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A Computer Code for Predicting Multistage Axial-Flow Compressor Performance by a Meanline Stage-Stacking Method

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SUMMARY

A FORTRAN computer code for predicting the off-design performance of multistage axial-flow compressors is presented. The code, which was developed at the NASA Lewis Research Center, uses a meanline stage-stacking method. Stage and cumulative compressor performance is calculated from representative meanline velocity diagrams located at rotor inlet and outlet meanline radii.

Numerous options are available within the code:

(1) Nondimensional stage characteristics may be input directly or calculated from stage design performance input.

(2) Stage characteristics may be modified for off-design speed and blade reset.

(3) Rotor design deviation angle may be modified for off-design flow, speed, and blade setting angle.

(4) Units of input and output may be SI or U.S. customary.

Many of the code's options use correlations that are normally obtained from experimental data. These empirical correlations permit modeling the trends in stage and overall performance by a simple one-dimensional stage-stacking technique. However, the correlations may only be accurately applied to predict the performance of compressors similar to those compressors used in deriving the empirical correlations. The code is described in sufficient detail so that users may modify the correlations to suit their needs.

Example calculations for a two-stage fan without blade reset and for three single stages with inlet-guide-vane reset agree well with experimental data. For off-design compressor performance prediction, the main features of the stage-stacking method are (1) simplicity, (2) fast convergence, and (3) the ability to directly incorporate correlations from experimental data to model real flow conditions.

INTRODUCTION

The axial-flow compressor is widely used in aircraft engines. In addition to its inherent advantage of high mass flow per frontal area, it can give very good aerodynamic performance. However, good aerodynamic performance over an acceptable range of operating conditions is not easily attained. A successful design and development process for multistage axial-flow compressors requires that numerous criteria be satisfactorily met. These criteria include (1) design optimization based on design and off-design performance considerations (ref. 1), (2) prediction of part-speed performance and assurance of part-speed stall margin, and (3) determination of required starting bleed and the amount of variability of the inlet-guide-vane (IGV) and stator-blade rows to match the stages.

Both experimental and analytical programs can be used in the development process for multistage axial-flow compressors. Since compressor experimental development in test facilities is expensive and time consuming, any insight into the onset and location of troublesome flow regimes that can reduce the amount of testing is very valuable. One natural information source is experimental data from similar compressor stages. But such data in sufficient detail are rarely available. New compressors are usually extrapolations from the data of their predecessors.

Analytical methods that contain good flow modeling are an alternative way of gaining the insight needed for compressor development. There are, of course, several levels of sophistication for analytical programs; but in

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general, only the level of sophistication required to evaluate the relevant flow phenomenon is desired in order to minimize complexity and to give high computational efficiency. Compared with other more sophisticated two- and three-dimensional models for compressor flow, the stage-stacking method is very simple. The simplicity of a one-dimensional compressible flow model enables the stage-stacking method to have excellent convergence properties and short computer run time (ref. 2). The simplicity of the model results in manageable computer codes that ease the incorporation of correlations directly linked to experimental test data to directly model real flow phenomena.

The stage-stacking computer code discussed in this report was developed and used at the NASA Lewis Center during the past several years. It has been routinely used to generate performance maps for compressors evaluated experimentally at Lewis. Correlations from experimental data to model real flow phenomena were added so that the code's performance predictions agreed with the measured performance. The code is an extension of the stage-stacking method of reference 3. The present code either accepts nondimensional stage characteristics as input or will calculate these characteristics from aerodynamic input available from compressor design codes such as reference 4.

The code is described in sufficient detail herein to permit a user to modify the correlations from experimental data within the code. It is anticipated that at times revised correlations may better suit the particular needs of the user. The code itself is written in FORTRAN, and U.S. customary units are used in the coded correlations and calculations.

CALCULATION PROCEDURE

The calculation procedure is discussed in three parts. First, the stage-stacking method is described. Second, optional calculations available to the computer code user are described. Third, the computer code STGSTK is outlined.

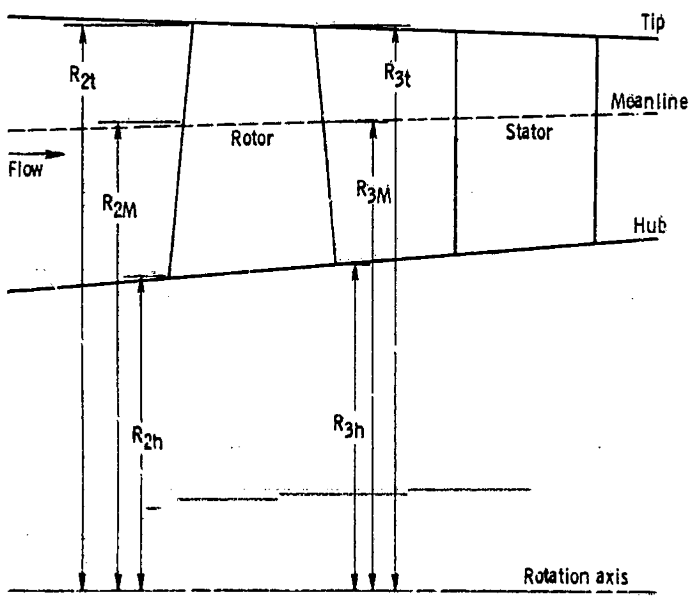

Figure 1. - Radii locations for a typical stage.

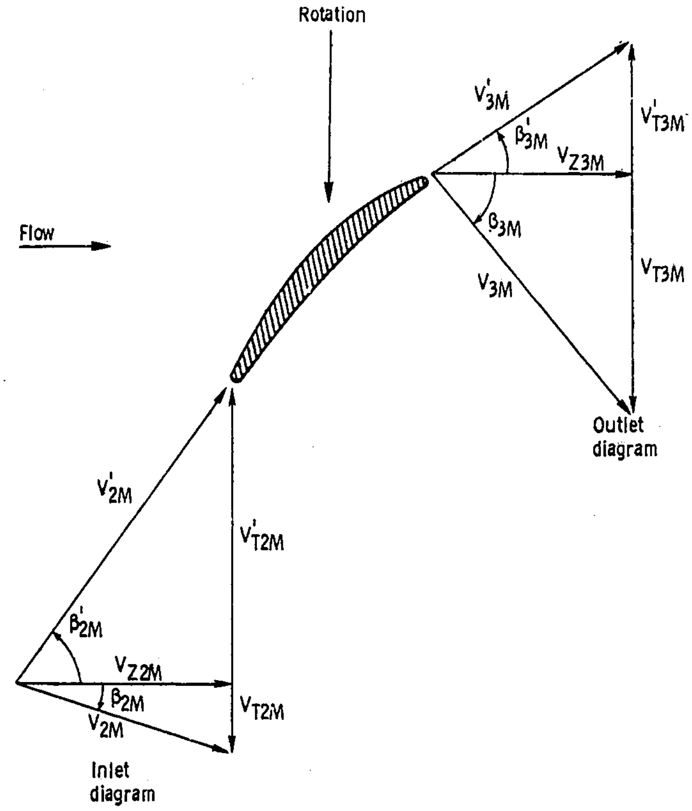

Figure 2. - Typical meanline inlet and outlet velocity diagrams for a rotor.

Stage-Stacking Method

To describe the stage-stacking method, first the flow assumptions are discussed and then the stage characteristics and the stacking procedure.

Flow assumptions. - One-dimensional compressible flow is assumed. Flow continuity can therefore be expressed as

$$W = \rho A V_Z \tag{1}$$

where A is the annulus area. All symbols are defined in appendix A.

Flow continuity is satisfied in the axial velocity V_Z calculation at the rotor inlet and outlet axial locations (fig. 1) of each stage. Thus, for a given flow and speed and stage inlet flow conditions of total pressure and temperature and absolute flow angle β_{2M}, a meanline velocity diagram (fig. 2) can be obtained at the rotor inlet. And, by assuming that the stage overall pressure ratio and adiabatic efficiency apply at the rotor exit, a meanline velocity diagram can be obtained at the rotor exit. If rotor exit total pressure and temperature are then assumed to apply at the inlet of the next rotor, meanline velocity diagrams can be obtained at every rotor inlet and exit from the overall stage performance parameters of pressure ratio Pr and adiabatic efficiency η_{ad}. These rotor inlet and outlet meanline velocity diagrams obtained from overall stage performance parameters are assumed to represent the stage and are referred to as representative meanline velocity diagrams within this report. Alterations to these representative meanline velocity diagrams are assumed to alter the associated stage performance parameters. Specific calculations are used to

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vary the representative meanline velocity diagrams and to predict changes in the associated stage performance parameters Pr and η_{ad}.

Stage characteristics. - The stage performance characteristics consist of three nondimensional quantities - adiabatic efficiency η_{ad}, pressure coefficient ψ, and flow coefficient φ. They are calculated from

$$\varphi = \frac{V_{Z2M}}{U_{2T}} \tag{2}$$

$$\psi = \frac{C_p \eta_{ad} (T_3 - T_2)}{U_{3T}^2} \tag{3}$$

$$\eta_{ad} = \frac{Pr^{(\gamma-1)/\gamma} - 1}{Tr - 1} \tag{4}$$

The stage characteristics are usually presented as adiabatic efficiency versus flow coefficient $\eta_{ad}(\varphi)$ and pressure coefficient versus flow coefficient $\psi(\varphi)$. Figure 3 shows typical stage characteristics for which the stage design point (reference condition) is at peak adiabatic

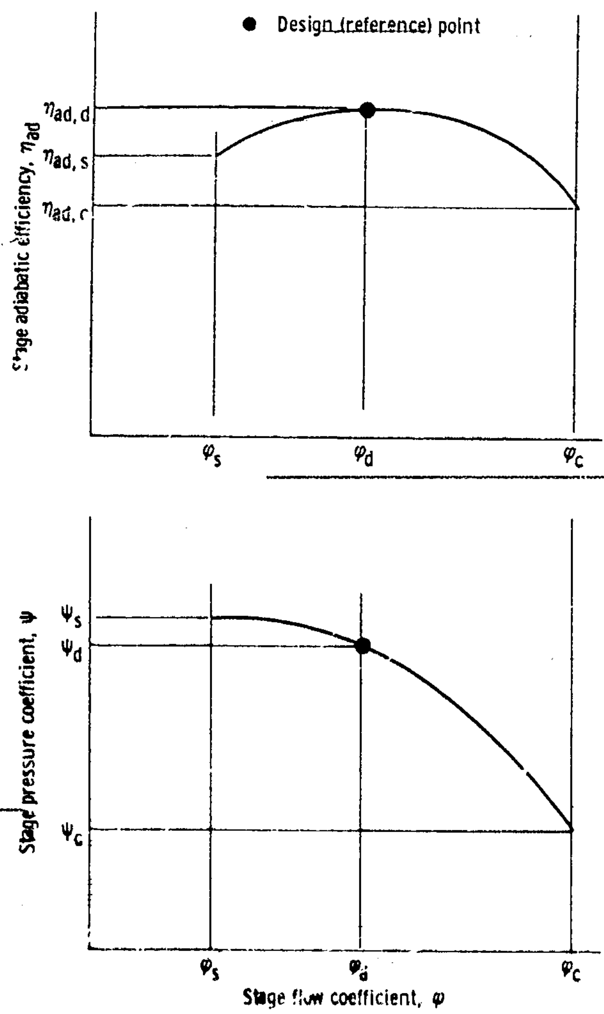

Figure 3. - Typical nondimensional stage characteristics.

efficiency. At some low flow coefficient φ_s the stage will stall, and at some high flow coefficient φ_c the stage will choke. Ideally the stage characteristics are independent of both compressor size and speed.

One option of the computer code STGSTK is either to input the stage characteristics $\eta_{ad}(\varphi)$ and $\psi(\varphi)$ or to input only the overall stage performance Pr and η_{ad} at a design or reference point and have the computer code calculate the stage characteristics. If the code option is used to input only the overall stage performance Pr and φ_{ad} at a design or reference point, the calculated stage characteristics are obtained from representative meanline velocity diagrams at the rotor inlet and outlet. These velocity diagrams are used to represent the overall stage flow, pressure ratio, and adiabatic efficiency and not just blade element performance at the midspan point.

Stacking procedure. - Once the appropriate stage characteristics are obtained, the stage-stacking procedure involves a straightforward calculation process. The overall compressor inlet flow conditions must be known, and they are used as the overall inlet flow condition for the first stage. Then, for various selected compressor speeds and flows, the calculation process is repeated for each stage as follows:

(1) Calculate the representative meanline velocity diagram at the rotor inlet and then the stage flow coefficient φ.

(2) From the stage characteristics $\eta_{ad}(\varphi)$ and $\psi(\varphi)$, obtain the stage overall adiabatic efficiency η_{ad} and pressure coefficient.

(3) Calculate the representative meanline velocity diagram at the rotor outlet and then the overall total pressure P and temperature T at the stage outlet, and use these values for the next stage inlet P and T. This process is repeated for each stage; and the cumulative compressor performance, which consists of compressor overall adiabatic efficiency, temperature ratio, and pressure ratio, is calculated. The end result is a compressor overall performance map of adiabatic efficiency and pressure ratio versus flow for various speeds.

Optional Calculations

Optional calculations performed within the computer code STGSTK are executed for three major reasons: code input selection, blade reset conditions, and stage characteristic adjustments for real flow effects. Concerning optional calculations for code input selection, the primary option is whether or not stage characteristics $\eta_{ad}(\varphi)$ and $\psi(\varphi)$ are input. This input option has been discussed in the section Stage characteristics. If stage characteristics $\eta_{ad}(\varphi)$ and $\psi(\varphi)$ are not input, the code will calculate them based on the input of overall stage performance Pr and η_{ad} at a design or reference point.

For blade reset conditions, optional calculations are performed within the STGSTK code to alter the stage characteristic $\psi(\varphi)$. An example of calculated changes in the stage characteristic $\psi(\varphi)$ because of reset of upstream stator vanes is shown in figure 4. Details of how the code STGSTK alters the stage characteristics for blade reset $\Delta\gamma_0$ of a blade with setting angle γ_0 are given in appendix B. Basically the blade reset $\Delta\gamma_0$ alters the flow angles of the meanline representative velocity diagrams associated with the stage. New representative velocity diagrams are calculated that determine the new stage characteristic $\psi(\varphi)$ for the stage.

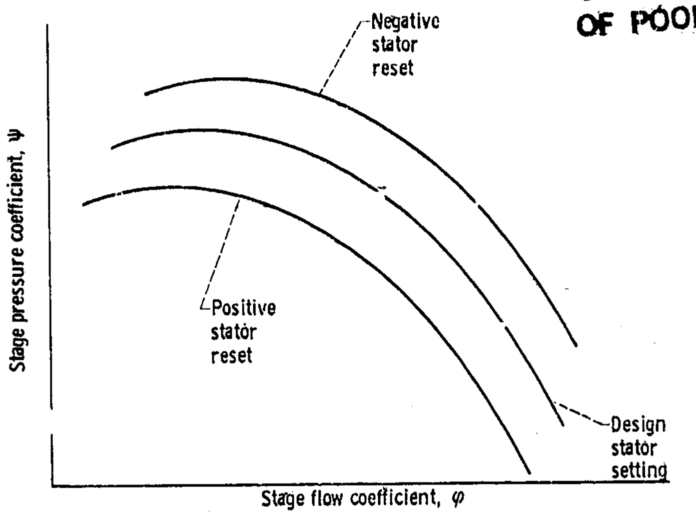

Figure 4. - Example of calculated changes of stage characteristic for a reset of upstream stator vanes.

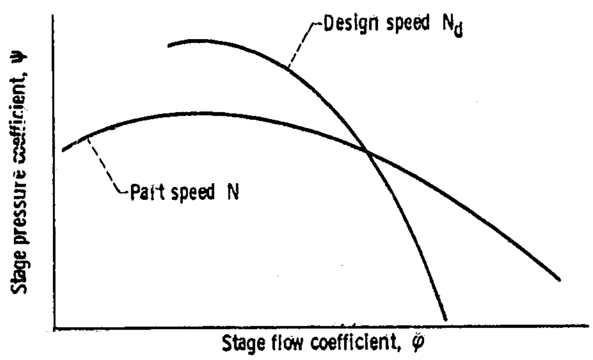

Figure 5. - Example of calculated change of stage characteristic for part-speed operating condition.

The remaining optional calculations adjust the stage characteristics for real flow effects that are not directly modeled by one-dimensional compressible flow. Three of these optional real flow adjustments are available. The first real flow adjustment alters the stage characteristic $\psi(\varphi)$ for part-speed conditions. This option is especially applicable for stages that have high inlet relative Mach numbers. Figure 5 shows the nature of the optional stage characteristic $\psi(\varphi)$ adjustment for part speed. At the part-speed condition, as compared wi h design speed, the pressure coefficient ψ drops by an amount $\Delta\psi$ and the range of the flow coefficient φ is expanded.

The second real flow adjustment option alters the stage characteristic $\eta_{ad}(\varphi)$ for part-speed conditions. This adjustment option for $\eta_{ad}(\varphi)$ at part speed consists of two parts: (1) the expansion of the range of the flow coefficient φ, which is identical to the adjustment used for the stage characteristic $\psi(\varphi)$ discussed in the previous paragraph, and (2) a change in the level of η_{ad} at part speed, which is controlled by values of the input variable ETARAT, which is discussed later in the section Input Data.

The third real flow adjustment option involves alterations of rotor deviation angle δ_R under any combination of three conditions: off-design flow coefficient φ, rotative speed N, and blade setting angle γ_0. A change in the rotor deviation angle δ_R changes the rotor outlet relative flow angle β_{3M}. This in turn alters the rotor outlet representative meanline velocity diagram and changes the stage characteristic $\psi(\varphi)$.

Computer Code Outline

The computer code STGSTK consists of a main routine and eight subroutines. Figure 6 gives a line representation of the subroutine calls. This section briefly summarizes the calculations within each subroutine. Details of the calculations are given in appendix B.

The main computer routine is entitled MAIN. MAIN is the central control routine and it calls the major subroutines. The major subroutines do three things: (1) process the input and output data, (2) calculate parameters for the compressor design (reference) point, and (3) perform the optional

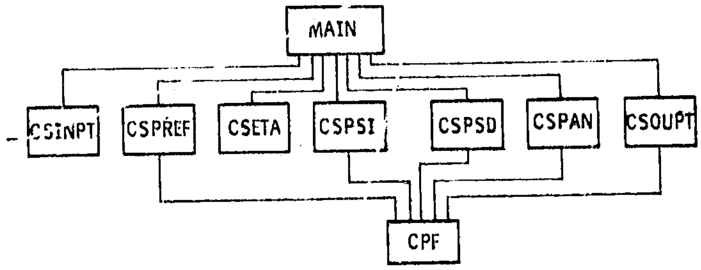

Figure 6. - Line representation of subroutine calls for stage-stacking program.

calculations discussed previously. A list of the subroutines and their primary purposes follows.

CSINPT - read and write the input data

CSPREF - calculate design (reference) parameters

CSETA - obtain optional stage characteristic $\eta_{ad}(\varphi)$ at design speed

CSPSI - obtain optional stage characteristic $\psi(\varphi)$ at design speed

CSPSD - perform option to alter pressure coefficient ψ at off-design speeds

CSPAN - perform option to alter stage characteristic $\psi(\varphi)$ because of blade reset

CSOUPT - calculate and write the output data

CPF - calculate specific heat C_p and its ratio γ

Other optional calculations are located within the STGSTK code as follows. MAIN contains an option to alter the flow coefficient φ at off-design speeds. CSPSI, CSPSD, and CSPAN contain an option to alter the rotor deviation angle δ_R for off-design flow, speed, and blade setting angle, respectively.

COMPUTER CODE USER INFORMATION

This section provides information for someone who wants to use the STGSTK code. The input data are described and an example input data set is given. The output data computed by STGSTK are also described. For a guide to the optional calculations that may be selected, the user may refer to the section Optional Calculations presented previously.

Input Data

All input data needed to use the stage-stacking program are described in this section. The input data are described in the same sequence as they are used by the program. Except for the title card and specific-heat polynomial coefficients CPCO, all the input format is for floating-point numbers in fields of 10. Figure 7 shows the location of input. Except for CPCO the

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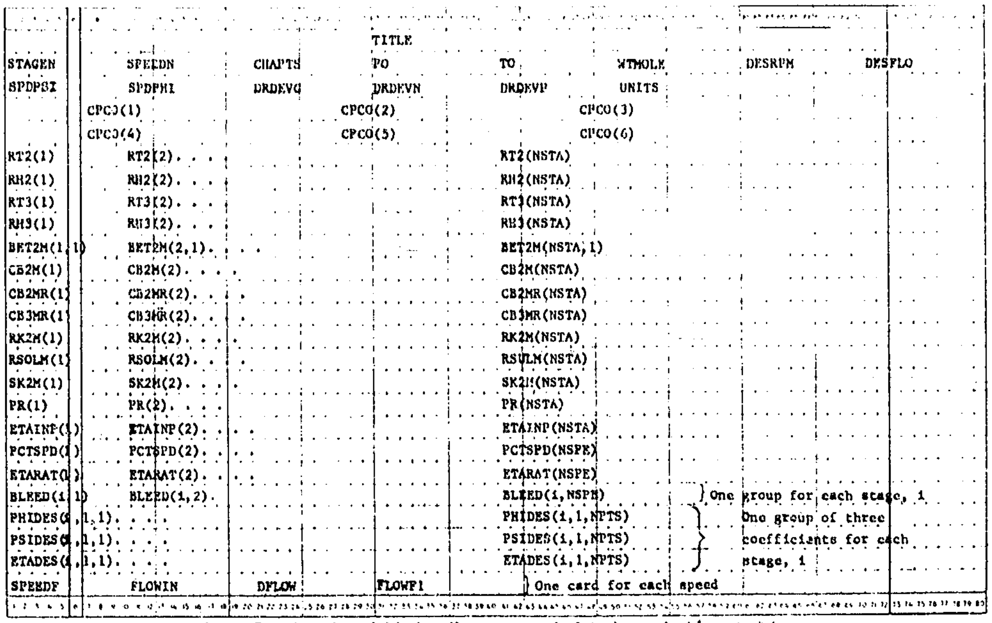

Figure 7. - Input variable locations on cards for stage-stacking program.

units of the input data can be selected as either all SI or all U.S. customary. Program subroutine CSINPT reads and prints the data.

The following is a list of the input data as they are read by subroutine CSINPT. For each input variable name listed, its format, description, and units are included.

TITLE, 18A4	title card on which any alphanumeric data can be used; one card needed
STAGEN, F10	number of stages
SPEEDN, F10	number of speed lines
CHAPTS, F10	number of points used to describe stage characteristic
PO, F10	inlet total pressure, N/cm^2 (psi)
TO, F10	inlet total temperature, K (°R)
WTMOLE, F10	molecular weight
DESRPM, F10	design rotative speed, rpm
DESFLO, F10	design flow, kg/sec (lb/sec)
SPDPSI, F10	alters ψ value for off-design speed when equal to 1.0
SPDPHI, F10	alters φ value for off-design speed when equal to 1.0
DRDEVG, F10	alters rotor deviation angle for blade reset when equal to 1.0

DRDEVN, F10	alters rotor deviation angle for off-design speed when equal to 1.0
DRDEVP, F10	alters rotor deviation angle for off-design φ when equal to 1.0
UNITS, F10	used to specify units of input; use 1.0 for SI, 0.0 for U.S. customary
CPCO, E20.8	specific-heat C_p polynomial coefficients in U.S. customary units (Btu $°R^{-1}$/lb ... Btu $°R^{-6}$/lb)
RT2, F10	rotor inlet tip radius, cm (in.)
RH2, F10	rotor inlet hub radius, cm (in.)
RT3, F10	rotor outlet tip radius, cm (in.)
RH3, F10	rotor outlet hub radius, cm (in.)
BET2M, F10	rotor inlet absolute flow angle at meanline radius, deg
CB2M, F10	change in rotor inlet absolute flow angle at meanline radius, deg
CB2MR, F10	change in rotor inlet relative flow angle at meanline radius, deg
CB3MR, F10	change in rotor outlet relative flow angle at meanline radius, deg
RK2M, F10	rotor inlet blade metal angle at meanline radius, deg
RSOLM, F10	rotor blade row solidity at meanline radius
SK2M, F10	stator inlet blade metal angle at meanline radius, deg
PR, F10	design stage pressure ratio used to calculate PSIDES
ETAINP, F10	design stage adiabatic efficiency used to calculate ETADES
PCTSPD, F10	value of rotative speed expressed as a decimal fraction of design speed; design speed value or 1.0 must be the first value for this input variable
ETARAT, F10	ratio of adiabatic efficiency at design speed to adiabatic efficiency at speed corresponding to PCTSPD; 1.0 is normally the first value for this input variable
BLEED, F10	bleed flow for a particular stage and speed corresponding to PCTSPD, kg/sec (lb/sec)
PHIDES, F10	stage flow coefficient at design speed

PSIDES, F10 — stage pressure coefficient at design speed; when input PR is not zero, PSIDES must be zero

ETADES, F10 — stage adiabatic efficiency at design speed; when input ETAINP is not zero, ETADES must be zero

SPEEDF, F10 — decimal fraction of design speed for a particular speed line

FLOWIN, F10 — value of lowest flow for speed line designated by SPEEDF, kg/sec (lb/sec)

DFLOW, F10 — change in flow for speed line designated by SPEEDF, kg/sec (lb/sec)

FLOWFI, F10 — value of highest flow for speed line designated by SPEEDF, kg/sec (lb/sec)

Example Input Data Set

The example program data set listed in this section is for the NASA Lewis two-stage fan having the low-aspect-ratio, first-stage rotor blading of reference 5. The fan design information is used for the input data. SI units are used except for the Cp polynomial coefficients.

```
NASA TWO STAGE FAN,  LOW R1 AR,  TP-1493            SI  INPUT
2.          5.          8.          10.135    288.17    28.97       16042.8     33.248
1.          1.          1.          1.        1.        1.
      0.23746571E 00       0.21961999E-04      -0.87791479E-07 CP VS T 0000-1700 R
      0.13991136E-09      -0.78056154E-13       0.15042604E-16
25.420      23.960
9.891       13.604
24.628      23.566
12.088      14.696
.0          .0
.0          .0
.0          .0
.0          .0
56.15       55.46
1.68        1.57
36.10       36.15
1.5906      1.5087
.8471       .8690
1.          .9          .8          .7          .5
1.          1.017       1.029       1.017       1.023
.0
.0
.31         .35         .38         .42         .43         .44         .45         .46
.0
.0
.40         .42         .44         .45         .46         .48         .51         .53
.0
.0
1.          32.         .2          35.
.9          27.         .5          32.
.8          21.         .5          28.
.7          17.         .5          24.
.5          11.         .5          18.
```

Output Data

All output data generated by the stage-stacking program are described in this section. The output data consist of two types:

(1) Intermediate output for changes in the stage characteristics because of blade reset and off-design flow conditions

(2) Final output for the predicted compressor performance along the selected speed lines

The program's MAIN routine writes the intermediate output. Subroutine CSOUPT writes the final output. The units of the output data are either all SI or all U.S. customary depending on the value of the input parameter UNITS. For SI output, UNITS equals 1.0; for U.S. customary output, UNITS equals 0.0.

The following is a list of the output data in the same order as they are written by the program. For each output variable listed, its description and units are included.

PHIREF — stage flow coefficient at design flow, speed, and blade setting angles

PSIREF — stage pressure coefficient at design flow, speed, and blade setting angles

DPHIA — change in flow coefficient PHIREF because of rotor- or stator-blade reset

DPSIA — change in pressure coefficient PSIREF because of rotor- or stator-blade reset

FLOCAL — calculated flow for a stage at design speed if blade reset is specified, kg/sec (lb/sec)

BET2M — rotor inlet absolute flow angle at design speed and flow and specified blade reset, deg

BET3MR — rotor outlet relative flow angle at design speed and flow and specified blade reset, deg

RINCM — rotor incidence angle at design speed and flow and specified blade reset, deg

RDFM — rotor diffusion factor at design speed and flow and specified blade reset, deg

SINCM — stator incidence angle at design speed and flow and specified blade reset, deg

DPSIS — change in pressure coefficient PSIREF because of off-design speed effects

PHI — calculated stage flow coefficient for selected speeds with blade reset effects included

PSI	calculated stage pressure coefficient for selected speeds with blade reset effects included
ETA	calculated stage adiabatic efficiency for selected speeds
TAU	stage temperature rise coefficient
PR	stage pressure ratio
C-ETA	compressor cumulative adiabatic efficiency

EXPERIMENTAL DATA COMPARED WITH CODE PREDICTIONS

The example calculations by the stage-stacking code discussed in this section are of two types: (1) calculations to predict overall compressor performance, and (2) calculations to predict flow reduction by inlet vane reset. The example calculations illustrate the procedure used for the stage-stacking code. The code's predictions are compared with experimental test data.

Two-Stage Fan Performance

These calculations were performed for the two-stage fan of reference 5, which has a design pressure ratio of 2.4 and an inlet tip speed of 429 m/sec. The previous section Example Input Data Set lists the input data set. These input data select the following program calculation options: (1) stage characteristics $\eta_{ad}(\varphi)$ and $\psi(\varphi)$ will be calculated from a reference design-point stage pressure Pr and adiabatic efficiency η_{ad}, (2) $\psi(\varphi)$ will be altered for off-design speed, and (3) rotor deviation will be adjusted for off-design speed and flow. Appendix C lists all the program output data. Stage performance and cumulative compressor predicted performance are listed for various flows at five selected speeds.

In figure 8 the overall fan performance calculated by the stage-stacking program is compared with the experimental measured performance reported in reference 5. At design speed for any given pressure ratio the measured flow is greater than the calculated flow. This occurs because the calculated performance at design speed was forced through the fan's design point, and the measured data indicated that the fan performed at a higher flow than its intended design flow. For the off-design part speeds the discrepancies between the calculated and experimental data are similar but less severe. This would tend to support the credibility of the program to predict overall compressor performance at part-speed, off-design flow. No judgment can be made from these fan data on the program's ability to account for vane reset since the fan was tested with no inlet guide vanes and with fixed stators.

Single-Stage Performance with Variable Inlet Guide Vanes

When an inlet guide vane (IGV) is reset to increase the absolute flow angle β_2 at the following rotor inlet, the corrected flow at the rotor

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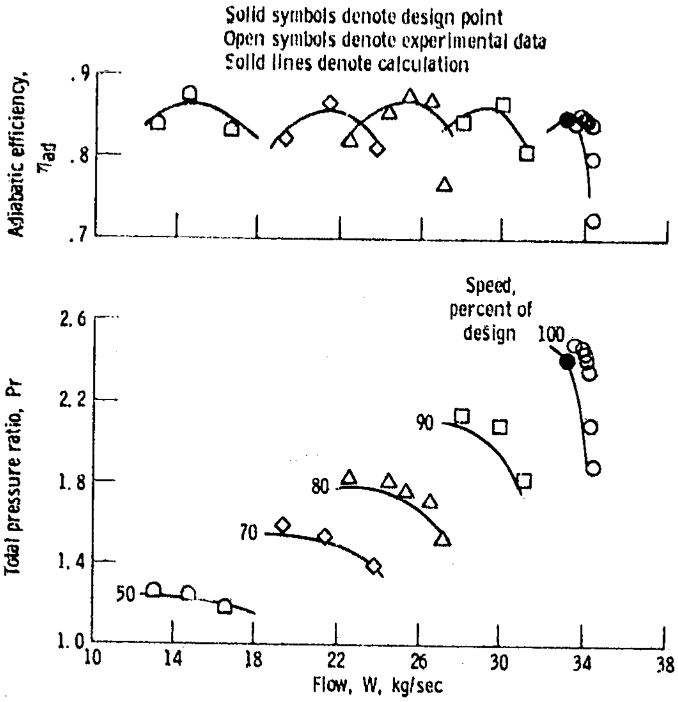


Figure 8. - Comparison of calculated performance by stage-stacking code to experimental data for NASA two-stage fan of reference 5.

inlet will be reduced. Also, the stage pressure ratio Pr will decrease, and this may cause the corrected flow at the stage exit to decrease. Corrected-flow reduction at the stage exit will depend on the amount of IGV reset, the design speed, and the stage performance.

Calculations are performed for each of the three single-stage compressors with variable inlet guide vanes for which experimental data were reported in references 6 to 8. For these stages, the design rotor inlet tip speeds are 347, 457, and 427 m/sec, and the measured stage pressure ratios at peak stage efficiency are 1.42, 1.72, and 1.52, respectively. For each stage a comparison of the calculated to the experimental overall performance data at various IGV setting angles is shown in figures 9 to 11. Figure 12 shows the corrected-flow reduction ratio at the stage outlet versus IGV setting angle at peak stage efficiency for design speed and 80 percent of design speed. The open symbols are for measured data and the lines are for calculated output from the stage-stacking program. Figure 13, which was derived from figure 12, shows the IGV reset angle required to reduce the corrected flow (at the stage outlet) by 10 percent versus rotor inlet tip design speed for 100 and 80 percent of design speed.

Agreement between the calculated and measured IGV reset for a given flow reduction and tip speed is better at design speed than at 80 percent of design speed. However, for both speeds the trends of the calculated and measured data are very similar. This indicates that as the rotor speed goes up, IGV reset must be increased for a given flow reduction ratio W/W_d. This influence of rotor speed on the vane-reset flow reduction relationship was previously discussed in reference 9.

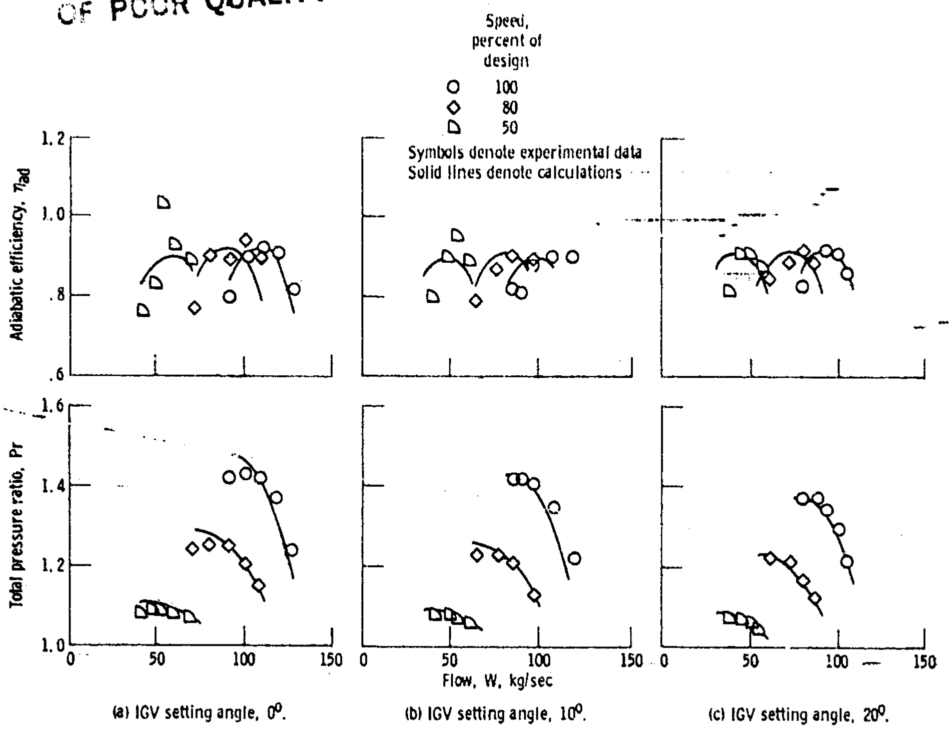


Figure 9. - Comparison of calculated to experimental performance data for the 347-m/sec-design-speed single-stage compressor of reference 6 at various inlet guide vane setting angles.

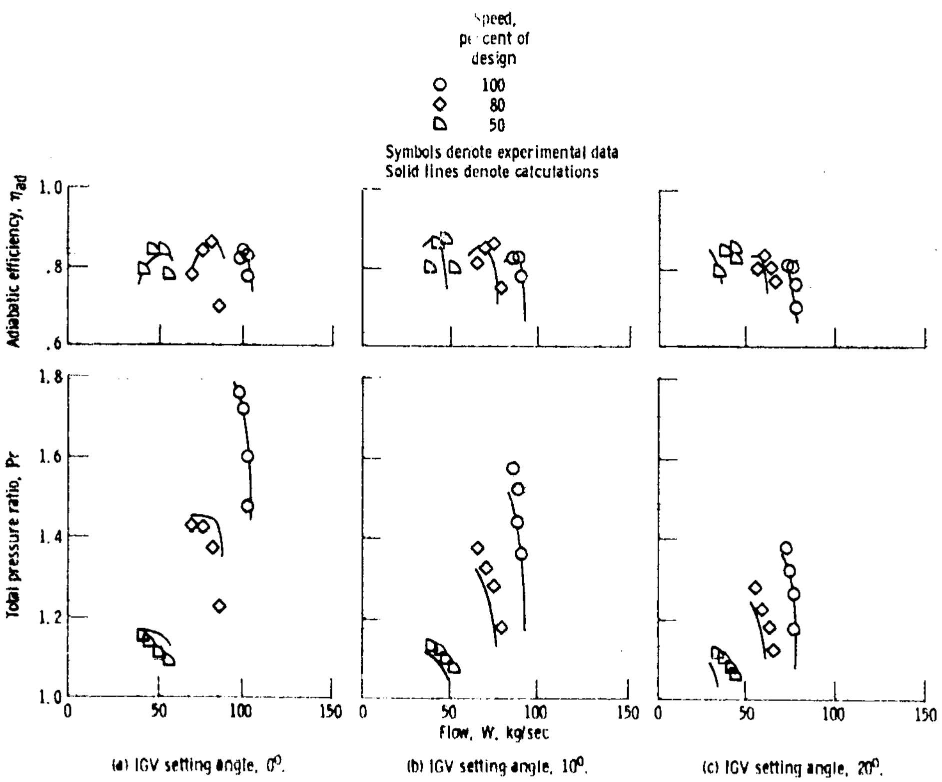
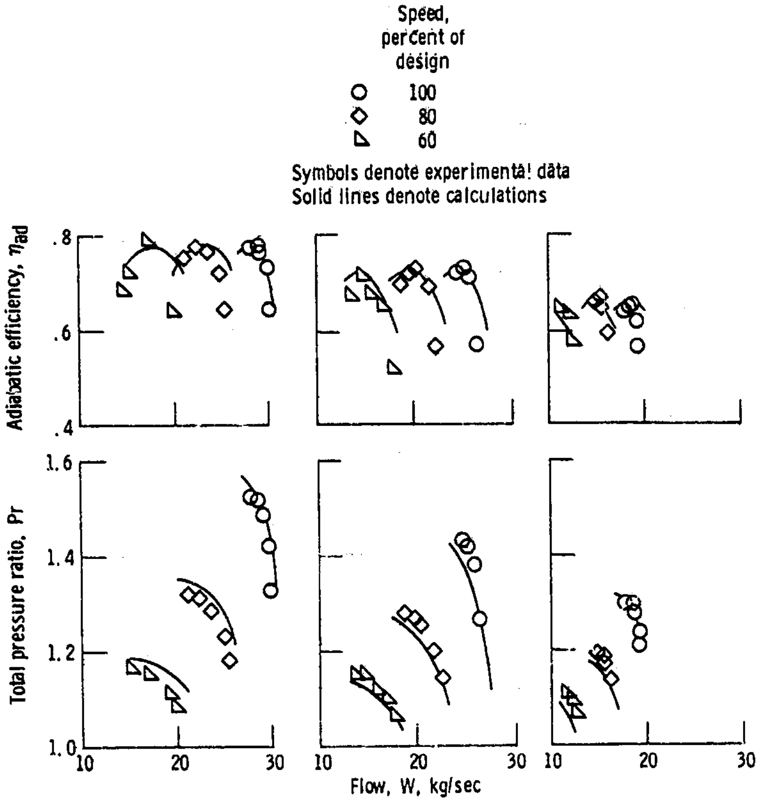


Figure 10. - Comparison of calculated to experimental performance data for the 457-m/sec-design-speed single-stage compressor of reference 7 at various inlet guide vane setting angles.



(a) IGV setting angle, 0°.
(b) IGV setting angle, 18°.
(c) IGV setting angle, 45°.

Figure 11. - Comparison of calculated to experimental performance data for the 427-m/sec-design-speed single-stage compressor of reference 8 at various inlet guide vane setting angles.

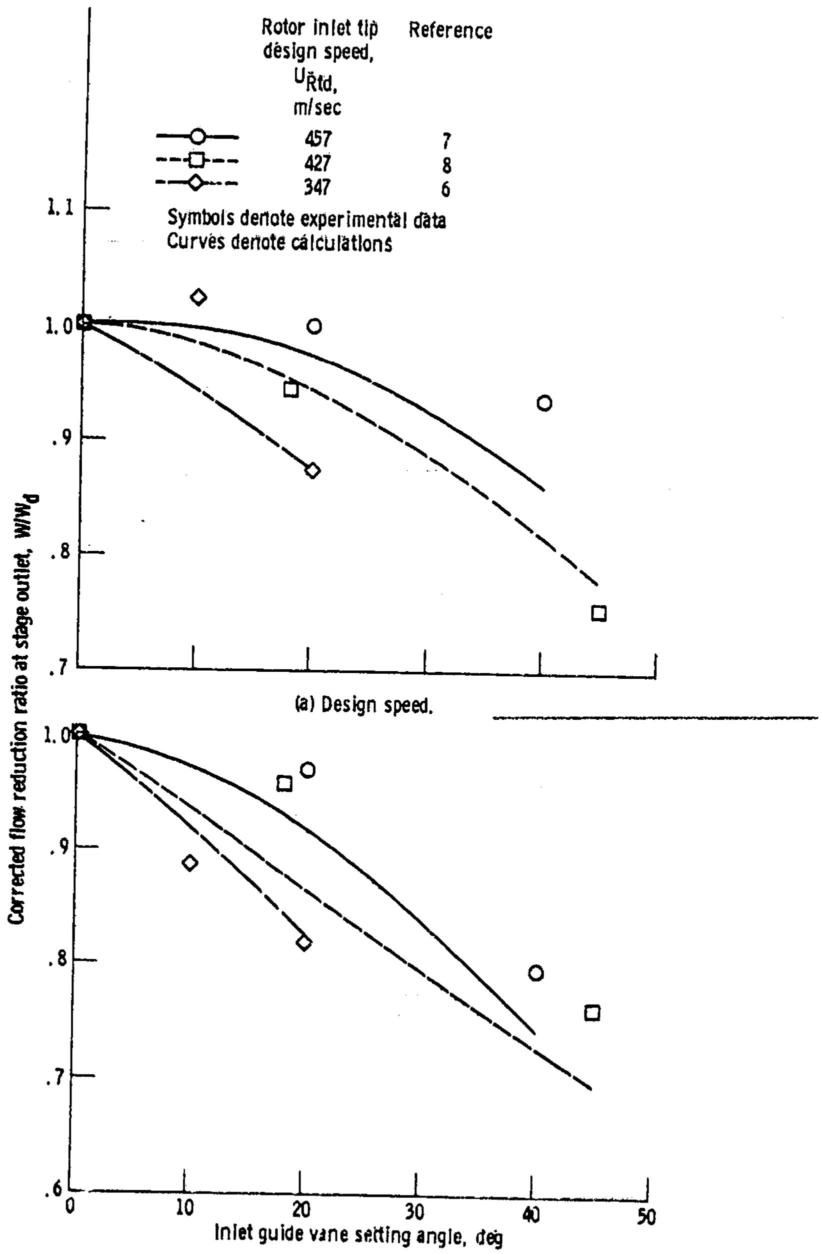


Figure 12. - Corrected flow reduction ratio at stage outlet, at peak efficiency, as a function of inlet guide vane setting angle for three single-stage compressors.

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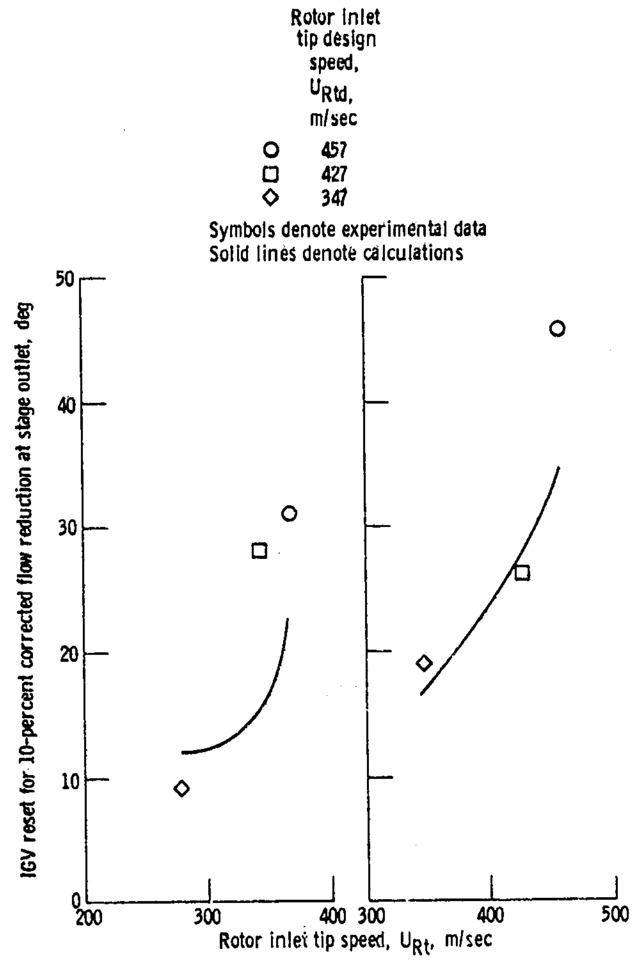


(a) 80 Percent of design speed. (b) Design speed.

Figure 13. - Required inlet guide vane reset for a 10-percent corrected flow reduction at the stage outlet, at peak efficiency, as a function of rotor inlet tip speed.

CONCLUDING REMARKS

A computer code for predicting off-design performance for multistage axial-flow compressors has been discussed in this report. The meanline stage-stacking method used has the following properties:

(1) It is a one-dimensional, compressible flow model with fast convergence.

(2) Overall stage performance is represented by meanline velocity diagrams at the rotor inlet and outlet.

(3) Options are included to calculate the stage characteristics and to adjust them for blade reset and real flow effects.

(4) Experimental test data can be applied directly to correlations of model real flow conditions.

(5) Accurate off-design predictions can be made for a limited range of compressors.

Example calculations compared with experimental data for the stage-stacking code reported herein give the following indications:

(1) The code's calculation options to alter stage characteristics and rotor deviation angles for off-design conditions resulted in a performance prediction for a two-stage, 2.4-pressure-ratio fan that compared well with experimental data.

(2) The code's calculations to alter stage characteristics and rotor deviation angles due to blade reset resulted in a flow reduction prediction with inlet-guide-vane reset for three single-stage compressors that compared satisfactorily with experimental data trends.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, October 8, 1981

APPENDIX A

SYMBOLS

The following is a list of symbols defined as used in the text and figures of this report. Only basic SI units for these symbols are given. The user information section of the report defines the computer program input and output data with appropriate SI and U.S. customary units as required by the program.

A	annulus area, m^2
C_p	specific heat at constant pressure, J/kg K
$C_1, \ldots, C_6$	coefficients for C_p polynomial, $JK^{-1}/kg \ldots JK^{-5}/kg$
D_f	diffusion factor
i	incidence angle, deg
N	rotative speed, rpm
P	total pressure, N/m^2
Pr	pressure ratio
R	gas constant, J/kg K
T	total temperature, K
Tr	temperature ratio
t	static temperature, K
U	wheel speed, m/sec
V	velocity, m/sec
W	flow, kg/sec
β	flow angle, deg
γ	ratio of specific heats
γ_0	blade setting angle
$\Delta\gamma_0$	blade reset
δ	deviation angle, deg
η_{ad}	adiabatic efficiency
κ	blade metal angle, deg
ρ	static density, kg/m^3

σ	blade solidity
φ	flow coefficient
ψ	pressure coefficient

Subscripts:

c	choke
d	design condition
H	highest value
h	hub
i	indicates φ, N, or γ_0 subscript
L	lowest value
M	meanline
N	speed
R	rotor
S	stator
s	stall
T	tangential
t	tip
Z	axial
φ	flow coefficient
2	rotor inlet
3	rotor outlet

Superscript:

( )'	relative to rotor

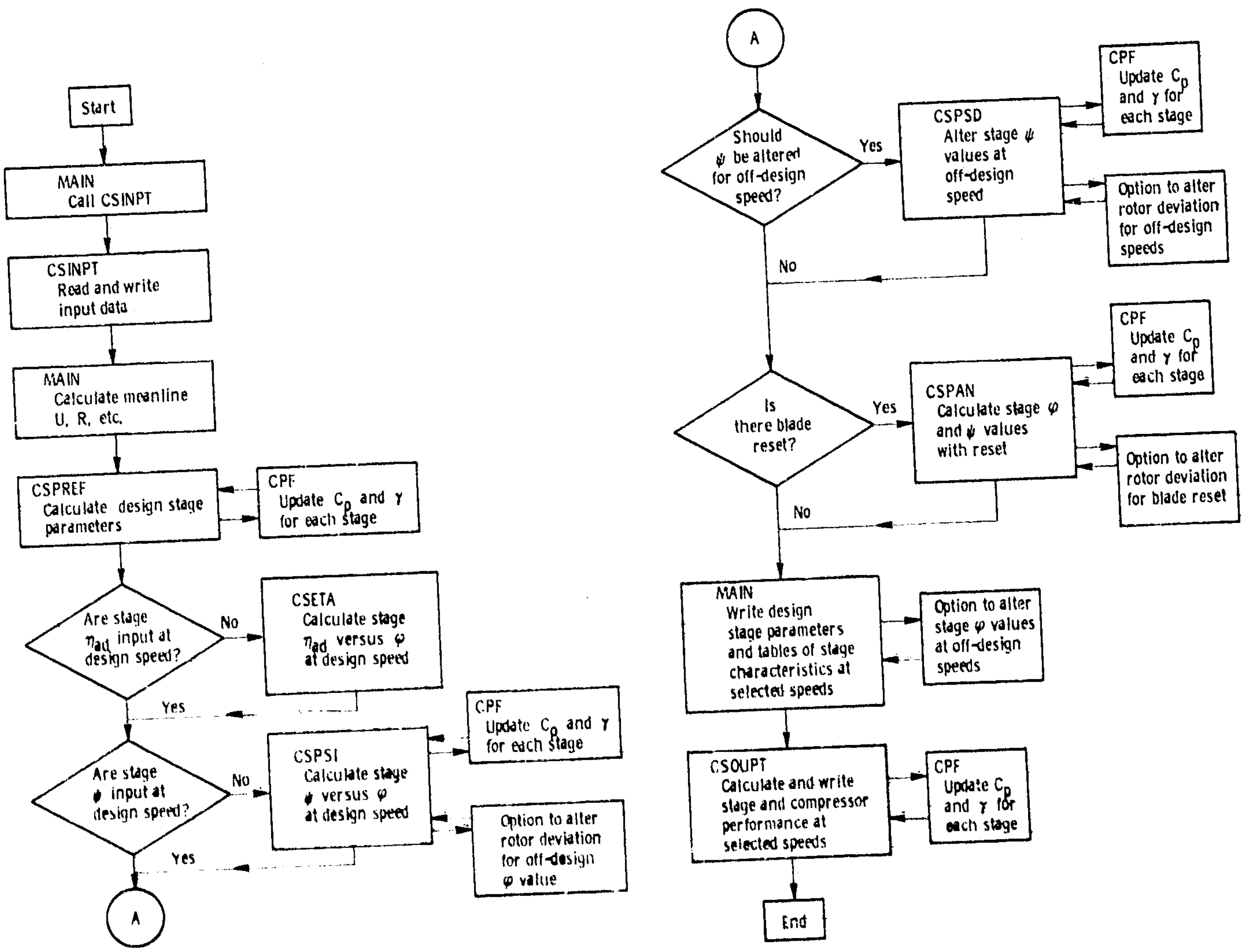
APPENDIX B

CODE CALCULATION DETAILS

Details of calculations within the code routines are discussed. Generally a routine's calculations are discussed within a subsection for the routine. However, program options common to several routines and program options within the main routine are discussed in separate subsections for the option. Routines and program options are discussed in the sequence used by the program. A guide to this sequence is the calculation flow chart of figure 14.

Main Routine

The main computer code routine is entitled MAIN, and it calls all of the computer code major subroutines. A description of the sequence of subroutine calls from MAIN and brief descriptions of the calculations within



each subroutine called from MAIN will be used to discuss the overall program structure. Other major items performed within MAIN are also discussed.

MAIN first calls subroutine CSINPT. The primary purpose of subroutine CSINPT is to read and write the input data required to run the computer code. After calling CSINPT, MAIN calculates several parameters associated with the rotor inlet and outlet for each stage. Among these parameters are the rotor inlet and outlet meanline radii, which are calculated from

$$R_{2M} = \left(R_{2T}^2 - \frac{A_2}{2\pi}\right)^{1/2} \tag{B1}$$

$$R_{3M} = \left(R_{3T}^2 - \frac{A_3}{2\pi}\right)^{1/2} \tag{B2}$$

Symbols are defined in appendix A. At these meanline radii, representative meanline velocity diagrams will be calculated for each stage.

MAIN next calls subroutine CSPREF, which calculates design (reference) velocity diagrams at the meanline radii for each stage. The design velocity diagrams are based on the design values of speed, flow, and blade setting angles. CSPREF also calculates the design values of (reference) flow coefficient φ_d, pressure coefficient ψ_d, and adiabatic efficiency $\eta_{ad,d}$ for each stage from the following general expressions:

$$\varphi = \frac{V_{Z2M}}{U_{2T}} \tag{B3}$$

$$\psi = \frac{C_p \eta_{ad}(T_3 - T_2)}{U_{3T}^2} \tag{B4}$$

$$\eta_{ad} = \frac{Pr^{(\gamma-1)/\gamma} - 1}{Tr - 1} \tag{B5}$$

The values of C_p and γ are a function of static temperature and are obtained from subroutine CPF, whenever needed, by all subroutines throughout the calculation procedure.

If the stage characteristic $\eta_{ad}(\varphi)$ at design speed is not input, MAIN calls subroutine CSETA to obtain $\eta_{ad}(\varphi)$ for the stage at design speed. If the stage characteristic $\psi(\varphi)$ at design speed is not input, MAIN calls subroutine CSPSI to obtain $\psi(\varphi)$ for the stage at design speed. Also, MAIN has an optional call to subroutine CSPSD, which alters the pressure coefficient values for off-design speeds. If a rotor or stator is reset, MAIN calls subroutine CSPAN, which alters the stage characteristic $\psi(\varphi)$ affected by the reset. Within MAIN there is an optional calculation that alters the flow coefficient φ values for off-design speeds. Within subroutines CSPSI, CSPSD, and CSPAN there is an optional calculation that alters rotor deviation angle for off-design values of flow, speed, and blade setting angle, respectively.

MAIN writes the intermediate output data, which consists primarily of the following: (1) design values for each stage φ, ψ, and η_{ad} and specified flow angles, (2) changes in design values of stage φ and ψ because of blade reset, and (3) tabulated stage characteristics of $\psi(\varphi)$

and $\eta_{ad}(\varphi)$ at specified speeds. These stage characteristics are used to calculate the compressor performance map.

The final subroutine called by MAIN is CSOUPT. Subroutine CSOUPT reads the selected speeds and flows at which compressor performance is desired. At the selected speed and flow conditions CSOUPT calculates and writes individual stage and cumulative compressor performance parameters.

Subroutine CSINPT

The primary purpose of subroutine CSINPT is to read and write the input data that the program requires. The main text of this report has a section entitled Input Data that contains the information that a user needs to prepare an input data set for this program. This input data section explains the input data format, purpose, and units. CSINPT is coded with an option to enable the units of the input to be either all SI or all U.S. customary. The write statements within CSINPT do not contain units and are therefore applicable to both SI or U.S. customary input data. CSINPT writes the input in the same units in which the input was read. A portion of the final lines of coding of CSINPT converts input of SI units into U.S. customary units. This conversion of the units of SI input data into U.S. customary units permits the FORTRAN expressions for the program calculations to be formulated in terms of U.S. customary units.

For input of design stage performance there is an option of either of the following inputs: (1) stage pressure ratio Pr and adiabatic efficiency η_{ad}, or (2) stage characteristics, which consist of pressure coefficient versus flow coefficient $\psi(\varphi)$ and adiabatic efficiency versus flow coefficient $\eta_{ad}(\varphi)$. When either of these two input options is used as input, the input parameters for the option not used are input as zeros. Program subroutines called after CSINPT calculate values for the parameters that were not input by option.

Subroutine CSPREF

At design speed and flow, subroutine CSPREF calculates (1) velocity diagrams at the meanline radii for each rotor inlet and outlet, and (2) selected performance parameters for each stage. Figure 2 shows the meanline velocity diagrams associated with a typical rotor. CSPREF performs a one-dimensional, compressible, inviscid flow calculation at each rotor inlet and outlet to obtain the meanline velocity diagrams for design input conditions.

The sequence of calculations in CSPREF is as follows:

(1) From input design β_{2M}, W, N, and A_2, calculate by iteration (with C_p and γ functions of t_2) the design values for V_{Z2M} and φ.

(2) If design stage Pr and η_{ad} are input, calculate design ψ.

(3) If stage characteristics $\psi(\varphi)$ and $\eta_{ad}(\varphi)$ at design speed are input, obtain ψ, η_{ad}, and Pr by linear interpolation.

(4) Calculate β_{2M} and V_{T2M}.

(5) For design N and W, calculate by iteration the design values for V_{T3M} and V_{Z3M}, with Euler's equation solved for V_{T3M} as

$$V_{T3M} = \frac{1}{U_{3M}} \left[C_p(T_3 - T_2) + U_{2M}V_{T2M}\right] \qquad \text{(B6)}$$

and C_p and γ functions of t_3.

(6) Calculate design β'_{3M}, the rotor and stator incidence angles, and the rotor diffusion factor by using

$$i_{MR} = \beta'_{2M} - \kappa_{2MR} \tag{B7}$$

$$i_{MS} = \beta'_{3M} - \kappa_{2MS} \tag{B8}$$

$$D_{fR} = 1 - \frac{V'_{3M}}{V'_{2M}} + \frac{R_{3M}V_{T3M} - R_{2M}V_{T2M}}{(R_{3M} + R_{2M})\sigma_{RM}V'_{2M}} \tag{B9}$$

These calculations within CSPREF are repeated for each stage of the compressor for which input was read by CSINPT.

Subroutine CPF

This subroutine is used to obtain values of C_p and γ as a function of static temperature t. CPF is called by the previously discussed subroutine CSPREF and also is called by subroutines CSPSI, CSPSD, CSPAN, and CSOUPT. Subroutine CPF calculates C_p from a fifth-degree polynomial of t expressed by

$$C_p = C_1 + C_2t + C_3t^2 + C_4t^3 + C_5t^4 + C_6t^5 \tag{B10}$$

where the polynomial coefficients C_1 to C_6 are input data read by CSINPT. The value of γ is then calculated from

$$\gamma = \frac{C_p}{C_p - R} \tag{B11}$$

CPF also calculates various other functions of γ used by the calling subroutines for the flow calculations.

Subroutine CSETA

This subroutine is called by MAIN when values of stage characteristic $\eta_{ad}(\varphi)$ at design speed are not usable input (i.e., the input value for η_{ad} is 0.0). CSETA obtains values of η_{ad} for each stage at the various input φ for the stage. The following procedure is used within subroutine CSETA:

(1) A curve is generated for $\eta_{ad}(\varphi)$ as depicted in figure 15. This curve consists of two parabolas. The first parabola extends from the minimum flow (stall) coefficent φ_s to the design flow coefficient φ_d. The second parabola extends from the design flow coefficient φ_d to the maximum flow (choke) coefficient φ_c.

(2) For each stage the generated curve for $\eta_{ad}(\varphi)$ has the properties:

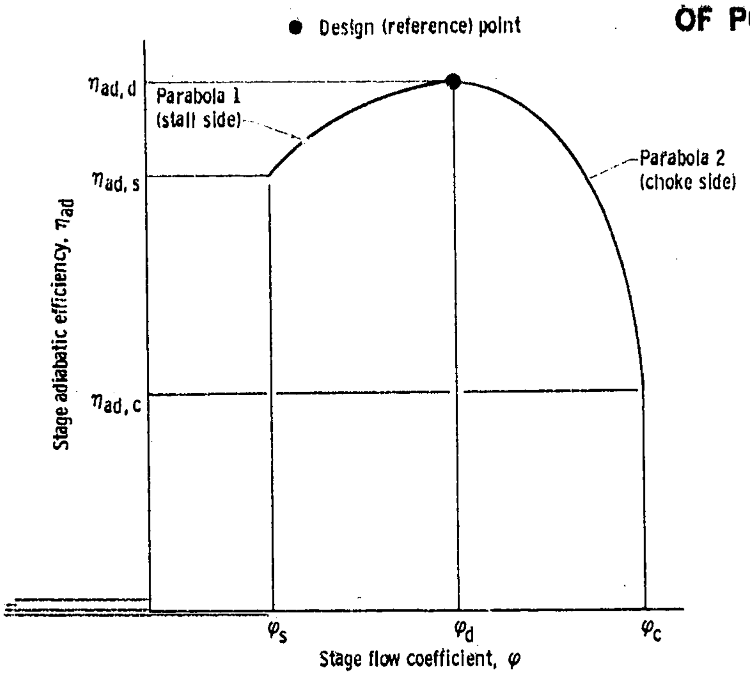


Figure 15. - Properties of curve fit for stage adiabatic efficiency as a function of stage flow coefficient generated by subroutine CSETA.

$$\frac{d\eta_{ad}}{d\varphi} = 0 \qquad \text{at} \quad \varphi = \varphi_d$$

$$\eta_{ad} = \eta_{ad,d} \qquad \text{at} \quad \varphi = \varphi_d$$

$$\eta_{ad} = 0.9\ \eta_{ad,d} \qquad \text{at} \quad \varphi = \varphi_s$$

$$\eta_{ad} = 0.8\ \eta_{ad,d} \qquad \text{at} \quad \varphi = \varphi_c$$

The peak η_{ad} is located at the design (reference) condition.

(3) After the curve as described above is generated for stage $\eta_{ad}(\varphi)$, subroutine CSETA then calculates a η_{ad} value for every input φ for the stage.

This procedure is repeated within CSETA for each stage of the compressor. The merit of this particular procedure depends on its ability to simulate performance for the type of compressor being studied. Another procedure may better meet the needs of the user. The isolation of this procedure within a single subroutine readily permits its identification for alteration.

Subroutine CSPSI

This subroutine is called by MAIN when values of stage characteristic $\psi(\varphi)$ at design speed are not usable input (i.e., the input value for ψ is 0.0). CSPSI obtains values of ψ for each stage at the various input φ for the stage. The following calculation procedure is used within subroutine CSPSI:

(1) Assume design values calculated in CSPREF for β'_{2Md}, β_{2Md}, φ_d, and β_{3Md}.

(2) For an input φ, calculate V_{Z2M} from

$$V_{Z2M} = V_{Z2Md}\left(\frac{\varphi}{\varphi_d}\right) \tag{B12}$$

calculate the flow W corresponding to the input φ from

$$W_2 = \rho_2 A_2 V_{Z2M}$$

(3) For the value for W_2 and the design rotative speed N_d, calculate by iteration with V_{T3M} obtained from

$$V_{T3M} = U_{3M} - V_{Z3M} \tan \beta'_{3M} \tag{B13}$$

and $T_3 - T_2$ obtained from

$$T_3 - T_2 = \frac{1}{C_p}\left(U_{3M}V_{T3M} - U_{2M}V_{T2M}\right) \tag{B14}$$

the pressure coefficient corresponding to the input φ from

$$\psi = \frac{C_p \eta_{ad}(T_3 - T_2)}{U_{3T}^2} \tag{B15}$$

with the following conditions:

(1) $W_3 = W_2$

(2) C_p and γ are functions of t_3 obtained from subroutine CPF

(3) $\beta'_{3M} = \beta'_{3Md} + \Delta\beta'_{3M\varphi}$, where $\Delta\beta'_{3M\varphi}$ is obtained from an option to alter rotor deviation angle for off-design φ values.

These calculations within CSPSI are repeated for every input φ value for each stage of the compressor.

Subroutine CSPSD

This subroutine is called by MAIN when the user has specified the option to alter the pressure rise coefficient ψ calculated at design speed for off-design speeds. Subroutine CSPSD calculates a change in the pressure rise coefficient $\Delta\psi_N$ for an off-design rotative speed N. The calculation procedure is as follows:

(1) Assume design values calculated in CSPREF for β'_{2Md}, β_{2Md}, φ_d, and β_{3Md}.

(2) For an input off-design rotative speed N, calculate V_{Z2M} from

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$$V_{Z2M} = V_{Z2Md}\left(\frac{N}{N_d}\right) \qquad (B16)$$

and the flow corresponding to the input N from

$$W_2 = \rho_2 A_2 V_{Z2M} \qquad (B17)$$

(3) For this value of W_2 and the off-design rotative speed N, with V_{T3M} obtained from

$$V_{T3M} = U_{3M}\left(\frac{N}{N_d}\right) - V_{Z3M} \tan \beta'_{3M} \qquad (B18)$$

and $T_3 - T_2$ obtained from

$$T_3 - T_2 = \frac{1}{C_p}\frac{N}{N_d}\left(U_{3M}V_{T3M} - U_{2M}V_{T2M}\right) \qquad (B19)$$

calculate by iteration the change in the pressure rise coefficient $\Delta\psi_N$ corresponding to the off-design speed N from

$$\Delta\psi_N = \frac{C_p \eta_{ad,d}(T_3 - T_2)}{\left(U_{3T}\frac{N}{N_d}\right)^2} - \psi_d \qquad (B20)$$

with the following conditions:

(1) $W_3 = W_2$
(2) C_p and γ are functions of t_3 obtained from subroutine CPF.
(3) $\beta'_{3M} = \beta'_{3Md} + \beta'_{3MN}$, where $\Delta\beta'_{3MN}$ is obtained from an option to alter the rotor deviation angle for off-design N values.

These calculations are repeated within CSPSD for every input N value for each stage of the compressor. CSPSD changes the pressure coefficient ψ by an amount $\Delta\psi_N$ for an off-design part speed N. The overall effect of a typical stage characteristic $\psi(\varphi)$ is depicted in figure 16.

Subroutine CSPAN

CSPAN, which is called from MAIN, checks the value of input CB2M, CB2MR, and CB3MR for each compressor stage. If any of this input is not equal to zero, a blade reset has been specified and CSPAN proceeds to alter the stage design flow coefficient φ_d and the pressure coefficient ψ_d. A new stage characteristic $\psi(\varphi)$ for the blade reset is calculated as follows:

(1) Update the rotor inlet and outlet flow angle from

$$\beta_{2M} = \beta_{2Md} + \Delta\beta_{2M} \qquad (B21)$$

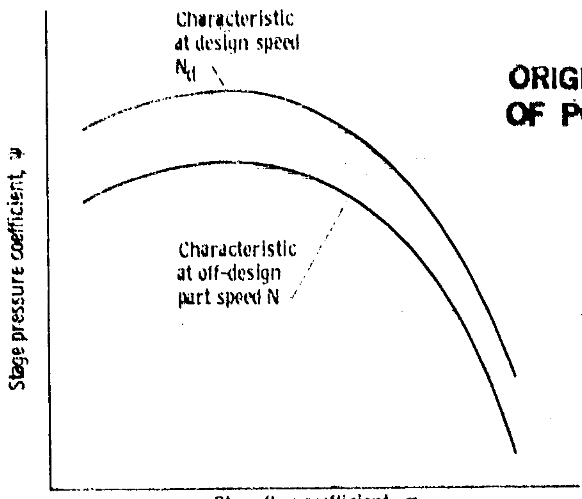

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Figure 16. - Effects of program option to alter pressure coefficient for off-design part speed on a typical stage characteristic ψ (φ).

$$\beta'_{2M} = \beta'_{2Md} + \Delta\beta'_{2M} \tag{B22}$$

$$\beta'_{3M} = \beta'_{3Md} + \Delta\beta'_{3M} \tag{B23}$$

(2) Assume design values calculated in CSPREF for other parameters. Calculate V_{Z2M} from

$$V_{Z2M} = \frac{U_{2M}}{\tan\beta_{2M} + \tan\beta'_{2M}} \tag{B24}$$

Determine the change in the flow coefficient $\Delta\varphi_{\gamma_0}$ corresponding to blade reset $\Delta\gamma_0$ from

$$\Delta\varphi_{\gamma} = \frac{V_{Z2M}}{U_{2T}} - \varphi_d \tag{B25}$$

and the flow from

$$W_2 = \rho_2 A_2 V_{Z2M} \tag{B26}$$

(3) For this value of W_2 and the blade reset $\Delta\gamma_0$, calculate by iteration the change in the pressure rise coefficient $\Delta\psi_{\gamma}$ corresponding to blade reset $\Delta\gamma$ from

$$\Delta\psi_{\gamma} = \frac{C_p \eta_{ad,d}(T_3 - T_2)}{U_{3T}^2} - \psi_d \tag{B27}$$

with the following conditions:

(1) $W_3 = W_2$

(2) C_p and γ are functions of t_3 and obtained from subroutine CPF.

(3) $\beta'_{3M} = \beta'_{3Md} + \Delta\beta'_{3M\gamma}$, where $\Delta\beta'_{3M\gamma}$ is obtained from an option to alter rotor deviation angle because of blade reset.

and where V_{T3M} is obtained from

$$V_{T3M} = U_{3M} - V_{Z3M} \tan \beta'_{3M} \qquad \text{(B28)}$$

and $T_3 - T_2$ is obtained from

$$T_3 - T_2 = \frac{1}{C_p} [U_{3M}V_{T3M} - U_{2M}V_{T2M}] \qquad \text{(B29)}$$

These calculations are repeated within CSPAN for each stage of the compressor. For an example of how CSPAN alters the stage characteristic $\psi(\varphi)$ for blade reset, consider the case where the vane (or stator) just upstream of a stage is reset (or rotated) by an amount $\Delta\gamma_0$. For this example, $\Delta\beta_{2M} = \Delta\gamma_0$ and $\Delta\beta'_{2M}$ and $\Delta\beta'_{3M}$ are both equal to zero. Figure 4 shows generally how the stage characteristic will be altered by CSPAN. Note that the level of the pressure rise coefficient ψ and the range of the flow coefficient φ are both altered by the upstream stator reset $\Delta\gamma_0$.

Subroutine CSOUPT

This subroutine calculates and writes individual stage and cumulative compressor performance parameters for various selected speeds and flow conditions. Output written by CSOUPT is in either all SI or all U.S. customary units as specified by the value of the input parameter UNITS. A summary of the coding within CSOUPT is as follows:

(1) Read input, which consists of speed fraction N/N_d, lowest flow W_L, flow increment ΔW, and highest flow W_H. Calculations are performed for the input speed fraction N/N_d at flow increments ΔW from W_L to W_H.

(2) Calculate the meanline representative velocity diagram at the rotor inlet meanline radius for flow W and A_2, where C_p and γ are functions of t obtained from CPF.

(3) Calculate the stage flow coefficient $\varphi = V_{Z2M}/U_{2T}$. Normally this calculated φ will be within the range of φ for this stage. Then, calculate by linear iterpolation, from the stage characteristics for this stage, the stage pressure rise coefficient ψ and stage adiabatic efficiency. However, if the calculated φ for this stage is not within the range of φ for this stage, CSOUPT is coded to stop calculations for this flow W and to print a message with the calculated φ and a statement that this stage is in a stall or choke condition.

(4) Calculate the stage temperature and pressure ratio and cumulative compressor adiabatic efficiency and pressure ratio.

(5) Calculate the meanline representative velocity diagram at the rotor outlet meanline radius for flow W and A_3, where C_p and γ are functions of t obtained from CPF.

(6) Using the preceding calculated meanline velocity diagrams calculate (1) rotor and stator incidence angles and (2) rotor diffusion factor.

(7) Write the preceding calculated stage and compressor parameters for the selected flow W and speed fraction N/N_d.

This procedure is repeated for each selected flow for the speed fractions selected from the input speeds read by subroutine CSINPT. After all calculations are performed for a set of data for one compressor, subroutine CSOUPT is coded to return to the main routine MAIN at the beginning of MAIN, and another set of data for another compressor will be processed if it is available.

Option to Alter φ Value for Off-Design Speeds

Within the main routine MAIN there is an user option to alter the flow coefficient φ values for off-design speeds because of real flow effects. This option is executed for each stage according to the user's specified value of the input parameter SPDPHI. Figure 17 depicts the general effect of this program option to alter flow coefficient for off-design part speed on a typical stage characteristic $\psi(\varphi)$. The general effect is that the range of the φ values is increased for off-design part speed. The expression within MAIN used to alter φ is obtained from the following:

$$\varphi_N = \varphi + \left(1 - \frac{N}{N_d}\right) \tag{B30}$$

where

$$\Delta\varphi_N = \varphi_N - \bar{\varphi} \tag{B31}$$

and

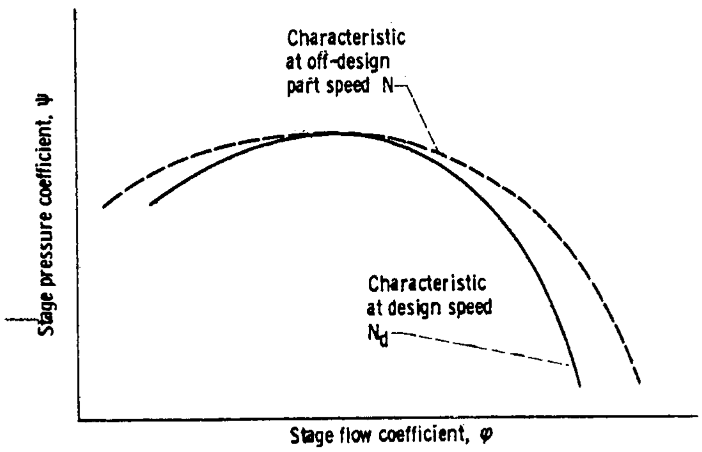

Figure 17. - Effects of program option to alter flow coefficient for off-design part speed on a typical stage characteristic ψ (φ).

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$$\varphi_N = \varphi \left(\frac{\varphi}{\varphi_d}\right)^{N_d/N} \tag{B32}$$

Substituting equations (B32) and (B31) into equation (B30) yields the altered φ_N for off-design part speed N as

$$\varphi_N = \varphi \left\{1 + \left[\left(\frac{\varphi}{\varphi_d}\right)^{N_d/N} - 1\right]\left(1 - \frac{N}{N_d}\right)\right\} \tag{B33}$$

Equation (B33) is coded into MAIN to alter φ for off-design part speed N.

Option to Alter Rotor Deviation Angle

Within subroutines CSPSI, CSPSD, and CSPAN there is an optional calculation that, if desired, alters the rotor deviation angle δ_R for off-design values of the flow coefficient φ, rotative speed N, and blade setting angle γ_0, respectively. This option will be executed for each stage, and the option is selected by means of the input parameters DRDEVP, DRDEVN, and DRDEVG for $\Delta\delta_{R\varphi}$, $\Delta\delta_{RN}$, and $\Delta\delta_{R\gamma_0}$, respectively. Figure 18 shows the various angles associated with a typical rotor meanline blade element. At the rotor outlet the relative flow angle β'_{3M} is related to the deviation angle δ_R by

$$\delta_R = \beta'_{3M} - \kappa_{3M} \tag{B34}$$

So for a fixed rotor exit blade metal angle κ_{3M}

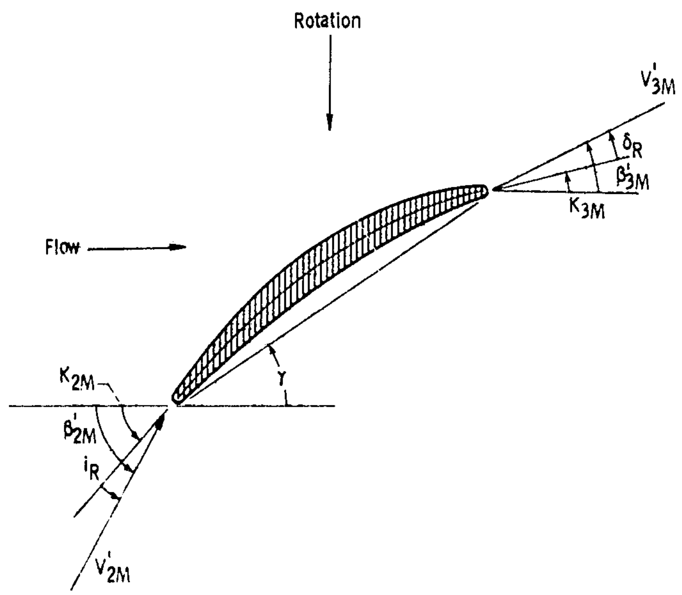

Figure 18. - Angles associated with a typical rotor meanline blade element.

$$\Delta\delta_R = \Delta\beta'_{3M} \tag{B35}$$

and the option to alter rotor deviation angle can be expressed in terms of a change in rotor exit relative flow angle $\Delta\beta'_{3M}$. The expression within subroutines CSPSI, CSPSD, and CSPAN used to alter rotor deviation angle is as follows:

$$\Delta\beta'_{3Mi} = -10\left[\left(\frac{V'_{3M}}{V'_{2M}}\right)_i - \left(\frac{V'_{3M}}{V'_{2M}}\right)_d\right] \tag{B36}$$

where the subscript i represents φ, N, and γ_0 for subroutines CSPSI, CSPSD, and CSPAN, respectively. The design relative velocity ratio $(V'_{3M}/V'_{2M})_d$ is calculated within subroutine CSPREF.

APPENDIX C

EXAMPLE PROGRAM OUTPUT LISTING

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The data set from the section Example Input Data Set was used as input data for the example program output listing given in this appendix.

```
                    ** STAGE STACKING PROGRAM **

                 NASA TWO STAGE FAN,  LOW R1 AR,  TP-1493         SI  INPUT

  STAGES    SPEEDS    POINTS     PO IN     TO IN    MOLE WT   DES RPM  DES FLOW
   2.000     5.000     8.000    10.135   288.170    28.970 16042.797    33.248

  SPDPSI    SPDPHI    DRDEVG    DRDEVN    DRDEVP     UNITS
     1.0       1.0       1.0       1.0       1.0       1.0

   CPCO(1)     CPCO(2)     CPCO(3)     CPCO(4)     CPCO(5)     CPCO(6)
0.23747E 00 0.21962E-04-0.87791E-07 0.13991E-09-0.78056E-13 0.15043E-16

   STAGE       RT2       RH2       RT3       RH3     BET2M      CB2M     CB2MR     CB3MR      RK2M     RSOLM      SK2M
       1   25.4200    9.8910   24.6280   12.0880      0.00      0.00      0.00      0.00     56.15    1.6800     36.10
       2   23.9600   13.6040   23.5660   14.6960      0.00      0.00      0.00      0.00     55.46    1.5700     36.15
0

   STAGE        PR    ETAINP
       1    1.5906    0.8471
       2    1.5087    0.8690
0

  PCTSPD    ETARAT
```

1.0000	1.0000
0.9000	1.0170
0.8000	1.0290
0.7000	1.0170
0.5000	1.0230

0

BLEED(STAGE,PCT SPD) TABLE

	STAGE NUMBER											
PCT SPD	1	2	3	4	5	6	7	8	9	10	11	12
1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

0

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 1

1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
0.3100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.3500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.3800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

0

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 1

0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

0

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 2

1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
0.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.4800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

0

INPUT DESIGN CHARACTERISTICS FOR STAGE-- 2

0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES	PHIDES	PSIDES	ETADES
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

0

STAGE	PHIREF	PSIREF	ETAREF	DPHIA	DPSIA	FLOCAL	BET2M	BET3MR	RINCM	RDFM	SINCM
1	0.4278	0.2398	0.8471	0.0000	0.0000	0.00	0.00	46.68	4.44	0.4656	5.65
2	0.4616	0.2689	0.8690	0.0000	0.0000	0.00	0.00	47.51	4.96	0.4678	5.26

0

DPSIS(STAGE,PCT SPD) TABLE

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PCT SPD	STAGE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.9000	-0.0168	-0.0164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.8000	-0.0306	-0.0305	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.7000	-0.0411	-0.0415	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.5000	-0.0544	-0.0561	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

COMPUTED CHARACTERISTICS FOR STAGE NO. 1

1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
PHI	PSI	ETA	PHI	PSI	ETA	PHI	PSI	ETA
0.3100	0.2802	0.7624	0.3007	0.2634	0.7754	0.2895	0.2496	0.7845
0.3500	0.2774	0.8102	0.3430	0.2605	0.8239	0.3345	0.2467	0.8337
0.3800	0.2680	0.8332	0.3753	0.2511	0.8473	0.3695	0.2373	0.8573
0.4200	0.2460	0.8467	0.4192	0.2292	0.8611	0.4181	0.2154	0.8713
0.4300	0.2385	0.8463	0.4303	0.2216	0.8607	0.4306	0.2079	0.8708
0.4400	0.2202	0.8227	0.4414	0.2034	0.8367	0.4432	0.1896	0.8466
0.4500	0.1881	0.7665	0.4526	0.1712	0.7795	0.4559	0.1574	0.7887
0.4600	0.1447	0.6777	0.4639	0.1279	0.6892	0.4687	0.1141	0.6973

COMPUTED CHARACTERISTICS FOR STAGE NO. 1

0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
PHI	PSI	ETA	PHI	PSI	ETA	PHI	PSI	ETA
0.2757	0.2391	0.7754	0.2364	0.2258	0.7799	0.0000	0.0000	0.0000
0.3238	0.2363	0.8239	0.2922	0.2230	0.8288	0.0000	0.0000	0.0000
0.3623	0.2269	0.8473	0.3399	0.2136	0.8523	0.0000	0.0000	0.0000
0.4167	0.2049	0.8611	0.4124	0.1916	0.8662	0.0000	0.0000	0.0000
0.4310	0.1974	0.8607	0.4323	0.1841	0.8658	0.0000	0.0000	0.0000
0.4454	0.1791	0.8367	0.4528	0.1658	0.8416	0.0000	0.0000	0.0000
0.4601	0.1470	0.7795	0.4740	0.1337	0.7841	0.0000	0.0000	0.0000
0.4751	0.1037	0.6892	0.4960	0.0904	0.6933	0.0000	0.0000	0.0000

COMPUTED CHARACTERISTICS FOR STAGE NO. 2

1.000 PCT SPD			0.900 PCT SPD			0.800 PCT SPD		
PHI	PSI	ETA	PHI	PSI	ETA	PHI	PSI	ETA

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0.4060	0.2741	0.7821	0.3941	0.2577	0.7954	0.3869	0.2435	0.8048
0.4200	0.2828	0.8294	0.4158	0.2664	0.8435	0.4107	0.2523	0.8534
0.4400	0.2820	0.8583	0.4377	0.2656	0.8729	0.4349	0.2514	0.8832
0.4500	0.2779	0.8659	0.4487	0.2615	0.8807	0.4472	0.2474	0.8910
0.4600	0.2714	0.8689	0.4598	0.2550	0.8837	0.4596	0.2409	0.8941
0.4800	0.2493	0.8564	0.4821	0.2329	0.8709	0.4848	0.2188	0.8812
0.5100	0.1914	0.7819	0.5160	0.1750	0.7952	0.5236	0.1608	0.8046
0.5300	0.1405	0.6952	0.5388	0.1241	0.7070	0.5500	0.1100	0.7154

0

COMPUTED CHARACTERISTICS FOR STAGE NO. 2

0.700 PCT SPD			0.500 PCT SPD			0.000 PCT SPD		
PHI	PSI	ETA	PHI	PSI	ETA	PHI	PSI	ETA
0.3778	0.2325	0.7954	0.3502	0.2180	0.8001	0.0000	0.0000	0.0000
0.4041	0.2413	0.8435	0.3839	0.2267	0.8485	0.0000	0.0000	0.0000
0.4313	0.2404	0.8729	0.4195	0.2259	0.8781	0.0000	0.0000	0.0000
0.4452	0.2364	0.8807	0.4389	0.2218	0.8858	0.0000	0.0000	0.0000
0.4593	0.2299	0.8837	0.4584	0.2154	0.8889	0.0000	0.0000	0.0000
0.4883	0.2078	0.8709	0.4996	0.1933	0.8761	0.0000	0.0000	0.0000
0.5334	0.1498	0.7952	0.5663	0.1353	0.7999	0.0000	0.0000	0.0000
0.5647	0.0990	0.7070	0.6144	0.0845	0.7112	0.0000	0.0000	0.0000

1

** COMPUTED OUTPUT DATA **

0

PERCENT SPEED = 1.000 INLET FLOW = 32.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4053	0.2541	0.3018	0.8418	1.6321	0.8418	1.6321	32.0000	5.74	0.5035	9.59
2	0.4286	0.2824	0.3355	0.8419	1.5326	0.8316	2.5013	32.0000	6.74	0.5127	9.36

0

PERCENT SPEED = 1.000 INLET FLOW = 32.200

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4088	0.2522	0.2991	0.8429	1.6265	0.8429	1.6265	32.2000	5.53	0.4980	8.59

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2	0.4334	0.2822	0.3325	0.8488	1.5330	0.8357	2.4933	32.1999	6.48	0.5078	8.90

0

PERCENT SPEED = 1.000 INLET FLOW = 32.400

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4124	0.2502	0.2964	0.8442	1.6207	0.8442	1.6207	32.3999	5.32	0.4924	8.08
2	0.4382	0.2820	0.3296	0.8558	1.5334	0.8399	2.4852	32.3999	6.22	0.5029	8.44

0

PERCENT SPEED = 1.000 INLET FLOW = 32.600

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4160	0.2482	0.2936	0.8454	1.6150	0.8454	1.6150	32.5999	5.12	0.4868	7.57
2	0.4432	0.2807	0.3261	0.8607	1.5313	0.8431	2.4730	32.5999	5.95	0.4969	7.89

0

PERCENT SPEED = 1.000 INLET FLOW = 32.800

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4196	0.2463	0.2909	0.8466	1.6092	0.8466	1.6092	32.7999	4.91	0.4812	7.05
2	0.4482	0.2786	0.3223	0.8646	1.5277	0.8458	2.4584	32.7999	5.68	0.4903	7.28

0

PERCENT SPEED = 1.000 INLET FLOW = 33.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4232	0.2436	0.2878	0.8466	1.6016	0.8466	1.6016	32.9999	4.70	0.4748	6.47
2	0.4539	0.2754	0.3176	0.8671	1.5215	0.8471	2.4367	32.9999	5.37	0.4819	6.51

0

PERCENT SPEED = 1.000 INLET FLOW = 33.200

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4269	0.2408	0.2845	0.8464	1.5936	0.8464	1.5936	33.1999	4.49	0.4682	5.86
2	0.4599	0.2715	0.3125	0.8689	1.5140	0.8480	2.4127	33.1998	5.05	0.4728	5.68

0

PERCENT SPEED = 1.000 INLET FLOW = 33.400

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4306	0.2374	0.2810	0.8449	1.5837	0.8449	1.5837	33.3998	4.28	0.4608	5.19
2	0.4666	0.2641	0.3054	0.8648	1.4990	0.8452	2.3740	33.3998	4.69	0.4595	4.49

0

PERCENT SPEED = 1.000 INLET FLOW = 33.600

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4343	0.2306	0.2758	0.8361	1.5641	0.8361	1.5641	33.5998	4.06	0.4491	4.18
2	0.4773	0.2523	0.2940	0.8581	1.4749	0.8371	2.3070	33.5998	4.13	0.4384	2.59

0

PERCENT SPEED = 1.000 INLET FLOW = 33.800

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4381	0.2237	0.2704	0.8271	1.5445	0.8271	1.5445	33.7998	3.85	0.4370	3.14
2	0.4884	0.2330	0.2789	0.8354	1.4352	0.8214	2.2167	33.7998	3.55	0.4089	-0.01

0

PERCENT SPEED = 1.000 INLET FLOW = 34.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4420	0.2139	0.2636	0.8117	1.5172	0.8117	1.5172	33.9998	3.63	0.4211	1.79
2	0.5035	0.2040	0.2555	0.7981	1.3762	0.7957	2.0879	33.9998	2.77	0.3632	-3.94

0

PERCENT SPEED = 1.000 INLET FLOW = 34.200

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4458	0.2014	0.2550	0.7899	1.4827	0.7899	1.4827	34.1998	3.41	0.4009	0.12
2	0.5232	0.1579	0.2178	0.7248	1.2850	0.7524	1.9052	34.1998	1.78	0.2877	-10.14

0

PERCENT SPEED = 1.000 INLET FLOW = 34.400

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM

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1	0.4498	0.1886	0.2458	0.7675	1.4478	0.7675	1.4478	34.3997	3.19	0.3793	-1.66

0 FOR STAGE 2 , COMPUTED PHI IS 0.5451 CHOKE

PERCENT SPEED = 0.900 INLET FLOW = 27.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3623	0.2549	0.3042	0.8379	1.4965	0.8379	1.4965	27.0000	8.32	0.5085	10.58
2	0.4157	0.2663	0.3159	0.8432	1.4046	0.8319	2.1020	27.0000	7.46	0.4755	6.96

0

PERCENT SPEED = 0.900 INLET FLOW = 27.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3705	0.252[illegible]	0.2993	0.8438	1.4913	0.8439	1.4913	27.5000	7.82	0.4972	9.52
2	0.4260	0.266[illegible]	0.3104	0.8571	1.4050	0.8421	2.0952	27.4999	6.89	0.4650	5.91

0

PERCENT SPEED = 0.900 INLET FLOW = 28.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3788	0.2494	0.2940	0.8484	1.4843	0.8484	1.4843	27.9999	7.32	0.4852	8.40
2	0.4370	0.2656	0.3046	0.8719	1.4053	0.8519	2.0858	27.9999	6.29	0.4542	4.81

0

PERCENT SPEED = 0.900 INLET FLOW = 28.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3872	0.2452	0.2881	0.8511	1.4749	0.8511	1.4749	28.4999	6.81	0.4720	7.17
2	0.4491	0.2613	0.2967	0.8807	1.3990	0.8577	2.0634	28.4999	5.63	0.4392	3.35

0

PERCENT SPEED = 0.900 INLET FLOW = 29.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3957	0.2409	0.2822	0.8538	1.4655	0.8538	1.4655	28.9999	6.31	0.4583	5.94
2	0.4617	0.2532	0.2869	0.8827	1.3863	0.8602	2.0316	28.9999	4.95	0.4205	1.59

0

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PERCENT SPEED = 0.900 INLET FLOW = 29.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4045	0.2365	0.2762	0.8565	1.4559	0.8565	1.4559	29.4999	5.79	0.4455	4.68
2	0.4747	0.2403	0.2746	0.8752	1.3654	0.8583	1.9879	29.4999	4.27	0.3969	-0.59

0

PERCENT SPEED = 0.900 INLET FLOW = 30.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4133	0.2321	0.2701	0.8593	1.4462	0.8593	1.4462	29.9999	5.27	0.4322	3.42
2	0.4882	0.2226	0.2596	0.8574	1.3366	0.8519	1.9329	29.9999	3.56	0.3676	-3.20

0

PERCENT SPEED = 0.900 INLET FLOW = 30.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4223	0.2270	0.2637	0.8610	1.4352	0.8610	1.4352	30.4999	4.75	0.4181	2.08
2	0.5027	0.1976	0.2396	0.8249	1.2962	0.8387	1.8603	30.4998	2.81	0.3286	-6.55

0

PERCENT SPEED = 0.900 INLET FLOW = 31.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4315	0.2197	0.2560	0.8581	1.4193	0.8581	1.4193	30.9998	4.23	0.4011	0.53
2	0.5202	0.1656	0.2125	0.7789	1.2452	0.8186	1.7673	30.9998	1.93	0.2762	-10.90

0

PERCENT SPEED = 0.900 INLET FLOW = 31.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4408	0.2044	0.2439	0.8380	1.3866	0.8380	1.3866	31.4998	3.69	0.3740	-1.82

FOR STAGE 2 , COMPUTED PHI IS 0.5470 CHOKE

0

PERCENT SPEED = 0.800 INLET FLOW = 21.000

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STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3053	0.2486	0.3100	0.8018	1.3698	0.8018	1.3698	21.0000	11.93	0.5330	14.20

FOR STAGE 2 , COMPUTED PHI IS 0.3762 STALL

0

PERCENT SPEED = 0.800 INLET FLOW = 21.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3134	0.2480	0.3060	0.8106	1.3689	0.8106	1.3689	21.5000	11.41	0.5224	13.17

FOR STAGE 2 , COMPUTED PHI IS 0.3861 STALL

0

PERCENT SPEED = 0.800 INLET FLOW = 22.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3215	0.2475	0.3020	0.8195	1.3681	0.8195	1.3681	21.9999	10.88	0.5121	12.15
2	0.3961	0.2469	0.2998	0.8236	1.2955	0.8141	1.7723	21.9999	8.57	0.4468	5.38

0

PERCENT SPEED = 0.800 INLET FLOW = 22.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3297	0.2478	0.2982	0.8285	1.3672	0.8285	1.3672	22.4999	10.36	6.5019	11.13
2	0.4062	0.2506	0.2968	0.8443	1.3008	0.8290	1.7785	22.4999	8.00	0.4400	4.57

0

PERCENT SPEED = 0.800 INLET FLOW = 23.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3380	0.2458	0.2940	0.8361	1.3652	0.8361	1.3652	22.9999	9.84	0.4911	10.07
2	0.4163	0.2521	0.2928	0.8610	1.3032	0.8411	1.7790	22.9999	7.40	0.4311	3.59

0

PERCENT SPEED = 0.800 INLET FLOW = 23.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3464	0.2435	0.2893	0.8417	1.3615	0.8417	1.3615	23.4999	9.31	0.4794	8.94

2	0.4281	0.2517	0.2876	0.8749	1.3032	0.8510	1.7742	23.4999	6.77	0.4202	2.44

PERCENT SPEED = 0.800 INLET FLOW = 24.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3548	0.2413	0.2847	0.8474	1.3577	0.8474	1.3577	23.9999	8.79	0.4679	7.81
2	0.4396	0.2499	0.2819	0.8862	1.3013	0.8595	1.7668	23.9999	6.14	0.4082	1.21

PERCENT SPEED = 0.800 INLET FLOW = 24.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3634	0.2390	0.2801	0.8532	1.3540	0.8532	1.3540	24.4999	8.26	0.4564	6.67
2	0.4513	0.2452	0.2749	0.8921	1.2957	0.8656	1.7543	24.4998	5.51	0.3938	-0.22

PERCENT SPEED = 0.800 INLET FLOW = 25.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3720	0.2362	0.2753	0.8580	1.3495	0.8580	1.3495	24.9998	7.73	0.4445	5.51
2	0.4636	0.2374	0.2662	0.8921	1.2860	0.8684	1.7354	24.9998	4.85	0.3763	-1.89

PERCENT SPEED = 0.800 INLET FLOW = 25.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3808	0.2323	0.2699	0.8606	1.3429	0.8606	1.3429	25.4998	7.20	0.4315	4.26
2	0.4768	0.2258	0.2551	0.8853	1.2713	0.8667	1.7073	25.4998	4.15	0.3543	-3.92

PERCENT SPEED = 0.800 INLET FLOW = 26.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3896	0.2283	0.2645	0.8631	1.3364	0.8631	1.3364	25.9998	6.67	0.4184	3.00
2	0.4904	0.2104	0.2418	0.8702	1.2518	0.8613	1.6729	25.9998	3.45	0.3282	-6.24

```
 PERCENT SPEED =     0.800            INLET FLOW =   26.500
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
         1      0.3986     0.2242     0.2590     0.8657     1.3298     0.8657     1.3298    26.4998
         2      0.5044     0.1894     0.2249     0.8424     1.2253     0.8508     1.6295    26.4998      6.14     0.4054      1.75
0                                                                                                       2.73     0.2953     -9.06

 PERCENT SPEED =     0.800            INLET FLOW =   27.000
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
         1      0.4076     0.2201     0.2535     0.8683     1.3232     0.8683     1.3232    26.9998      5.60     0.3924      0.50
         2      0.5190     0.1676     0.2060     0.8136     1.1981     0.8409     1.5853    26.9998      1.99     0.2595    -12.03
0

 PERCENT SPEED =     0.800            INLET FLOW =   27.500
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
         1      0.4168     0.2160     0.2480     0.8709     1.3165     0.8709     1.3165    27.4998      5.07     0.3793     -0.76
         2      0.5340     0.1407     0.1829     0.7694     1.1649     0.8264     1.5336    27.4998      1.25     0.2157    -15.48
0

 PERCENT SPEED =     0.800            INLET FLOW =   28.000
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
         1      0.4261     0.2105     0.2417     0.8710     1.3077     0.8710     1.3077    27.9998      4.53     0.3648     -2.12
 FOR STAGE  2 , COMPUTED PHI IS   0.5505 CHOKE
0

 PERCENT SPEED =     0.700            INLET FLOW =   17.000
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
         1      0.2775     0.2390     0.3075     0.7772     1.2641     0.7772     1.2641    17.0000     13.76     0.5357     15.44
 FOR STAGE  2 , COMPUTED PHI IS   0.3618 STALL
0

 PERCENT SPEED =     0.700            INLET FLOW =   17.500
      STAGE        PHI        PSI        TAU        ETA        PR       C-ETA      C-PR   STG-FLOW    R-INCM     R-DFM     S-INCM
```

1	0.2863	0.2385	0.3034	0.7860	1.2635	0.7860	1.2635	17.5000	13.18	0.5238	14.24

FOR STAGE 2 , COMPUTED PHI IS 0.3733 STALL

0

PERCENT SPEED = 0.700 INLET FLOW = 18.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2950	0.2380	0.2994	0.7948	1.2629	0.7949	1.2629	17.9999	12.60	0.5122	13.06
2	0.3848	0.2349	0.2906	0.8083	1.2154	0.7949	1.5349	17.9999	9.21	0.4283	4.26

0

PERCENT SPEED = 0.700 INLET FLOW = 18.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3038	0.2374	0.2954	0.8037	1.2622	0.8037	1.2622	18.4999	12.03	0.5008	11.90
2	0.3965	0.2387	0.2878	0.8296	1.2195	0.8098	1.5393	18.4999	8.55	0.4202	3.28

0

PERCENT SPEED = 0.700 INLET FLOW = 19.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3127	0.2369	0.2915	0.8127	1.2616	0.8127	1.2616	18.9999	11.45	0.4896	10.74
2	0.4082	0.2411	0.2844	0.8480	1.2221	0.8235	1.5418	18.9999	7.88	0.4111	2.24

0

PERCENT SPEED = 0.700 INLET FLOW = 19.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3217	0.2364	0.2877	0.8218	1.2610	0.8218	1.2610	19.4999	10.87	0.4785	9.60
2	0.4201	0.2408	0.2797	0.8608	1.2220	0.8346	1.5409	19.4999	7.22	0.3999	1.04

0

PERCENT SPEED = 0.700 INLET FLOW = 20.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3307	0.2346	0.2833	0.8281	1.2588	0.8281	1.2588	19.9999	10.30	0.4664	8.39
2	0.4326	0.2400	0.2747	0.8737	1.2215	0.8442	1.5377	19.9999	6.52	0.3881	-0.20

0

PERCENT SPEED = 0.700 INLET FLOW = 20.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3398	0.2324	0.2787	0.8336	1.2562	0.8337	1.2562	20.4999	9.73	0.4541	7.16
2	0.4455	0.2362	0.2682	0.8807	1.2181	0.8505	1.5301	20.4998	5.82	0.3736	-1.65

0

PERCENT SPEED = 0.700 INLET FLOW = 21.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3489	0.2301	0.2742	0.8392	1.2535	0.8392	1.2535	20.9998	9.15	0.4419	5.94
2	0.4586	0.2303	0.2606	0.8835	1.2125	0.8549	1.5198	20.9998	5.12	0.3573	-3.22

0

PERCENT SPEED = 0.700 INLET FLOW = 21.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3582	0.2279	0.2698	0.8448	1.2508	0.8448	1.2508	21.4998	8.58	0.4298	4.73
2	0.4718	0.2203	0.2509	0.8782	1.2030	0.8556	1.5047	21.4998	4.41	0.3373	-5.05

0

PERCENT SPEED = 0.700 INLET FLOW = 22.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3675	0.2248	0.2649	0.8486	1.2471	0.8487	1.2471	21.9998	8.01	0.4170	3.48
2	0.4859	0.2096	0.2404	0.8720	1.1927	0.8549	1.4875	21.9998	3.68	0.3161	-6.97

0

PERCENT SPEED = 0.700 INLET FLOW = 22.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3768	0.2210	0.2597	0.8510	1.2427	0.8510	1.2427	22.4998	7.44	0.4037	2.18
2	0.5004	0.1922	0.2260	0.8506	1.1761	0.8469	1.4615	22.4998	2.93	0.2880	-9.38

0

PERCENT SPEED = 0.700 INLET FLOW = 23.000

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STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3863	0.2172	0.2545	0.8534	1.2381	0.8534	1.2381	22.9998	6.87	0.3904	0.90
2	0.5153	0.1731	0.2097	0.8257	1.1579	0.8379	1.4336	22.9998	2.18	0.2570	-11.96

0

PERCENT SPEED = 0.700 INLET FLOW = 23.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3959	0.2133	0.2493	0.8558	1.2336	0.8559	1.2336	23.4998	6.30	0.3771	-0.38
2	0.5305	0.1536	0.1919	0.8001	1.1394	0.8295	1.4056	23.4998	1.42	0.2241	-14.63

0

PERCENT SPEED = 0.700 INLET FLOW = 24.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4055	0.2095	0.2440	0.8583	1.2290	0.8583	1.2290	23.9998	5.73	0.3638	-1.64
2	0.5462	0.1291	0.1701	0.7594	1.1165	0.8169	1.3722	23.9997	0.65	0.1843	-17.70

0

PERCENT SPEED = 0.500 INLET FLOW = 11.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2469	0.2253	0.2855	0.7892	1.1215	0.7892	1.1215	11.0000	15.82	0.5067	15.27

FOR STAGE 2 , COMPUTED PHI IS 0.3461 STALL

0

PERCENT SPEED = 0.500 INLET FLOW = 11.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2584	0.2247	0.2811	0.7992	1.1212	0.7993	1.1212	11.5000	15.04	0.4923	13.58
2	0.3624	0.2212	0.2705	0.8176	1.1043	0.8048	1.2381	11.5000	10.52	0.3970	2.64

0

PERCENT SPEED = 0.500 INLET FLOW = 12.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2781	0.2241	0.2768	0.8095	1.1208	0.8095	1.1208	12.0000	14.26	0.4781	11.92

2	0.3788	0.2254	0.2680	0.8412	1.1064	0.8214	1.2401	12.0000	9.56	0.3860	1.21

0

PERCENT SPEED = 0.500 INLET FLOW = 12.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2817	0.2235	0.2727	0.8196	1.1205	0.8197	1.1205	12.5000	13.48	0.4642	10.30
2	0.3953	0.2265	0.2640	0.8579	1.1070	0.8348	1.2404	12.5000	8.61	0.3727	-0.34

0

PERCENT SPEED = 0.500 INLET FLOW = 13.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.2934	0.2227	0.2686	0.8294	1.1201	0.8294	1.1201	13.0000	12.71	0.4504	8.72
2	0.4120	0.2261	0.2594	0.8716	1.1069	0.8465	1.2398	13.0000	7.67	0.3586	-1.91

0

PERCENT SPEED = 0.500 INLET FLOW = 13.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3051	0.2204	0.2640	0.8352	1.1188	0.8352	1.1188	13.5000	11.95	0.4358	7.10
2	0.4291	0.2239	0.2539	0.8819	1.1059	0.8545	1.2372	13.4999	6.72	0.3430	-3.54

0

PERCENT SPEED = 0.500 INLET FLOW = 14.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3168	0.2181	0.2594	0.8409	1.1175	0.8410	1.1175	13.9999	11.19	0.4213	5.52
2	0.4464	0.2194	0.2473	0.8870	1.1037	0.8600	1.2334	13.9999	5.77	0.3259	-5.25

0

PERCENT SPEED = 0.500 INLET FLOW = 14.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3286	0.2158	0.2549	0.8468	1.1162	0.8468	1.1162	14.4999	10.43	0.4070	3.98
2	0.4638	0.2125	0.2395	0.8872	1.1004	0.8632	1.2283	14.4999	4.84	0.3070	-7.05

0

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PERCENT SPEED = 0.500 INLET FLOW = 15.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3405	0.2134	0.2504	0.8524	1.1149	0.8525	1.1149	14.9999	9.68	0.3928	2.47
2	0.4814	0.2030	0.2302	0.8817	1.0959	0.8637	1.2217	14.9999	3.91	0.2862	-8.95

0

PERCENT SPEED = 0.500 INLET FLOW = 15.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3524	0.2098	0.2455	0.8547	1.1128	0.8548	1.1128	15.4999	8.94	0.3780	0.94
2	0.4996	0.1933	0.2206	0.8761	1.0912	0.8624	1.2143	15.4999	2.98	0.2651	-10.83

0

PERCENT SPEED = 0.500 INLET FLOW = 16.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3644	0.2062	0.2406	0.8570	1.1108	0.8571	1.1108	15.9999	8.20	0.3633	-0.55
2	0.5181	0.1772	0.2073	0.8550	1.0834	0.8543	1.2035	15.9999	2.04	0.2387	-13.05

0

PERCENT SPEED = 0.500 INLET FLOW = 16.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3764	0.2025	0.2357	0.8593	1.1088	0.8594	1.1088	16.4999	7.46	0.3487	-2.00
2	0.5367	0.1610	0.1931	0.8337	1.0757	0.8467	1.1927	16.4999	1.11	0.2116	-15.27

0

PERCENT SPEED = 0.500 INLET FLOW = 17.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.3886	0.1989	0.2308	0.8616	1.1067	0.8617	1.1067	16.9999	6.73	0.3343	-3.41
2	0.5556	0.1446	0.1781	0.8122	1.0678	0.8396	1.1818	16.9999	0.20	0.1838	-17.48

0

PERCENT SPEED = 0.500 INLET FLOW = 17.500

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM

1	0.4008	0.1952	0.2259	0.8640	1.1047	0.8640	1.1047	17.4999	6.01	0.3198	-4.80
2	0.5747	0.1264	0.1612	0.7844	1.0592	0.8312	1.1700	17.4998	-0.71	0.1539	-19.79

0

PERCENT SPEED = 0.500 INLET FLOW = 18.000

STAGE	PHI	PSI	TAU	ETA	PR	C-ETA	C-PR	STG-FLOW	R-INCM	R-DFM	S-INCM
1	0.4130	0.1914	0.2210	0.8662	1.1026	0.8662	1.1026	17.9998	5.29	0.3056	-6.14
2	0.5942	0.1058	0.1414	0.7485	1.0494	0.8216	1.1571	17.9998	-1.62	0.1205	-22.26

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APPENDIX D

PROGRAM SOURCE CODE LISTING

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C *** STGSTK - A COMPUTER CODE FOR PREDICTING MULTISTAGE AXIAL FLOW
C     COMPRESSOR PERFORMANCE USING A MEANLINE STAGE STACKING METHOD.
C     BY R. J. STEINKE, NASA LEWIS RESEARCH CENTER
C
C *** THIS MAIN ROUTINE CALLS ALL MAGOR SUBROUTINES AND WRITES
C     INTERMEDIATE OUTPUT
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),     -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),      -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)      -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                      V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                      -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      DIMENSION NSTG(12)
      DATA   NSTG/1,2,3,4,5,6,7,8,9,10,11,12/
      RU=1545.44
      PI=3.14159217
      G= 32.1740
      AJ=778.12
      RAD=57.29578
      DO 7 II=1,12
    7 NSTAGE(II)= NSTG(II)
C
   10 CALL CSINPT
C *** CALCULATE FIXED PARAMETERS
      PO = PO*144.0
      DO 20  I=1,NSTA
      AREA2(I)= (RT2(I)+RH2(I))*(RT2(I)-RH2(I))*PI/144.0
      AREA3(I)= (RT3(I)+RH3(I))*(RT3(I)-RH3(I))*PI/144.0
      RM2(I)= SQRT(RT2(I)**2 - AREA2(I)*72.0/PI)
      RM3(I)= SQRT(RT3(I)**2 - AREA3(I)*72.0/PI)
      UM2(I)= RM2(I)*DESRPM*RPMRAD
      UM3(I)= RM3(I)*DESRPM*RPMRAD
      BET2M(I,1) = BET2M(I,1)/RAD
      RK2M(I) = RK2M(I) + CB2MR(I)
      SK2M(I) = SK2M(I) + CB2M(I+1)
      CB2M(I)= CB2M(I)/RAD
      CB2MR(I)= CB2MR(I)/RAD
      CB3MR(I)= CB3MR(I)/RAD
   20 CONTINUE
      CALL CSPREF
      IF(ETADES(1,1,1) .EQ. 0.0)  CALL CSETA
      IF (PSIDES(1,1,1).EQ.0.0) CALL CSPSI
      IF (SPDPSI.EQ.1.0) CALL CSPSD
      CALL CSPAN
      DO 51 I=1,NSTA
      BET2M(I,1) = BET2M(I,1) * RAD
   51 BET3MR(I,1) = BET3MR(I,1) * RAD
C *** WRITE INTERMEDIATE OUTPUT
      WRITE (6,2120)
      IF (UNITS.EQ.1.0) FLOCAL(I,1) = FLOCAL(I,1)*0.453592
      WRITE (6,2051) (NSTAGE(I),PHIREF(I),PSIREF(I),ETAREF(I),DPHIA(I), -
     XDPSIA(I),FLOCAL(I,1),                                             -
     X                  BET2M(I,1),BET3MR(I,1),RINCM(I),RDFM(I),SINCM(I),-
     XI=1,NSTA)
      IF (UNITS.EQ.1.0) FLOCAL(I,1) = FLOCAL(I,1)/0.453592
 2051 FORMAT (110H     STAGE     PHIREF     PSIREF     ETAREF      DPHIA    -
     X DPSIA     FLOCAL      BET2M     BET3MR      RINCM       RDFM,10H     S-
```

```
     XINCM//(5X,I5,5F10.4,4F10.2,F10.4,F10.2))
      DO 52 I=1,NSTA
      BET2M(I,1) = BET2M(I,1) / RAD
   52 BET3MR(I,1) = BET3MR(I,1) / RAD
      WRITE (6,2120)
      WRITE (6,2052) (NSTAGE(I),I=1,12), (PCTSPD(J), (DPSIS(I,J), I=1,12-
     1),J=1,NSPE)
 2052 FORMAT (20X,27H DPSIS(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/-
     18H PCT SPD,12(I5,3X)//(13F8.4))
      DO 60  I=1,NSTA
      DO 60  J=1,NSPE
      DO 60  K=1,NPTS
      PHI(I,J,K) = PHIDES(I,1,K) + DPHIA(I)
C *** OPTION TO ALTER FLOW COEFICIENT FOR OFF DESIGN SPEEDS
      IF (SPDPHI.EQ.1.0) PHI(I,J,K) = PHI(I,J,K)*(1.0 + ((PHI(I,J,K)/PHI-
     XREF(I))**(1.0/PCTSPD(J)) - 1.0)*1.0*ABS(1.0 - PCTSPD(J)))
      PSI(I,J,K) = PSIDES(I,1,K) + DPSIA(I) + DPSIS(I,J)
      ETA(I,J,K) = ETADES(I,1,K)*ETARAT(J) + DETA(I)
   60 CONTINUE
      DO 70  I=1,NSTA
      WRITE (6,2120)
      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=1,3),((PHI(I,J,K),PSI(I,J,K),-
     1ETA(I,J,K),J=1,3),K=1,NPTS)
      IF(NSPE.LT.4)  GO TO 70
      WRITE (6,2120)
      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=4,6),((PHI(I,J,K),PSI(I,J,K),-
     1ETA(I,J,K),J=4,6),K=1,NPTS)
      IF(NSPE.LT.7) GO TO 70
      WRITE (6,2120)
      WRITE(6,2060) NSTAGE(I),(PCTSPD(J),J=7,9),((PHI(I,J,K),PSI(I,J,K),-
     1ETA(I,J,K),J=7,9),K=1,NPTS)
   70 CONTINUE
 2060 FORMAT (20X,39H COMPUTED CHARACTERISTICS FOR STAGE NO.,I3//3(5X,  -
     1F10.3,10H  PCT SPD ,5X)//3(30H   PHI       PSI       ETA    )/(9F1-
     20.4))
      CALL CSOUPT
      GO TO 10
 2120 FORMAT (1H0////)
      END


      SUBROUTINE CSINPT
C *** SUBROUTINE CSINPT READS AND WRITES THE INPUT DATA
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),        -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)        -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                         V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
   10 READ(5,1000,END=999) (TITLE(I),I=1,18)
      WRITE(6,2000) (TITLE(I),I=1,18)
 1000 FORMAT (18A4)
 2000 FORMAT (1H1////20X,30H ** STAGE STACKING PROGRAM ** ////20X,      -
     118A4////)
      READ (5,1010) STAGEN, SPEEDN, CHAPTS, PO, TO, WTMOLE,DESRPM,DESFLO
      WRITE(6,2010) STAGEN, SPEEDN, CHAPTS, PO, TO, WTMOLE,DESRPM,DESFLO
      RG = RU/WTMOLE
      DCP = RG/AJ
      GJ = G*AJ
      G2J = GJ*2.0
      RPMRAD = PI/360.0
```

```
 1010 FORMAT (8F10.0)
 2010 FORMAT (80H    STAGES    SPEEDS    POINTS     PO IN     TO IN   MO-
     1LE WT    DES RPM  DES FLOW//(8F10.3)////)
      READ (5,1010) SPDPSI, SPDPHI, DRDEVG, DRDEVN, DRDEVP, UNITS
      WRITE (6,2011) SPDPSI, SPDPHI,DRDEVG, DRDEVN, DRDEVP, UNITS
 2011 FORMAT (60H    SPDPSI    SPDPHI    DRDEVG    DRDEVN    DRDEVP    -
     XUNITS//(6F10.1)////)
      READ (5,1020) (CPCO(I),I=1,6)
      WRITE(6,2020) (CPCO(I),I=1,6)
 1020 FORMAT (3E20.8)
 2020 FORMAT (072H     CPCO(1)     CPCO(2)     CPCO(3)     CPCO(4)     C-
     1PCO(5)     CPCO(6)//(6E12.5)////)
      NSTA = STAGEN
      NSPE= SPEEDN
      NPTS = CHAPTS
      READ (5,1010) (RT2(I),I=1,NSTA)
      READ (5,1010) (RH2(I),I=1,NSTA)
      READ (5,1010) (RT3(I),I=1,NSTA)
      READ (5,1010) (RH3(I),I=1,NSTA)
      READ (5,1010) (BET2M(I,1),I=1,NSTA)
      READ (5,1010) (CB2M(I),  I=1,NSTA)
      READ (5,1010) (CB2MR(I), I=1,NSTA)
      READ (5,1010) (CB3MR(I), I=1,NSTA)
      READ (5,1010) (RK2M (I), I=1,NSTA)
      READ (5,1010) (RSOLM(I), I=1,NSTA)
      READ (5,1010) (SK2M(I),I=1,NSTA)
      READ (5,1010) (PR(I),I=1,NSTA)
      READ(5,1010) (ETAINP(I),I=1,NSTA)
      WRITE(6,2030) (NSTAGE(I),RT2(I),RH2(I),RT3(I),RH3(I),BET2M(I,1),  -
     XCB2M(I),CB2MR(I),CB3MR(I),RK2M(I),RSOLM(I),SK2M(I), I=1,NSTA)
 2030 FORMAT (110H     STAGE       RT2        RH2       RT3       RH3    -
     X BET2M       CB2M      CB2MR      CB3MR      RK2M      RSOLM,10H   -
     XSK2M//(5X,I5,4F10.4,5F10.2,F10.4,F10.2))
      WRITE (6,2120)
      WRITE (6,2031) (NSTAGE(I), PR(I), ETAINP(I), I=1,NSTA)
 2031 FORMAT (30H    STAGE        PR    ETAINP//(5X,I5,2F10.4))
      READ (5,1010) (PCTSPD(J),J=1,NSPE)
 2120 FORMAT (1H0////)
      READ (5,1010) (ETARAT(J),J=1,NSPE)
      WRITE (6,2120)
      WRITE (6,2121) (PCTSPD(J),ETARAT(J), J=1,NSPE)
 2121 FORMAT (20H    PCTSPD    ETARAT//(2F10.4))
      DO 21 I=1,NSTA
      READ (5,1010) (BLEED(I,J),J=1,NSPE)
   21 CONTINUE
      WRITE (6,2120)
      WRITE (6,2041) (NSTAGE(I),I=1,12), (PCTSPD(J), (BLEED(I,J), I=1,12-
     1),J=1,NSPE)
 2041 FORMAT (20X,27H BLEED(STAGE,PCT SPD) TABLE//40X, 13H STAGE NUMBER/-
     18H PCT SPD,12(I5,3X)//(13F8.3))
      DO 30  I=1,NSTA
      READ (5,1010) (PHIDES(I,1,K),K=1,NPTS)
      READ (5,1010) (PSIDES(I,1,K),K=1,NPTS)
      READ (5,1010) (ETADES(I,1,K),K=1,NPTS)
   30 CONTINUE
      DO 50  I=1,NSTA
      WRITE (6,2120)
      WRITE(6,2050) NSTAGE(I),(PCTSPD(J),J=1,3),((PHIDES(I,J,K),PSIDES(I-
     1,J,K),ETADES(I,J,K),J=1,3),K=1,NPTS)
      IF(NSPE.LT.4) GO TO 50
      WRITE (6,2120)
      WRITE(6,2050) NSTAGE(I),(PCTSPD(J),J=4,6),((PHIDES(I,J,K),PSIDES(I-
     1,J,K),ETADES(I,J,K),J=4,6),K=1,NPTS)
      IF(NSPE.LT.7) GO TO 50
      WRITE (6,2120)
      WRITE(6,2050) NSTAGE(I),(PCTSPD(J),J=7,9),((PHIDES(I,J,K),PSIDES(I-
     1,J,K),ETADES(I,J,K),J=7,9),K=1,NPTS)
   50 CONTINUE
 2050 FORMAT (20X,41H INPUT DESIGN CHARACTERISTICS FOR STAGE--,I3//3(5X,-
     1F10.3,10H  PCT SPD ,5X)//3(30H    PHIDES    PSIDES    ETADES)/(9F1-
     20.4))
C *** CHANGE METRIC INPUT INTO ENGLISH UNITS
      IF (UNITS.NE.1.0) GO TO 53
```

```
      PO = PO/0.689476
      TO = TO*9.0/5.0
      DESFLO = DESFLO/0.453592
      DO 51 I=1,NSTA
      RT2(I) = RT2(I)/2.54
      RH2(I) = RH2(I)/2.54
      RT3(I) = RT3(I)/2.54
      RH3(I) = RH3(I)/2.54
      DO 52 J = 1,NSPE
   52 BLEED(I,J) = BLEED(I,J)/0.453592
   51 CONTINUE
   53 RETURN
  999 STOP
      END


      SUBROUTINE CSPREF
C *** SUBROUTINE CSPREF CALCULATES PARAMETERS AT DESIGN SPEED AND FLOW
C     CONDITIONS
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)       -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                        V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      J= 1
      I= 1
      TT(I)= TO
      PT(I)= PO
   20 RHOT= PT(I)/(TT(I)*RG)
      TS= TT(I)
      RHOS= RHOT
      UT2(I)= RT2(I)*DESRPM*RPMRAD
      UT3(I)= RT3(I)*DESRPM*RPMRAD
C *** CALCULATIONS AT ROTOR INLET
   30 VZ2M(I,J) = DESFLO/(RHOS*AREA2(I))
      V= VZ2M(I,J)/COS(BET2M(I,J))
      CP= CPF(TS)
      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))**GF1
      TS= TT(I)*(RHOS/RHOT)**GM1
      WCAL= RHOS*AREA2(I)*VZ2M(I,J)
      IF(ABS(WCAL - DESFLO) .GT. 0.01)  GO TO 30
      CPREF(I) = CP
      GF1REF(I) = GF1
      PHIREF(I)= VZ2M(I,J)/UT2(I)
      DO 40  K=2,NPTS
      IF(PHIREF(I)-PHIDES(I,J,K))  50,60,40
   40 CONTINUE
      K= NPTS
   50 PSIREF(I)= (PSIDES(I,J,K)-PSIDES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J, -
     1K-1))/    (PHIDES(I,J,K)-PHIDES(I,J,K-1)) + PSIDES(I,J,K-1)
      ETAREF(I)= (ETADES(I,J,K)-ETADES(I,J,K-1))*(PHIREF(I)-PHIDES(I,J, -
     1K-1))/    (PHIDES(I,J,K)-PHIDES(I,J,K-1)) + ETADES(I,J,K-1)
      GO TO 70
   60 PSIREF(I)= PSIDES(I,J,K)
      ETAREF(I)= ETADES(I,J,K)
   70 CONTINUE
      IF (PSIREF(I).EQ.0.0) GO TO 71
      PR(I)= (1.0 + PSIREF(I)*UT3(I)*UT3(I)/(GJ*CP*TT(I)))**GF2
   71 CONTINUE
      IF(ETAREF(I).EQ.0.0)  ETAREF(I)= ETAINP(I)
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      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAREF(I)
      TT(I+1)= TT(I)*TR(I)
      IF (PSIREF(I).EQ.0.0) PSIREF(I) = GJ*CP*(TT(I+1)-TT(I))*ETAREF(I) -
     X/UT3(I)**2
      PT(I+1)= PT(I)*PR(I)
      TRO(I)= TT(I+1)/TO
      PRO(I)= PT(I+1)/PO
      I= I+1
      IF(I .LE. NSTA)  GO TO 20
      DO 80  I=1,NSTA
      VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
      VT2MR= UM2(I) - VT2M
      BET2MR(I,J)= ATAN2(VT2MR,VZ2M(I,J))
      TS= TT(I+1)
      RHOT= PT(I+1)/(TT(I+1)*RG)
      RHOS= RHOT
C *** CALCULATIONS AT ROTOR OUTLET
   81 VZ3M(I,J)= DESFLO/(RHOS*AREA3(I))
      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UM2(I)*VT2M)/UM3(I)
      V= SQRT(VZ3M(I,J)**2 + VT3M**2)
      CP= CPF(TS)
      RHOS = RHOT*(1.0-V*V/(G2J*CP*TT(I+1)))**GF1
      TS = TT(I+1)*(RHOS/RHOT)**GM1
      WCAL= RHOS*AREA3(I)*VZ3M(I,J)
      IF(ABS(WCAL-DESFLO) .GT. 0.01)  GO TO 81
      BET3M(I,J) = ATAN2(VT3M,VZ3M(I,J))
      SINCM(I) = BET3M(I,J)*RAD - SK2M(I)
      VT3MR= UM3(I) - VT3M
      BET3MR(I,J)= ATAN2(VT3MR,VZ3M(I,J))
      RINCM(I)= BET2MR(I,J)*RAD - RK2M(I)
      V2MR= VZ2M(I,J)/COS(BET2MR(I,J))
      V3MR= VZ3M(I,J)/COS(BET3MR(I,J))
      V3DV2R(I) = V3MR/V2MR
      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +  -
     XRM2(I))/RSOLM(I)/V2MR
      DB2M(I,J) = BET2M(I,J)
      DB2MR(I,J) = BET2MR(I,J)
      DB3M(I,J) = BET3M(I,J)
      DB3MR(I,J) = BET3MR(I,J)
      B2MB3R(I,J)  = BET2MR(I,J) - BET3MR(I,J)
   80 CONTINUE
  100 RETURN
      END


      FUNCTION CPF(TS)
C *** SUBROUTINE CPF(TS) CALCULATES SPECIFIC HEAT FROM STATIC
C     TEMPERATURE USING FIFTH DEGREE POLYNOMIAL
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),     -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),       -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),        -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)        -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                          V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                         -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      CPF = CPCO(1)+(CPCO(2)+(CPCO(3)+(CPCO(4)+(CPCO(5)+ CPCO(6)*TS)*TS)-
     X *TS)*TS)*TS
      GAMMA = CPF/(CPF - DCP)
      GM1 =  GAMMA - 1.0
      GF1 =  1.0/GM1
      GF2 =  GAMMA/GM1
      GF3 =  1.0/GF2
```

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      RETURN
      END
```

```
      SUBROUTINE CSETA
C *** SUBROUTINE CSETA GENERATES ADIABATIC EFFICIENCY VERSUS FLOW
C     COEFICIENT
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)       -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                          V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                       -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      J = 1
C *** TWO PARABOLAS ARE USED FROM STALL AND CHOKE TO DESIGN CONDITIONS
      DO 10  I=1,NSTA
      PSMPRS= (PHIDES(I,J,1) - PHIREF(I))**2
      PCMPRS = (PHIDES(I,J,NPTS) - PHIREF(I))**2
      AS= -0.1*ETAREF(I)/PSMPRS
      AC= -0.2 * ETAREF(I)/PCMPRS
      BS= -2.0*PHIREF(I)*AS
      BC= -2.0*PHIREF(I)*AC
      CS= ETAREF(I) + AS*PHIREF(I)**2
      CC= ETAREF(I) + AC*PHIREF(I)**2
      DO 20  K=1,NPTS
      IF(PHIDES(I,J,K) - PHIREF(I)) 11,12,13
   11 ETADES(I,J,K) = (AS*PHIDES(I,J,K) + BS)*PHIDES(I,J,K) + CS
      GO TO 20
   12 ETADES(I,J,K)= ETAREF(I)
      GO TO 20
   13 ETADES(I,J,K) = (AC*PHIDES(I,J,K) + BC)*PHIDES(I,J,K) + CC
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CSPSI
C *** SUBROUTINE CSPSI CALCULATES PRESSURE COEFICIENTS FOR INPUT FLOW
C     COEFICIENTS
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)       -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                          V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                       -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      J=1
      DO 100 K=1,NPTS
      I=1
```

```
      TT(I) = TO
      PT(I) = PO
   10 VZ3M(I,J) = VZ2M(I,J)*PHIDES(I,J,K)/PHIREF(I)
      V2MR = VZ3M(I,J)/COS(DB2MR(I,1))
      BET3MR(I,J) = DB3MR(I,1)
      VT2M = VZ3M(I,J)*TAN(DB2M(I,1))
      V2S = V12M**2 + VZ3M(I,J)**2
      RHOT = PT(I)/(TT(I)*RG)
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
      TS = TT(I)
      ID = 0
   11 VT3M = UM3(I) - VZ3M(I,J)*TAN(BET3MR(I,J))
      CP = CPF(TS)
      DT = (UM3(I)*VT3M - UM2(I)*VT2M)/(GJ*CP)
      TRA = (DT + TT(I))/TT(I)
      PTA3 = PT(I)*(1.0 + ETADES(I,J,K)*(TRA - 1.0))**GF2
      TTA3 = DT + TT(I)
      RHOT = PTA3/(TTA3*RG)
      V3S = VT3M**2 + VZ3M(I,J)**2
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))**GF1
      TS = TTA3*(RHOS/RHOT)**GM1
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
      IF (TRA.GE.1.0) GO TO 12
      DT = 0.0
      GO TO  13
   12 ID = ID + 1
      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN FLOW
C     COEFICIENT
      IF (DRDEVP.EQ.1.0)
     XDB3MRP(I,K) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
      BET3MR(I,J) = DB3MR(I,1) + DB3MRP(I,K)
      IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 11
   13 PSIDES(I,J,K) = GJ*CP*DT*ETADES(I,J,K)/UT3(I)**2
      DV3DV2 = V3DV2R(I)
      FV3DV2 = V3MR/V2MR
      I = I + 1
      IF (I.LE.NSTA) GO TO 10
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CSPSD
C *** SUBROUTINE CSPSD ALTERS PRESSURE RISE COEFICIENTS FOR OFF DESIGN
C     SPEEDS
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)       -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                       V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                       -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      DO 100 J=1,NSPE
      I = 1
      TT(I) = TO
      PT(I) = PO
   10 VZ3M(I,J) = VZ2M(I,1)*PCTSPD(J)
      V2MR = VZ3M(I,J)/COS(DB2MR(I,1))
      BET3MR(I,J) = DB3MR(I,1)
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      ID = 0
      VT2M= VZ2M(I,1)*PCTSPD(J)*  TAN(DB2M(I,1))
      V2S = VT2M**2 + VZ3M(I,J)**2
      RHOT = PT(I)/(TT(I)*RG)
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
      TS = TT(I)
   11 VT3M = UM3(I)*PCTSPD(J) - VZ3M(I,J)*TAN(BET3MR(I,J))
      CP = CPF(TS)
      DT = (UM3(I)*VT3M - UM2(I)*VT2M)/(GJ*CP)*PCTSPD(J)
      TRA =  (DT + TT(I))/TT(I)
      PTA3 = PT(I)*(1.0 + ETAREF(I)*(TRA - 1.0))**GF2
      TTA3 = DT + TT(I)
      RHOT = PTA3/(TTA3*RG)
      V3S = VT3M**2 + VZ3M(I,J)**2
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3))**GF1
      TS = TTA3*(RHOS/RHOT)**GM1
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
      IF (I.NE.1) GO TO 12
      DVZ3M = VZ3M(I,J)
   12 CONTINUE
      ID = ID + 1
      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR OFF DESIGN SPEEDS
      IF (DRDEVN.EQ.1.0)                                               -
     XDB3MRN(I,J) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
      BET3MR(I,J) = DB3MR(I,1) + DB3MRN(I,J)
      IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 11
      DPSIS(I,J) = GJ*CP*DT*ETAREF(I)/(UT3(I)*PCTSPD(J))**2 - PSIREF(I)
      DPSIS(I,J) = DPSIS(I,J) - DPSIS(I,1)
      I= I + 1
      IF (I.LE.NSTA) GO TO 10
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CSPAN
C *** SUBROUTINE CSPAN ALTERS FLOW AND PRESSURE RISE COEFICIENTS FOR
C     BLADE RESET
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),    -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),      -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),       -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)       -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                      V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPIS, PO, TO, DESRPM, DESFLO, UNITS                       -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      J=1
      I=1
      TT(I)= TO
      PT(I)= PO
   90 TS= TT(I)
      DPHIA(I) = 0.0
      DPSIA(I) = 0.0
      DETA(I) = 0.0
      IF((CB2M(I) + CB2MR(I) + CB3MR(I)).EQ.0.00) GO TO 93
      BET2M(I,J)=  DB2M(I,J) + CB2M(I)
      BET2MR(I,J)=  DB2MR(I,J) + CB2MR(I)
      BET3MR(I,J) =  DB3MR(I,J) + CB3MR(I)
      VZ2M(I,J)= UM2(I)/(TAN(BET2M(I,J))+ TAN(BET2MR(I,J)))
      V2MR = VZ2M(I,J)/COS(BET2MR(I,J))
```

```
C *** CHANGE IN FLOW COEFICIENT FOR RESET
      DPHIA(I)= VZ2M(I,J)/UT2(I) - PHIREF(I)
      VZ3M(I,J)= VZ2M(I,J)
      VT2M= VZ2M(I,J)*TAN(BET2M(I,J))
      V2S = VT2M**2 + VZ3M(I,J)**2
      RHOT = PT(I)/(TT(I)*RG)
      RHOS = RHOT*(1.0 - V2S/(G2J*CPREF(I)*TT(I)))**GF1REF(I)
      DESFLC = RHOS*AREA2(I)*VZ3M(I,J)
      FLOCAL(I,J) = DESFLC
   92 VT3M= UM3(I) - VZ3M(I,J) *TAN(BET3MR(I,J))
      CP = CPF(TS)
      DT= (UM3(I) * VT3M - UM2(I)*VT2M)/(GJ*CP)
      TRA  = (DT + TT(I))/TT(I)
      PTA3   = PT(I)*(1.0 + ETAREF(I)*(TRA  -1.0))**GF2
      TTA3   = DT + TT(I)
      RHOT= PTA3   /(TTA3   *RG)
      V3S = VT3M**2 + VZ3M(I,J)**2
      RHOS = RHOT*(1.0 - V3S/(G2J*CP*TTA3   ))**GF1
      TS = TTA3   *(RHOS/RHOT)**GM1
      WCAL = RHOS*AREA3(I)*VZ3M(I,J)
      VZ3M(I,J) = DESFLC/(RHOS*AREA3(I))
      V3MR = VZ3M(I,J)/COS(BET3MR(I,J))
C *** OPTION TO ALTER ROTOR DEVIATION ANGLE FOR BLADE RESET
      IF (DRDEVG.EQ.1.0)                                             -
     XDB3MRG(I) = -(10.00/RAD)*(V3MR/V2MR - V3DV2R(I))
      BET3MR(I,J) = DB3MR(I,J) + CB3MR(I) + DB3MRG(I)
      IF (ABS(WCAL-DESFLC).GT.0.01) GO TO 92
C *** CHANGE IN PRESSURE RISE COEFICIENT FOR RESET
      DPSIA(I) = GJ*CP*DT/(UT3(I)*UT3(I))*ETAREF(I) -  PSIREF(I)
   93 I = I+1
      IF (I.LE.NSTA) GO TO 90
  100 RETURN
      END
```

```
      SUBROUTINE CSOUPT
C *** SUBROUTINE CSOUPT CALCULATES AND WRITES STAGE AND COMPRESSOR
C     PERFORMANCE PARAMETERS
      COMMON /VECTOR/ CPCO(6), TITLE(18), RT2(12), RH2(12), RT3(12),     -
     XRH3(12), PHIREF(12), PSIREF(12), ETAREF(12), PHIDES(12,9,8),       -
     XPSIDES(12,9,8), ETADES(12,9,8), PHI(12,9,8), PSI(12,9,8), ETA(12,9-
     X,8), DPHIA(12), DPSIA(12), DETA(12), NSTAGE(12), PCTSPD(9),        -
     XBET2M(12,9), BLEED(12,9), TT(13), PT(13), PR(12), TR(12), PRO(12),-
     XTRO(12), ETAO(12), BET3MR(12,9), VZ2M(12,9), VZ3M(12,9), AREA2(12)-
     X, AREA3(12), RM2(12), RM3(12), UT2(12), UT3(12), UM2(12), UM3(12) -
     X,BET2MR(12,9),DPSIS(12,9),RSOLM(12),  RK2M(12), CB2M(12), CB2MR(  -
     X12), CB3MR(12), RINCM(12), RDFM(12), SK2M(12), SINCM(12), BET3M(12-
     X,9), PHIFIX(12), DPHIF(12),CPREF(12), GF1REF(12),ETAINP(12)        -
     X,FLOCAL(12,9), ETARAT(9), DB2M(12,9), DB2MR(12,9),DB3M(12,9),DB3MR-
     X(12,9), B2MB3R(12,9),                        V3DV2R(12),DB3MRG(12)-
     X,DB3MRN(12,9), DB3MRP(12,8)
      COMMON /SCALER/ RU, PI, G, AJ, RAD, RG, DCP, GJ, G2J, RPMRAD, NSTA-
     X, NSPE, NPTS, PO, TO, DESRPM, DESFLO, UNITS                        -
     X,CP,GAMMA,GM1,GF1,GF2,GF3,SPDPSI,SPDPHI,DRDEVG, DRDEVN, DRDEVP
      WRITE(6,2070)
 2070 FORMAT (1H1////20X,27H ** COMPUTED OUTPUT DATA **////)
C *** READ SPEED AND FLOWS
   80 READ (5,1010) SPEEDF, FLOWIN,DFLOW, FLOWFI
      IF (UNITS.NE.1.0) GO TO 81
      FLOWIN = FLOWIN/0.453592
      DFLOW  =  DFLOW/0.453592
      FLOWFI = FLOWFI/0.453592
   81 CONTINUE
      IF (UNITS.EQ.1.0) FLOWIN = FLOWIN*0.453592
      WRITE(6,2080) SPEEDF, FLOWIN
      IF (UNITS.EQ.1.0) FLOWIN = FLOWIN/0.453592
 2080 FORMAT (1H0////                                                    -
     I          17H PERCENT SPEED = ,F8.3,10X,15H  INLET FLOW = ,F8.3//080-
     1H     STAGE        PHI        PSI        TAU        ETA        PR  -
     2C-ETA        C-PR,40H  STG-FLOW     R-INCM      R-DFM     S-INCM/)
      DO 82 J=1,NSPE
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      IF (SPEEDF.EQ.PCTSPD(J)) JS=J
   82 CONTINUE
C *** CALCULATE THE OUTPUT
      I=1
      TT(I)= TO
      PT(I)= PO
      WTFLOW = FLOWIN
   91 RHOT= PT(I)/(TT(I)*RG)
      TS= TT(I)
      RHOS= RHOT
C
      WTFLOW = WTFLOW - FLOWIN*BLEED(I,JS)
      U2 = UT2(I)*SPEEDF
      U3 = UT3(I)*SPEEDF
      UMM2 = UM2(I)*SPEEDF
      UMM3 = UM3(I)*SPEEDF
  100 VZ = WTFLOW/(RHOS*AREA2(I))
      V= VZ/COS(BET2M(I,1))
      CP= CPF(TS)
      RHOS= RHOT*(1.0-V*V/(G2J*CP*TT(I)))**GF1
      IF ((V*V).GT.(G2J*CP*TT(I))) GO TO 113
      TS= TT(I)*(RHOS/RHOT)**GM1
      WCAL = RHOS*VZ*AREA2(I)
      IF(ABS(WCAL-WTFLOW).GT.0.01)  GO TO 100
      PHIC = VZ/U2
      IF (PHIFIX(I).NE.0.0) PHIC = PHIC + DPHIF(I)
      IF(PHIC.LT.PHI(I,JS,1)) GO TO 110
      IF(PHIC.GT.PHI(I,JS,NPTS)) GO TO 120
      DO 130  K=2,NPTS
      IF(PHIC-PHI(I,JS,K))  140,150,130
  130 CONTINUE
      K= NPTS
  140 PSIC=(PSI(I,JS,K)-PSI(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1     (PHI(I,JS,K)-PHI(I,JS,K-1)) + PSI(I,JS,K-1)
      ETAC=(ETA(I,JS,K)-ETA(I,JS,K-1))*(PHIC-PHI(I,JS,K-1))/
     1     (PHI(I,JS,K)-PHI(I,JS,K-1)) + ETA(I,JS,K-1)
      GO TO 160
  150 PSIC= PSI(I,JS,K)
      ETAC= ETA(I,JS,K)
  160 CONTINUE
      PR(I) = (1.0 + PSIC*U3*U3/    (GJ*CP*TT(I)))**GF2
      TAU = PSIC/ETAC
      TR(I)= 1.0 + (PR(I)**GF3-1.0)/ETAC
      TT(I+1)= TT(I)*TR(I)
      PT(I+1)= PT(I) *PR(I)
      TRO(I)= TT(I+1)/TO
      PRO(I)= PT(I+1)/PO
      IF(I.EQ.1)  GF3S = GF3
      GF30= (GF3 + GF3S)/2.0
      ETAO(I)= (PRO(I)**GF30 - 1.0)/(TRO(I) - 1.0)
      VT2M = VZ * TAN(BET2M(I,1))
      VT2MR = UMM2   - VT2M
      BET2MR(I,JS)= ATAN2(VT2MR,VZ)
      RINCM(I)= BET2MR(I,JS) * RAD - RK2M(I)
      V2MR= VZ/COS(BET2MR(I,JS))
      RHOT= PT(I+1)/(TT(I+1)*RG)
      TS= TT(I+1)
      RHOS= RHOT
  161 VZ3M(I,JS)=WTFLOW/(RHOS*AREA3(I))
      VT3M= (CP*(TT(I+1)-TT(I))*GJ + UMM2  *VT2M)/UMM3
      VS= VZ3M(I,JS)**2 + VT3M**2
      CP= CPF(TS)
      RHOS= RHOT*(1.0-VS/(G2J*CP*TT(I+1)))**GF1
      IF((VS).GT.(G2J*CP*TT(I+1))) GO TO 113
      TS= TT(I+1) * (RHOS/RHOT)**GM1
      WCAL= RHOS*AREA3(I)*VZ3M(I,JS)
      IF(ABS(WCAL-WTFLOW).GT.0.01)  GO TO 161
      BET3M(I,JS) = ATAN2(VT3M,VZ3M(I,JS))
      SINCM(I) = BET3M(I,JS)*RAD - SK2M(I)
      VT3MR = UMM3   - VT3M
      BET3MR(I,JS)= ATAN2(VT3MR,VZ3M(I,JS))
      V3MR = VZ3M(I,JS)/COS(BET3MR(I,JS))
      RDFM(I)= 1.0 - V3MR/V2MR + (RM3(I)*VT3M - RM2(I)*VT2M)/(RM3(I) +   -
```

```
     XRM2(I))/RSOLM(I)/V2MR
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW*0.453592
C *** WRITE THE OUTPUT
      WRITE (6,2090) I,PHIC,PSIC,TAU,ETAC,PR(I),ETAO(I),PRO(I),WTFLOW
     X,RINCM(I),RDFM(I),SINCM(I)
      IF (UNITS.EQ.1.0) WTFLOW = WTFLOW/0.453592
 2090 FORMAT (5X,I5,8F10.4,F10.2,F10.4,F10.2)
      I= I+1
      IF(I.LE.NSTA)  GO TO 91
      GO TO 111
  110 WRITE(6,2100) I,PHIC
      GO TO 111
  120 WRITE(6,2110)I,PHIC
      GO TO 113
 2100 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H STALL)
 2110 FORMAT (10H FOR STAGE,I3,18H , COMPUTED PHI IS,F8.4,06H CHOKE)
  111 FLOWIN = FLOWIN + DFLOW
      IF (FLOWIN.LE.FLOWFI) GO TO 81
  113 IF (JS.LT.NSPE) GO TO 80
      DO 112 I=1,NSTA
      DO 112 J=1,NSPE
  112 DPSIS(I,J) = 0.0
      RETURN
 1010 FORMAT (8F10.0)
      END
```

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