPG, V, USI, OEF 8
124 PARAM //C, 4, MPY/V, N, CARNO/C, N, 0/C, N, 0 $ 8
125 OFP UGV, UPG1, UQG1, UEF1, UE 1, //V, N, CARNO 8
126 SAVE CARNO 8
127 COND P2, JUMPPLOT 8
128 PLOT PLTMOV, GPSETS, ELSE IS, CASECC, BGPOT, EQE, IN, SIL, PUGV, UG, PGE, OES1, /PLUTX2/V, N, USI, V, N, LLSET/V, N, JUMPPLOT/V, N, PLTFLG/V, N, PFILE 8
129 SAVE PFILE 8
130 QRTMSU PLUTX2/ 8
131 LABEL P2 8
132 FA1 FCT, EPT, BGPOT, SIL, GPTT, CSTM/X1, X2, ECPT, GPCT/V, N, LUSET/ V, N, NUSIMP/C, N, 0/V, N, NUSENL/V, N, GEN 8
133 DSMG1 CASECC, GPTT, SIL, EOT, CGV, CSTM, MPT, ECPT, GPCT, DT, KDOG/ V, N, ODCODSET 8
134 CHKPNK KDOG 8
135 COND NUAO, ALAO 8
136 EQUIV PQQA, PG 8
137 LABEL NUAO 8
138 PARAM //C, N, ADD/V, N, SHIF1/C, N, -1/C, N, 0 $ 8
139 PARAM //C, N, ADD/V, N, COUT1/V, N, ALWAYS=1/V, N, NEVER=1 $ 8
140 PARAM //C, N, ADD/V, N, USEPSI/C, N, 0/C, N, 0 $
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT OMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16
LEVEL 2.0 NASAHAN OMAP COMPILER - SOURCE LISTING

141 PARAM YS/C,N,NULL/C,N,/C,N, /C,N, /V,N,NOYS $
142  JUMP  UUTLTP  TOP $
143  LABEL  UUTLTP  TOP $
144  EQUIV  PG,PG1/NUYS $
145  CHKPNT  PGI $
146  PARAM  /C,N,KLOCK, V,N,TO $
147  EQUIV  KDG,G,KO,N/MP,F2 $
148  CHKPNT  KGN $
149  CONU  LBL2U, MP,F2 $
150  MCE2  USET, GM, KDG, .../KDO, ... $
151  CHKPNT  KDO $
152  LABEL  LBL 2U $
153  EQUIV  KUNN, KU,F/SINGLE $
154  CHKPNT  KDF $
155  CONU  LBL3U, SINGLE $
156  SCE1  USET, K0,N, .../KDF, KDF, KDS, ... $
157  CHKPNT  KDF, KU,F, KDO $ $
158  LABEL  LBL30 $ $
159  EQUIV  KDF, KDAA/OMI T $ $
160  CHKPNT  KDAA $ $
161  COND  LBL5D, OMI T $ $
162  SMPZ  USET, GO, KDF, KDAA $ $
163  CHKPNT  KDAA $ $
164  LABEL  LBL50 $ $
165  ADD  KAA, KDAA / KBLL / C,N, (1.0, 0.0) / V,N, CSIGN $ $

3.27-7 (9/30/78)
RIGID FORMATS

RIGID FORMATS

RIGID FORMAT OSS AP LISTING

SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL: 2.0

ISTRAN DMAP COMPILERT- SOURCE LISTING

166 ADD KFS,KDF5, KDFS / V.A,C,0.01 / V.A,CSIGN
167 ADD KDF5, KDFS / V.A,0.01 / V.A,CSIGN
168 COND PGEK,NOYES
169 copy KASS,YS, PSS/ C.N,1/C.N,1/C.N,1
170 copy KASS,YS, PSS/ C.N,1/C.N,1/C.N,1
171 COND LEFS, PF5, PSS/PL/C.N,A/C.N,F/C.A,S
172 EQUIV PN,P5X/MPCF2
173 COND LBLE5,MPCF2
174 copy USG, PN, PGX/PL/C.N,A/C.A,M
175 LABEL LBLS $ 
176 COND PG5,PG5/PGS/C.N,1.0,0.01
177 EQUIV PG5, PG5/ALLWYS $ 
178 LABEL PG5 $ 
179 EQV PG5, PG5$/
180 PBY UG5 / A5UGV $ 
181 PBGZ KALL/ALLV,N,POWER/V,N,NET $ 
182 SAVE NET,POWER $ 
183 CMKDNT LBLL $ 
184 CRTPSN / C.N,C,A,NET $ 
185 CRTPSN / C.N,C,A,POWER $ 
186 LISP INLPPEC $ 
187 LISP INLPPEC $ 
188 PATX4 / C.A, KLECK/V.A,TI $ 
189 COND NOALL,ALCAN $ 

3.22-8 (9/30/78)
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LISTING
SERIES 3

DISPLACEMENT APPROACH, RIGID FORMAT 16
LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

Y,ZXOR IGN/V,Y,FXCOO R/V,Y,FXCOO R $

191 CUND DOVE, IFAIL $
192 PARAM //C,N,MPY /V,Y,IPRTCL /C,N,O $
193 PARAM //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $
194 CUND NUAI L, ALoad $
195 GP3 GEOM3A,EQXLIN,GEOM2/SLTA, GPTTA/V,N,NOASL/V,N,NOGRAV/V,N,NOATL $
196 SSGL SLTA, GPTTA, CSTM, SILEST, MPT, GPTTA, EDT, MGG, CASECCA, DIT /PGA /V,N, LUSET /C,N, L$
197 ADD PG1, PG2 /PGL $ 
198 LABEL NUAI L $ 
199 EQUIV PG1, PG2 /ALOAD $ 
200 CHKPT PG2 $ 
201 SSGL USET, GM, YS, KDFS, GU, PG2 /P80, PBS, PBL $ 
202 SSGL LBL, KBLL, PBL ..., /WLV, RUBLV /C,N-1/V,Y, IRES/V,N, NOSKIP/V,N, EPSI $ 
203 SAVE EPSI $ 
204 CHKPT UWLV, RUBLV $ 
205 CUND LBL93, IRES $ 
206 MATGR GPL, USET, SILEST, RUBLV /C,N, L $ 
207 LABEL LBL93 $ 
208 SDR1 USET, UWLV, YS, GO, GM, PBS, KDFS, KBS5, /UBGV, UBG/C,N, I/C,N, DS1 $ 
209 CHKPT UBGV, UBG $ 
210 CUND NUAI L, ALoad $ 
211 EQUIV UBGV, AUGV $ 
212 LABEL NUAI L $ 
213 ADD UBGV, UGV /UGV/C,N,-1.0,0.01 $ 

3.22-9 (9/30/78)
RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16
LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

214 DSMGL CASECC,GPTT,SIL,EDIT,UGV, CSTM, MPT, ECPT, GPCI, DIT/UKDGGL/V, N, DSCGSET $  
215 CMPNT UKDGGL $  
216 MPYAD UKDGGL,UGV,PGO/PGII/C,N,0/C,N,1/C,N,1/C,N,1 $  
217 ACG PGII,PG1 / PG12 $  
218 OSCICK PG2,PGL2,UGV // C,Y, EPS10=1,E-5 / V,N,DSEPS1 / C,Y,NT=10 / V,N, TO / V,N, TI / V,N,DONE / V,N,SHIFT / V,N,COUNT/C,Y, BETAD=4 $  
219 SAVE DSEPS1, DONE, SHIFT, COUNT $  
220 CUND DONE, DONE $  
221 CUND SHIFT, SHIFT $  
222 EQUIV PG, PG1 / NEVER $  
223 EQUIV PGII, PG1 / ALWAYS $  
224 EQUIV PG, PGII / NEVER $  
225 REPT INPUT1, 1000 $  
226 TAPPT PGII, PG1 // $  
227 LABEL SHIFT $  
228 ADD UKDGGL, KGGL1 / KGGL1/C,N,1/-1.0,0.0 $  
229 CHKPTT KGGL1 $  
230 EQUIV UBVV, UJV / ALWAYS/ KGGL1, KGGL1 / ALWAYS $  
231 CHKPTT KGGL $  
232 EQUIV KGGL, KGGL1 / NEVER/ LGV, UBVV / NEVER $  
233 REPT Output1, 1000 $  
234 TAPPT KGGL1, KGGL, UBVV, // $  
235 LABEL DONE $  
236 PARAM // C,N, NO / V,Y, KTOUT=-1 $  
237 CUND JMPK TOUT, KTOUT $
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT OMP LISTING
SERIES O

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

238 ALC KGG,KGG / KTOT / C,,N,,(1.0,0.0) / V,,N,,CSIGN $
239 OUTPUT KTOT,..., / C,,Y,,LOCATION=-1 / C,,Y,,INPTUNIT=0 $
240 OUTPUT..., / C,,N,-3 / C,,N,0 $
241 LABEL JMPKOUT $
242 CHKPTN CSTM $
243 ALC CASECC,EDT,EQEXIN,UGGV,ALGDB,CSTM,BGPD / CASECC,GEUM38 / C,,N, -1/C,,N,-1/V,,Y,,STREAM/V,,Y,,PGEOM/V,,Y,,IPRTCF/S,N,1FAIL/V,,Y,,SIGN/ V,,Y,,STKNG/V,,Y,,FAEQVR/V,,Y,,FYQODR/V,,Y,,FYQODR $
244 SUNK2 CASECC,CSTM,NUM,PJ,EDT,EQEXIN,STL,GPTT,EDT,BGPD,1,0QG,0UBG,EST,..., / OQGIN1,UQGIN1,DES31,UEFB1,PUBGVI / C,,N,0DS1 $
245 DFP UWGVI,0QG1,0EB1,0EB1,0/S, /V,,N,,CARDNU $
246 SAVE CARDNU $
247 CKPL USEF2,UBLV,,YS,GO,GM,BSS,KBFS,KBSS / AUBGVI,APGG,AGQG / C,,N,, 1/C,,N,0DS1 $
248 GPFDR CASECC,UGGV,KEM,DEIC,ECT,EQEXIN,GPECT,APGG,AGQG / JNRYV1, OQGIN1 'C,,N,,STATICS $
249 DFP ONKGY1,0QFPB1,..., / $
250 CUND P3,JUMPPLOT $
251 PLUT PLTPAR,GPSETS,ELSETS,CASECC,BGPD,1,0QG,0UBG,1,GPECT, QES1/PLUTX3/V,,N,,HSIL/V,,N,,LUSET/V,,N,,JUMPPLOT/V,,N,,PLTLG/V,,N,, PFILE $
252 SAVE PFILE $
253 PRN4SG PLUTX3/ $
254 LABEL P3 $
255 JUMP FINIS $
256 LABEL ERROR1 $
257 PRTPARM //C,,N,-1/C,,N,0DIFFSTIF $
258 LABEL ERROR2 $
259 PRTPARM //C,,N,-2/C,,N,0DIFFSTIF $
RIGID FORMATS

RIGID FORMAT OMAH LISTING
SERIES O

DISPLACEMENT APPROACH, RIGID FORMAT 16
LEVEL 2.0 NASTRAN OMAH COMPILER - SOURCE LISTING

260 LABEL ERWOK4 $
261 @PTPARM //C,N,-4/C,N,DIFFSTIF $
262 LABEL ERROR5 $
263 @PTPARM //C,N,-5/C,N,DIFFSTIF $
264 LABEL FINIS $
265 END $

**NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM**
3.22.2 Description of DHAP 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 DHAP 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 DHAP 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 DHAP No. 21 if no undeformed structure plot request.

18. PLTBT 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. TAI generates element tables for use in matrix assembly and stress recovery.

29. Go to DHAP 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 DHAP No. 39 if no stiffness matrix is to be assembled.

37. EMA assembles stiffness matrix \([K_{gg}]\) and Grid Point Singularity Table.

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

41. EMA assembles mass matrix \([M_{gg}]\).

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

45. Go to DHAP 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 \([K^*_{gg}]\) to \([K_{gg}]\) if no general elements.

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

52. SMA3 adds general elements to \([K^*_{gg}]\) to obtain stiffness matrix \([K_{gg}]\).

56. GP4 generates flags defining members of various displacement sets (USET), forms multiprint constraint equations \([R_g](u_g) = 0\) and forms enforced displacement vector \((Y_g)\).
RIGID FORMATS

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. DFP 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 $[R_g] = [R_{mg}; R_n]$ and solves for multipoint constraint transformation matrix $[G_m] = -[R_m]^{-1}[R_n]$.

75. MCE2 partitions stiffness matrix

$$[K_{gg}] = \begin{bmatrix} K_{nn} & K_{nm} \\ K_{mn} & K_{mm} \end{bmatrix}$$

and performs matrix reduction

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

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.

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

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

$$[K_{ff}] = \begin{bmatrix} \tilde{K}_{aa} & K_{ao} \\ K_{oa} & \tilde{K}_{oo} \end{bmatrix}$$

solves for transformation matrix $[G_o] = -[K_{oo}]^{-1}[K_{oa}]$ and performs matrix reduction $[K_{aa}] = [\tilde{K}_{aa}] + [K_{oa}][G_o]$.
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

90. RMBG2 decomposes constrained stiffness matrix \( [K_{aa}] = [L_{kk}][U_{kk}] \).
92. SSG1 generates non-aerodynamic static load vectors \((P^\text{NA})\).
95. Go to DMAP No. 105 if no aerodynamic loads.
96. ALG generates aerodynamic load data.
102. SSG1 generates aerodynamic load vector \((P^\text{A})\).
104. Add \((P^\text{NA})\) and \((P^\text{A})\) to form total load vector \((P)\).
106. Equivalence \((P)\) to \((P^\text{NA})\) if no aerodynamic loads.
108. Equivalence \((P)\) to \((P^\text{A})\) if no constraints applied.
110. Go to DMAP No. 113 if no constraints applied.
111. SSG2 applies constraints to static load vectors

\[
(P) = \begin{pmatrix}
\tilde{P}_n \\
\tilde{P}_m \\
\tilde{P}_f \\
\tilde{P}_o
\end{pmatrix}, \quad (P_n) = (\tilde{P}_n) + (G^T_m)(P_m),
\]

Equivalence \((P^\text{NA})\) to \((P^\text{A})\) if no aerodynamic loads.
\[
(P) = \begin{pmatrix}
P_n \\
P_m \\
P_f \\
P_o
\end{pmatrix}
\]

114. SSG3 solves for displacements of independent coordinates

\[
(u) = [K_{aa}]^{-1}(P) \]

solves for displacements of omitted coordinates

\[
(u^o) = [K_{oo}]^{-1}(P) \]

116. SSG3 calculates residual vector (RULV) and residual vector error ratio for independent coordinates

\[
(\delta P) = (P) - [K_{aa}](u)
\]

\[
c_e = \frac{(u^T_e)(\delta P)}{(P^T_e)(u_e)}
\]

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

\[
(\delta P^o) = (P^o) - [K_{oo}](u^o)
\]

\[
c_o = \frac{(u^T_o)(\delta P^o)}{(P^T_o)(u^o)}
\]

3.22-15 (9/30/7)}
RIGID FORMATS

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. SOR1 recovers dependent displacements

\[
\begin{align*}
(u_0) &= [G_0](u_x) + (u_0^d) , \\
(u_0) &= (u_0) , \\
(u_n) &= (u_n) , \\
(u_m) &= [G_m](u_m), \\
(u_m) &= (u_m).
\end{align*}
\]

and recovers single-point forces of constraint

\[
(q_s) = -(P_s) + [K_s^T](u_n) + [K_s^s](Y_s).
\]

122. SOR2 calculates element forces and stresses (ØEF1, ØES1) and prepares load vectors, displacement vectors and single-point forces of constraint for output (ØPG1, ØUGVI, PIUGVI, ØOG1).

125. ØFP formats tables prepared by SOR2 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. PLOT generates all requested static deformed structure plots.

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

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

133. DSHG1 generates differential stiffness matrix \([K^d_{gg}]\).

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

136. Equivalence (\(p^H\)) to (\(P_n\)) to remove aerodynamic loads from total load vector before entering differential stiffness loop. New aerodynamic loads will be generated in \(\phi_{uc}\).

142. Go to next DMAP instruction if cold start or modified \(\phi_{art}\). OUTLP<TOP will be altered by the Executive System to the proper action inside the loop for unmodified restarts within the loop.

143. Beginning of outer loop for differential stiffness iteration.

144. Equivalence (\(P_n\)) to (\(P_g\)) if no enforced displacements.

147. Equivalence \([K^d_{gg}]\) to \([K^d_{nn}]\) if no multipoint constraints.

3.22-16 (9/30/78)
STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

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

150. MCE2 partitions differential stiffness matrix

\[
\left[ k^d_{nn} \right] = \begin{bmatrix}
    k^d_{nn} & k^d_{nm} \\
    k^d_{mn} & k^d_{mm}
\end{bmatrix}
\]

and performs matrix reduction \([k^d_{nn}] = (k^d_{nn}) \cdot (G^T_m)[k^d_{mn}] + [k^d_{mm}][G_m] + [G^T_m][k^d_{mm}][G_m].\]

153. Equivalence \([k^d_{nn}]\) to \([k^d_{ff}]\) if no single-point constraints.

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

156. SCE1 partitions out single-point constraints

\[
\left[ k^d_{nn} \right] = \begin{bmatrix}
    k^d_{ff} & k^d_{fs} \\
    k^d_{fs} & k^d_{ss}
\end{bmatrix}
\]

159. Equivalence \([k^d_{ff}]\) to \([k^d_{aa}]\) if no omitted coordinates.

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

162. SMP2 partitions constrained differential stiffness matrix

\[
\left[ k^d_{ff} \right] = \begin{bmatrix}
    k^d_{aa} & k^d_{ao} \\
    k^d_{oa} & k^d_{oo}
\end{bmatrix}
\]

and performs matrix reduction \([k^d_{aa}] = (k^d_{aa}) \cdot (G^T_o)[k^d_{ao}] + [k^o_o][G_o] + [G^T_o][k^d_{oo}][G_o].\]

165. ADD \([k^d_{aa}]\) and \([k^d_{aa}]\) to form \([k^b_{aa}]\).

166. ADD \([K^b_{fs}]\) and \([K^b_{fs}]\) to form \([K^b_{fs}]\).

167. ADD \([K^b_{ss}]\) and \([K^b_{ss}]\) to form \([K^b_{ss}]\).

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

169. MPYAD multiply \([k^b_{ss}]\) and \((Y_s)\) to form \((P_{ss})\).

170. MPYAD multiply \([k^b_{fs}]\) and \((Y_s)\) to form \((P_{fs})\).

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

172. Equivalence \((P_{gy})\) to \((P_g)\).

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RIGID FORMATS

179. ADD \((P_{g1})\) and nothing to create \((P_{go})\).
180. Copy \((u^A_g)\) to \((u^A_g)\) to initialize aerodynamic displacements.
181. RNBG2 decomposes the combined differential stiffness matrix and elastic stiffness matrix.
\[
[K^{b}_{xz}] = [r^{b}_{xz}][u^{b}_{xz}].
\]
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 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.
188. 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 \((P^A_g)\).
197. ADD \((P^1_g)\) and \((P^A_g)\) to form total load vector \((P^2_g)\).
201. SSG2 applies constraints to static load vectors
\[
(P^2_g) = \begin{pmatrix}
(p^b_n) \\
(p^b_m)
\end{pmatrix}, \quad (p^b) = (p^b_n) + [G^T_m](p_m^b),
\]
\[
(p^b_n) = \begin{pmatrix}
(p^b_f) \\
(p^b_s)
\end{pmatrix}, \quad (p^b) = (p^b_f) - [K^d_f_s](y_s),
\]
\[
(p^b_f) = \begin{pmatrix}
(p^b_e) \\
(p^b_o)
\end{pmatrix} \text{ and } (p^b) = (p^b_e) + [G^T_o](p_o^b).\]
202. SSG3 solves for displacements of independent coordinates for current differential stiffness load vector
\[
(u^b) = [K^{b}_{xz}]^{-1}(p^b).
\]

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STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

and calculates residual vector, \( \Delta P^b \) and residual vector error ratio for current differential stiffness load vector

\[
\Delta P^b_k = (P^b_k) - [k_{k_k}^b](u^b_k),
\]

\[
e^b_k = \frac{(u^b_k)^T(\Delta P^b_k)}{(P^b_k)^T(u^b_k)}.
\]

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

\[
(u^b_0) = [G_0](u^b_0) + (u^b_0),
\]

\[
(u^b_0) = (u^b_0),
\]

\[
(u^b_0) = (u^b_0),
\]

\[
(u^b_0) = (u^b_0),
\]

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

\[
(q^b_s) = -(P^b_s) + [k_{s_f}^b](u^b_s) + [k_{f_f}^b](y^b_s).
\]

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

211. Equivalence \( u^b_g \) to \( u^b_g \).

213. ADD \(- (u^b_g)\) and \( (u^b_g)\) to form \( u^d_g\).

214. DSHGI generates differential stiffness matrix \([k^d_g]\).

216. HPYAD form load vector for inner loop iteration.

\[
(P^g_{11}) = (P^g_{12}) = (P^g_{12})
\]

217. ADD \((P^g_{11})\) and \((P^A_{11})\) to form \((P^g_{11})\).

218. DSHCK 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 \((P^g_{11})\) to \((P^g_{11})\).
RIGID FORMATS

223. Equivalence \((P_{g1})\) to \((P_{g})\).

224. Equivalence breaks previous equivalence of \((P_{g1})\) to \((P_{g1})\).

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

226. TABPT table prints vectors \((P_{g1})\), \((P_{g})\), and \((P_{g})\).

228. ADD \([-\Delta K_{g1}]\) and \([K_{g1}]\) to form \([K_{g1}^{d}]\).

230. Equivalence \((U_{g})\) to \((U_{g})\) and \([K_{g1}]\) to \([K_{g1}^{d}]\).

231. Equivalence breaks previous equivalence of \([K_{g1}^{d}]\) to \([K_{g1}^{d}]\) and \((U_{g})\) to \((U_{g})\).

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

234. TABPT table prints \([K_{g1}^{d}]\), \([K_{g1}^{d}]\) and \((U_{g})\).

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

238. ADD \([K_{g1}^{d}]\) and \([K_{g1}^{d}]\) to form \([K_{TOTAL}^{d}]\).

239. OUTPUT1 outputs \([K_{TOTAL}^{d}]\) 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 STREAM2 bulk data cards on the system punch, if requested.

244. SDR2 calculates element forces and stresses \((\Delta EFB), (\Delta ESBI))\) and prepares displacement vectors and single-point forces of constraint for output \((\Delta PUBGV1, \Delta PUBGV1, \Delta PBVG1))\) for all differential stiffness solutions.

245. OFP 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. GPFDRL calculates for requested sets the grid point force balance and element strain energy for output.

249. OFP formats the tables prepared by GPFDRL 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. PLGT generates all requested deformed differential stiffness structure plots.

253. PRTHSG 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 ERROR MESSAGE NO. 1 - NO STRUCTURAL ELEMENTS HAVE BEEN DEFINED.

259. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 2 - FREE BODY-SUPPORTS NOT ALLOWED.

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STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

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.
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 EPSIΩ value supplied by the user on a PARAM bulk data card. (The default value of EPSIΩ is 1.0E-5.)

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

4. reason 3 means insufficient time remaining to achieve convergence to the EPSIΩ value supplied by the user on a PARAM bulk data card. (The default value of EPSIΩ 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 DONE: -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.
RIGID FORMATS

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 LOAD, 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 level.

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.
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 ENG.

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

4. COUPMASS - CPBAR, CPBAR, 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. MT - optional - the integer value of this parameter limits the maximum number of iterations. The default value is 10 iterations.
RIGID FORMATS

7. **EPS1G** - 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. **PGEOM** - 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. PGEOM=3 causes the punching of GRID cards and the modified ALGDB table on DI cards. The default, -1, suppresses punching of any cards.

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

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

14. **ZORIGN, FXCOOR, FYCOOR, FZCOOR** - optional in static aerothermoelastic analysis. These are modification factors. The defaults are ZORIGN = 0.0, FXCOOR = 1.0, FYCOOR = 1.0, and FZCOOR = 1.0.
15. **KTOUT** - optional in static aeroelastic 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.
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

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 0

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GU ERR=2 NOLIST NOJEECK NUREF NOUSCAR

1 BEGIN AERO NJ.9 COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS $  
2 FILE PHIL=APPEND/AJLL=APPEND/SAVE=APPEND/CASEYY=APPEND/CLAML=APPEND/UVG=APPEND/WHIL=APPEND $  
3 COMPL  GEOM1,GEOM2,GPL,GEEXIN,GPOT,CSTM,BGPOT,SIL/V,N,LUS/BV,N,NOGPOT $  
4 SAVE LUS/E,N/NOGPOT $  
5 CHKPT GPL,GEEXIN,GPOT,CSTM,BGPOT,SIL $  
7 PURGE DIJE,D2JE/NOJJE $  
8 GIF GLO42,LEXIN/ELT $  
9 CHKPT ECT $  
10 GIF JUST,GPL,V,N,NOGRAV $  
11 CHKPT GPIT $  
12 ESA ECT,EPOT,BGPOT,SIL/OPIT,CSTM/EST,GPCT,/V,N,LUS/BV,N,NUSIM/C,N,1/V,N,NUSIM/V,A,NUSIM/C,N,1/GENEL $  
13 SAVE NUGENL,NUSIM,GENEL $  
14 END ERRJK1,NUSIM $  
15 END UGPST/GENEL $  
16 CHKPT EST,GPCT,GEI,UGPST $  
17 PARA //C,N,ADD/V,N,NUKGGX/C,N,1/C,N,0 $  
18 PARA //C,N,ADD/V,N,NUKGGX/C,N,1/C,N,0 $  
19 PARA //C,N,NOP/V,V,KGIN=-1 $  
20 CHKPT JMPKGGIN,KGIN $  
21 PARA //C,N,ADD/V,N,NUKGGX/C,N,1/C,N,0 $  
22 INPUT / KGIN,/,V,Y,LOCATION=-1/C,Y,INPUT=0 $  

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RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

AERU APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASIKAN DMAP COMPILER - SOURCE LISTING

23 EQUIV KGGX, KGX
24 CMPNT KGX
25 LABEL JMPKGGIN
27 SAVE NOKGGX, NUGGGX
28 CMPNT KELM, AJICT, HELM, NDICT
29 CMPNT JMPKGGX, NUGGGX
30 EMA GPECT, AJICT, KELM /KGX, GPST
31 CMPNT KGGX, GPST
32 LABEL JMPKGGX
33 CMPNT ERKORl, NUGGGX
34 EMA GPECT, NDICT, HELM /MUG, /C, N, -1 /C, Y, WMASS = 1.0
35 CMPNT KGG
36 CMPNT LGPGW, GRDPNT
37 CMPNT BGPUT /C, STM, EKEXIN, MUG /LUPWG /V, Y, GRDPNT = -1 /C, Y, WMASS
38 CMPNT OGPW, ************
39 LABEL LGPGW
40 EQUIV KGX, KG /NUGGENL
41 CMPNT KG
42 CMPNT LBL11, NUGGENL
43 CMPNT GEL, KGX, KG /V, N, IDSET /V, N, NUGGENL /V, N, NOSEMIP
44 CMPNT KG
45 LABEL LBL11
46 CMP CASECC, GEOM5, EQEXIN, SIL, UPDDT, BGPUT /C, STM /RG, /USET, ASET /V, N,

3.73-2 (9/30/78)
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT OMAP LISTING
SERIES 0

AERO APPROACH. RIGID FORMAT 9

LEVEL 2.0 NASTRAN OMAP COMPILER - SOURCE LISTING

! USE /VtNrMP,f 1/VrArMPGF 2/Vtth*St NGLE/V*N#UM1T/VrNeREACT/C.N.O/
! SAVE MPCF1,SINGLE,UNIT,REACT,NOSET,MPCF2,REPEAT,NCL,NOA 

! PARAM //C,N,JNT/Vt,V,REAQCUGA /Vt,N,REACT 

! G0 CHKPT CYCO 

L USE /VtNrMP,f 1/VtNrNUL/VtNrNOA, /CrYrSud1O 

47 SAVE MPCF1,SINGLE,UNIT,REACT,NOSET,MPCF2,REPEAT,NCL,NOA 

48 PARAM //C,N,JNT/Vt,V,REAQCUGA /Vt,N,REACT 

49 CHKPT CYCO 

50 PURGE GM,G40/MPCF1/GU,G90/OMIT/KFS,QPC/SINGLE 

51 QPCYC GECN,EQERXN,USET /CYCO/ Vt,V,CYCLE /Vt,N,NUGO 

52 SAVE NUGO 

53 CHKPT CYCO 

54 CHKPT ENKURS,REAQCUGA 

55 CHKPT LBL4,GREV 

56 QPSH GPL,GPST,USET,SIL/IDPS1/Vt,N,NOGST 

57 SAVE NUGST 

58 CHKPT LBL4,NUGST 

59 JFP QPS1,111,111,111,111,111 

60 LABEL LBL4 

61 E奎V KGG,KNN/MPCF1/MGG,MNN/MPCF1 

62 CHKPT KNN,MNN 

63 CHKPT LBL2,MPCF1 

64 MCFI USET,KGG/GM 

65 CHKPT GM 

66 MCF2 USET,CN,KGG,MGG,,,KNN,MNN, 

67 CHKPT KNN,MNN 

68 LABEL LBL2 

69 E奎V KNN,KFF/SINGLE/MNN,MFF/SINGLE 

70 CHKPT KFF,MFF 

3.23-3 (9/30/78)
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<td>KFF, KAA, UNIT/ MFF, MAA, UNIT $</td>
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<td>76</td>
<td>CK0PNT</td>
<td>KAA, MAA $</td>
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COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES 0

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN UMAP CUMPIILEK - SOURCE LISTING

94 PARAM /C,N,MPY / V,N,CARDNO / C,N0 / C,N0 
95 UFP UEGS,LAMK,... / V,N,CARDNO 
96 SAVE CARDNO 
97 CUNU ERROR,N,NEIGV 
98 CYC12 CYC1,...,PHIA,LAMK,...,PHIA,LAMA / C,N,BACK / V,Y,NGS / V,Y, KINDEX / V,Y,CYCLE0 / C,N1 / V,N,NUGO 
99 SAVE NUGO 
100 CUNPNT LAMA,PHIA 
101 CUNU ERROR,N,NUGO 
102 SUER USET,...,PHIA,...,GU,GH,N,... / PHIG,..., C,N1 / C,NREIG 
103 SUER CASECC,CST,...,QPT,...,DIL,...,EUEXIN,SIL,...,BGPDT,LAMA,...,PHIG,EST,... / PHIG,...,C,NREIG 
104 UFP DPHIG,...,... / V,N,CARDNO 
105 SAVE CARU VI J 
106 APERU EUT,USET,HGPJT,CST,...,EUEXIN,GH,GO / AERO,ACPT,FLIST,GTKA,PVCT / V,Y,VK/NJ/V,Y,MAMLCH/V,Y,MAXYCH/V,Y,REF/V,Y,MTYPE/V,N,NELV/V,Y,KINDEX=-1 
107 SAVE NK,NJ 
108 CUNPNT AERO,ACPT,FLIST,GTKA,PVCT 
109 UFP HIAP,PVCT, / PHIA,...,C,N1 
112 SAVE NUK2P,P,NUM2P,P,NUB2P 
113 PURGE K2DD/M2K,P/MZDO/NJMX2P/H2DD/NOB2P 

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RIGID FORMATS

RIGID FORMAT OMAP LISTING
SERIES U

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN OMAP COMPILER - SURFACE LISTING

CMPEV/C,N,DI SP/C,N,NOAL/C,N,0.0/C,N,0.0/C,N,0.0/V,N,NUKDPP/V,
N,NUKDPP/V,N,NUKD2PP/V,N,NUKDPP/V,N,NUKDPP/V,N,NUK2PP/V,
N,NUKDPP/V,N,NUKD2PP/V,N,NUKDPP/V,N,NUKDPP/V,N,NUKD2PP/V,
N,NUKDPP/V,N,NUKD2PP/V,N,NUKDPP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKDPP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
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N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
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N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,N,NUKD2PP/V,
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 CHKPT AJJL,SKJ,D1JK,D2JK $
139 CUND NUDJE,NUDJE $
140 INPUT /DIJE,D2JE,,/C,Y,POSITION=-1/C,Y,UNITNUM=11/ C,Y,USRLABEL=TAPE10 $
141 LABEL NUDJE $
142 PARAM //C,N,ADD/VN,XQHHL/C,N,1/C,N,0 $
143 CAMP AJJL,SKJ,D1JK,D2JK,K,PHIDH,D1JE,D2JE,USED,AERO/QHHL,QJHL/V,
N,NUDE/VN,XJHHL $
144 SAVE XQHHL $
145 CHKPT QHHL,QJHL $
146 PARAM //C,N,4P/VN,NUP/C,N,-1/C,N,1 $
147 PARAM //C,Y,4P/VN,NUP/C,N,1/C,N,1 $
148 PARA4 //C,N,4P/VN,NDH/C,N,0/C,N,1 $
149 PARA4 //C,N,4P/VN,FLOOP/V,Y,NUDJE=-1/C,N,0 $
150 JUMP LOUPTUP $
151 LABEL LOUPTUP $
152 FAI KHH,BHHL,PHY,JHHL,CASEC,FLIST/FSAVE,KXHH,BXHH,MY-M/VN,FLOOP/V,
N,TSTART $
153 SAVE FLOOP,TSTART $  
154 CALL KXHH,BXHH,MY-M,FED,CASEC/PHIM,CLAMA,UCEIGS/V,N,EIGVS $
155 SAVE EIGVS $  
156 CUND LBLZAP,EIGVS $  
157 CUND LBL16,NUH $  
158 VDK CASEC,EOQYN,USED,PHIM,CLAMA,,/GPHH,/C,N,CEIGEN/C,N,MODAL/C,
N,123/VN,NUH/VN,NUP/VN,N,FMODE $  
159 SAVE NUH,NUP $  
160 CUND LBL16,NDH $  

3.23-7 (9/30/78)
RIGID FORMATS

RIGID FORMAT NMAP: LISTING
SERIES J
AERO APPROACH, RIGID FORMAT 9
LEVEL 2.0 NAStRAN DMAP COMPILER - SOURCE LISTING

161  UDF  OPHI,,,///V,N,CARDNO $  
162  SAVE  CARUNU $  
163  LABEL  LBL16 $  
164  LAD  PHII,CLAMAL,FSAVE/PHII,CLAMAL,CASEYY,OVG/V,N,TSTART/C,Y,VREF=  
165  SAVE  TSTART $  
166  CHKPT  PHII,CLAMAL,CASEYY,OVG $  
167  COND  CONTINUE,TSTART $  
168  LABEL  LBL1AP $  
169  COND  CONTINUE,FLOOP $  
170  REPI  LOOP1UP,100 $  
171  JUMP  ERRJR3 $  
172  LABEL  CONTINUE $  
173  CHKPT  OVG $  
174  PARA4  XYCDB//C,N,PRES/C,N,C,N,V,N,NOXYCDB $  
175  COND  NOXYUT,NOXYCDB $  
176  XYPTRA4  XYCDB,OVG,,///XYPICE/C,N,VG,C,N,PSET/V,N,PFIE/V,N,CARDNO $  
177  SAVE  FILE,CARUNU $  
178  XYPLOJ  XYPICE// $  
179  LABEL  NOXYOLT $  
180  PARA4  //C,N,AND/V,N,PJUMP/V,N,NOP-=-1/'N,JMPPLOJ $  
181  COND  FINIS,PJUMP $  
182  QUDACC  CASEYY,CLAMAL,PHII,CASECC,,/CLAMAL,CPHII,CASEZZ,,/C,N,  
183  CCRI  CPHII,PHIH/PHID $  
184  CHKPT  CPHII $  

3.23-8 (9/30/76)
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FJRMAT UMAP LISTING
SERIES 3
AERU APPROACH, RIGID FORMAT 9
LEVEL 2.0 N'STRAN UMAP COMPILER - SOURCE LISTING

105 EQUIV  CPHIU,CPHIP/NUA S
106 CUMU  LUL14/NUA S
107 CCKI  USETO++,CPHID++,GUDGND++,KFS++,/CPHIP++,QPC/C,N,L/C,N,DYNAMICS S
108 LABEL  LUL14 S
109 CHKPT  CPHIP++QPC S
110 EQUIV  CPHIU,CPHIP/NUUE S
111 CUMU  LULNUE,NUUE S
112 VEC  USETO/RP/C,N,D/C,N,A/C,N,E S
113 PRTN  CPHIU++,RP/CPHIP++,C,N,L/C,N,3 S
114 LABEL  LULNUE S
115 SCR2  CASEZ,CSTM,MPT31,T,EDYDN,SILD++,BGPDT,CLAMALL,QPC,CPHIP,EST++,/
 ,QPC1,UCPHIP,UESC1,UEFC1,PLPHIP/C,N+CFIGN S
116 CHKPT  CPHIP S
117 CFP  UCPHIP,UCPCI,UESC1,UEFC1++,//V,N,CARDNO S
118 CUMD  P3,JUMPPLUT S
119 PLOT  PLT1PAR,CPF,CTS,ELSETS,CASEZ,BGPDT,EDYDN,SILD++,CPHIP++,//PLOTX3/
 V,N,NSILV/V,LUSET/V,N,JUMPPLUT/V,N,PLTFLG/V,N,PFILW S
200 PRTMSC  PLT1X3// S
201 PLABL  PJS S
202 JUMP  FINIS S
203 LABEL  ERROR1 S
204 PRTPARH //C,N+1/C,N,F SUB SUM S
205 LABEL  ERROR2 S
206 PRTPARH //C,N+2/C,N,F SUB SCN S
207 LABEL  ERROR3 S
208 PRTPARH //C,N+3/C,N,F SUB SCN S

3.23-9 (9/30/78)
RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

ACRO APPROACH, RIGID FORMAT 9
LEVEL 2.0 NASIRAN DMAP COMPILER - SOURCE LISTING

209 LAHLL ERR046
210 PR1PAK //C,4-4/C,N,F SUBSIM 8
211 LABEL ERR0146
212 PR1PAK // C,N,-4 / C,N,CYCMODES 8
213 LABEL ERR0256
214 PR1PAK // C,N,-5 / C,N,CYCMODES 8
215 LABEL FIN146
216 ENC 8

* * * * **U ERRORS FOUND - EXECUTE NASTRAN PROGRAM**
3.23.2 Description of DMAP Operations for Compressor Blade Cyclic Modal Flutter Analysis

3. GPI 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. TAI 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. INPUTI reads the user supplied stiffness matrix from tape (GINO file INPT).

23. Equivalence $[K^x_{gg}]$ to $[K^{IN}]$.

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 $[K^x_{gg}]$ 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. GPWIG generates weight and balance information.

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

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

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

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

46. GP4 generates flags defining members of various displacement sets (USEI), 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.
RIGID FORMATS

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. pFP 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 \([R_g] = [R_m] + [R_n]\) and solves for multipoint constraint transformation matrix \([G_m]^T = -[R_m]^{-1}[R_n]\).

66. MCE2 partitions stiffness and mass matrices

\[
[K_{gg}] = \begin{bmatrix}
K_{nn} & K_{nm} \\
K_{mn} & K_{mm}
\end{bmatrix}
\quad\text{and}\quad
[M_{gg}] = \begin{bmatrix}
M_{nn} & M_{nm} \\
M_{mn} & M_{mm}
\end{bmatrix}
\]

and performs matrix reductions

\[
[K_{nn}] = [R_{nn}] + [G_m^T][K_{mn}] + [K_{mn}] + [G_m^T][K_{mm}][G_m]
\]

\[
[M_{nn}] = [A_{nn}] + [G_m^T][M_{mn}] + [M_{mn}] + [G_m^T][M_{mm}][G_m].
\]

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.

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

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.
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

78. SMP1 partitions constrained stiffness matrix

\[ [K_{ff}] = \begin{bmatrix} \bar{K} & K_{ao} \\ K_{oa} & \bar{K} \end{bmatrix} \]

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

\[ [M_{ff}] = \begin{bmatrix} \bar{M} & M_{ao} \\ M_{oa} & \bar{M} \end{bmatrix} \]

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 \([G_m^d]\) to \([G_m]\) 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

\[ [K_{kk} - \lambda M_{kk}](u_k) = 0, \]

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. OFP 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.
RIGID FORMATS

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

102. SDR1 recovers dependent components of the eigenvectors

\[
\begin{align*}
\{\phi_o\} &= \left[G_o\right]\{\phi_a\}, \\
\{\phi_s\} &= \{\phi_n\}, \\
\{\phi_m\} &= \left[G_m\right]\{\phi_n\}, \\
\{\phi_f\} &= \{\phi_g\}.
\end{align*}
\]

103. SDR2 prepares eigenvectors for output (OPHIG).

104. DFIP 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

\[
[M] = \left[\phi_a^T\right] [M_{aa}] [\phi_a^T]
\]

111. MTRXIN selects the direct input matrices \([K_{pp}], [M_{pp}], \text{ and } [C_{pp}]\).

114. Equivalence \([M_{pp}] \text{ to } [M_{dd}], [B_{pp}] \text{ to } [B_{dd}] \text{ and } [K_{pp}] \text{ to } [K_{dd}] \text{ if no constraints applied.}

116. GKEAD applies constraints to direct input matrices \([K_{pp}], [M_{pp}], \text{ and } [M_{dd}], \text{ and } [C_{dd}] \text{ (see Section 9.3.3 of the Theoretical Manual) and forms } [G_{md}] \text{ and } [G_{od}].

3.23-14 (9/30/78)
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

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

$$
\begin{align*}
[K_{hh}] &= [K_h^1; 0^1 0] + [\phi_{dh}^T](K^2_{dd})[\phi_{dh}] , \\
[M_{hh}] &= [m_1; 0 0] + [\phi_{dh}^T](M^2_{dd})[\phi_{dh}] , \\
[B_{hh}] &= [b_1; 0 0] + [\phi_{dh}^T](B^2_{dd})[\phi_{dh}] .
\end{align*}
$$

where

$$KDAMP = 1$$

$$KDAMP = -1 \text{ (default)}$$

$m_i$ - modal masses

$b_i = m_i 2g f_i g(f_i)$

$k_i = m_i 4 g^2 f_i$

$m_i$ - modal masses

$b_i = 0$

$k_i = (1 + g(f_i)) 4 g^2 f_i^2 m_i$

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. PRIMSG prints error messages associated with structure plotter.

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

130. PLT generates all requested undeformed structure plots.

132. PRIMSG 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 matrix list $[A_{jj}]$, the area matrix $[S_{kj}]$, and the downwash coefficients $[D^i_{jk}]$ and $[D^j_{jk}]$.

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

140. INPUT2 provides the user-supplied downwash factors due to extra points $([D^i_{je}], [D^j_{je}])$. 

3.23-15 (9/30/78)
RIGID FORMATS

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

\[
\begin{bmatrix}
\theta_{dh} & \phi_{dh} \\
\end{bmatrix} = \begin{bmatrix}
\phi_{e1} & \phi_{ee} \\
\phi_{e1} & \phi_{ee} \\
\end{bmatrix}
\]

\[
G_{kl} = (G_{de})^T
\]

\[
[D_{dh}] = \begin{bmatrix} D_{je} & D_{ke} \end{bmatrix}
\]

\[
[D_{de}] = \begin{bmatrix} D_{je} & D_{ke} \end{bmatrix}
\]

For each \((m,k)\) pair:

\[
[D_{dh}] = [D_{de}] = \left( k[D_{de}] \right)
\]

for each group:

\[
[D_{de}] = \left( A_{dd} \right)^{-1}
\]

\[
[D_{de}] = \left( S_{kj} \right)[D_{de}]
\]

\[
[D_{de}] = \left( G_{ke} \right)^T
\]

\[
[D_{de}] = \begin{bmatrix} D_{de} & D_{ke} \end{bmatrix}
\]

149. PARAM initializes the flutter loop counter (FLPOP) to zero.

150. Go to next DMAP instruction if cold start or modified restart. LORPTOP 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. FAP 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:

\[
M_{hh}^x = (k^2/b^2)M_{hh} + (p/2) Q_{hh}
\]

\[
K_{hh}^x = K_{hh}
\]

\[
B_{hh}^x = 0
\]
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

154. CEAD extracts complex eigenvalues from the equation

\[ \left[ M_{hh} \dot{\phi}^2 + B_{hh} \dot{\phi} + K_{hh} \right] \phi_h = 0 \]

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. OFP 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 CLAML, Case Control to CASEYY, and V-g plot data to ØVGY.

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. XYPL0T 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. MODACC selects a list of eigenvalues and vectors whose imaginary parts (velocity in input units) are close to a user input list.

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

\[ [\phi^C_d] \cdot [\phi_{dh}][\phi_h] \]

185. Equivalence \([\phi^C_d] \cdot [\phi_{dh}][\phi_h]\) if no constraints applied.

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

107. SDR1 recovers dependent components of eigenvectors

\[
\begin{align*}
\phi_d^C &= [G_d^C](\phi_d^C), \\
\{\phi_p\} &= (\phi_d^C + \phi_e^C).
\end{align*}
\]

\[
\begin{align*}
\left\{\phi_d^C - \phi_e^C\right\} &= (\phi_h^C + \phi_e^C), \\
(\phi_h^C) &= [G_h^C](\phi_h^C + \phi_e^C).
\end{align*}
\]

and recovers single-point forces of constraint \(q_5\) =

\[
[K_{f_5}](\phi_f), \left\{\phi_5\right\} = (Q_5^C).
\]

190. Equivalence \([\phi_d^C]\) to \([\phi_e^C]\) 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.

\[
(\phi_d^C) = \left\{
\begin{array}{c}
\phi_d^C \\
\phi_e^C
\end{array}
\right\}
\]

195. SDR2 calculates element forces and stresses \((\phiFC, \phiESC)\) and prepares eigenvectors and single-point forces of constraint for output \((\phiC, \phiESC)\). It also prepares \(\phiCH\) for deformed plotting.

197. BFP 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. PLOT prepares all deformed structure plots.

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

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

204. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 1 - MASS MATRIX REQUIRED FOR MODAL FORMULATION.

206. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FOR 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 EIGENVALUES 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.
FIG ID FORMATS

3.23.3 Output for Compressor Blade Modal Flutter Analysis

The Real Eigenvalue 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 $\rho$, $k$, $1/k$, $\sigma$, $\sigma_{\text{sound}}$, $V$, $g$ and $f$ for each complex eigenvalue.

$V-g$ and $V-f$ plots may be requested by the XYZOUT 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 (SORTi) and $(m, k, \rho)$ may be requested for all complex eigenvalues kept, as either real and imaginary parts or magnitude and phase angle ($0^\circ$ - $360^\circ$ 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 OFREQUENCY 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.

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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 \([K^{2pp}]\), mass \([M^{2pp}]\), and damping \([B^{2pp}]\) must be selected via the keywords K2PP, M2PP, or B2PP.

3. CMETHOD must be used to select an EIGC card from the Bulk Data Deck.

4. FMETHOD must be used to select a FLUTTER card from the Bulk Data Deck.

5. METHOD must be used to select an EIGR card that exists in the Bulk Data Deck.

6. SDAMPING must be used to select a TABDMPI 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. CPUPMASS - CPBAR, CPROD, CPQUAD1, CPQUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPODPLT, CPTPLT, CPTBSC - 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.
RIGID FORMAT

4. LFREQ and HFREQ - required unless LMODES 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, LMODES must be set to 0.

5. LMODES - 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 default value will request all modes to be used.

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

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

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

9. PRINT - optional in modal flutter analysis. The BCD value NO, of this parameter will suppress the automatic printing of the flutter summary for the k method. The flutter summary table will be printed if the BCD value is YES for wing flutter, or YESB for blade flutter. The default is YES.

10. CTYPE - required - the BCD value of this parameter defines the type of cyclic symmetry as follows:
    (1) ROT - rotational symmetry
    (2) DRL - dihedral symmetry, using right and left halves
    (3) DSA - dihedral symmetry, using symmetric and anti-symmetric components

11. NSEGS - required - the integer value of this parameter is the number of identical segments in the structural model.
COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

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

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

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

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

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

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

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

3.23-23 (9/30/78)
FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149 FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149.1 Entry Point: UD0300

4.149.2 Purpose

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

4.149.3 DMAP Calling Sequence

ALG CASECC, EDT, EQEXIN, (AUGV), ALGDB, CSTM, BGPDT/ CASECCA, GEOM3A/ S, Y, APRESS/ S, Y, ATEMP/ V, Y, STREAML/ V, Y, PGEOM/ V, Y, IPRT/ S, N, IFAIL/ V, Y, SIGN/ V, Y, ZORIGIN/ V, Y, FXC00R/ V, Y, FYC00R/ V, Y, FZC00R $

4.149.4 Input Data Blocks

CASECC - Case control data table
EDT - Aerodynamic bulk data cards
EQEXIN - Equivalence between external grid or scalar numbers and internal numbers
AUGV ) - 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.

4.149-1 (9/30/78)
FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

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
GEDM3A - Static load and temperature table

Note:

1. CASECCA and GEDM3A 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 STREAM1 and STREAM2 cards. STREAML = 1, punch STREAM1 cards. STREAML = 2, punch STREAM2 cards. STREAML = 3, punch both STREAM1 and STREAM2 cards.

PGEOM - Input - integer - default = -1. Controls the punching of blade geometry bulk data cards. PGEOM = 1, punch GRID cards. PGEOM = 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.
FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

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.

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

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

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

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

4.149.7 Method

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

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

(c) The GEOM3A data block contains aerodynamic load and temperature data. If parameter APRESS > 0, then PLOAD2 cards with set identification number 60 are stored on GEOM3A. If parameter ATEMP > 0, then TEMP and TEMPD cards with set identification number 70 are stored on GEOM3A.

4.149.3 (9/30/78)
FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

(d) Parameters STREAML and PCCOM control the punching of bulk data cards STREAML, STREAML2, GRID, CTRIA2, PTRIA2 and DT1. The ALG module may be used in a one module DMAP program as a compressor blade mesh and geometry generator as follows:

BEGIN $
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: UD03PO

1. Entry Point: UD03PO
2. Purpose: Generate data blocks CASECCA and GEOM3A.
3. Calling Sequence: CALL UD03PO (SCR1)

4.149.4 (9/30/78)
4.149.8.5 Subroutine Name: UD03AP

1. Entry Point: UD03AP

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

3. Calling Sequence: CALL UD03AP (IFNAME, IFNM)
FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149.8.6 Subroutines: UD03AN, UD03AR, UD03C1-UD0319, UD0325, UD0326, UD0329, UD0330 and UDGI-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 minimize open core, ALG could look as follows:

```
UD0300
  UD03PR
  UD03RO
  UD03AP
  UD03AN
  UD0313
  UD0314
  UD0315
  UD0316
  UD0317
  UD0318
  UD0319
  UD031C
  UD0325
  UD0329
  UD0332
  UD0339
  UD0341
  UD0343
  UD0345
  UD0347
  UD0349
  UD0351
  UD0353
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  UD0375
  UD0377
  UD0379
  UD0381
  UD0383
  UD0385
  UD0387
  UD0389
  UD0391
  UD0393
  UD0395
  UD0397
  UD0399
  UD0301-UD0307
  UD0309-UD0312
  UD0325
  UD0329
  UD0330
  UDGI-UDG9
  /ALGXX/
```

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 \( \text{[G}_{ka}\rceil^T \) (GTKA) and the partitioning vector PVECT.

4.150.3 DMAP Calling Sequence

APDB EDT, USET, BGPDT, CSTM, EQEXIN, GM, GQ/ AERQ, ACPT, RLIST, 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

GQ - 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.

4.150-1 (9/30/78)
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.

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

MYTYPE - Input - BCD - default = COSINE. This controls which components of the cyclic modes are to be used in the modal formulation. MYTYPE = SINE for sine components and MYTYPE = COSINE 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 AERO, 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:

\[
\begin{align*}
[G^T_{kg}] &\rightarrow \begin{bmatrix} [E^T_{KN}] \\ [G^T_{KM}] \end{bmatrix} \\
[G^T_{KN}] &\rightarrow [G^T_{m}] [G^T_{KM}] + [E^T_{KN}] \\
[G^T_{KN}] &\rightarrow \begin{bmatrix} [G^T_{Kf}] \\ [G^T_{KS}] \end{bmatrix}
\end{align*}
\]

4.150-3 (9/30/78)
FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

\[
\begin{bmatrix}
G_{Kf}^T \\
G_{Ka}^T
\end{bmatrix} = \begin{bmatrix} 
G_{Kf}^T \\
G_{Ka}^T 
\end{bmatrix} 
\]

\[
(G_{Ka}^T) = (G_{G})^T (G_{Kb}^T) + (G_{Ka}^T)
\]

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 \( U_b \) are null).

4.150.8 Subroutines Called

Utility routines BSLOC, CALCV, SSG2D, TRANS 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, NSTM, NLINE, LCMTH, ACSTM, NODEX, NODEI, ISILC, XYZ).

4.150.9 Design Requirements

Open core is located at /APD81/. APDB uses five scratch files.

4.150.10 Diagnostic Messages

System fatal messages 3001, 3002, 3003, 3008 and 3037 may occur. The APDB module also generates its own messages that are not numbered. These messages are self-explanatory.
6.1.1.16 Rigid Format Error Messages for Static and Aeroelastic 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, SPOT, or Scalar Connection cards, or all defined degrees of freedom have been constrained by SPC, MPC, OMIT, or GRDSEL 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

NO. 1 - MASS MATRIX REQUIRED FOR MODAL FORMULATION.

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.

NO. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FOR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHOD must select an EIGR set in the Case Control Deck.

NO. 3 - ATTEMPT TO EXECUTE MORE THAN 100 LOOPS.

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.

NO. 4 - REAL EIGENVALUES REQUIRED FOR MODAL FORMULATION.

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

NO. 1 - MASS MATRIX REQUIRED FOR MODAL FORMULATION.

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.

NO. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FOR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHOD must select an EIGR set in the Case Control Deck.

NO. 3 - ATTEMPT TO EXECUTE MORE THAN 100 LOOPS.

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.

NO. 4 - REAL EIGENVALUES REQUIRED FOR MODAL FORMULATION.

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 SUPPORT 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.
### NASTRAN DICTIONARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Parameter value used to control utility module MATGPR print of A-set matrices.</td>
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<td>CSHEAR                IB</td>
<td>Shear panel element connection definition card.</td>
</tr>
<tr>
<td>CSLDT3                IB</td>
<td>Triangular slot element connection definition card for acoustic analysis.</td>
</tr>
<tr>
<td>CSLDT4                IB</td>
<td>Quadrilateral slot element connection definition card for acoustic analysis.</td>
</tr>
<tr>
<td>CSP                   IC</td>
<td>Selects a set of contact surface points.</td>
</tr>
<tr>
<td>CSP                   IB</td>
<td>Contact surface point set definition.</td>
</tr>
<tr>
<td>CSTM                  DBT</td>
<td>Coordinate System Transformation Matrices.</td>
</tr>
<tr>
<td>CSTMA                 DBT</td>
<td>Coordinate System Transformation Matrices - Aerodynamics.</td>
</tr>
<tr>
<td>CTETRA                IB</td>
<td>Tetrahedron element connection definition card.</td>
</tr>
<tr>
<td>CTBDRDG               IB</td>
<td>Toroidal ring element connection card.</td>
</tr>
<tr>
<td>CTBRPRG               IB</td>
<td>Trapezoidal ring element connection card.</td>
</tr>
<tr>
<td>CTBSC                 IB</td>
<td>Basic bending triangular element connection definition card.</td>
</tr>
<tr>
<td>CTRIA1                IB</td>
<td>General triangular element connection definition card.</td>
</tr>
<tr>
<td>CTRIA2                IB</td>
<td>Homogeneous triangular element connection definition card.</td>
</tr>
<tr>
<td>CTRIARG               IB</td>
<td>Triangular ring element connection card.</td>
</tr>
<tr>
<td>CTRMEM                IB</td>
<td>Triangular membrane element connection definition card.</td>
</tr>
<tr>
<td>CTRPLT                IB</td>
<td>Triangular bending element connection definition card.</td>
</tr>
<tr>
<td>CTUBE                 IB</td>
<td>Tube element connection definition card.</td>
</tr>
<tr>
<td>CTWIST                IB</td>
<td>Twist panel element connection definition card.</td>
</tr>
<tr>
<td>CURVILINESSYMBOL      IC</td>
<td>Request to connect points with lines and/or to use symbols for X-Y plots.</td>
</tr>
<tr>
<td>CVISC                 IB</td>
<td>Viscous damper element connection definition card.</td>
</tr>
<tr>
<td>CWEDGE                IB</td>
<td>Wedge element connection definition card.</td>
</tr>
</tbody>
</table>
### NASTRAN DICTIONARY

<table>
<thead>
<tr>
<th>Code</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORCE2</td>
<td>IB</td>
<td>Static load definition (magnitude and four grid points).</td>
</tr>
<tr>
<td>FORCEAX</td>
<td>IB</td>
<td>Static load definition for conical shell problem.</td>
</tr>
<tr>
<td>FREEPT</td>
<td>IB</td>
<td>Defines point on a free surface of a fluid for output purposes.</td>
</tr>
<tr>
<td>FREQ</td>
<td>IB</td>
<td>Frequency list definition.</td>
</tr>
<tr>
<td>FREQ$</td>
<td>M</td>
<td>Indicates restart with change in frequencies to be solved.</td>
</tr>
<tr>
<td>FREQ1</td>
<td>IB</td>
<td>Frequency list definition (linear increments).</td>
</tr>
<tr>
<td>FREQ2</td>
<td>IB</td>
<td>Frequency list definition (logarithmic increments).</td>
</tr>
<tr>
<td>FREQRESP</td>
<td>P</td>
<td>Parameter used in SDR2 to indicate a frequency response problem.</td>
</tr>
<tr>
<td>FREQUENCY</td>
<td>IC</td>
<td>Selects the set of frequencies to be solved in frequency response problems.</td>
</tr>
<tr>
<td>FRL</td>
<td>DBT</td>
<td>Frequency Response List.</td>
</tr>
<tr>
<td>FRQSET</td>
<td>P</td>
<td>Used in FRRD to indicate user selected frequency set.</td>
</tr>
<tr>
<td>FRRD</td>
<td>FMS</td>
<td>Frequency and Random Response - Displacement approach.</td>
</tr>
<tr>
<td>FSAVE</td>
<td>DBT</td>
<td>Flutter Storage Save Table.</td>
</tr>
<tr>
<td>FSLIST</td>
<td>IB</td>
<td>Defines a free surface of a fluid in a hydroelastic problem.</td>
</tr>
<tr>
<td>Functional Module</td>
<td>PH</td>
<td>An independent group of subroutines that perform a structural analysis function.</td>
</tr>
<tr>
<td>FXCOORD</td>
<td>PU</td>
<td>Aerodynamic modification factor (D-16).</td>
</tr>
<tr>
<td>FYCOORD</td>
<td>PU</td>
<td>Aerodynamic modification factor (D-16).</td>
</tr>
<tr>
<td>FZCOORD</td>
<td>PU</td>
<td>Aerodynamic modification factor (D-16).</td>
</tr>
<tr>
<td>IC</td>
<td>Transient analysis initial condition set selection.</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>The first card of any data deck is the identification (ID) card. The two data items on this card are ACD values.</td>
<td></td>
</tr>
<tr>
<td>IFAIL</td>
<td>Set negative by ALG if convergence fails (D-16).</td>
<td></td>
</tr>
<tr>
<td>IFP</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>IFP1</td>
<td>Input File Processor 1. The preface module which processes the Case Control Deck and writes the CASECC, PCDX, and XCDX data blocks.</td>
<td></td>
</tr>
<tr>
<td>IFP3</td>
<td>Input File Processor 3. The preface module which processes bulk data cards for a conical shell problem.</td>
<td></td>
</tr>
<tr>
<td>IFP4</td>
<td>Input File Processor 4. The preface module which processes bulk data cards for a hydroelastic problem.</td>
<td></td>
</tr>
<tr>
<td>IMAG</td>
<td>Output request for real and imaginary parts of some quantity such as displacement, load, single point force of constraint element force, or stress.</td>
<td></td>
</tr>
<tr>
<td>IPAC</td>
<td>Parameter constant used in executive module PARAM.</td>
<td></td>
</tr>
<tr>
<td>INCLUDE</td>
<td>Used in set definition for structure plots.</td>
<td></td>
</tr>
<tr>
<td>INERTIA</td>
<td>Used in printing rigid format error messages for Static Analysis with Inertia Relief (D-2).</td>
<td></td>
</tr>
<tr>
<td>INERTIA RELIEF</td>
<td>Selects rigid format for static analysis with inertia relief.</td>
<td></td>
</tr>
<tr>
<td>INPT</td>
<td>A reserved NASTRAN physical unit (Tape) which must be set up by the user when used.</td>
<td></td>
</tr>
<tr>
<td>INPUT</td>
<td>Generates most of bulk data for selected academic problems.</td>
<td></td>
</tr>
<tr>
<td>Input Data Block</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Input Data Cards</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>INPUT1</td>
<td>Reads data blocks from GINO-written user tapes.</td>
<td></td>
</tr>
<tr>
<td>INPUT2</td>
<td>Reads data blocks from FORTRAN-written user tapes.</td>
<td></td>
</tr>
<tr>
<td>INPUT3</td>
<td>Dummy user input module.</td>
<td></td>
</tr>
<tr>
<td>INPUT4</td>
<td>Dummy user input module.</td>
<td></td>
</tr>
<tr>
<td>Internal Sort</td>
<td>Same order as external sort except when SEQGP or SEQEP bulk data cards are used to change the sequence.</td>
<td></td>
</tr>
<tr>
<td>INV</td>
<td>Inverse power eigenvalue analysis option - specified on ELIX, ELGB or EIGC cards.</td>
<td></td>
</tr>
<tr>
<td>IPRT</td>
<td>Controls printing of aerodynamic results.</td>
<td></td>
</tr>
<tr>
<td>IREF</td>
<td>Defines reference streamline for blade flutter.</td>
<td></td>
</tr>
<tr>
<td>IRES</td>
<td>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).</td>
<td></td>
</tr>
</tbody>
</table>
### NASTRAN DICTIONARY

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KDSS</td>
<td>DBM</td>
<td>Partition of differential stiffness matrix.</td>
</tr>
<tr>
<td>KFF</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KFS</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KGG</td>
<td>DBM</td>
<td>Stiffness matrix generated by Structural Matrix Assembler.</td>
</tr>
<tr>
<td>KGGIN</td>
<td>PU</td>
<td>Positive value selects KGGX from INPUT1.</td>
</tr>
<tr>
<td>KGGSUM</td>
<td>DBM</td>
<td>Sum of elastic and differential stiffness matrices (D-16, A-9).</td>
</tr>
<tr>
<td>KGGL</td>
<td>DBM</td>
<td>Stiffness matrix for linear elements. Used only in the Piecewise Linear Analysis Rigid Format (D-6).</td>
</tr>
<tr>
<td>KGMLPG</td>
<td>P</td>
<td>Purge flag for KGGL matrix. If set to -1, it implies that there are no linear elements in the structural model. (D-6).</td>
</tr>
<tr>
<td>KGGNL</td>
<td>DBM</td>
<td>Stiffness matrix for the nonlinear elements. Used in the Piecewise Linear Analysis Rigid Format only. (D-6).</td>
</tr>
<tr>
<td>KGGX</td>
<td>DBM</td>
<td>Stiffness matrix excluding general elements.</td>
</tr>
<tr>
<td>KGGXL</td>
<td>DBM</td>
<td>Stiffness matrix for linear elements (excluding general elements). Used in the Piecewise Linear Analysis Rigid Format only. (D-6).</td>
</tr>
<tr>
<td>KHH</td>
<td>DBM</td>
<td>Stiffness matrix used in modal formulation of dynamics problems (D-10 thru D-12).</td>
</tr>
<tr>
<td>KLL</td>
<td>DBM</td>
<td>Stiffness matrix used in solution of problems in static analysis (D-1, D-2, D-4, D-5, D-6).</td>
</tr>
<tr>
<td>KLR</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KN</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KPR</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KSS</td>
<td>DBM</td>
<td>Partition of stiffness matrix.</td>
</tr>
<tr>
<td>KTOTAL</td>
<td>DBM</td>
<td>Sum of elastic and differential stiffness matrices (D-16, A-9).</td>
</tr>
<tr>
<td>KTOUT</td>
<td>PU</td>
<td>Positive value outputs KTOTAL to OUTPUT1.</td>
</tr>
<tr>
<td>KXHH</td>
<td>DBM</td>
<td>Total modal stiffness matrix - h-set.</td>
</tr>
</tbody>
</table>
NASTRAN DICTIONARY

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 DEFORMATION 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).

MEDMA 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.

METHOD IC Selects method for real eigenvalue analysis.

METHODS 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.

MKAER01 IB Provides table of Mach numbers and reduced frequencies (k).

MKAER02 IB Provides list of Mach numbers (m) and reduced frequencies (k).

MLL DBM \( [M_{kk}] \) - Partition of mass matrix.

MLR DBM \( [M_{kr}] \) - Partition of mass matrix.

MNN DBM \( [M_{nn}] \) - Partition of mass matrix.

MODA DBM \( [M_{oa}] \) - Partition of mass matrix.

MODA FMX This module is reserved for user implementation.

MODACC FMS Mode Acceleration Output Reduction Module.

NTYPE PU Controls cyclic mode component selection.

7.1-21 (9/30/78)
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Parameter value used in MATGPR to print P-set matrices.</td>
</tr>
<tr>
<td>Packed Format</td>
<td>A matrix is said to be in packed format if only the nonzero elements of the matrix are written.</td>
</tr>
<tr>
<td>PAPER SIZE</td>
<td>Selects paper size for structure plots using table plotters.</td>
</tr>
<tr>
<td>PARTN</td>
<td>Matrix partitioning functional module.</td>
</tr>
<tr>
<td>PBAR</td>
<td>Bar property definition card.</td>
</tr>
<tr>
<td>PBL</td>
<td>A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).</td>
</tr>
<tr>
<td>PBS</td>
<td>A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).</td>
</tr>
<tr>
<td>PCW</td>
<td>Plot control data block (table for use with structure plotter functional module PLTSET).</td>
</tr>
<tr>
<td>PCONEAX</td>
<td>Conical shell element property definition card.</td>
</tr>
<tr>
<td>PDAMP</td>
<td>Scalar damper property definition card.</td>
</tr>
<tr>
<td>PDF</td>
<td>Dynamic load matrix for frequency analysis.</td>
</tr>
<tr>
<td>PDT</td>
<td>Linear dynamic load matrix for transient analysis.</td>
</tr>
<tr>
<td>PDUM1</td>
<td>Property definition card for dummy elements 1 through 9.</td>
</tr>
<tr>
<td>PELAS</td>
<td>Scalar elastic property definition card.</td>
</tr>
<tr>
<td>PEN</td>
<td>Selects pen size for structure plots using table plotters.</td>
</tr>
<tr>
<td>PENSIZE</td>
<td>Selects pen size for X-Y plots using table plotters.</td>
</tr>
<tr>
<td>PERSPECTIVE</td>
<td>Specifies perspective projection for structure plots.</td>
</tr>
<tr>
<td>PF1LE</td>
<td>Parameter used by PLOT module.</td>
</tr>
<tr>
<td>PG</td>
<td>Incremental load vector used in Piecewise Linear Analysis (D-6).</td>
</tr>
<tr>
<td>PG1</td>
<td>Static load vector generated by SSG1.</td>
</tr>
<tr>
<td>PGEOM</td>
<td>Controls punching of GRID, CTRIA2, PTRIA2 and DTI cards from ALG.</td>
</tr>
<tr>
<td>PGG</td>
<td>Appended static load vector (D-1, D-2).</td>
</tr>
<tr>
<td>Term</td>
<td>Type</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>PUGV1</td>
<td>DBT</td>
</tr>
<tr>
<td>PUNCH</td>
<td>IC</td>
</tr>
<tr>
<td>PURGE</td>
<td>EM</td>
</tr>
<tr>
<td>Purge</td>
<td>PH</td>
</tr>
<tr>
<td>PVECT</td>
<td>DBM</td>
</tr>
<tr>
<td>PVISC</td>
<td>IB</td>
</tr>
<tr>
<td>PVT</td>
<td>PH</td>
</tr>
<tr>
<td>P1</td>
<td>PU</td>
</tr>
<tr>
<td>P2</td>
<td>PU</td>
</tr>
<tr>
<td>P3</td>
<td>PU</td>
</tr>
<tr>
<td>QBDY1</td>
<td>IB</td>
</tr>
<tr>
<td>QBDY2</td>
<td>IB</td>
</tr>
<tr>
<td>QBG</td>
<td>DBM</td>
</tr>
<tr>
<td>QDMEM</td>
<td>IC</td>
</tr>
<tr>
<td>QDMEM1</td>
<td>IC</td>
</tr>
<tr>
<td>QDMEM2</td>
<td>IC</td>
</tr>
<tr>
<td>QDPLT</td>
<td>IC</td>
</tr>
<tr>
<td>QG</td>
<td>DBM</td>
</tr>
<tr>
<td>QHBDY</td>
<td>IB</td>
</tr>
<tr>
<td>QHHL</td>
<td>DBML</td>
</tr>
<tr>
<td>QJHL</td>
<td>DBML</td>
</tr>
<tr>
<td>QP</td>
<td>DBM</td>
</tr>
<tr>
<td>QPC</td>
<td>DBM</td>
</tr>
<tr>
<td>QR</td>
<td>DBM</td>
</tr>
<tr>
<td>QS</td>
<td>DBM</td>
</tr>
<tr>
<td>QUAD1</td>
<td>IC</td>
</tr>
<tr>
<td>QUAD2</td>
<td>IC</td>
</tr>
<tr>
<td>QVECT</td>
<td>IB</td>
</tr>
<tr>
<td>QVOL</td>
<td>IB</td>
</tr>
</tbody>
</table>

**7.1-32 (9/30/78)**
<table>
<thead>
<tr>
<th><strong>SIGNA</strong></th>
<th><strong>P</strong></th>
<th>Defines Stefan-Boltzmann constant in heat transfer analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SIGN</strong></td>
<td><strong>PU</strong></td>
<td>Controls the type of static aerothermal analysis performed.</td>
</tr>
<tr>
<td><strong>SIL</strong></td>
<td><strong>DBT</strong></td>
<td>Scalar Index List for all grid points.</td>
</tr>
<tr>
<td><strong>SILA</strong></td>
<td><strong>DBT</strong></td>
<td>Scalar Index List - Aerodynamics.</td>
</tr>
<tr>
<td><strong>SILD</strong></td>
<td><strong>DBT</strong></td>
<td>Scalar Index List for all grid points and extra scalar points introduced for dynamic analysis.</td>
</tr>
<tr>
<td><strong>SILGA</strong></td>
<td><strong>DBT</strong></td>
<td>Scalar Index List - Aerodynamic boxes only.</td>
</tr>
<tr>
<td><strong>SINE</strong></td>
<td><strong>IC</strong></td>
<td>Conical shell request for sine set boundary conditions.</td>
</tr>
<tr>
<td><strong>SINGLE</strong></td>
<td><strong>P</strong></td>
<td>No single-point constraints.</td>
</tr>
<tr>
<td><strong>SKIP BETWEEN FRAMES</strong></td>
<td><strong>IC</strong></td>
<td>Request to insert blank frames on SC 4020 plotter for X-Y plots.</td>
</tr>
<tr>
<td><strong>SKJ</strong></td>
<td><strong>DBM</strong></td>
<td>Integration matrix.</td>
</tr>
<tr>
<td><strong>SKPMGG</strong></td>
<td><strong>P</strong></td>
<td>Parameter used in statics to control execution of functional module SMA2.</td>
</tr>
<tr>
<td><strong>SLBDY</strong></td>
<td><strong>IB</strong></td>
<td>Defines list of points on interface between axisymmetric fluid and radial slots.</td>
</tr>
<tr>
<td><strong>SLOAD</strong></td>
<td><strong>IB</strong></td>
<td>Scalar point load definition.</td>
</tr>
<tr>
<td><strong>SLT</strong></td>
<td><strong>DBT</strong></td>
<td>Static Loads Table.</td>
</tr>
<tr>
<td><strong>SMA1</strong></td>
<td><strong>FMS</strong></td>
<td>Structural Matrix Assembler - phase 1 - generates stiffness matrix ( [K_{gg}] ) and structural damping matrix ( [K_{dd}] ).</td>
</tr>
<tr>
<td><strong>SMA2</strong></td>
<td><strong>FMS</strong></td>
<td>Structural Matrix Assembler - phase 2 - generates mass matrix ( [H_{gg}] ) and viscous damping matrix ( [B_{gg}] ).</td>
</tr>
<tr>
<td><strong>SMA3</strong></td>
<td><strong>FMS</strong></td>
<td>Structural Matrix Assembler - phase 3 - add general element contributions to the stiffness matrix ( [K_{gg}] ).</td>
</tr>
<tr>
<td><strong>SMP1</strong></td>
<td><strong>FMS</strong></td>
<td>Structural Matrix Partitioner - part 1.</td>
</tr>
<tr>
<td><strong>SMP2</strong></td>
<td><strong>FMS</strong></td>
<td>Structural Matrix Partitioner - part 2.</td>
</tr>
<tr>
<td><strong>SMPYAD</strong></td>
<td><strong>FMM</strong></td>
<td>Performs multiply-add matrix operation for up to five multiplications and one addition.</td>
</tr>
<tr>
<td><strong>SOL</strong></td>
<td><strong>IA</strong></td>
<td>Specifies which rigid format solution is to be used when APP is DISPLACEMENT.</td>
</tr>
<tr>
<td><strong>Solution Points</strong></td>
<td><strong>PH</strong></td>
<td>Points used in the formulation of the general ( K ) system.</td>
</tr>
<tr>
<td><strong>SOLVE</strong></td>
<td><strong>FMM</strong></td>
<td>Solves a set of linear algebraic equations.</td>
</tr>
<tr>
<td><strong>SORT1</strong></td>
<td><strong>IC</strong></td>
<td>Output is sorted by frequency or time and then by external ID.</td>
</tr>
<tr>
<td><strong>SORT2</strong></td>
<td><strong>IC</strong></td>
<td>Output is sorted by external ID and then by frequency or time.</td>
</tr>
<tr>
<td><strong>SORT3</strong></td>
<td><strong>M</strong></td>
<td>Output is sorted by individual item or component and then by frequency or time.</td>
</tr>
<tr>
<td><strong>SPC</strong></td>
<td><strong>IB</strong></td>
<td>Single-point constraint and enforced deformation definition.</td>
</tr>
<tr>
<td>Code</td>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SPC</td>
<td>IC</td>
<td>Single-point constraint set selection.</td>
</tr>
<tr>
<td>SPC$</td>
<td>M</td>
<td>Indicates restart with change in single-point constraint set selection.</td>
</tr>
<tr>
<td>SPC1</td>
<td>IB</td>
<td>Single-point constraint definition.</td>
</tr>
<tr>
<td>SPCADD</td>
<td>IB</td>
<td>Single-point constraint set combination definition.</td>
</tr>
<tr>
<td>SPCAX</td>
<td>IB</td>
<td>Conical shell single-point constraint definition.</td>
</tr>
<tr>
<td>SPCF</td>
<td>IC</td>
<td>Abbreviated form of SPCFORCE.</td>
</tr>
<tr>
<td>SPCFORCE</td>
<td>IC</td>
<td>Single-point constraint force output request. (UM-2.3,4.2)</td>
</tr>
<tr>
<td>SPILL1</td>
<td>PH</td>
<td>Secondary storage devices are used because there is insufficient main storage to perform a matrix calculation or a data processing operation.</td>
</tr>
<tr>
<td>SPLINE</td>
<td>DBT</td>
<td>Splining Data Table.</td>
</tr>
<tr>
<td>SPLINE1</td>
<td>IB</td>
<td>Defines surface spline.</td>
</tr>
<tr>
<td>SPLINE2</td>
<td>IB</td>
<td>Defines beam spline.</td>
</tr>
<tr>
<td>SPPOINT</td>
<td>IB</td>
<td>Scalar point definition card.</td>
</tr>
<tr>
<td>SSG1</td>
<td>FMS</td>
<td>Static Solution Generator - part 1.</td>
</tr>
<tr>
<td>SSG2</td>
<td>FMS</td>
<td>Static Solution Generator - part 2.</td>
</tr>
<tr>
<td>SSG3</td>
<td>FMS</td>
<td>Static Solution Generator - part 3.</td>
</tr>
<tr>
<td>SSG4</td>
<td>FMS</td>
<td>Static Solution Generator - part 4.</td>
</tr>
<tr>
<td>SSGHT</td>
<td>FMM</td>
<td>Solution generator for nonlinear heat transfer analysis.</td>
</tr>
<tr>
<td>STATIC</td>
<td>IC</td>
<td>Requests deformed structure plot for problem in Static Analysis.</td>
</tr>
<tr>
<td>STATICS</td>
<td>IA</td>
<td>Selects statics rigid format for heat transfer or structural analysis.</td>
</tr>
<tr>
<td>STATICS</td>
<td>P</td>
<td>Parameter used in SDR2 to indicate Static Analysis.</td>
</tr>
<tr>
<td>STEADY STATE</td>
<td>IA</td>
<td>Selects rigid format for nonlinear static heat transfer analysis.</td>
</tr>
<tr>
<td>STEREOSCOPIC</td>
<td>IC</td>
<td>Requests stereoscopic projections for structure plot.</td>
</tr>
<tr>
<td>STREAML</td>
<td>PU</td>
<td>Controls the punching of STREAML1 and STREAML2 cards from ALG.</td>
</tr>
<tr>
<td>STREAML1</td>
<td>IB</td>
<td>Gives blade streamline data.</td>
</tr>
<tr>
<td>STREAML2</td>
<td>IB</td>
<td>Gives blade streamline data.</td>
</tr>
<tr>
<td>STRESS</td>
<td>IC</td>
<td>Element stress output request. (UM-2.3,4.2)</td>
</tr>
<tr>
<td>Structural Element</td>
<td>PH</td>
<td>One of the finite elements used to represent a part of a structure.</td>
</tr>
<tr>
<td>SUBCASE</td>
<td>IC</td>
<td>Subcase definition.</td>
</tr>
<tr>
<td>SUBCOM</td>
<td>IC</td>
<td>This subcase is a linear combination of previous subcases.</td>
</tr>
<tr>
<td>SUBSEQ</td>
<td>IC</td>
<td>Specifies coefficients for SUBCOM subcases.</td>
</tr>
<tr>
<td>SUBTITLE</td>
<td>IC</td>
<td>Output labeling data for printer output.</td>
</tr>
<tr>
<td>SUPAX</td>
<td>IB</td>
<td>Fictitious support for conical shell problem.</td>
</tr>
</tbody>
</table>
NASTRAN DICTIONARY

ZORIGN    PU    Aerodynamic modification factor (D 16).

7.1-47 (9/30/78)