Axial Flow Compressor Design Computer Programs
Incorporating Full Radial Equilibrium

Part II Radial Distribution of Total Pressure
and Flow Path or Axial Velocity Ratio
Specified (Program III)

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS3-7277

Allison Division • General Motors
Indianapolis, Indiana
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Axial Flow Compressor Design Computer Programs
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Part II—Radial Distribution of Total Pressure
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Specified (Program III)

by
H. F. Creveling, R. H. Carmody

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Allison Division • General Motors
Indianapolis, Indiana
AXIAL FLOW COMPRESSOR DESIGN COMPUTER PROGRAMS
INCORPORATING FULL RADIAL EQUILIBRIUM
PART II—RADIAL DISTRIBUTION OF TOTAL PRESSURE AND FLOW
PATH OR AXIAL VELOCITY RATIO SPECIFIED (PROGRAM III)

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SUMMARY

The technical objectives of the contract included generating a computer programmed compressor aerodynamic design system which accounts for full radial equilibrium of the flow, including streamline curvature and radial gradients in total enthalpy and entropy. It was desired that the design system have the capability of producing design information for given annulus geometry or, alternatively, computing annulus geometry along with aerodynamic design information. These capabilities are available as alternative options in the computer program described herein. The option in which design is performed for given annulus geometry is designated as Modification I; the option designated as Modification II requires input of axial velocity ratio at the mid-streamline for each rotor and stator, and establishes annulus geometry subject to certain limitations described later in this report. The resulting design-point computation is iterative, with efficiencies determined through the use of correlated blade element profile loss data and the loss associated with a normal shock in the blade passages, where appropriate. The computer program is written with "buffer" storage capacity for up to ten sets of profile loss parameter data, each set including hub, mean, and tip data for diffusion factor values between 0 and 1.0. These profile loss data sets are elected by the program user for any given design calculation from a master file of up to 999 profile loss parameter sets. In this program, energy addition is determined through specification of the profile of total pressure at each rotor exit, and through specification of limiting values on five aerodynamic parameters for each stage. These aerodynamic parameters are:

1. Rotor tip diffusion factor
2. Stator hub diffusion factor
3. Stator hub Mach number
4. Rotor hub relative exit angle
5. Rotor tip exit whirl velocity
The program accepts design input data for a specified maximum number of stages and, barring any error messages from the calculation, computes aerodynamic performance until either the maximum number of stages is reached or the specified overall pressure ratio is attained. The design computations may be based on 5, 7, 9, or 11 streamlines, at the user's option. Hub and tip blockages are input separately, at each axial station, as the unblocked fraction of local geometric annulus area. The program user has the capability of specifying the total mass flow at each axial calculation station. Any changes in mass flow are distributed proportionally among all streamtubes involved in the design computation.

The computation and the corresponding program logic are developed in detail in Appendix A (System of Equations and Computations) and Appendix C (Program Flow Charts). The Fortran IV Source Deck listing of the computer program is shown in Appendix B.

Input format and the preparation of required input data are presented in Appendix D, along with the data set describing two sample design problems. Appendix E illustrates the format of program output, through presentation of the computed results for both sample design problems.

INTRODUCTION

As a part of Contract NAS3-7277 for the NASA-Lewis Research Center, four axial flow computer programs were developed. The first (Reference 1) assumed simple radial equilibrium of static pressure and constant efficiency radially—limits are specified on hub and tip ramp angles, axial velocity ratio across blade rows, rotor hub and stator tip loadings, rotor exit relative flow angle, and stator hub Mach number; the velocity diagram and stage-by-stage performance are calculated.

The second program (Reference 2) accounts for complete radial equilibrium of flow. Losses are evaluated on the basis of blade element loss prediction methods. Radial distribution of energy is specified as a polynomial variation of whirl velocities at the exit of each rotor blade row; rotor tip loadings are specified as are limiting values of rotor hub relative exit angles, stator hub Mach numbers, stator hub loadings, and the compressor flow path.

A third program, Axial Flow Design Program III, was developed under this contract and is reported herein. Program III differs from Program II in that the radial distribution of energy is established by specifying the polynomial variation of total pressure at the exit of each rotor blade row, and there is the option of specifying either the flow path or the axial velocity ratios and calculating the resulting flow path. Program III also offers the option of specifying as blade element data either the flow angle at the shock or the ratio of supersonic to total turning, to calculate values of shock loss coefficient.
SYMBOLS

Note: The primary symbols are illustrated schematically in Figure 1.

\( a \) \hspace{1cm} \text{sonic velocity, \( \text{ft/sec} \)}

\( A, B, C, D, E \) \hspace{1cm} \text{constants in total pressure profile and whirl velocity polynomials}

\( b \) \hspace{1cm} \text{axial spacing of computational stations, \( \text{in.} \)}

\( c_p \) \hspace{1cm} \text{specific heat at constant pressure, \( \text{BTU}/\text{lb}_m \cdot \text{R}^\circ \)}

\( D \) \hspace{1cm} \text{diffusion factor; total derivative}

\( F \) \hspace{1cm} \text{blade force on gas, \( \text{lb}_f/\text{lb}_m \)}

\( F, G, K, W \) \hspace{1cm} \text{constants, variously defined in Equations (A-38) through (A-40) and in Equations (A-43) through (A-45)}

\( g_c \) \hspace{1cm} \text{universal gravitational constant, 32.174 \( \text{ft-lb}_m/\text{lb}_f \cdot \text{sec}^2 \)}

\( H \) \hspace{1cm} \text{enthalpy, \( \text{BTU}/\text{lb}_m \)}

\( J \) \hspace{1cm} \text{conversion factor, 778 \( \text{ft-lb}_f/\text{BTU} \)}

\( L \) \hspace{1cm} \text{overall compressor axial length, \( \text{in.} \)}

\( M \) \hspace{1cm} \text{Mach number}

\( m \) \hspace{1cm} \text{molecular weight, \( \text{lb}_m/\text{mole} \)}

\( n \) \hspace{1cm} \text{axial station index}

\( N \) \hspace{1cm} \text{number of axial stations}

\( p \) \hspace{1cm} \text{fraction of blade height,} \hspace{1cm} \frac{R - R_{HG}}{R_{TG} - R_{HG}}

\( P \) \hspace{1cm} \text{pressure, \( \text{lb}_f/\text{in.}^2 \text{abs} \)}

\( Q \) \hspace{1cm} \text{heat transfer rate, \( \text{BTU}/\text{lb}_m \cdot \text{sec} \)}

\( R \) \hspace{1cm} \text{radius, \( \text{in.} \)}

\( R_c \) \hspace{1cm} \text{total pressure ratio}

\( R_i \) \hspace{1cm} \text{\( \delta \text{th} \) rotor}
\( \kappa \) gas constant, \( \text{ft}-\text{lb}_f/\text{lb}_m-R^e \)

\( S \) entropy, \( \text{BTU}/\text{lb}_m-R^e \)

\( S_i \) \( i \)th stator

\( t \) time, sec

\( T \) temperature, \( ^\circ R \)

\( U \) wheel speed, \( \text{ft}/\text{sec} \)

\( V \) fluid velocity, \( \text{ft}/\text{sec} \)

\( w \) mass flow rate, \( \text{lb}_m/\text{sec} \)

\( x \) fraction of blade span

\( Z \) axial coordinate, in.

**Greek**

\( \alpha \) ramp angle, degrees

\( \beta \) air angle, measured from engine axis, degrees

\( \gamma \) ratio of specific heats

\( \delta \) blockage; unblocked fraction of annulus area

\( \Delta \) change; final value minus initial value

\( \eta \) adiabatic efficiency

\( \theta \) circumferential coordinate, radians

\( \nu \) Prandil-Meyer angle, degrees

\( \rho \) density, \( \text{lb}_m/\text{ft}^3 \)

\( \sigma \) solidity

\( \phi \) air turning angle, degrees

\( \omega \) angular speed, radians/second

\( \varsigma \) blade total pressure loss coefficient
### Subscripts

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<thead>
<tr>
<th>Subscript</th>
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<tr>
<td>1</td>
<td>rotor entrance station</td>
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<td>2</td>
<td>rotor exit station</td>
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<td>3</td>
<td>stator exit station</td>
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<tr>
<td>e</td>
<td>effective value (of hub or tip radius)</td>
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<td>g</td>
<td>geometric value (of hub or tip radius)</td>
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<td>H</td>
<td>hub section</td>
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<td>i</td>
<td>ideal</td>
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<td>j</td>
<td>designates value of variable at reference streamline</td>
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<td>L</td>
<td>limiting value</td>
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<td>maximum value</td>
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<td>profile</td>
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<td>R</td>
<td>rotor, radial component</td>
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<td>S</td>
<td>stator; stage</td>
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<td>s</td>
<td>shock</td>
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<td>supersonic</td>
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<td>axial component</td>
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### Superscript

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<td>-</td>
<td>relative value of a variable</td>
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Figure 1. Schematic presentation of symbols.
THE TECHNICAL DISCUSSION

The Modification I/II program, bearing Allison identification Q-45, accounts for full radial equilibrium including radial gradients in total enthalpy and entropy. Specific heat is treated as a function of temperature with the exception of the computation of shock loss, where $c_p$ is assumed constant; elsewhere in the calculation, all integrations involving $c_p$ in the integrand are performed for variable $c_p$. The program will not calculate supersonic axial flows; a check is made at the mean streamline of each axial station and the computation is terminated whenever an axial Mach number greater than 1.0 is encountered in three consecutive passes of the calculation.

For use of Mod I, the program requires description of the flow path geometry, including location of all axial stations, plus hub and tip blockages at all stations. The computation of adiabatic efficiencies uses blade profile loss parameter data input as a function of diffusion factor for hub, mean, and tip sections. This profile loss data is interpolated and extrapolated to any point along the blade length by means of a second degree curve fit. Shock loss is computed at each streamline position by means of the shock model of Reference 3, using the ratio of supersonic turning to total turning input as a function of blade span for each blade row, or alternatively using input-specified values of flow angle at the shock.

For use of Mod II, where stage flow path geometry is established by computation, the inlet geometry is input as for Mod I. For each blade row, limits on hub and tip ramp angle must be given, along with an initial value of aspect ratio (difference in inlet geometric radii, divided by axial length) and the ratio of exit axial velocity to inlet axial velocity for the row at the midstreamline. Hub and tip ramp angles ($a_H$ and $a_T$) are shown in Figure 1. The computation of annulus geometry for any given blade row begins with the specified initial value of aspect ratio and $a_T = 0$. In any required reduction of annulus area at the exit of a blade row, $a_H$ is first increased to its limit value, if necessary. Next, $a_T$ is increased to its given limit value, and, if necessary, the aspect ratio is finally reduced by an appropriate amount, to achieve the required level of exit axial velocity. Under no circumstances is a positive value of $a_T$ permitted. Inasmuch as Mod II can yield irregular geometry, depending upon input constraints, the curvature of streamlines can produce severe gradients in flow properties and result in failure of the calculation with appropriate error messages printed out. Input of reasonable constraints is discussed further in Appendix D. Adiabatic efficiencies are computed as in Mod I.

As mentioned in the summary, the program draws its input-specified profile loss data sets from a master file or library of up to 999 loss-data sets. This master file appears as permanent data and is located at the rear of the program deck; this library of loss data sets is the only information
stored as permanent data. Up to ten of the profile loss-data sets may be selected for use in any one compressor design calculation. Each loss-data set consists of 20 values of profile loss parameter \((\bar{x}_p \cos \beta_2)/2\sigma\) for each of the hub (10% span), mean (50% span), and tip (90% span) sections. These 60 values of loss parameter appear on 5 cards; each card consists of 12 fields of 6 columns each. The values of loss parameter for the hub section are entered first; next the values for the mean and tip sections. At each blade section, values are entered corresponding to increasing values of diffusion factor. The program automatically assigns the 20 loss-parameter values at any blade section to the 20 diffusion factor values 0, 0.1, 0.15, 0.20, 0.25, ..., 1.0.

Aerodynamic design of each stage is governed by specified limiting values for each of five aerodynamic design parameters. These parameters are:

1. Rotor tip diffusion factor
2. Stator hub diffusion factor
3. Stator hub Mach number
4. Rotor hub exit relative flow-angle
5. Rotor tip exit swirl velocity

The program provides two alternative logic paths ensuring that the input-specified limiting values of these parameters are not violated in any stage. The program user may elect to: (1) drive the calculation to satisfaction of the most restrictive of its aerodynamic limits at each stage or (2) adjust the calculation at each stage so that all aerodynamic design parameters for that stage are less than or equal to their specified limiting values.

PROGRAM DESCRIPTION

The basic equations of motion which govern the three-dimensional flow of an incompressible compressible gas through a turbomachine have been derived in many reports such as Reference 4.

The pertinent equations for steady axisymmetric flow in cylindrical coordinates are:

**Continuity Equation**

\[
\frac{1}{R} \frac{\partial (\rho RV_R)}{\partial R} + \frac{\partial (\rho V_Z)}{\partial Z} = 0
\]  

(1)
Radial Equation of Motion

\[
g_c \frac{\partial H_t}{\partial R} = g_c F_R + g_c J_T \frac{\partial S}{\partial R} + \frac{V_\theta}{R} \frac{\partial (RV_\theta)}{\partial R} + V_Z \left( \frac{\partial V_Z}{\partial R} - \frac{\partial V_R}{\partial Z} \right) \quad (2)
\]

Circumferential Equation of Motion

\[
0 = g_c F_\theta - \frac{1}{R} \left[ V_R \frac{\partial (RV_\theta)}{\partial R} + V_Z \frac{\partial (RV_\theta)}{\partial Z} \right] \quad (3)
\]

Axial Equation of Motion

\[
g_c J \frac{\partial H_t}{\partial Z} = g_c F_Z + g_c J_T \frac{\partial S}{\partial Z} + \frac{V_\theta}{R} \frac{\partial (RV_\theta)}{\partial Z} - V_R \left[ \frac{\partial V_Z}{\partial R} - \frac{\partial V_R}{\partial Z} \right] \quad (4)
\]

Energy Equation

\[
\frac{DH_t}{dt} = Q + \frac{\omega}{g_c J} \frac{D(RV_\theta)}{dt} \quad (5)
\]

Gradient of Entropy

\[
\frac{DS}{dt} = \frac{Q}{T} \quad (6)
\]

Condition of Integrability

\[
\frac{\partial}{\partial R} \left( \frac{F_R}{R F_\theta} \right) = \frac{\partial}{\partial Z} \left( \frac{F_Z}{R F_\theta} \right) \quad (7)
\]

Equations (1) through (7) relate eight unknowns in \( F_R, F_\theta, F_Z, V_R, V_\theta, V_Z, S, \) and \( H_t. \)

The compressor design analysis considered for this study considers full radial equilibrium and radial gradients in total enthalpy and entropy. The simplifying assumptions are:

1. Only stations between blade rows are to be considered; therefore, \( F_R, F_\theta, \) and \( F_Z \) are zero.

2. Heat transfer is zero therefore \( Q \) is zero.

3. Consideration need be given only to the radial equation of motion.

With these assumptions, Equations (3), (4), (6), and (7) are eliminated. Equation (1) is then rewritten for convenience as
\[ w = 2 \pi \int_{R_H}^{R_T} \rho v Z R dR \] (8)

and Equation (2) is then written as:

\[ V_Z^2 - V_{Z_j}^2 = 2 g_c J \int_{T_t}^{T_j} c_p (T) \frac{dT}{R} - (V_{\theta}^2 - V_{\theta_j}^2) - 2 \int_{R_j}^{R} \frac{V_{\theta}^2}{R} dR - 2 g_c J \int_{R_j}^{R} \frac{\partial S}{\partial R} dR + 2 \int_{R_j}^{R} V_Z \frac{\partial V_R}{\partial R} dR \] (9)

where the subscript \( j \) here refers to the reference streamline used in the integration. The energy equation becomes

\[ g_c J (\Delta H_t) = \omega \Delta (R V_{\theta}) \] (10)

As outlined earlier, the program user may elect to solve this system of equations by specifying flow path geometry or, alternatively, by computing the annulus geometry for each designed stage using specified mid-streamline axial velocity ratio plus specified constraints on flow path. Energy addition for a stage is established using a profile of total pressure at the rotor exit, given in the form:

\[ \frac{P_t}{P_{t_i}} = \frac{A}{B + p} + C + Dp + Ep^2 \] (11)

and limiting values for the aerodynamic design parameters of each stage. Adiabatic efficiencies are computed through use of input profile loss data and the shock loss across a normal shock in the blade passage (Reference 3).

With blade inlet conditions known, exit velocity conditions are then computed iteratively through Equations (8) and (9) for Mod I. For Mod II, where exit axial velocity at the mid-streamline is established through the given ratio for a blade row and the known inlet axial velocity, Equations (8) and (9) are used to establish the exit annulus area required to satisfy continuity and radial equilibrium at the blade row exit. Hub and tip ramp angles and aspect ratio are varied in the sequence outlined earlier.
The primary objective of this computer program is to calculate design parameters and performance in accordance with full radial equilibrium and with efficiencies determined from input blade element profile loss data, while ensuring that the specified limiting values of the five aerodynamic stage design parameters are not violated in any stage. During iterative solutions of Equations (8) and (9), efficiency and energy addition are revised as required to achieve this objective.

The detailed procedure to accomplish the objectives of this program and the development of the program logic to automate this design performance analysis are discussed in the following subsection. A detailed summary of the calculations is given in Appendix A.

DEVELOPMENT OF PROGRAM LOGIC

The given functional form for total pressure at the rotor exit and the specified limiting values for the five aerodynamic design parameters combine to control the energy addition in any given stage. The limiting values of the aerodynamic parameters each represent a corresponding limiting value of rotor exit whirl velocity at the streamline where the parameter is specified. One of these five values of whirl velocity is most restrictive on stage design and is used in conjunction with efficiency and with the specified form for rotor exit total pressure to establish stage energy addition.

At a point in the stage design computations, limiting values of the aerodynamic parameters may be used to establish stage energy addition, using current axial and radial velocities and current efficiency. Using the given limiting values of $D_{SH}$, $M_{SH}$ and $\beta_{2H}^t$, it is possible to compute three values for rotor effective hub exit tangential velocity. On the assumption that all aerodynamic parameters increase monotonically with one another and with local tangential velocity, the lowest of the three values of tangential velocity just computed is used to compute a rotor hub total temperature rise. With rotor entrance conditions and current rotor effective hub efficiency, this is used to compute rotor effective hub exit total pressure. The polynomial describing $P_t/P_{Tt}$ for this rotor is used to establish a value for $P_{Tt}$ directly.

Now, separately, the limiting value for $D_{RT}$ is used to compute a value for tangential velocity at the rotor effective tip exit. This value is compared with the fifth aerodynamic design parameter, the given maximum value of rotor effective tip exit tangential velocity, and the smaller of the two values used along with the current rotor effective tip efficiency to establish a second value of $P_{Tt}$. The smaller of the two computed values of $P_{Tt}$ is taken, and the given total pressure profile is used to establish a distribution of $P_t$ at the rotor exit. The current distribution of efficiency yields the distribution of total temperature and the associated rotor exit tangential velocity distribution directly.
The methods of rewriting the expressions for the limiting values of stage aerodynamic parameters to solve for rotor exit values of $V_0$ are developed in Appendix A.

1. The expression for the rotor tip diffusion factor is

$$D_{RT} = 1.0 - \frac{\frac{V'_{2T}}{V'_{1T}}}{\frac{V'_{2T}}{\sigma_{RT} V'_{1T}}}$$

which rearranges to

$$V^2_{\theta 2T} + G V_{\theta 2T} + W = 0 \quad (12)$$

where

$$G = \left[\frac{-2 (U_{2T} + KF)}{1.0 - K^2}\right]$$

$$W = \left[\frac{V^2_{Z2T} + U^2_{2T} + V^2_{R2T} - F^2}{1.0 - K^2}\right]$$

$$K = \frac{1}{2 \sigma_{RT}}$$

$$F = \left[(1.0 - D_{RT}) V_{1T} + \frac{U_{1T} - V_{\theta 1T} - U_{2T}}{2 \sigma_{RT}}\right]$$

Therefore,

$$V^2_{\theta 2T} = \frac{-G \pm \sqrt{G^2 - 4W}}{2} \quad (13)$$

where the calculation is restricted to positive, real roots. When the limiting value of rotor tip diffusion factor is used to evaluate $F$, the chosen solution of Equation (13) represents a critical value of rotor tip exit whirl velocity, satisfying the limiting value specified for rotor tip diffusion factor.

2. The expression for the stator hub diffusion factor is
DSH = 1.0 - \frac{V_{3H}V_{\theta 2H} - V_{\theta 3H}}{V_{2H}^2 + \frac{2\sigma S_H V_{2H}}{2}} \quad (14)

which rearranges to

V_{\theta 2H}^2 + G V_{\theta 2H} + W = 0

where

G = \frac{-2KF}{F^2 - 1.0}

W = \frac{K^2 - \frac{V_{Z2H}^2}{V_{2H}} - \frac{V_{R2H}^2}{V_{2H}}}{F^2 - 1.0}

K = \left[ \frac{V_{Z3H}^2 + V_{\theta 3H}^2 + V_{R3H}^2}{1.0 - DSH} \right]^{1/2} \frac{V_{\theta 3H}}{2\sigma S_H}

F = \frac{1}{2\sigma S_H (DSH - 1.0)}

Hence,

V_{\theta 2H} = \frac{-G \pm \sqrt{G^2 - 4W}}{2} \quad (15)

where the calculation is again restricted to positive, real roots. Using the limiting value of DSH to evaluate K and F, the resulting solution of Equation (15) represents a critical value of V_{\theta 2H}, based on the specified limit for DSH in the given stage.

3. The expression for the stator hub Mach number is

M_{SH} = \frac{V_{2H}}{a_{SH}}
where

\[ a_{SH} = \sqrt{\gamma \ g_c \ R \ T_{SH}} \]

This rearranges to

\[ V_{\theta 2H}'' = \left[ \frac{1}{2} \left( \frac{2}{M_{SH}^{2}} - a_{SH}^{2} - (V_{Z2H}^{2} + V_{R2H}^{2}) \right) \right]^{1/2} \]  

If the limiting value of stator hub entrance Mach number is used in Equation (16), there results the corresponding critical value of \( V_{\theta 2H}'' \).

4. The relative exit flow angle at the rotor hub is expressed as

\[ \beta_{2H}' = \tan^{-1} \left[ \frac{V_{\theta 2H}'}{\sqrt{\left( V_{Z2H}^{2} + V_{R2H}^{2} \right)}} \right]^{1/2} \]

it follows that

\[ V_{\theta 2H}' = \left( V_{Z2H}^{2} + V_{R2H}^{2} \right)^{1/2} \tan (\beta_{2H}') \]  

and

\[ V_{\theta 2H} = U_{2H} - V_{\theta 2H}' \]

The limiting value of \( \beta_{2H}' \) may be used to solve for the corresponding critical value of \( V_{\theta 2H}'' \).

The computer program satisfies the stage aerodynamic design parameters in either of two optional ways. The user may elect to: (1) reduce the energy addition for any stage whenever necessary to avoid violation of any of the limiting values specified for the five aerodynamic parameters or (2) use the most critical of the five limiting aerodynamic parameters to establish the energy addition for each calculation pass in each stage of the compressor. The latter or "drive" option ensures that each stage of the final compressor design will satisfy the critical one of the five specified limiting values of design parameters. The "no drive" option ensures only that no designed stage will exceed any of its specified limits.
The radial profile of axial velocity at an axial station is obtained by using the tangential velocity distribution in the radial equilibrium equation (9), and carrying out the integration from a reference streamline \( j \) to all other streamlines. For inlet and Mod I stage design computations, the term \( V_j^2 \) serves as the constant of integration and must be adjusted to satisfy continuity; \( V_j^2 \) is established by trial and error at each axial station, for each pass of the design computation. For use of Mod II, the reference streamline \( j \) in any blade row is also taken as the mid-streamline, where axial velocity ratio is given. Thus, the inlet axial velocity and the given ratio fix the exit axial velocity at the mid-streamline, and the blade row exit annulus dimensions are established iteratively according to the previously described sequence of ramp angle and aspect ratio adjustment seeking simultaneous satisfaction of radial equilibrium and continuity.

The program begins a design computation by reading in the specified data on which the design is to be based, including: (1) the coefficients describing variation with temperature, (2) the loss data sets elected from the master file, and (3) data basically describing the machine to be designed, including relative error tolerances to be used in the iterative computations, and the design data for each of the maximum number of stages. The stage data includes:

- Limiting values for the aerodynamic parameters
- Specific loss data sets to be used for rotor and stator
- Flow increments in rotor and stator
- Polynomial coefficients describing exit total pressure distribution for rotor and exit whirl velocity distribution for stator
- Blade solidity distributions
- Distributions of the ratio of supersonic turning to total turning or of flow angle at the passage shock in rotor and stator
- For Mod II, limiting values for hub and tip ramp angles and initial values for rotor and stator aspect ratio

The program considers ten axial stations at any one point in its iterative design computations. The first five axial stations of the flow path represent the inlet, and the program computes three exit stations behind the last stage being designed. Hence, the program initially considers only the first stage, with the inlet ducting and the program-computed exit ducting making up the remaining eight axial stations initially considered.

The program begins its computation by evaluating \( T_i, P_i \) and \( c_p(T) \) in the inlet. Setting \( V_R \) and \( V_0 \) in the inlet to zero, and assuming \( dR/dZ \) and \( d^2R/dZ^2 \) both zero at the front of the machine, the program then sets mass flow rate throughout the inlet equal to the flow rate at the first station. Using flow increment data specified at each blade row for which data is input, total flow rate at each of the maximum number of blade rows is then computed.
Having established the number of streamtubes and the midstream index streamline to be used in axial velocity computations, the program next establishes a simple radial equilibrium solution of the flow equations for the inlet only; to initially establish flow conditions in the first rotor, the program either picks up the input geometry or computes a first approximation to rotor annulus geometry, depending upon whether the Mod I or the Mod II option has been selected by the user. (In the case of Mod II design computations, the second stage and subsequent rotors are first taken as a copy of the last upstream rotor.) The initial approximation of rotor one flow conditions is obtained using a loading based on the given limiting value of $D_{RT}$ and a midstreamline axial velocity ratio of 0.9, assuming free vortex flow and $\eta_R = 0.90$. Next the first stator exit geometry is either picked up from input data or estimated as required, and stator exit flow conditions are initially established using the given stator exit tangential velocity distribution and $\eta_S = 0.89$. Next, flow properties in the outlet are established and the limiting values of the aerodynamic parameters are checked; any necessary adjustments in the temperature and pressure profiles are made. Next, the program establishes the current outlet ducting and computes the flow properties there. To this point, only simple radial equilibrium has been employed in flow calculations. Next, the program establishes the full radial equilibrium solution to the flow equations for the ten stations initially considered. Streamline curvature effects and radial gradients in total enthalpy and entropy are included.

Next, the stage aerodynamic limits for the stage(s) among the ten axial stations currently considered are checked and any necessary iteration on the design of these stage(s) is performed, accounting for full radial equilibrium. This iteration may be accomplished with either the "drive" option or "no-drive" requested by the program user. Continuity is satisfied at every pass and convergence is established on efficiency.

When convergence is fully established, the desired pressure ratio input for this design is compared with the cumulative pressure ratio at the exit of the last stage in the current converged design. If the desired pressure ratio has not been met, and if the specified maximum number of stages allows, another stage is added to the design at this point. Two stations from the front of the design flow path are deleted, fully converged, at this point and the exit ducting is re-established in the "new" ten-station design flow path.

When a new stage is added, the current values of slopes, curvatures and axial velocities from the immediately preceding stage are used in the first pass on the new stage, and the design is redone (i.e., convergence is re-established) for all ten stations currently considered by the computer. The check of cumulative pressure ratio is made, and another stage added as before if needed and if available. The design computation may stop at numerous points and produce one of a number of error messages if difficulty is encountered for physical or numerical reasons. The stopping points and corresponding error messages are shown in the program flow charts and in the source deck listing, Appendices C and B, respectively.
PROGRAM RESTRICTIONS

It has been pointed out already that use of the limiting values of the aerodynamic stage design parameters $D_{RT}$, $D_{SH}$, and $M_{SH}$ to establish corresponding critical values of tangential velocity, is subject to restrictions on the choice of roots in establishing $V_{\theta 2}$ values at hub or tip.

A further restriction applies to the specification of limiting values for rotor tip diffusion factor and stator hub diffusion factor in a stage. If a maximum value of diffusion factor is exceeded in either case, both the corresponding roots for $V_{\theta 2}$ are complex, and physical meaning is lost. The program has error messages imbedded in the logic so that this condition may be readily determined:

The maximum level of rotor tip diffusion factor for the inlet flow conditions, tip speed, axial velocity ratio, and solidity can be easily established. The diffusion factor is

$$D_R = 1 - \frac{V_2^2}{V_1^2} + \frac{V_{\theta 1}^2 - V_{\theta 2}^2}{2 \sigma V_1}$$  \hspace{1cm} (19)

or

$$D_R = 1 - \frac{V_{Z2}^2}{|\cos \beta_2^1 V_1^2|} + \frac{(U_1 - V_{\theta 1}) - V_{Z2} \tan \beta_2^1}{2 \sigma V_1}$$  \hspace{1cm} (20)

Since with established inlet conditions and $V_{Z2}$ the rotor diffusion factor is dependent only on $V_{\theta 2}^1$ or $\beta_2^1$, Equation (20) can be solved for its maximum value. Differentiating, with $\beta_2^1$ considered to be in the first or fourth quadrant,

$$\frac{d (D_R)}{d \beta_2^1} = - \frac{V_{Z2}}{\cos^2 \beta_2^1 V_1} \sin \beta_2^1 - \frac{V_{Z2}}{2 \sigma V_1} \frac{1}{\cos^2 \beta_2^1}$$  \hspace{1cm} (21)

Setting the right hand side to zero and solving for $\beta_2^1$, it is found that

$$\beta_2^1_{DR \text{ max}} = \arcsin \left( - \frac{1}{2 \sigma} \right)$$  \hspace{1cm} (22)

and that $D_R$ is at its maximum value. Substitution of Equation (22) into Equation (20) yields
Similarly, the maximum level of stator hub diffusion factor for given flow conditions and solidity may be established. The stator diffusion factor is

\[ D_S = 1.0 - \frac{V_3}{V_2} + \frac{V_{\theta_2} - V_{\theta_3}}{2 \sigma V_2} \]  

or

\[ D_S = 1.0 - \frac{V_3 \cos \beta_2}{V_{Z_2}} + \frac{\cos \beta_2 \left( \frac{V_{Z_2} \tan \beta_2 - V_{\theta_3}}{2 \sigma V_{Z_2}} \right)}{2 \sigma V_{Z_2}} \]  

Considering \( \beta_2 \) to lie in the first or fourth quadrant, it is possible to establish the following derivative:

\[ \frac{dD_S}{d \beta_2} = \sin \beta_2 \left( \frac{V_3}{V_{Z_2}} + \frac{V_{\theta_3}}{2 \sigma V_{Z_2}} \right) + \frac{1}{2 \sigma} \left[ \frac{1 - \sin^2 \beta_2}{\cos \beta_2} \right] \]  

It follows that

\[ \left( \beta_2 \right)_{D_S \text{ max}} = \arctan \left( \frac{\cos \beta_2}{\frac{1}{2 \sigma} \left[ \frac{V_3}{V_{Z_2}} + \frac{V_{\theta_3}}{2 \sigma V_{Z_2}} \right]} \right) \]  

Substituting Equation (27) into Equation (25) results in the expression

\[ D_S \text{ max} = 1.0 - \frac{\cos (\beta_2) D_S \text{ max}}{V_{Z_2}} \left[ V_3 + \frac{1}{2 \sigma} \left[ \frac{V_{Z_2}}{2 \sigma} \left( \frac{V_3}{V_{Z_2}} + \frac{V_{\theta_3}}{V_{Z_2}} \right) \right] + V_{\theta_3} \right] \]
REFERENCES


APPENDIX A

SYSTEM OF EQUATIONS AND COMPUTATIONS
The system of equations and computations presented in this appendix constitute an iterative design system for computing performance of multistage axial-flow compressors. It has been pointed out that the computation considers only stations between blade rows, in addition to inlet and exit stations. Full radial equilibrium of the flow is computed, including radial gradients of total enthalpy and entropy. Flow is assumed axisymmetric and the gas is considered ideal, with $c_p$ taken as a function of temperature.

The computer-programmed design system will handle a maximum of 12 stages, with the design of individual stages limited by input-specified maximum values of five aerodynamic parameters in each stage. These parameters are: rotor tip diffusion factor, stator hub diffusion factor, stator hub inlet Mach number, rotor hub exit relative flow angle, and rotor tip exit whirl velocity. As described under Development of Program Logic and in Appendix D, the program user may elect to design all stages such that the axial flow compressor satisfies the most critical of the five aerodynamic limits. Alternatively, the program user may elect to design with only the assurance that no aerodynamic limits are violated anywhere in a converged design.

In summary, the following information is given:

- Specific heat at constant pressure, as a function of temperature
- Molecular weight of the gas
- Maximum number of stages in the planned design
- Minimum mass-averaged overall pressure ratio
- Total mass flow rate
- Number of streamlines to be considered in the design computation
  (5, 7, 9, 11)
- Fraction of the total flow passing between the hub and each successive streamline

Furthermore, in the inlet ducting and at the compressor entrance, the following items are given:

- Inlet total pressure
- Inlet total temperature
- Axial location of all inlet stations
- Hub radius and blockage at each axial station
- Tip radius and blockage at each axial station
- Radial variation of inlet guide vane loss coefficient (input by streamline)
- Radial variation of inlet guide vane-exit whirl velocity
- Tip speed at the inlet of the first rotor
For each of the maximum number of stages in the design, the following items are given:

- Blockages at hub and tip and geometry information for Mod I or Mod II
- Radial distribution of solidity (rotor, stator)
- Radial distribution of rotor exit $P_t/P_{tT}$
- Radial distribution of stator exit whirl velocity
- Profile loss parameter correlations at hub, mean, tip (rotor, stator)
- Radial distribution of the ratio of supersonic turning to total turning (rotor, stator) or of the relative flow angle at the passage shock
- Limiting values for rotor tip and stator hub diffusion factors
- Limiting value of stator hub inlet Mach number
- Limiting value of rotor hub exit relative flow angle
- Limiting value of rotor tip exit tangential velocity

The basic equations employed in this design system are displayed in the description of computations presented here. The equations are presented in cylindrical coordinates, assuming axisymmetry and neglecting body forces. The solution is necessarily an iterative one, proceeding to the satisfaction of several error tolerances specified as input and described in Appendix D.

**CONTINUITY EQUATION**

\[ w = 2\pi \int_{R_{He}}^{R_{Te}} \rho \frac{\varphi}{R} RdR \]  

\[ (A-1) \]

From geometric input dimensions and blockage, aerodynamic hub and tip radii are determined at each axial station. From the definitions

\[ \delta_H = \frac{R_T^2 - R_{He}^2}{R_T^2 - R_H^2} = \text{hub blockage factor} \]  

\[ (A-2) \]

\[ \delta_T = \frac{R_{Te}^2 - R_H^2}{R_T^2 - R_H^2} = \text{tip blockage factor} \]  

\[ (A-3) \]

where blockage factor is the decimal portion of geometric area not blocked, there results the expressions

\[ R_{He} = \left[ \delta_H R_H^2 + (1 - \delta_H) R_T^2 \right]^{1/2} \]  

\[ (A-4) \]

\[ R_{Te} = \left[ \delta_T R_T^2 + (1 - \delta_T) R_H^2 \right]^{1/2} \]  

\[ (A-5) \]

A-2
The annulus is subdivided into \((j-1)\) streamtubes, where \(j\) is input as the number of streamlines considered in the design. The fraction of the total mass flow passing between the hub and each of the \(j\) streamlines is given as input and

\[
\text{DELM (j)} = 2\pi \int_{R_{He}}^{R} \rho V_z R \, dR
\]  
(A-6)

ENERGY EQUATION

\[
H_{t2} - H_{t1} = \frac{1}{g c_j} \left[ U_2 V_{\theta_2} - U_1 V_{\theta_1} \right]
\]  
(A-7)

\(T_{t2}\) is determined by an iterative solution of the equation

\[
H_{t2} - H_{t1} = \int_{T_{t1}}^{T_{t2}} c_p(T) \, dT
\]  
(A-8)

solving for the upper limit of the integral.

The exit total temperature for the rotor at any streamline is determined using exit total pressure and efficiency. The adiabatic efficiency is then re-determined by calculating an isentropic temperature rise from an iterative solution of

\[
\frac{J}{K} \left[ \int_{T_{t1}}^{T_{t2}} \frac{dT}{c_p(T)} \right]
\]

\[
P_{t2} = P_{t1} e^{\frac{J}{K} \left[ \int_{T_{t1}}^{T_{t2}} \frac{dT}{c_p(T)} \right]}
\]  
(A-9)

and solving Equation (A-8) for \(H_{t2, i}\). Efficiency is then found from

\[
\eta = \frac{H_{t2, i} - H_{t1}}{H_{t2} - H_{t1}}
\]  
(A-10)
RADIAL EQUILIBRIUM EQUATION

\[ v_Z^2 - v_{Zj}^2 = 2g_cJ \int_{t_j}^{T_t} c_p(T) dT - \left( v_\theta^2 - v_{\theta j}^2 \right) - 2 \int_{R_j}^{R} \frac{v_\theta^2}{R} dR \]  

(A-11)

\[-2g_cJ \int_{R_j}^{R} T \frac{\partial S}{\partial R} dR + 2 \int_{R_j}^{R} v_Z \left( \frac{\partial V_R}{\partial Z} \right)_R dR\]

The entropy gradient term of the radial equilibrium equation is evaluated from the following expression

\[ 2g_cJ \int_{R_j}^{R} T \frac{\partial S}{\partial R} dR = 2g_cJ \int_{R_j}^{R_2} T \frac{\partial}{\partial R} \left[ \int_{T_{t1}}^{T_{t2}} c_p(T) \frac{dT}{T} - \frac{R}{J} \ln \frac{P_2}{P_1} \right] dR \]  

(A-12)

The streamline curvature term is evaluated from

\[ 2 \int_{R_j}^{R} v_Z \left( \frac{\partial V_R}{\partial Z} \right)_R dR = 2 \int_{R_j}^{R} v_Z \left( \frac{\partial V_R}{\partial Z} \right)_\psi dR = 2 \left[ \frac{V_R^2 - V_{R_j}^2}{2} \right] \]  

(A-13)

where the subscript \( \psi \) designates a derivative taken along a streamline.

EQUATION OF STATE

\[ f = \frac{P}{RT} \]  

(A-14)

STATIC-TO-TOTAL AND RELATIVE-TO-ABSOLUTE CONVERSIONS

From the definition of total enthalpy, the relationship

\[ H_t - H = \frac{V^2}{2g_cJ} \]  

(A-15)

is established.
Static temperature is evaluated iteratively from

\[ H_t - H = \int_{T}^{T_t} c_p(T) dT \] \hspace{1cm} (A-16)

and static pressure is calculated from

\[ P = P_t e^{\int_{T}^{T_t} \frac{c_p(T) dT}{T}} \] \hspace{1cm} (A-17)

Relative total enthalpies are determined from

\[ H'_t - H_t = \frac{1}{2 \rho_0 J} \left[ \sqrt{\mathbf{V}^2} - \sqrt{\mathbf{V}'^2} \right] \] \hspace{1cm} (A-18)

Relative total temperature is found iteratively from

\[ H'_t - H = \int_{T}^{T_t} c_p(T) dT \] \hspace{1cm} (A-19)

and relative total pressure is evaluated using the expression

\[ P'_t = P_t e^{\int_{T}^{T_t} \frac{c_p(T) dT}{T}} \] \hspace{1cm} (A-20)

**LOSS CALCULATION**

The total pressure loss coefficient is defined for rotors as

\[ \tilde{\omega}'_t = \frac{P'_{t_2,1} - P'_{t_2}}{P'_{t_1} - P_1} \] \hspace{1cm} (A-21)
and for stators as

\[
\bar{\omega}_t = \frac{P_{t2} - P_{t3}}{P_{t2} - P_2}
\]  \hspace{1cm} (A-22)

The total loss coefficient is taken as the sum of profile and shock loss coefficients

\[
\bar{\omega}_t = \bar{\omega}_p + \bar{\omega}_s
\]  \hspace{1cm} (A-23)

The shock loss coefficient is calculated on the basis of the normal-shock-in-passage model presented in Reference 3 (See References in report). In this computation, the specific heat of the gas is evaluated at local temperature but is not treated rigorously as a variable. For each stage in a design calculation, the computer program receives as input a radial distribution of either:

(a) the ratio of supersonic turning to total turning for both rotor and stator or

(b) the distribution of flow angle at the shock for rotor and stator. Supersonic turning is computed as

\[
\phi_{ss} = \left( \beta'_1 - \beta'_2 \right) \frac{\phi_{ss}}{\phi_{total}}
\]  \hspace{1cm} (A-24)

For stators, the absolute air angles are substituted. If the relative inlet Mach number is equal to or greater than 1.0, the inlet Prandtl-Meyer angle is calculated from

\[
v_1 = \sqrt{\frac{\gamma + 1}{\gamma - 1}} \tan^{-1} \sqrt{\frac{\gamma - 1}{\gamma + 1} \left( M_1^2 - 1 \right)} = \tan^{-1} \sqrt{M_1^2 - 1}
\]  \hspace{1cm} (A-25)

The Prandtl-Meyer angle at the intersection of the assumed normal shock with the suction surface is calculated from

\[
v_{ss} = v_1 + \phi_{ss}
\]  \hspace{1cm} (A-26)

The Mach number at this location is then determined from an iterative solution of the expression

\[
v_{ss} = \sqrt{\frac{\gamma + 1}{\gamma - 1}} \tan^{-1} \sqrt{\frac{\gamma - 1}{\gamma + 1} \left( M_{ss}^2 - 1 \right)} = \tan^{-1} \sqrt{M_{ss}^2 - 1}
\]  \hspace{1cm} (A-27)

The effective shock upstream Mach number, from which the pressure ratio across the shock is computed, is

\[
M_e = \frac{1}{2} \left( M_1' + M_{ss}' \right)
\]  \hspace{1cm} (A-28)
Using the normal shock relationship, Equation (99), Reference 5 (in report),

\[
\left( \frac{P_{t2}'}{P_{t1}'} \right)_{\text{normal shock}} = \left[ \frac{(\gamma + 1) M_e^2}{(\gamma - 1) M_e^2 + 2} \right]^{\gamma/\gamma-1} \left[ \frac{\gamma + 1}{2\gamma M_e^2 - (\gamma - 1)} \right]^{1/\gamma-1} \quad (A-29)
\]

the shock total pressure ratio is determined. The shock loss coefficient is then evaluated as

\[
\bar{s}_s = \frac{1 - \left( \frac{P_{t2}'}{P_{t1}'} \right)_{\text{normal shock}}}{1 - \left( \frac{P_1}{P_{t1}'} \right)} \quad \text{(A-30)}
\]

where

\[
\frac{P_1}{P_{t1}'} = \left[ 1 + \frac{\gamma - 1}{2} M_1^2 \right]^{-\gamma/\gamma-1} \quad \text{(A-31)}
\]

Now, if the inlet relative Mach number is less than 1.0, the effective upstream shock Mach number is calculated as

\[
M_e' = \frac{M_1'}{2} (1 + M_{ss}') \quad \text{(A-32)}
\]

where \(M_{ss}'\) is a function of \(\phi_{ss}\) determined by iterative solution of the equation

\[
\phi_{ss} = \sqrt{\frac{\gamma + 1}{\gamma - 1}} \tan^{-1} \sqrt{\frac{\gamma - 1}{\gamma + 1} \left( M_{ss}'^2 - 1 \right)} - \tan^{-1} \sqrt{M_{ss}'^2 - 1} \quad \text{(A-33)}
\]

If \(M_e'\) is greater than 1.0, \(\bar{s}_s\) is evaluated using Equations (A-29), (A-31) and (A-30) as before.

The profile loss coefficient is determined from blade element loss data, input as profile loss parameter \(\frac{\bar{s}_p \cos \beta}{2 \sigma}\) correlated as a function of diffusion.
factor for hub, mean and tip sections as described earlier and in Appendix D. The hub and tip loss data sets are associated with 15% span and 90% span, respectively. Blade diffusion factor is calculated as

\[ D_R = 1.0 - \frac{V_2' - V_{\theta 1}' - V_{\theta 2}'}{2\sigma V_1'} \]  
(For rotors)  \hspace{1cm} (A-34)

and

\[ D_S = 1.0 - \frac{V_3' - V_{\theta 2}' - V_{\theta 3}'}{2\sigma V_2'} \]  
(For stators)  \hspace{1cm} (A-35)

where solidity, \( \sigma \), is determined at the average radius associated with a stream surface in the blade passage.

When the diffusion factor is established for the flow along a given streamline in a given blade row, the average percent span for that streamline in the passage is used to establish a profile loss parameter value associated with the given streamline. The loss parameter is established using a circular interpolation along the blade span, using the mean section loss parameter value and the hub or tip section value, as appropriate. Both loss parameter values are taken at the diffusion factor level computed for the subject streamline. The interpolation takes the form

\[ \left[ \frac{\bar{\omega}_p \cos \beta_2'}{2\sigma} \right]_x = \frac{\bar{\omega}_p \cos \beta_2'}{2\sigma} \left[ 0.5 + r - \frac{r^2}{\sqrt{(x-0.5)^2 + r^2}} \right] \]  \hspace{1cm} (A-36)

where \( r = \frac{(0.16 + d^2)}{2d} \) and \( d = \left[ \left( \frac{\bar{\omega}_p \cos \beta_2'}{2\sigma} \right)_{0.9, 0.1} \right] \).  \hspace{1cm} (A-36)

The profile loss coefficient is then computed directly, using solidity and stream-plane relative exit flow angle at the subject streamline.

The total loss coefficient is used to establish an actual exit total pressure using Equation (A-21) or Equation (A-22), as appropriate. This exit total pressure is used to re-establish adiabatic efficiency through the use of Equations (A-9), (A-8) and (A-10), as described earlier.
ENERGY ADDITION—Determined by Stage Aerodynamic Design Parameters

As described earlier, and in Appendix D, the computer program user may elect to design each compressor stage to satisfy the critical one of the five limiting values specified for its aerodynamic design parameters, or the user may elect to design only with the assurance that all converged stage designs will not violate any of the prescribed aerodynamic limits. Satisfaction of the critical one of five aerodynamic limits in each converged stage design occurs in the so-called "drive" option, where the rotor exit total pressure level is adjusted to satisfy the critical aerodynamic limit at each re-assessment of loading in each stage during design computations. By contrast, the "no-drive" program option merely adjusts the rotor exit total pressure level sufficiently to avoid a violation of an aerodynamic limit each time such a violation is encountered during re-assessment of loading. It is possible and likely that during design computations prior to convergence in any given stage, the rotor exit total pressure in this program option will be reduced to a level such that none of the five design-limiting criteria are equalled in the converged design.

Summarizing, each of the five design criteria may be used to establish a corresponding level of rotor exit total pressure; that is, each aerodynamic limit may be used to determine a level of the rotor exit total pressure at a given point in the design computations. In the "drive" program option, the lowest of these five levels is chosen and used to define the rotor exit whirl velocity distribution at that point in the calculation. In the "no-drive" program option, the rotor exit total pressure level is changed to correspond to the lowest of the five limiting values only if one or more of the aerodynamic design parameters is found to be greater than its corresponding limit value.

Expressions for the tangential velocity in terms of aerodynamic parameters are developed as follows.

1. **Tangential velocity in terms of rotor tip diffusion factor**

   The diffusion factor at the rotor tip is given by

   
   \[
   D_{RT} = 1.0 - \frac{V'_{2_T}}{V'_{1_T}} + \frac{V'_{\theta 1_T} - V'_{\theta 2_T}}{2\sigma_{RT} V'_{1_T}} \tag{A-37}
   \]

   or

   
   \[
   D_{RT} = 1.0 - \frac{V'_{1_T} - U_{1_T} - U_{2_T} + V'_{\theta 2_T}}{2\sigma_{RT} V'_{1_T}}
   \]
This may be rearranged as

\[ v_2' = \frac{V\theta_T}{2\sigma_{RT}} + \left[ (1.0 - D_{RT}) \cdot v_{1T}' + \frac{U_{1T} - V\theta_1T - U_{2T}}{2\sigma_{RT}} \right] \]

or as

\[ v_2' = K \cdot V\theta_T + F \quad (A-38) \]

where

\[ K = \frac{1}{2\sigma_{RT}} \]

and

\[ F = \left[ (1.0 - D_{RT}) \cdot v_{1T}' + \frac{U_{1T} - V\theta_1T - U_{2T}}{2\sigma_{RT}} \right] \]

now

\[ v_2' = \left[ (U_{2T} - V\theta_2T)^2 + V_{R2T}^2 + V_{Z2T}^2 \right]^{1/2} \quad (A-39) \]

Squaring and equating (A-38) and (A-39) results in

\[ U_{2T}^2 - 2U_{2T} \cdot V\theta_2T + V_{\theta 2T}^2 + V_{R2T}^2 + V_{Z2T}^2 = K^2 \cdot V_{\theta 2T}^2 + 2KF \cdot V\theta_2T + F^2 \]

which reduces to

\[ V_{\theta 2T}^2 + \left[ \frac{-2 \cdot (U_{2T} + KF)}{1.0 - K^2} \right] \cdot V\theta_2T + \left[ \frac{V_{Z2T}^2 + U_{2T}^2 + V_{R2T}^2 - F^2}{1.0 - K^2} \right] = 0 \]

A-10
or

\[ V_{\theta}^2 T + GV_{\theta}^2 T + W = 0 \]  \hspace{1cm} (A-40)

where

\[ G = \frac{-2 \left( U_{2T} + KF \right)}{1.0 - K^2} \]

and

\[ W = \frac{\left[ V_{2T}^2 + U_{2T}^2 + V_{R2T}^2 - F^2 \right]}{1.0 - K^2} \]

The absolute tangential velocity at the rotor tip may be obtained by solving Equation (A-40).

\[ V_{\theta}^2 T = \frac{-G \pm \sqrt{G^2 - 4W}}{2} \]  \hspace{1cm} (A-41)

The calculation is restricted to positive real roots.

2. Tangential velocity in terms of stator hub diffusion factor

The stator hub diffusion factor is expressed as

\[ D_{SH} = 1.0 - \frac{V_{3H}}{V_{2H}} + \frac{V_{\theta 2H} - V_{\theta 3H}}{2\sigma_{SH} V_{2H}} \]  \hspace{1cm} (A-42)

This equation may be arranged as

\[ V_{2H} = -K + FV_{\theta 2H} \]  \hspace{1cm} (A-43)
where

\[
K = \frac{\left[ v^2_{Z3H} + v^2_{\theta 3H} + v^2_{R3H} \right]^{1/2} + v^2_{\theta 3H} \sigma_{SH}}{1.0 - D_{SH}}
\]

and

\[
F = \frac{1}{2\sigma_{SH} (D_{SH} - 1.0)}
\]

Now, expressing \( V^2_{2H} \) in terms of its components and squaring Equation (A-43), there results

\[
V^2_{\theta 2H} + V^2_{\theta 2H} G + W = 0
\]

(A-44)

where

\[
G = -\frac{2KF}{F^2 - 1.0}
\]

\[
W = \frac{K^2 - V^2_{Z2H} - V^2_{\theta 2H}}{F^2 - 1.0}
\]

Hence,

\[
V_{\theta 2H} = \frac{-G \pm \sqrt{G^2 - 4W}}{2}
\]

(A-45)

where the calculation is again restricted to positive, real roots. Using the limiting value of \( D_{SH} \) to evaluate \( K \) and \( F \), the resulting solution of Equation (A-45) represents a critical value of \( V_{\theta 2H} \).
3. Tangential velocity in terms of stator hub Mach number

The sonic velocity at a stator hub is

\[
a_{SH} = \sqrt{\gamma g_c R T_{2H}} \quad (A-46)
\]

and

\[
\frac{V_{2H}}{a_{SH}} = M_{SH} \quad (A-47)
\]

This may be written as

\[
M_{SH} = \frac{a_{SH}}{\sqrt{\left[V_{\theta 2H}^2 + V_{R2H}^2 + V_{Z2H}^2 \right]^{1/2}}} \quad (A-48)
\]

Squaring and rearranging results in

\[
V_{\theta 2H} = \left[\frac{M_{SH}^2 a_{SH}^2 - \left(V_{Z2H}^2 + V_{R2H}^2\right)}{a_{SH}}\right]^{1/2} \quad (A-49)
\]

Note that where the quantity shown in parentheses here is negative, the limiting value of \(M_{SH}\) cannot be satisfied by adjusting \(V_{\theta 2H}\). The program produces an error message when this condition is encountered.

4. Tangential velocity in terms of rotor hub exit relative flow angle

The relative exit flow angle at the hub is

\[
\beta_{2H}' = \tan^{-1}\left[\frac{V_{\theta 2H}'}{\left(V_{Z2H}^2 + V_{R2H}^2\right)^{1/2}}\right] \quad (A-50)
\]

Thus,

\[
V_{\theta 2H}' = \left(V_{Z2H}^2 + V_{R2H}^2\right)^{1/2} \tan \left(\beta_{2H}'\right)
\]

A-13
and

\[ V_{\theta 2H} = U_{2H} \left( \frac{V_{Z2H}^2}{V_{R2H}} + \frac{V_{R2H}^2}{V_{Z2H}} \right)^{1/2} \tan \left( \beta'_{2H} \right) \]  

(A-51)

The limiting value of \( \beta'_{2H} \) is employed to evaluate \( V_{\theta 2H} \).
APPENDIX B

FORTRAN IV SOURCE DECK LISTING
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SUBROUTINE AN EXIT

*** THIS SUBROUTINE ADDS AN EXIT TO THE MACHINE BASED ON
A HORIZONTAL TIP AND THE HUB CALCULATED FROM THE RATIO
OF THE AREA OF THE STATION TO THE AREA OF THE LAST
STATOR EXIT.

LOGICAL FPATH
DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL ERROR, YES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), UHI(32), BLADE(29), B(32),
X CO(10,11), CPI(32,11), CPCO(16), C(32,11),
X C (32,11), CUX(10,11), CUUX(10,11), CUXD(29,1),
C X (32,11), CUXI(10,11), CUUX(10,11), CXUAD(29,1),
C X (32,11), DAI(10), DEL(11), DEPLY(10,11),
C X (32,11), DF(20), DFAC(29,11), DFL(29), DFLOW(32),
C X (32,11), EMACH(29,11), FOUND(20,3,10), FRDEL(10,11), GAMMA(32,11),
C X (32,11), HNN(29), HUB(32), IKK(10), MACH(29,11),
C X (32,11), OBAR(29,11), POT(32,11), R(32,11), RCURVE(10,11),
C X (32,11), RH(32,11), PHI(32,11), RINF(11), ROSTAG(11),
C X (32,11), RS(32), RSLAPE(10,11), RTRAIL(11), SOC0(29,5),
C X (32,11), SOLID(29,11), SSC0(29,5), TERM1(10,11), TERMA(11),
C X (32,11), TERM(11), THERM(11), TIP(32), TITLE(12),
C X (32,11), TO(32,11), TST(11), TSS(11), U(32,11),
C X (32,11), COMMON /SCALER/ A, AA, A1DA0, A202A0, A303A0, A404A0,
X ASOSAO, B, BB, CC, CM, CMEEAN, CMEEANP, COINTG,
X CPI2, CPI3, CPI4, CPI5, CPI6, CP02, CP03, CP04,
X CP05, DAMP, DCP, DD, DIFCM, DT, DUMMY, ERAS1,
X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X POCO, Q, RPM, TCP, TERM0, TESTH, TESTR, TEST5,
X TOCO, TOL, TOLAT, TOLB2, TOLMIN, TOLS, TOLTP, TOLCP,
X TOLCX, TOLR, TOTINT, TOTPR, V, VMI
COMMON /INTEGR/ I, IB, I01, IDUMP, ERROR, IERROR, IERROR, IFIRST,
X IG, IOUTTR, IPASS, IS, IT, J, JIN, JJ,
X JH, JMI, K, K1, KK, L, LIMIT, LSTAGE,
X MSTATE, MINES, NTUBES, NX, NX1, YES
X EQUIVALENCE (ATAR(1,1), ATAR(1,1), (FLOW1), DFLOW1)
COMMON /VECOM/ ALH(29), ALT(29), ALTER,
X ASPECT(29), FPATH, SAVEA(29)

IF (FPATH) DT = X(LSTATE) - X(LSTATE-1)
AA = RS(LSTATE)**2
BB = RH(LSTATE)**2
DO 10 JK=1,3
JL=LSTATE+JK
IF (FPATH) X(JL) = X(JL-1) + DT
RS(JL) = RS(LSTATE)
RH(JL) = SCRT(AA + (BB-AA)*ATAR(1,JK))
10 CONTINUE
RETURN
END

B-1
Q45. - EFN SOURCE STATEMENT - IFN(S) -

11/02/67

SUBROUTINE Q45
COMMON /VNE/ NBLADE
INTEGER PLANE
COMMON /VGEOM/ ALH(29), ALT(29), ALTE
INTEGER ALTE,NBLADE,GCOUNT
INTEGER FPATH,NO FAIL
LOGICAL FPATH,NO FAIL
DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IMERR, YES
COMMON /MATRIX/
COMMON /SCALER/
COMMON /INTEGR/
COMMON /SPECIAL/ NORM(14), NX2, NOFAIL

1 CONTINUE
*** READ THE INPUT
CALL INPUT

*** INITIALIZE THE COUNTERS
*** ALTERATIONS TO BLADE ROW GEOMETRY IS MADE SEQUENTIALLY DOWN
*** STREAM, ONE SMALL CHANGE TO EACH BLADE ROW UNTIL ALL HAVE
*** CONVERGED. THE FIRST BLADE ROW IS AT STATION 5.
*** INITIALLY THE NUMBER OF BLADE ROWS CONSIDERED IS 2. AT MOST
*** 6 WILL BE CONSIDERED.

ALTER = 5
Q45. - EFN SOURCE STATEMENT - IFN(S) - 11/02/67

NBLADE= 2
115 IPASS= 1
GCOUNT= 0
120 CONTINUE
DAMP= 1.0
LC6=0
C *** SET UP THE ROTOR CALL ROTOUT
I= I+1
C *** SET UP THE STATOR CALL STAOUT
130

C *** CALCULATE CONDITIONS AT THE OUTLET CALL OUTLET
C *** CHECK THE FLOW PARAMETERS AND MAKE ADJUSTMENTS IN THE
C TEMPERATURE AND PRESSURE PROFILES AS REQUIRED CALL DRIVE
C *** SET THE ITERATION COUNTER TO ZERO
139 LC6= 0
C *** PRINT OUTPUT AT THIS POINT, TRANSFER TO A NEW DATA SET
140 IF (LC6.GT.50) CALL ERROR(19)
C *** CALCULATE THE AXIAL VELOCITIES INCLUDING CURVATURE EFFECTS
LC5= 0
142 CALL CAXIAL
LC5= LC5+1
IF (LC5.GT.50) CALL ERROR(18)
C*** TURN THE LOADING ITERATION TRIGGER ON.
NO FAIL= .TRUE.
IPASS= 4
C *** CHECK THE LOADING PARAMETERS AGAINST THEIR DESIRED LIMITS.
C IF THEY ARE NOT CLOSE MAKE APPROPRIATE CHANGES IN THE ROTOR
C TEMPERATURE PROFILE.
CALL DRIVE
C *** HAVE ALL OF THE FLOW PARAMETER REQUIREMENTS BEEN MET
IF (.NOT. NO FAIL) GO TO 142
IPASS= 2
C *** CALCULATE THE LOSSES CALL LOSS
146 LC6=LC6+1
I=LSTAGE-1
C *** IPASS WILL BE EQUAL TO 3 IF THE LOSSES DO NOT CORRELATE
C WITH THE EFFICIENCIES IF (IPASS.EQ.3) GO TO 140
GCOUNT= GCOUNT +1
C *** CHECK THE GEOMETRY ITERATION COUNTER
IF (GCOUNT.GT.100) CALL ERROR(35)
ERROR= .FALSE.
C *** IS THE GEOMETRY TO BE CALCULATED
A-3
**O45. - EFN SOURCE STATEMENT - IFN(S)**

IF (FPATH) CALL GEOM
C *** IS THE GEOMETRY CORRECT
IF (IERKUP) GO TO 139
C *** CHECK THE AXIAL VELOCITIES
ONE MORE TIME
CALL CAXIAL
C
C *** CALCULATE THE MASS AVERAGED PRESSURE RATIO

DO 155 J=1,NLINES
TERM(B(J)= TO(LSTAGE,J)
C
C *** SCLVES FOR TERM(B(J) IN GASK*ALOG(P)_LSTAGE,J)/P0(1,1) =
INTEGRAL FROM TO(1,1) TO TERM(B(J) OF (CP/T) DT

CALL THERM2(PO(LSTAGE,J)/P0(1,1),TERM(B(J),TO(1,1))
TERM(B(J)=TERM(B(J)/TO(1,1)

155 DEPV(9,J)= RHO(LSTAGE,J)*CX(LSTAGE,J)*R(LSTAGE,J)
1= LSTAGE
L=9
CALL INTEG(DEPV,2)
SUM= RINT(NLINES)-RINT(1)
L=8
DO 157 J=1,NLINES

157 DEPV(8,J)= [TERM(B(J)-1.1)*DEPV(9,J)
CALL INTEG(DEPV,2)
V= RINT(NLINES)-RINT(1)
MAPR= EXPI(JOULE/THERM3(V/SUM+1.0)*TO(1,1))/THERM3(TO(1,1))/GASK

C *** IF THE MASS AVERAGED PRESSURE EXCEEDS THE PRESSURE RATIO DESIRED THE CALCULATION IS COMPLETE

IF (MAPR.GE.TOPR) GO TO 175
C
C *** SINCE THE MASS AVERAGED PRESSURE RATIO HAS NOT BEEN MET WE CHECK TO SEE IF ANOTHER STAGE MAY BE ADDED. IF NOT THE FLOW PARAMETERS WILL BE PRINTED

IF ((LSTAGE-5)/2.GE.KSTAGE) GO TO 170
C
C *** INITIALIZE THE CALCULATION TO ADD ONE MORE STAGE

IFIRST=MAX( IFIRST, LSTAGE-3)
I= LSTAGE + 1
IB= IB+2
IB= IB+2
NB= NX+2
NX= NX+2
NX2= NX2+2
NBLADE= MIN(NBLADE + 2, 6)
LSTAGE=LSTAGE+2
C
C *** SINCE THE CALCULATION AND CHECKING IS TO BE CONTINUED UPSTREAM FOR NO MORE THAN 3 WHOLE STAGES, IT IS ASSUMED THAT OR(DX), Z2P/ZK2 AND D(CX)/CX AT STAGES PREVIOUS TO THESE WILL NOT BE AFFECTED BY THE ADDITION OF ONE MORE
**Q45. - EFN SOURCE STATEMENT - IFN(I) -**

**C**
**C**
**C**

**STAGE. THEREFORE THE VALUES CALCULATED FOR THE PREVIOUS**
**CONFIGURATION ARE TO BE SAVED FOR USE IN THE NEW**
**CONFIGURATION**

***NOTE: ONE VERSION OF THE ITERATION USES DR/DX AND DICR/DX.***

DO 160 J=1,NLINES
RSLOPE(1,J)=RSLOPE(3,J)
RCURVE(1,J)=RCURVE(3,J)
160 CSLOPE(1,J)=CSLOPE(3,J)
GO TO 115

**C**
**C**

***PRINT MESSAGE TO INDICATE THAT THE DESIRED PRESSURE RATIO***
***HAS NOT BEEN MET***

170 CALL ERROR(9)
175 CALL OUTPUT

**C**

***RETURN FOR A NEW DATA SET***

IF (I.GE.0) GO TO 1
RETURN
END
**SUBROUTINE CAXIAL**

### C

***** CALCULATES AXIAL VELOCITIES WHICH SATISFY THE AXIAL-VELOCITY EQUATION***

**DOUBLE PRECISION TITLE**

REAL MACH, MAPR, MOLEWT, JOULE

DIMENSION ATAS(25,11), FLOW(32)

**LOGICAL IERROR, YES**

COMM /MATRIX/ ALPHA(10,11), ATAR(29,11), R2(29), C1(1)
X BETA(10,11), BHI(32), BLADE(29), RT(32), C2(1)
X CD(10,11), CPI(32,11), CPCD(6), CR(32,11), C3(1)
X CSLOPE(10,11), CU(32,11), CUCD(5), CUC(32,5), C4(1)
X CX(32,11), CXM(10,11), CAX(32,11), CXRCD(29), C5(1)
X CXS(10,11), DAI(10), DELM(11), DEP(10,11), C6(1)
X DF(20,11), DFAC(29,11), DF2(29,11), DFLOW(32), C7(1)
X EMACH(29,11), FOUN(32,10), FRED(10,11), GAMMA(32,11), C8(1)
X HNN(29), HUB(32), IKK(10), MACH(29,11), C9(1)
X OBAR(29,11), PO(32,11), R(32,11), RCURVE(10,11), C10(1)
X RM(32), RMH(32,11), RINT(11), RISTAG(11), C11(1)
X RSL(32), RSLCD(10,11), RTRAL(11), SOCD(29,5), C12(1)
X SOLID(29,11), SSOCD(29,5), TERN(10,11), TERM(11), C13(1)
X TERM8(11), TIP(32), TITLE(12), C14(1)
X TOL(32,11), TSTAT(11), WI(32,11), W(11), C15(1)
X X(32)

COMM /SCALER/ A, AA, A10A0, A102A0, A303A0, A404A0, CAX 1.27
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, CMEANP, C01G, C X 2.29
X CP12, CPI3, CPI4, CPI5, CPI6, CPI7, CPI8, CPI9, CPI4, C02A0, C04A0, C04A1, CAX 3.28
X CP05, DCP, DC, DC, DC, DC, DC, DC, DC, DC, CAX 3.22
X G, GASK, GJ, GR, GR2, GR3, JOULE, MAPR, MOLEWT, CAX 3.31
X PDC, Q, RPM, TQP, TQR, TQR, TQR, TQRAH, TQRAH, CAX 3.38
X TOCO, TOL, TOL, TOL, TOL, TOL, TOL, TOL, TOL, TOL, CAX 3.33
X TOCLC, TOLR, TOLR, TOLR, TOLR, V, V, V, V, CAX 3.34
X COMMON /INTEGR/ L, IB, IB, IB, IB, IB, IB, IB, IB, IB, CAX 3.35
X I, IOUO, IPASS, IS, IT, JT, JW, J1, J, J2, J3, CAX 3.36
X XJ, XM1, K, Kf, K1, L, LIMITS, LSTEPS, LSTAGE, LIMITS, CAX 3.37
X MSTATE, MINES, NTUBES, Nex, NX, NX, YES, CAX 3.38
EQUIVALENCE (ATRL1, ATRL1), (FLOW1, DFLOW1)

**COMMON /ENERGY/ H, T, GAMMER**

**REAL LIMIT**

C

***** SET LIMITS ON AXIAL VELOCITY TO RESTRAIN THE ITERATION.***

TEST = 1.56
LIMIT = 1.6
L = 0
DO 1 I = IB, NX
L = L + 1

**C *** SATISFY CONTINUITY.***

CALL STREAM
DO 1 J = 1, NLINES

B-6
CAX. - EFN SOURCE STATEMENT - IFN(S1) - 

C *** SAVE THE AXIAL VELOCITIES.
BETA(L,J) = CX(I,J)
1 CONTINUE
DAMP = 10.0
C
C *** INITIALIZE THE ITERATION COUNTER
LOOPY = 0
5 CONTINUE
C *** TURN THE CONVERGENCE TRIGGER ON.
YES = .FALSE.
LOOPY = LOOPY + 1
C
C *** ERROR WILL PRINT THE RESULTS OF THE LAST ITERATION
AND TRANSFER TO A NEW DATA SET
IF (LOOPY .GT. 250) CALL ERROR(4)
DO 125 J = 1, NLINES
C
C *** GET FIRST AND SECOND DERIVATIVES OF R WITH RESPECT TO X
125 CALL XDERIV(X, RSLPE, RCURVE)
C
L = 0
DO 130 I = I1, NX
L = L + 1
CM2 = CX(I, J) ** 2
DO 120 J = 1, NLINES
C
C *** SAVE THE AXIAL VELOCITIES
CX(I, J) = (4.0 * BETA(L, J) + CX(I, J)) * 0.2
BETA(L, J) = CX(I, J)
CU2(J) = CU1(J) ** 2
120 DEPVIL(J) = CU2(J) / R(I, J)
CALL INTEG (DEPV, 2)
A = THERM(I, J)
DO 130 J = 1, NLINES
C
C *** CALCULATE THE ENTHALPY AND CENTRIFUGAL FORCE TERMS AS WELL AS
THE RADIAL VELOCITY TERM.
130 TERM(L, J) = (GJ * (THERM(I, J)) - A)
X + CR(I, JM) ** 2 - CR(I, J) ** 2
X - (CU2(J) - CU2(JM)) - 2.0 * INT(J)
X / CM2
C
C *** FIND ENTHALPY GRADIENT TERM IN AXIAL-VELOCITY EQUATION
C *** OBTAIN FIRST DERIVATIVE OF DEPV WITH RESPECT TO RADIUS,
RESULT IS IN CO
C
C *** NOTE... THE REFERENCE TERMS HAVE BEEN LEFT OUT OF THIS
EQUATION SINCE THEIR DERIVATIVES ARE ZERO
L = 0
DO 245 I = I1, NX
L = L + 1
C
B-7
DO 233 J=1,NLINES
*** DETERMINE PART OF THE ENTROPY TERM.
DEPV(L,J) = THER*2*(T(J,J)/DGP - ALOG(PO1,J))
H = -(C(J,J)**2 +CR(J,J)**2 +CU(J,J)**2)/GJ
T = T(J,J)
CALL CRTALP
233 CONTINUE
ALPHA(L,J) = 0.0
DO 235 J=2,NLINES
C *** INTEGRATE THE STATIC TEMPERATURE WITH RESPECT TO ENTROPY.
235 ALPHA(L,J) = ALPHA(L,J-1) +0.5*DT*(TSTAT(J) +TSTAT(J-1))
X = (DEPV(L,J) -DEPV(L,J-1))
210 DO 220 J=1,NLINES
C *** OBTAIN THE FIRST DERIVATIVE OF RADIAL VELOCITY WITH RESPECT
C TO AXIAL LENGTH.
C 220 CALL XDERIV(CR,C Slope,CD)
C L=0
DO 490 I=1,NX
ILL = 0
C *** HELP IS ALTERED TO REDUCE THE EFFECT OF CURVATURE WHEN
C THE ITERATION IS NOT NEAR THE SOLUTION
HELP=1.0
L=L+1
225 DO 240 J=1,NLINES
C *** COMPUTE RADIAL VELOCITIES.
240 CX(J,J) = CX(J,J-1)*SLOPE(L,J)
CM = CX(J,J)/CM
CM2 = HELP*CM**2
245 DO 250 J=1,NLINES
C *** STREAMLINE-CURVATURE TERM IN AXIAL VELOCITY EQUATION
250 DEPV(L,J) = CX(J,J)*SLOPE(L,J)/CM2
CALL INTEG(DEPV,2)
365 ILL = ILL +1
370 DO 400 J=1,NLINES
C *** COMBINE THE TERMS IN THE AXIAL VELOCITY EQUATION.
TERM = (INT(J) +INT(J) +ALPHA(1,J) -ALPHA(1,J))/CM2
X = TERM/(L,J)/HELP
IF (TERM) 381,365,383
380 TERM = 0.0
GO TO 400
C *** CHECK VALUES OF VELOCITY RATIO AGAINST REASONABLE LIMITS
381 IF (TERM>GT-.99) GO TO 390
C *** ALTER HELP TO REDUCE CURVATURE EFFECTS (TEMPORARILY)
C
HELP = HELP*1.1
IF (TERM<.LT.25) GO TO 365
TERM = LIMIT
GO TO 400
383 IF (TERM<.LT.TEST) GO TO 390
HELP = HELP*1.1
IF (TERM<.LT.25) GO TO 365
TERM = LIMIT
GO TO 400
C *** CALCULATE NEW AXIAL VELOCITY.
390 TERM = SQRT(1.0 + TERM)
400 CXNEW(I,J) = TERM*CM
410 CONTINUE
C *** COMPAR VELOCITIES INTO CURVATURE EQUATION WITH THOSE OUT
DO 440 J = 1, NAX
IF (ABS(CXNEW(I,J) - CX(I,J))/CX(I,J)) gt TOLCX) GO TO 450
440 CONTINUE
C GO TO 455
C *** UNSUCCESSFUL CONVERGENCE ON CX
450 YES = .TRUE.
455 DO 460 J = 1, NAX
CX(I,J) = CX(I,J) + CXNEW(I,J)*0.5
460 CONTINUE
C *** SATISFY CONTINUITY
CALL STREAM
C *** MAKE AN ADJUSTMENT ON THE STREAMLINE POSITIONS.
CALL MOVE
490 CONTINUE
C *** CHECK CONVERGENCE OF AXIAL VELOCITIES
1010 L = 0
DO 700 I = IB, NX
L = L + 1
DO 700 J = 1, NAX
IF (ABS((BETA(I,J) - CX(I,J))/CX(I,J)) gt TOLCX) GO TO 1020
700 CONTINUE
L = 0
GO TO 1021
1020 YES = .TRUE.
1021 L = L + 1
C *** MOVE THE LIMITS ON AXIAL VELOCITY. 
TEST = 1.02*TEST 
LIMIT = SQRT(1.0 + TEST)

CAIX
- EFN SOURCE STATEMENT - IFN(S) -
11/02/67
CAIX 471
CAIX 472
CAIX 473
CAIX 474
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CAIX 481
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CAIX 515
CAIX 516
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CAIX 518
CAIX 519
CAIX 520
CAIX 521
CAIX 522
CAIX 523
CAIX 524
IF (YES) GO TO 5
IT = 0
RETURN
END

CAX. - EFN SOURCE STATEMENT - IFN(S) -

11/08/67

CAX 525
CAX 524
CAX 527
CAX 529
SUBROUTINE COPY
LOGICAL FPATH
COMMON /VGEOM/ ALH(29), ALT(29), ALTER.
* ASPECT(29), FPATH, SAVEA(29)
* DOUBLE PRECISION TITLE
REAL MACF, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
* X BETA(10,11), BM(32), BLADE(29), BT(32),
* X CO(10,11), CPI(32,11), CPCO(1), CR(32,11),
* X CSL0PE(10,11), CU(11), CUI(32,11), CUCO(29,5),
* X CX(32,11), CXM(10,11), CXNEW(10,11), CXRAD(29),
* X CXS(10,11), DA(10), DELM(11), DEPV(10,11),
* X DFI(20), DFAC(29,11), DFL(29), DFLW(32),
* X EMACH(29,11), FOUN(20,23,10), FRDEL(10,11),
* X HNN(29), HUB(32), IKK(10), MACH(29,11),
* X OBAR(29,11), PJU(32,11), R(32,11), RCUVF(10,11),
* X RH(32), RHOI(32,11), RINT(11), ROSTAG(11),
* X RSI(21), RSOLE(10,11), RTRAIL(11), SDCO(29,5),
* X SOLID(29,11), SSCU(29,5), TERM1(10,11), TERM(11),
* X TERN(11), TEKMC(11), TIP(32), TITLE(12),
* X TOL(32,11), TSTAT(11), UI(32,11), W(11),
* X TOL(32)
COMMON 'SCALER/ A, AA, A10A0, A20A0, A30A0, AA0440, ASUM,
* X ASUM, BB, CC, CM, CMEAN, CMEANP, COINTG,
* X CPI2, CPI3, CPI4, CPI5, CPI6, CP02, CP03, CP04,
* X COP5, DAMP, DCP, DD, DIFC, DT, DUMMY, ERAS,
* X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
* X PEND, C, RPM, TCP, TERM, TESTBH, TFSTD, TESTMS,
* X TOCG, TOL, TOLAT, TOLB, TOLM, TOLMS, TOLTIP, TOLCP,
* X TOLC, TOLR, TOTINT, TOTPR, Vt, VMI
COMMON /INTERG/ I, IB, I1B, IO, IDUMP, IERROR, IFIRST,
* X G, IOU, IPASS, IS, IT, J, JIN, JJ, JSM,
* X JM, JMI, K, KL, KK, L, LIMIT, LSTAGE,
* X MSTAGE, NLTENGE, NTUBES, NX, NY, YES
EQUIVALENCE (ATAR(1,1), AtAS(1,1)), (FLOW(1), DFLOW(1))
L = I-2
*** IS THE GEOMETRY BEING CALCULATED.
IF (FPATH) GO TO 20
*** PICK UP THE HUB AND TIP RADIUS.
RH(I) = HUB(I)
RS(I) = TIP(I)
GO TO 30
*** SET THE TIP, ESTIMATE THE HUB (LOW) AND COMPUTE THE SPACING.
20 RS(I) = RS(I-1)
DT = (RS(I-1) - RH(I-1))/ASPECT(I)
RH(I) = MIN(RH(I), RH(I-1) + DT*AHLH(I))
XI(I) = X(I-1) + DT
*** ESTIMATE THE AXIAL VELOCITIES, SET THE EFFICIENCY (ON THE
HIGH SIDE) AND ESTIMATE THE TEMPERATURE AND PRESSURE.
30 CALL RSTART
DG 50 J=1,NLINES
CX(I,J) = (CX(:J) * CX(J,JM)) * 0.5

B-11
COPY. - EFN SOURCE STATEMENT - IFN(S) - 11/02/67

ATAR(I,J)=SQR(ATAR(L,J))
PO(I,J)= PO(I-1,J)*PO(L,J)/PO(L-1,J)
TO(I,J)= TO(I-1,J)*TO(L,J)/TO(L-1,J)
CALL THERMP
CUT(I,J)= CU(L,J)
50 CR(I,J)= CR(L,J)
L= 2
CALL STREAM
CALL MOVE
RETURN
END
**DATA** - EFN SOURCE STATEMENT - IFN(S) -  

**SUBROUTINE CATAL**

*** THIS SUBROUTINE PREPARES A MASTER TAPE OF LOSS DATA. 
IF A PERMANENT FILE IS USED THIS ROUTINE IS TO BE 
DISCARDED (THE ENTRY MUST BE CHANGED ALSO). 

DOUBLE PRECISION TITLE 
REAL 'MACH', 'MAPR', 'MOLEWT', 'JOULE 
DIMENSION ATAS(29,11), FLOW(32) 
LOGICAL IERROR, YES 
COMMON /MATRIX/ ALPHAT(10,11), ATAR(29,11), B2(29), 
 X BETAT(10,11), BH(32), BLADE(29), BT(32), 
 X CO(10,11), CPI(32,11), CPCO(6), CR(32,11), 
 X CSLOPE(10,11), CU(11), CUI(32,11), CUCO(29,5), 
 X CX(32,11), CXN(10,11), CXRATO(29), 
 X CXS(10,11), DAI0(10), DEPV(10,11), 
 X DFI(20), DFAC(29,11), DFLO(29), 
 X EMACH(29,11), FOUND(20,3,10), FRDEL(10,11), 
 X HMIN(29), HUB(32), IKK(10), 
 X IQBAR(29,11), PO(32,11), R(32,11), RCURVE(10,11), 
 X SIM(32), RHO(32,11), RINT(11), ROSTAG(11), 
 X RS(32), RSL(10,11), RTRAIL(11), SOCO(29,5), 
 X SOL(29,11), SSCO(29,5), TERMA(11), 
 X TERN(11), TIC(32), TIP(32), TITLE(12), 
 X TOL(32,11), TST(11), U(32,11), W(11), 
 X X(32) 
COMMON /SCALER/ A, AA, A10A0, A20A0, A30A0, A40A0, 
 X AS0A0, P, BB, CC, CP, CMEAN, CMEANP, CINTG, 
 X CPI2, CPI3, CPI4, CPI5, CPI6, CPCO2, CPCO3, CPCO4, 
 X CP05, DAMP, DCF, DD, DIFCM, DT, DUMMY, ERAS1, 
 X G, GASK, GJ, GR, GZ, JOULE, MAPR, MOLEWT, 
 X GPCO, Q, RPM, TCP, TERMD, TESTBH, TESTS, TESTS3, 
 X TOLCK, TOLH, TOTINT, TOTPR, V, VMI, 
 X COMMN /INTEGR/ I, IB, IB1, IDUMP, IERROR, IFIRST, 
 X IG, IOUTTR, IPASS, IS, IT, J, JIN, JJ, 
 X J, JM, J(K), K1, K, LIMIT, LSTAGE, 
 X MSTAGE, NINES, NTUBES, NX, NXI, YES 
EQUIVALENCE (ATAR(1,1), ATAS(1,1)), (FLOW(1), DFLOW(1)) 
DIMENSION Z(387) 
EQUIVALENCE (CO, Z) 
WRITE (6,333) Z 
333 FORMAT (1H1, '////(12X20A4)1) 
READ (5,910)I0 
910 FORMAT (24I3) 
READ 2 
DO 920 =, I1, I2 
920 FORMAT (12F6.0) 
RENT 4 
CALL Q45 
RETURN 

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B-15
DATA

END

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DATA 55
SUBROUTINE DERIV(R,RSLOPE,RCURVE,A)

COMMON /INTEGR/ I, IB, IB1, IDUMP, IERROR, IFIRST,
X IG, IOUTTR, IPASS, IS, IT, J, JIN, JJ, JM, JMI, K, KL, KK, L,
X LIMIT, LSTAGE, MSTAGE, NLINES, NTUBES, NX, NX1, YES
!
DO 5 I=IB1,NX1
L = L+1
AA = (R(I-1,J) -R(I,J))/(X(I-1)-X(I))
BB = (R(I+1,J) -R(I,J))/(X(I+1)-X(I))
RSLOPE(L,J) = (R(I+1,J) -R(I-1,J))/(X(I+1) -X(I-1))
5 RCURVE(L,J) = (AA -BB)/(X(I-1) -X(I+1))*2.0
RETURN
END
SUBROUTINE DRIVE

*** OPTIMIZES TO ONE OF FIVE LIMITS

DOUBLE PRECISION TITLE
REAL MACK, MAPR, MULEX, JDOLE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IEROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), R2(29),
X BETA(10,11), HX(32), BLADE(29), BT(32),
X CO(10,11), CP(32,11), CPCO(16), CR(32,11),
X CSLPHE(10,11), CU(11), CJ(32,11), CUCO(29,5),
X CX(32,11), CAM(10,11), CNEW(10,11), CRATO(29),
X CXS(10,11), DA(10), DELM(11), DEPV(10,11),
X DFI(29), DFACT(29,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUND(20,3,10), FRDEL(10,11),
X HMIN(29,11), HUB(13,11), IKK(10), MACH(29,11),
X DEARI(29,11), POI(32,11), F(32,11), RCUVE(10,11),
X RH(32), RMM(32,11), RINT(11), ROSTAG(11),
X RS(32), RSLPHE(10,11), RTRAIL(11), SNCJ(29,5),
X SOLID(29,11), SSCO(29,5), TERM(110,11), TERA(11),
X TERRM(11), TINC(11), TIP(132),
X T(32,11), TSTAT(11), W(32,11), W(11),
X X(32),
COMMON /SCALER/ A, AA, A1G0, A2G0, A303A0, A404A0,
X A505A0, B, G, CC, CM, CMEAN, CMFANP, COINTG,
X CIP2, CPI3, CPI4, CPI5, CIP6, CP02, CP03, CP04,
X CP05, CAMP, DCP, DD, DIFCM, DT, DUMMY, DRS,
X G, GASK, GJ, GR, GR2, J2, JOULE, MAPP, MOLEW,
X OCIQ, Q, RPM, TCP, TERN, THERM, TESTH, TESTS,
X TGO, TOL, TOLAT, TOLB2, TOLMN, TOLMS, TOLTP, TOLCP,
X TOLX, TOL, TOLINT, TOTPR, V, VMI
COMMON /INTEGRAL/ I, IB, I, IBI, IDUMP, IF, IFERROR, IFI,
X :?I, IOUTTR, IPASS, IS, IT, J, JIN, JJ,
X JM, JMK, K, KL, KK, L, LIMIT, LSTAGE,
X MSTAGE, NELINES, NTUBES, NX, NX1, Y,
COMMON /ATAS(11)/, ATAS(11), FLOW(32), DFL(32),
COMMON /ENERGY/ R, T, GAMMER,
COMMON /VMIN/ V0(29)
COMMON /SPECIAL/ NORM(14), NORM(12), NOFAIL
LOGICAL NDFAIL
REAL MSW, NURM
IF (LSTAGE.GT.11) GO TO 8

C **** CALCULATE INLET GUIDE VANE EXIT QUANTITIES

T = TUCO
B = THERM(11)
D = 5 J = 1, NELINES
CU(5,J) = (CUCO(5,1)/R(5, J) + CUCO(5,2))/R(5,J) + CUCO(5,3)
X = (CUCO(5,4) + CUCO(5,5)R(5,J))/R(5,J)
H = -(C(5,J)**2 + CR(5,J)**2 + CU(5,J)**2)/GJ
CA = IANTLP
C = C = PUCO -W(J)*(PUCO -PUCO*F(XP1(1TEGRM(TSTAT(J)-B)/DCP))

B-18
A CONTINUE
DO 50 = 1, IFIRST, LSTAGE, 2

C *** COMPUTE PERTINENT QUANTITIES
J = 1/2
A = (RI1, NLINES) - (RI1-1, NLINES) - (RH(I) + RH(I-1)) / (RS(I) + RS(I-1))
X = -(RH(I) + RH(I-1))
SOLID(I, NLINES) = SOC(I, 1) / (SOC(I, 2) + A) + SOC(I, 3) + (SOC(I, 4) / X)
V = SOC(I, 1) / X
W = SOC(I, 1, NLINES) + (CR(I-1, NLINES) * 2) + CR(I-1, NLINES) * 2

C *** IS THIS AN UPDATE WITH NEW EFFICIENCIES
IF (IPASS.EQ.3 .OR. IPASS.EQ.2) GO TO 15
A = SORT(CXI1, NLINES) * 2 + CR(I, NLINES) * 2
X = (CU(I, NLINES) - U(I, NLINES)) * 2
DRT = 1.0 - A / V + (CU(I-1, NLINES) - CU(I-1, NLINES) - U(I, NLINES) + CU(I, NLINES))
X = N(LINES) / (V*SOLID(I, NLINES) + 2.0)
A = SORT(CXI1, 1) * 2 + CR(I, 1) * 2 + CU(I, 1) * 2
B = SORT(CXI1, 1) * 2 + CR(I, 1) * 2 + CU(I, 1) * 2
DSH = 1.0 - A / V + (CU(I, 1) - CU(I+1, 1)) / (B / SOLID(I+1, 1))
M = -H * A / GJ
T = TOL(I, 1)
CALL ENTHP
CALL GAM
M = 3 / SQRT(GR2) * GAMM + STHAT(J)
REL FLD = ATAN(U(I, 1) - CU(I, 1)) / SQRT(CXI1, 1) * 2 + CR(I, 1) * 2

C *** CHECK FOR LIMIT VIOLATIONS
IF ((OPT - DFL(I) / DFL(I), GT. TOLB2
X * DR ... - DFL(I+1) / DFL(I+1), GT. TOLR2
X * DR ... - MSH - HMN(I) / HMN(I), GT. TOLB2
X * DR ... - (CU(I, NLINES) - VO(I)) / VO(I), GT. TOLB2
X * DR ... - HMIN(I+1) - RFLO.GT. TOLB2 ) GO TO 10

C *** IS CALL OF THE LIMITS TO BE MET
IF (LIMIT.NE.0) GO TO 50

C *** HAS ONE OF THE LIMITS BEEN MET
IF ((ABS(CXI1 - DFL(I)) / DFL(I), LT. TOLB2) .OR.
X = ABS(CXI1 - DFL(I+1)) / DFL(I+1), LT. TOLR2 .OR.
X = ABS(MSH - HMIN(I1) / HMIN(I1), LT. TOLB2 .OR.
X = ABS(CXI1, NLINES) - VO(I) / VO(I), LT. TOLB2 .OR.
X = ABS(REL FLD - HMIN(I+1), LT. TOLB2 ) .AND. NO FAIL ) GO TO 50

10 NO FAIL = .FALSE.

C *** CALCULATE THE TANGENTIAL VELOCITY FROM
THE ROTOR TIP D-FACTOR

Q = 0.5/SCLDIC(1,NLINES)
A = V*(1.0 - CFL(1)) + U(1-1,NLINES) - U(1-1,NLINES) - U(1,NLINES) - U(1,NLINES)
CO(1,1) = -2.0*U(1,NLINES) + A*Q/(1.0 - A*Q)
CO(1,2) = (CRI(1,NLINES)*2 + CR(1,NLINES)*2 + U(1,NLINES)*2 - A*A)/I

Y = 0.0 - A*Q)
ERAS1 = (C1(1,1)*2 - 4.0*C1(1,2)
IF (ERAS1.LT.0.0) CALL ERROR(33)
ERAS1 = SQRT(ERAS1)
B = -CO(1,1) - ERAS1
IF (B.LE.0.0) B = -CO(1,1) + ERAS1
B = 0.5*B
B = AMIN(VD11(1,B)
I = U(1,NLINES)*2 - U(1-NLINES)*C1(1-1,NLINES)*ATAI(1,NLINES)

X = 0.0/6
T = TC(1-1,NLINES)
CALL ENTHALP
PTIP = P0(1-1,NLINES)*EXP((THERM3(1,TSTAT(J)) - THERM3(T))/DCP)

*** CALCULATE THE TANGENTIAL VELOCITY FROM
THE HUB ABSOLUTE MACH NUMBER

SCOC = CX(1,1)*2 + CR(1,1)*2
V = SCOC + U(1,1)*2
H = -V/G
T = TD(1,1)
CALL ENTHALP
CALL GAM
VM1 = GR*GAM*ER*TSTAT(J)
A = VM1*HMM(1)*2 - SCOC
IF (A.LT.0.0) CALL ERROR(39)
CUMNN = SQRT(A)

*** CALCULATE THE TANGENTIAL VELOCITY FROM
THE HUB RELATIVE FLOW ANGLE

CUBETA = U(1,1) - SQRT(CX(1,1)*2 + CR(1,1)*2)*TAN(HMM(1+1))

*** CALCULATE THE TANGENTIAL VELOCITY FROM
THE STATUR HUB D-FACTOR

AA = (-SQRT(CX(1+1,1)*2 + U(1+1,1)*2 + CR(1+1,1)*2) - 
X) CUX(1+1,1)/2./SOLID(1+1,1)/(DFL(1+1,1-1))
BB = 5/(DFL(1+1-1)/SOLID(1+1,1))
CC = 4*A*B/(bb*BB-1.1)
AA = (CX(1,1)*2 + CR(1,1)*2) - AA*A)/I - BB*BB)
AA = CC*CC - AA

*** ERROR TRANSFER TO A NEW DATA SET

IF (AA.LT.0.0) CALL ERROR(11)
AA = SQRT(AA)

*** CHECK FOR MULTIPLE POSITIVE ROOMS

CUX(1,1) = -CC*AA

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C *** SELECT THE MINIMUM OF THE HUB TANGENTIAL VELOCITIES

\[
\text{CU}(i,1) = \text{MINM(CU}(i,1), \text{CUH}, \text{CURETA})
\]

\[
H = (\text{CU}(i,1) \times U(i,1) - \text{CU}(i-1,1) \times U(i,1)) \times \text{ATAR}(i,1) \times 2.0 / GJ
\]

T = TO(i-1,1)

CALL ENThALP

A = (KI(i,1) - RH(I))/(R*S(i) - RH(I))

A = NORM(K) \times \text{CU}(i,1)/(\text{CU}(i,1) + A) \times \text{CU}(i,3)

X = (\text{CU}(i,1) + \text{CU}(i,5) \times A)

C *** CALCULATE THE REQUIRED TIP TOTAL PRESSURE

PO(i,NLINES) = \text{MINM} PTIP, PO(i-1,1) \times \text{EXP}((\text{TH}M3(T\text{STAT}(J)))

X = \text{THERM}3(T)/DCP \times A

C *** DETERMINE FLOW PARAMETERS

15 DO 20 J=1,NTUBES

C *** DETERMINE THE TOTAL PRESSURES FROM THE PROFILE

A = (K(i,J) - RH(I))/(R*S(i) - RH(I))

20 PO(I,J) = PO(I,NLINES) \times NORM(K) \times (\text{CU}(I,1)/(\text{CU}(I,2) + A) \times \text{CU}(I,3))

DO 30 J=1,NLINES

IF (PO(I,J) \times LE.POI(I-1,J)) CALL ERROR (22)

C *** GET THE TOTAL TEMPERATURE PROFILE

CALL THERM2(PO(I,J)/PO(I-1,J),TO(I,J)/TO(I-1,J))

H = THERM1(TO(I,J)) - THERM1(TO(I-1,J))

H = H/ATAR(I,J)

C *** COMPLETE THE CORRESPONDING TANGENTIAL VELOCITY

\[
\text{CU}(i,J) = (0.50 \times H \text{GJ} + \text{CU}(i-1,J) \times U(i-1,J)) / U(i,J)
\]

T = TO(I-1,J)

CALL ENThALP

TO(I,J) = T\text{STAT}(J)

H = ATAS(I,J) \times H

CALL ENThALP

PO(I+1,J) = PO(I-1,J) \times \text{EXP}((\text{TH}M3(T\text{STAT}(J)) - \text{TH}M3(T))/DCP)

CALL THERM2

TO(I,J) = T0(I,J)

CP(I+1,J) = CP(I,J)

\[
\text{GAMMA}(I+1,J) = \text{GAMMA}(I,J)
\]

C *** DETERMINE THE TANGENTIAL VELOCITY AT THE STATOR EXIT

30 CU(I+1,J) = (\text{CU}(I+1,1)/RI(I+1,J) \times \text{CU}(I+1,3))/RI(I+1,J)

X = (\text{CU}(I+1,4) \times \text{CU}(I+1,5) \times R(I+1,J) \times R(I+1,J))

B-21
50 CONTINUE
*** UPDATE THE EXIT

DU 60 I=1,X,NX
DC 60 J=1,NLINES
PD(I,J)= PD(I-1,J)
CU(I,J)= CU(I-1,J)*R(I-1,J)/R(I,J)
CP(I,J)= CP(I-1,J)
TC(I,J)= TC(I-1,J)
60 GAMMA(I,J)= GAMMA(I-1,J)
RETURN
END
SUBROUTINE ENALP
DOUBLE PRECISION TITFL
COMMON /ENERGY/ T, GAMER

*** CALCULATES THE TEMPERATURE RISE CORRESPONDING TO AN ENTHALPY CHANGE

REAL MATM, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)

LOGICAL IERROR, YES:
COMMON /MATRI/ ALPHA(10,11), ATAR(29,11), B2(29),
X BELA(10,11), BMI(32), BLADE(29), HT(32),
X C0(10,11), CP(32,11), CPCO(64), CR(32,11),
X CSLP(10,11), GU(11), CU(32,11), CUCO(29,5),
X CXY(32,11), CXM(10,11), CUSEW(10,11), CUSE(29,29),
X CXS(10,11), DA(11), DELM(11), DEP(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUND(20,3,10), FRDEL(10,11), GAMMA(32,11),
X HMA(29), HUB(32), IKK(10), MACH(29,11),
X OB(29,11), PO(32,11), K(32,11), RCURVE(10,11),
X RHE(32), RHO(32,11), INT(11), RO(JSTAG(11),
X RS(32), KSOLVE(10,11), RTRAIN(11), SOCO(29,5),
X SOL(29,11), SSOC(29,5), TERM(10,11), TERM(11),
X TERMS(11), TERMC(11), TIP(32),
X TO(32,11), TSTAG(11), U(32,11),
X T3(32)

X 505A, P, BB, CC, CM, CMEAN, CMEANP, CINTG,
X CP12, CP13, CP14, CP15, CP16, CP02, CP03, CP04,
X CP05, CAMP, UCP, DD, DFCM, DT, DUMMY, ERAS,
X G, GASK, UG, GK, GR2, JOULE, MAPR, MOLEWT,
X PUCO, Q, RPM, TCP, TERM, TESTB, TESTD, TESTS,
X TECO, TOL, TOLAT, TOLIB, TOLMIN, TOL45, TOLTP, TOLCP,
X TOLX, TOLA, TCTINT, TOTPR, V, VMI
COMMON /INTEGR/ I, IB, IBI, IDUMP, 'ERROR, IFIRST,
X IG, IOUT, IPASS, IS, IT, J, JIM, JJ,
X JF, JML, K, K1, KK, L, LIMIT, LITAGE,
X MSTATE, MLINES, NTURE, NX, NX1, YES

EQUVALENCE (ATAK(1,1), ATAS(1,1)), (FLOW(1),DFLOW(1))

HOT= THERMI(T)
TSTAT(1)= H/CP(1,1) + T
DO 10 IER=1,25
HIT= THERMI(TSTAT(1))
E=H-HIT + HOT
TSTAT(1)= H/CP(1,1) + TSTAT(1)
IF (ABS(E) .LE. 0.01) GO TO 20
10 CONTINUE
CALL ERROR(9)
20 RETURN
END
SUBKOUTINE ERROR (IERR)
DOUBLE PRECISION TITLE
REAL MACR, MAPK, MOLEWT, JOULF
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29), EPRO 962
X BETAL(10,11), BNL(32), BBAE(9), AT(32), EPRO 963
X CO(10,11), CPE(32,11), CPCE(6), CRI(32,11), ERR 964
X CSLKPE(10,11), GUZ2(11), CUI(32,11), CJOC(29,5), ERR 970
X CX1(32,11), CX(10,11), DXNEW(10,11), CXRTG(29), ERR 971
X CXS(10,11), DA(10), DELM(11), DEXP(10,11), ERR 972
X DFZ(20), DFACIT(29,11), DFIL(29), DFLOW(32), ERR 973
X EMACH(29,11), FUNKD(29,3,10), FREDL(10,11), GAMMA(32,11), ERR 974
X HNN(29), HUB(32), IKK(10), MACH(29,11), EPRO 975
X QHAR(29,11), PQD(32,11), H(32,11), RCURVE(10,11), ERR 976
X RMD(32), PHU(32,11), RINT(11), ROSTAG(11), ERR 977
X RS(32), RSLKPE(10,11), RTRAIL(11), SOCO(29,5), ERR 978
X SCLD(29,11), SSCD(29,5), TERM(10,11), TERM(11), ERR 979
X TERM(11), TCM(11), TIP(32), TITLE(12), ERR 980
X TOL(32,11), TSTAT(11), UT(32,11), W(11), ERR 981
X X(32), ERR 982
COMMON /SCALER/ A, AA, A10A0, A202A0, A303A0, A404A0, ERR 983
X AS05AO, B, BA, CC, CP, CMEAN, CMANP, CMINGT, ERR 984
X CPI2, CPI3, CPI4, CPI5, CPI6, CPI7, CPI8, CPI9, CPI10, ERR 985
X CPIO5, DAPM, DCP, DD, DIFC, DT, DUMMY, ERA1, ERR 986
X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT, ERR 987
X POCO, C, RPM, TCP, TERM, TESTBH, TESTDS, TESTMS, ERR 988
X TOCO, TOL, TOLAT, TOLB7, TOLMIN, TOLMS, TOLTP, TOLCP, ERR 989
X TOC, TOL, TOLAT, TOLB7, TOLMIN, TOLMS, TOLTP, TOLCP, ERR 989
X TOLCX, TOLR, TOLINT, TOLPR, V, VML, ERR 990
COMMON /INTEGR/ I, IB, IBL, IDUMP, IERROR, IFIRST, ERR 991
X UG, ICUTRE, IPASS, IS, IT, J, JIN, JJ, ERR 992
X JNM, JN1, J, K, K, K, L, LIMIT, LSTAGE, ERR 993
X NSTAGE, NLIINES, NTURES, NX, NX1, YES
X EQUIVALEANCE (ATAR(11), ATAS(1,1)), (FLOW(1),DFLOW(1))
COMMON /ENERG/ F, T, GAMMER
COMMON /VMIN/ V(29)
INTEGER ALTER
COMMON /SPEC/ NORM(14), NX2, NO FAIL
COMMON /VGEN/ ALH(29), ALI(29), ALTER
COMMON /ASC/ (29)
COMMON /FPATH/ (29)
COMMON /SAVEA/ (29)
DATA IER /0/
WRITE (6,5) IERR
5 FORMAT (/// 13H ERROR NUMBER 13///)
IER = IER + 1
IF (IER.GT.25) GO TO 1050
GO TO 110, 110, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
X 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250
X 260, 270, 280, 290, 300, 310, 320, 330, 340, 350, IERR
10 WRITE (6,11)
11 FORMAT (9X 65H THE LOSS DATA SFT REQUESTED FROM THE MASTER FILE IS
X NOT AVAILABLE )
K1 = 1
GO TO 1040
20 WRITE (6,21) 1
21 FORMAT (9X 57H THE AXIAL MACH NUMBER OF THE MIDDLE STREAMLINE AT STFRRN015
XATION I3 / 9X 14 EXCEEDS 1.0 )
GO TO 1300
30 WRITE (6,21) : 1
31 FORMAT (9X 44H CONTINUITY COULD NOT BE SATISFIED AT STATION I3 )
GO TO 1000
40 WRITE (6,91)
41 FORMAT (9X 40H HELIX AXIAL VELOCITY ITERATION HAS FAILED )
GO TO 1000
50 WRITE (6,51) DELM
51 FORMAT (9X 52H HELIX FRACTIONAL MASS FLOWS ARE NOT INCREASING / 9X
X 11F10.3 / 9X 24H THEY WILL BE CHANGED TO )
A= 1.0/FLCAT(NITRES)
DELM= 0.0
GO 52 J=2,NLINES
52 DELM(J)= DELM(J-1)+A
WRITE (6,53) DELM
53 FORMAT (9X 11F10.3)
GO TO 1040
60 WRITE (6,61)
61 FORMAT (9X 52H THE NUMBER OF STREAMLINES MUST BE EITHER 5,7,9 OR 11 )
X /9X 21H EXECUTION TERMINATED )
GO TO 1030
70 WRITE (6,71)
71 FORMAT (9X 35H NO MORE THAN 12 STAGES CAN HE INPUT )
MSTAGE= 12
GO TO 1040
80 WRITE (6,81HI,1,J)
81 FORMAT (9X 23H HELIX ENTHALPY OF E14.5, 30H HAS LEAD TO A FAI )
XURE TO FIND /9X 26H HELIX TEMPERATURE NEAR STATION I3, 15H AND STREAML )
X13 )
GO TO 1020
90 WRITE (6,91)
91 FORMAT (9X 58H THE DESIRED PRESSURE RATIO COULD NOT BE MET (WARNING
X ONLY ) )
GO TO 1040
100 WRITE (6,101)
101 FORMAT (9X 68H EITHER A NON-POSITIVE INLET TEMPERATURE OR PRESSUR )
X HAS BEEN READ IN )
TCO= ABS(TOCU)
PCO= ABS(PCOC)
IF (TCO>PCO, EQ.0.0 ) GO TO 1010
GO TO 1040
110 WRITE (5,111)
111 FORMAT (9X 34H HELIX STATOR HUB D-FACTOR AT STATION 13, 16H IS UNATTAF )
XINABLE )
GO TO 1000
120 WRITE (6,121)
121 FORMAT (9X 60H HELIX NEGATIVE STATIC TEMPERATURE HAS BEEN CALCULATED )
A T ERR 1044
X STATION I3, 5H CHECK /9X 33H HELIX INLET CONDITIONS AND THE AREA )
GO TO 1020
130 WRITE (6,131)
131 FORMAT (9X 36H HELIX NEGATIVE AREA IS NEEDED AT STATION I3 )
GO TO 1000
140 WRITE (6,141)
141 FORMAT (9X 44H NON-POSITIVE ASPECT RATIO HAS BEEN READ IN)
ASPECT1= 2.5
ERROR - LFN SOURCE STATEMENT - IFN(S) - 11/02/67

GO TO 1040 ERR01073
150 WRITE (6,151) 1 ERR01074
151 FORMAT (9X 5HA NON-POSITIVE TOTAL TEMPERATURE HAS BEEN FOUND AT SERR01075
STATION 13 ) ERR01075
IER= IER +5 ERR01076
GO TO 1020 ERR01077
160 WRITE (6,161) J+1 ERR01078
161 FORMAT (9X 13DON STREAMLINE 13, 13H NEAR STATION 13, 52H A NON-POS-FRR01079
XITIVE STATIC TEMPERATURE HAS BEEN DETECTED ) ERR01080
GO TO 1020 ERR01081
170 WRITE (6,171) BLADE(I) ERR01082
171 FORMAT (9X I5, 44H IS AN ILLEGAL SELECTION OF A LOSD DATA SET. / ERR01083
X 9X 24HT WILL BE CHANGED TO 1. ) ERR01084
IER= IER +5 ERR01085
BLADE(I)= 1 ERR01086
GO TO 1040 ERR01087
180 WRITE (6,181) ERR01088
181 FORMAT (9X 64HNONE OF THE AERODYNAMIC LIMITS COULD BE MET AT ONE ERR01089
XT THE STAGES) ERR01090
GO TO 1060 ERR01091
190 WRITE (6,191) ERR01092
191 FORMAT (9X 38HTHE ITERATION ON EFFICIENCY HAS FAILED ) ERR01093
GO TO 1600 ERR01094
200 WRITE (6,201) ICUTTR ERR01095
201 FORMAT (112, 29H IS AN ILLEGAL OUTPUT TRIGGER ) ERR01096
ICUTTR= 1 ERR01097
GO TO 1040 ERR01098
210 WRITE (6,211) ERR01099
211 FORMAT (9X 45HAN UNREASONABLE HUB BLOCKAGE HAS BEEN READ IN ) ERR01100
8H(I)= 1.0 ERR01101
GO TO 1040 ERR01102
220 WRITE (6,221) I ERR01103
221 FORMAT (9X 59HTHE TOTAL PRESSURE HAS DROPPED ACROSS THE ROTOR AT SERR01104
STATION 13 ) ERR01105
GO TO 1000 ERR01106
230 WRITE (6,231) I ERR01107
231 FORMAT (9X 44HTHE HUB AND TIP RAMP ANGLE LIMITS AT STATION 13 /9X ERR01108
X 25HAVE BEEN READ IN AS ZERO ) ERR01109
RHUD(I)= 20.0 ERR01110
GO TO 1040 ERR01111
240 GO TO 1010 ERR01112
250 WRITE (6,251) ERR01113
251 FORMAT (9X 45HAN UNREASONABLE TIP BLOCKAGE HAS BEEN READ IN ) ERR01114
3T(I)= 1.0 ERR01115
GO TO 1040 ERR01116
260 WRITE (6,261) I ERR01117
261 FORMAT (9X 44HTHE ITERATION ON TEMPERATURE RISE HAS FAILED ) ERR01118
GO TO 1000 ERR01119
270 WRITE (6,271) ERR01120
271 FORMAT (9X 13DON STREAMLINE 13, 11H AT STATION 13, 54H A NON-POS-FRR01121
XITIVE STATIC TEMPERATURE HAS BEEN CALCULATED ) ERR01122
IER= IER +9 ERR01123
GO TO 1000 ERR01124
280 WRITE (6,281) I ERR01125
281 FORMAT (9X 58HAN UNREASONABLE D-FACTOR LIMIT HAS BEEN READ IN AT SERR01126
STATION 13 ) ERR01127

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ERROR.  -  IFN  SOURCE STATEMENT  -  IFN(S)  -

0FL(I)= 0.3
GO TO 1040
290 WRITE (6,291) I, J
291 FORMAT (9X 57HTHE PRANDLE-MEYER ANGLE ITERATION HAS FAILED NEAR STATION I3)
   XATION I3, 14H ON STREAMLINE I3 )
   GO TO 1000
300 WRITE (6,301) I
301 FORMAT (9X 33HTHE MERIDIONAL MACH NO. LIMIT AT STATION I3, 49H IS TOO LOW ERR01132
   X, THE MERIDIONAL MACH NO. IS GREATER 19X 15HTHAN THE LIMIT. )
   GO TO 1000
310 GO TO 1010
320 WRITE (6,321) I
321 FORMAT (9X 83HEITHER A PRESSURE DROP OR A NON-POSITIVE TEMPERATURE ERR01141
   X HAS BEEN CALCULATED AT STATION I3)
   IER= IER +9
   GO TO 1000
330 WRITE (6,331) I
331 FORMAT (9X 33HTHE ROTOR TIP D-FACTOR AT STATION I3, 15H CAN NOT REFRR01146
   X MET )
   GO TO 1000
340 WRITE (6,341) ALTER
341 FORMAT (9X 55HTHE EXIT AREA REQUIRED BY THE VELOCITY RATIO AT STATION I3 A
   XION I3, 19X 21H CAN NOT BE DETERMINED )
   GO TO 1000
350 WRITE (6,351) I
351 FORMAT (9X 36HTHE ITERATION IN GEOMETRY HAS FAILED )
1000 CALL OUTPUT
1010 CALL Q45
1020 CALL PDU: P(NU+ALPHA,X(32),1,A,VML,1,1,YES,2,NOR,M,NOFAIL,1,VO,VO(29)
   X,1,AL,SAVEA(29),1)
   GO TO 101C
1030 CALL EXIT
1040 RETURN
1050 WRITE (6,1051)
1051 FORMAT (9X 56HTOC MANY ERROR HAVE BEEN DETECTED. EXECUTION TERMINERRR01163
   XATED )
   GO TO 1030
END

11/02/67
SUBROUTINE GAM

*** THIS SUBROUTINE CALCULATES THE RATIO OF SPECIFIC HEATS

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE

DIMENSION ATAS(29,11), FLOW(32)

LOGICAL IEPRIOR, YES

COMMON /MTRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETAI(10,11), BH(32), BLADE(29), RT(32),
X CI(10,11), CP(32,11), CPCO(6), CRI(32,11),
X CSLOPE(10,11), CU(32,11), CUCO(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CXRATII(29),
X CAS(10,11), DA(10), DELM(11), DEPV(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUNDO(29,3,101), FRDEI(10,11), GAMMA(32,11),
X HNN(29), HUB(32), IKK(10), MACH(29,11),
X OBAR(29,11), PUI(32,11), R(32,11), RCUVE(10,11),
X RHI(32), KHOI(32,11), RINT(11), ROSTAG(11),
X RS(32), ASLOPE(10,11), RTRAIL(11), SOC0(29,5),
X SOLI(29,11), SSCO(29,5), TERM1(10,11), TERMA(11),
XTERM(11), TERNCI(11), TIP(32), TITLE(12),
X TG(32,11), TSTAT(11), U(32,11), W(11),
X(32)

COMMON /SCALE/ A, AA, A10A0, A2D2A0, A303A0, A404A0,
X AQ05A0, B, BB, CC, C, CM, CMEAN, CMEANP, CINTG,
X CPI2, CPI3, CPI4, CPI5, CPI6, CPI, CP02, CP03, CP04,
X CP05, CAMP, DCP, D/2, DIFCM, DT, DUMMY, EAS1,
X G, CASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X PGCO, C, RPM, TCP, TERMD, TESTRH, TESTOS, TESTMS,
X TGC0, TGL, TGLAT, TOLB2, TOLMIN, TOLMS, TOLTP, TOLCP,
X TLOCX, TOLR, TOTINT, TOTPR, V, VMI

COMMON /INTEGR/ I, IB, IBI, IJUMP, IERROR, IFIRST,
X IG, IUUTTR, IPASS, IS, IT, J, JIN, JJ,
X JMP, JP1, K, KL, KK, L, LIMIT, LSTAGF,
X MSTATE, MLNLS, NTUBES, NX, NXL, YES

EQUIVALENCE (ATAR(1,1), ATAS(1,1)), (FLOW, DFLOW)

COMMON /ENERGY/ F, T, GAMMER

A= CPC(11) + (PCPO2) + (PCPIU3) + (PCPIV4) + (PCPIV5) + PCPIV6
X #STAT(J) #STAT(J) #STAT(J)
X #STAT(J) #STAT(J)
GAMMER= A/(A - DCP)
RETURN
END
SUBROUTINE GEOM
COMMON /VANE/ NBBLADE
DOUBLE PRECISION TITLE
REAL MACP, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL ERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), R2(29),
X BETA(10,11), BM(32), BLADE(29), RT(32),
X CC(10,11), CPI(32,11), CPC0(16), CR(32,11),
X C5L0PE(10,11), CUI(32,11), CUCO(29,5), C9UO(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CXRATO(29),
X CXS(10,11), DAT(10), DELM(11), DEPV(10,11),
X DFL(201), DFACT(29,11), DFL(29), DFL0W(32),
X EMACH(29,11), FOUND(20,3,10), FREDL'0,11, GAMMA(32,11),
X HMIN(29), HUB(32), IKK(10), MACH(29,11),
X OBARI(29,11), POI(32,11), R(32,11), KCPUV(10,11),
X RHE(32), RH0(32,11), RINT(11), RSTAG(11),
X RS(32), SLOPE(10,11), RTRAIL(11), SCDC(29,5),
X SCLID(29,11), SUCO(29,5), TERM(10,11), TERA(11),
X TERMSH(11), TERM(11), TIP(32), TITLE(12),
X TL(32,11), TSTAT(11), U(32,11), W(11),
X X(32)
COMMON /SCALER/ A, AA, A10A0, A202A0, A303A0, A404A0,
X A505A0, R, BB, CC, CM, CMEAN, CMEANP, CUNITG,
X CP12, CPI3, CPI4, CPI5, CPI6, CPO2, CPO3, CPO4,
X CP05, DIMP, DCP, D0, DIFCM, DT, DUMMY, ERASL,
X G, GASH, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X PPC0, G, RPM, TCP, TERM, TESTBH, TESTDS, TEST4S,
X TCO, TOL, TOLAT, TOLB2, TOLMIN, TOLMS, TOLTIP, TOLCP,
X TOLCX, TOLR, TOLT, TTOPR, V, VMT
COMMON /INTEGR/ I, IB, IBL, IDUMP, IERROR, IFIRST,
X IGE, IOUTR, IPASS, IS, IT, J, JIN, JJ,
X J, JM, JMT, K, KL, KK, K, L, LIMIT, LSTAGE,
X MSTAGE, NLINES, NTUBES, NX, NX1, YES
EQUIVALENCE (ATAR(11,1), ATAS(1,1)), (FLOW(11), DFLOW(11))
INTEGER ALTER
COMMON/SPECIAL/ NORM(14), MX2, NO FAIL
COMMON /VEOEM/ ALH(29), ALT(29), ALTM,
X ASPECT(29), FPPTH, SAVEA(29)
REAL NOHP

C *** ITERATION DAMPING FACTOR
DATA DURARD / 0.4 /
C
C *** SET THE BLADE ROW COUNTER TO ZERO
NTRY = 0
C
C *** AFTER ONE BLADE ROW HAS BEEN ALTERED THE PROGRAM WILL
C LOOK AT ALL OF THE OTHER BLADE ROWS BEFORE CHECKING
C OR ALTERING THIS ONE AGAIN
10 ALTER = ALTER + 1
C
C *** IF THE BLADE ROW JUST CHECKED OR ALTERED WAS PHYSICALLY

B-29
GEOM. - EFN SOURCE STATEMENT - IFN(S) -

THE LAST BLADE ROW IN THE COMPRESSOR RETURN TO THE
FIRST ONE BEING CONSIDERED

IF (ALTER.GT.LSTAGE) ALTER= IFIRST

*** CALCULATE THE VELOCITY RATIO
V TO J = CX(ALTER,JM)/CX(ALTER-1,JM)

*** CHECK THE ACTUAL VELOCITY RATIO AGAINST THE DESIRED RATIO
IF (ABS(V TO J -CXRAT(ALTER)) .GT. TOL.TIP) GO TO 30

*** INCREMENT THE BLADE ROW COUNTER
NTRY = NTRY+1

*** HAVE ALL BLADE ROWS BEEN CHECKED
IF (NTRY.LE.NBLADE) GO TO 10

20 RETURN

*** INDICATE THAN AN UNDESIRABLE RATIO HAS BEEN FOUND
30 ERROR = .TRUE.

*** SAVE THE HUB, TIP AND AXIAL COORDINATES
OLD HUB = RH(ALTER)
OLD TIP = RS(ALTER)
OLD X = X(ALTER)

*** CALCULATE THE TIP AND HUB LIMITS
TIP LIMIT = RS(ALTER-1) + (X(ALTER) - X(ALTER-1)) * ALT(ALTER)
HUB LIMIT = RH(ALTER-1) + (X(ALTER) - X(ALTER-1)) * ALH(ALTER)

*** DETERMINE THE EXIT AREA
AREA = (RS(ALTER) - RH(ALTER)) * (RS(ALTER) + RH(ALTER))

*** CALCULATE AN AREA CHANGE
CHANGE = AREA * ((V TO J - CXRAT(ALTER)) ** F.TARD - 1.0)

*** TEST FEASIBILITY OF THE AREA CHANGE
IF (-D AREA .GE. AREA.OR.D AREA.GE.CLD HUB**2) CALL ERROR (34)

*** IS THE AREA TO BE INCREASED
IF (D AREA.GT.0.0) GO TO 70

*** DETERMINE THE NEW HUB
RH(ALTER) = SQRT(RH(ALTER)**2 - D AREA)

*** IS THE HUB LESS THAN THE LIMIT
IF (RH(ALTER) .LT. HUB LIMIT) GO TO 90

*** CALCULATE THE AREA TO BE OBTAINED FROM THE TIP
D AREA = (HUB LIMIT - RH(ALTER)) * (HUB LIMIT + RH(ALTER))

*** SET THE HUB ON ITS LIMIT
RH(ALTER) = HUB LIMIT

*** DETERMINE THE TIP RADIUS
RS(ALTER) = SQRT(RS(ALTER)**2 + D AREA)

B-30
GEOm. - EFN SOURCE STATEMENT - IFN(S) -

C  *** IS THE TIP ABOVE ITS LIMIT
IF (RS(ALTER) .GE. TIP LIM) GO TO 90

C  *** CALCULATE THE ANNULUS AREA
AREA = (RS(ALTER) - RH(ALTER)) *(RS(ALTER) + RH(ALTER))

C  *** DETERMINE THE ASPECT RATIO FROM THE REQUIRED AREA
40 AA = (ALT(ALTER) - ALH(ALTER)) *(ALT(ALTER) + ALH(ALTER))

C  *** CHECK FOR TWO POSITIVE ROOTS
IF (AA .EQ. 0.0) GO TO 50
BB = (RS(ALTER-1) * ALT(ALTER) - RH(ALTER-1) * ALH(ALTER)) / AA
CC = ((RS(ALTER-1) - RH(ALTER-1)) *(RS(ALTER-1) + RH(ALTER-1)) - AREA)
X / AA
AA = -BB + SQRT(BB**2 - CC)
GO TO 60

50 AA = ((RS(ALTER-1) - RH(ALTER-1)) *(RS(ALTER-1) + RH(ALTER-1)) - AREA)
X / (2.0 * ALH(ALTER) *(RS(ALTER-1) + RH(ALTER-1)))

60 ASPCT = (RS(ALTER-1) - RH(ALTER-1)) / AA

C  *** RETARD THE ASPECT RATIO CHANGE
IF (ABS((ASPECT(ALTER) - ASPCT) / ASPECT(ALTER)) .GT. 0.1)
X ASPECT = ASPECT(ALTER) *(1.0 + SIGN(0.1, ASPCT - ASPECT(ALTER)))

C  *** CHECK THE LIMIT
ASPECT(ALTER) = AMIN1 (ASPECT, SAVEA(ALTER))

C  *** CALCULATE THE AXIAL LENGTH
DT = (RS(ALTER-1) - RH(ALTER-1)) / ASPECT(ALTER)
X(ALTER) = X(ALTER-1) + DT

C  *** SET THE HUB AND TIP ON THEIR LIMITS
RH(ALTER) = RH(ALTER-1) + DT * ALH(ALTER)
RS(ALTER) = RS(ALTER-1) + DT * ALT(ALTER)
GO TO 90

C  *** IS THE ASPECT RATIO ON ITS LIMIT
70 IF (ASPECT(ALTER) .EQ. SAVEA(ALTER)) GO TO 80
AREA = AREA + D AREA
GO TO 40

C  *** DETERMINE THE TIP RADIUS
80 RS(ALTER) = SQRT(RS(ALTER)**2 + D AREA)

C  *** IS THE TIP ABOVE ITS LIMIT
IF (RS(ALTER) .LE. RS(ALTER-1)) GO TO 90
D AREA = (RS(ALTER) - RS(ALTER-1)) *(RS(ALTER) + RS(ALTER-1))

C  *** SET THE TIP HORIZONTAL
RS(ALTER) = RS(ALTER-1)

C  *** DETERMINE THE NEW HUB
RH(ALTER) = SQRT(RH(ALTER)**2 - D AREA)
90 I = ALTER
GEOM. - EFN SOURCE STATEMENT - IFN(S) -

C
*** MOVE THE STREAMLINES
CALL RADIUS

C
*** EVALUATE THE PRESSURE NORMALIZING FACTOR IF THIS
IS A ROTOR EXIT
K = I/2
IF (K+K.NE.1) GO TO 95
A = (R(I,1,1,NLINES) - R(I,1,1))/ASPECT(I)
NORM(A) = 1.0/(CUCO(I,1,1)/CUCO(I,1,2) + A) + CUCO(I,3)
X = (CUCO(I,4) + CUCO(I,5)*A)*A

C
*** IS THIS THE LAST BLADE ROW
95 IF (ALTER.EQ.LSTAGE) GO TO 130
K = ALTER + 1

C
*** UP-DATE THE DOWN STREAM BLADE ROWS
DO 120 I=K,LSTAGE
DT = (RS(I-1,1) - R(I-1,1))/ASPECT(I)
HUB LIM = R(I-1,1) + DT*ALH(I)
TIP LIM = RS(I-1,1) + DT*ALT(I)
A = R(I-1,1) + (R(I,1) - OLD HUB)*DT/(X(I-1) - OLD X)
B = RS(I-1,1) + (RS(I,1) - OLD TIP)*DT/(X(I-1) - OLD X)
OLD HUB = R(I,1)
OLD TIP = PS(I)
OLD X = X(I)
X(I) = X(I-1) + DT
R(I,1) = A
RS(I,1) = B

C
*** CHECK THE LIMITS
IF (RS(I,1).LT.TIP LIM) GO TO 100
IF (R(I,1).GT.HUB LIM) GO TO 110
GO TO 120

100 RS(I,1) = TIP LIM
110 R(I,1) = HUB LIM
120 CALL RADIUS
130 CALL AN EXIT

C
*** UP-DATE THE COMPRESSOR EXIT
DO 140 I=NX2,NX
140 CALL RADIUS
GO TO 20
END

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INEST. - EFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE INEST

*** MAKES INITIAL ESTIMATES OF AXIAL VELOCITIES FOR
STATIONS BETWEEN BLADE ROWS

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLENT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL ERROR, YES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BM(32), BLADE(29), BT(32),
X CC(10,11), CPI(32,11), CPO(6), CR(32,11),
X CSLOPE(10,11), CUI(11), CUI(32,11), CUO(29,5),
X CX(32,11), CXM(10,11), CNEW(10,11), CXR(10,29),
X CXS(10,11), DA(10), DELM(11), DEP(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUN(20,3,10), FROEL(10,11),
X HMP(29), HUB(32), IK(10), MACH(29,11),
X OBAR(29,11), PDI(32,11), R(32,11), REC(10,11),
X RH(32), RHO(32,11), RINT(11), RO(10),
X RS(32), RSLOPE(10,11), RT(11), SO(29,5),
X SOLID(29,11), SS(29,5), TERM(10,11), T(11),
X TIP(11), TNC(11), TIP(32), TITLE(12),
X TO(32,11), TST(11), U(32,11), W(11),
X X(32)

COMMON /SCALER/ A, AA, A10A0, A20A2A0, A30A3A0, A40A4A0,
X A50A5A0, B, BB, CC, CM, CMAN, CMANP, COINTG,
X CIP12, CIP13, CIP14, CIP15, CIP16, CPO, CPO2, CPO3, CPO4,
X CPO5, DMP, DCP, DD, DIFCP, DT, DUMMY, ERAS1,
X G, GASK, GJ, GR, GRZ, JOULE, MAPR, MOLENT,
X POCO, C, RPM, TCP, TERM, TESBM, TEST2, TEST1, TES1,
X TUCO, TO, TOLAT, TOLB, TOLI, TOLS, TOLTP, TOLCP,
X TOLCX, TOLR, TOTIN, TOTPR, V, VMI,
X COMMON /INTEGR/ I, IB, IB, IDUMP, IERROR, IFIRST,
X IO, IDTR, IPASS, IS, IT, J, JIN, JJ,
X JM, JML, K, K1, KK, L, LIMIT, LSTAG,
X MSTAGE, N LINES, NTUBES, NX, NXL, YES
EQUIVALENCE (ATAR(1,1),ATAS(1,1)), (FLOW(11),DFLOW(11))

HELP=1.0

*** ESTIMATE MID-STREAM VELOCITIES

ROSTAG(II)=PO(I,JM)/TO(I,JM)*GASK
CX(I,JM)=FLOW(I)/(ROSTAG(JM)*(RSM(1)**2-RHM(1)**2))/3.1415927
V=CX(I,JM)**2+CUI(I,JM)**2)/GJ/CPI(I,JM)
ERASI= 1.0-V/TO(I,JM)

*** ERROR TRANSFER TO A NEW DATA SET

IF (ERASI.LE.0.0) CALL ERROR(12)
CX(I,JM)=CX(I,JM)/ERAS1**((1./GMMA(I,JM)-1.))
70 CONTINUE
CM2=CM2*HELP
CM2=CM2*HELP

B-33
*** Calculate values of Cu**2 and estimate static temperatures

DO 100 J=1,NLINES
   CU2(J)=CU(J)**2
   V=(CM2+CU2(J))/GJ/CP(J)
100 TSTAT(J)=TO(I,J)-V

*** Calculate values of Term and radial derivative term

DO 110 J=1,NLINES
   TERM(J)=GJ*(CP(I,J)*TO(I,J)-CP(I,JM)*TO(I,JM))-(CU2(J)-CU2(JM))**2
   IF (TO(I,J)*LT.TOCO) CALL ERROR (15)
110 CONTINUE

*** Calculate derivative of DEPV with respect to radius, result is in CO

*** Calculate values of TermB

DO 120 J=1,NLINES
120 DEPV(J)=CU2(J)/R(I,J)
DO 200 J=1,NLINES
   TERMB(J)=2.0*RINT(J)

*** Calculate CX/CM and CX distributions

DUMMY=(((TE(MA(J)-TERM(J))/CM2)+1.0
   IF (DUMMY)130,140,140
130 CONTINUE
   HELP=HELP*1.25
   GO TO 10
140 IF (DUMMY<1.0)155,150,155
150 CXM(L,J)=1.0
   GO TO 160
155 CXM(L,J)=SQR(DUMMY)
160 CX(I,J)=CMXL(J)*CX(I,J)
200 CONTINUE
   AA= CX(I,JM)**1.6
   BB= CX(I,JM)**0.4
   DO 400 J=1,NLINES
      IF (CX(I,J)SU,AA) CX(I,J)=AA
      IF (CX(I,J)LT,BB) CX(I,J)=BB
400 CONTINUE
210 RETURN
END
SUBROUTINE INLET
C
*** YIELDS INITIAL ESTIMATE OF FLUID FLOW IN THE INLET

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BH(32), BLADE(29), BT(32),
X CSI(10,11), CPI(32,11), CPO(6), CR(32,11),
X CSLOPE(10,11), CU(32,11), CUO(129,5), CRU(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CXRATO(29),
X CXS(10,11), DA(10), DELM(11), DEPP(10,11),
X DF(20), DFAC(T,129,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUND(20), FRDEL(10,11), GAMMA(32,11),
X HMIN(29), HUB(32), IKK(10), MACH(29,11),
X QBAR(29,11), PD(32,11), R(32,11), RCURVE(10,11),
X RH(32), RHO(32,11), RINT(11), ROSTAG(11),
X RS(32), RSLP(10,11), RT(11), SOCO(29,5),
X SOL(10,11), SSC(29,5), T(11), TERMIN(11),
X TERM(11), TERM(11), TIP(32), TITLE(12),
X TOL(32,11), TST(11), U(32,11), W(11),
X X(32)
COMMON /SCALER/ A, AA, A10A0, A20A0, A30A0, A40A0,
X A50A0, B, BB, CC, CM, CMAT, CMATP, CMINE,
X CPI12, CPI13, CPI14, CPI15, CPI16, CPI3, CPI3, CPI3,
X CPO, D, DCP, DCP, DCP, DCP, DCP, DCP,
X G, G, G, G, G, G, JOULE, MAPR, MOLEWT,
X POCO, C, RPM, TCP, THERM, TEBH, TEST, TESTS,
X TOCO, TOL, TOL, TOL, TOL, TOL, TOL, TOL,
X TOLXC, TOLXC, TOLXC, TOLXC, TOLXC, TOLXC, TOLXC, V, VMI
COMMON /INTEGR/ I, IB, IB, IB, IERROR, IFIRST,
X IG, INTR, IPASS, IS, IT, J, JIN, JJ,
X JM, JPL, K, KI, KK, L, LIMIT, LSTAGE,
X MSTAGE, NLINES, NTUBES, NX, NX, YES
EQUIVALENCE (ATAR(1,1),ATAS(1,1), (FLOW(1),DFLOW(1))

DO 10 I=1,5
C
*** GET INITIAL STREAMLINE RADIUS ESTIMATE

CALL RSTART
C
*** GET INITIAL ESTIMATE OF FLUID FLOW

IF (INE.NE.5) GO TO 5
DO 4 J=1,NLINES
4 CU(5,J) = (CU(5,1)/K(5,J) + CUO(5,2)/R(5,J) + CUO(5,3)
X + (CUO(5,4) + CUO(5,5)*R(5,J)))*R(5,J)
5 CALL INEST
C
*** SOLVE CONTINUITY EQUATION

10 CALL STREAM
RETURN
END

B-35
0 READ (5,11) (TITLE(I),I=1,12)
0 READ (5,5) (CP0(I),I=1,6)

0 *** calculate the coefficients needed in the various operations involving cp

0 WRITE (6,12)
0 FORMAT (1MO)
0 CP02=CP03(3)/2.
0 CP03=CP03(4)/3.
INPUT. -  EFN  SOURCE STATEMENT - IFN(S).

CPO4=CPCO(5)/4.
CPO5=CPCO(6)/5.
A10AO=CPCO(1)/CPCO(1)
A202AO=CPC2/CPCO(1)
A303Ao=CPC3/CPCO(1)
A404Ao=CPC4/CPCO(1)
A505Ao=CPCS/CPCO(1)
COINTG= THERM1510.688
CPI2=CPCO(2)/2.
CPI3=CPCO(3)/3.
CPI4=CPCO(4)/4.
CPI5=CPCO(5)/5.
CPI6=CPCO(6)/6.
11 FORMAT (12A6)
KK=1
C
*** INPUT INDEX TO INDICATE WHICH LOSS DATA SETS TO USE
READ (5,910) (IKK(I,J),J=1,10)
K1= IKK(1)
C
*** REWIND MASTER TAPE OF LOSS DATA
935 REWIND 4
DO 950 LI,1,IG
C
*** READ LOSS DATA FROM MASTER TAPE
READ (4) ((FOUND(K,J,KK),K=1,20),J=1,3)
C
*** IS THIS SET DESIRED
IF (K1.LY.1,OR.K1.GT.IG) CALL ERROR(1)
937 IF (K1.NE.L) GO TO 950
C
*** STORE LOSS DATA FROM MASTER TAPE INTO PROPER ALLOCATION
C
TO BE USED IN LOSS SUBROUTINE
C
IF (KK.EQ.10) GO TO 960
KK=KK+1
K1=IKK(KK)
IF (K1.EQ.0) GO TO 960
950 CONTINUE
GO TO 935
960 REWIND 4
KK= KK-1
910 FORMAT (24I3)
C
*** READ THE SCALER QUANTITIES
READ (5,15) MSTAGE, NLINES, IDOUTTR, FPATH, IDUMP, LIMIT,
X FLOW(1), MOLEW, TCGO, TCGO, TOTPR, TOLCX, TOLR, TOLCP, RPM, DAMP
X, TOLMIN, TOLB2, TOLAT, TOLMS, TOLIP, ATAR(1,1), ATAR(1,2), ATAR(1,3)
C
*** ERROR WILL SET THE TEMPERATURE OR PRESSURE TO THE ABSOLUTE
C
VALUE OF SAME AND WILL GO TO A NEW DATA SET IF ONE OF THE

B-37
PAGE 154

IF (POCO.LE.0.0.OR.TOCO.LE.0.0) CALL ERROR(10)

C  *** THE NUMBER OF STREAMLINES MUST BE 5,7,9 OR 11, ERROR
C  WILL TERMINATE EXECUTION

IF (NLINES.LT.5.OR.NLINES.GT.11.OR.MOD(NLINES,2).EQ.0)
  X CALL ERROR(6)

C  *** ERROR RESETS THE NUMBER OF STAGES TO BE CONSIDERED TO 12.
C  NOTE...NEXT DATA SET MAY NOT EXECUTE PROPERLY

IF (MSTAGE.GT.12) CALL ERROR(7)

15 FORMAT (315,L5,2(5,4F10.5/7F10.5/7F10.5))
  NX=2*MSTAGE + 8

C  *** READ THE INLET GEOMETRY AND BOUNDARY LAYER BLOCKAGE FACTORS

READ (5,35) (X(I), RH(I), BH(I), RS(I), BT(I), ASPECT(I),I=1,NX)

IF (FPATH) GO TO 1002

DO 1001 I=6,NX
  HUB(I) = RH(I)
  TIP(I) = RS(I)
1001 CONTINUE

GO TO 1004

1002 NX = NX-3

DO 1003 I=6,NX
  CXRAT(I) = X(I)
  IF (ASPECT(I).LE.0.0) CALL ERROR(14)
  SAVEA(I) = ASPECT(I)
  IF (RH(I).EQ.0.0.AND.RS(I).EQ.0.0) CALL ERROR(23)
  ALT(I) = -ABS(TAN(RS(I)/57.295781))
1003 ALH(I) = ABS(TAN(RH(I)/57.295781))
  NX = NX+3

C  STREAMLINE. THESE NUMBERS MUST INCREASE MONOTONICALLY

1004 READ (5,25) (DEL*(J),J=1,NLINES)
  NTUBES = NLINES-1
  DO 3 I=1,NTUBES
    IF (DEL*(I).GE.DEL*(I+1)) CALL ERROR(5)
3 CONTINUE

C  *** READ THE 'OSS FACTORS ACROSS THE INLET GUIDE VANE
C  FOR THE J-TH STREAMLINE

8 READ (5,20) (W(I),I=1,NLINES)

READ (5,35) (GUCO(5,J),J=1,5)
READ (5,20) (ATAK(6,J),J=1,NLINES)
READ (5,20) (ATAK(7,J),J=1,NLINES)

5 FORMAT (3E20.8)
20 FORMAT (7F10.5)

B-38
INPUT. - EFN SOURCE STATEMENT - IFN(S) -

35 FORMAT (6F10.5)

CALL DATE(DA)
WRITE (6,39) (TITLE(I), I=1,12), (DA(I), I=1,2)
WRITE (6,40) MSTAGE,TOTPR,NLINES,POCO,FLOW(1),TOCO,MO.EWT,RPM,
X TOLCX, TOLB2, TOLAT, TOLR
IF (FPATH) WRITE(6,21) TOLTIP

21 FORMAT (/9X 37HTHE AXIAL VELOCITY RATIO TOLERANCE IS (7.4 /)

WRITE (6,38) (DELNJ,J=1,NLINES)
38 FORMAT (/9X 79HTHE FRACTION OF THE TOTAL MASS FLOW BETWEEN THE HUB
X AND THE J-TH STREAMLINE IS. // 9X 11F7.3 )
WRITE (6,41) NLINES, (W(I), I=1,NLINES)

C
*** WRITE OUT INLET GEOMETRY

39 FORMAT (1H124X14A6)

40 FORMAT (/9X46HTHE INLET GUIDE VANE LOSS COEFFICIENTS FOR THE I3,
X 34H STREAMLINES ARE (FROM HUB TO TIP) // 10X 11F7.4 //)

42 FORMAT ( 9X B5HTHE RATIO OF THE AREAS OF THE LAST 3 STATIONS TO THE INLET
XE AREA OF THE LAST STATOR EXIT ARE F7.4, 211H.F7.4, 2H .)

45 FORMAT (1H1 /// 45X 2H-- 3A4, 15HDESCRIPTION--//=//23X7HSTATIONX
X5HAXIAL11X3HHB6X12HHUB BLOCKAGE7X3HTIP7X12HTIP BLOCKAGE // 25X
X 3HNO.5X10HCORDINATE 6X5HRADIUSX6HFACCTOR 8X6HRADIUS 8X6HFACCTOR/
X 35X5H(IN. ) 10X 5H(IN. ) 23X5H(IN. ) //)

46 FORMAT (20X17, 5F14.3)

WRITE (6,57) (CUCO(I,J), J=1,5)
57 FORMAT ( 9X 6HTHE INLET GUIDE VANE EXIT TANGENTIAL VELOCITY IS SPIN
XECIFIED BY / 9X 3HA = E15.6, 3X 3HB = E15.6, 3HC = E15.6, 3X 3HD =
X E15.6, 3X 3HE = E15.6 //)
WRITE (6,58) CPGC

58 FORMAT (1H033X53HTHE SPECIFIC HEAT POLYNOMIAL IS IN THE FOLLOWING

INPU1818
INPU1821
INPU1822
INPU1823
INPU1824
INPU1825
INPU1826
INPU1827
INPU1828
INPU1829
INPU1830
INPU1831
INPU1832
INPU1833
INPU1834
INPU1835
INPU1836
INPU1837
INPU1838
INPU1839
INPU1840
INPU1841
INPU1842
INPU1843
INPU1844
INPU1845
INPU1846
INPU1847
INPU1848
INPU1849
INPU1850
INPU1851
INPU1852
INPU1853
INPU1854
INPU1855
INPU1856
INPU1857
INPU1858
INPU1859
INPU1860
INPU1861
INPU1862
INPU1863
INPU1864
INPU1865
INPU1866
INPU1867
INPU1868
INPU1869
INPU1870
INPU1871
INPU1872
XFORM // 3X 4HCP = E12.5,3H + E12.5,5H*T + E12.5,8H*T**2 + E12.5,  
X 8H*T**3 + E12.5,8H*T**4 + E12.5,5H*T**5 //)
  INPU1874
  INPU1875
  INPU1876
  INPU1877
  INPU1878
  INPU1879
  INPU1880
  INPU1881
  INPU1882
  INPU1883
  INPU1884
  INPU1885
  INPU1886
  INPU1887
  INPU1888
  INPU1889
  INPU1890
  INPU1891
  INPU1892
  INPU1893
  INPU1894
  INPU1895
  INPU1896
  INPU1897
  INPU1898
  INPU1899
  INPU1900
  INPU1901
  INPU1902
  INPU1903
  INPU1904
  INPU1905
  INPU1906
  INPU1907
  INPU1908
  INPU1909
  INPU1910
  INPU1911
  INPU1912
  INPU1913
  INPU1914
  INPU1915
  INPU1916
  INPU1917
  INPU1918
  INPU1919
  INPU1920
  INPU1921
  INPU1922
  INPU1923
  INPU1924
  INPU1925
  INPU1926
  INPU1927

WRITE (6,42) ATAR(1,1), ATAR(1,2), ATAR(1,3)
DA(1)= TIL(1)
DA(2)= TIL(2)
DA(3)= TIL(3)
NN= 5
IF (FPATH) GO TO 36
DA(1)= TIL(4)
DA(2)= TIL(5)
DA(3)= TIL(6)
NN= NX
36 WRITE (6,45) DA(1),DA(2),DA(3)
   DO 37 J=1, NN
   WRITE (6,46) J, X(J), RH(J), BH(J), RS(J), BT(J)
37 CONTINUE
   NN= NX -3
   IF (FPATH) WRITE (6,22) (I,X(I),ASPECT(I),RH(I),BH(I),RS(I),BT(I))
   X(I)=6. NN)
22 FORMAT (1H6 44X 30H---- GEOMETRIC PARAMETERS ---- // 10X 9HBLADEF  
   INPU189
   X ROW 5X10HAXIAL VEL. 5X12HASPECT RATIO 6X 8HUB RAMP 6X 12HUB BL  
   INPU193
   XOKCAGE 4X 8HTIP RAMP 6X 12HTIP BLOCKAGE / 10Y 9HEXIT STA. 5X 11HRA  
   INPU189
   X(T) 0/1 21X 11HANGLE LIMIT 7X 6MFACOR 6X 11HANGLE LIMIT 7X  
   INPU189
   X 6MFACOR // (116,4F16.3,2F15.3)
   N=2*MSTAGE + 4
C
*** READ THE STAGE DATA

   DO 60 I=5,N+2
   RLAD (5,25) OFL(I+1), HMN(I+1), HMN(I+2), OFL(I+2), VO(I+1),  
   X BLADE(I+1), BLADE(I+2),DLOW(I+1),DFLOW(I+2),  
   X (CUCOI+1,J),J=1,5,  
   X (SSCOI+1,J),J=1,5,  
   X (SSCOI+2,J),J=1,5,  
   X (SSCOI+2,J),J=1,5,  
   X (SSCOI+2,J),J=1,5  
60 CONTINUE

25 FORMAT (5F10.4/215,2F10.4/(5E10.4)

C
*** CHECK THE BLOCKAGE FACTORS

   NN=NN+1
   DO 61 I=1,NN

C
*** ERROR SETS THE BLOCKAGE FACTOR TO 1.0

IF (BT(1),GT.1.0.OR.BT(1),LE.0.5) CALL ERROR (25)
IF (BH(1),GT.1.0.OR.BH(1),LE.0.5) CALL ERROR (21)

61 CONTINUE
   DO 70 I=5,N
   B2(I+1)=CUCO(I+1,2)
70 CONTINUE
   NX=NN+4

B-40
**C SPECIFIC PEA**

**THE INLET TO THE FIRST STATION**

**C**

**C** ***CALCULATE THE GAS CONSTANT***

\[ GASK = G/MCLEWT \]

\[ DCP = GASK / JOULE \]

\[ GR = 64.348 * GASK \]

\[ GH2 = GR * 5 \]

**C** ***CALCULATE THE TOTAL TEMPERATURE, TOTAL PRESSURE, AND SPECIFIC HEAT IN THE INLET***

**I=1**

**J=1**

**TO(1,1) = TOCO**

**CALL THERMP**

**DO 101 J=1,NLINES**

**DO 99 I=1,5**

**TO(1,J) = TOCO**

**P0(I,J) = POCO**

**CP(I,J) = CP(1,1)**

**99 GAMMA(I,J) = GAMMA(1,1)**

**C** ***SET THE RADIAL AND WHIRL VELOCITIES TO ZERO***

**DO 100 I=1,NX**

**CUL(I,J) = 0.**

**100 CR(I,J) = 0.**

**C** ***DR/DX AND D2R/DX2 AND D(CX)/DX ARE ASSUMED ZERO AT THE INLET TO THE MACHINE***

**RSLOPE(I,J) = 0.**

**RCURVE(I,J) = 0.**

**101 CSLOPE(I,1) = 0.**

**NX = NX - 3**

**DO 105 I = 6,NX**

**IF (DFL(I) <= 0.0) OR DFL(I) >= 0.9) CALL ERR(28)***

**105 IF (BLADE(I).LT.1.OR.BLADE(I).GT.KK) CALL ERR(17)***

**C** ***CONVERT THE RELATIVE FLOW ANGLES TO RADIANS***

**DO 106 I=7,NX,2**

**106 HMN(I) = HMN(I)/57.2957755**

**C** ***SET THE MASS FLOW RATE THROUGH THE INLET TO THE VALUE AT THE FIRST STATION***

**FLOW(2) = FLOW(1)**

**FLOW(3) = FLOW(1)**

**FLOW(4) = FLOW(1)**

---

**B-41**
INPUT. - EFN SOURCE STATEMENT - IFN(S) -

FLOW(5)=FLOW(1)

C
*** CALCULATE THE TOTAL FLOW RATE AT EACH STATION

DO 110 I=5,N
110 FLOW(I-1)= FLOW(I)+DFLOW(I+1)

C
*** SET THE FLOW RATE AT THE LAST 3 STATIONS EQUAL TO THE
C FLOW RATE AT THE LAST STATOR EXIT

FLOW(N+2)= FLOW(N+1)
FLOW(N+3)= FLOW(N+1)
FLOW(N+4)= FLOW(N+1)

C
*** CALCULATE THE NUMBER OF STREAMTUBES

NTUBES= NLINES-1
JMI= NLINES/2

C
*** CHECK AND CALCULATE THE OUTPUT TRIGGER...

1 = ALL STREAMLINES
2 = EVERY OTHER ONE
3 = MEAN, HUB, AND TIP
4 = HUB AND TIP

IF (IOUTTR.LT.1.0) OR. IOUTTR.GT.4) CALL ERROR(20)
IF (IOUTTR.LT.3) GO TO 113
IF (IOUTTR.EQ.4) GO TO 112
IOUTTR=JMI
GO TO 113

112 IOUTTR=NTUBES
113 IFIRST=6

C
*** CALCULATE THE MID-STREAMLINE INDEX

JM= JMI+1

C
*** INITIALIZE THE INDICES (THE FIRST ROTOR INLET
C IS AT STATION NUMBER 5)

LSTAGE=7
NX=10
L= 1
NX1=9

C
*** CALCULATE THE SIMPLE RADIAL EQUILIBRIUM SOLUTION

IB= 1
IB1= 2
NX2=8

C
** OF THE FLOW EQUATIONS IN THE INLET

IPASS=1
KPM= RPM/RS(5)
CALL INLET
I= 6
RETURN
INTEG. - FFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE INTEG (VDEP, IFCON)

*** PERFORMS NUMERICAL INTEGRATIONS OF THE VDEP VS. R CURVE

*** TRAPEZOIDAL RULE INTEGRATION

DIMENSION VDEP(10,11)

DOUBLE PRECISION TITLE

REAL MACH, MAPR, MOLEWT, JOULE

DIMENSION ATAS(29,11), FLOW(32)

LOGICAL IERROR, YES

COMMCM/MATRIX/ ALPHA(10,11), ATAR(29,11), R?(29),

X BETA(10,11), BH(32), BLADE(29), BT(32),

X CFO(10,11), CPI(32,11), CPC(06), CR(32,11),

X CSLIDE(10,11), CU(32,11), CUCO(29,5),

X CX(32,11), CXM(10,11), CANEW(10,11), CXRATO(29),

X CXS(10,11), DA(10), DELM(11), DEPV(10,11),

X DFL(20), DFACT(29,11), DFIL(29), DFLOW(32),

X EMACH(29,11), FOUND(20,3,10), FROEL(10,11), GAMMA(32,11),

X HMN(29), HML(32), IKK(10), RCUR(10,11),

X OBARI(29,11), PD(32,11), RI(32,11), ROSTAG(11),

X RH(32), RHO(32,11), RINT(11), SOC(29,5),

X RST(32), RSLOPE(10,11), RTRA(11), SOR(29,5),

X SOLID(29,11), SSLO(29,5), TEM(10,11), SMA(11),

X TERM(11), TERM(11), TIP(32), TIT(12),

X TOL(32,11), TSTST(11), WI(11),

X X(32)

COMMCM/SCALER/A, AA, A10A0, A202A0, A303A0, A404A0,

X A505A0, B, BB, CC, CM, CMIN, CMEX, CMAPR, COINTG,

X CPIL2, CPI3, CPI4, CPI5, CPI6, CPI7, CPI8, CPOD, CPO4,

X CPO5, DAMP, DCF, D0, DFECM, DT, DUMMY, ERASL,

X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,

X POCO, C, RPM, TCP, TRMD, TESTB, TESTD, TESTS, TESTS

X TOC1, TOL, TOLAT, TOL82, TOL4IN, TOLMS, TOLIP, TOLCP,

X TOLCPX, TOLR, TOTINT, TOTPR, V, VMI

COMMCM/INTEGR/I, IB, IBL, IBLDUMP, IERROR, IFIRST,

X IG, IICUTTR, IPASS, IS, IT, J, JIN, JJ,

X JM, JMI, K, KI, KK, L, LIMIT, LSTAGE,

X MSTAGE, ALINES, NTUBES, NX, NXI, YES

EQUIVALENCE (ATAR(1,1),ATAS(1,1)), (FLOW(1),DFLOW(1))

RINT(1)=0.0

GO TO (50,90), IFCON

C

*** CALCULATES INTEGRAL OF VDEP * R OR DR

50 DO 15 J=1,NTUBES

10 DA(J) = (VDEP(L,J)*R1(J,J)+VDEP(L,J+1)*R1(J+1,J+1)) * (R1(J,J+1)-R1(J,J)) * 5

15 RINT(J+1) = RINT(J) + DA(J)

GO TO 150

C

*** CALCULATE NTUBES VALUES OF INCREMENTAL INTEGRALS FOR CURVE

VDEP VS. R (RIJ TO R(J+1))

90 DO 115 J=1,NTUBES

B-43
INTEG. - EFN SOURCE STATEMENT - IFN(S) - 11/02/67

100 CA(J)=(VDEP(L,J)+VDEP(L,J+1))*(R(I,J+1)-R(I,J))*.5
115 RINT(J+1)= RINT(J) +CA(J)
150 B=RINT(JM)
DO 200 J=1,NLINES
200 RINT(J)= RINT(J)-B
RETURN
END
SUBROUTINE LOSS

C

*** MATCHES LOSS WITH ADIABATIC EFFICIENCY

LOGICAL NO FAIL
COMMON /SPECIAL/ NRM(14),NX2,NOFAIL
INTEGER BLADE
REAL LOSE
DOUBLE PRECISION TITLE
DOUBLE PRECISION TITLE
REAL MAC, MAPR, MULEMT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IFRRUR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), R2(29),
X BETAI0(11), BM1(32), BLADE(29), BT(32),
X C(10,11), CPI(32,11), CPCO(16), CR(32,11),
X CSLOPE(10,11), CU(32,11), CU(32,11), CUCN(29,5),
X CXI52,11, CMX(10,11), CXNEW(11,11), CXRAT(29),
X CSXI52,11, DA(10), DELX(11), DEPX(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLOW(32),
X EMACH(29,11), FOUND(20,3,10), FROEL(10,11), GAMMA(32,11),
X HNM(29), HUB(32), IKK(10), MACH(29,11),
X OBARI52,11, PDI(32,11), R(32,11), RCUV(10,11),
X RH(32), RHO(32,11), RINT(11), POSTAG(11),
X RS(32), RSLOPE(10,11), RTRAIL(11), SDCO(29,5),
X SOLII52,11, XSSC(29,5), TEROH(10,11), TERM(11),
X TERM(11), TEREH(11), TIP1(22), TITLE(12),
X TOI52,11, TSTAT(11), U(32,11), W(11),
X X(32)
COMMON /SCALER/ A, AA, AI0AO, A202, A203A0, AI04A0, A202A0, A203A0, AI04A0, LOSE2129
X A50SA, A, B, CC, CM, CHEAN, CMANF, COINTG,
X CPI12, CPI13, CPI14, CPI15, CPI16, CPI6, COP2, COP3, COP4,
X CP65, CP65, CDP, DDF, DIFFC, DT, DUMMY, ERAS,
X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEMT,
X POCO, C, RPM, TCP, THERMO, TESTBH, TESTS, TESTHS,
X TGCO, TOL, TOLAT, TOLB, TOLATN, TOLMS, TOLTP, TOLCP,
X TOLCK, TOLR, TOLNT, TOTPR, V, VM,
COMMON /INTEGR/ I, IB, IB1, IDUMP, IFRRUR, IFRST,
X IG, IDUTTR, IPASS, IS, IT, J, JIN, JJ,
X J, J1, K, K1, KK, L, LIMIT, LSTAGE,
X MESTAGE, MINDS, NTUBES, NX, NX1, YES
EQUIVALENCE (ATAR(11), ATAR(11), (FLOW(11), DFLW(11),
COMMON /ENERGY/ H, T, GAMERH,
DATA RADIUS /57.29578/

C

*** OBAR CONTAINS THE LOSS FUNCTION

L=-1
DO 10 I=IFIRST,LSTAGE,2
L=L+2
DO 10 J=1,NLINES

C

*** CALCULATE ABSOLUTE RELATIVE VELOCITY

CXM(L,J) = CX((L-1,J)**2+(CI1(L-1,J)-UI(L-1,J)**2+CR(L-1,J)**2

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LOSS. — EFN SOURCE STATEMENT — IFN(S) —

C

*** CALCULATE ABSOLUTE VELOCITY

CXM(L+1,J)=CX(I,J)**2 + CU(I,J)**2 + CR(I,J)**2

C

*** CALCULATE RELATIVE FLOW ANGLE

BETA(L,J)= ATAN((U(I-1,J)-CU(I-1,J))/SORT(CX(I-1,J)**2 +

X CR(I-1,J)**2))

C

*** CALCULATE RELATIVE FLOW ANGLE

BETA(L+1,J)=ATAN((U(I,J)-CU(I,J))/SORT(CX(I,J)**2+CR(I,J)**2))

C

*** CALCULATE ABSOLUTE FLOW ANGLE

ALPHA(L+1,J)=ATAN(CU(I,J)/SORT(CX(I,J)**2 + CR(I,J)**2))

C

*** CALCULATE ABSOLUTE FLOW ANGLE

ALPHA(L+2,J)=ATAN(CU(I+1,J)/SORT(CX(I+1,J)**2 + CR(I+1,J)**2))

C

*** CALCULATE RELATIVE MACH NUMBER

MACH(I,J)= SQRT(CXM(L,I,J)/(GR2*GAMMER*TSTAT(J)))

C

*** CALCULATE ABSOLUTE MACH NUMBER

L= -CXM(L+1,J)/GJ

T= TO(I,J)

CALL ENTP

CALL GAM

MACH(I+1,J)= SQRT(CXM(L+1,J)/(GR2*GAMMER*TSTAT(J)))

10 CONTINUE

L=0

DO 20 I=IFIRST,LSTAGE

L=L+1

DO 20 J=1,NLINES

C

*** CONSTANT TERM USED IN LOSS

TERM(I,J)= SQRT((GAMMA(I-1,J)+1.)/(GAMMA(I-1,J)-1.))

20 CONTINUE

L=-1

DO 30 I=IFIRST,LSTAGE,2

L=L+2

K= L+1

DO 30 J=1,NLINES

C

*** COMPUTE SUPERSONIC TURNING ANGLE

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Ioss. - EFN SOURCE STATEMENT - IFN:S -

A = (R(I,J)+R(I-1,J)-R(H)-R($-$1))/ (S(I)+S(-1)-R($-$)+R($-$)), LOSE211
B = (R(I,J)+R(I-1,J)-R(H)+R($-$))/ (S(I)+S(+1)-R($-$)+R($-$)), LOSE212
AA = (SSC(1,1)+SSC(1,2)+A) + SSCO(1,3), LOSE213
X = (SSCO(1,4) + SSCO(1,5), A) + A, LOSE214
BB = SSCO(+1,1) + SSCO(+1,2) + B + SSCG(+1,3)
X = (SSCC(+1,4) + SSCO(+1,5) + B) + B, LOSE215

IF (AND(I,DUMP,4) .NE. 0) GO TO 25
FRDEL(L,J) = AA*(BETA(L,J) - BETA(L+1,J))
FRDEL(+1,J) = BB*(ALPHA(L+1,J) - ALPHA(L+2,J))
GO TO 26
C
*** CALCULATE THE SUPersonic TURNING ANGLE FROM THE SHOCK ANGLE.
25 FRDEL(L,J) = BETA(L,J) - AA/RADIAN
FRDEL(+1,J) = ALPHA(L+1,J) - BB/RADIAN
26 CONTINUE

C
*** TEST FOR SUPERSONIC VELOCITY
1F (MACH(I,J) .LT. 1.0) GO TO 28
A = (MACH(I,J) - 1.0) * (MACH(I,J) + 1.0)
C
*** IF FLOW IS SUPERSONIC ADD PRANDTL-MEYER ANGLE TO
C
SUPERSONIC TURNING ANGLE
FRDEL(L,J) = FRDEL(L,J) * TAN(1/SQRT(A)/TAN(L,J)) -
X ATAN(SQRT(A))
28 IF (MACH(I+1,J) .LT. 1.0) GO TO 30
A = (MACH(I+1,J) - 1.0) * (MACH(I+1,J) + 1.0)
C
*** IF FLOW IS SUPERSONIC ADD PRANDTL-MEYER ANGLE TO
C
SUPERSONIC TURNING ANGLE
FRDEL(+1,J) = FRDEL(+1,J) * TAN(1/SQRT(A)/TAN(L+1,J)) -
X J) * ATAN(SQRT(A))
30 CONTINUE
L = 0
DO 60 I = FIRST, LSTAGE
L = L + 1
DO 60 J = 1, N LINES
C
*** INITIALIZE PROFILE SHOCK AND LOSS FUNCTION
QBAR(I,J) = 0.0
C
*** CALCULATE PROFILE SHOCK
Q = U, 1
CXS(L,J) = 1.
IF (FRDEL(L,J) .LT. 0.0) GO TO 44
DO 43 IS = 1, 100
C
*** CALCULATES DIFFERENCE BETWEEN PRANDTL-MEYER ANGLE FOR MACH
C
NUMBER CXS(L,J) AND SUPERSONIC EXPANSION ANGLE
VMI = SHOCK(CXS(L,J),FRDEL(L,J))
LO  LSE2266
IF (ABS(VMIN),LE.0.001) GO TO 44 LSE2267
IF (VM1.GT.0.0) GO TO 43 LSE2268
CXS(L,J)=CXS(L,J)-Q LSE2269
Q= 0/3.0 LSE2270
43 CXS(L,J)= CXS(L,J) + Q LSE2271
CALL ERROR(29) LSE2272
44 IF (MACH(I,J).GE.1.0) GO TO 45 LSE2273

C *** CALCULATE SUBSONIC SHOCK

EMACH(I,J)=MACH(I,J)*(1.0+CXS(L,J))**0.5 LSE2274
IF (EMACH(I,J)-1.0) 60,60,50 LSE2275

C *** CALCULATE SUPERSONIC SHOCK

45 EMACH(I,J)=(MACH(I,J)+CXS(L,J))*0.5 LSE2276

C *** COMPUTE SHOCK LOSS

50 OBAR(I,J)=1.0-(((GAMMA(I-1,J)+1.0)*0.5*EMACH(I,J)**2) LSE2277
X/(1.0+0.5*(GAMMA(I-1,J)-1.0)*EMACH(I,J)**2) LSE2278
X**((GAMMA(I-1,J)/(GAMMA(I-1,J)-1.0))*(GAMMA(I-1,J)**2*0. LSE2279
X/(GAMMA(I-1,J)+1.0)*EMACH(I,J)**2-(GAMMA(I-1,J)-1.0) LSE2280
X/(GAMMA(I-1,J)+1.0)**((1.0/(1.0-GAMMA(I-1,J)))) LSE2281
X/(1.0-1.0/(1.0*(GAMMA(I-1,J)-1.0)*MACH(I,J)**2*0.5) LSE2282
X**((GAMMA(I-1,J)/(GAMMA(I-1,J)-1.0))) LSE2283
60 CONTINUE LSE2284

65 L=1 LSE2285
DO 80 I=FIRST,LSTAGE,2 LSE2286
L=L+2 LSE2287
DO 80 J=1,NLINES LSE2288
A= (R(I,J)+R(I-1,J)-K(I)-R(I-1))/R(I)+R(I-1)-PH(I)-R(I-1)) LSE2289
C *** CALCULATE ROTOR MEAN SOLIDITY

SOLID(I,J)= SOCC(I-1,1)/(SOC(I-1,2)+A) +SOCC(I-1,3) LSE2290
X+(SOC(I-1,4)+SOC(I-1,5)*A)*A LSE2291

C *** CALCULATE ROTOR D-FACTOR

AA=SORT((CX(I-1,J)**2+U(I-1,J)-CU(I-1,J)**2+CR(I-1,J)**2)) LSE2292
DFACT(I,J)= 1.0-SORT((CX(I,J)**2+U(I,J)-CU(I,J)**2+CR(I,J)**2)) LSE2293
X/AA+U(I,J)-CU(I,J)-U(I,J)+CU(I,J)**2/SOLID(I,J)/AA LSE2294
A=RS(I)=-R(I) LSE2295
C *** COMPUTE ROTOR PROFILE LOSSES

C *** COMPUTE LOSE READS THE PROFILE LOSS FROM THE INPUT MAPS

C OBAR(I,J)=OVAR(I,J)+LOSE(DFACT(I,J),(R(I,J)-R(I,J))/A)* LSE2296
X BLADE(I,J)*2.0*SOLID(I,J)/COS(AMN1(BETA(I,J),1.2217)) LSE2297
A= (R(I,J)+R(I,J))**2 LSE2298
C *** CALCULATE STATOR MEAN SOLIDITY

SOLID(I,J)= SOCC(I+1,1)/(SOC(I+1,2)+B) +SOCC(I+1,3) LSE2300

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)+(SOCO(I+1,4) +SOCO(I+1,5)*B)*B

C  *** COMPUTE STATOR D-FACTOR
AA=SQR({(CX(I,J)**2+CU(I,J)**2+CR(I,J)**2))
DFACT(I+1,J)=1.0-SQR({(CX(I,J)**2+CU(I,J)**2+CR(I+1,J)**2))}
X AA+(CU(I,J)-

C  *** COMPUTE STATOR PROFILE LOSSES

C  *** READS THE PROFILE LOSS FROM THE INPUT MAPS

C  *** CALSULATE THE STATIC ENTHALPY MINUS THE TOTAL

C  *** GET THE STATIC TEMPERATURE

C  *** CALCULATE THE STATIC PRESSURE AT THE ROTOR INLET

C  *** COMPUTE THE TOTAL RELATIVE PRESSURE

C  *** COMPUTE THE TOTAL IDEAL PRESSURE

C  *** CALCULATE THE EXIT RELATIVE TOTAL PRESSURE FROM THE

LOSE2322
LOSE2323
LOSE2324
LOSE2325
LOSE2327
LOSE2328
LOSE2329
LOSE2330
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LOSE2376
LOSE2377

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**LJSS. - EFN SOURCE STATEMENT - IFN(S) -**

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I = TO(I,J)

CALL ENTHALP

C

*** CALCULATE THE EXIT TOTAL PRESSURE

P = P*EXP((THERM3(T) - THERM3(TSTAT(J)))/DCP)

C

*** GET THE ICEAL EXIT TOTAL TEMPERATURE

CALL THERM2(P/PC(I-1,J),T,TO(I-1,J))

C

*** COMPUTE THE CORRESPONDING EFFICIENCY

EFF = (THERM1(T) - THERM1(TO(I-1,J)))/X

PO(I,J) = P

C

*** CHECK THE CONVERGENCE

IF (ABS((ATAR(I,J) - EFF)/ATAR(I,J)) * GT, TOLAT) IPASS = 3

ATAR(I,J) = EFF

H = -(CX(I,J)**2 + CR(I,J)**2 + CU(I,J)**2)/GJ

T = TO(I,J)

CALL ENTHALP

C

*** CALCULATE THE STATIC PRESSURE AT THE INLET TO THE STATOR

P STAT = PC(I,J)*EXP((THERM3(TSTAT(I,J)) - THERM3(T)) / DCP)

C

*** CALCULATE THE STATOR EXIT PRESSURE (TOTAL) FROM THE LOSS COEFFICIENT

P = PC(I,J) - OBAR(I+1,J) * (PO(I,J) - P STAT)

C

*** GET THE ICEAL TOTAL TEMPERATURE

CALL THERM2(P/PO(I-1,J),T,TO(I-1,J))

C

*** COMPUTE THE EFFICIENCY

EFF = (THERM1(T) - THERM1(TO(I-1,J)))/X

C

*** CHECK FOR CONVERGENCE

IF (ABS((ATAR(I+1,J) - EFF)/ATAR(I+1,J)) * GT, TOLAT) IPASS = 3

ATAR(I+1,J) = EFF

100 CONTINUE

101 CONTINUE

NO FAIL = 'FALSE'

CALL DRIVE

RETURN

END
REAL FUNCTION LOSE(ARG, PERTH, TYPE)

*** YIELDS LOSS PARAMETER FROM INPUT MAPS AS A FUNCTION OF
PERCENT BLADE HEIGHT AND D-FACTOR AND CIRCULAR INTERPOLATION
ALONG THE RADIUS.***

INTEGER TYPE, FIRST
DOUBLE PRECISION TITLE
REAL MACF, MAPR, MOLEWT, JOULE
DIMENSION ATAS(25,11), FLOW(32)
LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B(29),
X BET(10,11), BM(32), BLADE(29), BT(32),
X CD(10,11), CR(32,11), CRP(6), CR(32,11), CR(32,11),
X CSL(10,11), CUX(32,11), CUX(32,11), CUR(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CXRATO(29),
X CXS(10,11), DA(10), DELM(11), DEP(10,11),
X DF(21), DFACT(29,11), DFL(29), DFLOW(32),
X EMA(29,11), FOUN(20,3,10), FRDEL(10,11), GAMMA(32,11),
X HMIN(29), HUH(32), IKK(10), MACH(29,11),
X OB(29,11), P(32,11), P(32,11), R(10,11),
X RHI(32), RHO(32,11), RINT(11), ROOTG(11),
X RI(32), RS(10,11), RTRAIL(11), SCO(29,5),
X SOL(29,11), SSCO(29,5), TERM(110,11), TFM(11),
X TEM(11), TERM(11), TIP(22), TITLE(12),
X TIM(32,11), TSTAT(32,11), U(32,11),
X X(32), COMMON /SCALER/ A, AA, AA, A(10,11), A(20,20), A(30,30), A(40,40),
X AS(34,40), B, BB, CC, CM, CMEAN, CM: , COINTG,
X CPI(2,13), CPI(3), CPI(4), CPI(5), CPI(6), CPI(7), CPI(8), CPI(9),
X CP(2,5), DMP, DCP, DD, DIFCAP, DT, DUMMY, ERAS,
X G, GASK, GJ, G, GR, GR2, JOULE, MAPR, MOLEWT,
X C(2,13), AP(3), TCP, TERM, TESTBH, TESTO, TESTS,
X TOC, TOC, TOL(3), TOL(4), TOL(5), TOL(6), TOL(7), TOL(8),
X TOLC, TOLC, TOLT, TOLP(4), V, VMI,
COMMON /INTEGR/ A, AA, B, BB, C, CC, CM, CMEAN, CM: , COINTG,
X ICUTR, IPASS, IS, IT, J, J, J, JJ, JJ,
X JO, JO, JO, JO, JO, JO, JO, JO, JO, JO,
X MSTATE, MSTATE, NSTAT, NX, NX, NX, YES,
EQUIVALENCE (ATAR(11), ATAS(1,1)), (FLOW(1), DFLOW(1)),
FIRST = 1
10 FIRST = FIRST + 1
IF (DF(First) LT ARG AND FIRST LT 20) GO TO 10
JJ = 1
IF (PERHT GT 0.5) JJ = 3
DEL = (ARG - DF(First) - 1)/(DF(First) - DF(First - 1))
FCT1 = (FoundFIRST(2, TYPE) - FoundFIRST(1, TYPE)) * DEL
X + FoundFIRST(1, TYPE)
FCT2 = (FoundFIRST(JJ, TYPE) - FoundFIRST(1, JJ, TYPE)) * DEL
X + FoundFIRST(1, JJ, TYPE)
DEL = FCT2 - FCT1
IF (ABS(DEL) GT 0.01) GO TO 20
LOSE = FCT1
RETURN
LOSE = EFN SOURCE STATEMENT - IFN(S) -

20 RAD = 0.5*SQRT(DEL*2 +0.16)/SIN(2.5*DEL)
LOSE = FCT1 +RAD*(1.0 -COS(ABS(PERHT -0.0)/RAD))
RETURN
END
MOVE - IEFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE MOVE

*** CAUSES THE RELOCATION OF THE STREAMLINES BASED ON
FRACTIONAL MASS FLOW. (STREAM MUST BE CALLED FIRST)

DOUBLE PRECISION TITLE
REAL MACH, MAPA, MOLFWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)

LOGICAL ERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BRI(32), PLAOF(11), BT(32),
X C(10,11), CPI32(11), CPCO(6), CF(32,11),
X CSLOPE(10,11), CUI32(11), CUC(29,5), MOV(32,11),
X CXT(10,11), CXM(10,11), CXNEW10,11, CXRAT(29),
X CXS(10,11), DDL10, DFL(11), DFPMV10,11,
X DFMC(3), DFLACT(29,11), DFL(29),
X EMACH(29,11), FOUND(20,3,10), FROEL(10,11), GAMMA(32,11),
X HNN(29), HUB1(32), I1K(10), MAGC(29,11), MOV(32,11),
X DEAKI(29,11), PO32(11), P(32,11), R(32,11), RCURVE(10,11),
X H(32), RHO132(11), RHOT(11), RINT(11), RPOST(11), MOV(32,11),
X RS(32), RSLLOPE(10,11), RRAI11(11), SOC(29,5), MOV(32,11),
X SOI1(29,11), SSCOU29,11, TERM110,11, TERM(11), MOV(32,11),
X TERM(1), TERM(11), TIP(32), TITLE(12), MOV(32,11),
X TOC32,11, TSTAT(11), U(32,11), MOV(32,11),
X X(32)

COMMON /SCALER/ A, AA, ALAC, A202A0, A303A0, A404A0,
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, COINTG,
X CPI2, CPI3, CPI4, CPI5, CPI6, CPI8, CPI2, CPI3, CPI4,
X CPI5, CPO5, CPO6, DCP, DD, DIFC, DT, DUMMY, ERAS1,
X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X PCO, G, RPM, TCP, TERRD, FSTRE, TESTOS, TEST5,
X PCIe, TOL, TOLAT, TOLB2, TOLMIN, TOLMS, TOLTOL, TOLCP,
X TULC, TULR, TCTNT, TOPR, Vv, VMT

COMMON /INTEGER/ I, IB, IB1, IDUMP, IERROR, IFIRST,
X IG, IICUTR, IPASS, IS, IT, J, JIN, JJ,
X JPM, JMI, K, KI, KK, L, LIMIT, LSTATE,
X MSTATE, N_LINES, NTURES, NX, NX1, YES

EQUIVALENCE (ATAR(1,1),ATAS(1,1), (FLOW(1),DFLOW(1))

TERMCI(1)=0.0
TERMCI(N_LINES)=1.0
TERM(1)=0(1,1)
TERM(1)= R(1,1)
TERM(1)= r1(1,NLINES)
TERM(1)=CXM(11)
TERM(1)=CXM(NLINES)
D=U30 J+2, NTURES
TERM(1)= R(1,1)
TERM(1)=CXM(11)
TERM(1)=CAJ-11/TOTINT
C *** CHECK THE MASS FLOW BETWEEN EACH STREAMLINE
IF (ABS(TERMCI(J)-OCLMIJ))/GT. 0.005) YES=.TRUE.
350 CONTINUE

C *** CALCULATE STREAMLINE RADII TO GIVE SPECIFIED MASS FLOW
C FRACTION THROUGH EACH STREAMTUBE

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**REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR:**

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MOVE. - EFN SOURCE STATEMENT - EFN(S) -

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DO 505 J=1,N TUBES
CALL SLINE(RTRAIL(J),TERM,TERMA,N LINES,RTRAIL(J))
504 R TRAIL(J) = R(I,J) *(RTRAIL(J) - R(I,J))/DAMP

*** CALCULATE VALUES OF CX AT NEW STREAMLINE RADIUS

CALL SLINE(RTRAIL(J),TERM,TERMA,NLINES,DEPV(L,J))
505 CONTINUE
CX(I,J) = CX(L,J) * CMEANP
CX(I,NLINES) = CX(L,NLINES) * CMEANP
DO 510 J=1,N TUBES
CX(I,J) = DEPV(L,J) * CMEANP
R(I,J) = RTRAIL(J)
510 U(I,J) = R(I,J) * FFM
RETURN
END
```

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OUTLET - IFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE OUTLET

REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)

LOGICAL ERROR, YES

COMM /MTRX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BLADE(29), BT(32),
X CO(10,11), CPI(32,11), CPI2(4), CPR(32,11),
X CSLOPE(10,11), CU2(11), CU32(11), CU40(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CXRAT(10),
X CXS10,11), JAI(10), DELM(11), DEP(10,11),
X DF(20), DFAC(29,11), DFDEL(29), DFLOM(32),
X EMACH(29,11), FOUNO(20,3,10), FREDL(10,11),
X HNN(29), HUB(32), I(10), MAC(29,11),
X OBAR(29,11), O(32,11), P(32,11), PCURV(10,11),
X RH(32), RHOI(32,11), RINT(11), RCTAG(11),
X RS(32), RSLPE(10,11), RTRAIL(11), SOCG(29,5),
X SOLI(29,11), SSO32(29,5), TERM1(10,11), TERMA(11),
X TFRM(11), TIP(32), TITLE(12),
X TO(32,11), TSTAT(11), U(32,11), W(11),
X X(32)

COMM /SCALER/ A, AA, A10AC, 20240, A030A0, A040A0,
X AB50A0, B, BB, CC, C, CMEAN, CMEANP, COINTG,
X CPI2, CPI3, CPI4, CPI5, CPI6, CP02, CRO3, CP04,
X CPOS, CAMP, COP, CD, DIFCM, DT, DUMMY, ERAS1,
X G, GASK, GJ, GK, GR2, JOULE, MAPR, MOLEWT,
X POCO, Q, RPM, TCP, TERM, TESTE, TESTD, TESTS,
X TOCO, TUL, TULAT, TOLB2, TOLMIN, TOLMS, TOLIP, TOLCP,
X T1CLCX, TOLR, TOLINT, TOLPR, U, VMI

COMM /INTEGR/ I, IB, IB1, TDUMP, TERROR, TEXIT,
X IG, IDUTR, IPASS, IS, IT, J, JIN, JJ, LIM, LIMIT, LSTAGE,
X IJ, IJ1, IJ2, K, KI, KK, L, LIMIT, LSTAGE,
X MTCSTAGE, MNTLINE, MTUBES, NX, NXY, YES

EQUIVALENCE (ATAR,1,1),ATAS(1,11), (FLOW,DFLOW)

CALL RSTART
DO 5 J=1,NLINES

*** SET FLOW PROPERTIES AS CONSTANT ALONG STREAMLINE
CP(I,J),CFLSTAGE(J)
GAMMA(I,J),GAMMA(LSTAGE,J)
CUT(I,J),GULSTAGE(J),R(I,J)
TO(I,J),TC(LSTAGE,J)

B-55
OUTL. - EFN SOURCE STATEMENT - IFN(S) -

5 PCI(I,J)=PCI(LSTAGE,J)

C

*** GET INITIAL ESTIMATE OF AXIAL VELOCITY

IF (LSTAGE.NE.7) GO TO 6
CALL INFST
GO TO 10

6 DO 7 J=1,NLINES

7 CX(I,J)= CX(I-1,J)

C

*** CALCULATE SIMPLE RADIAL EQUILIBRIUM SOLUTION OF FLOW

C CONDITIONS

8 CALL STREAM

10 CALL MOVE

RETURN

END

11/02/67
SUBROUTINE OUTPUT

DIMENSION PMA(29), PMAB(29), TMA(29), TMAB(29), TMAEP(29)
DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLENT, JOULE
DIMENSION ATAS(29,11), FLOW(32)

LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BH(32), BLADE(29), BT(32),
X CC(10,11), CP(32,11), CPCO(6), CR(32,11),
X CSLOPE(10,11), CU(11), CUCO(29,5),
X CX(32,11), CXN1(10,11), CXRAT(29),
X CXS(10,11), DA(10), DELM(11), DEPV(10,11),
X DF(20), DPACT(29,11), DFL1(29),
X EMACH(29,11), FOUND(20,3,10), FRDEL(10,11), GAMMA(32,11),
X HN(29), HUB(32), IKK(10), MACH(29,11),
X OBARI(29,11), PO(32,11), R(32,11), RCurve(10,11),
X RH(32), RHO(32,11), RINT(11), ROSTAG(11),
X RS(32), RSLOPE(10,11), RTRAIL(11), SOCO(29,5),
X SOLID(29,11), SSCO(29,5), TERM1(10,11), TERM(11),
X TERM(11), TERNC(11), TIP(32), TITLE(12),
X TO(32,11), TSTAT(11), U(32,11), W(11),
X X(32)

COMMON /SCALER/ A, AA, A10A0, A20A0, A303A0, A40A0,
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, CTINT,
X CPI2, CPI3, CPI4, CPI5, CPI6, CPO2, CPO3, CPO4,
X CPO5, DCP, DCP, OCR, DIFCM, DT, dummy, ERA1,
X G, GASK, GJ, GJ, GR, GR2, JOULE, MAPR, MOLENT,
X PGO, G, RPM, TCP, TTRD, TEST0, TESTS, TESTS,
X TOGO, TOL, TOL, TOL, TOLB, TOL, TOLB, TOL, TOLB,
X TOLC, TOL, TOL, TOL, TOL, TOL, TOL, TOL, TOL,
X TOLC, TOL, TOL, TOL, TOL, TOL, TOL, TOL, TOL,
COMMON /INTEGR/ I, IB, IB, IDUMP, IERROR, IFIRST,
X IG, IOUSTR, IPASS, IS, IT, J, JIN, JJ,
X JMK, JMK, K, K1, KK, L, LIMIT, LSXGE,
X MUSAGE, MINES, NTUBES, NX, NX, YES
EQUIVALENCE (ATAR(1,1),ATAS(1,1), (FLOW(1),DFLOW(1))

COMMON /VMIN/ VD(29)
COMMON /ENERGY/ H, T, GAMMER

TMAEP(5) = THERM1(TO(1,1))

B = TMAEP(5)
I = TOGO
IB = 1
IB1 = 2
NX1 = 5
DO 610 J=1,NLINES,IOUSTR
RSLOPE(1,J) = 0
RCURVE(1,J) = 0

610 CALL DERIV(R,RSLOPE,RCURVE,X)

WRITE (6,201)

201 FORMAT (1HI)
N=0
DO 58 I=1,5
DO 58 J=1,NLINES,IOUSTR
C *** CALCULATE ABSOLUTE VELOCITY (INLET)
C
C *** CALCULATE STATIC TEMPERATURE (INLET)
C
H = -CMX(I,J)**2/GJ
CALL ENALP
CALL GAM
CXMWI(I,J) = TSTAT(J)
C *** CALCULATE ABSOLUTE MACH NUMBER (INLET)
CXLV= CXM(I,J)/SQRT(GR2*GAMMA*TSTAT(J))
C *** CALCULATE ABSOLUTE FLOW ANGLE (INLET)
A = SQRT(CXI(I,J)**2 + CR(I,J)**2)
ALPHA(I,J) = ATAN(CU(I,J)/A)*57.2957795
RCURVE(I,J) = RCURVE(I,J)/(SQRT(1 + RSLOPE(I,J)**2)**3)
RSLOPE(I,J) = ATAN(RSLOPE(I,J))*57.2957795
58 CONTINUE
DO 71 I = 1,5
IF (I.GE.5) GO TO 64
C *** PRINT INLET DATA
WRITE (6,61) I
61 FORMAT (1HO/10X18H----STATION NUMBER 13,5H---- //5X70HS.L. STREAM
XINE MACH ABS. VEL. AXIAL VEL. RADIAL VEL. 4X
X3HSSTREAMLINE FLOW ANGLE/5X27HNO. RADIUS (IN.)
X NUMBER 6X3H(FT/SEC) 5X8H(FT/SEC) 5X12HSLOPE (DEGS)
X 4X9HCURVATURE 5X 9H(DEGREES) / 96X 5H1/IN. /)
GO TO 265
C *** PRINT INLET GUIDE VANE EXIT DATA
WRITE (6,64) I
64 FORMAT (1HO/10X18H----STATION NUMBER 13,31H---- (INLET GUIDE VA
XNE EXIT) //5X70HS.L. STREAMLINE ABS. MACH ABS. VEL. AXIA
XL VEL. RADIAL VEL. 4X3HSSTREAMLINE FLOW ANGLE /OUT.2673
X 5X27HNO. RADIUS (IN.) NUMBER 6X3H(FT/SEC) 5X8H(FT/SEC) 5X8H(FT/OUT.2674
X/SEC) 5X12HSLOPE (DEGS) 4X9HCURVATURE 5X9H(DEGREES) / 96X 5H1/IN. /)
DO 67 J = 1,NLINES,1
CALL GAM
ERAS1 = GR2*GAMMA*TSTAT(J)
C *** COMPUTE RELATIVE VELOCITY (FIRST ROTOR ENTRANCE)
C10(5,J) = CX(5,J)**2 + (CU(5,J)-U(5,J))**2 + CR(5,J)**2
C1O(5,J) = SQRT(CIO(5,J))
B-58
C
*** COMPUTE RELATIVE MACH NUMBER (FIRST ROTOR ENTRANCE)
WRITE (6,68) J,R(I,J),CXS(I,J),CXM(I,J),CX(I,J),CR(I,J),
X RSLOPE(I,J),RCURVE(I,J),ALPHA(I,J)
67 CXS(5,J)= CO(5,J)/SQRT(ERAS1)
WRITE (6,272)
272 FORMAT (1HO 4X15S,L. STREAMLINE3X11HTOTAL PRES. 3X11HTOTAL TEMP.
X 3X 9HREL. VEL.3X10WHIRL VEL. 6X8HRERLATIVE 7X 9HR. FLOW 4X
X 1LHHEEL SPEED / 5X29HNO. RADIUS (IN.) (LB/SQ IN.) 4X9H DEGREES
X 4X 8H(FT/SEC) 5X8H(FT/SEC) 7X 8HMACH NO. 7X 9HANG. (DEG) 6X
X 8H(FT/SEC)
DO 273 J=1,NLINES,1OUTTR
C
*** CALCULATE RELATIVE FLOW ANGLE INTO THE FIRST ROTOR
72 BETA(2,J)=ATAN(U(5,J)-CU(5,J))/SQRT(CXS(5,J)**2+CR(5,J)**2))
X 57.2957795
273 WRITE (6,274) J,R(I,J),PO(5,J),TO(5,J),CO(5,J) , CU(5,J),
X CXS(5,J),BETA(2,J),U(5,J)
274 FORMAT (17,F11.4,F14.2,3F13.2,F15.3,2F15.3)
GO TO 71
269 00 69 J=1,NLINES,1OUTTR
69 WRITE (6,68) J,R(I,J),CXS(I,J),CXM(I,J),CX(I,J),CR(I,J),
X RSLOPE(I,J),RCURVE(I,J),ALPHA(I,J)
WRITE (6,271)
269 WRITE (6,270) J,R(I,J),PO(5,J),TO(5,J)
270 FORMAT (17,F11.4,F14.2,F13.2)
271 FORMAT (1HO 4X43HS,L. STREAMLINE TOTAL PRES. TOTAL TEMP. / 5X
X 42HNO. RADIUS (IN.) (LB/SQ IN.) (DEGREES) / )
71 CONTINUE
IF (LIMIT.EQ.0) WRITE (6,250)
250 FORMAT (//////// 41X 37HITERATION ON LOADING WAS TAKING PLACE )
C
*** INITIALIZE MASS AVERAGE ROUTINE
TMA(5)=1.0
PMA(5)=1.0
00 100 IS=6,LSTAGE,2
C
*** SET INDICES FOR DERIVATIVE ROUTINE
1B=IS-1
IB1= IS
NX1=IS+1
N=N+1
OUT. - EFN SOURCE STATEMENT - [FN(S) -

**DEPV(5,1)= X(IS)-X(IS-1)**

**DEPV(5,2)= X(IS+1)-X(IS)**

*** CALCULATE ROTOR HUB AND STATOR HUB RAMP ANGLE

**ALPHA(3,1)= ATAN((RH(IS)-RH(IS-1))/DEPV(5,1))*57.2957795**

**ALPHA(4,1)= ATAN((RH(IS+1)-RH(IS))/DEPV(5,2))*57.2957795**

*** CALCULATE ROTOR TIP AND STATOR TIP RAMP ANGLE

**ALPHA(3,2)= ATAN((RS(IS)-RS(IS-1))/DEPV(5,1))*57.2957795**

**ALPHA(4,2)= ATAN((RS(IS+1)-RS(IS))/DEPV(5,2))*57.2957795**

*** CALCULATE THEORETICAL TEMPERATURE RISE

**C ALL THERM2(PO(JJ, J)/POCO *TERMB(J),518.688)**

**TERMB(J)= TERMB(J)/518.688**

*** COMPUTE MASS FLOW RATE PER STREAMLINE

**10 DEPV(9,J)= RHO(JJ, J)*CX(JJ, J)*R(JJ, J)**

**L=9**

**I=JJ**

*** INTEGRATE MASS FLOW RATE, RESULT IN RINT

**C ALL INTEG(DEPV,2)**

**SUM= RINT(NLINES)-RINT(1)**

**DD 20 J=1,NLINES**

**20 DEPV(8,J)= (TERMB(J)-1.)*DEPV(9,J)**

**L=8**

**C ALL INTEG(DEPV,2)**

**V=KINT(NLINES)-RINT(1)**

*** CALCULATE MASS AVERAGED TEMPERATURE AND PRESSURE

**TMA(JJ)= (V/SUM+1.)*518.688**

**PMA(JJ)=EXP((THERM3(TMA(JJ))-COINTG)/DCP)**

**DO 30 J=1,NLINES**

**30 DEPV(8,J)= (TO(JJ, J)/518.688-1.)*DEPV(9,J)**

**CALL INTEG(DEPV,2)**

**V=RINT(NLINES)-RINT(1)**

**TMA(JJ)= (V/SUM+1.)*518.688/TO(1,1)**

*** COMPUTE MASS AVERAGED EFFICIENCY

**TMAEP(JJ)= THERM1(TMA(JJ)*TOCO)**

**35 CONTINUE**

*** DETERMINE MASS AVERAGE TEMPERATURES AND PRESSURES

B-60
OUT. - EFN SOURCE STATEMENT - IFN(S) -

TMAB(IS)=TMA(IS)/TMA(IS-1)
TMAB(IS+1)=TMA(IS+1)/TMA(IS-1)
PMAB(IS)=PMA(IS)/PMA(IS-1)
AA= TMA(IS)*TO(1,1)
BB= AA
CC= TMA(IS+1)*TO(1,1)
DD= CC

C *** YIELDS THEORETICAL TEMPERATURE RISE

CALL THERM2(PMA(IS),AA,TO(1,1))
CALL THERM2(PMA(IS)/PMA(IS-1),BB,TMA(IS-1)*TO(1,1))
CALL THERM2(PMA(IS+1),CC,TO(1,1))
CALL THERM2(PMA(IS+1)/PMA(IS-1),DD,TMA(IS-1)*TOCO)

C *** OVERALL MASS AVERAGE ROTOR EFFICIENCY

CXS(6,1)= (THERM1(AA)-TMAEP(5))/TMAEP(IS-1):AEP(5)
PMAB(IS+1)=PMA(IS+1)/PMA(IS-1)

C *** MASS AVERAGE ROTOR EFFICIENCY

CXS(6,2)=(THERM1(BB)-TMAEP(IS-1))/TMAEP(IS-1)

C *** OVERALL MASS AVERAGE STAGE EFFICIENCY

CXS(7,1)=THERM1(CC)-TMAEP(5)/TMAEP(IS-1)-TMAEP(5)

C *** MASS AVERAGE STAGE EFFICIENCY

CXS(7,2)=THERM1(DD)-TMAEP(IS-1)/TMAEP(IS-1)

DO 40 J=1,NLINES
FRDEL(1,J)= THERM1(TO(IS-1,J))
FRDEL(2,J)= THERM1(TO(IS,J))
FRDEL(3,J)= THERM1(TO(IS+1,J))
TERM=TO(IS,J)
TERMA(I)=TO(IS,J)
CALL THERM2(PO(IS,J)/PO(IS-1,J),TERM,TO(IS-1,J))

C *** YIELDS THEORETICAL TEMPERATURE RISE

CALL THERM2(PO(IS+1,J)/PO(IS-1,J),TERMA(I),TO(IS-1,J))

C *** DETERMINE ROTOR AND STAGE EFFICIENCY

ATA(I,J)= (THERM1(TEMA)-FRDEL(1,J))/FRDEL(2,J)-FRDEL(1,J)
ATA(S+1,J)= (THERM1(TEMA(I))-FRDEL(1,J))/FRDEL(3,J)-FRDEL(1,J)

C *** COMPUTE ABSOLUTE VELOCITY (ROTOR EXIT)

CXM(I,J)=SQRT(CX(IS,J)**2+CU(IS,J)**2+CR(IS,J)**2)

C *** CALCULATE ROTOR STATIC TEMPERATURE

H= -CXM(I,J)**2/GJ
CALL ENTHALP
CXNEW(1,J)= TSTAT(J)
CALL GAM
ERAS1= GR2*GAMER*TSTAT(J)
CO(8,J)= PD(IS,J)*EXP((THERM3(TSTAT(J))-THERM3(T))/DCP)

*** CALCULATE ROTOR RELATIVE VELOCITY

CO(5,J)= CX(IS,J)**2 + (CU(IS,J)-U(IS,J))**2 + CR(IS,J)**2
CO(5,J)=SQRT(CO(5,J))

*** CALCULATE STATOR RELATIVE VELOCITY

CO(6,J)= CX(IS+1,J)**2 + (CU(IS+1,J)-U(IS+1,J))**2 + CR(IS+1,J)**2
CO(6,J)=SQRT(CO(6,J))

*** CALCULATE ROTOR RELATIVE MACH NUMBER

CXS(1,J)= CO(5,J)/SQRT(ERAS1)

*** GET A*/S (ROTOR)

IF (EMACH(IS,J).LT.1.0) EMACH(IS,J)=1.0
A= GAMMA(IS-1,J)
BETA(2,J)= BETA(2,J)/57.29578
EMACH(IS,J)= COS(BETA(2,J))/(0.5*(A+1.0))**(-0.5*(A+1.0)/(A-1.0))
X/MACH(IS,J)**(1.0+0.5*(A-1.0)*MACH(IS,J)**2)**(0.5*(A+1.0)/(A-1.0))
X**((A/(A-1.0))
X*=((A+1.0)/(2.0*A*EMACH(IS,J)**2 + 1.0 - A)**(1.0/(A-1.0)))
BETA(2,J)= BETA(2,J)/57.29578
A=SQRT(CX(IS,J)**2 + CR(IS,J)**2)

*** CALCULATE ABSOLUTE FLOW ANGLE

ALPHA(1,J)= ATAN(CU(IS,J)/A)*57.29578

*** CALCULATE RELATIVE FLOW ANGLE

BETA(1,J)= ATAN((U(IS,J) - CU(IS,J))/A)*57.29578

*** CALCULATE TOTAL TEMPERATURE RATIO (ROTOR)

CC(1,J)= TO(IS,J)/TO(IS-1,J)

*** CALCULATE TOTAL PRESSURE RATIO (ROTOR)

CO(3,J)= PD(IS,J)/PD(IS-1,J)

*** CALCULATE TOTAL TEMPERATURE RATIO (STATOR)

CC(2,J)= TO(IS+1,J)/TO(IS,J)

*** CALCULATE TOTAL PRESSURE RATIO (STATOR)
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OUT.  - EFN SOURCE STATEMENT  - IFN(S) -

C CO(I,J)= PO(I,S+1,J)/PO(I,S,J)
     TO AXIAL LENGTH. RESULTS ARE IN RSLOPE AND RCURVE

C CALL DERIV(R,RSLOPE,RCURVE,X)

C *** CALCULATE ROTOR CURVATURE

C RCURVE(2,J)= RCURVE(2,J)/(SQRt(1.+RSLOPE(2,J)**2)**3)

C *** CALCULATE STATOR CURVATURE

C RCURVE(3,J)= RCURVE(3,J)/(SQRt(1.+RSLOPE(3,J)**2)**3)

C *** CALCULATE ROTOR SLOPE

C RSLOPE(2,J)= ATAN(RSLOPE(2,J)*)57.297795

C *** CALCULATE STATOR SLOPE

C RSLOPE(3,J)= ATAN(RSLOPE(3,J)*)57.297795

C *** GET A/S (STATOR)

C IF (EMACH(I,S+1,J)LT.1.0) EMACH(I,S+1,J) = 1.0

C A= GAMMA(I,S,J)

C ALPHA(I,J)= ALPHA(I,J)57.29578

C EMACH(I,S+1,J)= COS(ALPHA(I,J))/((0.5*(A+1.0)**(-0.5*(A+1.0))/(A-

C X 1.0)/MACH(I,S+1,J)(*1.0+0.5*(A-1.0)*MACH(I,S+1,J)**2)**(0.5*(A+1.0)

C X /A-1.0))**((A+1.0)*EMACH(I,S+1,J)**2/((A-1.0)*EMACH(I,S+1,J)**2

C X +2.0))** (A/A-1.0)

C X *((A+1.0)/((2.0**2*EMACH(I,S+1,J)**2 +1.0 -A)**2(1.0/A-1.0)))

C ALPHA(I,J)= ALPHA(I,J)*57.29578

C *** CALCULATE ABSOLUTE VELOCITY (STATOR)

C CXM(2,J)= SQRT(CX(I,S+1,J)**2+CU(I,S+1,J)**2+CR(I,S+1,J)**2)

C *** CALCULATE STATIC TEMPERATURE (STATOR)

C M= -CXM(2,J)**2/GJ

C T= TO(I,S+1,J)

C CALL ENTP

C CALL GAM

C CXNEW(2,J)= TSTAT(J)

C ERAS1= GRI2*GAMER*TSTAT(J)

C CO(9,J)= PO(I,S+1,J)*EXP((THERM3(TSTAT(J))-THERM3(T))/DCP)

C *** CALCULATE ABSOLUTE MACH NUMBER (STATOR)

C CXS(2,J)= CXM(2,J)/SQRT(ERAS1)

C *** CALCULATE STATOR RELATIVE MACH NUMBER

C CO(7,J)= CO(6,J)/SQRT(ERAS1)

B-63
C  *** CALCULATE STATIC PRESSURES
   OUT.2959
   OUT.2960
   OUT.2961
   OUT.2962
   OUT.2963
   OUT.2964
   OUT.2965
   OUT.2966
   OUT.2967
   OUT.2968
   OUT.2969
   OUT.2970
   OUT.2971
   OUT.2972
   OUT.2973
   OUT.2974
   OUT.2975
   OUT.2976
   OUT.2977
   OUT.2978
   OUT.2979
   OUT.2980
   OUT.2981

C  *** CALCULATE RELATIVE FLOW ANGLE (STATOR)
   OUT.2982
   OUT.2983
   OUT.2984
   OUT.2985
   OUT.2986
   OUT.2987

C  *** CALCULATE ABSOLUTE FLOW ANGLE (STATOR)
   OUT.2988
   OUT.2989
   OUT.2990
   OUT.2991
   OUT.2992
   OUT.2993
   OUT.2994
   OUT.2995
   OUT.2996
   OUT.2997
   OUT.2998
   OUT.2999
   OUT.3000
   OUT.3001
   OUT.3002
   OUT.3003
   OUT.3004
   OUT.3005
   OUT.3006

C  *** CONVERT INPUT DATA BACK TO DEGREES
   OUT.3007
   OUT.3008
   OUT.3009
   OUT.3010
   OUT.3011
   OUT.3012
   OUT.3013
   OUT.3014
   OUT.3015
   OUT.3016
   OUT.3017

C  *** WRITE STAGE PARAMETERS
   OUT.3018
   OUT.3019

50 FORMAT(1H1)'/30X47H'//// FINAL FLOW PARAMETERS FOR STAGE NUMBEROUT.2992
   OUT.2993
   OUT.2994
   OUT.2995
   OUT.2996
   OUT.2997
   OUT.2998
   OUT.2999
   OUT.3000
   OUT.3001
   OUT.3002

53 WRITE (6,50) N, DFL(IS), HMN(IS+1), HMN(IS), DFL(IS+1), V0(IS)
   OUT.3003
   OUT.3004
   OUT.3005
   OUT.3006
   OUT.3007

54 CONTINUE

51 FORMAT(1//4X) '/11H' // ROTOR--- 48X 12H--- STATOR--- // 11X
   OUT.3008
   OUT.3009
   OUT.3010
   OUT.3011
   OUT.3012
   OUT.3013
   OUT.3014
   OUT.3015
   OUT.3016
   OUT.3017

55 FORMAT(1//24X)
   OUT.3018
   OUT.3019
   OUT.3020
   OUT.3021
   OUT.3022
   OUT.3023
   OUT.3024
   OUT.3025
   OUT.3026
   OUT.3027
   OUT.3028
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   OUT.3063
   OUT.3064
   OUT.3065
   OUT.3066

B-64
OUT. - EFN SOURCE STATEMENT - IFN(S) -

\[ S_W = C(X(IS,JM)) / C(X(IS-1,JM)) \]

\[ A = C(X(IS+1,JM)) / C(X(IS,JM)) \]

\[ Q = (R(IIS) - RH(IIS)) / DEPV(5,2) \]

\[ AA = (R(IIS-1) - RH(IIS-1)) / DEPV(5,1) \]

WRITE(6,56) AA, RH(IIS), R(IIS), ALPHA(3,1),

\[ X ALPHA(3,2), DEPV(5,1), FLOW(IS), C(XS(6,2)), Q, \]

\[ X RHI(IS-1), R(IIS+1), ALPHA(4,1), ALPHA(4,2), DEPV(5,2), \]

\[ X FLOW(IS+1), C(XS(7,2)), SQCO, DH(IS), BT(IS), \]

\[ X PMA(IS), TMAB(IS), PMA(IS), TMAB(IS), C(XS(6,1)), \]

\[ X A, BH(IS+1), BT(IS+1), PMA(IS+1), TMAB(IS+1), C(XS(7,1)), \]

WRITE(6,275) BLADE(IS), BLADE(IS+1)

275 FORMAT (11X 9HLOSS DATA / 11X 8HSET USED // 9H - ROTOR-- 17 //

X 9H - STATOR-- 17 )

C

*** PRINT ROTOR EXIT QUANTITIES

WRITE (6,57)

57 FORMAT(1H)///41X36H******/ROTOREXIT****///2X4HS.L.///OUT.3046

X 57H STREAMLINE AXIAL VEL. WHIRL VEL. RADIAL VEL. ///OUT.3047

X 52HABS. VEL. ABS. MACH ABS. FLOW REL. FLOW /3X3HNO. ///OUT.3048

X 528 RADUS (IN.) (FT/SEC) (FT/SEC) (FT/SEC) ///OUT.3049

X 52H(FT/SEC) NUMBER ANGLE (DEG) ANGLE (DEG) / ///OUT.3050

DO 60 J=1,NLINES,1,QUITR

WRITE(6,59) J,R(IS,J),C(IS,J),C(UI,J),CRI(IS,J),CXM(1,J),

X MACH(IS+1,J),ALPHA(1,J),BET(1,J),


60 CONTINUE

WRITE(6,651)

65 FORMAT(1H)/2X4HS.L.43H TOTAL TEMPS. TOTAL PRES. ADIABATIC ///OUT.3061

X 38MDIFFUSION WHEEL SPEED SOLIDITY 8X 4HA/S 6X ///OUT.3062
OUT. - EFN SOURCE STATEMENT - IFN(S) -

%11HLLOSS CCEFF. OUT.3063
X /3X3HNO.4X 5HRATIO 9X OUT.3064
X 5HRATIO6XL0HEFFICIENCY5X6HFACTOR 7X 8H(FT/SEC) / ) OUT.3065
DO 70 J=1,NLINES,1OUTTR OUT.3066
WRITE (6,66) J,CO(1,J),CO(3,J),ATAR(IS,J),DFACT(IS,J),UIJS,J), OUT.3067
X SOLID(IS,J),EMACH(IS,J),OBAR(IS,J) OUT.3068
70 CONTINUE OUT.3069
WRITE (6,281) OUT.3070
281 FORMAT (I40//2X415,L10H TOTAL TEMP. TOTAL PRES. STATIC TEMP.OUT.3071
X STATIC PRES. SLOPE CURVATURE REL. VEL. REL. MOUT.3072
XACH /3X3HNO.3X 9H(DEGREES)3X11H(LB/SQ IN.) 4X9H(DEGREES) 5X OUT.3073
X 11H(LB/SC IN.) 2X9H(DEGREES)19X51H/IN.8X8H(FT/SEC) 7X6HNUMBER /) OUT.3074
DO 282 J=1,NLINES,1OUTTR OUT.3075
282 WRITE (6,283) J,TC(IS,J),PO(IS,J),CXNEW(1,J),CO(8,J),RSLOPE(2,J), OUT.3076
X RCURVE(2,J),CO(5,J),CXS11,J) OUT.3077

C *** PRINT STATOR EXIT QUANTITIES

WRITE (6,75) OUT.3078
75 FORMAT (I40//40X38H**-----** STATOR EXIT ***-----** // 2X OUT.3079
X4HS.L57H STREAMLINE AXIAL VEL. WHIRL VEL. RADIAL VEL. OUT.3080
X 52HABS. VEL. ABS. MACH ABS. FLOW REL. FLOW /3X3HNO. OUT.3081
X 58H RADIUS (IN.) (FT/SEC) (FT/SEC) OUT.3082
X 52H(FT/SEC) NUMBER ANGLE (DEG) ANGLE (DEG) / ) OUT.3083
DO 80 J=1,NLINES,1OUTTR OUT.3084
WRITE (6,59) J,R(IS+1,J),CX(IS+1,J),CU(IS+1,J),CR(IS+1,J), OUT.3085
X CAXM(2,J),CXS12,J),ALPHA(2,J),BETA(2,J) OUT.3086
80 CONTINUE OUT.3087
WRITE (6,65) OUT.3088
DO 85 J=1,NLINES,1OUTTR OUT.3089
WRITE (6,66) J,CO(2,J),CO(4,J),ATAS(IS+1,J),DFACT(IS+1,J), OUT.3090
X U(IS+1,J),SOLID(IS+1,J),EMACH(IS+1,J),OBAR(IS+1,J) OUT.3091
85 CONTINUE OUT.3092
WRITE (6,281) OUT.3093
DO 284 J=1,NLINSF,1OUTTR OUT.3094
284 WRITE (6,283) J,TO(IS+1,J),PO(IS+1,J),CXNEW(2,J),CO(9,J),RSLOPE(3,OUT.3095
XJ),RCURVE(3,J),CO(6,J),CO(7,J) OUT.3096
100 CONTINUE OUT.3097

C *** PRINT OUTLET QUANTITIES

WRITE (6,110) OUT.3098
110 FORMAT (I40//40X40H*** OUTLET FLOW PARAMETERS ****/// OUT.3099
X 13X3HST1X5HAYTAL7X9XGEOMETRYC3X9XGEOMETRYC4X12HUB BLOCKAGE 3X OUT.3100
X 12HTIP BLOCKAGE. 13X3HNO.5X10HCORDINATEC4X10HUB RADIUS 4X OUT.3101

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PAGE 180

X /)
JJ=LSTAGE + 1
DO 120 J=JJ,NX
120 WRITE (6,115) J,X(J),RH(J),RS(J),BH(J),BT(J)
115 FORMAT (10X15,F15.3,F14.3,F14.3)
WRITE (6,130) JJ
130 FORMAT (1H0/50X14HSTATION NUMBER I4 // 5H S.L. 3X10HSTREAMLINE 4X OUT.3123
X 10HAXIAL VEL. 3X10HWHIRL VEL. 4X11HRADIAL VEL. 4X 9HABS. VEL. 5X OUT.3124
X 9HABS. MACH 4X11HTOTAL TEMP. 3X11HTOTAL PRES. / 4H NO.4X11HRADIUSOUT.3125
X IN. 3X 8H(FT/SEC) 6X8H(FT/SEC) 6X8H(FT/SEC) 6X8H(FT/SEC) 7X OUT.3126
X 6HNUMBER 7X 9H(1DEGS R) 4X11H(IN SQ IN) /)
KJ=0
DO 140 IJ=JJ,NX
KJ=KJ+1
DO 140 J=1,NLINES
C *** CALCULATE ABSOLUTE VELOCITY (OUTLET)
CXM(KJ,J)= SQRT(CX(I,J)**2 + CU(I,J)**2 + CR(I,J)**2)
C *** CALCULATE STATIC TEMPERATURE (OUTLET)
H= -CXM(KJ,J)**2/GJ
T= TO(I,J)+
CALL ENTHALP
CXNEW(KJ,J)= TSTAT(I)
CALL GAM
ERAS1= GR2*GAMMER*TSTAT(I)
C *** CALCULATE ABSOLUTE MACH NUMBER (OUTLET)
CXS(KJ,J)= CXM(KJ,J)/SQRT(ERAS1)
140 CONTINUE
KJ=0
DO 150 IJ=JJ,NX
IF(IJ.GT.JJ) WRITE (6,160) IJ
KJ=KJ+1
DO 150 J=1,NLINES,1OUTR
150 WRITE (6,165) J,R(I,J),CX(I,J),CU(I,J),CR(I,J),CXM(KJ,J),
X CXS(KJ,J),TO(I,J),PO(I,J)!
160 FORMAT (1H050X14HSTATION NUMBER I4//)
IF (AND(IDUMP,2).NE.0.0) WRITE (7,18) (X(I),RH(I),BH(I),RS(I),
X BT(I),I=1,NX)
18 FORMAT (5F10.5)
RETURN
*** FINISHED AT LAST.........
B-87
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

11/02/67

SUBROUTINL ROTOUT
REAL *4RM
COMMON /SPECIAL/ NORM(14), XZ, NOFAIL
COMMON /VEOEM/ ALI(29), ALT(29), ALTER,
X ASPECT(29), FPATH, SAVEA(29)
LOGICAL FPATH
LOGICAL NO FAIL

C

*** COMPUTES ROTOR EXIT GEOMETRY

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEW, JOUFL
DIMENSION ATAS(29,11), FLOW(32)

LOGICAL ERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAP(29,11), BZ(29),
X BETA(10,11), RII(32), BLAOE(29), BT(32),
X CD(10,11), CPI(32,11), CPCD(6), CH(32,11),
X CSL(10,11), CU(37,11), CRCO(29,5),
X CX(32,11), CM(10,11), CXNE(10,11), CXRAT(29),
X CXS(10,11), DA(101), DELL(11), DFPV(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLM(32),
X EMAC(29,11), FOUNO(20,3,10), FRIVEL(10,11), GAMMA(10,11),
X HMP(29), HIU(32), IKK(101), MACH(29,11),
X OBAR(29,11), POI(32,11), R(32,11), RCURF(10,11),
X RHI(32), RHO(132,11), RINT(11), ROSTAG(11),
X RSA(32), RSL(1011), RTRA(1111), ROCO(29,5),
X SOLI(129,11), SSCO(29,5), TEMI(10,11), TRMA(11),
X TPRM(11), TEMC(11), TIP(32), TITLE(12),
X TOST(23,11), TSTAT(11), U(32,11), W(11),
X X(32)

COMMON /SCALER/ A, AA, A,B,AO, A202A0, A303A0, A404A0,
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, COINTG,
X CPI2, CPI3, CPI4, CPI5, LPI6, CPO7, CPO8, CPO9,
X CP05, DAMP, DCP, DD, DIFCM, DT, DUMMY, ERIAI,
X G, CASK, GJ, GR, GR2, JOULE, MAPR, MOLEW,
X PUCO, C, RPH, TCP, TMRP, TESTBH, TFSDDS, TESTMS,
X TCGO, TOL, TGLAT, TOL62, TOLMIN, TOLMS, TOLTP, TOLCP,
X TCTLEX, TMLR, TOTINT, TOTPR, U, VMI

COMMON /INTEGR/ I, IN, IB, IDUMP, IERROR, IFIRST,
X IG, ICUT, IPASS, IS, IT, J, JEN, JH,
X JH, JML, K, K1, KK, L, LIMIT, LSTAGE,
X MSTAGE, NLINES, NTURES, NX, NXI, YES

EQUIVALENCE (ATAP(11,11), ATAS(1,11)), (FLOW(1), CFLOW(1))

L = 1
CAMP = 100.0
IF (LSTAGE,NE,7) GO TO 45
IF (.NOT. FPATH) GO TO 20

*** PICK UP ROTOR GEOMETRY
RS(6) = RS(5)
DT = (RS(5) - RH(5)) / ASPFC(6)
X6 = X(5) + DT
RH(6) = RH(5) + DT * AMIN(C,6, 0.R*ALM(6))
GO TO 25

20 RH(1) = HUB(1)

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**REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR:**

**ROTOR. - EFN SOURCE STATEMENT - IFN(5) -**

ROTI3778
ROTI3779
ROTI3279
ROTI3280
ROTI3281
ROTI3282
ROTI3283
ROTI3284
ROTI3285
ROTI3286
ROTI3287
ROTI3288
ROTI3289
ROTI3290
ROTI3291
ROTI3292
ROTI3293
ROTI3294
ROTI3295
ROTI3296
ROTI3297
ROTI3298
ROTI3299
ROTI3300
ROTI3301
ROTI3302
ROTI3303
ROTI3304
ROTI3305
ROTI3306
ROTI3307
ROTI3308
ROTI3309
ROTI3310
ROTI3311
ROTI3312
ROTI3313
ROTI3314
ROTI3315
ROTI3316
ROTI3317
ROTI3318
ROTI3319
ROTI3320
ROTI3321
ROTI3322
ROTI3323
ROTI3324
ROTI3325
ROTI3326
ROTI3327

**B-70**
SUBROUTINE RSTART
C
*** CALCULATES EQUAL AREA ESTIMATE OF STREAMLINE POSITION
C
AND WHEEL SPEED

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(24,11), FLOW(32)

LOGICAL ERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), A2(22),
X BETA(10,11), BM(32), BLADE(29), BT(32),
X CC(10,11), CP(32,11), CPCO(6), CR(32,11),
X CSLCP(10,11), CU(32,11), CUCO(29,5),
X G/32(11), CXM(10,11), CXRATD(29),
X G/35(10,11), DA(20), DEL4(11), DEPV(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLOW(32),
X EMAGH(29,11), FOUNDI(20,3,10), FRDEL(10,11),
X HMM(29), MURH(32), IKKI(10), MACH(29,11),
X OBART(29,11), P0(32,11), R(32,11), MCRUCE(10,11),
X RHI(32), RH0D(32,11), RINT(11), MPOSTG(11),
X RST(32), RSLPE(10,11), RTKAIL(11), MSSC(29,5),
X SCILD(29,11), SSCU(29,5), TERM(110,11), 
X TERM(11), TTERM(11), TIP(32), TITLF(12),
X TL(32,11), TSTAT(11), U(32,11), W(11),
X X(32)

COMMON /SCALE/ A, AA, AITAO, A202AO, A33AO, A404AO,
X A505AO, B, BB, CC, CM, CMEAN, CMENP, COINTG,
X CIPI2, CPI3, CPI4, CPI5, CIP6, CP02, CP03, CP04,
X CP05, DAP, DCP, DD, DIFCM, DT, DUMMY, ERAI,
X G, GASK, GD, OR, GZ, JOULE, MAPR, MOLEWT,
X PECS, C, RPM, TCP, TEMO, TEFISH, TESTS, TESTS,
X TOGC, TOL, TOLAT, TOLB, TOLMIN, TOLMS, TOLTP, TOLCP,
X TGOCK, TOLR, TOTINT, IOUTPR, V, VMI

COMMON /INTEGR/ I, IA, IN, IOMP, IFR, IFST, IFST,
X IG, IOUUT, IPASS, IS, IT, J, JIN, JJ,
X JM, JML, K, KL, KK, L, LIMIT, LSTAT,
X MSTAGE, NLLINES, NTUBES, NX, YX1, YES

EQUIVALENCE (ATAR(1,1),ATAS(1,1)), (FLOW(1),DFLOW(1))

A= (RS(11)-RH(11))*RS(11)+RH(11)
AA= RS(11)**2 -A*BH(1)
B= RH(11)**2 +A*BTH(1)
CC=BB-AA
DD= RPM
DO 10 J=1,NLLINES
ERAS=A AA*DEL4(J)*CC

C      *** ERROR TRANSFER TO A NEW DATA SET
IF (FRAS1.LE.0.0) CALL FRRO(13)
R(I,J)= SCR(REAS1)
10 UT(I,J)=R(I,J)*DD
RETURN
END

B-71
FUNCTION SHOCK(Z,Y)

*** Calculates supersonic expansion angle minus Prandtl-Meyer angle

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLFWT, JOULF
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), R21(10), SHOC(3384)
X BETAL(10,11), RHI(32), BLADE(29), BY(32), SHOC(3385)
X CD(10,11), CP(32,11), CPCO(6), CP(32,11), SHOC(3386)
X CSLOPE(10,11),CU2(11), CU(32,7), CUCO(29,5), SHOC(3387)
X CX(32,11), CXM(10,11), CXNEW(1,11), CXRAT(29), SHOC(3388)
X CX(32,11), DAI(10), DELM(10), CEPV(10,11), SHOC(3389)
X CF(20), DFACT(29,11), DFJ(10), DELF(32), SHOC(3390)
X EMACH(29,11), FUND(20,3,10), FROEL 0,11,1, SHOC(3391)
X HNN(29), HUB(32), IJK(10), MACH(29,11), SHOC(3392)
X OBAR(29,11), PNI(32,11), R31(11), MACHVE(10,11), SHOC(3393)
X RMH(32), RMO(32,11), RINT(11), MACH(10), SHOC(3394)
X RSI(32), RSLOPE(10,11), RTAIL(11), MACH(10), SHOC(3395)
X SOLIDT(29,11), SSCO(29,5), TERN(10,11), TFRMA(11), SHOC(3396)
X TERM(11), TIP(32), TITLE(12), SHOC(3397)
X T0T(32,11), USTAT(11), W(11), SHOC(3398)
X X(32)

COMMON /SCALER/ AA, A, A10AO, A202AO, A303AO, A404AO, SHOC(3399)
X AS05AO, BA, CC, CM, CMMEAN, CMFAWP, CINTG, SHOC(3400)
X CP12, CP13, CP14, CP15, CP16, CP02, CP03, CP04, SHOC(3401)
X CP05, DMAP, DC, DO, DIFCP, DI, DUMMY, ERAS1, SHOC(3402)
X G, CASK, G, GJ, GK, G2, JOULE, MAPR, MOLEWT, SHOC(3403)
X PGFC, C, RPM, TCP, TRFMD, TESTBH, TESTOS, TESTMS, SHOC(3404)
X TUCO, TOI, TOI, TOLR2, TOL4IN, TOL45, TOLTIP, TOLCP, SHOC(3405)
X TCLCP, TULK, TOTINT, TOTPR, V, VMI, SHOC(3406)
COMMON /INTEGR/ I, IBL, IB1, IBL, IDUMP, IERRUR, IFIRST, SHOC(3407)
X IG, IOUSTR, IPASS, IS, IIT, J, JIN, JJ, SHOC(3408)
X JM, JPL, K, KL, KK, L, LIMIT, LSTATE, SHOC(3409)
X MSTATE, ALINES, NTURES, NX, NX1, YES, SHOC(3410)
EQUIVALENCE (ATAR(1,1), ATAS(1,1), FLOW(1),DFLOW(11))

SHOCK = Y - TERM(1,1)*ATAN(SQRT((Z-1.0)*(Z+1.0)))/TERM(1,1) +
X ATAN(SQRT((Z-1.0)*(Z+1.0)))
RETURN
END
SUBROUTINE SLINE(X,XT,YT,N,ANS)
DIMENSION XT(500),YT(500)
IF (N-1) 3,3,11
11 IF (X-XT(1)) 3,3,4
2 RETURN
3 ANS=YT(1)
GOTO 2
4 IF (X-XT(N)) 7,5,5
5 ANS=YT(N)
GOTO 2
6 ANS=(YT(N)-YT(N-1))*(X-XT(N-1))/(XT(N)-XT(N-1))+YT(N-1)
GOTO 2
7 K=N-1
DO 8 I=2,K
8 CONTINUE
IF (X-XT(I)) 9,11,8
9 CONTINUE
GOTO 6
10 ANS=YT(I)
GOTO 2
END
SUBROUTINE STAOUT

*** COMPUTES STATOR EXIT GEOMETRY

COMMON /VGEOM/ ALTI(29), ALT(29), ALTER,
X ASPECT(29), FPATH, SAVEA(29)
LOGICAL FPATH
DOUBLE PRECISION TITLE
REAL MACP, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETAI(10,11), BH(32), BLADE(29), BT(32),
X CO110,11, CPI(32,11), CPO(6), CI32,11),
X CSLOPE(10,11), CU2(11), CU32,11), CUCD(29,5),
X CX(32,11), CXM(10,11), CXXEQ(10,11), CXXAT(29),
X CXS(11,10), DAI(10), DELM(11), DEPY(10,11),
X DFI(201), DFACT(29,11), DFIL(29), DFLOW(32),
X EMACH(29,11), FOUND(20,3,10), FREDL(10,11), GAMMA(32,11),
X HNN(29), HUB(32), IKK(10), MACH(29,11),
X OBAR(29,11), POI(32,11), R(32,11), RCURVE(10,11),
X RH32, RHOI(32,11), RINT(11), ROSTAG(11),
X RS(32), RSLOPE(10,11), RTRAIL(11), SOCIO(29,5),
X SOLIO(29,11), SSCO(29,5), TERM1(10,11), TERM(11),
X TERNMB(11), TERNM(11), TIP(32), TITLE(12),
X T0I(32,11), TSTAT(11), U(32,11), W(11),
X X(32)
COMMON /SCALER/ A, AA, A10A0, A202A0, A303A0, A404A0,
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, CONG,
X CP12, CPI3, CPI4, CPI5, CPI6, CPI2, CP03, CP04,
X CP05, CP06, CPC, DD, DFCM, DT, DUMMY, ERAS1,
X GI, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X RPO, RPM, TCP, TDER, THERM, TEST, TOEMS, TESTS,
X SOCO, TOL, TOLAT, TOLB2, TOLMIN, TOLS, TOLTP, TOLCP,
X TOLCX, TOLR, TOTINT, TOTPR, V, VMI,
COMMON /INTEGR/ I, IB, IB1, IDUMP, IERROR, IFIRST,
X IG, IOUTTR, IPASS, IS, IT, J, JIN, JJ,
X JM, JML, K, K1, L, LIMIT, LSTAG,
X MSTAGE, NLINE, NTUBE, NX, NXI, YES
EQUVALENCE (ATAR(11,1), ATAS(11,1)), (FLOW(1), DFLOW(1))

L = 1
IF (LSTAGE, NE, 7) GO TO 45
IF (.NOT. FPATH) GO TO 20

*** ESTIMATE THE FIRST STATOR GEOMETRY IF REQUIRED

RSI7 = RS6
DT = (RS6 - RHE(61), ASPECT(7)
RH(7) = RH(6) + DT*A MINI(0.6, 0.8*ALH(7))
X(7) = X(6) + DT
GO TO 25

*** PICK UP THE STATOR GEOMETRY
20 WH(I)= HUB(I)
     RS(I)= TIP(I)
25 CALL RSTART
    DO 3 J=1,NLINES

C   *** INITIALIZE THE FLOW PARAMETERS

    TO(I,J)= TO(I-1,J)
    CP(I,J)=CP(I-1,J)
    GAMMA(I,J)= GAMMA(I-1,J)
3   PD(I,J)= PD(J)*(0.89*(TO(I,J)-TOCO)/TOCO +1.0)**
   X (GAMMA(I,1)/(GAMMA(I,1) -1.0))
   CALL INEST
   CALL STREAM
   CALL MOVE
   RETURN

C   *** ESTIMATE THE DOWN-STREAM STATOR PROPERTIES

45  CALL COPY
    RETURN
    END
SUBROUTINE STREAM

*** COMPUTES AXIAL VELOCITY DISTRIBUTIONS WHICH SATISFY
CONTINUITY AND LOCATES STREAMLINE POSITIONS

DOUBLE PRECISION TITLE
REAL NACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL ERROR, YES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BETA(10,11), BLADE(29), BT(32),
X CC(10,11), CPCI(32,11), CPGO(6), CR(32,11),
X CSLLOPE(10,11), CUI(32,11), CUCO(29,5),
X CX(32,11), CXNEW(10,11), CXRATO(29),
X CXS(10,11), DAI(10), DEPV(10,11),
X EFI(20), DFAC(29,11), DFLOW(32),
X EMACH(29,11), FOUN(20,3,10), FRDEL(10,11), GAMMA(32,11),
X HNN(29), HUB(32), IKK(10), MACH(29,11),
X OBAR(29,11), P0(32,11), R(32,11), KCURVE(10,11),
X RH(32,11), RHQ(32,11), RINT(11), ROSTAG(11),
X RS(32,11), RSLLOPE(10,11), RTRAIL(11), SOC0(29,5),
X SOLID(29,11), SOCO(29,5), TERM1(10,11), TERMA(11),
X TERM1(11), TERMC(11), TIP(32), TITLE(12),
X TO(32,11), TSTAT(11), U(32,11), W(11),
X X(32)

COMMON /SCALER/ A, AA, AIC0, A202A0, A303A0, A4040,
X A505A0, B, BB, CC, CM, CMEAN, CMEANP, COUNI,
X CPI2, CPI3, CPI4, CPI5, CPI6, CP02, CP03, CP04,
X CRM5, Dcpp, DD, DIFCM, DT, DUMMY, ERAS1,
X G, GASK, GJ, GR, G2, JOULE, MAPR, MOLENT,
X POC0, Q, RPL, RGP, TERM2, TESTBH, TESOTS, TESTMS,
X TOCC, TOL, TOLAT, TOLB2, TOLM, TOLS, TOLTP, TOLCP,
X TOLCR, TOLR, TOTINT, TOTP, V, VMI

COMMON /INTEGR/ I, IB, IB2, IDUMP, IERROR, IFIRST,
X IG, IOUTTR, IPASS, IS, IT, J, JIN, JJ,
X JM, JMI, K, KL, KI, L, LIMIT, LSTAGE,
X NSTAGE, NINES, NTUBES, NX, NXL, YES

EQUVALENCE (ATAR(1,1),ATAS(1,11), (FLOW(1),DFLOW(1))
COMMON /ENERGY/ H, T, GAMMER

CMEAN=CXI(J,M)

*** COMPUTE VALUES OF CXM,ROSTAG,AND TERMA, (CU**2+CR**2)

DO 150 J=1,NLINES
CXM(L,J)=CX(I,J,M)/CMEAN

150 TERMA(J)=CU(I,J)**2+CR(I,J)**2
NCOUNT=1

*** START OF LOOP ON CM CONVERGENCE

J= JM
INDIC=0

155 H= -(CMEAN**2+TERMA(J))/GJ

B-78
CALL ENTHALP

*** ERROR TRANSFER TO A NEW DATA SET
IF (VMI.LE.0.3) CALL ERROR(27)
VMI= SQRT(VMI)
IF (CMEAN-VMI) 205, 205, 160
160 IF (INDIC)=165, 170, 165

*** PROGRAM NOT SUITABLE FOR SUPersonic FLOW, GO TO A
NEW DATA SET
165 CALL ERROR(21)
170 INDIC=1
CMEAN= VMI*0.75
205 DO 260 J=1, NLTIES
CX(I,J)=CMEAN*CM(L,J)
H = -(CX(I,J)**2 +TERMA(J))/GJ
T = TOI(I,J)
CALL ENTHALP

*** CALCULATE STATIC DENSITY
B = POI(I,J)*EXP((THERM3(TSTAT(J)) - THER 3(TOJ(I,J)))/DCP)
RHO(I,J) = B/ TSTAT(J)/ GASK
DEPV(L,J) = RHO(I,J)*CM(L,J)
260 CONTINUE

*** CALCULATE INTEGRAL O6 RHO*CMU*R VS. R FROM HUB TO TIP,
(TOTINT), AND NEW VALUE OF CMEAN
275 CALL INTEG(DEPV, 1)
TOTINT=RINT(NLINES)-RINT(I)
CMEANP=FLOW(I)/6.2831853/TOTINT

*** CHECK CONVERGENCE OF CM
DIFCM=ABS((CMEAN-CMEANP)/CMEAN)
IF (DIFCM>TOLR) 300, 300, 280
280 IF (NCOUNT) 301, 290, 285

*** ERROR WILL CAUSE TRANSFER TO NEXT DATA SET
285 CALL ERROR(3)
290 NCOUNT=NCOUNT+1
CMEAN=CMEANP
J= JM
GO TO 155

*** SUCCESSFUL CONVERGENCE ON CM

*** USE CONVERT() VALUES OF INTEGRAL OF RHO*CMU*R VS. R FROM
RIJ TO RJ+1), (DA VALUES), TO CALCULATE VALUES OF - -
DEPV(L,J)=INTEGRAL RHO*CMU*R VS. R FROM RH TO RIJ)/TOTINT
CMEAN

B-77
300 CONTINUE
   DO 400 J=1, N LINES
400   CX(I,J) = CXM(I,J)*G'MEANP
700   RETURN
   END
**FUNCTION THERM1(T)**

***CALCULATES H = INTEGRAL FROM 0.0 TO T OF CP DT, WHERE CP IS GIVEN AS A FIFTH DEGREE POLYNOMIAL***

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLENT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, YES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X BetA(10,11), B H(32), BLADE(29), BT(32),
X CO(10,11), CPI(32,11), CPCO(6), CR(32,11),
X CSLPE(10,11), CUI(32,11), CUCO(29,5),
X CX(32,11), CXM(10,11), CXNEW(10,11), CRATO(29),
X CXS(10,11), DA(10), DLM(11), DEPV(10,11),
X D F(20), DFACT(29,11), DFR(32,11), DFLOW(32),
X EMACH(29,11), FOUN(20,3,10), FREDL(10,11),
X H MN(29), HUB(32), TT Kl(10), MACH(29,11),
X O BaR(29,11), P0(32,11), RT(32,11), RCurve(10,11),
X R M(32), RH0(32,11), RINT(11), ROSTAG(11),
X RS(10,11), RSLOP(10,11), RTRAIL(11), SOC0(29,5),
X SOLID(29,11), SSC0(29,5), TERM(10,11),
X TERMB(11), TERC(11), TIP(32), TITLE(12),
X TO(32,11), TSTAT(11,11), U(32,11), W(11),
X X(32)

COMMON /SCALER/ A*, AA, AT(10,11), ATAR(29,11), B2(29),
X A SQ5A0, B*, BB, CC, CM, CMEAN, CMEANP, COINTG,
X CP12, CP13, CPI4, CPI5, CPI6, CP02, CP03, CP04,
X CP0S, D AMP, DC, DD, DIFCM, DT, DUMAY, ERAS1,
X G*, GASK, GJ, GR, GRZ, JOULE, MAPR, MOLENT,
X GPO, GP0, GRP, RPM, TCP, TERM, TESTBD, TESTOS, TESTS,
X GT0, TOL, TOLA, TLo, TLMB, TOLO, TOLMIN, TOLMS, TOLTIP, TOLCP,
X TOLC*, TOLR*, TOTINT, TOTPR, V, VMI,
X COMMON /INTEGR/ I, IB, IB1, IDUMP, IERROR, IFIRST,
X IG, IQUITR, IPASS, IS, IT, J, JIN, JJ,
X JH, JML, K, K1, KK, L, LIMIT, LSTAGE,
X M STAGE, N LINES, NTUBES, NX, NX1, YES
EQUIVALENCE (ATAR(11,1), ATAS(11,1), (FLOW(11),DFLOW(11))

THERM1 = (CPCO(1)+(CI P12+(CP13+(CPI4+(CPI5+CPI6)*T)*T)*T)*T)*T
RETURN
END

**B-70**
SUBROUTINE THERM2(POVER, TOP, T)

*** SOLVES FOR TOP IN GASK * ALOG(POVER) = INTEGRAL FROM T

TO TOP OF (CP/T) DT, WHERE CP IS GIVEN AS A FIFTH DEGREE

POLYNOMIAL. (SEE THERM1).

DOUBLE PRECISION TITLE
REAL MAPC, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOM(32)
LOGICAL IERROR, YES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), BZ(29,11), THER3684, THER3685
  X G(JA), BH(32), BLADE(29), BT(32), THER3686, THER3687
  X COI(10,11), CPI(32,11), CP01(6), CRI(32,11), THER3688, THER3689
  X CSLOPE(10,11), CU(32,11), CYCOI(29,5), THER3690, THER3691
  X CXI(10,11), CXM(10,11), CXNEW(10,11), THER3692, THER3693
  X CXS(10,11), DA(10), DELM(11), THER3694
  X DF(20), DFACT(29,11), DEP(10,11), THER3695
  X EMACH(29,11), FOUND(20,3,10), DFLM(29,11), THER3696
  X HMON(29), HUB(32), GAMMA(32,11), THER3697
  X OBARI(29,11), PI(32,11), MACH(29,11), THER3698
  X RH(32), RHO(32,11), RCURVE(10,11), THER3699
  X RSI(32), RSLIDE(10,11), ROSTAG(11), THER3700
  X SOLID(29,11), SSC(29,5), RSET(11), THER3701
  X TERM(11), TERM(11), SOLCO(29,5), THER3702
  X TO(32,11), TSTAT(11), TERM(11), THER3703
  X X(32)

COMMON /SCALER/ A, AA, A10A0, A20A0, A303A, A404A,
  X AS50A0, B, BB, CC, C, CMA, CMEAP, CMEAN, CMEAP, CMEAP,
  X CP12, CP13, CP14, CP15, CPM, CP02, CP03, DP04,
  X CP05, DMP, DDP, DD, DIFCM, DT, DUMMY, ES1,
  X G, GASK, J, GR, GR2, JOULE, MAPR, MOLEWT,
  X POCO, G, RPM, TCP, TERMO, TESTBH, TESTOS, TESTMS,
  X TUCO, TOL, TOLAT, TOLB, TOLM, TOLHS, TOLTIP, TOLCP,
  X TOLCK, TOLR, TOTINT, TOPTPR, V, VM, THER3704

COMMON /INTEGR/ I, IA, IB, IB1, IDUMP, IERROR, IFIRST,
  X IG, IGJTR, IPASS, IS, IT, J, JIN, JJ,
  X JM, JML, K, K1, KK, l, LIMIT, LSTAGE,
  X MASTAGE, MLINES, MTEBES, NX, NX1, YES

EQUVALECE (ATAR(1,1), ATAS(1,1)), (FLOW(1), DFLOW(1))

XA= ALOG(POVER)*DCP
BOT= THERM3(T)
DO 20 NN=1,50
DT= TOP*XAX - THERM3(TOP) + BOT/CPO(1,1)
TOP=TOP + CT
IF (ABS(DT).LE.TOLCP) GO TO 15
20 CONTINUE

*** ERROR TRANSFER TO A NEW DATA SET

CALL ERROR(26)

15 RETURN
END

B-80
FUNCTION THERM3(T)

*** CALCULATE THE INTEGRAL OF CP/T DT FROM 0.0 TO T

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL ERROR, YES
COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), BZ(29),
X BET(10,11), BH(32), BLADE(29), BT(32),
X CO(10,11), CP(32,11), CPCO(6), CR(32,11),
X CSLOPE(10,11), CU(32,11), CU(29,5),
X CX(32,11), CXM(10,11), CNEW(10,11), CXRAT(29),
X CXS(10,11), DA(10), DELM(11), DEPV(10,11),
X DF(20), DFACT(29,11), DFL(29), DFLW(32),
X EMACH(29,11), FOUN(20,3,10), FROEL(10,11), GAMMA(32,11),
X HNN(29), HUB(32), IK(10), MACH(29,11),
X OBARI(29,11), PO(32,11), R(32,11), RCURVE(10,11),
X RH(32), RHO(10), INT(11), POSTAG(11),
X RSL(32), RSL(10), KRAIL(11), SOSC(29,5),
X SOLID(29,11), SSCO(29,5), THER(10,11), THER(32,11),
X THERM(11), THERM(11), TIP(32), TITLE(12),
X TO(32,11), TSTAT(11), U(32,11),
X T(X32)
COMMON /SCALER/ A, AA, A10A0, A20A0, A30A0, A40A0, A40A0,
X A50A0, B, BB, CC, CM, CMEAN, CMEANP, COINTG,
X CPI2, CPI3, CPI4, CPI5, CPI6, CPI7, CPR0, CPR0,
X COP0, DAPM, DCP, DL, DIFCM, DT, DUMMY, ERAS1,
X G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X POCO, Q, RPM, TCP, THERM, TESTBH, TESTHT, TESTHS,
X TOCO, TOL, TOLAT, TOLB, TOLMIN, TOLMS, TOLTH, TOLTP, TOLCP,
X TOLC, TULR, TOTINT, TOTPR, V, VMI,
COMMON /INTEGR/ i, IB, IBL, IDUMP, ERROR, IFIRST,
X IG, IGUTTR, IPASS, J, IJ, J, JIN, JG,
X JN, K, K1, K2, K3, LIN, LIMIT, LSTAG,
X MTEST, MINT, NTUBES, NX, NX1, YES
EQUIVALENCE (ATAR(1:1),ATAS(1:1)), (FLOW(1),DFLOW(1))

THERM3 = CPCO(1)*(LOG(T)(CPCO(1)+CPO2+CPO3+CPO4+CPO5*T)*T)*T
X *T*
RETURN
END
SUBROUTINE THERMP

*** CALCULATE SPECIFIC HEAT AT CONSTANT PRESSURE (CP) AS A
FUNCTION BEING A FIFTH DEGREE POLYNOMIAL. THEN THE
RATIO OF SPECIFIC HEATS IS CALCULATED AS CP/(CP-0686)

DOUBLE PRECISION TITLE
REAL MACH, MAPR, MOLEWT, JOULE
DIMENSION ATAS(29,11), FLOW(32)
LOGICAL IERROR, IYES

COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),
X: BETA(10,11), BT(32),
X: CO(10,11), CPO(6), CR(32,11),
X: CSLOPE(10,11), CU132, CUCO(29,5),
X: CX(11), CXNEW(10,11), CXRATO(29),
X: CXS(10,11), DAI(10), DELM(11), DEPV(10,11),
X: DF(20), DFACT(29,11), DFL(29),
X: EMACH(29,11), FOUNDF(20,3,10), FRDEL(10,11), GAMMA(32,11),
X: HMIN(29), IKK(10), MACH(29,11),
X: OMEGA(29,11), RIC(32,11), RCURVE(10,11),
X: RHI(32), RINT(11), ROSTAG(11),
X: RS(32), RTRAIL(11), SOCO(29,5),
X: SOLID(29,11), THER3B0(11),
X: TERM(11,11), TIP(32), TITLE(12),
X: TO(32,11), TSTAT(11), U(32,11), W(11),
X: T(32)

COMMON /SCALER/ A, AA, AIA0, A02A0, A303A0, A404A0,
X: B505A0, B, BB, CC, CM, CMEAN, CMEANP, C3INTG,
X: C12, C12, C14, C15, C16, C16, CPO2, CPO3, CPO4,
X: CPO5, DCF, DD, DIFCM, DT, DUMMY, ERAS,
X: G, GASK, GJ, GR, GR2, JOULE, MAPR, MOLEWT,
X: PCO, Q, RPM, TCP, TERMD, TESTBH, TESTDS, TESTMS,
X: TOCO, TOL, TOLAT, TOLB2, TOLMIN, TOLMS, TOLTP, TOLCP,
X: TOLX, TOLX, TOLINT, TOPTR, V, VMI

COMMON /INTEGR/ I, IB, IBL, IDUMP, IERROR, IFIRST,
X: IG, IPUTTR, IPASS, IS, IT, J, JIN, JJ,
X: JM, K, JK, K1, KK, L, LIMIT, LSTAGE,
X: MSTATE, MSTATE, NTUBES, NX, NX, YES

EQUVALENCE (ATAR(1,1),ATAS(1,1)), (FLOW(11),DFLOW(1))

CP(I,J) = CPOC(I1)+CPCO(2)+CPCO(3)+CPCO(4)+CPCO(5)+CPCO(6)*
X TO(I,J)*TO(I,J)*TO(I,J)*TO(I,J)*TO(I,J)*TO(I,J)
CV = CP(1,J) - DCP
GAMMA(I,J)=CP(I,J)/CV
RETURN
END
**SUBROUTINE XDER IV(Y, DYDX)***

*** CALCULATE THE FIRST AND SECOND DERIVATIVE OF Y WITH RESPECT TO X (AXIAL LENGTH)***

**DIMENSION Y(32,11), DYDX(10,11)**

**DOUBLE PRECISION TITLE**

**REAL MAC, MAP, MOLENT, JOULE**

**DIMENSION ATAS(29,11), FLOW(32)**

**LOGICAL IERROR, YES**

**COMMON /MATRIX/ ALPHA(10,11), ATAR(29,11), B2(29),**

**X BETAX(10,11), BH(32), BLADE(29), BT(32),**

**X HAPPY(10,11), CPI(32,11), CPQD(6), CRI(29,11),**

**X CSLOPE(10,11), CUS(32,11), CUS(29,11), CUS(29,11),**

**X CTY(32,11), CXM(10,11), CXNEW(10,11), CXRAT(129),**

**X CXS(10,11), DEL(11), DEP(10,11),**

**X DF(20), DFACT(29,11), DFL(29), DFLOW(32),**

**X EMACH(29,11), FOUND(20,3,10), FRDEL(10,11), GAMMA(32,11),**

**X HMM(29), HUB(32), IKK(10), MACH(29,11),**

**X OBAR(29,11), PC(32,11), PINT(11), ROSTAG(11),**

**X RHM(32), RHO(32,11), RINT(11), ROSTAG(11),**

**X RS(32), RLSPE(10,11), RTRA11, SOC0(29,11),**

**X SOLID(29,11), SSO(129,11), STEM(10,11), TERMA(11),**

**X TERMB(11), TERC(11), TIP(11), TITLE(12),**

**X TG132,11, TSTA(11), U(32,11), W(11),**

**X Y(32)**

**COMMON /SCALER/ A, AA, A10A0, A20A0, A30A0, A404A0,**

**A505Ao, B, BB, CC, CM, CMEAN, CMNAP, CINTG,**

**CPI2, CPI3, CPI4, CPI5, CPI6, CP2Q, CPQ2, CPQ3, CPQ4,**

**CPQ5, DINF, DCP, DD, DIFCP, DT, DUMMY, ERA51,**

**G, G, GAS1, GJ, GR, GR2, JOULE, MAPR, MOLENT,**

**X PACO, Q, RPM, TCP, TERN, TESTBH, TESTDS, TESTMS,**

**X TDCO, TOL, TOL, TOLB2, TOLMIN, TOLMS, TOTTP, TOLCP,**

**X TOLCX, TOLR, TOTT, TTPR, V, VMI**

**COMMON /INTEGR/ I, IB, IBI, IDUMP, IERROR, IFIRST,**

**X IG, IOUT, IPASS, IS, IT, J, JIN, JJ,**

**X J* J, K, KL, KK, L, LIMIT, LSTAGE,**

**X MSTAGE, MLINE, NTUBES, NX, NXL, YES**

**EQUIVALENCE (ATAR(1,1), ATAS(1,1)), (FLOW(1), DFLOW(1))**

**DYDX(10, J)=0.0**

L=1

DO 5 I=181, NX1

L=L+1

AA=V(I-1,J)-Y(I,J)/(X(I-1)-X(I))

BB=V(I+1,J)-Y(I,J)/(X(I+1)-X(I))

DYDX(L,J)= (Y(I+1,J)-Y(I-1,J))/(X(I+1) -X(I-1))

CONTINUE

END

---

B-83
APPENDIX C

PROGRAM FLOW CHARTS
SUBROUTINE ANEXIT

ADD AN EXIT TO THE MACHINE BASED ON A HORIZONTAL TIP AND THE HUB CALCULATED FROM THE RATIO OF THE AREA OF THE STATION TO THE AREA OF THE LAST STATOR EXIT

\[ DT = X(L\text{STAGE}) - X(L\text{STAGE}-1) \]

\[ FP:\text{PATH} \]

\[ F \]

\[ AA = RS(L\text{STAGE})^2 \]
\[ BB = RH(L\text{STAGE})^2 \]

\[ D\Theta < 10 \]
\[ JK = 1, 3 \]

\[ JL = L\text{STAGE} + JK \]

\[ X(JL) = X(JL-1) + DT \]

\[ FP:\text{PATH} \]

\[ F \]

\[ T \]

\[ \text{SHEET 2} \]
\[ \begin{align*}
R_S(JL) &= R_S(L\text{STAGE}) \\
R_H(JL) &= \sqrt{AA + (BB - AA) \times ATAR(1, JK)}
\end{align*} \]
COMPUTE RADIAL VELOCITIES

\[
CAXIAL
\]

FROM SHEET 1

DO 340 J=1,NLINE

CALL TWVX(DEL,2)

COMPARE VELOCITY INTO CURVATURE EQUATION WITH THOSE OUT

TERM=TERM+1

CALCULATE NEW AXIAL VELOCITY

TERMD=TERM

DO 340 J=1,NLINE

TERM=TERM+1

FIND STREAMLINE-CURVATURE TERM IN AXIAL VELOCITY EQUATION

TERM=TERM-1

HELP=HELP+1

ALTER HELP TO REDUCE CURVATURE EFFECTS (TEMPORARILY)

TERM=TERM+1

CHECK VALUE OF VELOCITY AGAINST REASONABLE LIMITS

TERM=TERM+1

COMBINE THE TERMS IN THE AXIAL VELOCITY EQUATION

TERMD=(RINT(3)+RINT(4)+(ALPHA/1.33)+1.33+HELP)/(CM2+TERM*HELP)

END
DATAL S.R.

SUBROUTINE DATAL

READ "i G"

REWIND 2

DO 920 i=1,iG

READ ((ck(k,j),k=1,20),j=1,3)

920 WRITE 2 ((ck(k,j),k=1,20),j=1,3)

END FILE 2

CALL MAIN

RETURN

PREPARES A MASTER TAPE OF LOSS DATA.

IF A PERMANENT FILE IS USED, THIS ROUTINE IS TO BE DISCARDED (THE ENTRY MUST ALSO BE CHANGED.)
DRIVE
STEP 1 OF 1

(SUBROUTINE DRIVE)

OPTIMIZES TO ONE OF FIVE LIMITS

YES

STAGE GT 11

(CALCULATE INLET GUIDE VANE EXIT QUANTITIES)

T = TGC0
\( \beta = \text{THERM} 3(T) \)

DO 5
\( \beta = \text{LIMK} \)

CU(5, J) = (CUCO(5, J) + CR(5, J) + CUCO(5, J))/
(\( K(5, J) + CUCO(5, J) + (CUCO(5, J) + CR(5, J)) \)
* (\( K(5, J) + K(5, J) \))

H = (CUX(5, J) * 2 + CR(5, J) * 2) * CUC(5, J)

CALL ENTHAL

RR(5, J) = (CUCO(5, J) + CR(5, J) + CUCO(5, J))/
(CUCO(5, J) + CR(5, J) + CUCO(5, J))

CALL G3M

CALL ENTP

I: THIS AN UPDATE WITH NEW EFFECTIVITIES

I: COMPUTE PERTINENT QUANTITIES

DO 50
T = RR(5, J)

CONTINUE
IF (DAT*DFL(I))/DFL(I) .GT. TOLB2
OR. (CIRH*DFL(I)/DFL(I) .GT. TOLB2
OR. (MSH-HMN(I))/HNN(I) .GT. TOLB2
OR. (CIX(NLINES) - VO(I))/VO(I) .GT. TOLB2
OR. HNN(I+1) - REL FLOW .LT. TOLB2)

(CUBESN = W(N,1) - sqrt((CIX(N,1) + 2 + CR(N,1)) * 2) * tan((HNN(N+1) - 1))

CALCULATE THE TANGENTIAL VELOCITY FROM THE HUB RELATIVE FLOW ANGLE

CUMMN = SQRT(8)

G.M.O.O = YES
CALL ERROR (30)

CALCULATE THE TANGENTIAL VELOCITY FROM THE HUB ABSOLUTE MACH NUMBER

IF (ABS((DAT*DFL(I))/DFL(I)) .LT. TOLB2
OR. ABS((CIRH*DFL(I)/DFL(I) .LT. TOLB2
OR. ABS((MSH-HMN(I))/HNN(I) .LT. TOLB2
OR. ABS((CIX(NLINES) - VO(I))/VO(I) .LT. TOLB2
OR. ABS((REL FLOW-HMN(I+1)) .LT. TOLB2), AND NO FAIL)

NO FAIL = FALSE

CALCULATE THE TANGENTIAL VELOCITY FROM THE ROTOR TIP D-FACTOR

ERAIL = SQRT(EARAS)

IF (ERAIL .LT. 1.0)
CALL ERROR (33)

EMAIL = 1.0

CALL ERROR (33)
DRIVE
SHEET 4 OF 7

COMPUTE THE CORRESPONDING TANGENTIAL VELOCITY

DETERMINE THE TANGENTIAL VELOCITY AT THE STATOR EXIT

30

\[
CU(I+1, J) = \frac{CUCO(I+1, J) + CUCO(I+1, J)}{R(I+1, J)}
\]

40

\[
\text{RETURN}
\]

\[
\text{CONTINUE}
\]

UPDATE THE EXIT

\[
\text{CONTINUE}
\]

DO 60 I = 1, N-blog

DO 60 J = 1, M-1

\[
PO(I, J) - PO(I-1, J)
\]

\[
CU(I, J) = \frac{CU(I-1, J) + R(I-1, J)}{R(I, J)}
\]

\[
CP(I, J) = CP(I-1, J)
\]

\[
TO(I, J) = TO(I-1, J)
\]
### I. J = 1

\[
K = \frac{1}{2}
\]

\[
A = \frac{R(I, N\text{LINES}) + A(I - 1, N\text{LINES}) - (R(I) + RH(I - 1))}{(RS(I) + RS(I - 1) - (RH(I) + RH(I - 1)))}
\]

\[
S\text{OLID}(I, N\text{LINES}) - S\text{OCO}(I, I)/(S\text{OCO}(I, 2) + A) + S\text{OCO}(I, 3) + (S\text{OCO}(I, 4) + S\text{OCO}(I, 5) + A) * A
\]

\[
A = \frac{(R(I, 1) + A(I + 1, I) - RH(I) - RH(I + 1))}{(RS(I) + RS(I + 1) - RH(I) - RH(I + 1))}
\]

\[
S\text{OLID}(I + 1, I) = S\text{OCO}(I + 1, I)/(S\text{OCO}(I + 1, 2) + A) + S\text{OCO}(I + 1, 3) + (S\text{OCO}(I + 1, 4) + S\text{OCO}(I + 1, 5) + A) * A)
\]

\[
V = S\text{QRT}(C(I - 1, N\text{LINES}) * * 2 + C(I - 1, N\text{LINES}) * * 2 + (C(I, N\text{LINES}) - U(I, N\text{LINES})) * * 2)
\]

### II. A = S\text{QRT}(C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + (C(I, N\text{LINES}) - U(I, N\text{LINES})) * * 2)

\[
D\text{AT} = 1.0 - A/V + (U(I - 1, N\text{LINES}) - C(U(I - 1, N\text{LINES}) - U(I, N\text{LINES}) + C(U(I, N\text{LINES}))/V) / S\text{OLID}(I, N\text{LINES})/2.0
\]

\[
A = S\text{QRT}(C(I + 1, 1) * * 2 + C(I + 1, 1) * * 2 + C(U(I + 1, 1) * * 2)
\]

\[
B = S\text{QRT}(C(I, I) * * 2 + C(I, I) * * 2 + C(U(I, I) * * 2)
\]

\[
D\text{SH} = 1.0 - A/B + (C(U(I, I) - C(U + 1, I)))/B / S\text{OLID}(I + 1, I)/2.0
\]

\[
H = -B * B / G\text{U}
\]

\[
T = T0(I, I)
\]

### III. Q = 0.5 / S\text{OLID}(I, N\text{LINES})

\[
A = V * (1.0 - DFL(I)) + (U(I - 1, N\text{LINES}) - C(U(I, N\text{LINES}) - U(I, N\text{LINES})) * * Q)
\]

\[
C(I, 2) = -2 * (U(I, N\text{LINES}) + A * Q) / (I - Q * Q)
\]

\[
C(I, 2) = (C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2 + C(I, N\text{LINES}) * * 2)
\]

\[
E\text{RAS}1 = C(I, I) * * 2 - 4 * C(I, I, 2)
\]
<table>
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<tr>
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<td>TITLE</td>
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<td></td>
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</table>

**IV.**  
\[ B = 0.5 \times B \]
\[ B = \text{AMINI}(V_0(T), B) \]
\[ H = (U(I, NLINES) - B - U(I-1, NLINES)) \times \text{ATAR}(I, NLINES) \times J_0(GJ) \]
\[ T = TO(I-1, NLINES) \]
\[ \text{CALL ENTAHP} \]
\[ PTIP = \text{PO}(I-1, NLINES) \times \text{EXP}(3 \times \text{TSTAT}(U) - \text{THERM}(3(T))) / \text{DCP} \]

**V.**  
\[ SQCO = C_7(I, 1) \times 2 + CR(I, 1) \times 2 \]
\[ V = SQCO - CU(I, 1) \times 2 \]
\[ H = -V/GJ \]
\[ T = TO(I, 1) \]
\[ \text{CALL ENTAHP} \]
\[ \text{CALL GAM} \]
\[ VMI = GR2 \times \text{GAMMER} \times \text{TSTAT}(U) \]
\[ A = VMI \times HMN(I) \times 2 - SQCO \]

**VI.**  
\[ AA = (\pm \sqrt{C_A(I+1, 1) \times 2 + CU(I+1, 1) \times 2 + CR(I+1, 1) \times 2} - CU(I+1, 1) / 2.1 )/ \text{SOLID}(I, I+1, I) / \text{DFL}(I, I+1, I) \]
\[ BB = 0.5 / (\text{DFL}(I+1, I) / \text{SOLID}(I+1, I)) \]
\[ CC = AA \times BB / (BB \times BB - L) \]
\[ AA = ((C_A(I, 1) \times 2 + CR(I, 1) \times 2) - AA) / (1 - BB \times BB) \]
\[ AA = CC \times CC \times A \]

**VII.**  
\[ CU(I, 1) = \text{AMINI}(CU(I, 1), CUHMN, CUBETA) \]
\[ H = (CU(I, 1) \times U(I, I) - CU(I-1, I) \times U(I, I)) \times \text{ATAR}(I, 1) \times 2.0/GJ \]
\[ T = TO(I-1, 1) \]
\[ \text{CALL ENTAHP} \]
\[ A = (A(I, 1) - RH(I)) / \text{RS(I)} - RH(I) \]
\[ A = \text{NORM}(K) \times (CU(I, 1) / (CUO(I, 1) + ((CUO(I, 1) + A) \times (CUO(I, 3) + (CUO(I, 4) + (CUO(I, 5) + A)))))) \]
VIII. \[ A = (R(I,J) - RH(I))/(RS(I) - RH(I)) \]

\[ 20 \quad PO(I,J) = PO(I,NLINES) * NORM(K) * (CUCO(I,1) + \sum_{i} \sum_{j} (CUCO(I,i) + CUCO(I,j) + CUCO(I,k) \ast A) \ast A) \]

IX. \[ \text{CALL THERM2}(PO(I,J)/PO(I+1,J), TO(I,J), TO(I-1,J)) \]
\[ H = THERMI(TO(I,J)) \ast THERMI(TO(I-1,J)) \]
\[ H = H \ast ATAR(I,J) \]

X. \[ CU(I,J) = (0.5 \ast H \ast GJ + CU(I-1,J) \ast U(I-1,J)) \]
\[ /U(I,J) \]
\[ TO = TO(I-1,J) \]
\[ \text{CALL ENTHALP} \]
\[ TO(I,J) = TSTAT(J) \]
\[ H = ATAS(I+1,J) \ast H \]
\[ \text{CALL ENTHALP} \]
\[ PO(I+1,J) = PO(I-1,J) \ast EXP((\text{THERM3}(TSTAT(J)) - \text{THERM3}(T)) / DCP) \]
\[ \text{CALL THERMP} \]
\[ TO(I+1,J) = TO(I,J) \]
\[ CP(I+1,J) = CP(I,J) \]
\[ GAMMA(I+1,J) = GAMMA(I,J) \]
SUBROUTINE ENTHALP

CALCULATES THE TEMP. RISE CORRESPONDING TO AN ENTHALPY CHANGE

\[ \theta T = \text{THERM1}(T) \]

\[ T\text{STAT}(j) = H/\text{CP}(i,j) + T \]

DO 10 ITER = 1, 25

\[ \text{HIT} = \text{THERM1}(T\text{STAT}(j)) \]

\[ E = H - \text{HIT} + \theta T \]

\[ T\text{STAT}(j) = E/\text{CP}(1,j) + T\text{STAT}(j) \]

10

ABS(E) \leq 0.01 F

CALL ERROR(?)

T

RETURN
GAM

SUBROUTINE GAM

CALCULATES THE RATIO OF SPECIFIC HEATS

\[ A = \text{CPCO}(1) + \text{CPCO}(2) + \text{CPCO}(3) + \text{CPCO}(4) + \text{CPCO}(5) + \text{CPCO}(6) \times \text{TSTAT}(J) \times \text{TSTAT}(J) \times \text{TSTAT}(J) \times \text{TSTAT}(J) \times \text{TSTAT}(J) \times \text{TSTAT}(J) \]

\[ \text{GAMMER} = A / (A - \text{DCP}) \]

RETURN
(SUBROUTINE GEOM)

ITERATION DAMPING FACTOR

Determine DATA RETAIN 10.41

SET THE BLADE ROW COUNTER TO ZERO

NTYR = 0

IF ALL BLADE ROWS BEEN CHECKED

NTYR - NTYR + 1

INCREMENT THE BLADE ROW COUNTER

YES: INDICATE THAT AN UNDESIRABLE RATIO HAS BEEN FOUND

NO: RETURN

IF ONE BLADE ROW HAS BEEN ALTERED, THE PROGRAM WILL LOOK AT ALL OTHER BLADE ROWS BEFORE CHECKING OR ALTERING THIS ONE AGAIN

IO ALTER - ALTER + 1

IF THE BLADE ROW JUST CHECKED OR ALTERED WAS PHYSICALLY THE LAST BLADE ROW IN THE COMBINED, RETURN TO THE FIRST ONE BEING CONSIDERED

CALCULATE THE VELOCITY RATIO

V FOR AIR = (AIR)(UHUB) / (AIR)(UTIP)

CALCULATE THE TIP AND HUB LIMITS

TIP LIMIT = (ALTER)(TIP)

HUB LIMIT = (ALTER)(HUB)

SAVE THE HUB, TIP AND AIRY Coordinates
GEOM
SHEET 4 OF 5

IS THE EXPLOD RATIO ON ITS LIMIT?

70

DENIEN THE TIP RADIUS

YES

DETERMINE THE NEW HUB

RH(ALTER) = SQRT(RH(ALTER) * 2.0 / AREA)

IS THE TIP RADIUS ITS LIMIT?

YES

A = (R((I,M,LINES) - RH(I)) / (R(S) - RH(I))
NORM(R) = CL/CUCO(I,1)/(CUCO(I,3) - A - CUCO(I,3))
+ (CUCO(I,2) + CUCO(I,5) * A) * A)

NO

X = X + 1

EVALUATE THE PRESSURE NORMALIZING FACTOR IF THIS IS NOT A EXIT

CALL RAD/A

MOVE 1 TO STREAMLINE

SET THE TIP HORIZONTAL

R(S) = R(S) + C(S) / (ALTER I)

NO
SUBROUTINE INEST

MAKES INITIAL ESTIMATES OF AXIAL VELOCITIES FOR STATIONS BETWEEN BLADE ROWS

HELP=1.0

ESTIMATE MID-STREAM VELOCITIES

\[ \text{ROSTAG(JM)} = \text{PO(I, JM)} \times \text{TO(I, JM)} \times \text{GASK} \]

\[ \text{CX(I, JM)} = \text{FLOW(I)} / (\text{ROSTAG(JM)} \times (\text{RS1}) \times 1.5 \times 1.5 \times 2.7) \]

\[ \text{REL} = 1.0 \times \text{V} / \text{TO(I, JM)} \]

ERROR TRANSFER TO A NEW DATA SET

\[ \text{ERASI} \]

\[ \text{CX(I, JM)} = \text{CX(I, JM)} \times \text{ERASI} \times \text{(I/ (\text{GAMMA(I, JM)} - 1.))} \]

TO CONTINUE

\[ \text{CM2} = \text{CM2} \times \text{CM2} \times \text{HELP} \]

CALCULATE VALUES OF \( \text{CU} \times 2 \) AND ESTIMATE STATIC TEMPERATURES

\[ \text{TERM A(I)} = \text{G1} \times \text{CP(I, J)} \times \text{TO(I, J)} \times \text{CP(I, JM)} \]

\[ \text{TO(I, JM)(1 - (\text{CU2(J)} - \text{CU2(JM)}))} \]

\[ \text{DO} 110 \]

\[ J = \text{J_LINES} \]

\[ \text{DO 110} \]

\[ \text{TSTAT(I)} = \text{TO(I, J)} - 1 \]

\[ \text{CU2(I)} = \text{CU2(I, J)} \times 2 \]

\[ \text{V} = (\text{CM2} \times \text{CU2(J)}) / \text{GJ} / \text{CP(I, J)} \]

\[ \text{DO} 110 \]

\[ J = \text{J_LINES} \]
CALCULATE DERIVATIVE OF DEP WITH
RESPECT TO RADINS; RESULT IS IN CD
CALCULATE VALUES OF TEMPB
D0 120
J=1,NLINES
120
DEP(L,J)=CU2(J)/AI(J,J)
D=3*60
J=1,NLINES
TEMPB(J)=2.0*RINT(J)
CALCULATE C3LM AND C3 DISTRIBUTIONS
DUMMY=((TEAMA(J)-TEMPB(J))/C3)*1.0
HELP=HELP*1.25
CONTINUE
DO 400
J=1,NLINES
400
400

AA=CA(I,J)*1.6
400
200
CONTINUE
BB=CD(I,J)*0.4
200
CONTINUE
CA(I,J)=CA(J,I)*AA
CA(I,J)=CA(J,I)*BB
CA(I,J)=CA(J,I)*BB
CONTINUE
CA(I,J)=CA(J,I)*BB
RETURN

DUMMY -1.0
DUMMY
DUMMY -1.0

0.0

1.0
INLET
SHEET 1 OF 2

SUBROUTINE INLET

DO 10
I = 1, 5

GET INITIAL STREAMLINE RADIUS ESTIMATE

CALL RSTART

GET INITIAL ESTIMATE OF FLUID FLOW

YES

I.NE.5

NO

DO 4
J = 1, NLINES

4

CU(5, J) = (CUCO(5, 1)/R(5, J) + CUCO(5, 2)/R(5, J) + CUCO(5, 3) + CUCO(5, 4) + CUCO(5, 5) * R(5, J)) * R(5, J)

5

CALL INEST

TO SHEET 2
INLET
SHEET 2 OF 2

FROM
SHEET 1

SOLVE CONTINUITY EQUATION

10
CALL STREAM

RETURN
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

INPUT SHEET 1 OF 7

SUBROUTINE INPUT

DATA (TIL(L), T=1,4), GHE, LINL, LHT, GHE, FISU, LCH PATH

READ THE JOB TITLE, NECESSARY FOR DESCRIPTION

READ (TIL(L), T=1,4)

READ (CPOGL(I), I=1,6)

CALCULATE THE COEFFICIENTS NEEDED IN VARIOUS OPERATIONS INVOLVING CP

IF

K=1

INPUT INDEX TO INDICATE WHICH LOS. DATA SETS TO USE

READ (JAX(I), I=1,10)

READ L=1,12

READ MASTER TAPE OF LOSS DATA

STORE LOSS DATA FROM MASTER TAPE INTO PROPER ALLOCATION TO BE USED IN LOSS SUBROUTINE

FOUND(K,J,KK) = CX(K,J)

KK, EQ=10

NO

K = KK + 1

X1 = XKK(KK)

K, EQ=0

NO

X1 = X3

CONTINUE

YES

950

DO 495

495

65

1.5

K = K-1

READ(CX(K,J), K=1,20), J=1,3

READ LOSS DATA FROM MASTER TAPE

DO 350

350

L=1,12

Rewind

Rewind 2

READ THE SCALAR QUANTITIES

YES

CALL ERROR(I)

960

753

960

Rewind 2

Rewind

YES

CONTINUE

YES

23 THIS SET DESIRED?

NO

X1 = X3

X1, L=1 OR X1, G=4

YES

CONTINUE

NO

CONTINUE
INPUT
SHEET 2 OF 7

READ MTRGAE, NLINES, IOUTER, SPATH,
IDUMP, LIMIT, FLOW, IMOLEW, TCOG,
PCO, TOTPA, TOUT, TMA, TOL, RPM,
DAMP, TOLMIN, TOLC, TOLAT, TOLM3,
TOLTEP, ATAR(1,1), ATAR(1,2),
ATAR(1,3)

ERROR WILL SET THE TEMPERATURE OF
PRESSURE TO THE ABSOLUTE VALUE OF
SAME AND WILL GO TO A NEW DATA
SET IF ONE OF THE VALUES IS ZERO

POCO, LE<0.0,
TOSO, LE<0.0
YES CALL ERROR(10)
NO

THE NUMBER OF STAGES MUST BE
5, 7, 9 OR 15 ERROR WILL TERMINATE
EXECUTION

NLINES, LE<5.0,
NLINES, GE=15.0
YES CALL ERROR(6)
NO

ERROR REJECT: THE NUMBER OF STAGES TO BE
CONSIDERED TO 15
NOTE: NEXT DATA SET MAY NOT EXECUTE
PROPERLY

MTRGAE, GE<12
YES CALL ERROR(7)
INPUT
SHEET 4 OF 7

WRITE ATR(1,1), ATR(2,1), ATR(1,2)

DO (I=1, N)
   WRITE DTR(I,1), DTR(I,2)
   NN = NN + 1

IF PATH
   NN = NN - 1

GO TO 36

WRITE DTR(I,1), DTR(I,2)

DO 37 J = 1, NN
   WRITE J, Y(J), BH(J), AS(J), OT(J)

37 CONTINUE

NN = NN + 1

36 WRITE I = 1, NN
   WRITE (I, Y(I), ASPECT(I), NH(I), DH(I), AS(I), OT(I), I = 1, NN)

N = 2 + STAGE + Y

READ THE STAGE DATA

TO SHEET 5
   G1 CONTINUE
   DN(I), DL(I), OR NO
   YES CALL ERROR (22)
   DT(I), DL(I), OR NO
   YES CALL ERROR (23)

ERROR SET THE BLOCKAGE FACTOR TO 1.0

DO 62 I = 1, NN
   NN = NN + 1

62 CONTINUE

READ DFL(I), HMNN(1), HMNN(2), DFL(I),
   YO(1), BLADE(1), B, HMNN(2), DFLC(I), YC(I)
   (C101(I-1,1), J = 1, 5), (C111(I-1,1), J = 1, 5),
   (C101(I-1,2), J = 1, 5), (C111(I-1,2), J = 1, 5),
   (C101(I-1,3), J = 1, 5), (C111(I-1,3), J = 1, 5)
INPUT
SHIET 7 OF 7

I. \( CPO_2 = \frac{CP C_0 (3)}{2} \)
\( CP C_3 = \frac{CP C (4)}{3} \)
\( CP O_4 = \frac{CP C_0 (5)}{4} \)
\( CP O_5 = \frac{CP C_0 (6)}{5} \)
\( A10A0 = \frac{CP C_0 (2)}{CP C_0 (1)} \)
\( A202A0 = \frac{CP O_2}{CP C_0 (1)} \)
\( A303A0 = \frac{CP O_3}{CP C_0 (1)} \)
\( A404A0 = \frac{CP O_4}{CP C_0 (1)} \)
\( A505A0 = \frac{CP O_5}{CP C_0 (1)} \)
\( COUNT G = THER M 3(518.688) \)
\( CPI_2 = \frac{CP C_0 (2)}{2} \)
\( CPI_3 = \frac{CP C_0 (3)}{3} \)
\( CPI_4 = \frac{CP C_0 (4)}{4} \)
\( CPI_5 = \frac{CP C_0 (5)}{5} \)
\( CPI_6 = \frac{CP C_0 (6)}{6} \)

II. \( GAS K = \frac{G}{MOLEWT} \)
\( DCP = \frac{G AS K}{JOULE} \)
\( GR = 67.348 \times G AS K \)
\( GR_2 = GR \times .5 \)
INTEG S.R.

SUBROUTINE INTEG (VDEP, IFCON)

PERFORMS NUMERICAL INTEGRATIONS
OF THE VDEP VS. R CURVE.
TRAPEZOIDAL RULE INTEGRATION

RINT(i) = 0.0

GO TO (50, 90), IFCON

CALCULATES INTEGRAL
OF VDEP * R DR

DO 15 J = 1, NTUBES

DA(J) = (VDEP(L,J) * R(I,J) + VDEP(L,J+1)
* R(I,J+1) * (R(I,J+1) - R(I,J)) * .5

RINT(J+1) = RINT(J) + DA(J)

15

100

DA(J) = (VDEP(L,J) + VDEP(L,J+1)
* (R(I,J+1) - R(I,J)) * .5

RINT(J+1) = RINT(J) + DA(J)

115

B = RINT(JM)

DO 200 J = 1, NLIINES

RINT(J) = RINT(J) - B

200

RETURN
REAL FUNCTION LOSE
(ARG, PERHT, TYPE)

FiRST = 1

10 FiRST = FiRST + 1

IF (FiRST).LT. ARG .AND. 
FiRST .LT. 20

DF(FIRST), LT. ARG 
AND. 
FiRST .LT. 20

JJ = 1

IF PERHT .GT. .5

JJ = 3

DEL = (ARG - DF(FIRST - 1)) / (DF(FIRST) - DF(FIRST - 1))

FCT1 = ((FOUND(FIRST, 2, TYPE) - FOUND(FIRST - 1, 2, TYPE))
       * DEL) + FOUND(FIRST - 1, 2, TYPE)

FCT2 = ((FOUND(FIRST, JJ, TYPE) - FOUND(FIRST - 1, JJ, 
        TYPE)) * DEL) + FOUND(FIRST - 1, JJ, TYPE)

DEL = FCT2 - FCT1

ABS(DEL) > 0.001

NO

LOSE = FCT1

RETURN

YES

TO SHEET 2

C-35
LOSE FUNCTION

\[
\text{RAD} = 0.5 \times \sqrt{(\text{DEL} \times \text{DEL} + 0.16)} \\
\frac{1}{\sin(\arctan(2.5 \times \text{DEL}))}
\]

RETURN
LOSS
SHEET 1 OF 10

SUBROUTINE LOSS

DOAR CONTAINS THE LOSS FUNCTION

L = -1

L = L + 2

CALCULATE ABSOLUTE RELATIVE VELOCITY

\[ C_\text{RM}(I,J) = C_\text{X}(I\rightarrow J) \times 2 + (C_\text{U}(I\rightarrow J) - U(I\rightarrow J)) \times 2 + C_\text{R}(I,J) \times 2 \]

CALCULATE ABSOLUTE VELOCITY

\[ C_\text{RM}(I,J) = C_\text{X}(I,J) \times 2 + C_\text{U}(I,J) \times 2 + C_\text{R}(I,J) \times 2 \]

CALCULATE RELATIVE FLOW ANGLE

\[ \text{BETA}(I,J) = \tan((C_\text{X}(I,J) - C_\text{U}(I,J)) / \sqrt{C_\text{X}(I,J) \times 2 + C_\text{R}(I,J) \times 2}) \]

CALCULATE RELATIVE FLOW ANGLE

\[ \text{ALPHA}(I,J) = \arctan((C_\text{U}(I,J) - C_\text{FX}(I,J)) / \sqrt{C_\text{X}(I,J) \times 2 + C_\text{R}(I,J) \times 2}) \]

II

CALCULATE ABSOLUTE MACH NUMBER

\[ \text{MACH}(I,J) = \sqrt{C_\text{RM}(I,J) / (\text{PR} \times \text{GAMMA} \times \text{T}(I,J))} \]

CALCULATE RELATIVE MACH NUMBER

\[ C_\text{RM}(I,J) = C_\text{X}(I,J) \times 2 + C_\text{U}(I,J) \times 2 + C_\text{R}(I,J) \times 2 \]

CALCULATE RELATIVE FLOW ANGLE

\[ \text{BETA}(I,J) = \tan((C_\text{X}(I,J) - C_\text{U}(I,J)) / \sqrt{C_\text{X}(I,J) \times 2 + C_\text{R}(I,J) \times 2}) \]
IF FLOW IS SUPERSONIC ADD PRANDTL-MEYER ANGLE TO SUPERSONIC TURNING ANGLE

\[
\text{FAOEL}(L-1,J) = \text{FOREL}(L-1,J) + \text{TERM1}(L-1,J) \times \tan\left(\sqrt{d}\right) \times \text{TERM2}(L-1,J) / \tan\left(\sqrt{d}\right)
\]

\[
L = 0
\]

\[
\text{DO} \text{ LO} \text{TIL} (L=0)
\]

\[
L = L + 1
\]

\[
\text{DO} \text{ LO} \text{TIL} (L=\text{NUM})
\]

\[
\text{INITIALIZE PROFILE SHOCK AND LOSS FUNCTION}
\]

\[
\text{OBRA}(1,J) = 0.0
\]

\[
\text{CALCULATE PROFILE SHOCK}
\]

CALL ERROR(29)

\[
\text{CT8}(L,J) = \text{CAS}(L,J) - Q
\]

\[
\text{CAS}(L,J) = \text{CT8}(L,J) - Q
\]

\[
Q = Q / 3.0
\]

\[
\text{VM1(0,0)}
\]

\[
\text{ASUM(0,0,0,0)}
\]

\[
\text{VM1 - SHOCK(CT8(L,J), FAOEL(L,J))}
\]

CALCULATES DIFFERENCE BETWEEN PRANDTL-MEYER ANGLE FOR MACH NUMBER CAS(L,J) AND SUPERSONIC EXPANSION ANGLE

\[
\text{DO} \text{ LO} \text{TIL} (L=0)
\]

\[
\text{IF}(L,J) = 0.0
\]

\[
Q = 0.1/\text{CT8}(L,J) - 1
\]
LOSS
SHEET 5 OF 10

COMPUTE STATOR PROFILE LOSSES

\[ A = AS(i+1) - AH(i+1) \]

LOSS READS THE PROFILE LOSS FROM THE INPUT MAP

\[ \text{OBAR}(i+1) = \text{OBAR}(i) \times \text{LOSS} \times \text{OBAR}(i+1), (A(i+1) - \text{RIK}(i)) / \text{GLIDE}(i+1) \times 2.0 \times \text{SOLID}(i+1) / \cos \text{LAM}(\text{ALPHA}(i+1), i+1, 1, 3) \]

DO 80 I = 1, ISAM

80 CONTINUE

L = L + 1

DO 100 I = 1, ISAM, 2

L = L + 2

DO 100 J = 1, NUMS

CALL ENTHALP

P_Ideal = P_REAL * \exp((\text{THRM3}(T_STAT(i)) - B) / \text{DCP})

COMPUTE THE TOTAL IDEAL PRESSURE

CALL ENTHALP

P_STAT = P_Ideal * \exp((\text{THRM3}(T_STAT(i)) - B) / \text{DCP})

H = U(i, i, s) + (U(i, i, s) - 2.0 \times QU(i, i, s)) / Q

CALL ENTHALP

\( B = \text{THRM3}(T) \)

CALL ENTHALP

BE: THE STATIC TEMPERATURE

\[ H = -\left(C^2 - \text{CH}(i-1, s) - \text{CH}(i-1, s) + 2 - \text{CU}(i-1, s) \times (2) / (s^2) \right) \]

\[ T = (T \times (i-1, s)) \]
LOSS

CHECK FOR CONVERGENCE

ABS((ATAR(I+1,J) - EFF)/ATAR(I,J)) .GT. TOLAT

IF YES, IPASS = 3

IF NO, ATAS(I+1,J) = EFF

100 CONTINUE

101 CONTINUE

NO FAIL = .FALSE.

CALL DRIVE

RETURN
**DIV.** | **ALLISON** | **GMC.** | **REPORT NO.** | **PAGE** | **JOB NO.** | **PAGE**
--- | --- | --- | --- | --- | --- | ---
**TITLE** | Loss sheet 8 of 10 | | | | | |

**I.** \( \alpha_i(L+2, J) = \sqrt{\frac{\text{ATN}(C U(i+1, J) / S Q R T (C X(i+1, J) * * 2 + C R(i+1, J) * * 2))}{C A S(L, J) = C X(i-1, J) * * 2 + C U(i-1, J)}} \)

\( H = -C A S(L, J) / G J \)

\( T = T O(i-1, J) \)

*CALL ENTRAP*

*CALL GAM*

**II.** \( H = -C A M(L+1, J) / G J \)

\( T = T O(i, J) \)

*CALL ENTRAP*

*CALL GAM*

\( M A C H(i+1, J) = S Q R T(C A M(L+1, J) / G R 2 * G A M M E K * T S T A T(J))) \)

**III.** \( A = \frac{(R(i, J) + R(i-1, J) - R H(i) - R H(i-1))}{(R S(i) + R S(i-1) - R H(i) - R H(i-1))} \)

\( B = \frac{(R(i, J) + R(i-1, J) - R H(i) - R H(i+1))}{(R S(i) + R S(i+1) - R H(i) - R H(i-1))} \)

\( R R = \frac{(S S C O(i, I) + S S C O(i, 2) + A)}{S S C O(i, J) + (S S C O(i, 4) + S S C O(i, 5))} \times A \times A \)

\( B B = \frac{(S S C O(i+1, I) + S S C O(i+1, 2) + B)}{S S C O(i+1, 3) + (S S C O(i+1, 4) + S S C O(i+1, 5))} \times B \times B \)

**IV.** \( O B A R(I, J) = (1.0 - (G A M M A(i-1, J) + 1.0) \times 0.5 \times E M A C H(I, J) * * 2) / (I.0 + 0.5 * (G A M M A(i-1, J) - 1.0) * E M A C H(I, J) * * 2)) * * (G A M M A(i-1, J) / (G A M M A(i-1, J) - 1.0)) \)

\( (G A M M A(i-1, J) * 2.0 / (G A M M A(i-1, J) + 1.0) * E M A C H(I, J) * * 2 - (G A M M A(i-1, J) - 1.0) / (G A M M A(i-1, J) - 1.0)) * (I.0 / (G A M M A(i-1, J) - 1.0)) \times (I.0 - 1.0 / (I.0 + (G A M M A(i-1, J) - 1.0)))) \)
\[ (i-1,j) - 1.0) * \text{MACH}(i,j) * \{2 * 0.5 \times \{ \text{GAMMA}(i-1,j)/\text{GAMMA}(i-1,j) - 1.0) \}\}

\[ V. \quad A = \sqrt{R^2 + C^2 - \text{MACH}(i,j)} \]
\[ DFACT(I,J) = 1.0 * \sqrt{R^2 + C^2 - \text{MACH}(i,j)} \]
\[ (U(i-1,j) - C(i-1,j)) * 2 + \text{MACH}(i,j) ) \]
\[ A = R3(I-1,J)/2.1 \]
\[ \text{SOLID}(i,j)/AA \]

\[ VI. \quad OBA(R(I,J)) = OBA(R(I,J)) + \text{LOSE}(DFACT(I,J), R(I,J) - \text{MACH}(I)) \]
\[ A = R3(I,J) + 2.0 \]
\[ \text{SOLID}(I,J)/\text{COS}(\text{MACH}(I,J)) \]

\[ VII. \quad H = \sqrt{R^2 + C^2 - \text{MACH}(i,j)} \]
\[ DFACT(I+1,J) = 1.0 * \sqrt{R^2 + C^2 - \text{MACH}(i+1,j)} \]
\[ A = R3(I+1,J)/2.1 \]
\[ \text{SOLID}(I+1,J)/AA \]

\[ VII. \quad \text{PREL} = \text{PO}(I,J)*\exp(\text{THERM3(TSTAT}(J)) - B)/\text{GJ} \]
\[ H = (U(I,J) - U(I-1,J)) * (U(I,J) + U(I,J)) \]
\[ T = \text{TSTAT}(J) \]
\[ \text{CALL} \text{ENTALP} \]
\[ B = \text{THERM3}(T) \]

\[ IX. \quad P = P_{\text{IDEAL} - OBA(R(I,J)) + (\text{PREL} - \text{PSTAT})} \]
\[ H = -U(I,J)*(2.0*U(I,J) - U(I,J)) \]
\[ T = T0(I,J) \]
**Title:** LOSS

**Sheet 10 of 10**

\[ \text{EFF} = \frac{\text{THEAMI}(T) - \text{THEAMI}(T_0(I - 1, J))}{\text{THEAMI}(T_0(I, J)) - \text{THEAMI}(T_0(I - 1, J))} \]

\[ P_0(I, J) = P \]
SUBROUTINE MAIN

CONTINUE

READ THE INPUT

CALL INPUT

INITIALIZE THE COUNTERS

ALTER = 5
HALIDE = 2

IPASS = 1
CLOUNT = 0

CONTINUE

DAMP = 1.0
L.C 6 = 0

SET THE ROTOR

CALL ROUTER

PRINT OUTPUT AT THIS POINT.
TRANSFER TO A NEW DATA SET

LC6 = 0

SET THE ITERATION COUNTER TO ZERO

CALL DRIVE

CHECK THE FLOW PARAMETERS
AND MAKE ADJUSTMENTS IN
THE TEMPERATURE/PRESSURE
PROFILES AS REQUIRED

CALL OUTLET

CALCULATE CONDITIONS
AT THE OUTLET

CALL STATOR

SET UP THE
STATOR

I = I + 1

CALL ERROR(140)

LC6 GT 50

CALL ERROR(19)

CALCULATE THE AXIAL VELOCITIES
INCLUDING CURVATURE EFFECTS

LC5 = 0

CALL CAXIAL

LC5 = LC5 + 1

CALL STATOR

LC5 GT 50

CALL ERROR(18)

NO FAIL = TRUE.
IPASS = 4

CALL DRIVE

HAVE ALL OF THE FLOW
PARAMETER REQUIREMENTS
BEEN MET

NOT: NO FAIL

YES
**MAIN**

**SHEET 3 OF 3**

---

**IFM**

- If the mass average pressure ratio has not been met, we check to see if another stage may be added. If not, the flow parameters will be printed.

---

**LSTAGE = LSTAGE + 1**

---

**IFLSTAGE = MAX(IFIRST, LSTAGE + 1)**

---

Since the calculation and checking is to be continued upstream for no more than 3 whole stages, it is assumed that dR/dx, d2R/dx2, and d3R/dx3 at stage previous to these will not be affected by the addition of one more stage. Therefore, the values calculated for the previous configuration are to be saved for use in the new configuration.
SUBROUTINE MOVE

CAUSES THE RELOCATION OF THE STREAMLINES BASED ON FRACTIONAL MASS FLOW. (STREAM MUST BE CALLED FIRST)

I

DO 350 J=2,NIVELS

II

CHECK THE MASS FLOW BETWEEN EACH STREAMLINE

IF (XMM(J), RMM(J), DMM(J), NMM(J, 1:NIVELS) .LE. XMM(J) RMM(J), DMM(J), NMM(J, 1:NIVELS) .GE. XMM(J) RMM(J), DMM(J), NMM(J, 1:NIVELS)) THEN

YES

YES = .TRUE.

350 CONTINUE

NO

END

CALL SLINE (DELX(J), TEMC, TERN, NINES, RTAIL(J))

DO 305 J=2,NIVELS

CALL SLINE (RIMAL(J), TEMB, TERN, NINES, DEPIL(J))

RIMAL(J) = R(I,J) * (RTAIL(J) - R(I,J)) / DMM(J)

CALL SLINE (RIMAL(J), TEMB, TERN, NINES, DEPIL(J))

CALCULATE VALUES OF CT AT NEW STREAMLINE RADIUS

RETURN

510

U(I,J) = R(I,J) * RMM(J) / XMM(J) .GT. 0.25

CA(I,J) = DEPIL(J) * CMEANP

A(I,J) = RTAIL(J)

DO 510 J=2,NIVELS

CA(I,J) = CXM(J, I) * CMEANP

CA(I,NINES) = CXM(J, NINES) * CMEANP

510 CONTINUE
I. \[ \text{TERM}(i) = 0.0 \]
\[ \text{TERM}(\text{NLINES}) = 1.0 \]
\[ \text{TERM}A(i) = R(i, i) \]
\[ \text{TERM}A(\text{NLINES}) = R(i, \text{NLINES}) \]
\[ \text{TERM}B(i) = \text{CHM}(l, i) \]
\[ \text{TERM}B(\text{NLINES}) = \text{CHM}(l, \text{NLINES}) \]

II. \[ \text{TERM}A(j) = R(i, j) \]
\[ \text{TERM}B(j) = \text{CHM}(l, j) \]
\[ \text{TERM}(j) = \text{TERM}(j-1) + OA(j-1) / TOTINT \]
OUTLET S.R.

SUBROUTINE OUTLET

YIELDS INITIAL FLOW ESTIMATE FOR THE OUTLET

INITIALIZE OUTLET LOOP

K = i + 1

CALL AN EXIT

DO 10 J = K, NX

GET INITIAL VALUES OF STREAMLINE RADII

CALL RSTART

DO 5 J = I, NY

SET FLOW PROPERTIES AS CONSTANT ALONG STREAMLINE

CP(i,j) = CP(LSTAGE, J)
GAMMA(i,j) = GAMMA(LSTAGE, J)
CU(i,j) = CU(LSTAGE, J) * R(LSTAGE, J) / R(i,j)
TO(i,j) = TO(LSTAGE, J)

RETURN

CALL STREAM

CALC. SIMPLE RADIUS EQUILIBRIUM SOLUTION OF FLOW CONDITIONS

CALL IEST

DO 9 J = I, NY

CX(i,j) = CX(i-1,j)

F

LSTAGE < .7

GET INITIAL ESTIMATE OF AXIAL VELOCITY

5

PO(i,j) = PO(LSTAGE, J)
OUTPUT
SHEET Y OF 13

COMPUTE MASS FLOW RATE PER STREAMLIME

\[ \text{DEPV}(9, J) = \text{RHO}(J J, J) \times C \times (J J, J) \times R(J J, J) \]
\[ J = J J \]

INTEGRATE MASS FLOW RATE, RESULT IN RINT

CALL INTEG(DEPV, 2)

\[ \text{SUM} = \text{RINT} (\text{NLINES}) - \text{RINT}(1) \]

DO 20

J = 2, NLINES

\[ \text{DEPV}(8, J) = (\text{TEAMS}(J) - 1.) \times \text{DEPV}(9, J) \]
\[ L = 2 \]

CALL INTEG(DEPV, 2)

\[ \text{V} = \text{RINT} (\text{NLINES}) - \text{RINT}(1) \]

CALCULATE MASS AVERAGED TEMPERATURE AND PRESSURE

YIELDS THEORETICAL TEMPERATURE RISE

\[ \text{TMAP}(J J) = \text{THEM}1(\text{TMA}(J J) + \text{TOC}) \]

COMPUTE MASS AVERAGED EFFICIENCY

\[ \text{V} = \text{RINT} (\text{NLINES}) - \text{RINT}(2) \]
\[ \text{TMA}(J J) = (\text{V} / \text{SUM}1) \times 518.683 / \text{TOC}(1, J) \]

CALL INTEG(DEPV, 2)

DO 30

J = 3, NLINES

\[ \text{DEPV}(8, J) = (\text{TO}(J J, J) / 518.683 - 1.) \times \text{DEPV}(9, J) \]

DO 30

J = 1, NLINES

\[ \text{TMC}(J J) = (\text{V} / \text{SUM}1) \times 518.683 \]
\[ \text{PM}(J J) = \exp (\text{THEM}1(\text{TMA}(J J)) \times \text{SUM}1) / \text{CMV} \]
IV. \[\text{CALCULATE ROTOR STATIC TEMPERATURE} \]

\[\text{CALCULATE ROTOR RELATIVE VELOCITY} \]

\[ \text{CO}(5, j) = \text{C}(3, j) \times \sqrt{\frac{2(\text{CUI}(15, j) - 0(15, j))}{\text{CA}(15, j) \times 2}} \]
\[\text{CO}(5, j) = \text{SQRT}(\text{CO}(6, j)) \]

\[\text{CALCULATE STATOR RELATIVE VELOCITY} \]

\[ \text{CO}(6, j) = \text{C}(3, j) \times \sqrt{\frac{2(\text{CUI}(15, j) - \text{U}(15, j))}{\text{CA}(15, j) \times 2}} \]
\[\text{CO}(6, j) = \text{SQRT}(\text{CO}(6, j)) \]

\[\text{CALCULATE ROTOR RELATIVE MAE NUMBER} \]

\[ \text{CTM}(1, j) = \text{CO}(5, j) / \text{SQRT}(\text{ERA}(5, j)) \]

\[\text{GET} \# / 3 \text{ (ROTOR)} \]

\[ \text{EMAN}(13, j) = 1.0 \]

\[\text{EMAN}(13, j) = \text{EMAN}(13, j) \times 1.0 \]

\[\text{CALCULATE ABSOLUTE FLOW ANGLE} \]

\[ \text{ALN}(11, j) = \text{ALN}(11, j) / \text{ALN}(11, j) / \text{ALN}(11, j) \]

\[\text{GET FIRST AND SECOND DERIVATIVES OF RADIUS WITH RESPECT TO ROTOR LENGTH. RESULTS ARE IN \text{ASLOPE} AND \text{AORCIE}} \]

\[ \text{CO}(4, j) = \text{PO}(13, j) / \text{PO}(15, j) \]

\[\text{CALCULATE TOTAL PRESSURE RATIO (STATOR)} \]

\[ \text{CO}(7, j) = \text{G}(15, j) / \text{G}(13, j) \]

\[\text{CALCULATE TOTAL TEMPERATURE RATIO (STATOR)} \]

\[ \text{CO}(8, j) = \text{PO}(15, j) / \text{PO}(13, j) \]

\[\text{CALCULATE TOTAL PRESSURE RATIO (ROTOR)} \]

\[ \text{CO}(9, j) = \text{G}(13, j) / \text{G}(15, j) \]

\[\text{CALCULATE TOTAL TEMPERATURE RATIO (ROTOR)} \]

\[ \text{CO}(10, j) = \text{PO}(13, j) / \text{PO}(15, j) \]

\[\text{CALCULATE RELATIVE FLOW ANGLE} \]

\[ \text{ALN}(11, j) = \text{ALN}(11, j) / \text{ALN}(11, j) / \text{ALN}(11, j) \]

\[\text{REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR} \]
CALL DERIV(RSLOPE, ACURVE(1, 3))

CALCULATE MOTOR CURVATURE

ACURVE(3, 3) = ACURVE(3, 3) / (SQRT(1 + RSLOPE(2, 3) * 2) * 2)

CALCULATE STATOR CURVATURE

ACURVE(3, 3) = ACURVE(3, 3) / (SQRT(1 + RSLOPE(2, 3) * 2) * 2) * 2

CALCULATE MOTOR SLOPE

RSLOPE(2, 3) = ATAN(RSLOPE(2, 3)) * 57.2957795

CALCULATE STATOR SLOPE

RSLOPE(3, 3) = ATAN(RSLOPE(3, 3)) * 57.2957795

GET A*1/S (STATOR)

EMACH(ISG1, J) = 1.0

NO

YES

CALCULATE RELATIVE FLOW ANGLE

CALCULATE STATIC PRESSURE

CO(7, J) = CO(6, J) / SQRT(ERA2)

CALCULATE STATOR RELATIVE MACH NUMBER

CYS(2, J) = CAM(2, J) / SQRT(ERA2)

CALCULATE ABSOLUTE MACH NUMBER

CALCULATE STATIC TEMPERATURE

CAM(2, J) * SQRT(CA(ISG1, J) ** 2) * GCU(ISG1, J) ** 2 * GC

CALCULATE AUSTIN VELOCITY

...
\[ \text{CHM(KJ, J)} = \sqrt{\text{CH}(KJ, J) - \text{K}^2 \times \text{CU}(KJ, J)} \]

\[ \text{CAS(KJ, J)} = \text{CHM(KJ, J)} / \sqrt{\text{ERAS}E} \]

\[ \text{RETURN} \]

\[ \text{WRITE} \ (\text{J}, \text{KJ}) \]

\[ \text{DO 150} \]

\[ J = J + 1 \]

\[ \text{KJ} = \text{KJ} + 1 \]

\[ \text{WRITE} \ (\text{J}, \text{KJ}) \]

\[ \text{DO 150} \]

\[ \text{WRITE} \ \text{CH}(KJ, J), \text{CU}(KJ, J), \text{CR}(KJ, J), \text{CM}(KJ, J) \]
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</table>

I. \[ A = \text{SQRT}(CA(I, J) \times 2 \& CR(I, J) \times 2) \]  
   \[ \text{ALPHA}(I, J) = \text{ATAN}(\text{CU}(I, J) / A) \times 57.295775 \]  
   \[ \text{CURVE}(I, J) = \text{CURVE}(I, J) / (\text{SQRT}(I, A)) \]  
   \[ \text{RSLOPE}(I, J) = \text{RSLOPE}(I, J) \times 2 \times 2 \]  
   \[ \text{RSLOPE}(I, J) = \text{ATAN}(\text{RSLOPE}(I, J)) \times 57.295775 \]  

II. \[ \text{TMAP}(I) = \text{TMA}(I) / \text{TMA}(I - 1) \]  
   \[ \text{TMAP}(I, Q) = \text{TMA}(I, Q) / \text{TMA}(I - 1) \]  
   \[ \text{PMAP}(I) = \text{PHA}(I) / \text{PHA}(I - 1) \]  
   \[ \text{PP}(I) = \text{PMAP}(I) \times \text{TO}(I, I) \]  
   \[ \text{BB} = \text{PP} \]  
   \[ \text{CC} = \text{TMAP}(I, Q) \times \text{TO}(I, I) \]  
   \[ \text{OO} = \text{CC} \]  

III. \[ \text{FRDEL}(I, J) = \text{HERMI}(\text{TO}(I - 2, J)) \]  
   \[ \text{FRDEL}(I, J) = \text{HERMI}(\text{TO}(I, J)) \]  
   \[ \text{FRDEL}(I, J) = \text{HERMI}(\text{TO}(I, J)) \]  
   \[ \text{TERM} = \text{TO}(I, J) \]  

IV. \[ H = \text{CAM}(I, J) \times 2 / G \]  
   \[ T = \text{TO}(I, J) \]  
   \[ \text{CALL ENTAP} \]  
   \[ \text{CAME}(I, J) = \text{TSTAT}(J) \]  
   \[ \text{CALL GA} \]  
   \[ \text{EFAS} = \text{GR} \times \text{GA} \times \text{IMMER} \times \text{TSTAT}(J) \]  
   \[ \text{CO}(I, J) = \text{FO}(I, J) \times \text{EXP}(\text{HERMI}(\text{TSTAT}(J)) / \text{HERMI}(7)) / \text{OCP} \]  

V. \[ A = \text{GAMMA}(I, J) \]  
   \[ \text{BETA}(I, J) = \text{BETA}(I, J) / 57.295775 \]  
   \[ \text{EMACH}(I, J) = \text{COS}(\text{BETA}(I, J)) / ((0.5 \times (AQ1.0) \times -0.5 \times (AQ1.0) / (A-2.0) + \text{MA}(I, J) \times (0.5 \times (AQ1.0) / (A-2.0))) / (A-2.0)) = ((A \times 1.0) \times \text{EMACH}(I, J) \times 2) / (A-2.0) \]
((A - 1.0) * EMACH(IS, J) * * 2 & 2.0))
* *(A/(A - 1.0)) * ((A1.0)/(2.0 * A * EMACH(IS, J) * 2 & 1.0 - 1)) * *(1.0/
(A - 1.0)))
BETA(2, J) = BETA(2, J) * 57.29578
A = SQR(T(CX(IS, J) * * 2 & CR(IS, J) * * 2)

V.
R = GAMMA(IS, J)
ALPHA(IS, J) = ALPHA(IS, J) / 57.29578
EMACH(ISG1, J) = COS(ALPHA(IS, J)) /
((0.5 * (AG1.0)) * *(0.5 * (AG1.0) /(A -
1.0)) / EMACH(ISG1, J) *(I.O/0.5*(A - 1.0))
* MACh(ISG1, J) * * 2) * *(0.5 * (AG1.0) /
(A - 1.0)) *(0.5 * (AG1.0) * EMACH(ISG1, J)
* * 2) * ((A - 1.0) * EMACH(ISG1, J) * * 2 & 2.0))
* *(A1.0) * ((AG1.0) / (0.0 * R * EMACH(ISG1, J) * * 2 & 1.0 - 1)) * *(1.0/
(A - 1.0)))
ALPHA(IS, J) = ALPHA(IS, J) * 57.29578

VI.
N = XM(IS, J) * *
J = TO(ISG1, J)
CALL ENTAP
CALL GAM
CALL W2(IS, J) = TSTAT(J)
ERASJ = GRA * GAMER * TSTAT(J)
CO(9, J) = PC(ISG1, J) * EXP((THERM 3
(TSTAT(J)) - THERM3(T)) / DCP)

VII.
SQCO = CX(IS, JM) / CX(IS - 1, JM)
R = CX(IS, JM) / CX(IS, JM)
Q = (RS(IS) - RH(IS)) / DEPV(5, 2)
AA = (RS(IS) - RH(IS)) / DEPV(5, 1)
### IX.

\[
KJ = 0 \\
DO 140 IJ = JJ, N \times \\
KJ = KJ + 1 \\
DO 140 J = I, N \text{LINES}
\]

### X.

\[
H = -2 \times \text{IM}(KJ, J) \\
T = TO(IJ, J) \\
\text{CALL ENTALP} \\
\text{CNEW}(KJ, J) = T \text{STAT}(J) \\
\text{CALL GAM} \\
ERASI = GR2 \times \text{GAMMA} \times T \text{STAT}(J)
\]
**SUBROUTINE RADIUS**

\[
\begin{align*}
A &= (RS(I) - RH(I)) \times (RS(I) + RH(I)) \\
CC &= RH(I) \times 2 + A \times BT(I) \\
AA &= RS(I) \times 2 - A \times BH(I) \\
BB &= R(I, I) \times 2 \\
DD &= (CC - AA) \times R(I, N_LINES) \times 2 - BB \\
AX &= RPM \times 10471 \times 76
\end{align*}
\]

**DO 100**

\[ J = 1, N_LINES \]

\[
R(I, J) = \text{SQRT}(AA + DD \times (R(I, J) \times 2 - BB))
\]

**100**

\[
U(I, J) = R(I, J) \times AX
\]

**RETURN**
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
ROTOUT
SHEET 2 OF 3

FROM SHEET 1

50

\[ A = \frac{R(I,NLINES) - RH(I)}{RS(I) - RH(I)} \]

\[ K = I/2 \]

COMPUTE THE TOTAL PRESSURE PROFILE NORMALIZING FACTOR. NOTE: THE EQUATION MUST HAVE THE VALUE OF 1.0 AT THE TIP STREAMLINE.

\[ NORM(K) = \frac{1.0}{CUCO(I,1)/(CUCO(I,2) + A) + CUCO(I,3) + CUCO(I,Y) + CUCO(I,5) \times A} \]

RETURN

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### I. \( R_S(6) = R_S(5) \)
\[
R_T = (R_S(5) - RH(5)) \cdot \text{ASPECT}(6)
\]
\[
R_H(6) = R_H(5) + DT \cdot \text{AMIN1}(0.6, 0.8) \cdot ALH(6)
\]

### II.
\[
V = 0.9 \cdot \text{CA}(5, \text{N LINES})
\]
\[
S = \text{SO CO}(6, 1)/(\text{SO CO}(6, 2) + 1.0) + \text{SO CO}(6, 3) + \text{SO CO}(6, 4) + \text{SO CO}(6, 5)
\]
\[
V M I = \sqrt{2} \cdot \text{R}(\text{CA}(5, \text{N LINES})^2 + (\text{CU}(5, \text{N LINES}) - U(5, \text{N LINES}))^2)
\]
\[
Q = 0.5/3
\]
\[
A = V M I * (1.0 - \text{DFI}(6)) + (V(5, \text{N LINES}) - \text{CU}(4, \text{N LINES}) - U(4, \text{N LINES})) * Q
\]
\[
B = 2.0 * (U(6, \text{N LINES}) + 4 * G)(Q * Q - 1.0)
\]
\[
C = (V * V + U(6, \text{N LINES})^2 - A * A) / (1.0 - Q * Q)
\]
\[
E R A S I = B * B - 4.0 * C
\]

### III.
\[
DT = (U(6, \text{N LINES}) - \text{CU}(6, \text{N LINES}) - U(5, \text{N LINES})^2 - \text{CU}(5, \text{N LINES})^2) / G J / C P(1, 1) * 2.0
\]
\[
J = \text{N LINES}
\]
\[
T O(6, J) = T O C O + D T
\]
\[
C A L L \ \text{THERM}
\]
\[
D T = 0.9 * D T
\]
\[
C U(6, J) = C U(6, J) * A(6, J)
\]
\[
D O \ Y O L = 1, \text{N LINES}
\]
\[
T O(6, L) = T O C J
\]
\[
C P(6, L) = C P(6, J)
\]
\[
G A M M A(6, L) = G A M M A(6, J)
\]
\[
P O(6, L) = P O C O * (D T / T O C O + 1.0)^2 * (G A M M A(6, J)^2) / (G A M M A(6, J)^2 - 1.0)
\]
\[
Y O \ \text{CU}(6, L) = \text{CU}(6, J) / A(6, L)
\]
\[
L = 1
\]
SUBROUTINE RSTART

CALCULATES EQUAL AREA
ESTIMATE OF STREAMLINE
POSITION AND WHEEL SPEED

\[ AA = RS(i)^2 - RH(i)^2 \]
\[ BB = RS(i)^2 - AA*BH(i) \]
\[ CC = AA*(BH(i)+BT(i)-1.0) \]
\[ DD = RPM*1.0471976 \]

DO 10 J=1,NLINES

ERASI = BB + DELM(J)*CC

ERROR TRANSFER TO A NEW DATA SET

IF ERASI GT 0 THEN CALL ERROR(i

R(i,j) = SQRT(ERASI)

10 U(i,j) = R(i,j) * RPM

RETURN
SUBROUTINE SLINE
(X, XT, YT, N, ANS)

1. \( N - 1 \)
   \[ \text{ANS} = YT(i) \]

2. \( 3 \)
   \( X - XT(i) \)
   \[ \text{ANS} = YT(N) \]

3. \( 5 \)
   \( K = N - 1 \)

4. \( 4 \)
   \( X - XT(N) \)

5. \( 7 \)
   \( DO 8 \)
   \( i = 2, K \)

6. \( 10 \)
   \( \text{ANS} = YT(i) \)

7. \( 8 \)
   \( \text{CONTINUE} \)

8. \( 9 \)
   \( \text{ANS} = (YT(i) - YT(i-1)) \times (X - XT(i-1)) / (XT(i) - XT(i-1)) + YT(i-1) \)

9. \( 6 \)
   \( \text{ANS} = (YT(N) - YT(N-1)) \times (X - XT(N-1)) / (XT(N) - XT(N-1)) + YT(N-1) \)

10. \( 2 \)
    \( \text{RETURN} \)
SHOCK FUNCTION

FUNCTION SHOCK (L, Y)

SHOCK = Y - TERM1(L, J) * ATAN(SQRT((Z-1.0) * (Z+1.0)) / TERM1(L, J)) + ATAN(SQRT((Z-1.0) * (Z+1.0))

RETURN

CALCULATES SUPERSONIC Expansion ANGLE MINUS PRANDTL-MEYER ANGLE
SUCCESSFUL CONVERGENCE ON CM

USE CONVERGED VALUES OF INTEGRAL OF \( \rho \cdot c_m \cdot \rho \cdot \) vs. \( R \) FROM \( A(J) \) TO \( A(J+1) \), (DA VALUES), TO
CALCULATE VALUES OF -- \( \Delta P V(L,J) = \left( \int A(J) \right) / TOTINT \)

300
CONTINUE

DO 400
J = 1, N Lines

400
\( C(I,J) = C_M(L,J) \cdot CMEANP \)

700
RETURN
I. \( C \times M(L, J) = C \times (I, J) / C_{\text{MEAN}} \)

150 \( T_{\text{ERMA}}(J) = C_V(I, J) ** 2 + CR(I, J) ** 2 \)

\( N_{\text{COUNT}} = 1 \)

II. \( \text{INDIC} = 0 \)

\( J = JM \)

155 \( H = -(C_{\text{MEAN}} ** 2 + T_{\text{ERMA}}(J)) / G_J \)

\( T = TO(I, J) \)

CALL EN TALP

CALL GAM

\( VMI = G_R * 2 \times \text{GAMMER} * T_{\text{STAT}}(J) \)

III. \( B = \text{PO}(I, J) * \text{EXP}((\text{THERM}3(T_{\text{STAT}}(J))) - \text{THERM}3(\text{TO}(I, J))) / 1000 \)

\( \text{RHO}(I, J) = B / T_{\text{STAT}}(J) / G_A S K \)

\( \text{DEPV}(L, J) = \text{RHO}(I, J) * C \times M(L, J) \)
THRM1 FUNCTION

FUNCTION THERM1(T)

CALC. H = INTEGRAL FROM
0.0 TO T OF CP DT,
WHERE CP IS GIVEN AS
A 5TH DEGREE POLYNOMIAL

THRM1 = (CP0(1) + CP2 +
(CP3 + (CP4 + (CP5 +
CP6(T) * T) * T) * T) * T) * T)

RETURN
SUBROUTINE THERM2
(Power, Top, T)

Solves for Top in
G * ALOG(Power) =
INTEGRAL FROM T TO
TOP OF (CP/T) DT, WHERE
CP IS GIVEN AS A 5TH
DEGREE POLYNOMIAL.
(SEE THERM1)

XA = ALOG(Power) * OCP
BOT = THERM3(T)

DO 10
NN = 1, 50

10
ABS(DT) 
I.E. TOP < OCP

ERROR TRANSFER TO
A NEW DATA SET

CALL ERROR(26)

RETURN
THERM3 FUNCTION

FUNCTION THERM3 (T)

CALC. THE INTEGRAL OF CP/T DT FROM 0.0 TO T

THERM3 = CP01(I) * ALOG(T) + (CP02 + CP03 + (CP04 + CP05 * T) * T) * T

RETURN
THERMP

SUBROUTINE THERMP

CALC. SPECIFIC HEAT AT
CONSTANT PRESSURE (CP)
AS A FUNCTION BEING A
FIFTH DEG. POLYNOMIAL.
THEN THE RATIO OF
SPECIFIC HEATS IS CALC.
AS CP/(CP-.0686)

CP(i,j) = CPC@1(i) + (CPC@2(i) + (CPC@3(i) + (CPC@4(i) + (CPC@5(i) + CPC@6(i)
* TH(j,i)* TH(i,j))
* TH(j,i)* TH(i,j))

CV = CP(i,j) - DCP

GAMMA(i,j) = CP(i,j)/CV

RETURN
SUBROUTINE XDERIV (Y, DYDX, D2YD2X)

CALCULATES THE 1ST AND 2ND DERIVATIVE OF Y WITH RESPECT TO X (AXIAL LENGTH)

DYDX(10, J) = 0.0
D2YD2X(10, J) = 0.0
L = 1

DO 5 1 = 1, B1, NX1

L = L + 1
AA = (Y(i-1, J) - Y(i, J)) / (X(i-1) - X(i))
BB = (Y(i+1, J) - Y(i, J)) / (X(i+1) - X(i))
DYDX(L, J) = (Y(i+1, J) - Y(i-1, J)) / (X(i+1) - X(i-1))

5 D2YD2X(L, J) = (AA - BB) / (X(i-1) - X(i+1)) * 2.0

RETURN
APPENDIX D

INPUT FORMAT AND SAMPLE DATA SETS
APPENDIX D

Part A. Input Format—Data Preparation
Q45 DATA PREPARATION

The Q45 program is a compressor design program which iterates on efficiency through blade element loss correlation based on diffusion factor. Energy addition is based on either rotor tip diffusion factor, tip tangential absolute velocity, stator hub Mach number, rotor hub exit relative flow angle or stator hub diffusion factor. The energy addition can be limited by any one of these variables.

Two primary options have been incorporated in this design program. These are:

- Modification I—Annulus wall geometry defined to compute aerodynamics and axial velocities.
- Modification II—Mean streamline axial velocity ratio defined to compute aerodynamic and annulus wall geometry.

The procedure necessary to use these options will become evident in the following description of input data preparation. Reference can be made to the descriptive data sheets.

All data input in each field is specified either as an integer or as a floating point number. The integer must be right adjusted in its field. The non-integer input can be read in as an exponential which will take four columns in each field. This reduces the amount of significant numbers and computing accuracy.

All data cards are displayed by type in the sample data sheet appearing at the end of Part A of this appendix.

CARD 1—TITLE CARD

Alphanumeric information from Columns 1-72 which is printed out at the beginning of the output data.

CARDS 2 & 3—CONSTANT PRESSURE SPECIFIC HEAT AS FUNCTION OF ABSOLUTE TEMPERATURE

The constant pressure specific heat variable as a function of temperature is determined by:

\[ c_p = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + a_4 T^4 + a_5 T^5 \]

where \( T \) is in °R. The following sets of constants can be used as derived from Keenan and Kaye gas tables:
<table>
<thead>
<tr>
<th>Temperature</th>
<th>0° to 1700°R</th>
<th>500° to 3400°R</th>
<th>1500° to 5000°R</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_0)</td>
<td>0.23746571</td>
<td>0.257348261</td>
<td>0.18198209</td>
</tr>
<tr>
<td>(a_1)</td>
<td>0.219619999 (\times 10^{-4})</td>
<td>-0.82118436 (\times 10^{-4})</td>
<td>0.87076455 (\times 10^{-4})</td>
</tr>
<tr>
<td>(a_2)</td>
<td>-0.87791471 (\times 10^{-7})</td>
<td>0.11967112 (\times 10^{-6})</td>
<td>-0.28093746 (\times 10^{-7})</td>
</tr>
<tr>
<td>(a_3)</td>
<td>0.13991136 (\times 10^{-9})</td>
<td>-0.57795091 (\times 10^{-10})</td>
<td>0.50606304 (\times 10^{-11})</td>
</tr>
<tr>
<td>(a_4)</td>
<td>-0.78056154 (\times 10^{-13})</td>
<td>0.12572563 (\times 10^{-13})</td>
<td>-0.40556182 (\times 10^{-15})</td>
</tr>
<tr>
<td>(a_5)</td>
<td>0.15042604 (\times 10^{-16})</td>
<td>-0.10414624 (\times 10^{-17})</td>
<td>0.18191946 (\times 10^{-19})</td>
</tr>
</tbody>
</table>

**CARD 4—LOSS PARAMETER DATA SET BUFFER ZONE**

A total of up to ten loss data sets may be called from the library of permanent data described earlier. A loss data set consists of the loss parameter \(P_c \cos \beta_2^{1/2} \sigma\) versus diffusion factor at each of 10, 50 and 90% annulus height stations of the geometric annulus. (For the purposes of loss computation, blade height is measured from the hub.) The library may consist of a data deck as this program deck is presently set up or a logical storage unit. The loss-data set is prescribed as an integer and a total of 999 loss data sets can be defined in the library.

Card 4 is a buffer zone calling up to ten sets of losses. The data sets should be called in the buffer layer in increasing numerical order for read-in time saving. Needed fields in the buffer zone should be filled from left to right with no blank fields to the left of the last used field. As will be shown later, any one of these loss data sets in the buffer zone can be specified for any rotor or stator blade row as desired. However, loss-data sets specified in program data for individual blade rows are identified by an integer describing their location in the buffer zone—(e.g., if loss-data set 015 is retrieved from the master file and stored in the fifth sector of the buffer zone, it is identified as data set 005 when called up in the data for any given blade row).

**CARD 5—GENERAL DATA AND OPTIONS**

**Columns 1-5**

The maximum number of compressor stages desired is specified up to a maximum of 12 stages.

**Columns 6-10**

Number of streamlines desired for the aerodynamic analysis. Number that can be specified, which includes the annulus aerodynamic wall boundaries (2), is 5, 7, 9 or 11.
Columns 11-15

Option on printed output of computed data as function of streamline position. Options are:

- Integer 1: Print all streamline data computed
- Integer 2: Print odd number streamline data computed
- Integer 3: Print hub, mean and tip streamline data computed
- Integer 4: Print hub and tip streamline data computed

Columns 16-20

Option to compute annulus walls through input of mean streamline blade row axial velocity ratio or to read in annulus wall geometry. Read in "TRUE" for annulus walls calculation or "FALSE" for annulus walls geometry read-in.

Columns 21-25

Any one or several of the following options may be selected by inputting a trigger value equal to the sum of the integers corresponding to the desired individual options. The options are:

- Integer 1: Specify suction surface expansion from leading edge to normal shock intersection through fraction of total camber.
- Integer 2: Card-punch flow path coordinates.
- Integer 4: Specify suction surface expansion from leading-edge to normal shock intersection through flow angle at shock.

If options 1 and 2 are desired, input integer 3. Possible trigger values are 1, 2, 3, 4 and 6.

Columns 26-30

Instructions can be given to ensure that each stage has reached a limit on either rotor tip diffusion factor, maximum rotor tip tangential velocity, relative hub exit flow angle, stator hub Mach number or stator hub diffusion factor. The limit for each value is the value read in. The number "0" is used for this instruction.

Because of the iteration process, the rotor tip diffusion factor may be reduced to a lower value because of stator hub Mach number limit, for example. If this limit ceases to be a limiting value, the rotor tip diffusion factor can be
raised or left to remain at its last reduced value. If this latter alternative is
desired, then an integer "1" is read in for this instruction.

Summarizing, we have

Number 0: Drive calculation to one of its aerodynamic limits in
each stage.

Integer 1: In converged design, all parameters will be less than or
equal to their input limiting values.

Columns 31-40
Desired inlet flow rate in \( \text{lb}_m/\text{sec} \)

Columns 41-50
Molecular weight of gas in \( \text{lb}_m/\text{mole} \)

Columns 51-60
Inlet total temperature in °R

Columns 61-70
Inlet total pressure in psia

CARD 6—GENERAL DATA AND CONVERGENCE TOLERANCES

Columns 1-10
Desired overall pressure ratio. Calculation will cease when either over-
all pressure ratio or maximum number of stages from Card 5 is reached.

Columns 11-20
Relative error tolerance on iteration for axial velocity. This is used at
each streamline and at each axial station. Tolerance indicates accuracy on
successive calculations. A recommended value is 0.01. This convergence
tolerance is independent of all other tolerances.

Columns 21-30
Relative error tolerance on continuity. This is used at each axial station
and independent of all other convergence tolerances. A recommended value
for this relative error limit is 0.0005.
Columns 31-40

Relative error tolerance in iteration for total temperature on each streamline at each axial station. Tolerance indicates accuracy on successive calculations. A recommended value is 0.05 (°R). This convergence tolerance is independent of all other tolerances.

Columns 41-50

Rotor tip speed (ft/sec) at first rotor inlet defined by geometric axial station and case wall radius. Blade twist and rotor tip clearance are ignored.

CARD 7—CONVERGENCE TOLERANCES AND EXIT AREAS

Columns 1-10

Loading relative error tolerance defines the degree of convergence to be obtained during drive option on the controlling limit value for each stage. A recommended loading tolerance is 0.01.

Columns 11-20

Relative error tolerance on rotor and stage adiabatic efficiency for each streamline. A recommended efficiency tolerance is 0.01.


Columns 31-40

Degree of convergence on mean streamline axial velocity ratio across each blade row. A recommended tolerance is 0.01. Should be read in only if "TRUE" is specified on Card 5.

Columns 41-50, 51-60, and 61-70

Ratio of annulus areas at three axial stations downstream of the last stator exit station to annulus area at the last stator exit station.

CARD TYPE 8—FLOW PATH DATA. ANNULUS WALLS SPECIFIED.

As many Card Type 8 cards as axial stations are required through the last stage stator exit. There are five inlet stations, the fifth being the first rotor inlet station. For each stage specified on the input data, two additional cards are required. Thus, the maximum number of Card Type 8 cards is 29. The wall slopes at axial station number one should be zero since the method of analysis assumes them to be zero.
Columns 1-10. Axial coordinate station (in.)

Columns 11-20. Geometric hub radius (in.)

Columns 21-30

Blockage factor at hub expressed as fraction of geometric annulus area. Blockage factor of unity means zero blockage.

Columns 31-40. Geometric tip radius (in.)

Columns 41-50. Blockage factor at tip.

CARD TYPE 9—EXIT STATION DATA, ANNULUS WALLS SPECIFIED.

Three exit station cards are required for the exit annulus. The axial station data on these cards will be used if the maximum number of stages entered on Card 5 has been computed. Otherwise, the last three exit station axial locations will be those corresponding to the first three stations of the non-computed stage data. The exit stations' tip radius is always equal to the last stator exit tip radius.

Columns 1-10. Axial station location (in.)


Columns 21-30. Blockage factor at hub.

Columns 31-40. Blank.

Columns 41-50. Blockage factor at tip.

CARD TYPE 10—FLOW PATH DATA, ANNULUS WALLS COMPUTED.

For the five inlet stations, the Card Type 8 is used. Two Card Type 10 cards are used for each stage specified on Card 5 plus 3 exit stations (Card Type 11). Thus, the maximum number of Card Type 10 cards is 24.

Columns 1-10

Axial velocity ratio across the blade or vane row along the mean streamline.

Columns 11-20

Maximum hub ramp angle for the blade or vane row (degrees). This angle is based on a straight line relationship between stations. It is recommended that a linear variation between desired rotor one hub and last stator hub versus blade row number be used as an estimate for the first flow path calculation.
Columns 21-30. Blockage factor at hub.

Columns 31-40

Maximum case ramp angle (i.e., negative value) for the blade or vane row (degrees). Hub ramp angle statements apply here also except tip ramp angle is ≤ 0° and both hub and tip ramp angle limits cannot be zero for the same axial station.

Columns 41-50. Blockage factor at tip.

Columns 51-60

Blade or vane aspect ratio based on axial inlet station annulus height divided by axial station distance (i.e., projected chord).

CARD TYPE 11—EXIT STATION DATA, ANNULUS3 WALLS COMPUTED.

Three exit station cards are required for the exit annulus which specifies the blockage factor at hub and tip. The axial station locations are successively incremented from the last station a distance equal to the last station row axial spacing. The exit station tip radius is always equal to the last stator out tip radius.

Columns 1-10. Blank.


Columns 21-30. Blockage factor at hub.

Columns 31-40. Blank.

Columns 41-50. Blockage factor at tip.

CARD TYPE 12—STREAMTUBE MASS FLOW

The fractional mass flow to total annulus flow between the hub and each streamline specified on Card 5. Each value is entered in fields of 10 columns. Seven streamline values can be entered on the first Card Type 12. If 9 or 11 streamlines are specified, the additional streamline values are entered on a second Card Type 12. These additional values are entered in Columns 1-10 and 11-20 for 9 streamlines and Columns 1-10, 11-20, 21-30, and 31-40 for 11 streamlines. The first streamline value is obviously equal to zero.
CARD TYPE 13—INLET GUIDE VANE LOSS COEFFICIENTS

The loss coefficient, \( \bar{\alpha} = (P_{t1} - P_{t2})/(P_{t1} - P_1) \), for each streamline from hub to tip specified at axial station 5. Two cards are used if more than seven streamlines are specified as defined for Card Type 12. A value of zero is read in for each streamline if no vanes or zero loss is desired.

CARD TYPE 14—INLET GUIDE VANE EXIT WHIRL DISTRIBUTION

The whirl distribution is given by

\[
V_g = \frac{A}{R^2} + \frac{B}{R} + C + DR + ER^2
\]

where \( V_g \) is in ft/sec and R is in inches. The tangential velocity is defined as positive in the direction of rotor rotation. A value of zero is read in for each specified constant if no whirl is desired.

CARD TYPE 15—FIRST ROTOR ADIABATIC EFFICIENCY ESTIMATE

Estimate of rotor adiabatic efficiency for start of iteration. One value per streamline from hub to tip in fields of 10 columns. Two cards are used if more than seven streamlines are specified as defined for Card Type 12. Succeeding rotors assume previous rotor efficiency calculated as first estimate for this rotor.

CARD TYPE 16—FIRST STAGE ADIABATIC EFFICIENCY ESTIMATE

Estimate of stage adiabatic efficiencies for start of iteration on stator losses. One value per streamline specified from hub to tip as described for Card Type 15.

CARD TYPE 17—LOADING LIMIT DATA FOR EACH STAGE

Card Types 17 through 24 are placed in sequence as a group of cards for each stage specified on Card 5.

Columns 1-10. Rotor tip diffusion factor limit.

Columns 11-20. Stator hub inlet Mach number limit.

Columns 21-30. Relative flow angle limit at hub of rotor exit (degrees). Negative value signifies turning past axial direction.

Columns 41-50

Maximum rotor exit tip tangential velocity permissible (ft/sec).

CARD TYPE 18—BLADE LOSS AND TOTAL MASS FLOW CHANGE

Columns 1-5

Rotor loss parameter data set from buffer zone of Card 4 described by an integer identifying the position of the desired loss-data set in the buffer zone.

Columns 6-10

Stator loss parameter data set from buffer zone of Card 4 described by an integer identifying the position of the desired loss-data set in the buffer zone.

Columns 11-20

Mass flow added to or subtracted from rotor blade row and/or annulus walls within row (lbm/sec). This mass flow change is divided equally among streamtubes.

Columns 21-30

Mass flow added to or subtracted from stator blade row and/or annulus walls within row (lbm/sec). This mass flow change is divided equally among streamtubes.

CARD TYPE 19—ROTOR EXIT TOTAL PRESSURE PROFILE

The total pressure profile is defined by the following expression.

\[
\frac{P_t}{P_{\text{fT}}} = \frac{A}{B + p} + C + Dp + Ep^2
\]

where

\[
p = \frac{R - R_H}{R_g - R_H}
\]

Note that during design computations, this polynomial is normalized before each use. That is, the ratio \( P_t / P_{\text{fT}} \) is set to 1.0 for \( p = (R_T e - R_H)/(R_T g - R_H) \).
The program user should avoid using \( B = 0 \). In the case of zero blockage, \( p_{He} = 0 \) and for \( B = 0 \), the term \( A/(B + p) \) results in a division by zero at the hub.

| Columns 1-10 | Constant A |
| Columns 11-20 | Constant B |
| Columns 21-30 | Constant C |
| Column 31-40 | Constant D |
| Columns 41-50 | Constant E |

**CARD TYPE 20—ROTOR SHOCK LOSS PARAMETER**

Shock loss calculations require the suction surface Mach number at the incident shock location. Thus, the supersonic turning along the suction surface to shock intersection based on the normal shock model must be specified. One of two methods may be selected (Card 5, Columns 21-25). These are (1) ratio of supersonic turning to total turning, \( \phi_{ss}/\phi \); and (2) suction surface flow angle, \( \beta_{ss} \) (degrees) at shock intersection. These data are to be established along the streamline airfoil section. The method of input is identical to Card Type 19 where \( P_t/P_{t,r} \) is replaced by \( \phi_{ss}/\phi \) or \( \beta_{ss} \). The program user should beware of using \( \beta_{ss} \) on the first attempt at designing a given compressor. Very large shock losses can result, since it is difficult to guess appropriate values for \( \beta_{ss} \) in advance.

**CARD TYPE 21—ROTOR SOLIDITY**

Solidity, \( \sigma \), for the streamline airfoil section as a function of \( p \), the fraction of blade height. The method of input is identical to Card Type 19 where \( P_t \) is replaced by \( \sigma \).

**CARD TYPE 22—STATOR EXIT TANGENTIAL VELOCITY PROFILE**

Tangential velocity (ft/sec) distribution as a function of radius is given by

\[
V_\theta = \frac{A}{R^2} \cdot \frac{B}{R} + C + DR + ER^2
\]

where \( R \) is in inches. The fields for constants A through E are identical to Card Type 19.
CARD TYPE 23—STATOR SHOCK LOSS PARAMETER

Identical procedure to that for the rotor on Card Type 20.

CARD TYPE 24—STATOR SOLIDITY

Identical procedure to that for the rotor on Card Type 21.
APPENDIX D

Part B. Sample Design Problem Data Set
### ALLISON 7094 COMPUTER DATA SHEET

**Problem Title:** Example - 045 Annulus Wall Geometry Specified (Program III)

**JOB NUMBER**

**RETURN TO**

**CHARGE NO.**

**DEPT.**

**PAGE 1 OF 6**

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
<th>Column 5</th>
<th>Column 6</th>
<th>Column 7</th>
<th>Column 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>0.21962</td>
<td>E-04</td>
<td>977.91</td>
<td>E-07</td>
<td></td>
<td></td>
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**Functionality:**

- The table contains numerical data with various columns representing different parameters.
- The format suggests a scientific or engineering context, possibly related to calculations or specifications.

**Notes:**

- The data appears to be part of a larger set, possibly for a specific program or application.
- The values are likely to be results of computations or measured data points.
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**Job Number:**

**Charge No:**

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**Identification Number:**
### ALLISON 7094 COMPUTER DATA SHEET

**PROBLEM TITLE**: EXAMPLE - GAS AXIAL VELOCITY RATIO SPECIFIED (Program III)

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EXAMPLE—Q45 Axial Velocity Ratio Specified (Program III)

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**ALLISON 7094 COMPUTER DATA SHEET**

**PROBLEM TITLE**

EXAMPLE - Q45 Axial Velocity Ratio Specified (Program III)

**JOB NUMBER**

**RETURN TO**

**CHARGE NO**

**DEPT**

**PAGE 4 OF 6**

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APPENDIX E

OUTPUT FORMAT—SAMPLE DESIGN PROBLEMS
EXAMPLE — ANNULUS WALL GEOMETRY SPECIFIED (PROGRAM III) — 10/31/67

**** ADVANCED MULTISTAGE AXIAL-FLOW COMPRESSOR ****

*** ANALYSIS AT DESIGN CONDITIONS ***

---- INPUT DATA ----

THE MACHINE IS TO HAVE NO MORE THAN 10 STAGES

CALCULATIONS ARE TO BE PERFORMED AT 11 STREAMLINES

THE INLET MASS FLOW RATE IS 401.00 LB/SEC

MOLECULAR WEIGHT OF THE FLUID IS 28.47

AXIAL VELOCITY TOLERANCE IS 0.0100

THE EFFICIENCY TOLERANCE IS 0.0100

THE FRACTION OF THE TOTAL MASS FLOW BETWEEN THE HUB AND THE J-TH STREAMLINE IS:

0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000

THE INLET GUIDE VANE LOSS COEFFICIENTS FOR THE 11 STREAMLINES, ARE (FROM HUB TO TIP)

0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

THE INLET GUIDE VANE EXIT TANGENTIAL VELOCITY IS SPECIFIED BY

A = -0.000000E-38  B = -0.000000E-38  C = -0.000000E-38  D = -0.000000E-38  E = -0.000000E-38

THE SPECIFIC HEAT PLVYNCMIAL IS IN THE FOLLOWING FORM

Cp = 0.227476E 00 + 0.215621E-04 + C.877016E-07 + 0.13991E-09 + 0.78856E-13 + 0.15043E-16 + 0.94000 + 0.93000 + 0.92000 .

THE RATIOS OF THE AREAS OF THE LAST 2 STATIONS TO THE AREA OF THE LAST STATOR EXIT ARE 0.94000, 0.93000, 0.92000.
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*** Stage Input Parameters ***

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Loss Data Set Used

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- Stator: 2
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## FINAL FLOW PARAMETERS FOR STAGE NUMBER 7

### STAGE INPUT PARAMETERS

- **KICK TIP D-FACTOR LIMIT**: 0.4500
- **MHD RELATIVE FLOW ANGLE LIMIT AT THE ROTOR EXIT**: 20.0
- **SST ACH MACH NUMBER LIMIT (IN)**: 0.7300
- **STATOR D-FACTOR LIMIT**: 0.4700
- **MAXIMUM TIP TANGENTIAL VELOCITY**: 1000.0

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### AXIAL LENGTH (IN)

- **FICTR**: 1.00, **FSTCTR**: 0.90, **FICTR**: 0.90, **FSTCTR**: 0.90

### MASS FLOW (LB/SEC)

- **FICTR**: 401.0000, **FSTCTR**: 401.0000, **FICTR**: 401.0000, **FSTCTR**: 401.0000

### ADIABATIC EFF.

- **FICTR**: 0.4346, **FSTCTR**: 0.9183

### CUMULATIVE MASS AVE.

- **FICTR**: 10.9462, **FSTCTR**: 2.0975, **FICTR**: 0.8720, **FSTCTR**: 0.8695

### LOSS DATA SET (LEG)

- **FICTR**: 1, **FSTCTR**: 2

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| FSTCTR | 0.944 |

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### TIP BLOCKAGE FACTOR

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### MASS AVE.

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### TEMPERATURE RATIO

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EXAMPLE - AXIAL VELOCITY RATIO SPECIFIED (PROGRAM III)

**** ADVANCED MULTISTAGE AXIAL-FLOW COMPRESSOR ****
**** ANALYSIS AT DESIGN CONDITIONS ****

----- INPUT DATA -----

THE MACHINE IS TO HAVE NO MORE THAN 10 STAGES
CALCULATIONS ARE TO BE PERFORMED AT 11 STREAMLINES

THE INLET MASS FLOW RATE IS 401.00 LB/SEC
MOLECULAR WEIGHT OF THE FLUID IS 28.97
AXIAL VELOCITY TOLERANCE IS 0.0100
THE EFFICIENCY TOLERANCE IS 0.0100
THE AXIAL VELOCITY RATIO TOLERANCE IS 0.0100

THE FRACTION OF THE TOTAL MASS FLOW BETWEEN THE HUB AND THE I-TH STREAMLINE IS
0.000 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000

THE INLET GUIDE VANE LOAD COEFFICIENTS FOR THE 11 STREAMLINES ARE (FROM HUB TO TIP)
0.0000-0.0000-0.0000-0.0000-0.0000-0.0000-0.0000-0.0000-0.0000-0.0000-0.0000

THE INLET GUIDE VANE EXIT TANGENTIAL VELOCITY IS SPECIFIED BY
A = -0.0000000E+38  B = -0.0000000E+38  C = -0.0000000E+38  D = -0.0000000E+38  E = -0.0000000E+38

THE SPECIFIC HEAT POLYNOMIAL IS IN THE FOLLOWING FORM
CP = 0.23747E 00 + 0.21962E-04T + 0.67791E-07T**2 + 1.13991E-09T**3 + 0.73656E-12T**4 + 0.19043E-16T**5

THE RATIO OF THE AREAS OF THE LAST 3 STATIONS TO THE AREA OF THE LAST STATOR EXIT ARE 0.0400, 0.9700, 0.9200.
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*NOTE GUIDE VANE EXIT*

**STATION NUMBER 5**

ITERATION OF LOADING WAS TAKING PLACE
### Final Flow Parameters for Stage Number 1

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### Pressure

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### STREAMLINE AXIAL VEL. WHIRL VEL. RADIAL VEL. ABS. VEL. ABS. MACH ABS. FLUX REL. FLUX
NO. RADIUS (IN.) (FT/SEC) (FT/SEC) (FT/SEC) (FT/SEC) NUMBER ANGLE (DEG) ANGLE (DEG)
1 16.5778 575.744 -0.00 325.53 661.14 3.5795 -0.700 90.744 417.245
2 17.6692 557.159 -0.00 273.45 655.793 3.5751 -0.700 91.677
3 18.6639 613.146 -0.00 229.74 657.776 3.5726 -0.700 91.677
4 19.5867 625.424 -0.00 191.34 644.038 3.5717 -0.700 90.417
5 20.4535 634.774 -0.00 156.73 633.436 3.5711 -0.700 90.417
6 21.2752 641.969 -0.00 125.16 654.052 3.5734 -0.700 91.429
7 22.0997 647.535 -0.00 96.07 628.622 3.5737 -0.700 90.417
8 22.8131 651.874 -0.00 69.10 655.425 3.5707 -0.700 90.094
9 23.5901 659.199 -0.00 43.90 656.668 3.5799 -0.700 91.657
10 24.2445 657.736 -0.00 20.22 656.807 3.5711 -0.700 90.417
11 24.9292 659.629 -0.00 -2.70 659.633 3.5714 -0.700 90.417

### TOTAL TEMP. TOTAL PRES. ADIABATIC EFFICIENCY DIFFUSION WHEEL SPEED SOLIDITY A/S LOSS COEFF.
NO. RATIO RATIO EFFICIENCY FACTOR (FT/SEC) (FT/SEC) (FT/SEC)
1 1.0000 0.9908 0.9433 0.3340 705.74 1.839 0.7337 0.0370
2 1.0000 0.9925 0.9436 0.3245 646.12 1.697 0.7393 0.0279
3 1.0000 0.9936 0.9385 0.3247 695.17 1.465 0.7410 0.0274
4 1.0000 0.9943 0.9272 0.3236 940.16 1.339 0.7420 0.0274
5 1.0000 0.9949 0.9165 0.3237 917.77 1.273 0.7430 0.0279
6 1.0000 0.9953 0.9036 0.3265 1072.21 1.237 0.7447 0.0196
7 1.0000 0.9956 0.8873 0.3257 1084.84 1.203 0.7430 0.0196
8 1.0000 0.9958 0.8872 0.3262 1980.73 1.054 0.7421 0.0179
9 1.0000 0.9960 0.8852 0.3256 1980.73 1.024 0.7421 0.0179
10 1.0000 0.9962 0.8203 0.3236 1141.73 1.005 0.7434 0.0179
11 1.0000 0.9963 0.7944 0.3190 1196.50 1.000 0.7434 0.0179

### TOTAL TEMP. TOTAL PRES. STATIC TEMP. STATIC PRES. SLOPE CURVATURE REL. VEL. DEL. MACH
NO. (DEGREES) (LBS/SQ.IN.) (DEGREES) (LBS/SQ.IN.) (DEGREES) (DEGREES) (FT/SEC) NUMBER
1 578.50 21.09 542.04 12.80 29.89 0.7904 1034.747 7.9964
2 578.79 21.13 542.89 16.38 24.55 0.7237 1172.049 7.9931
3 579.30 21.15 543.64 16.47 23.99 0.7206 1109.427 0.9778
4 580.17 21.17 545.57 16.11 21.17 0.7467 1165.281 1.0011
5 580.98 21.18 545.40 16.47 16.31 0.8374 1179.467 1.0011
6 581.94 21.19 546.34 16.30 11.17 0.3297 1213.027 1.0011
7 582.16 21.19 547.50 16.49 11.17 0.3298 1224.661 1.0011
8 584.70 21.20 546.94 17.00 6.15 0.3163 1273.244 1.1112
9 536.45 21.20 550.57 17.00 3.91 0.7084 1304.835 1.1367
10 588.49 21.20 552.86 17.00 6.10 0.3039 1336.072 1.1403
11 590.33 21.21 554.63 17.00 -0.19 0.3016 1365.649 1.1403
### Final Flow Parameters for Stage Number 2

#### Stage Input Parameters

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--- Rotor ---

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<th>Whirl Velocity</th>
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Loss Data Set Used

- Rotor: 1
- Stator: 2
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<th>RADIAL VEL. (FT/SEC)</th>
<th>ABS. VEL. (FT/SEC)</th>
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<th>TOTAL TEMP. (DEG. R)</th>
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### Station Number 21

|      | 1  | 23.3388          | 646.196             | -0.00               | 5.40                | 646.22            | 0.4129              | 1098.37             | 157.2               |
|      | 2  | 25.5041          | 645.634             | -0.00               | 5.05                | 645.65            | 0.4126              | 1098.19             | 157.2               |
|      | 3  | 23.6688          | 645.482             | -0.00               | 4.65                | 645.00            | 0.4123              | 1099.46             | 157.2               |
|      | 4  | 25.8328          | 646.142             | -0.00               | 4.20                | 646.16            | 0.4121              | 1072.63             | 157.3               |
|      | 5  | 23.962           | 646.049             | -0.00               | 3.70                | 646.56            | 0.4119              | 1075.37             | 157.3               |
|      | 6  | 24.1590          | 647.448             | -0.00               | 3.16                | 647.46            | 0.4117              | 1078.88             | 157.3               |
|      | 7  | 26.3212          | 646.911             | -0.00               | 2.69                | 643.92            | 0.4115              | 1084.44             | 157.3               |
|      | 8  | 24.4229          | 651.095             | -0.00               | 2.00                | 651.10            | 0.4116              | 1092.26             | 157.3               |
|      | 9  | 24.6444          | 654.033             | -0.00               | 1.38                | 654.03            | 0.4116              | 1102.58             | 157.3               |
|      | 10 | 26.8058          | 657.781             | -0.00               | 0.75                | 657.78            | 0.4117              | 1116.57             | 157.3               |
|      | 11 | 24.9672          | 662.426             | -0.00               | 0.11                | 662.43            | 0.4118              | 1131.47             | 157.3               |

### Station Number 22

|      | 1  | 23.3572          | 652.021             | -0.00               | 0.00                | 652.02            | 0.4167              | 1068.32             | 157.2               |
|      | 2  | 25.5221          | 652.233             | -0.00               | 0.00                | 652.23            | 0.4169              | 1068.19             | 157.2               |
|      | 3  | 23.6858          | 652.963             | -0.00               | 0.00                | 652.96            | 0.4171              | 1069.89             | 157.2               |
|      | 4  | 25.8495          | 654.220             | -0.00               | 0.00                | 654.22            | 0.4172              | 1072.63             | 157.2               |
|      | 5  | 24.1013          | 655.040             | -0.00               | 0.00                | 655.04            | 0.4174              | 1075.37             | 157.3               |
|      | 6  | 24.1711          | 656.273             | -0.00               | 0.00                | 656.27            | 0.4175              | 1078.88             | 157.3               |
|      | 7  | 26.3312          | 658.100             | -0.00               | 0.00                | 658.10            | 0.4177              | 1084.44             | 157.3               |
|      | 8  | 24.4907          | 660.267             | -0.00               | 0.00                | 660.27            | 0.4178              | 1092.29             | 157.3               |
|      | 9  | 24.6409          | 663.768             | -0.00               | 0.00                | 663.77            | 0.4179              | 1102.54             | 157.3               |
|      | 10 | 24.8087          | 667.702             | -0.00               | 0.00                | 667.70            | 0.4181              | 1115.82             | 157.3               |
|      | 11 | 24.9676          | 672.478             | -0.00               | 0.00                | 672.48            | 0.4187              | 1131.47             | 157.3               |