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User's Manual for Axisymmetric Diffuser Duct (ADD) Code

Volume I—General ADD Code Description

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User's Manual for Axisymmetric Diffuser Duct (ADD) Code

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USER'S MANUAL FOR
AXISYMMETRIC DIFFUSER DUCT
(ADD) CODE

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1.0 SUMMARY

This User's Manual contains a complete description of the computer codes known as the AXISYMMETRIC DIFFUSER DUCT code or ADD code. It includes a list of references which describe the formulation of the ADD code and comparisons of calculation with experimental flows. The input/output and general use of the code is described in the first volume. The second volume contains a detailed description of the code including the global structure of the code, list of FORTRAN variables, and descriptions of the subroutines. The third volume contains a detailed description of the CODUCT code which generates coordinate systems for arbitrary axisymmetric ducts.

2.0 INTRODUCTION

This User's Manual describes the computer codes known collectively as the AXISYMMETRIC DIFFUSER DUCT code or ADD code. This code was originally developed for NASA Lewis Research Center under contract NAS3-15402. Important revisions, including the conformal mapping coordinate generator, were developed for the U.S. Army Air Mobility Research and Development Laboratory under Contract DAAJ02-73-C-0037. Further developments and improvements to the ADD code were funded by United Technologies Research Center and Pratt & Whitney Commercial Products Division. Additional improvements, including incorporation of a two equation model of turbulence and a compressible axisymmetric streamline curvature correction was funded under NASA contract NAS3-21853. Finally a new coordinate generator which permits 180 deg turns in a duct was developed under NASA contract DEN3-235.

All the important features of the basic analysis contained in the ADD code have been published in the open literature. The accuracy and reliability of the code has been demonstrated by published comparisons of calculated results with experimental data. The basic analysis used in the ADD code was developed by Anderson (Ref. 1 and 2). A description of the blade force calculation is given by Barber et.al.(Ref. 3). The code has been successfully applied to predicting the performance of the subsonic portion of mixed compression inlets by Bowditch (Ref. 4) and to predicting the pressure recovery of high Mach number diffusers by Povinelli (Ref. 5). Additional applications of the ADD code have been to analyze swirling flow in a precombustion diffuser and also the flow in an inlet with inlet guide vanes (see Barber et al. Ref. 3). Finally flows in small gas turbine ducts have been analyzed by McLallin and Kofskey (Ref. 6). The three turbulence models incorporated into the ADD code and also the compressible axisymmetric streamline curvature corrections have been evaluated by Anderson and Edwards (Ref. 7). Modified versions of the ADD code have been developed to analyze external flows such as underexpanded hot supersonic jets expanding into cold subsonic mainstreams by Vatsa et.al (Ref. 8) and also the high speed flow interaction between a propeller and nacelle by Egolf et al.(Ref. 9).

This User's Manual has been organized into several sections for the convenience of the users. Section 3.0 contains a description of the different versions of the ADD code and a description of their special features. This section should assist the general user in determining if the ADD code is applicable to the problem at hand. Section 4.0 contains a detailed description of the operation of the ADD code, including a typical run stream for UNIVAC computers, input/output formats and sample problems. In addition to operation of the code, this section contains a list of DIAGNOSTICS, which are internal checks within the code to measure the progress of the calculation. If the code fails and prints a DIAGNOSTIC, this section should assist the user in determining the cause of the failure and suggest a remedy. Sections 5.0 through 7.0 are written for the special user who wishes to modify or upgrade the code for a particular problem. This portion of the manual contains sections on the general structure of the code, definitions of COMMON block variables, and detailed descriptions of each of the subroutines. Sections 10.0 through 12.0 contain a description of the CODUCT code which is an alternate mesh generation code developed for NASA under Contract DEN3-235 (Ref. 10).

3.0 GENERAL DESCRIPTION

3.1 Versions of the ADD Code

Four versions of the ADD code are currently in general use. The basic code is called the ADD code and is described in Ref. 1, 2 and 3. The version of the code called the PREMIX code was developed for NASA Lewis Research Center under contract NAS3-21269. This version of the code was developed to analyze the performance of premixing prevaporizing fuel air mixing passages. It consists of three codes; ADD, PTRAK, and VAPDIF. The PREMIX/ADD code differs from the basic ADD code only in input/output which is in International Standards units. PREMIX/PTRAK code solves the problem of tracking vaporizing fuel droplets in a three dimensional flow field. PREMIX/VAPDIF solves the problem of discussion of fuel vapor into a moving air stream. These codes are described by Anderson et al. (Ref. 10) and applications of these codes to specific premixing passages are given by Anderson et al. (Ref. 11). The ADD/JET code is a version of the ADD code which is modified to treat the expansion of a hot underexpanded supersonic jet into a cold subsonic free stream. This version of the ADD code differs from the basic ADD code in the use of a computational grid and turbulence model more suited to jet flows. In addition it uses streamline curvature obtained from a separate calculation. A description of the principal features of this code and a comparison of calculated results with experimental data is given by Vatsa et al. (Ref. 8). The PROPFAN version of the ADD code was developed for NASA Lewis Research Center under contract NAS3-20961. A description of this code and preliminary results are presented by Egolf et al. (Ref. 9). This version of the ADD code was developed to treat the high speed flow interaction between a propeller and nacelle and differs from the basic ADD code in the use of a propeller lifting line analysis which is used in place of a compressor cascade analysis.

3.2 General Features of ADD Code

Program Language

The Axisymmetric Diffuser Duct (ADD) code source program is written in FORTRAN V computer language for use on a UNIVAC 1100/81A computer. Some machine specific language, such as PARAMETER and INCLUDE FØRTRAN statements is used. However, these statements may be replaced easily by eqivalent code for use on other machines. Successful conversion of the code to both IBM and CDC computers has been made and these versions of the code are available. The ADD code makes use of a UNIVAC routine NTRAN which stores and retrieves large data blocks on disc files; however, the ADD code is organized so that NTRAN is easily replaced by the equivalent FØRTRAN DEFINE FILE. Finally, it should be noted that the ADD code makes use of least squares spline fitting and smoothing subroutines provided by IMSL, Inc. which are available at all major computer centers.

Types of Fluids

The ADD code can treat any compressible fluid with constant thermodynamic properties for the gas constant R and the specific heats Cp and Cv. The molecular viscosity, which is temperature dependent, is estimated using Sutherland's law; the molecular thermal conductivity is calculated using a constant value for Prandtl number. The viscosity of the fluid at standard conditions and Prandtl number are input parameters. If these properties are not specified in the input data, the ADD code uses the properties of air at standard conditions.

Types of Flow Treated

The ADD code may be used to treat any subsonic compressible laminar or turbulent swirling flow in axisymmetric ducts or nonswirling flow in two-dimensional ducts. The duct shape may be annular or two-dimensional with both inner and outer walls; or, it may be an axisymmetric duct with only an outer wall. Subsonic flows have been calculated successfully up to choked conditions. The mixing of hot and cold flows in a duct have also been calculated successfully. The code, however, cannot calculate flows with significant regions of separated or reverse flow.

Duct Geometry Options (IØPT3)

The flow through any axisymmetric or two-dimensional duct can be calculated. Ducts with sharp discontinuities in flow area, which produce flow separation cannot be calculated.

For convenience, provision is made in the code to analyze flows in straight annular ducts (IØPT3=1) or in straight wall, annular diffusers (IØPT3=3) using only a few input parameters. For ducts of arbitrary shape (I0PT3=2), the coordinates (radii) of the inner and outer walls are specified at JLPTS equally-spaced axial stations. To assure that the curve representing the duct contour has continuous first and second derivatives, a least-squares spline fitting, smoothing and interpolation procedure is included in the code. This procedure is used whenever the number of streamwise stations (JL) is not equal to JLPTS. When the new C0DUCT code is used to generate coordinates I0PT3=4

The specification of the duct geometry must include a straight, annular inlet section whose length is at least equal to its height. Two-dimensional ducts are treated as annular ducts in which the height of the duct is small compared to the radius of the duct. Numerical experiments have shown that, if the height of the duct is less than 1/100 of the duct radius, the flow is essentially two-dimensional to an accuracy of three decimal places.

Inlet Flow Options (I0PT1)

Any arbitrary inlet flow conditions may be specified which is consistent with the equations of motion and the turbulence model. Two types of input data are required: (1) specification of the inviscid free stream and core flow conditions, and (2) specification of the laminar or turbulent boundary layer flow parameters. With (I0PT1=3, 4, 9), the flow is assumed to be turbulent and with (I0PT1=7, 8) the flow is assumed to be laminar. With IOPT1=3 or 7, the core flow is calculated assuming that the stagnation pressure and stagnation temperature is constant across the duct. The input Mach number and swirl angle determine the velocities and weight flow, and the static pressure is determined by solving the conservation equation for radial momentum. When I0PT1=4 or 8, the inlet core flow is determined by specifying KLL data points for fractional distance Y, stagnation pressure $P_T(Y)$, static pressure $P(Y)$, swirl angle $\alpha(Y)$, and stagnation temperature $T_T(Y)$. For I0PT1=9, the core flow is determined by specifying KLL data points for fractional distance Y, streamwise velocity $U_S(Y)$, stagnation pressure $P_T(Y)$, swirl velocity $U_\phi(Y)$, and stagnation temperature $T_T(Y)$. Isentropic flow relations and radial momentum conservation equations are used to determine the remaining variables. In addition, when I0PTL=4, 8 or 9, the corresponding exit flow data must be provided. If the exit plane data is not available, the inlet plane data may be repeated.

The boundary layer velocity and temperature profiles are constructed from known analytic solutions using the boundary layer displacement thickness δ^* and a power law (1/n) velocity profile. For laminar boundary layers (I0PT1=7, 8) a Balsius profile is assumed. For turbulent flows (I0PT1=3, 4, 9), Cole's boundary layer profile is used with the shape parameter determined for 1/n.

In many flow situations, it is often more convenient to specify the weight flow rather than velocity or Mach number. For these situations, the user may specify the weight flow when using I0PT1=4 or 8. The static pressure profile is automatically adjusted to obtain the required weight flow with the other input variables held fixed.

It should be noted that the initial plane conditions must satisfy the laws of motion and be compatible with the turbulence model. Therefore, the ADD code makes many checks on the input data to insure satisfactory starting conditions. As an example, the initial plane data is checked to determine if the radial momentum conservation equation is satisfied. If it is not satisfied, the input static pressure profile is replaced by the static pressure calculated from the radial momentum equation and a DIAGN0STIC message is printed. The weight flow calculated from the initial plane data is checked to see if it is greater than the choked-flow value. If it is greater, the calculation stops and the value of the choked weight flow is printed out. Checks are made to insure that the boundary layer profile can be matched to the free stream core flow; the necessary adjustments are made automatically and the calculation continues. In all cases where adjustments to the input data are made and the calculation continues, a DIAGN0STIC message is printed. When no adjustment is possible or when the flow situation is physically impossible, the calculation stops and the user is notified with a DIAGN0STIC message. A list of these DIAGN0STIC messages is given in Section 4.4

Grid Selection

The user may determine the calculation grid using input parameters or the grid may be determined automatically. In either case the user must specify the number of streamwise stations (JL) and the number of streamlines (KL). Experience has shown that a 50 x 50 mesh is suitable for most problems. Default options exist for both the distribution of mesh points in the cross flow direction as specified by the mesh distortion parameters DDS and the streamwise step size parameter KDS. In selecting the mesh distortion parameters DDS, numerical accuracy requires that a sufficient number of mesh points exist in the turbulent sublayer. In practice, the first mesh point from the wall should be at $Y^+ = 1.0$ and at least 20 mesh points should be in the boundary layer. Since these criteria depend on both the flow Reynolds number and wall friction coefficient, they are not convenient for the user to calculate a-priori. Therefore, if DDS is not specified in the input data, a value for DDS is calculated using an algorithm which produces good results for most cases. The value for the streamwise step size parameters KDS depends on the boundary layer thickness and rate of growth of the boundary layer. If KDS is not specified, the code selects a value for KDS between each streamwise station using an algorithm which produces satisfactory results for most cases.

Print Options (I0PT4)

The frequency and quantity of output are controlled by the print option I0PT4. If I0PT4 > 0, the output consists of the mean flow variables including streamwise velocity U_s, tangential velocity U_ϕ, swirl angle α, stagnation pressure P_T, stagnation temperature T_T, and Mach number M at each streamwise station for JL stations; this printout occurs every IOPT4th station. If IOPT4 ≤ -1, additional information is printed including the effective turbulent viscosity and thermal conductivity, the boundary layer solution in universal coordinates $U^+(Y^+)$, and the turbulent kinetic energy distribution; this information is printed every IOPT4th station.

Diagnostics

The ADD code makes numerous checks during the progress of the calculation. If the program is able to remedy a detected problem, a DIAGNOSTIC is printed and the calculation continues. If a fatal error is detected, the calculation stops and a DIAGNOSTIC notifies the user about the nature and location of the error. A complete list of DIAGNOSTICS is given in Section 4.4.

Coordinate Option (IOPT9)

The calculation of the coordinate system may be stored on a data file and retrieved for use in subsequent cases. If IOPT9=1, both the coordinates and the viscous flowfield are calculated. If IOPT9=2, the coordinate system is calculated and stored on file NINE and the calculation stops. If IOPT9=3, the coordinates stored on file NINE are recalled and the viscous flowfield is calculated. This feature is particularly useful when the user wishes to calculate several flows using the same duct geometry. If CODUCT is used IOPT9=3.

Data Files

A list of data files and storage requirements are given on Table 1, Section 5.5. The ADD code or CODUCT code generates two coordinate files. File NINETEEN is a coordinate file with a uniform mesh, and File NINE is a coordinate file with a mesh distorted to provide grid resolution in the boundary layers. In addition, the inviscid flow field solution is stored on File TWENTYTWO and the viscous solution is stored on file EIGHT. It is recommended that these files be registered and catalogued so that the data may be stored permanently over a period of several weeks. Proper use of these files allows the user increased flexibility in solving problems.

Start/Stop Options

A flow calculation may be started at coordinate station J=IOPT15 and it may be terminated at coordinate system station J=IOPT16. If IOPT15 is not specified, it is assigned a value IOPT15=1; if IOPT16 is not specified, it is assigned a value IOPT16=JL. The calculation of the flowfield may be continued (or restarted) at the JM coordinate station by specifying IOPT17=JM only if in the preceding calculation IOPT14 > 0.

Turbulence Models (I0PT12)

The ADD code is provided with four optional turbulence models described in Ref. 7. For I0PT12=0, 1, 2 algebraic turbulence models are used based on Prandtl's mixing length theory. For I0PT12=3, a two equation model of turbulence is used. Option I0PT12=0 uses a turbulence model which is well established for equilibrium turbulent flowfields and is therefore recommended for all calculations. The other options (I0PT12=1, 2, 3) are operational but these models have been applied to only a few flowfield situations; the use of these models is not recommended at the present time.

Blade Force Options (I0PT2), (I0PT5), (I0PT10)

Struts, inlet guide vanes, stators, and rotors are modeled in the ADD code as a-priori body forces. Three options exist in the code for calculating these forces. If measurements of stagnation pressure P_T, swirl angle α, and stagnation temperature T_T are available, the blade forces can be calculated from blade element theory by setting I0PT2=1. If I0PT5=2, the program uses the inlet/exit flow data for I0PT1=4. If I0PT5=1, separate data must be loaded for the blade force calculation. If I0PT2=3, the blade force is calculated from the flow conditions and blade geometry using blade element theory and empirical cascade correlations. If I0PT2=4, the blade force is calculated using the distributions of exit air angle $\alpha_2(Y)$ and loss coefficient $Z_B(Y)$.

I0PT10 determines whether the blade is stationary (I0PT10=0, stator) or rotating (I0PT10=1, rotor).

Spline Fitting Option JL $\neq$ JLPTS

Many duct contours can only be obtained by measuring coordinates from an engineering drawing. Since the ADD code requires curvature (i.e., second derivatives) these measured coordinates must be very accurate. In general practice this accuracy is not possible so therefore, a general spline fitting, smoothing, and interpolation routine is used. This subroutine makes use of a standard IMSL routine ICSVKU which is a spline fitting routine which optimizes the location of the knots or nodal points. The wall contour is numerically differentiated to obtain second derivatives. A spline is fitted to the second derivative and integrated analytically. Thus the wall contour is continuous up to the fifth derivative. This option is used when the number of output data points JL does not equal the number of input data points JLPTS.

Streamwise Curvature Correction I0PT7

When I0PT7=0, the ADD code uses the streamline curvature data stored on file NINE. When I0PT7=1, the ADD code calculates the compressible axisymmetric potential flow solution, the corresponding streamline curvatures and stores the results on file NINE. Subsequent calculations can then be made with I0PT7=0.

4.0 OPERATION OF ADD CODE

4.1 Runstream for ADD Code

The following runstream is sufficient to execute the ADD code on the UNIVAC 1100/81A computer using the Exec. 8 operating system.

```
@ASG,A        EIGHT.,D/O/TRK/500000
@USE          8.,EIGHT.
@ASG,A        NINE.,D/O/TRK/500000
@USE          9.,NINE.
@ASG,T        10,D/O/TRK/6000
@ASG,T        11,D/O/TRK/6000
@ASG,T        12,D/O/TRK/6000
@ASG,A        NINETEEN.,D/O/TRK/500000
@USE          19.,NINETEEN
@ASG,A        TWENTYTW0.,D/O/TRK/500000
@USE          22.,TWENTYTW0
@ASG,T        23,D/O/TRK/15000
@ASG,T        24,D/O/TRK/15000
@ASG,T        25,D/O/TRK/50000
@XQT          MAPADD

Input Data

@FIN
```

4.2 Input Format for ADD Code

The input format for the ADD code is described on the input data coding forms which follow. These coding forms are organized with one form per input data card. Each form contains the names of the variables, the format, and a description of the data. The input option card controls the data that must be read. Since not all cards are read, the user should make certain that the input data agrees with the input options.

In general the input data is read as follows:

Card 1 Title Card

Card 2 Option Card

Card 3 Mesh Parameter Card

*Card 4 Duct Geometry Card

+ data as required by IOPT3

*Card 5 Inlet Flow Card

+ data as required by IOPT1

Card 6 Force Data Card (If IOPT2 ≠ 0)

+ data as required by IOPT2, IOPT5, IOPT10

*Card 7 Reference Card

Card 8 Slot Flow Data Card

+ data

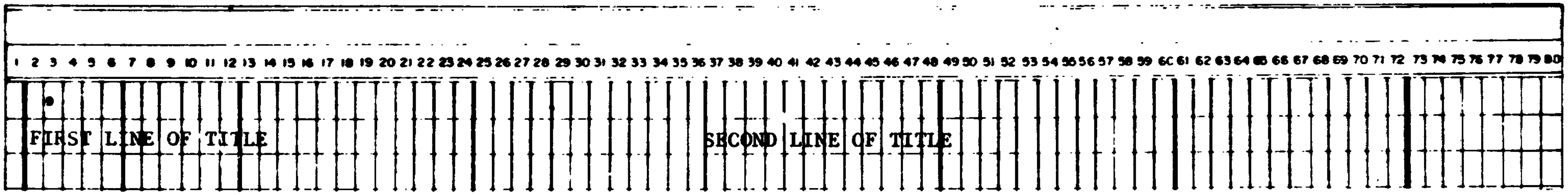
Card 9 Wall bleed data card

*Card 10 Interpolated output data card

* NOTE: Blank cards must be loaded when options are not used.
See detailed writeup.

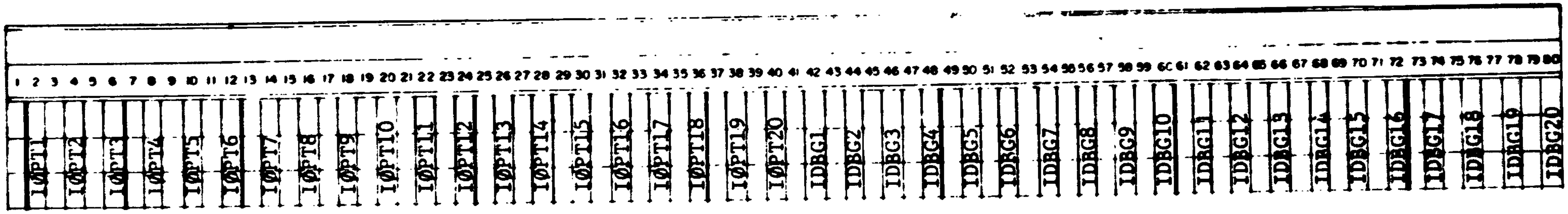
ADD CODE INPUT

Card 1 TITLE CARD FØRMAT (12A6)



ADD CODE INPUT

Card 2 OPTION CARD (40I2)



The input option parameters IØTP1 through IØPT20 determine program flow options to be executed by the ADD code and determine the input data cards to be read. These options are described on the following pages.

The input option parameters IDBG1 through IDBG20 are debug options not normally used.

IOPT1 (FLOWIN Option)

= 3 Inlet flow is computed by specifying data on Card 5 (turbulent flow).

= 4 Inlet and exit flow profiles are read from 2*KLL data cards following Card 5. Input, fractional distance Y, stagnation pressure $P_T(Y)$, static pressure $P(Y)$, swirl angle $\alpha(Y)$, and stagnation temperature $T_T(Y)$ (turbulent flow).

= 7 Inlet flow is computed by specifying data on Card 5 (laminar flow).

= 8 Same as 4 but for laminar flow

= 9 Same as 4 but: Input fractional distance Y, static pressure $P_T(Y)$, streamwise velocity $U_s(Y)$, swirl velocity $U_\phi(Y)$ and stagnation temperature $T_T(Y)$ (turbulent flow).

IOPT2 (FORCE Option)

= 0 No blade force

= 1 Calculate blade force from upstream/downstream flow data; input fractional distance Y, stagnation pressure $P_T(Y)$, static pressure $P(Y)$, swirl angle $\alpha(Y)$, and stagnation temperature $T_T(Y)$

= 2 Not available

= 3 Calculate blade force from cascade correlations

= 4 Calculate blade force from fractional distance Y, exit flow swirl angle $\alpha_2(Y)$, and loss coefficient $Z_B(Y)$

IOPT3 (GDUCT Option) Information follows Card 2

= 1 Calculate a straight. annular duct

= 2 Arbitrary duct with evenly spaced axial stations

= 3 Calculate a straight wall annular diffuser

= 4 Coordinates stored on data file

= 5 Arbitrary duct with arbitrary axial stations

IOPT4 (PRINT Option)

Print solution every IOPT4 station. For example, if IOPT4 = 3, every third station will be printed. If IOPT4 $\leq$ -1, the code provides an extended printout; this extended printout includes information about the boundary layer profiles and the turbulence model.

I0PT5 (STRUT INPUT Option)

Strut input data (if I0PT2 = 1) used to calculate strut forces from experimental data measured upstream and downstream of strut.

= 1 The upstream and downstream strut data cards are identical to the inlet and exit flow cards and are not read.

= 2 Read in required profiles.

I0PT6 (STRUT Thickness Effects)

0 Include strut forces plus thickness effects

1 Include strut thickness effects only.

I0PT7 (Axisymmetric Compressible Streamline Curvature Corections)

0 - No curvature correction

1 - Curvature correction

I0PT8 (WBLEED Option)

= 0 No Bleed

= 1 Bleed OD wall

= 2 Bleed ID wall

= 3 Bleed OD and ID wall

I0PT9 (COORDINATE Option)

= 0 Make an approximate calculation for both streamlines and potential lines--do not save flowfield on disk. Used only for I0PT3=1

= 1 Make exact calculation of streamlines and potential lines--store results on logical unit 9 and complete viscous flow calculation.

= 2 Same as 1 but terminate calculation after coordinate calculations are completed.

= 3 Read geometry from logical unit 9 and use in viscous flow calculation.

IOPT10 (ROTOR Option)

0 = Stator

1 = Rotor

IOPT11 (FLOW Option)

= 0 Interal flow.

= 1 External flow.

IOPT12 (TURBULENCE Option)

= 0 Use two-layer turbulence model.

= 1 Use two-layer turbulence model with low Reynolds number correction. (not tested)

= 2 Use two-layer turbulence model with streamline curvature correction.

= 3 Use two equation turbulence model (applicable to flows in annular diffusers only; i.e., diffusers with both inner and outer walls).

IOPT13 (SLOT Option)

= 0 No slot cooling.

= 1 Slot cooling.

*IOPT14 (GLOBAL Option)

= 0 Global iterations not used.

≥ 1 Global iterations used - backward differencing for streamwise velocity derivatives in vicinity of separation. (See Ref. 7)

IOPT15 (JFIRST Option)

Start flow calculation at station IOPT15--if omitted, IOPT15 = 1.

IOPT16 (JLAST Option)

Stop calculation at station IOPT16--if omitted, IOPT16 = JL.

IOPT17 (RESTART Option)

Restart a previously generated case at station IOPT17.

*NOTE: IOPT9 must be equal to 3 and KDS must be the same value as used in previous run and IOPT14 > 0 in previous run.

I0PT18 (Neglected Terms Print Option)

= 0 Not Used

= 1 Neglected terms are printed

I0PT19 (CALINV Option)

= 0 Calculate inviscid flow

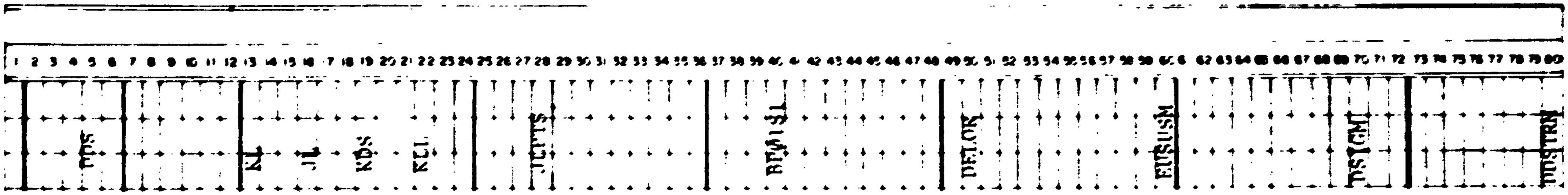
= 1 Calculate inviscid flow and stop

= 2 Read inviscid flow and continue

I0PT20 Not Used

ADD CODE INPUT

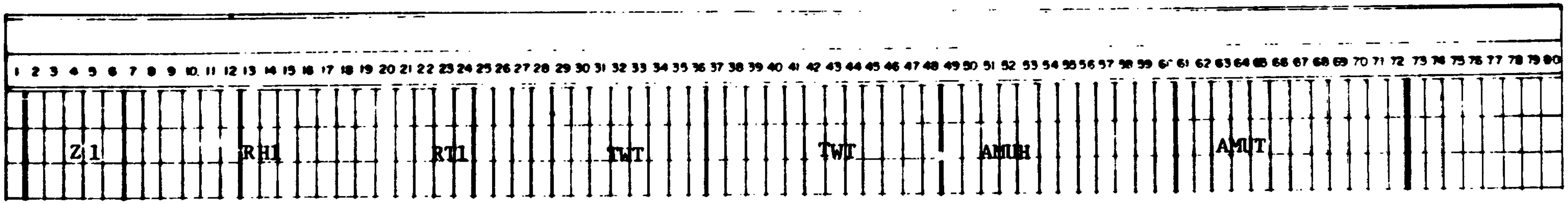
Card 3 MESH PARAMETER CARD FØRMAT (F10.5, 4I3, 3X, I3, 2X, 5F10.5)



DDS	Mesh Distortion Parameter in normal (radial) direction. The parameter will determine how closely grid points are spaced near the wall. If DDS is input at 0, the program will determine an appropriate value.
KL	Number of streamlines (3 ≤ KL ≤ 130); for most cases, set KL=50.
JL	Number of streamwise stations (3 ≤ JL ≤ 100); for most cases set JL=50.
KDS	Number of steps per station; if KDS=0, the program will determine the smallest KDS value that satisfies the criteria for numerical stability.
KLL	Number of input streamlines for inlet flow data (IØPT1 = 4,8,9). Program will interpolate input data on all KL streamlines.
JLPTS	Number of duct geometry input points for IØPT3=2. If JLPTS ≠ JL input data points will be smoothed and interpolated at calculation grid points.
BPØISI	Stretching parameter used in COOPST calculation (Default BPOISI=0, implies a uniform grid will be used in the calculation of potential lines and streamlines).

ADD CODE INPUT

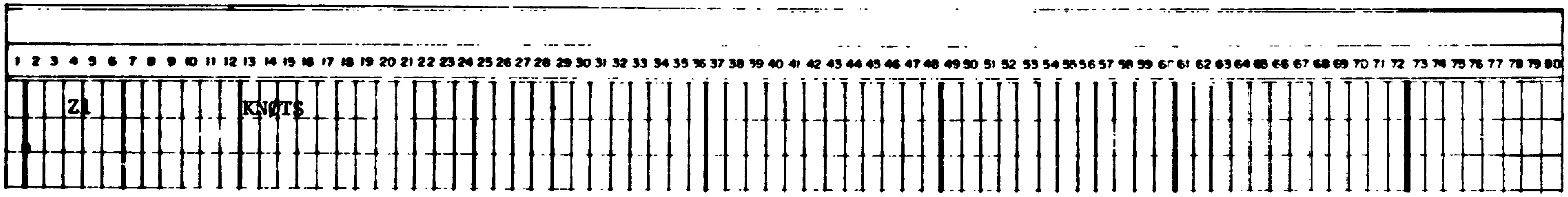
Card 4 DUCT GEOMETRY CARD FØRMAT (8F10.5)
IØPT3=1 STRAIGHT WALL ANNULAR DUCT



Z1	Length of duct	(ft)	
RH1	Hub radius	(ft)	
RT1	Tip radius	(ft)	
TWH	Hub wall temperature		deg R adiabatic wall if not specified
TWT	Tip wall temperature		deg R adiabatic wall if not specified
AMUH	Hub mass flow bleed		lbm/ft^2/sec
AMUT	Tip mass flow bleed		lbm/ft^2/sec

ADD CODE INPUT

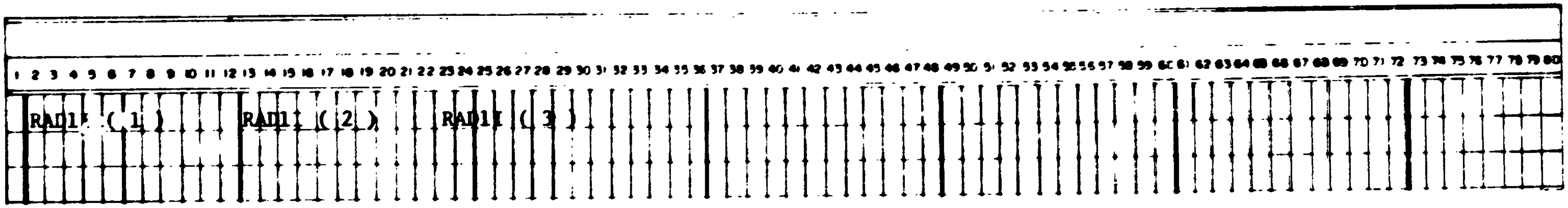
Card 4 DUCT GEOMETRY CARD FØRMAT (8F10.5)
IØPT3=2 READ DUCT COORDINATES



Z1	Length of duct (ft)
KNØTS	Number of nodal points 3 ≤ KNØTS ≤ 33 If not specified KNØTS = 5. The number of knots is used by the least squares spline fitting and interpolation routines when JL ≠ JLPTS

ADD CODE INPUT

Cards 4a DUCT O.D. RADIUS CARDS FØRMAT (8F10.5)
IØPT3 = 2 CARDS 4a FOLLOW CARD 4

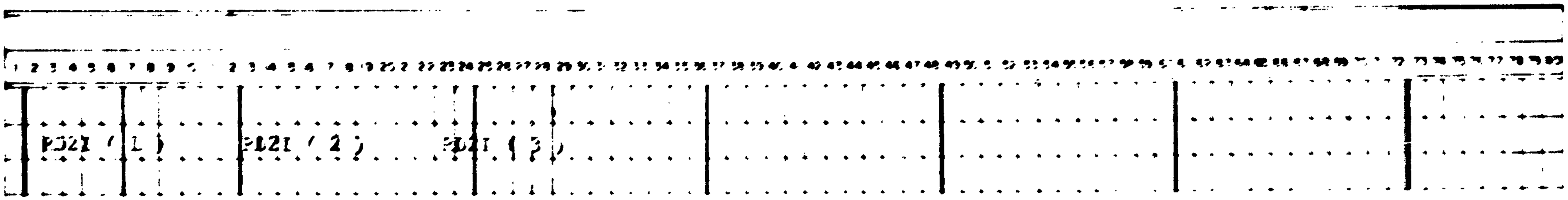


RADII(J) Tip (O.D.) duct radius (ft)
at JLPTS equally spaced axial stations
(8 entries per card)

ORIGINAL PAGE IS
OF POOR QUALITY

ADD CODE INPUT

Cards 4b DUCT I.D. RADIUS CARDS FØRMAT (8F10.5)
IØPT3=2 CARDS 4b FOLLOW CARD 4a

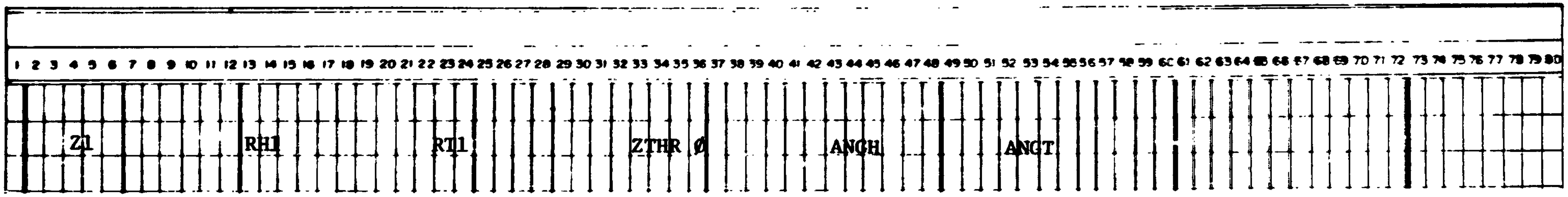


PD2I(I)	Hub (I.D.) duct radius (ft) at ILPTS equally spaced axial stations (8 entries per card)

ORIGINAL PAGE IS OF POOR QUALITY

ADD CODE INPUT

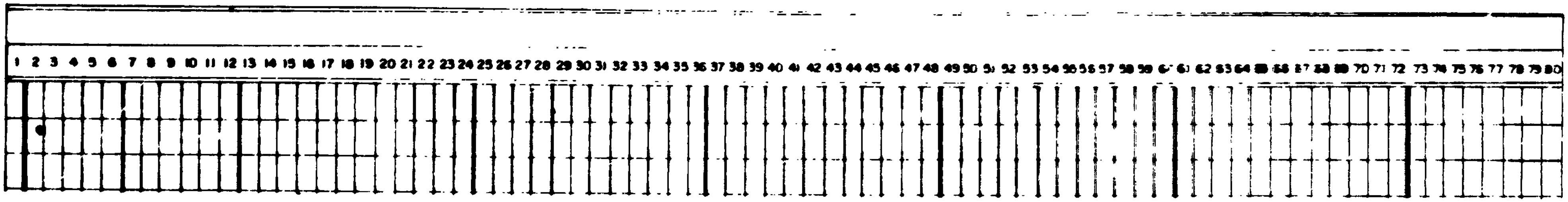
Card 4 DUCT GEOMETRY CARD FØRMAT (8F10.5)
IØPT3=3 STRAIGHT WALL ANNULAR DIFFUSER



Z1	Length of duct (ft)
RH1	Hub radius-station 1 (ft)
RT1	Tip radius-station 1 (ft)
ZTHRØ	Length of inlet throat (or straight) section (ft)
ANGH	Hub wall angle (deg.)
ANGT	Tip wall angle (deg.)

ADD CODE INPUT

Card 4 DUCT GEOMETRY CARD FØRMAT (8F10.5)
IØPT3 = 4 COORDINATES STØRED ON DATA FILE

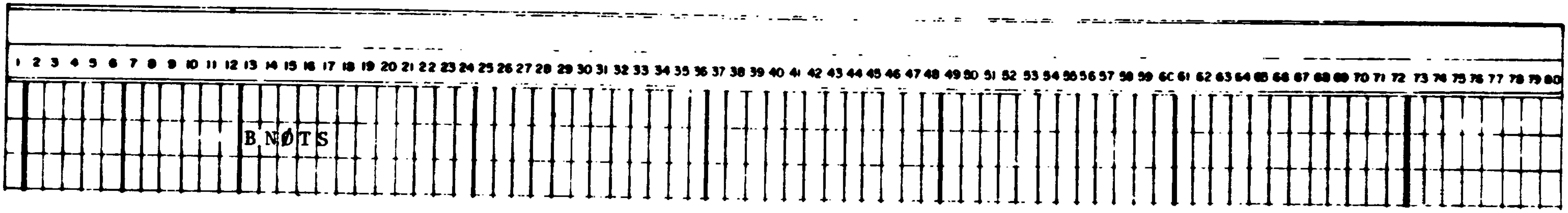


Load 1 (one) blank card.

ORIGINAL PAGE IS
OF POOR QUALITY

ADD CODE INPUT

Card 4 DUCT GEOMETRY CARD FØRMAT (8F10.5)
IØPT3=5 ARBITRARY DUCT - ARBITRARY SPACED AXIAL STATIONS

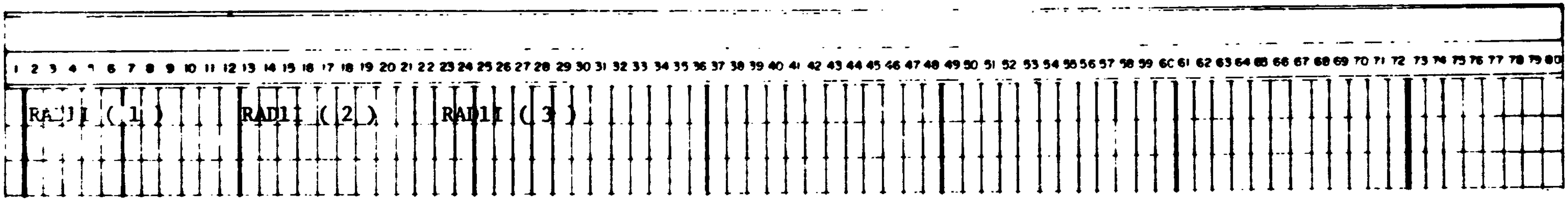


Z1 Length of duct (ft)

BNØTS Number of nodal points $3 \leq \text{BNØTS} \leq 33$
If not specified KNOTS = 5. The number of knots is used by the least squares spline fitting and interpolation routines when JL ≠ JLPTS

ADD CODE INPUT

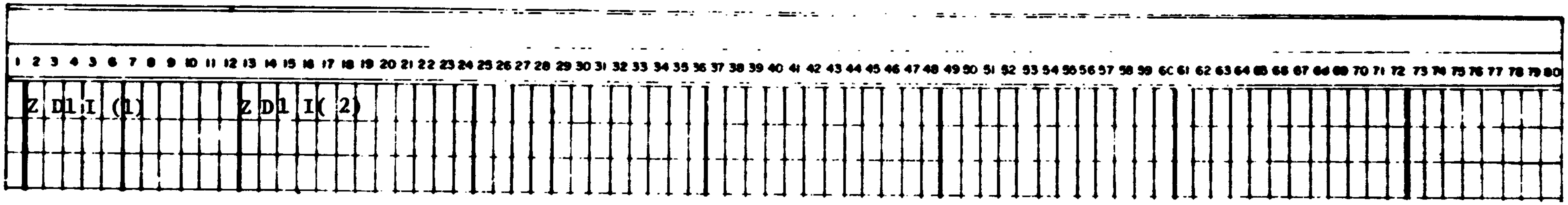
Cards 4a DUCT O.D. RADIUS CARDS F0RMAT (8F10.5)
I0PT3 = 5 CARDS 4a FOLLOW CARD 4



RADII(J) Tip (O.D.) duct radius (ft)
at JLPTS equally spaced axial stations
(8 entries per card)

ADD CODE INPUT

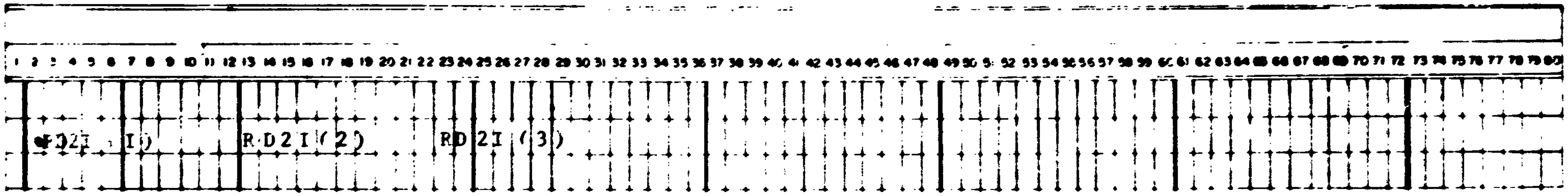
Cards 4b DUCT O.D. AXIAL STATIONS FØRMAT (8F10.5)
IØPT3 = 5 CARDS 4b FOLLOW CARDS 4a



ZD1I(J) Tip (O.D.) axial station (ft)
at JLPTS arbitrary axial stations
(8 entries per card)

ADD CODE INPUT

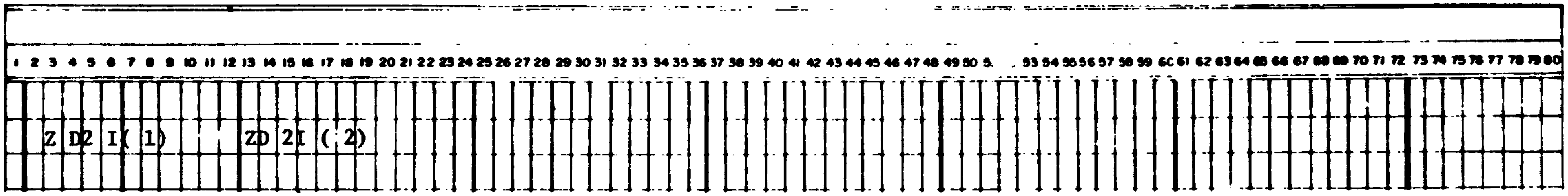
Cards 4c DUCT I.D. RADIUS CARDS FØRMAT (8F10.5)
IØPT3=2 CARDS 4c FOLLOW CARD 4b



RD2I(I) Hub (ID) duct radius (ft)
at JLPTS equally spaced axial stations
(8 entries per card)

ADD CODE INPUT

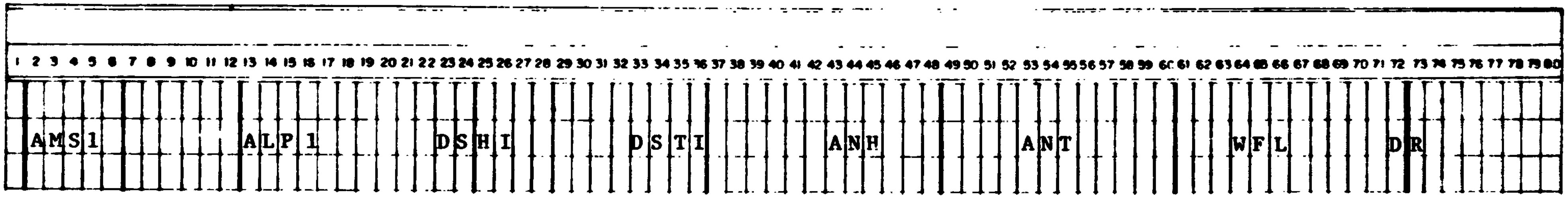
Card 4d DUCT I.D. AXIAL STATION FØRMAT (8F10.5)
IOPT3 = 5 CARDS 4d FOLLOW CARDS 4c



ZD2I(J) Hub (I.D.) axial station (ft)
at JLPTS arbitrary axial stations
(8 entries per card)

ADD CODE INPUT

Card 5 INLET FLOW CARD FØRMAT (7F10.5, 2F5.0)



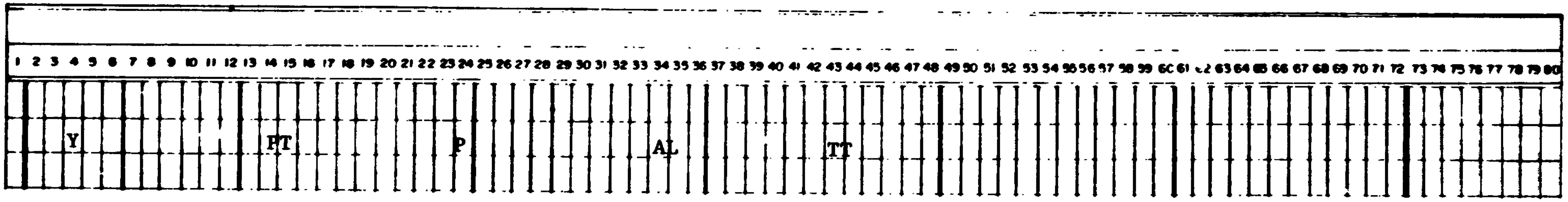
AMS1	Inlet Mach number
ALP1	Inlet swirl angle (deg)
DSHI	Hub boundary layer displacement thickness (ft)
DSTI	Tip boundary layer displacement thickness (ft)
ANH	Hub power law
ANT	Tip power law
WFL	Weight flow (lbm/sec)
DR	Equivalent sand roughness (μ in.)

NOTE:

1. If AMS1 is input, WFL will be calculated. If WFL is input, AMS1 will be calculated. If both AMS1 and WFL are input, AMS1 will be calculated.
2. For IØPT1=3,7 code uses data on cards 5 and 7.
3. For IØPT1=4,8.9 code uses data on card 5 (except AMS1 and ALP) and 2x KLL cards following card 5. If WFL is input, the static pressure profile will be adjusted until input and calculated weight flows agree.

ADD CODE INPUT

Cards 5A INLET/EXIT FLOW DISTRIBUTION FØRMAT (5F10.5)
IØPT1 = 4 2*KLL CARDS FOLLOWING CARD 5.



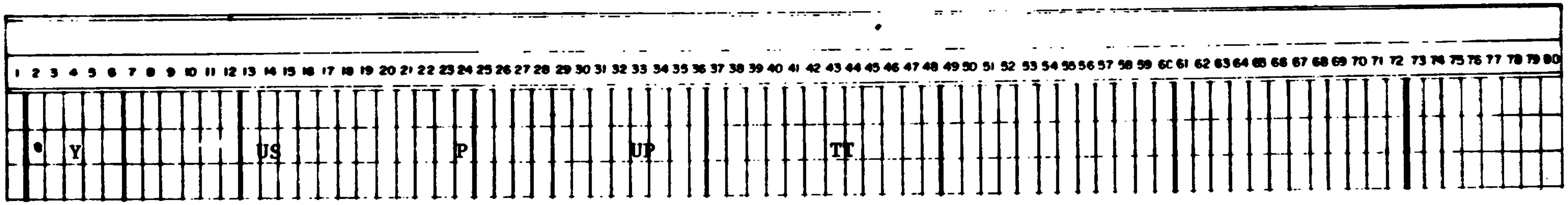
Y	Normalized distance across duct $Y = (r-r_H)/(r_T-r_H)$, $0 \leq Y \leq 1$ where r_H is hub radius at inlet (exit) station and r_T is tip radius at inlet (exit) station.
PT	Stagnation pressure psf abs
P	Static pressure psf abs
AL	Swirl angle (deg.)
TT	Stagnation temperature (°R)

NOTE:

1. Cards 1 through KLL are inlet conditions.
   Cards KLL+1 through 2*KLL are exit conditions.
2. Load cards with increasing Y including Y=0.0 and Y=1.0.
3. Program uses exit flow data only for plotting. If exit flow data are not available, use inlet flow data.

ADD CODE INPUT

Cards 5B INLET/EXIT FLOW DISTRIBUTION FØRMAT (5F10.5)
IØPT1 = 9 2*KLL CARDS FOLLOWING CARD 5.



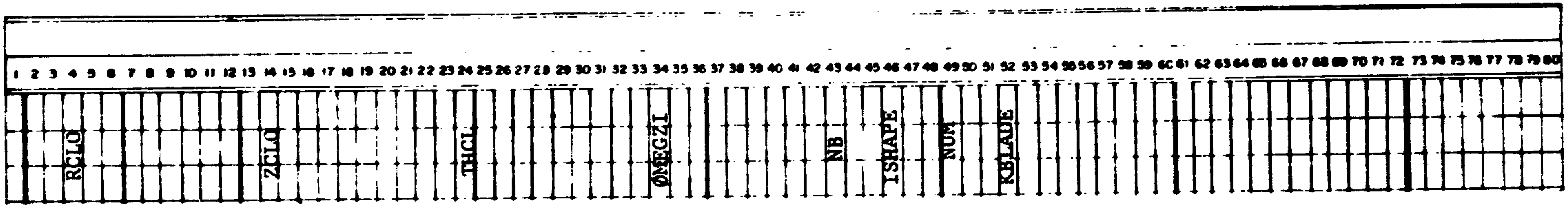
Y	Normalized distance across duct $Y = (r-r_H)/(r_T-r_H)$, $0.0 \leq Y \leq 1.0$
US	Streamwise velocity (ft/sec)
P	Static Pressure psf abs
UP	Swirl Velocity psf abs
TT	Stagnation temperature (°R)

NOTE:

1. Cards 1 through KLL are inlet conditions.
   Cards KLL+1 through 2*KLL are exit conditions.
2. Load cards with increasing Y including Y=0.0 and Y=1.0.
3. Program uses exit flow data only for plotting. If not available use inlet flow data.

ADD CODE INPUT

Card 6 FØRCE DATA CARD FØRMAT (4E 12.5, 413)
IF IØPT2 > 0

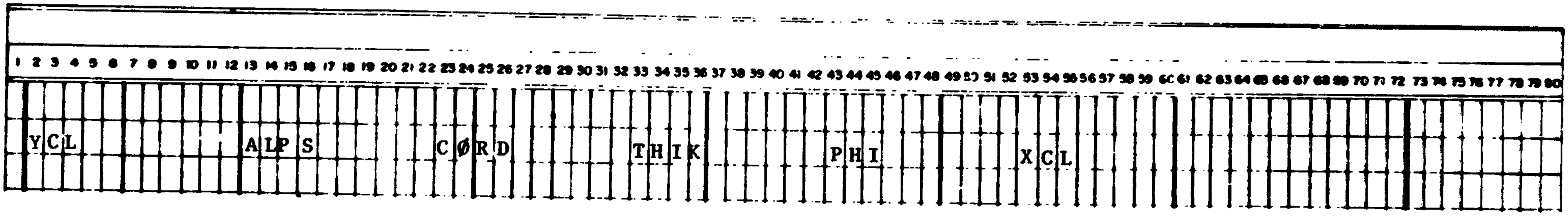


RCLO	Radial location for origin of stacking line (ft)
ZCLO	Axial location for origin of stacking line (ft)
THCL	Angle between stacking line and radius (deg)
ØMEGZI	Speed of rotor (rpm)
NB	Number of struts in blade row
ISHAPE	Airfoil section
	= 1 NACA 4 digit series uncambered airfoil (C_L,C_B correlation)
	= 2 Thin inlet guide vanes (α_2, Z_o correlation)
	= 3 NACA 4 digit series cambered airfoil (α_2, Z_B correlation)
	= 4 Arbitrary thickness airfoil (α_2, Z_B correlation)
	= 5 NACA 65A (A = 1. mean line) airfoil (α_2, Z_B correlation)
	= 6 NACA 65 CA (circular arc mean line) airfoil (α_2, Z_B correlation)
	= 7 NACA 65A (A - 1 mean line) airfoil (C_L, C_o correlation)
NUM	Number of input airfoil sections on slacking line $3 \leq$ NUM ≤ 20
KBLADE	Number of input data for arbitrary blade thickness distribution
	If ISHAPE = 4, KBLADE ≤ 50

*See Figure 4a.

ADD CODE INPUT

Cards 6a STRUT DATA CARDS FØRMAT (6F10.5)
NUM CARDS FOLLOWING CARD 6 IF IØPT2 > 0



**YCL Y location of input data at blade center line (stacking line) (ft)
ALPS Stagger angle (degrees from blade face)
CØRD Blade chord length (ft)
THIK Blade thickness/chord
*PHI Blade camber angle (equivalent circular arc camber in degrees)
XCL X distance to blade center line (ft)

NOTE:
1. NUM $\leq$ 20
2. Load data with increasing RCL

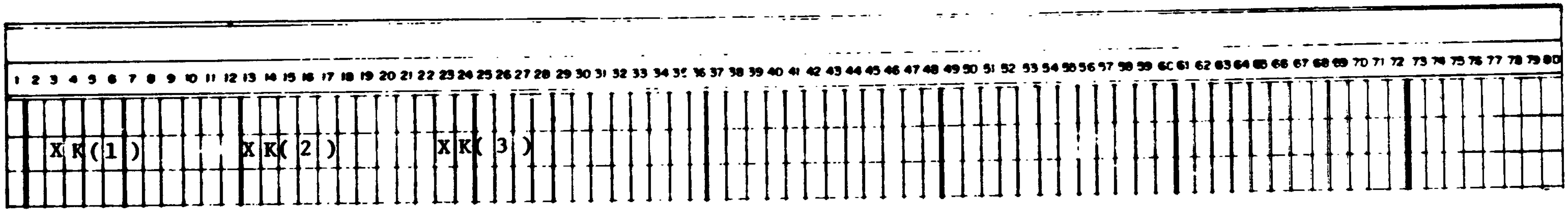
* The sign of PHI determines whether the blade passage accelerates or decelerates the flow

PHI > 0 flow decelerates (stator)
PHI < 0 flow accelerates (IGV)

** See Fig. 4b.

ADD CODE INPUT

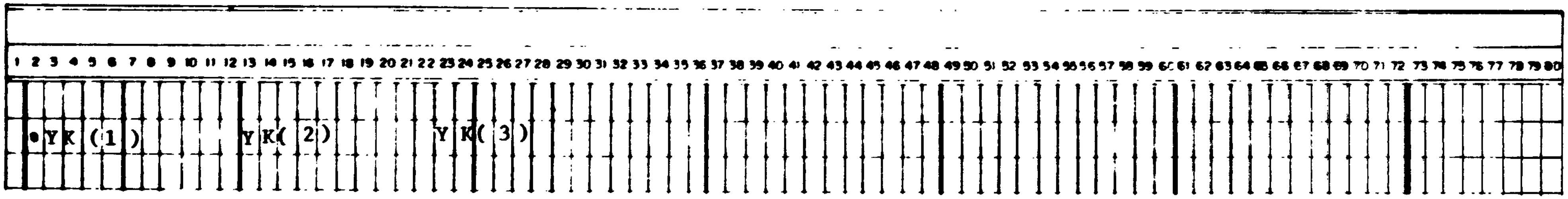
Cards 6b BLADE THICKNESS CARDS FØRMAT(8E10.0)
CARDS FOLLOWING CARDS 6a IF ISHAPE=4



XK(I) Decimal distance along chord line from blade leading $0 \le XK(I) \le 1.0$ I=1,KBLADE

ADD CODE INPUT

Cards 6c BLADE THICKNESS CARDS FØRMAT (8E10.5)
CARDS FOLLOWING CARDS 6b IF ISHAPE=4



YK(I) Blade thickness/chord I=1, KBLADE

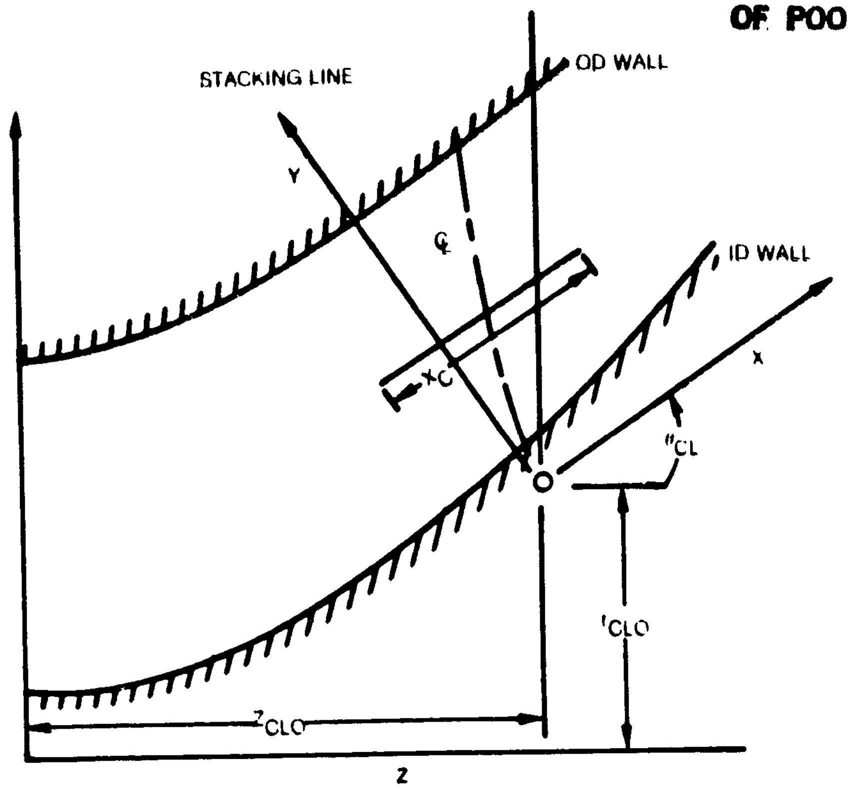


Fig. 4a. Location of Stacking Line

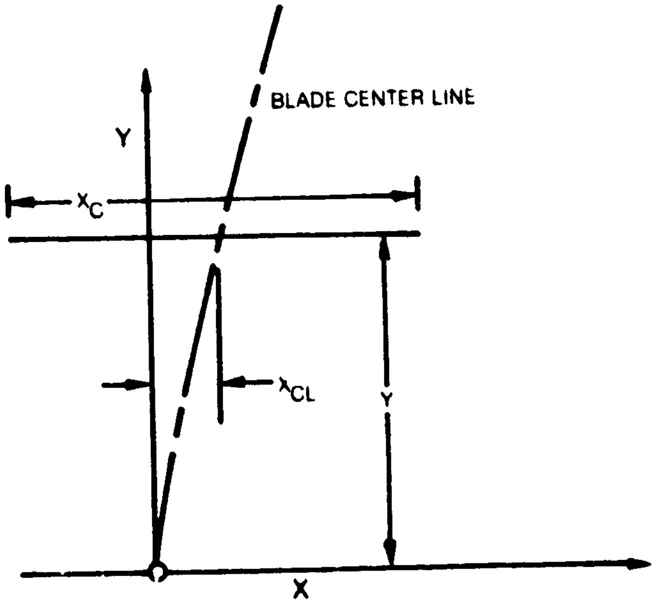
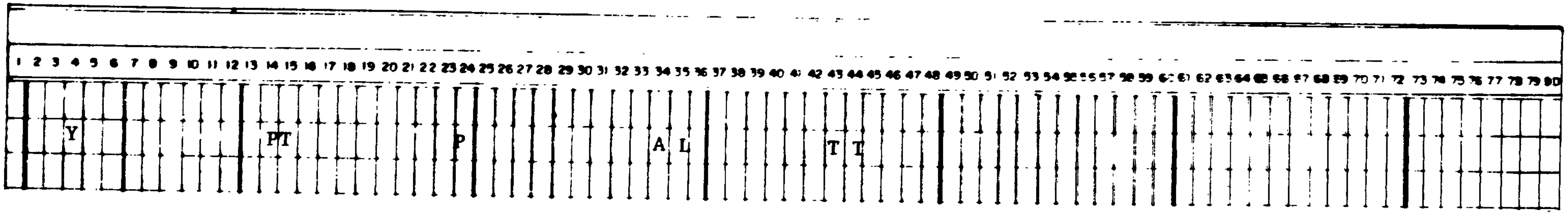


Fig. 4b. Blade Stacking Plane

81-10-63-24

ADD CODE INPUT

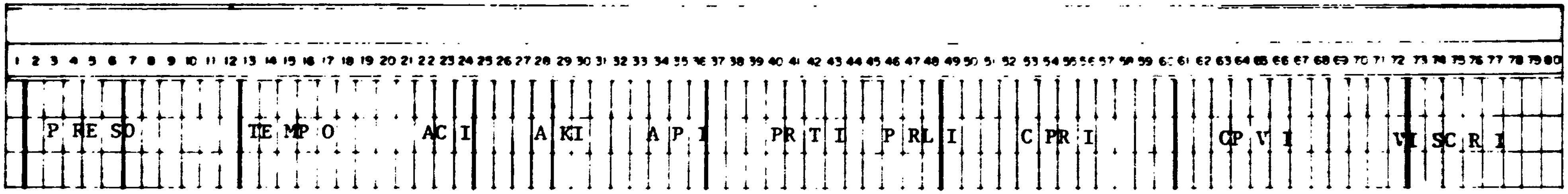
Cards 6d INLET/EXIT STRUT FLOW DISTRIBUTION FØRMAT (5F10.5) IOPT5>1
4 2*KLL CARDS FOLLOWING CARD 6 c IOPT2=4



Y	Normalized distance across duct $Y = (r-r_H)/r_T-r_H)$, $0 \leq Y \leq 1$ where r_H is hub radius at inlet (exit) station and r_T is tip radius at inlet (exit)
PT	Stagnation pressure psf abs
P	Static Pressure psf abs
AL	Swirl angle (deg.)
TT	Stagnation temperature (°R)
NOTE:	1. Cards 1 through KLL are inlet conditions. Cards KLL+1 through 2*KLL are exit conditions. 2. Load cards with increasing Y including Y=0.0 and Y=1.0 3. Program uses exit flow data only for plotting. If exit flow data are not available, use inlet flow data.

ADD CODE INPUT

CARD 7 REFERENCE CONDITIONS FØRMAT (2F10.5,5F6.0,3F10.5)

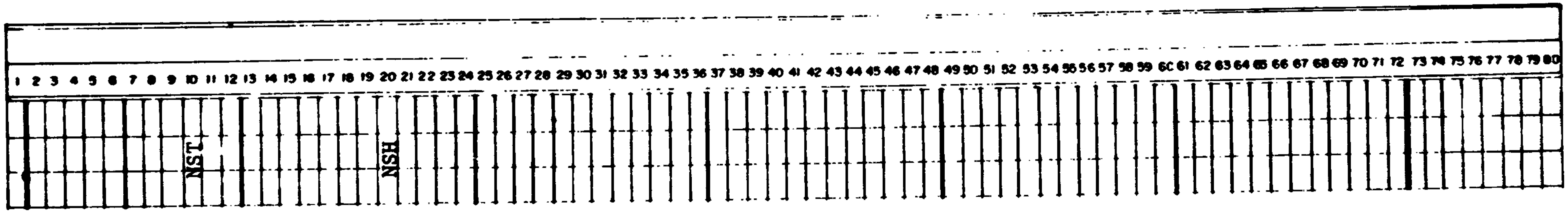


PRESO	Inlet stagnation pressure	(psf abs) default 2117 psf abs
TEMPO	Inlet stagnation temperature	(^oR) default 519^oR
ACI	Clauser constant	default (0.16)
AKI	Von Karman constant	default (0.41)
API	Von Driest constant	default (26.0)
PRTI	Prandtl number, turbulent	default (0.70)
PRLI	Prandtl number, laminar	default (0.90)
CPRI	Specific heat, constant pressure	default (5997) $ft^2/sec^2/^oR$
CVRI	Specific heat, constant volume	default (4283) $ft^2/sec^2/^oR$
VISCRI	Molecular viscosity	default (1.37E-06) slug/ft/sec

NOTE:
1. If not specified, the indicated default value is used.
2. If IØPT1=4,8or9, PRESØ and TEMPØ may be omitted

ADD CODE INPUT

CARD 8 SLOT DATA CARD FORMAT (2I10)
IF (IOPT13.NE.0)

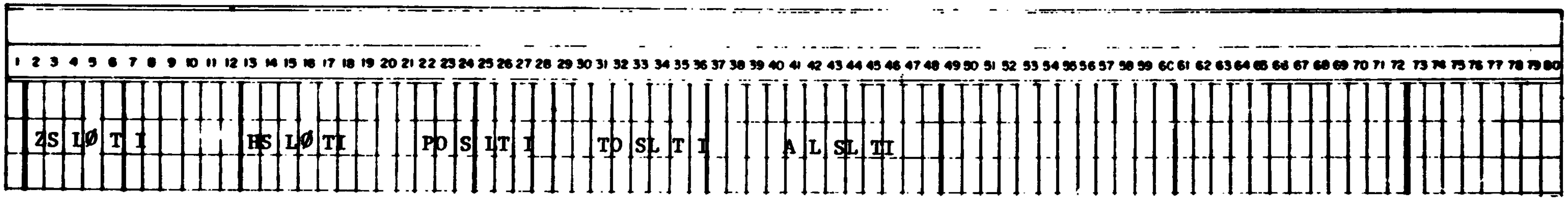


NST - Number of Slots on Tip Wall ($NST \leq 15$)

NSH - Number of Slots on Hub Wall ($NSH \leq 15$)

ADD CODE INPUT

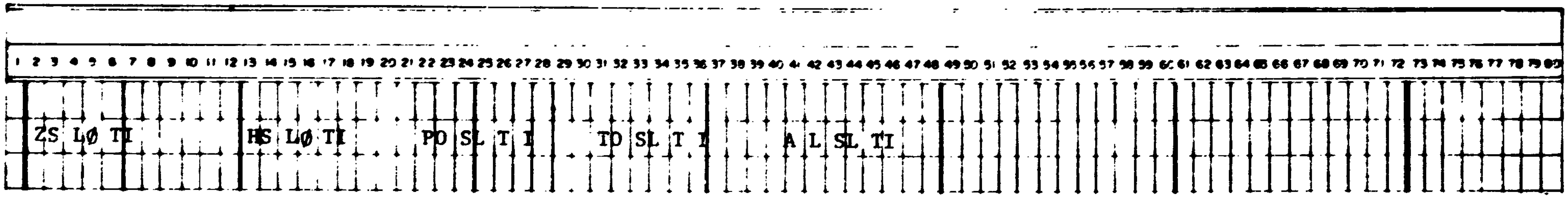
CARD 8A DESCRIPTION OF TIP WALL SLOTS FORMAT (510.S)
NST CARDS FOLLOW CARD 8



ZSLØTI	Axial location of slot (ft)
HSLØTI	Slot height (ft)
POSLTT	Total pressure (psf abs)
TOSLTI	Total temperature (^{o}R)
ALSLTI	Slot swirl angle (deg)

ADD CODE INPUT

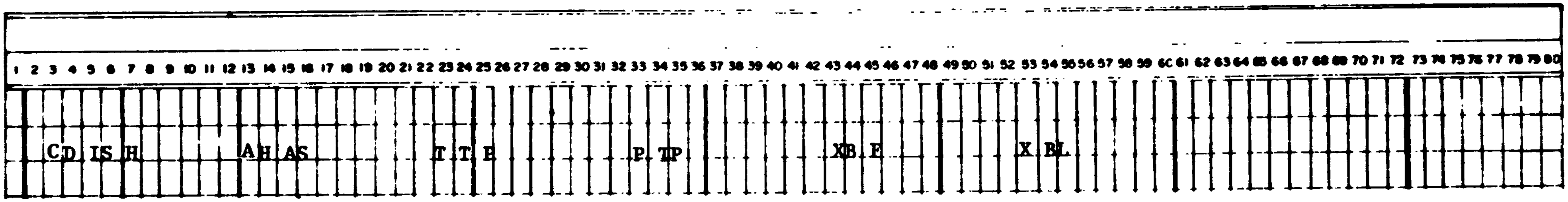
CARD 8B DESCRIPTION OF HUB WALL SLOTS FORMAT (510.S)
NSH CARDS FOLLOW CARD 8A



ZSL0II	Axial location of slot (ft)
HSL0II	Slot height (ft)
POSLII	Total pressure (psf abs)
TOSLII	Total temperature (^oR)
ALSLII	Slot swirl angle (deg)

ADD CODE INPUT

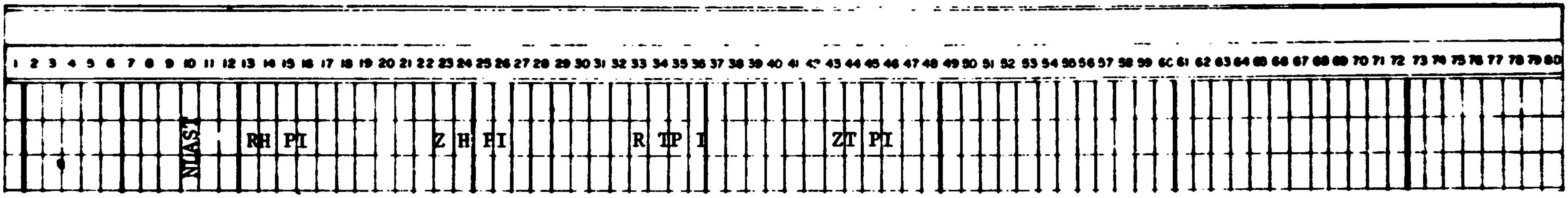
CARD 9 WALL BLEED DATA CARD FORMAT (6F10.5)



CDISH	Discharge coefficient for holes (dimensionless)	CDISH < 1.0
AHAS	Ratio of hole area to surface area	AHAS < 1.0
TTP	Plenum total temperature (deg. F)	
PTP	Plenum total pressure (psta)	
XBF	Wall distance - start wall bleed (ft)	
XBL	Wall distance - end wall bleed (ft)	

ADD CODE INPUT

CARD 10 INTERPOLATED OUTPUT DATA CARD FORMAT (I10, 4F10.5)



NLAST	Number of interpolated output data points NLAST ≤ 52
RHPI	Radial location of first (I.D.) point on output data line (ft)
ZHPI	Axial location of first (I.D.) point on output data line (ft)
RTPI	Radial location of last (O.D.) point on output data line (ft)
ZTPI	Axial location of last (O.D.) point on output data line (ft)

Note:
1. The first and last points must be outside the duct to resolve interpolation ambiguities.
2. Load one card for each output data interpolation as required.
3. Output card interpolation stops with a blank card. Load one blank card if no interpolated data is needed.

4.3 Output Description for ADD Code

The printed output on each page of the ADD code is largely self-explanatory. A detailed description of the printed output by page is given together with a sample output.

Title Page (1)

Printed by	0UTPUT
Calculated by	0UTPUT
Options	None

Description

This page presents a list of modifications made to the ADD code together with dates and report numbers.

Echo Print Pages

Printed by	ECØINP
Calculated by	ECØINP
Options	None

Description

The input data is read by subroutine REDINP. This input data is immediately printed with input labels by input data card number according to the input data sheets given in Section 4.2. This echo print is self explanatory and is intended to assist the user in setting up the data cards.

Coordinates of Blade Centerline Page (1)

Printed by	FLINE
Calculated by	BLDG0M, FLINE, SLETE
Options	Printed when I0PT2>0

Description

The location of the blade centerline in (r,z) coordinates is calculated by subroutine BLDG0M. With the (r,z) coordinates known for each blade input data point, subroutine FLINE calculates the (n,s) coordinates. Subroutine SLETE locates the upstream and downstream blade force calculation surfaces.

Page 1 Coordinates of Blade Centerline

Heading	Variable	Description
RADIAL LOC. OD WALL	r_{TCL} ,	Radius-intersection with OD wall (ft)
AXIAL LOC. OD WALL	z_{TCL} ,	Axial-intersection with OD wall (ft)
WALL DIST. OD WALL	x_{TCL} ,	Wall distance intersection with OD wall (ft)
RADIAL LOC. ID WALL	r_{HCL} ,	Radius intersection with ID wall (ft)
AXIAL LOC. ID WALL	z_{HCL} ,	Axial intersection with ID wall (ft)
WALL DIST. ID WALL	x_{HCL} ,	Wall distance intersection with ID wall (ft)

Heading	Variable		Description
POINT NO.	L	,	Blade input point numbers
RADIAL LOC.	r_{CL}	,	Radius of centerline (ft)
AXIAL LOC.	z_{CL}	,	Axial location of centerline (ft)
STRM. DIST.	x_{CL}	,	Streamwise distance (ft)
STRM. COOR.	s_{CL}	,	Streamwise coordinate
NORM. COOR.	m_{CL}	,	Normal coordinate
*STRM. STAT.	J	,	Streamwise station no.
*NORM. STAT.	K	,	Normal station no.

*NOTE: point L is located between

(J, J+1) and (K, K+1)

UPSTREAM STATION	JLEDG	,	Upstream force calculation surface
DOWNSTREAM STATION	JTEDG	,	Downstream force calculation surface

Input Flow Data Check Pages (3)

Printed by WRTCKI
Calculated by CKINPT
Options printed when: IOTP1 = 4 or 9
IOPT5 = 2

Description

Subroutine CKINPT checks the input data used to set up the inlet and exit flow field when IOPT1 = 4 or 9 and checks the data used to calculate the blade force when IOPT5 = 2. This subroutine solves the normal momentum equation using the input data to establish radial equilibrium. If the weight flow is not specified on the input data card, the boundary condition is set by the static pressure on the ID wall when IOPT11 = 0 and by the static pressure on the OD wall when IOPT11 = 1. If the weight flow is specified, the static pressure is set by the weight flow. In either case, the static pressure shown on these pages is that calculated from the normal momentum equations.

Page 1 Check Input for Weight Flow and Radial Equilibrium (IOTP1 = 3)

Heading	Variable	Description
Y/YT	Y/Y_T	Fractional distances across duct
TOTAL PRES	P_T	Total Pressure (psfa)
STATIC PRES	P	Static pressure (psfa)
SWIRL ANG.	α	Swirl Angle (deg)
TOTAL TEMP	T_T	Total temperature (deg R)

Page 1 Check Input for Weight Flow and Radial Equilibrium (IOPT1 = 9)

Heading	Variable	Description
Y/YT	Y/Y_T	Fractional distance across duct
STRM. VEL.	U_s	Streamwise velocity (ft/sec)
STAT. PRES.	P	Static pressure (psfa)
SWIRL VEL.	u_ϕ	Swirl velocity (ft/sec)
TOTAL TEMP.	T_T	Total temperature (deg R)

Page 2 Parameters Computed from Input Data

Heading	Variable	Description
Y/Y_T	Y/Y_T	Fractional distance
MACH	M	Mach number
STATIC TEMP.	T	Static temperature (deg R)
TOTAL VEL.	u	Velocity, ft/sec
STRM. VEL.	u_s	Streamwise velocity (ft/sec)
TANG. VEL.	u_ϕ	Tangential velocity (ft/sec)
ROTOR VEL.	v_B	Rotor velocity (ft/sec)
RELATIVE VEL.	$u_\phi - v_B$	Relative velocity (ft/sec)
RELATIVE ANG.	β	Relative angle (deg)
WT FLOW FRACTION	$W(Y)/W$	Fractional Weight flow

Page 3 Work Based on Input Data (IOPT5 = 2)

Heading	Variable	Description
Y/YT	Y/Y_T	Fractional distance
WORK IN DATA	$T_{T2}-T_{T1}$	Total temperature rise (deg R)
WORK IN ROTOR	$v_B(u_{\phi 2}-u_{\phi 1})$	Rotor work input (deg R)
ADIAB. EFF.	$\dfrac{(P_{I2}/P_{I1})^{\frac{\gamma-1}{\gamma}}-1}{T_{I2}/T_{I1}-1}$	Adiabatic efficiency
ADIAB. LOSS	$1-\left(\dfrac{P_{I2}}{P_T}\right)\left(\dfrac{T_{I2}}{T_{I1}}\right)^{\frac{-\gamma}{\gamma-1}}$	Total pressure loss

Input Data Pages (4)

Printed by	WRTINP
Calculated by	FNØRM, FLØWIN
Options	Pages are printed according to input options

Description

The input data is printed and labeled including; selected input options, mesh parameters, reference conditions set by BLØCK DATA and subroutine FNØRM, and average inlet flow conditions set by subroutine FLØWIN.

Page 1 Run Title

Heading	Variables		Description
ØPTIONS USED	IØPTϕ		Input options where $\phi = 1, 20$
MESH PARAMETERS			
DDS			Transverse mesh distortion parameter
KL			Number of streamlines
JL			Number streamwise stations coarse grid
KDS			Number steps/station fine grid
INLET FLØW PARAMETERS			
MS1	M_1		Inlet Mach number if specified
ALP1	α_1		Inlet swirl angle if specified
DSH	δ_H^*		Displacement thickness ID wall (ft)
DSJ	δ_T^*		Displacement thickness OD wall (ft)
ANH	n_H		Power law ID wall
ANT	n_T		Power law OD wall
WFL1	w		Weight flow if specified (lb/sec)
PERFØRMANCE PØINT			
WFLϕ	w	,	Calculated weight flow (lb/sec)
REY	$r_r \rho_r U_r / \mu r$	,	Reference Reynolds number
DYNP1	$\bar{q}_1$	,	Mass average dynamic pressure (psfa)
MACH1	M	,	Mass average Mach number
PRES1	$\bar{P}$	,	Mass average static pressure (psfa)
ATEMP1	$\bar{T}$	,	Mass average temperature (deg R)
OMEGZ	Ω	,	Rotor speed (rpm)
MACHA	$\tilde{M}$	,	Area average Mach number
REYH	$\bar{\rho} h \bar{u} / \mu$	,	Reynolds number based on mass average flow and inlet height
B1	B_1	,	Inlet blockage

REFERENCE CONDITIONS

PRESR	P_r	,	Reference pressure (psfa)
TEMPR	T_r	,	Reference temperature (deg R)
RHOR	ρ_r	,	Reference density (slug/ft^3)
CP	C_p	,	Specific heat (ft^2/deg)
CV	C_v	,	Specific heat (ft^2/deg)
VISCR	μ_r	,	Reference viscosity (slug/ft^3)
USR	u_r	,	Reference velocity (ft/sec)
RADR	r_r	,	Reference radius (ft)
SNDR	c_r	,	Reference speed of sound (ft/sec)
PR	P_r	,	Prandtl number

TURBULENCE PARAMETERS

AKAPPA	κ	,	Von Karman constant
ACHI	λ	,	Clauser constant
APLUS	A^+	,	Van Driest constant
PRT	P_{r_T}	,	Turbulent Prandtl number

Page 2 Inlet Flow Data If IOPT1 = 4,8

Heading	Variable		Description
SPANWISE LOCATION	Y/Y_T	,	Fractional distance
TOTAL PRESSURE	P_T	,	Total pressure (psfa)
STATIC PRESSURE	P	,	Static Pressure (psfa)
SWIRL ANGLE	α	,	Swirl angle (deg)
TOTAL TEMPERATURE	T_T	,	Total temperature (deg R)

Page 2 Inlet Flow Data If I0PT1 = 9

Heading	Variable		Description
SPANWISE LOCATION	Y/Y_T	,	Fractional distance
STREAMWISE VELOCITY	u_s	,	Streamwise velocity (ft/sec)
STATIC PRESSURE	P	,	Static pressure (psfa)
SWIRL VEL.	u_ϕ	,	Tangential velocity (ft/sec)
TOTAL TEMPERATURE	T_T	,	Total temperature (deg R)

Page 3 Strut Data

Heading	Variable		Description
RCLO1	r_{CLO}	,	Radial location of strut (ft)
ZCLO1	z_{CLO}	,	Axial location of strut (ft)
THCL1	θ_{CLO}	,	Rotation of strut (deg)
0MEGZ1	Ω	,	Rotor speed (rpm)
NB	N	,	Number of blades
YCL	y	,	Stacking line Y coordinate of ℄ (ft)
ALPS	α_s	,	Stagger angle (deg)
CH0RD	c	,	Chord (ft)
THICK/CHORD	t/c	,	Thickness/chord ratio
CAMBER	ϕ_c	,	Camber angle (deg)
XCL	x	,	X coordinate of ℄ (ft)
Y	Y/Y_T	,	Fractional distance
BETA1*	β^*_1	,	Inlet metal angle (deg)
BETA2*	β^*_2	,	Exit metal angle (deg)

Page 4 Strut Flow Variables I0TP5 = 2

This page is the same as the Inlet Flow Page 2.

Duct Geometry Pages (2)

Printed by	WRTGDC
Calculated by	GDUCT, C00RST, SM00TH
Options	None

Description

The output from GDUCT is printed on page 1 which contains the calculated duct coordinates for the ID and OD walls. When I0PT3 = 2 or 5 and JLPTS ≠ JL, this page contains the output from the least squares cubic spline smoothing routine subroutine SM00TH. The output from C00RST is printed on page 2 which contains a shortened summary of the calculated coordinates. Note that the wall coordinates for a given station number do not agree from page 1 to page 2. On page 1, the coordinates are given for equal axial stations when I0PT3 ≠ 5 and for equal wall arc length when I0PT3 = 5. On page 2, the coordinates are given for equal stations ΔS in the computational plane. The complete set of coordinate data is stored on Unit 9.

Page 1 Calculated Duct Geometry

Heading	Variable		Description
DUCTI(N)	D_N	,	Input parameters
STRM. STA	J	,	Streamwise station number
AXIAL DIST.	z	,	Axial corrdinate (ft)
RADIAL DIST.	r	,	Radial coordinate (ft)

Page 2 Calculated Duct Coordinates

Heading	Variable		Description
STRM. STA.	J	,	Streamwise station number
AXIAL DIST.	z	,	Axial distance (ft)
RADIAL DIST.	r	,	Radial distance (ft)
WALL DIST.	x	,	Wall arc length (ft)
CURV.	k	,	Curvature (1/ft)
1/MET COEF.	1/h	,	1/Metric coefficient (ft)

Gap Average Inviscid Flow Page

Printed by	WRTCAL
Calculated by	CALINV
Options	Printed for every JJ station JJ = I0PT15, I0PT16 depending on print option I0TP4

Description

Subroutine CALINV calculates the solution for the approximate inviscid rotational swirling flow field and the solution is stored on Unit 22.

Page 1 Gap Average Inviscid Flow

Heading	Variable		Description
JJ	JJ	,	Coarse grid station number
ZH	z_H	,	Axial location ID wall (ft)
ZT	z_T	,	Axial location OD wall (ft)
Y/YT	Y/Y_T	,	Fractional distance
TOTAL PRES.	P_T	,	Total pressure (psfa)
STATIC PRESS.	P	,	Static pressure (psfa)
SWIRL ANGLE	α	,	Swirl angle (deg)
TOTAL TEMP.	T_T	,	Total temperature (deg. R)
MACH	M	,	Mach number
STATIC TEMP.	T	,	Static temperature (deg. R)
TOTAL VEL.	u	,	Total velocity (ft/sec)
STRM. VEL.	u_S	,	Streamwise velocity (ft/sec)
TANG. VEL.	u_ϕ	,	Tangential velocity (ft/sec)
ROTOR VEL.	V_B	,	Rotor velocity (ft/sec)
RELATIVE VEL.	$u_\phi - v_B$	,	Relative Velocity (ft/sec)
RELATIVE ANGLE	β	,	Relative angle (deg)
NORM. VEL.	u_n	,	Normal velocity (deg)

Wall Bleed Conditions Page (1)

Printed by	WBLEED
Calculated by	WBLEED
Options	printed when I0PT8 > 0

Description

The wall bleed rate is estimated a-priori from the plenum conditions and the inviscid static pressure distribution using subroutine WBLEED.

Page 1 Wall Bleed Conditions

Heading	Variable	Description
DISCHARGE COEFFICIENT	C_{DIS}	, Discharge coefficient of holes
RATIO HOLE AREA TO SURFACE AREA	A_{HS}	, Ratio of hole to surface area
PLENUM STAGNATION PRESSURE	P_{TP}	, Plenum total pressure (psfa)
PLENUM STAGNATION TEMPERATURE	T_{TP}	, Wall distance start,bleed (ft)
WALL DISTANCE START BLEED	X_{BL}	, Wall distance stop bleed (ft)
WALL DISTANCE HUB WALL	X_H	, Wall distance ID (ft)
MASS BLEED HUB WALL	$\dot{W}_{HB}$	, Wall bleed rate ID (lb/sec/ft^2)
TOTAL BLEED HUB WALL	W_{HB}	, Integrated bleed (lb/sec)

Heading	Variable	Description
WALL DIST TIP WALL	x_T	, Wall distance OD (ft)
MASS BLEED TIP WALL	$\mathring{W}_{TB}$	, Wall bleed rate OD (lb/sec/ft^2)
TOTAL BLEED TIP WALL	$\bar{W}_{TB}$	, Integrated bleed (lb/sec)

Gap Average Flow Properties Pages (6)

Printed by	WRTSØV
Calculated by	SØLVI, TURB, TURB2Q, AMFØR
Options	Printed for every JJ station JJ=IØPT15, IØPT16 depending on IØTP4 IØPT4 > 0 print only page 1 IØPT4 < 0 print pages 1 through 8

Description

Subroutine SØLVI solves the equation of motion for turbulent compressible flow using subroutine TURB to calculate the eddy viscosity using algebraic turbulence models or subroutine TURB2Q using the two equation turbulence model. Subroutine SØLVI also integrates the work input by the blades and the entropy rise due to the dissipation function which is printed on page 6. The solution printed on pages 1 and 2 are stored on Unit 8.

Page 1 Gap Average Flow Properties

Heading	Variable		Description
JJ	JJ	,	Streamwise coarse grid number
JKDS	JKDS	,	Fine grid station number
AXIAL LOC.	z	,	Axial coordinate (ft)
RADIAL LOC.	r	,	Radial coordinate (ft)
WALL DIST.	x	,	Wall arc length (ft)
WALL TEMP.	T_w	,	Wall temperature if specified (deg R)
WALL BLEED	w_B	,	Wall bleed ($lb/ft^2/sec$)
STREAMLINE NO.	K	,	Transverse grid number
Y/Y_{TIP}	Y/Y_T	,	Fraction distance
STRM. VEL.	u_s	,	Streamwise velocity (ft/sec)
TANG. VEL.	u_ϕ	,	Tangential velocity (ft/sec)
NORM. VEL.	u_n	,	Normal velocity (ft/sec)
TOTAL VEL.	u	,	Total velocity (ft/sec)
SWIRL ANGLE	α	,	Swirl angle (deg)
MACH NO.	M	,	Mach number
TOTAL TEMP.	T_T	,	Total temperature (deg R)
TOTAL PRES.	P_T	,	Total pressure (psfa)
YPLUSH	Y^+_H	,	Universal distance to first grid point ID wall
YPLUST	Y^+_T	,	Universal distance to first grid point OD wall

Page 2 Gap Average Flow Properties

Heading	Variable		Description
JJ	JJ	,	Streamwise coarse grid no.
JKDS	JKDS	,	Streamwise fine grid no.
STREAMLINE NO.	K	,	Transverse grid no.
Y/YTIP	Y/Y_T	,	Fractional distance
WT. FLOW	w(Y)	,	Weight flow (lb/sec)
STATIC PRES.	P	,	Static pressure (psfa)
STATIC TEMP.	T	,	Static temperature (deg R)
DENSITY	ρ	,	Density (slugs/ft^3)
ENTROPY	$I/\mathcal{R}$	,	Entropy/gas constant
STRM. STRESS	τ_{us}	,	Streamwise stress (lb/ft^2)
TANG. STRESS	$\tau_{n\phi}$	,	Tangential stress (lb/ft^2)
HEAT FLUX	q	,	Heat flux (lb/ft/sec)

Page 3/4 Boundary Properties Hub/Tip Wall

Heading	Variable		Description
WALL VISCOSITY	μ_w	,	Viscosity at wall (slug/ft/sec)
WALL HEAT CON.	λ_w	,	Conductivity at wall (lb/sec/deg)
WALL TEMP	T_w	,	Wall temperature (deg R)
WALL DENS.	ρ_w	,	Wall density (slug/ft^3)
WALL STRESS	$(\tau_{ns}{}^2 + \tau_{n\phi}{}^2)^{1/2}$	,	Wall stress (lb/ft^2)
USTAR	u^*	,	Friction velocity (ft/sec)
QWALL	$q_w(u^*)^3$	,	Normalizing factor on heat flux (lb/ft/sec)
STREAMLINE NO.	K	,	Streamline number
Y	y	,	Distance from wall (ft)
VISC./WALL VISC.	μ_E/μ_w	,	Effective viscosity ratio
HEAT CON.	λ_E/λ_w	,	Effective conductivity ratio
YPLUS	$Y^+ = \rho_w u^* y/\mu_w$	,	Universal distance
UPLUS	$u^+ = u/u^*$	,	Universal velocity
TPLUS	$T^+ = \tau/\tau_w$	,	Universal stress
QPLUS	$Q^+ = q/(\rho_w u^{*3})$	,	Universal heat flux

Page 5 Gap Average Turbulence Properties

Heading	Variable		Description
STEAMLINE NO.	K	,	Streamline number
Y/YTIP	Y/Y_T	,	Fractional distance
REY. STRESS	$\overline{-u'v'}$	,	Reynolds stress (ft^2/sec^2)
TURB. K.E.	$\overline{u'u'}/2$	,	Turbulence kinetic energy (ft^2/sec^2)
DISSIPATION	$\nu \overline{\left(\frac{du'}{dy}\right)^2}$	,	Turbulence dissipation (ft^2/sec^3)
PRANDTL MIXING LENGTH	$\ell = \sqrt{\tau/\left(\frac{du}{dy}\right)^2}$	,	Prandtl mixing length (ft)
RICH. NO. S	R_{c_s}	,	Richardson number for streamline curvature
RICH NO. PHI	Ri_ϕ	,	Richardson number for swirling flow

Page 6 Gap Average Work, Loss, Efficiency

Heading	Variable		Description
STREAMLINE NO.	K	,	Streamline number
Y/YTIP	Y/Y_T	,	Fractional distance
WT. FLØW FRACTION	w(Y)/w	,	Weight flow fraction
ROTOR VEL.	v_B	,	Rotor velocity (ft/sec)
ABS. ANG.	$\alpha = \tan^{-1}(u_\phi/u_s)$	,	Absolute flow angle (deg)
REL. ANG.	$\beta = \tan^{-1}(u_\phi-v_B)/(u_s)$		Relative flow angle (deg)
WORK IN.	$T_{T_2}/T_{T_1}-1$	,	Work input
WORK OUT	$P_{T_2}/P_{T_1}-1$	,	Work output
LOSS	$1-\exp(-\Delta I)$	,	Loss
ADIABATIC EFFICIENCY	$\dfrac{(P_{T_2}/P_{T_1})^{\frac{\gamma-1}{\gamma-1}}}{T_{T_2}/T_{T_1}-1}$	,	Adiabatic efficiency

TRUNCATION ERROR	$\bar{T}$	,	Mass average total temperature (deg R)
EROTH	$\frac{\delta(\rho T)}{\bar{P}\bar{T}}$	,	Error in PT
EPRES	$\frac{\delta P}{\bar{P}}$	,	Error in P
ER0OS	$\frac{\delta(\rho u s)}{\bar{\rho}\bar{u}_s}$	,	Error in ρu_s
EUSUS	$\frac{\delta(u_s^2)}{\bar{u}_s^2}$	,	Error in u_s^2
EUPUP	$\frac{\delta(u_\phi^2)}{\bar{u}_\phi^2}$	,	Error in u_ϕ^2
EENTP	$\frac{\delta I}{\bar{I}}$	,	Error in I

Stream Thrust Average Page (1)

Printed by BMF0R
Calculated by BMF0R, AMF0R
Option None

Description

The stream thrust average quantities are calculated by subroutine AMF0R which computes an average Mach number which satisfies the one dimensional energy, continuity, and momentum (stream thrust) equations.

Page 1 Stream Thrust Average Properties

Heading	Variable	Description
STATION NO.	J	Streamwise station
ZL0C	$Z_{LOC}=(Z_H+Z_T)/2$	Mean axial distance (H)
AM	$\tilde{M}$	Average Mach number
BPR	$\tilde{P}$	Average static pressure (psf)
BPRO	$\tilde{P}_T$	Average total pressure (psf)
STRT	$\tilde{T}$	Stream thrust (lb)
ARA	α	Crossectional area (ft^2)
WC	W_c	Choked weight flow (lb/sec)
PTL0SS	$(\bar{P}_{TI}-\bar{P}_T)/\bar{P}_{TI}$	Total pressure loss
MAMIX	$\frac{1}{W}\int\frac{\lvert T-\bar{T}\rvert d_w}{\bar{T}}$	Total temperature mixing

Output Summary Pages (3)

Printed by	WRTSUM
Calculated by	SØLVI, FAVER
Option	None

Description

The mass flow weighted average flow properties are calculated by subroutine FAVER and printed on page 1. The remaining flow parameters printed on pages 2 and 3 are calculated by subroutine SØLVI.

Page 1 Mass Flow Weighted Average Flow

Heading	Variable		Description
STRM. STA	JJ	,	Streamwise station number
AXIAL DIST.	$\bar{z} = (z_H + z_T)/2$	,	Axial distance (ft)
STRM. VEL.	$\bar{u}_s$	,	Streamwise velocity (ft/sec)
TAN. VEL.	$\bar{u}_\phi$	,	Tangential velocity (ft/sec)
STATIC PRES.	$\bar{P}$	,	Static pressure (psfa)
STATIC TEMP.	$\bar{T}$	,	Static temperature (°R)
DENSITY	$\bar{\rho}$	,	Density (slug/ft^3)
MACH No.	$\bar{M}$	,	Mach number
TOTAL PRES.	$\bar{P}_T$	,	Total pressure (psfa)
TOTAL TEMP.	$\bar{T}_T$	,	Total temperature (deg. R)
LOSS	$1-\exp(I_1-I)$	,	Loss $(1-P_{TZ}/P_{T1})$
BLOCK	$B = 1 - \dfrac{W}{gA(\rho U)_\infty}$	,	Blockage

Page 2 Wall Pressure and Friction Coefficient

Heading	Variable		Description
STRM. STA.	JJ	,	Streamwise station
AXIAL DIST.	z	,	Axial distance (ft)
WALL DIST.	x	,	Wall arc length (ft)
PRES. COEF.	$(P-P_1)/q_\infty$	,	Pressure coefficient
STREM. FRICT. COEF.	τ_{ns}/q_∞	,	Streamwise friction coefficient
TANG. FRICT. COEF.	$\tau_{n\phi}/q_\infty$	,	Tangential friction coefficient
DYNP. PRES.	q_∞	,	Maximum dynamic pressure (psfa)

Page 3 Convective Heat Transfer

Heading	Variable		Description
STRM. STA	JJ	,	Streamwise station
AXIAL DIST.	z	,	Axial distance (ft)
WALL DIST.	x	,	Wall arc length (ft)
WALL TEMP.	T_w	,	Wall Temperature (deg R)
LOCAL QW	q_w	,	Wall heat flux (lb/ft/sec)
TOTAL QT	$q_T = \int q_w da$	,	Integrated heat flux (ft lb/sec)

Blade Force Pages (4)

Printed by	FØRC(2)
Calculated by	FØRC(1), FINVIS, CASC, GBLADE
Options	Printed when IØPT2 > 0

Description

The flow field variables calculated by subroutine FINVIS are printed on pages (1) and (2). These variables are printed for both the flow just upstream and just downstream of the blades. The blade row (cascade geometry) used by subroutine CASC is printed on page 3. The blade force, work and adiabatic efficiency calculated by subroutine FØRC are printed on page 4.

Page 1 Blade Force Flow Variables

Heading	Variable		Description
STREAMLINE NO.	K	,	Transverse grid number
Y/YTIP	Y/Y_T	,	Fractional distance
STRM. VEL.	u_s	,	Streamwise velocity (ft/sec)
TANG. VEL.	u_ϕ	,	Absolute tangential velocity (ft/sec)
REL. VEL.	w_ϕ	,	Relative tangential velocity (ft/sec)
TOTAL VEL.	u	,	Total absolute velocity (ft/sec)
ABS. ANG.	α	,	Absolute swirl angle (deg)
MACH NO.	M	,	Absolute Mach number
TOTAL TEMP.	T_T	,	Total temperature (deg R)
TOTAL PRES.	P_T	,	Total pressure (psfa)

Page 2 Blade Force Variables

Heading	Variable		Description
STREAMLINE NO.	K	,	Transverse grid number
Y/YTIP	Y/Y_T	,	Fractional distance
RADIUS	r	,	Radius (ft)
STAT. PRES.	P	,	Static pressure (psfa)
STAT. TEMP.	T	,	Static temperature (deg R)
DENSITY	ρ	,	Density (slug/ft^3)
ENTRØP/GAS CØNST.	$I/\mathcal{R}$	,	Entropy
ABS. ANG.	α	,	Absolute flow angle (deg)
REL. ANG.	β	,	Relative flow angle (deg)
BLADE VEL.	v_B	,	Rotor velocity (ft/sec)

Page 3 Cascade Parameters

Heading	Variable		Description
STREAMLINE NO.	K	,	Transverse grid number
RADIUS	r	,	Radius (ft)
THICK/CHORD	t/c	,	Thickness/chord
GAP	g	,	Gap (ft)
SOLD	σ	,	Solidity c/g
CHORD	c	,	Chord (ft)
CAMBER ANG.	ϕ_c	,	Circular arc camber angle (deg)
STAGGER ANG.	α_s	,	Stagger angle to axis (deg)
LOSS COEF.	Z_B	,	Loss coefficient

Page 4 Blade Force, Work, Efficiency

Heading	Variable		Description
STREAMLINE NO.	K	,	Transverse grid number
LIFT COEF.	C_L	,	Lift coefficient
DRAG COEF.	C_D	,	Drag coefficient
STRM. FORCE	F_S	,	Streamwise force/span, lb/ft
TANG. FORCE	F_ϕ	,	Tangential force/span, lb/ft
WORK INPUT	$C_p(T_{T2}-T_{T1})$	,	Work input, ft^2/sec^2
TT2/TT1-1	$T_{T2}/T_{T1}-1$	,	Total temperature increase
PT2/PT1-1	$P_{T2}/P_{T1}-1$	,	Total pressure increase
ADIAB. EFF.	ξ	,	Adiabatic efficiency

One Dimensional Boundary Layer Parameter Pages (2)

Printed by BLPARM
Calculated by BLPARM
Options None

Description

The inviscid flow field solution stored on Unit 22 is compared with the viscous solution stored on Unit 8 and the edge of the boundary layer is determined using a vorticity criteria. Then the displacement and momentum thicknesses are calculated using the definition derived in subroutine BLPARM. Note that for swirling flow with thick boundary layers and normal pressure gradients the definitions have an extended form.

Page 1/2 One Dimensional Hub/Tip Boundary Layer Parameters

Heading	Variable		Description
Z	z	,	Axial distance (ft)
DEL	δ	,	Boundary layer thickness (ft)
MACH	M_e	,	Edge Mach number
DELS	δ^*	,	Displacement thickness (ft)
THET	θ	,	Momentum thickness (ft)
H12	H_{12}	,	Shape factor
RETH	Re_θ	,	Reynolds number based on θ
DELH	δ_ϕ	,	Swirl displacement thickness (ft)
THEP	θ_ϕ	,	Swirl momentum thickness (ft)
CF	C_f	,	Skin friction coefficient

Interpolated Output data pages (7)

Printed by	FLINE, WRTFØU
Calculated by	FLINE, FØUTP
Options	Printed when NLAST > 0

Description

The (n,s) coordinates for the output data line are calculated and printed by subroutine FLINE. The interpolated solution on the output data line is calculated by subroutine FØUTP and printed by subroutine WRTFØU. The printed output from WRTFØU shows the solution in which the veolcity and stress components are resolved in three different coordinate systems. Pages 2 and 3 show the solution in the (n,s,ϕ) or ADD code coordinate system. Pages 4 and 5 show the solution in the (r,z,ϕ) or cylindrical coordinate system. Pages 6 and 7 show the solution in the the (Y,X,ϕ) coordinate system where Y is tangentent to the output data line and X is normal to the output data line.

Page 1 Coordinates of Output Data Line

Heading	Variable	Description
RADIAL LØC. OD WALL	r_{WT}	Radius intersection with OD wall (ft)
AXIAL LØC. OD WALL	z_{WT}	Axial intersection with OD wall (ft)
WALL DIST. OD WALL	x_{WT}	OD wall distance to intersection (ft)

Page 2 Gap Average Flow Properties at Output Data Station (N,S) Coordinate System

Heading	Variable	Description
AXIAL LOC. HUB	Z_H	, Axial wall coordinate ID (ft)
RADIAL LOC. HUB	r_H	, Radial wall coordinate ID (ft)
WALL DIST. HUB	X_H	, Wall distance ID (ft)
*WALL TEMP. HUB	T_H	, Wall temperature ID (deg. R)
WALL BLEED HUB	$\dot{W}_H$	, Wall bleed ID (lbn/ft^2/sec)
AXIAL LOC. TIP	Z_T	, Axial wall coordinate OD (ft)
RADIAL LOC, TIP	r_T	, Radial wall coordinate OD (ft)
WALL DIST. TIP	X_T	, Wall distance OD (ft)
*WALL TEMP TIP	T_T	, Wall temperature OD (deg. R)
WALL BLEED	$\dot{W}_T$	, Wall bleed OD (lbn/ft^2/sec)

*Note: For adiabatic walls $T_H = T_T = 0$.

STREAMLINE NO.	L	, Output data point number
Y/YTIP	Y/Y_T	, Fractional distance
STRM. VEL.	u_s	, Streamwise velocity (ft/sec)
TANG. VEL.	u_ϕ	, Tangential velocity (ft/sec)
NORM. VEL.	u_n	, Normal velocity (ft/sec)

Heading	Variable	Description
RADIAL LOC. ID WALL	r_{WH}	, Radius intersection with ID wall (ft)
AXIAL LOC ID WALL	z_{WH}	, Axial intersection with ID wall (ft)
WALL DIST ID WALL	x_{WH}	, ID wall distance to intersection (ft)
POINT NO. L	L	, Output data point number
RADIAL LOC. FT.	r_L	, Radial location of point L (ft)
AXIAL LOC FT	z_L	, Axial location of point L (ft)
STRM. DIST. FT	x_L	, Streamwise distance to point L (ft)
STRM. COOR. S	s_L	, Streamwise coordinate of point L
NORM. COOR N	n_L	, Normal coordinate of point L
*STRM. STAT. J	$J(s_L,n_L)$	, Streamwise mask point number
*NORM. STAT K	$K(s_L,n_L)$	, Normal mask point number

*The point (S_L,n_L) lies between (J, J+1) and (k,k+1).

Heading	Variable		Description
TOTAL VEL.	u	,	Total velocity (ft/sec)
SWIRL ANGLE	$\alpha = \tan^{-1}(U_\phi / U_s)$	,	Swirl angle (deg.)
MACH NO.	M	,	Mach number
TOTAL TEMP.	T_T	,	Total temperature (deg. R)
TOTAL PRES.	P_T	,	Total pressure (psta)

Page 3 Gap Average Flow Properties on Output Data Line (n,s) Coordinate System

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Heading	Variable		Description
STRMLINE NO.	L	,	Output data point no.
Y/YTIP	Y/Y_T	,	Fractional distance
WT. FLOW	W	,	Weight flow to point L (lb/sec)
STATIC PRES.	P	,	Static pressure (lb/ft^2)
STATIC TEMP.	T	,	Static temperature (deg. R)
DENSITY	P	,	Density (slugs/ft^3)
ENTROPY	I/R	,	Entropy (dimensionless)
STRM. STRESS.	σns	,	Streamwise stress (lb/ft^2)
TANG. STRESS	$\sigma_{n\phi}$	,	Tangential stress (lb/ft^2)
HEAT FLUX	q	,	Heat flux (lb/ft/sec)

Page 4 Gap Average Flow Properties at Output Data Station (r,z) Coordinate System

Heading	Variable		Description
STREAMLINE NO.	L	,	Output data point no.
Y/YTIP	Y/Y_T	,	Fractional distance
AXIAL VEL.	u_z	,	Axial velocity (ft/sec)
TANG. VEL.	u_ϕ	,	Tangential velocity (ft/sec)
RADIAL VEL.	u_r	,	Radial velocity (ft/sec)
TOTAL VEL.	u	,	Total velocity (ft/sec)
TAN(A)=UP/VZ	$\alpha=\tan^{-1}(U_\phi/U_z)$	,	Swirl angle (deg.)
MACH NO.	M	,	Mach number
TOTAL TEMP.	T_T	,	Total temperature (deg. R)
TOTAL PRES.	P_T	,	Total pressure (psfa)

Page 5 Gap Average Flow Properties at Output Data Station (r,z) Coordinate System

Heading	Variable		Description
STREAMLINE NO.	L	,	Output data point no.
ANGLE T	Θ	,	Angle between S and Z coordinate (deg.)
WT FLOW	W	,	Weight flow (lb/sec)
STATIC PRES.	P	,	Static pressure (psfa)
STATIC TEMP	T	,	Static temperature (deg. R)
DENSITY	P	,	Density (slug/ft^3)
ENTROPY	I/R	,	Entropy (dimensionless)
SIGRF	σ_{rz}	,	Stress component (psfa)
SIGRP	$\sigma_{r\phi}$	,	Stress component (psfa)
HEAT FLUX	q	,	Heat flux (lb/ft/sec)

Page 6 Gap Average Flow Properties at Output Data Station
(y,x) Coordinate System

Heading	Variable	Description
STREAMLINE NO.	L	, Output data point no.
Y/YTIP	Y/Y_T	, Fractional distance
UX VEL.	u_x	, U_x velocity (ft/sec.)
TANG. VEL.	u_ϕ	, Tangential velocity (ft/sec.)
UY VEL.	u_y	, U_y velocity (ft/sec.)
TOTAL VEL.	u	, Total velocity (ft/sec)
TAN(A)= UP/UX	$\alpha=\tan^{-1}(U_\phi/U_x)$	, Swirl angle (deg.)
MACH NO.	M	, Mach number
TOTAL TEMP.	T_T	, Total temperature (deg. R)
TOTAL PRES.	P_T	, Total pressure (psta)

Page 7 Gap Average Flow Properties at Output Data Station
(y,x) Coordinate System

Heading	Variable	Description
STREAMLINE NO.	L	, Output data point no.
ANGLE T	Θ	, Angle between X and Z coordinates (deg.)
WT. FLOW	W	, Weight flow to point L (lb/sec)
STATIC PRES.	P	, Static pressure (psfa)
STATIC TEMP.	T	, Static temperature (deg. R)
DENSITY	P	, Density (deg/ft^3)
ENTROPY	I/R	, Entropy (dimensionless)
SIGXY	σ_{xy}	, G_{xy} stress (psf)
SIGYP	$\sigma_{y\phi}$	, $G_{y\phi}$ stress (psf)
HEAT FLUX	q	, Heat flux (lb/ft/sec.)

4.4 Diagnostics for ADD Code

Numerous checks are made during the course of the calculation. If a minor error occurs, a DIAGN0STIC message is printed and the calculation continues. If a fatal error occurs, a DIAGN0STIC message is printed and the calculation stops. A description of the DIAGN0STICS is given in this section. The DIAGN0STIC message is always in the form:

DIAGNOSTIC NO. XX FOR ANNULAR DIFFUSER DECK

where xx refers to one of the errors listed. It should be noted that numerical values printed with the DIAGNOSTIC message will be in dimensionless form or in English units.

1) I0PT3 OUTSIDE RANGE OF ALLOWABLE DUCT OPTIONS

   This error is detected in Subroutine ALTMN. The input option must be between $1 \le I0PT3 \le 5$.

2) No solution exists in AMFOR

   This error is detected in Subroutine AMFOR. This subroutine solves the Mach number function

$$N = M\left(1 + \frac{\gamma+1}{2}\right)^{1/2} \Big/ \left(1 + \gamma M^2\right)$$

   for M given N. The function has a maximum at M = 1. Hence

$$N(1) = \left[2(1+\gamma)\right]^{-1/2}$$

   Solutions do not exit for values of $N > N(1)$.

3) MASS FLOW EXCEEDS THE MAXIMUM MASS FLOW POSSIBLE

   This error is detected in Subroutine AMINLT which solves the Mach number function

$$N = M\left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

   for M given N. This function has a maximum for M = 1 given by

$$N(1) = \frac{\gamma+1}{2}^{-\frac{\gamma+1}{2(\gamma-1)}}$$

   corresponding to choked flow.

4) ISHAPE AND I0PT2 ARE NOT CONSISTENT

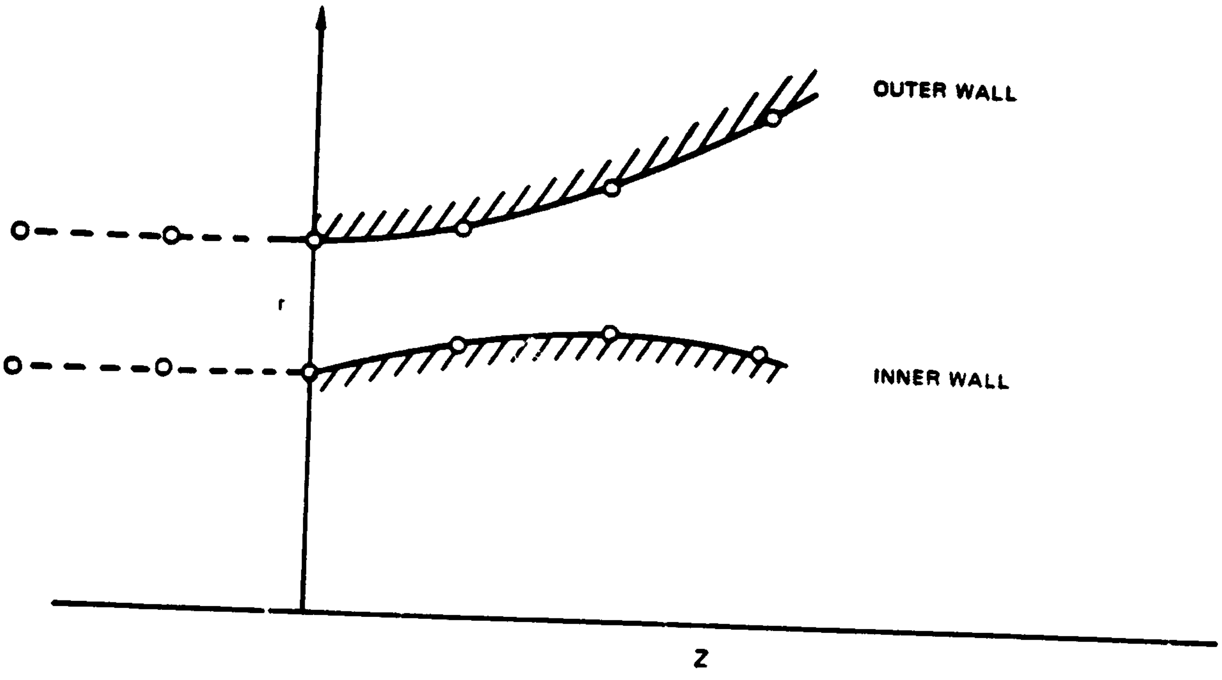
   This error is detected in subroutine CASC. For blade and strut calculations use only I0PT2=3 with any ISHAPE, where

$$3 \leq \text{ISHAPE} \leq 6$$

Otherwise, the calculation will stop.

5) FOR BEST RESULTS ADD A STRAIGHT ANNULAR CHANNEL INLET

This error is detected in Subroutine C00R1. In the construction of the duct coordinates, it is assumed that the inlet has no curvature as shown in the figure below. This is not a fatal error because small inlet curvatures may be tolerated. For best results add a straight annular section to the inlet as shown by the dotted lines in the figure.



Addition of Straight Annular Channel Inlet

6) PROGRAM ASSUMES INLET FLOW HAS CURVATURE

This error is detected in Subroutine C00R1. Same as diagnostic 5.

7) WALL CURVATURE IS TOO LARGE AT STATION X.

This error is detected in Subroutine C00R1 usually if the duct has a discontinuous change in wall curvature such as shown in the figure below.

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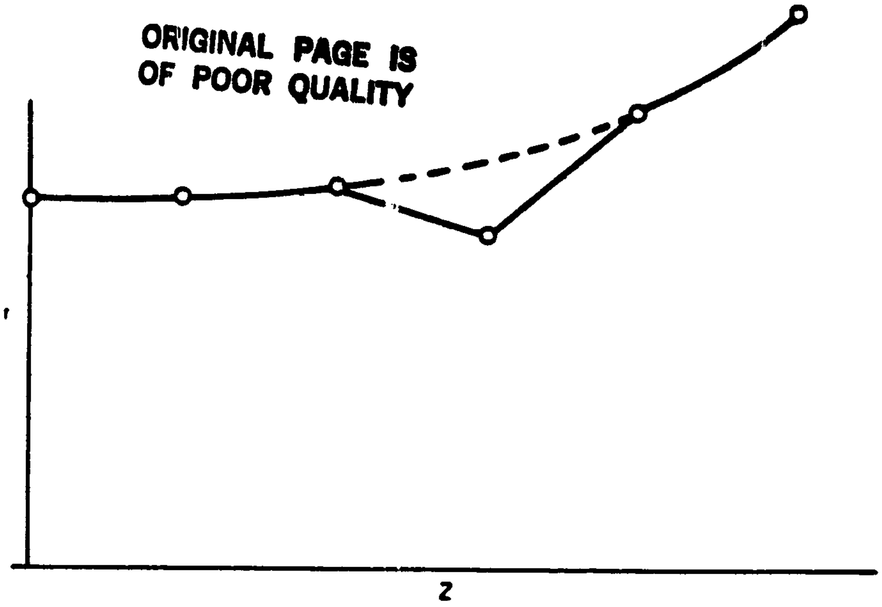


Discontinuous Change in Wall Curvature

8) Not Used

9) GREATER THAN 1.0 PERCENT NORMAL PRESSURE GRADIENT ERROR RECALCULATE STATIC PRESSURE

This error is detected in Subroutine ERPIN. This subroutine integrates the radial momentum equilibrium equation.

$$P_T - P_H = \gamma M_r^2 \int_0^1 \left[\frac{-\rho}{V} \frac{\partial V}{\partial n} U_s^2 + \frac{\rho}{R} \frac{\partial R}{\partial n} U_\phi^2 \right] \frac{d\eta}{XV}$$

and compares $(P_T - P_H)$ to that computed for the input inlet flow $(P_T - P_H)_1$. If the error given by

$$E = \left| 1 - \frac{P_T + P_H}{(P_T - P_H)_1} \right|$$

is greater than 0.01, the input initial static pressure distribution is replaced by the above pressure equation and the inlet flow is recalculated.

10) Not Used

11) MASS FLOW REQURED EXCEEDS MAXIMUM MASS FLOW POSSIBLE

This error is detected in Subroutine CKINPT. If it is determined that choked flow exists in the duct, this diagnostic will be printed; the weight flow must be reduced.

12) PRESSURE RISE EXCEEDS PERMISSIBLE PRESSURE RISE

This error is detected in Subroutine CKINPT and indicates that the deck cannot calculate properly the initial flow profiles. Check input for errors.

13) ITERATION OF BACK PRESSURE CALCULATION FAILS TO CONVERGE

This error is detected in Subroutine FINVIS.

In the calculation of strut forces, it has been assumed that the strut exit flow is subsonic and unseparated (i.e., $u_s > 0$). If these conditions are violated, no solution can be obtained. The calculation will stop.

14) BOUNDARY LAYER TOO THIN FOR MESH SPACING

This error is detected in Subroutine FLØWIN. The viscous flow calculation requires a finite initial boundary layer thickness. In addition, it requires enough mesh points to describe the inlet boundary layer velocity profile. The deck assumes arbitrarily that at least five mesh points are required. Thus, if this diagnostic occurs, increase the number of mesh points, KL, increase the mesh distortion parameter, DDS, or increase the assumed inlet boundary layer thickness. If DDS is input equal to zero, the program automatically sets the mesh distortion parameter to the appropriate value for turbulent flow.

15) TOTAL PRESSURE IS LESS THAN STATIC PRESSURE

This error is detected in Subroutine FLØWIN. A check is made on the input data for IØPT1= 4 to make sure that $P_T > P$.

16) INPUT DATA NOT IN RADIAL EQUILIBRIUM CORRECTIONS APPLIED TO STATIC PRESSURE

This error is detected in Subroutine FLØWIN. A check is made of the input static pressure data for IØPT1=4. If the static pressure data are not in radial equilibrium, it is assumed that the static pressure data are in error and that the other inlet data are correct. Then the static pressure profile is computed from

$$\frac{d\Pi}{d\eta} = 2\frac{\gamma}{\gamma-1}\left[\frac{-1}{XV}\ \frac{\partial V}{\partial n}\cos^2\alpha - \frac{1}{XR}\frac{\partial R}{\partial n}\ \sin^2\alpha\right]\Pi\left(\left(\frac{\Pi_0}{\Pi}\right)^{\frac{\gamma-1}{\gamma}} - 1\right)^{1/2}$$

with the ID wall static pressure as a boundary condition.

17) INPUT DDS MUST BE SPECIFIED

This error is detected in Subroutine FN0RM. At this time there is no algorithm to select automatically the mesh distortion parameter DDS for laminar flow.

18) BLADE DATA ERROR IN CKINPT ROUTINE

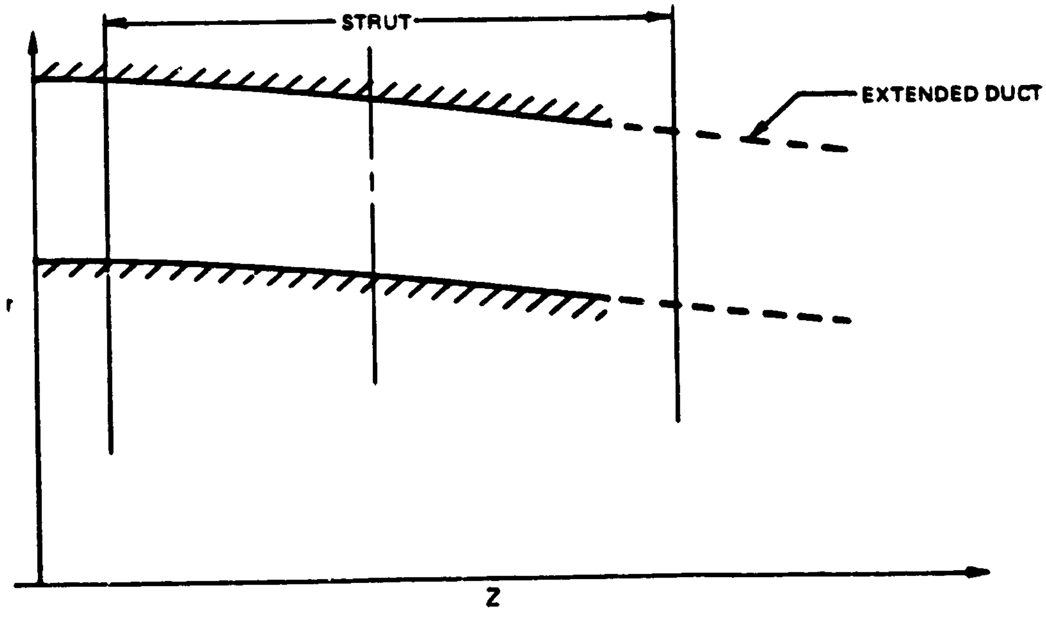
This error is detected in Subroutine CKINPT. Blade data have been input incorrectly and must be rearranged with Y increasing.

19) NO UNIQUE SOLUTION FROM MINVRT

This error is detected in Subroutine MINVRT. If the matrix used to solve for the turbulent flow solution is singular, no solution can be obtained. This situation may occur due to numerical truncation errors.

20) LEADING OR TRAILING EDGE INDEX OF STRUT OUT OF RANGE

This error is detected in Subroutine SLETE. In order to compute blade forces, the strut must be located entirely within the duct length. This problem may be eliminated by extending the duct as shown in the figure.



Extended Duct Section

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21) SLOT INPUT NOT IN INCREASING ORDER

This error is detected in Subroutine SL0TA.

The slot input data must be arranged in order of increasing axial distance. Check input data. The calculation stops if this error is detected.

22) CHOKED FLOW IN SLOT.

This error is detected in Subroutine SLTFL0. The slot weight flow is determined by the ratio of the stagnation pressure of the slot coolant fluid to the local wall static pressure. If this pressure ratio is too large the flow may be choked at the slot inlet. The calculation will stop.

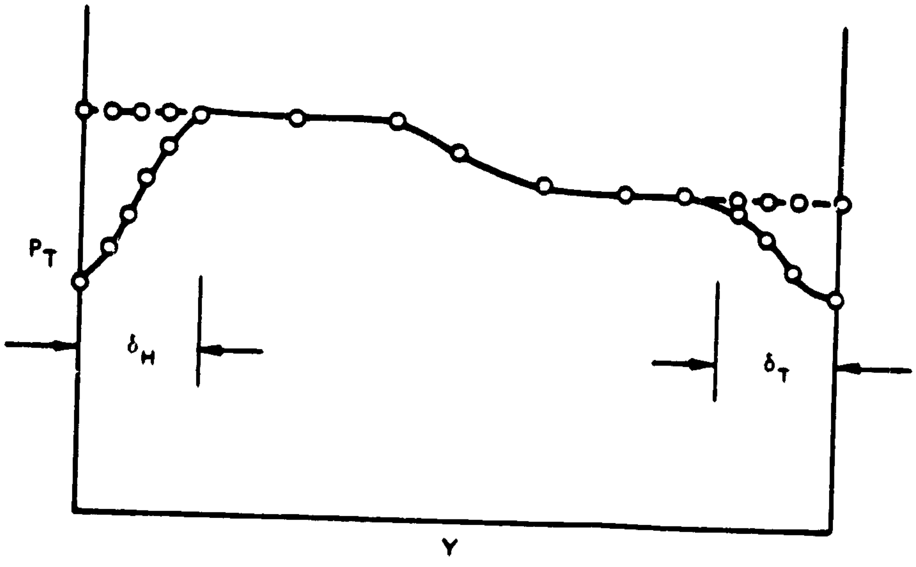
23) BOUNDARY LAYER OVERLAP OR TOO LARGE

This error is detected in Subroutine FL0WIN. For internal flow, the sum of the boundary layer thicknesses on the hub and tip walls must be less than the duct inlet height. Check input data.

24) SET TOTAL TEMPERATURE, PRESSURE, ANGLE TO VALUE AT EDGE OF BOUNDARY LAYER - CORRECTION APPLIED

This error is detected in Subroutine FL0WIN. For I0PT1=4, the calculated boundary layer profiles are matched to input inlet flow profiles.

A good match requires that the stagnation pressure, P_T, be constant in the experimentally determined boundary layer region as shown in the figure (dashed line).



Constructing the Inlet Flow

25) TRUNCATION ERROR CANNOT BE REDUCED BY STEP SIZE

This error is detected in Subroutine S0LVI. If the step size parameter (KDS) is not specified, it is selected automatically by checking the truncation error at each step. When an instability occurs, the program attempts to reduce the truncation error by reducing the streamwise step size. If the truncation error cannot be reduced below a minumum value, the calculation stops.

26) NUMERICAL INSTABILITY

This error is detected in Subroutine FC0RCT and Subroutine S0LVI and is an indication that the program has calculated negative temperature or pressures. The calculation stops if this problem occurs.

27) RHOCX ITERATION DID NOT CONVERGE, ERR =

This error is detected in Subroutine F0RCE. In determining the blade force, an iteration scheme is used to determine the downstream static pressure. If this iteration fails to converge, this diagnostic is printed together with the maximum error found in the iteration. The calculation, however, is not terminated.

28) I0PT3 = 2 OPTION NOT IN USE

This error is detected in Subroutine F0RCE but this option has been deleted from the current version of the ADD code.

29) SOLUTION REQUIRES REVERSE FLOW, INCREASE WFLOW

This error is detected in Subroutine CKINPT. For flows with radial pressure gradients, there is a minimum weight flow below which reverse flow exists. This problem can be corrected by increasing the weight flow. The calculation will stop.

30) LOAD DOWNSTREAM FLOW DATA CARDS

This error is detected in subroutine CALINV and indicates that the downstream flow data cards, required by I0PT1=4 or 9, have not been entered. The calculation will stop.

31) SOLUTION FOR BLADE FORCE DOES NOT EXIST

This error is detected in subroutine F0RCE. The blade force cannot be calculated because no inviscid flow solution can be calculated. (Same as DIAGN0STIC 29). The calculation will stop.

32) GRADIENT OF METRIC COEFFICIENT =
FOR BETTER RESULTS ADD STRAIGHT CHANNEL INLET

This error is detected in Subroutine C00R4. It is assumed that the inlet duct has no curvature. To avoid problems, add a straight annular section to the inlet. The calculation will continue.

33) INPUT TOO LARGE FOR COLE'S LAW
SET N < ____

This error is detected in subroutine FL0WIN.

Cole's friction law requires a certain relationship $H_{12} = H_{12}(R_e)$ such that there is an upper bound of $n < 10$. For a solution to exist,

$$A = \kappa \frac{U_e}{U^*}\left(1 - \frac{1}{H_{12}}\right) > 1.573$$

Setting

$$H_{min} = 1 - \frac{1}{\frac{1.5731}{\kappa \frac{\Pi e}{U^*}}}$$

Then

$$n < \frac{2}{H_{min}} - 1$$

The calculation will stop.

34) WEIGHT FLOW ITERATION MAY NOT CONVERGE IN SUBROUTINE CKINPT CHECK INPUT DATA.

The error is detected in Subroutine CKINPT. The weight flow iteration that determines the static pressure may not converge if the free stream inviscid flow is highly distorted. An input flow which is more uniform in stagnation pressure is required. The calculation will stop.

35) WFLI and I0PT11 OPTIONS INCOMPATIBLE.

This error is detected in subroutine ALTMN. The weight flow cannot be specified for external flow. The calculation will stop.

36) I0PT1 = 1 or I0PT1 = 2 OPTIONS NOT USED.

This error is detected in Subroutine ALTMN. The options I0PT1 = 1 and I0PT1 = 2 have been deleted from the code.

37) CONFLICT OF OPTIONS, I0PT14 < 0 IMPLIES SEPARATION AND GLOBAL ITERATIONS. AUTOMATIC STEP SIZE ALGORITHM CANNOT BE USED.

This error is detected in Subroutine S0LVI. When performing a global iteration (I0PT14 < 0), the same number of streamwise steps must be used for each iteration. Hence the automatic step size algorithm for the streamwise direction must not be used. The calculation will stop.

38) LET TOO SMALL FOR TURBULENT BOUNDARY LAYER
RET = XXXX

This error is detected in Subroutine CFC0LE. Cole's skin friction law is not valid for Reynolds numbers based on momentum thickness. RET less than 1000. For RET less than 1000, the boundary layer is laminar. The calculation will stop.

39) DATA LINE DOES NOT INTERSECT WALL WITHIN MESH

This error is detected in subroutine ALINE. The first and last points on the input data line must lie outside the duct and second and next to last must lie inside the duct. The calculation will stop.

40) INPUT DATA LINE DOES NOT INTERSECT WITHIN MESH

This error is detected in Subroutine CR0SS2. Check points on input data line to make sure that they lie inside the computational mesh. The calculation will stop.

41) CAMBER ANGLE ϕ IS OUTSIDE LIMITS OF CORRELATION

This error is detected in Subroutine CASC. If ISHAPE = 5 or 6, then for correlations in NACA SP36, $\phi > 0$. The calculation will continue but the user is outside limits of correlations.

42) IMSL LIBRARY FAILURE NO. XXX

This error is detected in Subroutine SM00TH. Check input coordinates specified on card(s) 4. Check ISCVKU routine from IMSL library.

4.5 Debug Options for ADD Code

When set equal to unity, these options allow intermediate results calculated by the subroutine indicated to be printed as an aid in debugging a troublesome case. Note that these outputs are not converted to units and reference must be made to the source code for interpretation of printout.

OPTION	SUBROUTINE	OBJECTIVE OF SUBROUTINE
IDBGI	TURB	Calculates two-layer turbulence model
IDBG2	FCØRCT	Calculates shear stresses and heat fluxes at each station
IDBG3	FLØWIN	Generates initial flow profiles
IDBG4	SLTFLØ	Calculates slot inlet flows
IDBG5	SØLVI	Calculates viscous flow solutions
IDBG6	CØØR	Generates required geometric parameters
IDBG7	FØRCE	Calculates forces generated by struts and blades
IDBG8	MINVRT	Inverts a matrix
IDBG9	SMØØTH	Smooths duct contour read via IØPT3 = 2
IDBG10	GDUCT	Calculates duct geometry
IDBG11	SLTFLØ	Obtains additional information from SLTFLØ - see IDBG4
IDBG12	SØLVI	Obtains additional information from SØLVI - see IDBG5
IDBG13	CKINPT	Checks inlet flow input for errors
IDBG14	SØLVI	Debugs the algorithm that automatically computes the maximum step size in the streamwise direction while assuring computational stability.
IDBG15		Specifies number of streamlines to use in COORST calculations (Default 25).
IDBG16	Not used.	
IDBG17	Not used.	

4.6 Sample Input for ADD Code

Two sample inputs to the ADD code are presented on the following pages. These cases correspond to the design studies described in Sections 4.1 and 4.2. The first sample is the input for the Axisymmetric Compressible Curvature Case and the second sample is the input for the Separated Flow Case.

Axisymmetric Compressible Curvature Case

The option card (line 2) indicates that the inlet flow is to be calculated assuming a constant stagnation pressure and stagnation temperature in the core flow (IOPT1=3). The duct geometry is to be read from input data cards (IOPT3=2). On the mesh parameter card (line 3), the default mesh distortion parameter (DDS=0) has been selected but the streamwise step size parameter has been input KDS=5. From line 3, it is noted that the duct coordinates at JLPTS=100 equally spaced axial stations are to be read. The length of the duct is 4.19375 ft (line 4). Lines 5 through 17 contain 100 data points for the tip radii and lines 18 through 30 contain 100 data points for the hub radii. The inlet Mach number is 0.7 (line 31).

Separated Flow Case

The option card (line 2) indicates that the inlet flow is to be calculated assuming a constant stagnation pressure and stagnation temperature in the core flow (IOPT1=3). The duct geometry is to be read from input data cards (IOPT3=2). On the mesh parameter card (line 3), the mesh distortion parameter (DDS=100) and the streamwise step size parameter has been input KDS=2. From line 3, it is noted that the duct coordinates at JLPTS=80 equally spaced axial stations are to be read and that the least squares spline smoothing routine will be used (JLPTS ≠ JL). The length of the duct is 1.764 ft (line 4). Lines 5 through 14 contain 80 data points for the tip radii and lines 5 through 24 contain 80 data points for the hub radii. The inlet Mach number is 0.287 (line 19), the stagnation pressure and the stagnation temperature default to atmospheric conditions (P_T = 1 atm and T_T = 519°R. For this card IOPT14=1 which indicates that global iterations will be used and for the first pass, the convection terms will be set to zero in regions of separated flow. If IOPT14>1 then windward differencing will be used in calculating the convection terms.

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```
SRI NACELLE     ZU=1.39792           AXISYMMETRIC COMP. CURVATURE CASE
 3 0 2-1 0 0 0 0 1 0 0 0 0 0 100 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 045 0 0
               45100 05 15  0100    0.0
 4.1937500
 3.9088000 3.9088000 3.9088000 3.9088000 3.9088000 3.9088000 3.9088000 3.9088000
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 3.9088000 3.9088000 3.9088000 3.9088000
  0.         0.         0.         0.         0.         0.         0.         0.
  0.         0.         0.         0.         0.         0.         0.         0.
  0.         0.         0.         0.         0.         0.         0.         0.
  0.         0.         0.         0.         0.         0.         0.         0.
  .0000000   .0153517   .0442766   .0701692   .0890174   .1064289   .1220368   .1370668
  .1521680   .1672672   .1823664   .1974656   .2125648   .2276640   .2427632   .2578624
  .2729616   .2880608   .3031600   .3179783   .3305650   .3401604   .3475105   .3531105
  .3571745   .3599170   .3615520   .3622897   .3621494   .3612102   .3595671   .3573149
  .3545486   .3513630   .3478531   .3441138   .3402399   .3363264   .3324682   .3287602
  .3252972   .3222012   .3196712   .3176739   .3161731   .3151329   .3145172   .3149793
  .3173295   .3196797   .3220299   .3243801   .3267303   .3290805   .3314307   .3337809
  .3361311   .3384813   .3408315   .3431817   .3455319   .3476821   .3502323   .3525825
  .3549326   .3572828   .3596330   .3619832
   0.76000    0.00000    0.00060    0.00100     7.0000     7.0000
```

```
ST90 DIFUSSER  SEPARATED FLOW CASE  RESTART - WINDWARD DIFF IOPT14 = 2
 3 0 2-1 0 0 0 0 1 0 0 0 0 1  4000                                  0
    100.00 130 98  2 12  0 80
    1.76400     5.00000
    0.55500     0.55500    0.55500    0.55500    0.55500    0.55500    0.55501    0.55504
    0.55512     0.55526    0.55548    0.55580    0.55623    0.55679    0.55749    0.55837
    0.55942     0.56068    0.56215    0.56386    0.56582    0.56805    0.57056    0.57338
    0.57652     0.58000    0.58363    0.58841    0.59407    0.60071    0.60825    0.61661
    0.62569     0.63542    0.64569    0.65644    0.66756    0.67898    0.69061    0.70236
    0.71414     0.72587    0.73746    0.74883    0.75988    0.77053    0.78070    0.79030
    0.79924     0.80743    0.81479    0.82124    0.82668    0.83102    0.83419    0.83610
    0.83665     0.83583    0.83373    0.83046    0.62611    0.82080    0.81461    0.80766
    0.80004     0.79186    0.78321    0.77421    0.76494    0.75552    0.74605    0.73661
    0.72733     0.71829    0.70961    0.70137    0.69370    0.68667    0.68041    0.67500
    0.40600     0.40600    0.40600    0.40600    0.40600    0.40600    0.40568    0.40475
    0.40327     0.40132    0.39895    0.39624    0.39323    0.39000    0.38661    0.38312
    0.37960     0.37610    0.37270    0.36946    0.36644    0.36370    0.36131    0.35934
    0.35783     0.35667    0.35651    0.35681    0.35904    0.36415    0.37179    0.38161
    0.39324     0.40633    0.42051    0.43543    0.45072    0.46627    0.48210    0.49808
    0.51408     0.52999    0.54565    0.56096    0.57577    0.58996    0.60340    0.61596
    0.62752     0.63794    0.64709    0.65484    0.66108    0.66566    0.66846    0.66935
    0.66820     0.66488    0.65926    0.65122    0.64062    0.62734    0.61125    0.59221
    0.57155     0.55066    0.52949    0.50801    0.48618    0.46395    0.44129    0.41817
    0.39452     0.37034    0.34556    0.32016    0.29409    0.26732    0.23981    0.21150
    0.28700     0.00000    0.00200    0.00200    7.00000    7.00000
```